ITP272 SENSOR TECHNOLOGIES AND PROJECT

L05: Data Communications

AGENDA

Part 1

- Types of Data communications
- DIO
- Analog Input
- PWM
- UART and USB

Part 2

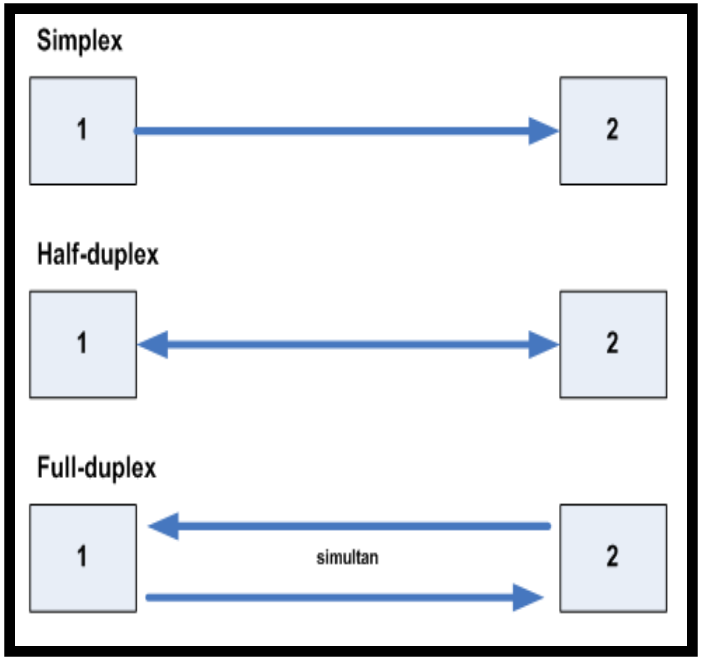
- I2C
- SPI
- Ethernet

TYPES OF DATA COMMUNICATION

Synchronous Vs Asynchronous

- Synchronous communication
  - Requires a clock signal for transmission and reception of data
- Asynchronous communication
  - a start signal is sent before each byte, character or code word and a stop signal is sent after each code word
  - start signal serves to prepare the receiving mechanism for the reception
  - stop signal serves to bring the receiving end to rest (ready for the reception of the next symbol)

TYPES OF DATA COMMUNICATION



- Simplex
  - Information sent only one way
- Half Duplex
  - Information sent both direction
  - One direction at any one time
- Full Duplex
  - Information sent both direction simultaneously

- Simplex, Half Duplex and Full Duplex
  - Describes mode of data communication
  - Not specific to only serial communications
  - Sometimes determine connection configuration

TYPES OF DATA COMMUNICATION

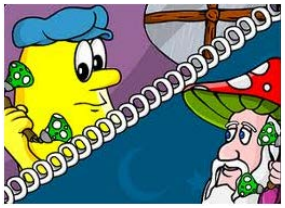
Example of **Simplex** Communication

Radio Broadcasting

Example of **Half Duplex** Communication

Walkie-Talkie communication

Example of **Full Duplex** Communication



Phone conversation

DATA COMMUNICATION FLOW

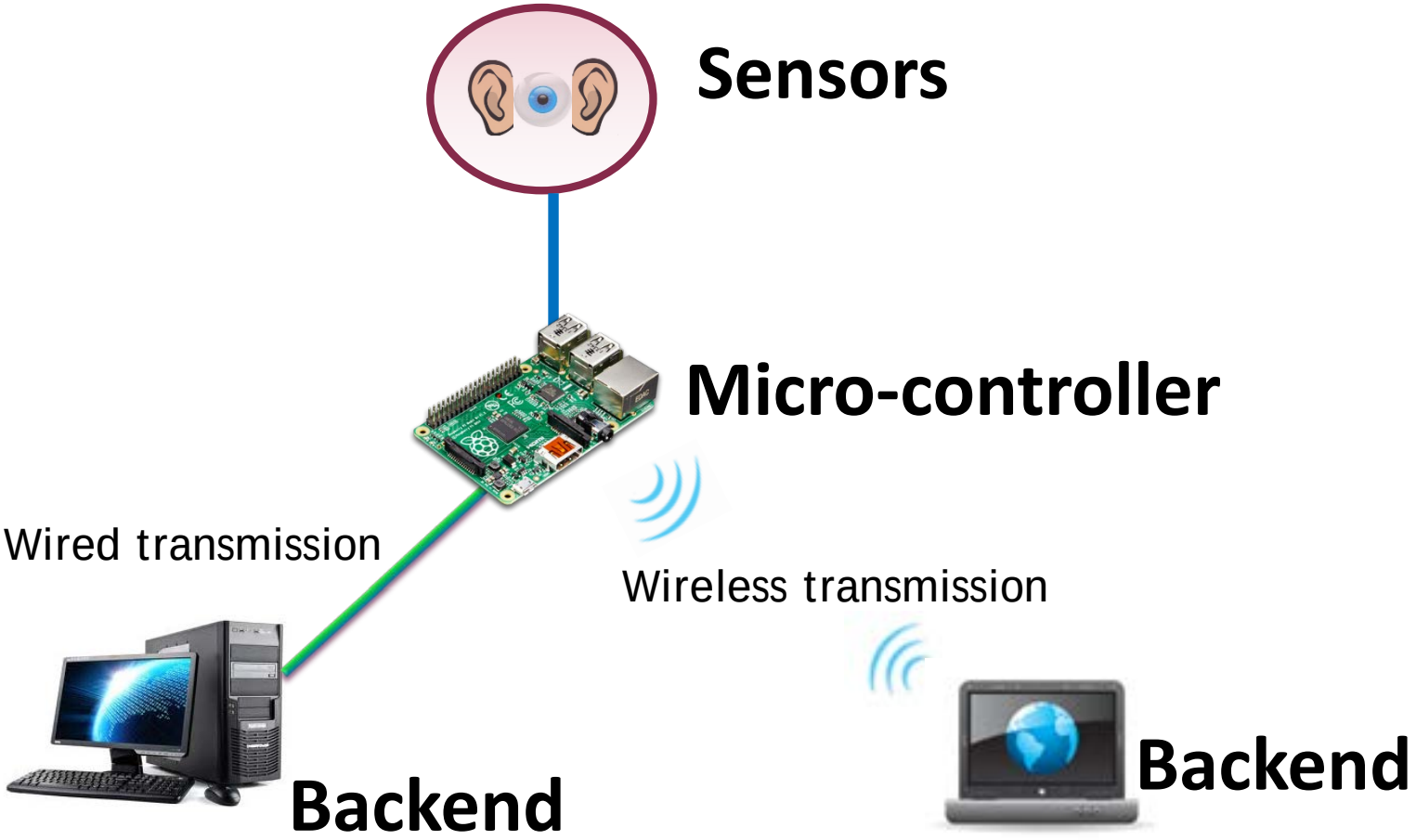
In a sensor system, how is data being transferred?

The following are the sensor data communication flow

- Sensor data is fed into a micro-controller
- Data is processed and transferred to backend machines
- Backend machines stores data
- Data are used for Analytical tools

DATA COMMUNICATION FLOW

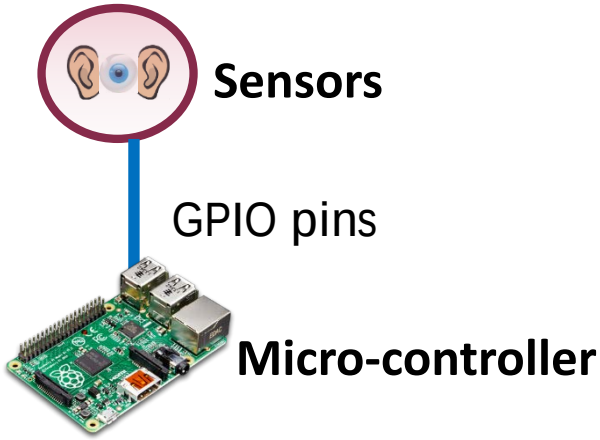
Sensor Data Communications Flow diagram



DATA COMMUNICATION

How does sensor send their data into the micro-controller?

- General Purpose Input/Output (GPIO) pins



GPIO pins

- Can be configured to be input or output
- Can be configured to be enabled or disabled

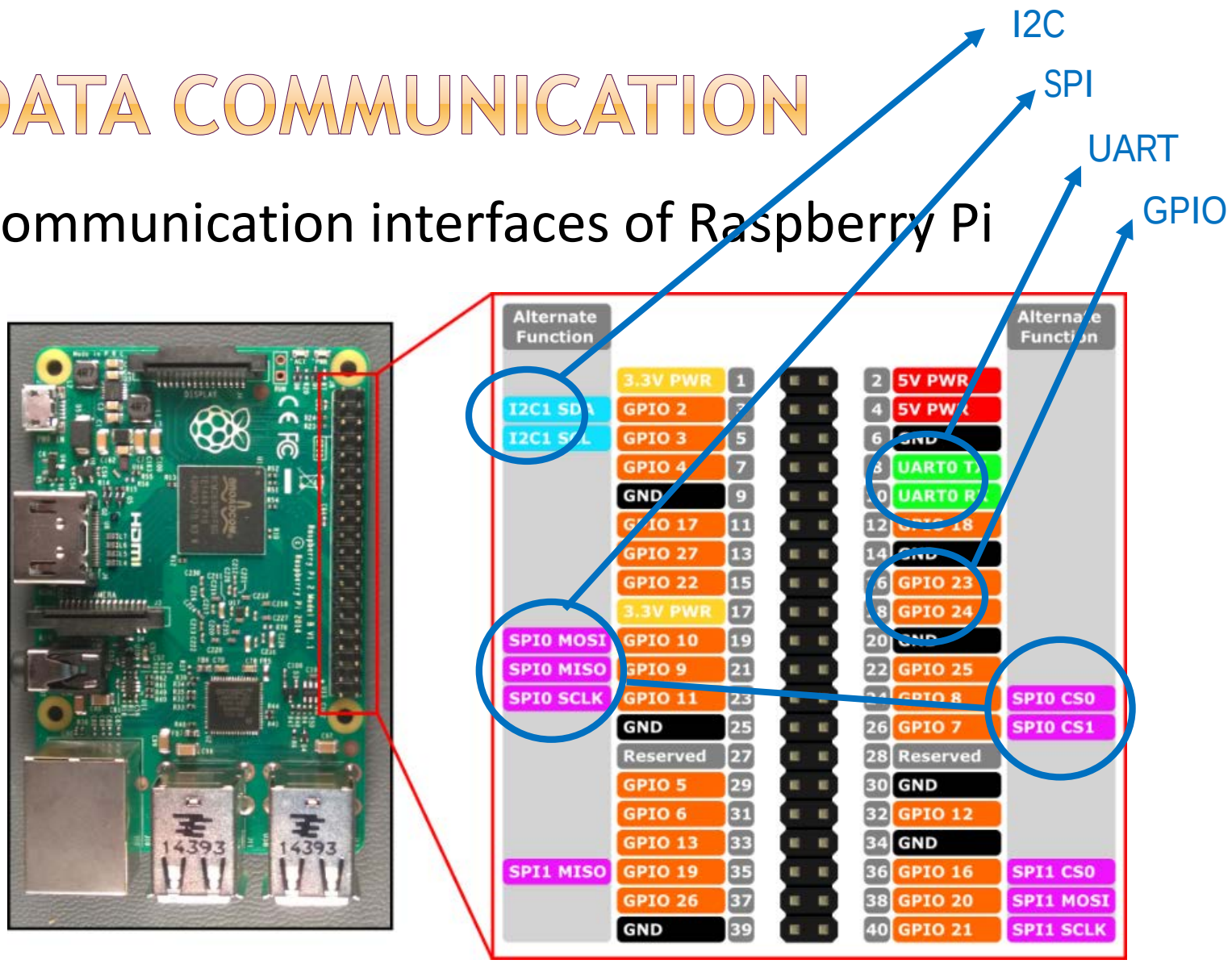
DATA COMMUNICATION

Various communication interfaces of GPIO pins

- Digital Input/Output (DIO)
- Analog Input
- Universal Asynchronous Receiver Transmitter (UART)
- Pulse Width Modulation (PWM)
- Inter-Integrated Circuit (I2C)
- Serial Peripheral Interface (SPI)

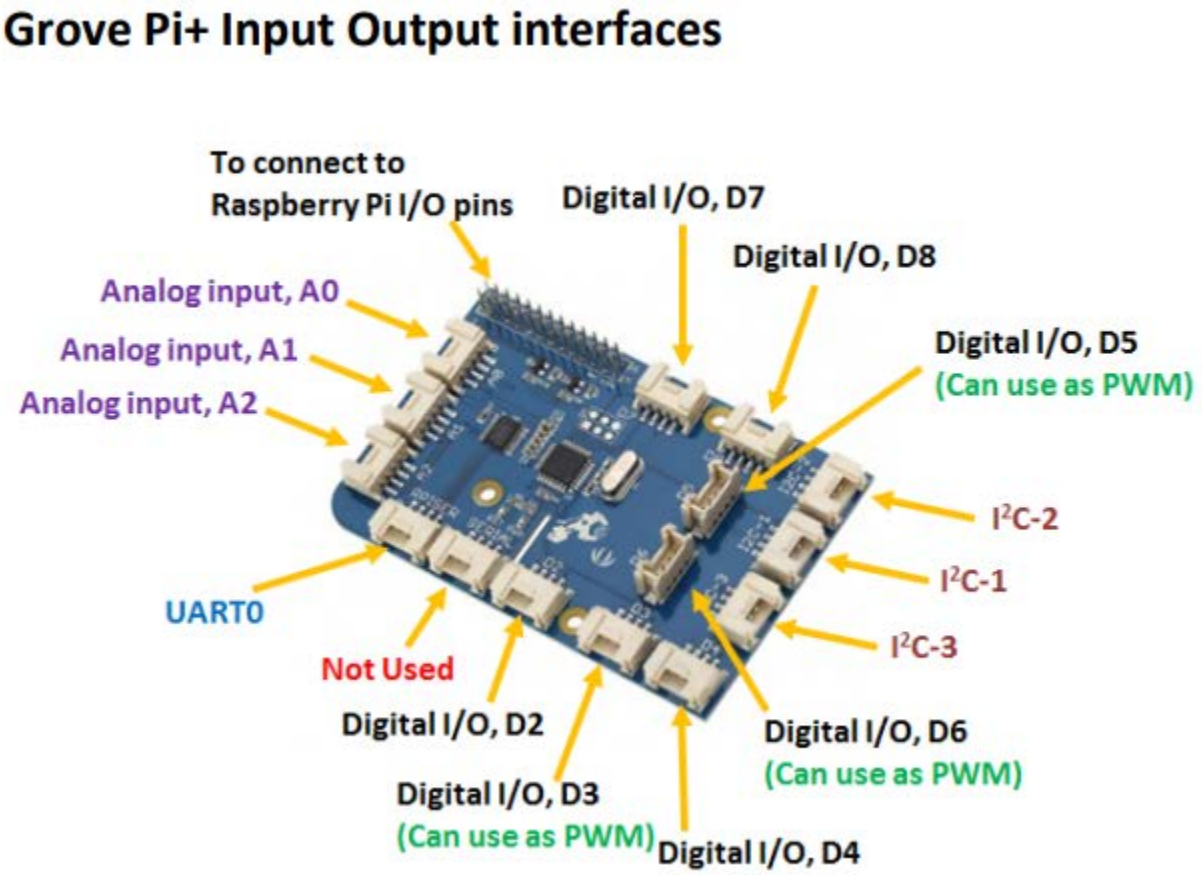
DATA COMMUNICATION

Communication interfaces of Raspberry Pi



DATA COMMUNICATION

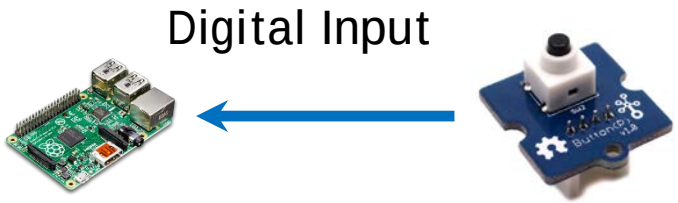
Communication interfaces of Grove Pi+



DIO

Digital Input/Output (DIO)

- A DIO pin can be configured to acts Digital Input of Digital Output



Digital Input

- This is used to sense voltage level of sensors connected to it
- It consist of 2 states
  - High (true)
    - When the incoming voltage is > high threshold voltage, it returns this state
  - Low (false)
    - When the incoming voltage is < low threshold voltage, it returns this state
- Usually, it is used to detect a status of a switch

This asyn method will run on it's own (like a thread) once you called it.

This is used to read in DIO from Grove Pi

DIO

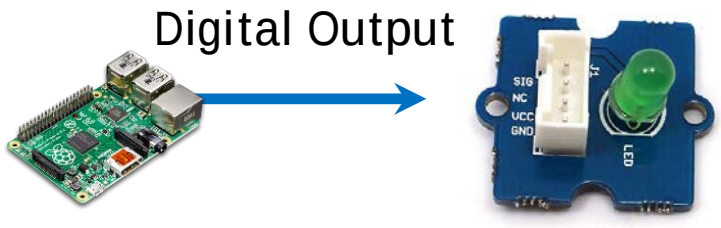
```
IButtonSensor button = DeviceFactory.Build.ButtonSensor(Pin.DigitalPin4);
```

```
//This is created to self monitor button status.
//When button is pressed, buttonPressed will be true.
//The main program can check for this buttonPressed to know whether button has been pressed
1 reference
private async void startButtonMonitoring()
{
    await Task.Delay(100);
    while (true)
    {
        Sleep(100);
        string buttonState = button.CurrentState.ToString();
        if (buttonState.Equals("On"))
        {
            Sleep(100);
            buttonState = button.CurrentState.ToString();
            if (buttonState.Equals("On"))
            {
                buttonPressed = true;
            }
        }
    }
}//End of startButtonMonitoring()
```

DIO

Digital Output

- This is used to output voltage to components connected to it
- It consist of 2 states
  - High (true)
    - Output a logic high voltage (usually 5V or 3.3 V) of the micro-controller to the component connected to it
  - Low (false)
    - Output a 0V voltage to the component connected to it
- It is commonly used to control LED output



ANALOG INPUT

Analog Input

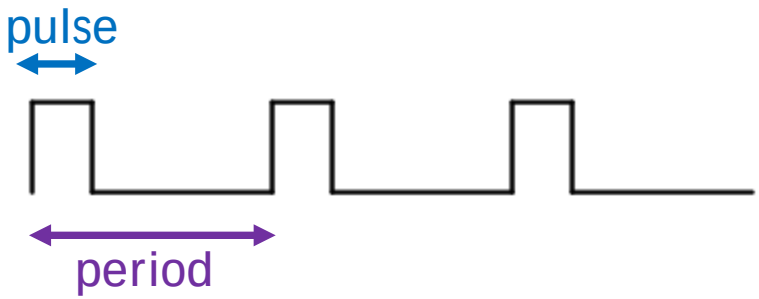
- This is used to measure voltage levels between 0 to a maximum voltage usually 3.3V or 5V
- The voltage goes through a Analog to Digital Convertor (ADC) to convert voltage into digital values to be processed by micro-controller
- The range of digital values depends on resolution of the ADC
- It is used for sensors that produce output as variations of voltages corresponding to the stimulus
- Example : Grove Light sensor

Analog Input

PULSE WIDTH MODULATION (PWM)

Pulse Width Modulation

- This is a technique where durations of high and low state of digital output are varied to form digital pulses
- The digital output keeps repeating cycles which starts from high state and switch to low state



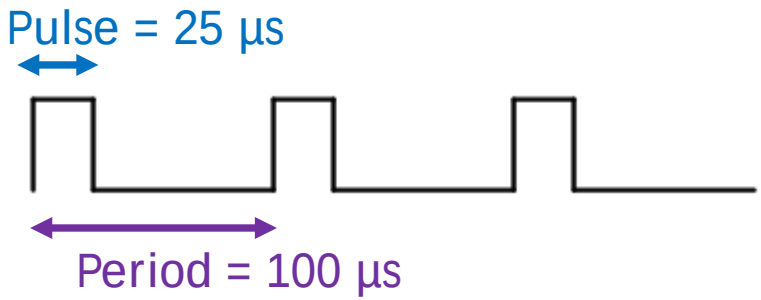
- The time duration of 1 cycle is known as period
- The time duration within the cycle where output state is high is known as the pulse

```
DeviceFactory.Build.GrovePi().AnalogWrite(buzzerPin, 60);
```

PULSE WIDTH MODULATION (PWM)

Pulse Width Modulation

- The percentage duration of the pulse within the period is known as the duty cycle



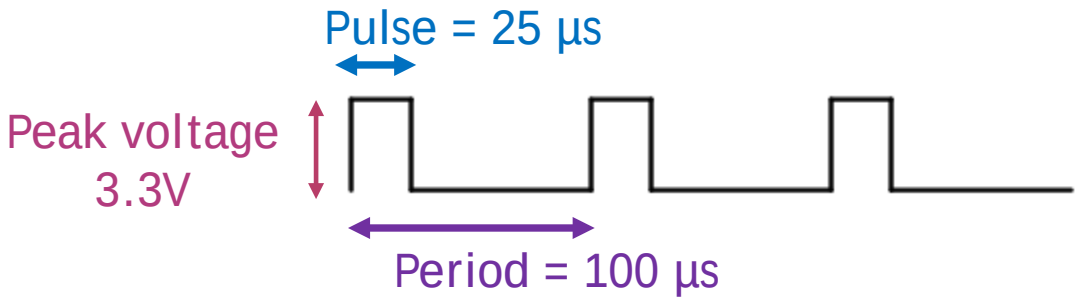
$$\text{Duty cycle} = \frac{\text{pulse}}{\text{period}} \times 100\ \%$$

- The duty cycle for the above is 25%

PULSE WIDTH MODULATION (PWM)

Pulse Width Modulation

- PWM is used to generate analog output from a digital output
- An average analog voltage can be varied corresponding to the duty cycle of a PWM



$$\text{Avg Voltage} = \frac{\text{Duty Cycle}}{100} \times \text{Peak Voltage}$$

- The average voltage is 0.25 x 3.3 V = 0.825 V

UART AND USB

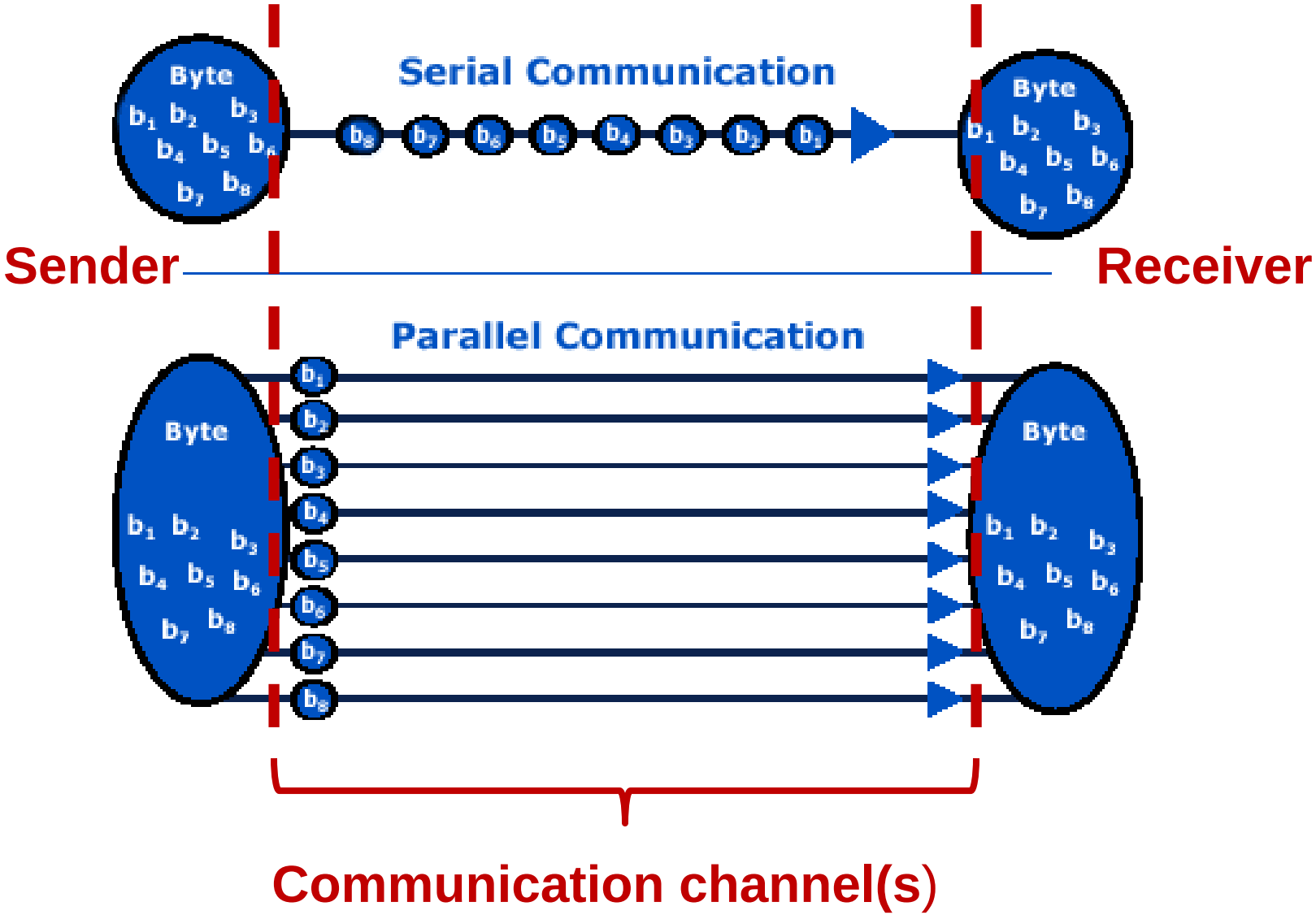
Serial and Parallel Communication

- Serial communication
  - Process of sending data **one** bit at a time, **sequentially** over **a communication channel**.

- Parallel communication
  - Process of sending **several** bits **simultaneously** along **multiple channels**.

- Communication channels
  - Refer to the medium used to convey info from sender (or transmitter) to receiver

UART AND USB


Byte
b1 b2 b3
b4 b5 b6
b7 b8
Serial Communication
b8 b7 b6 b5 b4 b3 b2 b1
Byte
b1 b2 b3
b4 b5 b6
b7 b8
Sender
Receiver
Parallel Communication
b1
b2
b3
b4
b5
b6
b7
b8
Byte
b1 b2 b3
b4 b5 b6
b7 b8
Byte
b1 b2 b3
b4 b5 b6
b7 b8
Communication channel(s)

Universal Asynchronous Receiver Transmitter

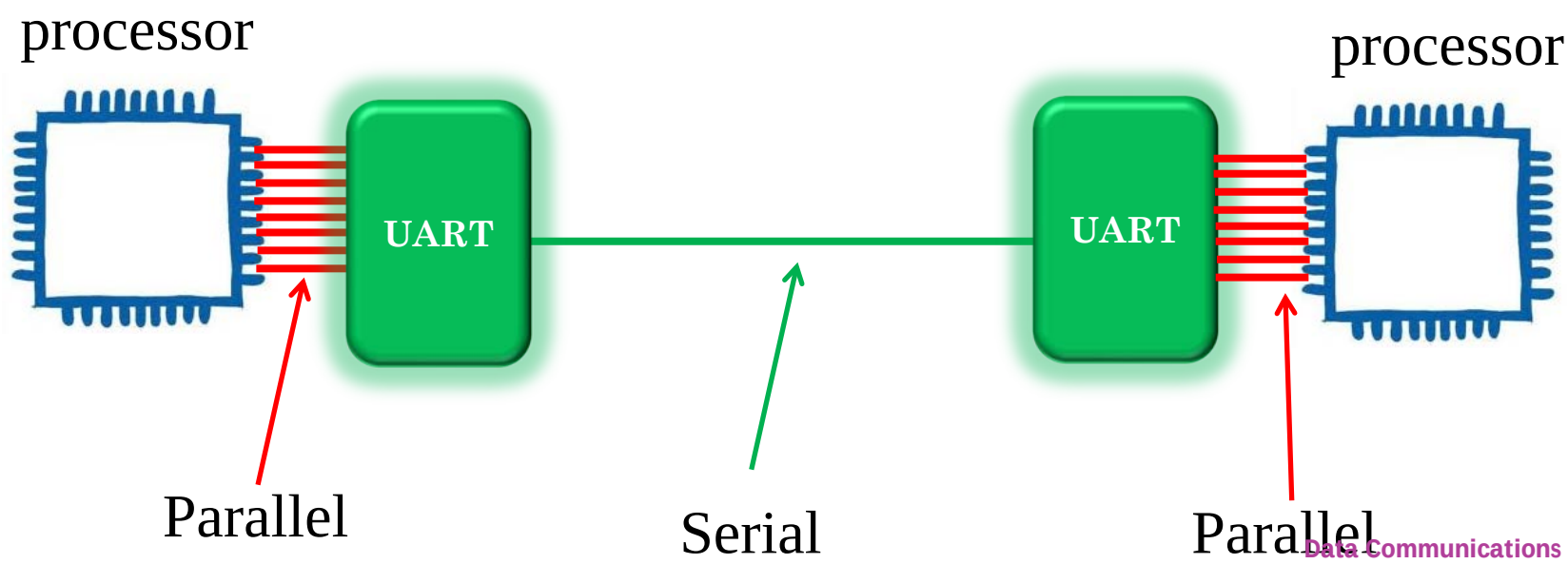
UART AND USB

- Computer processor operates at byte level.
- Data get around in parallel form
- But many data communication sends and receive data out serially 1 bit at a time
- How does a processor send data in serial form?
  - Use UART
- UART (pronounced “You Art”) is an industry acronym that stands for Universal Asynchronous Receiver Transmitter
- The UART is responsible for breaking apart bytes of data and transmitting it one bit at a time (i.e. serially). Likewise, the UART receives serialized bits and converts them back into bytes.

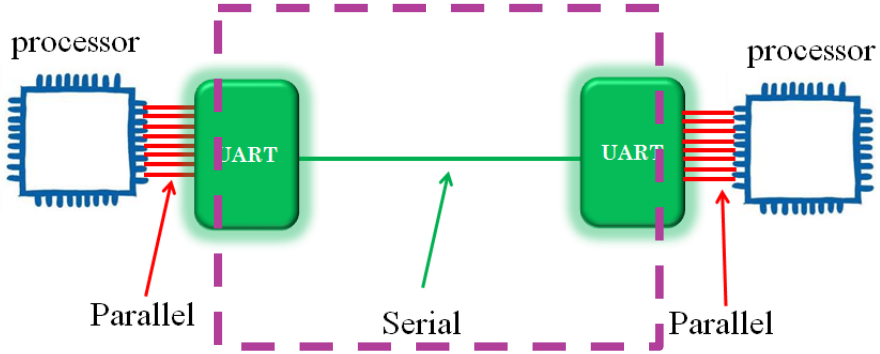
UART AND USB

Process of data comms between 2 processors using UART

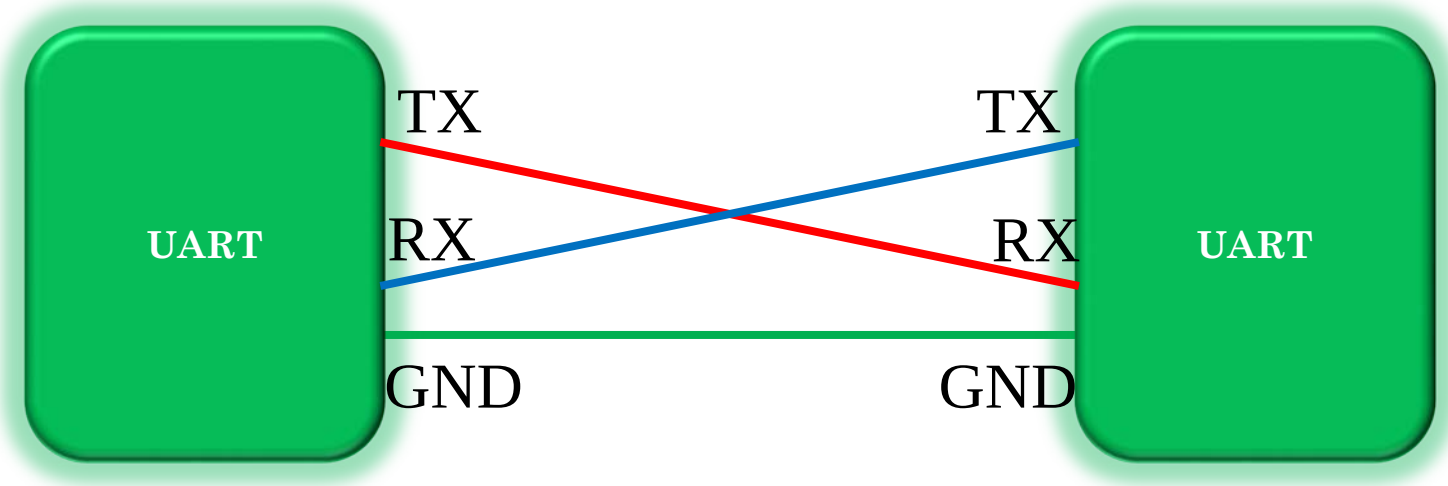
- Computer processor operates at **byte** level but serial transmission channel is in **bit** level
- The UART breaks data bytes(Parallel) from processor into data bits (serial) for transmission through the serial channel.
- The UART receives data bits (Serial) from channel and convert them back into bytes (parallel) to processed by processor



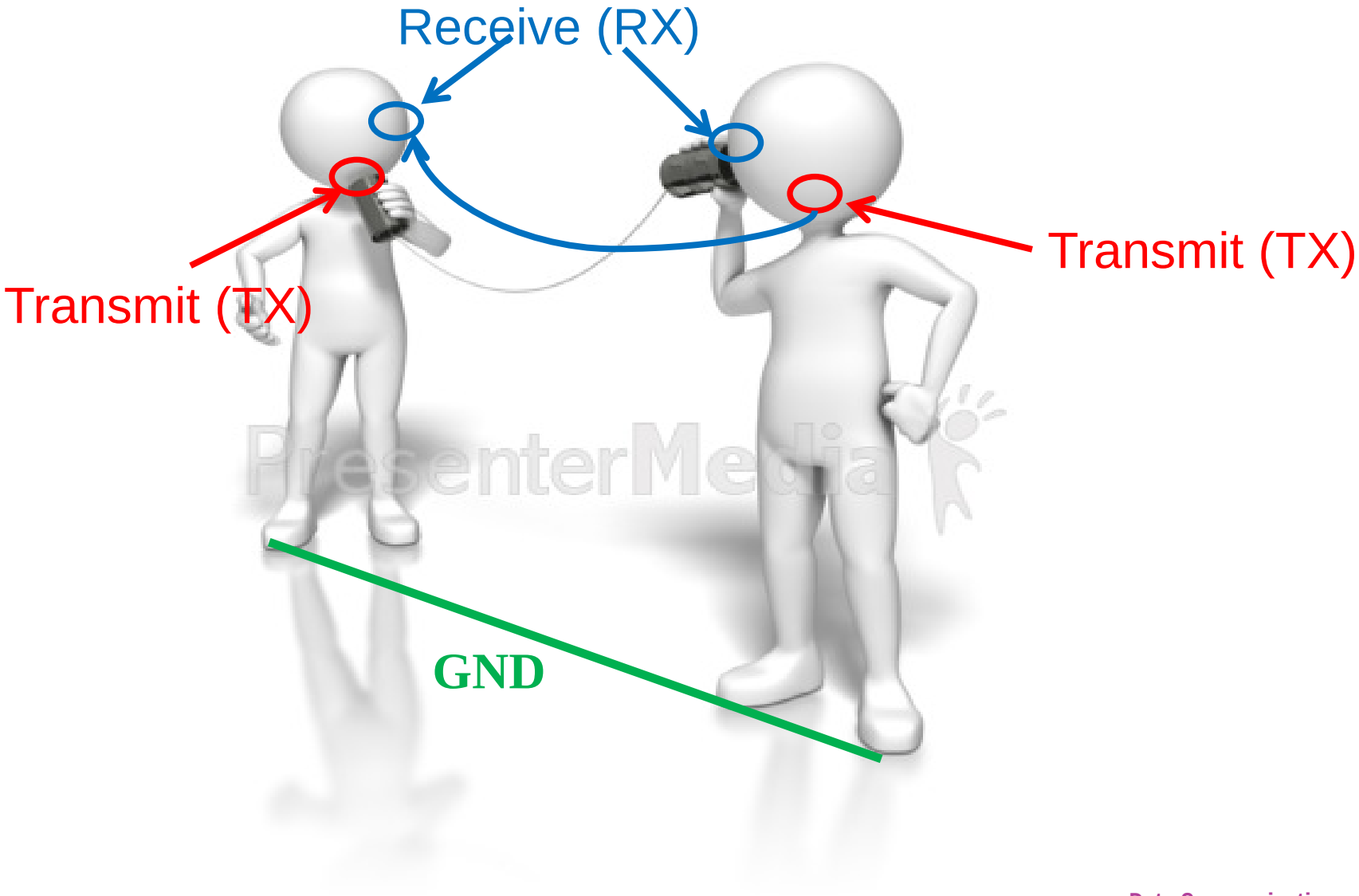
UART AND USB



- The UART serial communications requires 3 lines
  - Transmit (TX)
  - Receive (RX)
  - GND

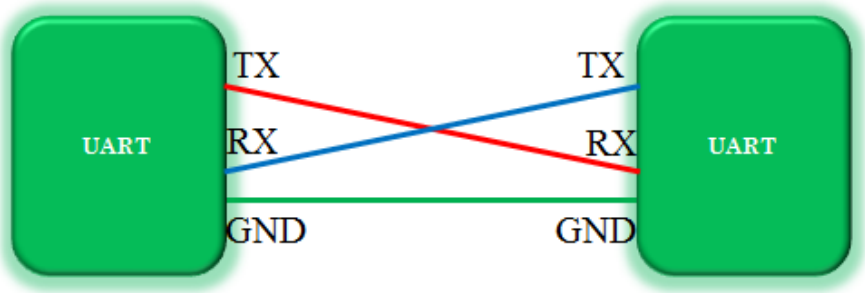


UART AND USB



UART AND USB

UART communications



- Full duplex communications
  - Can transmit and receive at the same time
- Asynchronous
  - Does not have a clock signal
- Peer to peer serial bus communication
  - Does not work with master-slave concept

UART AND USB

UART uses the following communications parameters:

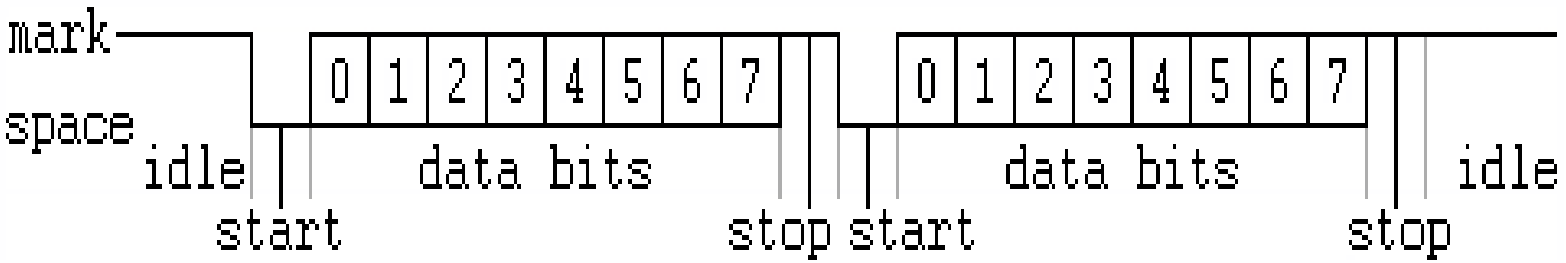
- Baud Rate
  - Rate (or speed) of data transmission (in Bits per sec, BPS)
- Stop Bits
  - Stop bits serve to bring the receiving device to rest in preparation for reception of next data
- Data Bits
  - Number of data bits in each character transmitted
- Parity
  - Bit that is added to data stream for error detection.

UART AND USB

Possible values for each Communication parameters

- Baud Rate
  - 1200, 2400, 4800, 9600, 19200, 38400, 57600, 115200
- Stop Bits
  - 1, 1.5, 2
- Data Bits
  - 7, 8
- Parity
  - ODD, EVEN, NONE

UART AND USB



- Data bits (0 – 7) 8 bits
- No parity bit
- 1 Stop bit

Even Parity Example: 0110 00 11 | 0 <= Even no of 1s

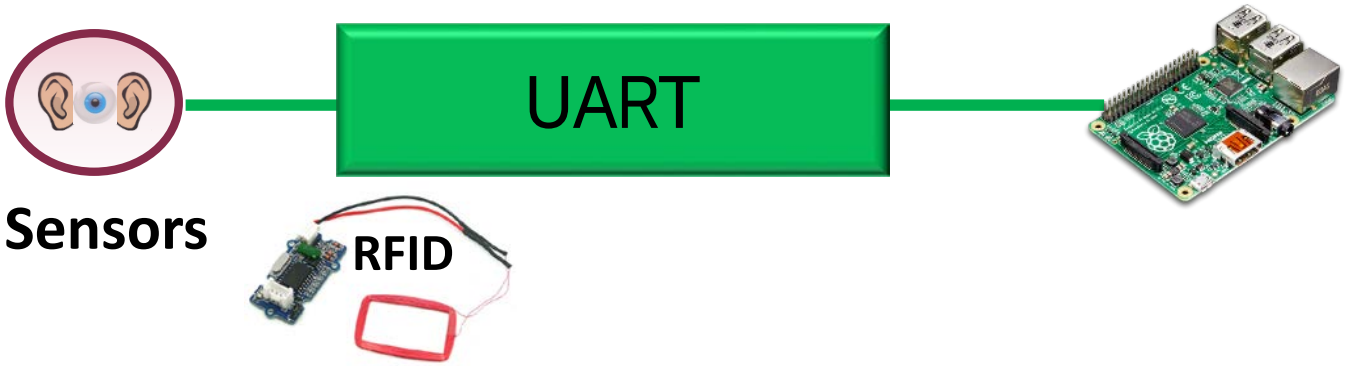
Odd Parity Example: 0110 00 11 | 1 <= Odd no of 1s

Data Bits Parity Bit

UART AND USB

UART communications

- Micro-controller to Sensor

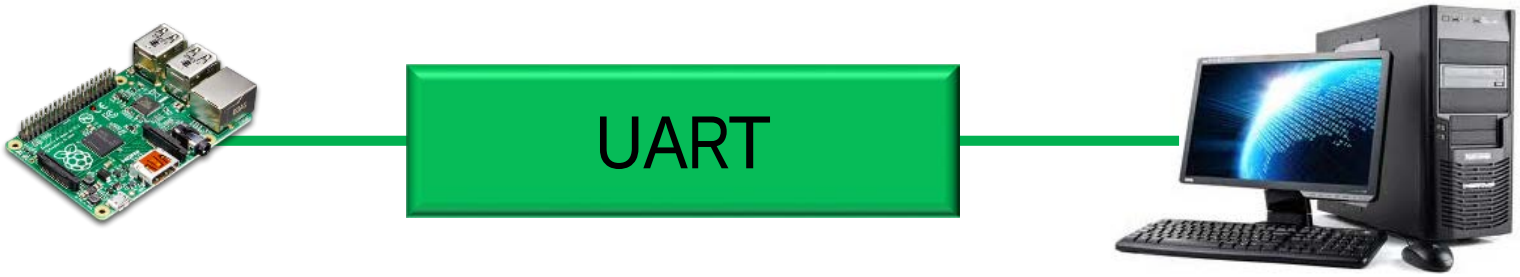


- Micro-controller to Micro-controller

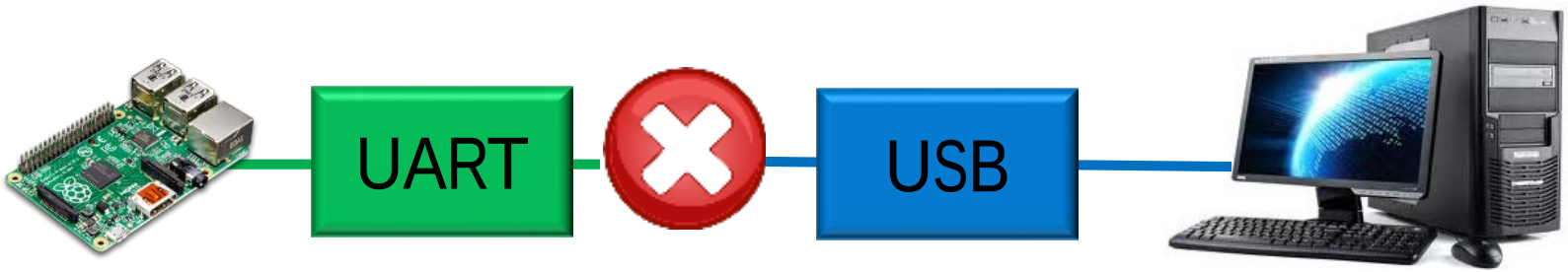
UART AND USB

UART communications to Wired Backend

- Micro-controller to Personal Computer (with UART)

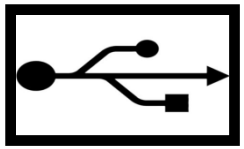


- Micro-controller to Personal Computer (Without UART)



Incompatible !!!

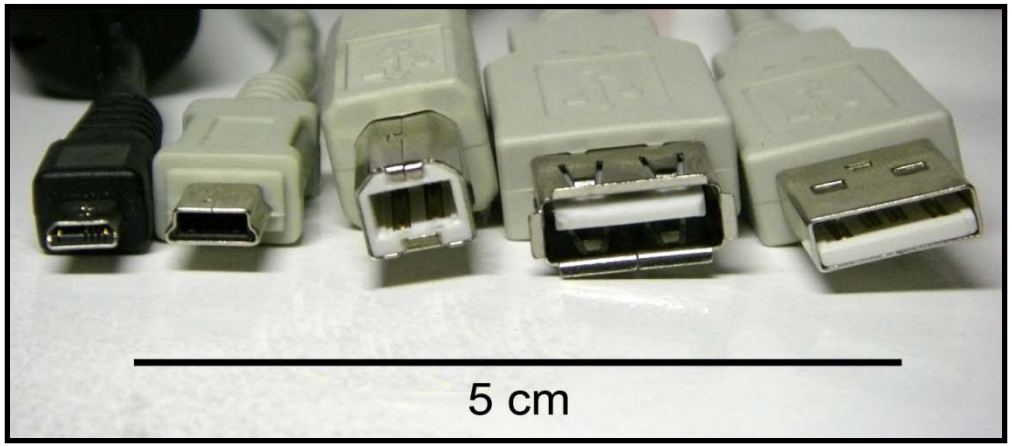
UART AND USB

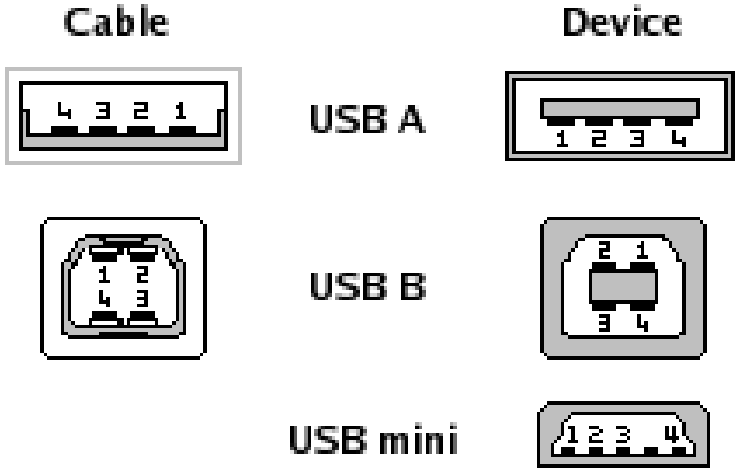


- Universal Serial Bus (USB) is a serial bus standard to connect devices to a host computer.
- Improve the plug and play capabilities by allowing hot swapping.
- Provide power to low-consumption USB devices
- Allow many devices to be used without requiring manufacturer specific device drivers to be installed.

UART AND USB

USB Connectors



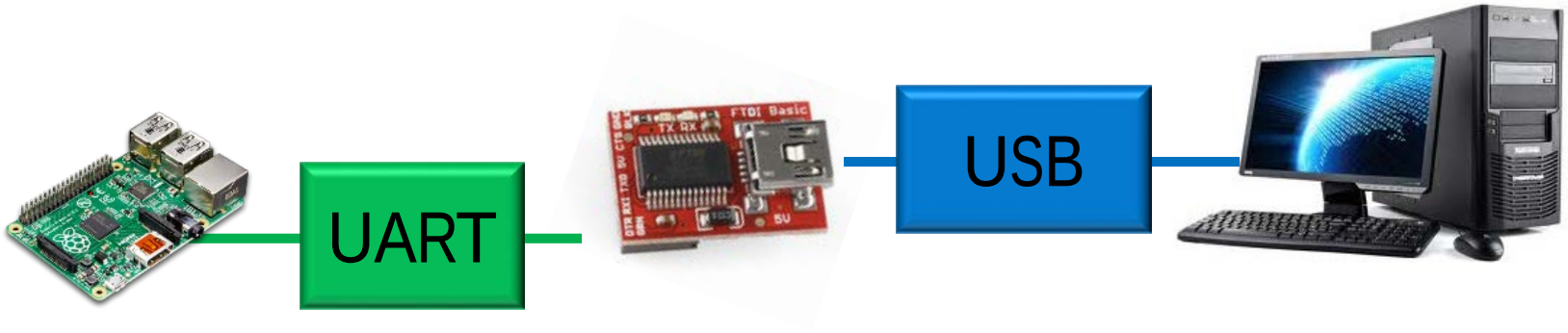


Pin	Signal	Description
1	VCC	+5V
2	D-	Data -
3	D+	Data +
4	GND	Ground

UART AND USB

USB UART Convertor

- It is circuit board that converts signal between UART and USB.
- It enables a device communicating on UART to be connected to another communicating on USB
- The above convertor has a USB UART IC (FT232RL) that does this conversion



INTER-INTEGRATED CIRCUIT (I^2C)

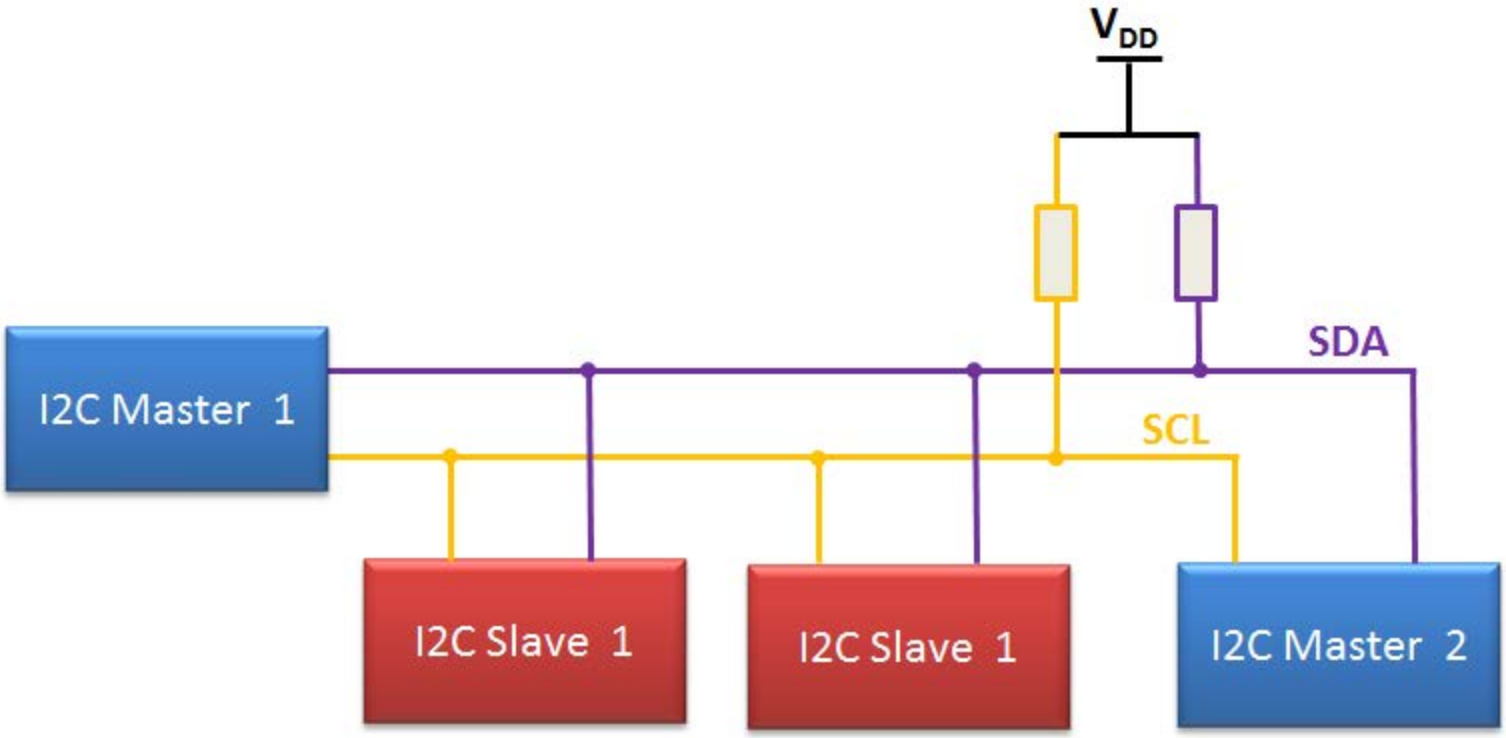
What is I2C

- It is a multi-master multi-slave serial bus invented by Philips used for communication between low-speed devices
- Each device connected to the bus must have a unique address
- It uses a addressing scheme (7 bits or 10 bits) for master to indicate which slave to get the data
- It uses two bidirectional lines
  - Serial Data Line (SDA) : Used to transmit data or address
  - Serial Clock (SCL) : Used to synchronised data transmission
- It is a half-duplex and synchronous communications

INTER-INTEGRATED CIRCUIT (I^2C)

I2C connections

- Typical I2C Bus Connections
- Requires pull up Resistors to power supply V_{DD} for both SCL and SDA



INTER-INTEGRATED CIRCUIT (I^2C)

I2C roles and modes of operation

- Each device on the bus may play either of these roles
  - Master Node : Generates the clock and initiates communication with slaves
  - Slave Node : Receives the clock and responds when addressed by the master

- Four possible modes of operation for the device
  - Master transmit : Master node is sending data to a slave
  - Master receive : Master node is receiving data from a slave
  - Slave transmit : Slave node is sending data to the master
  - Slave receive : Slave node is receiving data from the master

SERIAL PERIPHERAL INTERFACE (SPI)

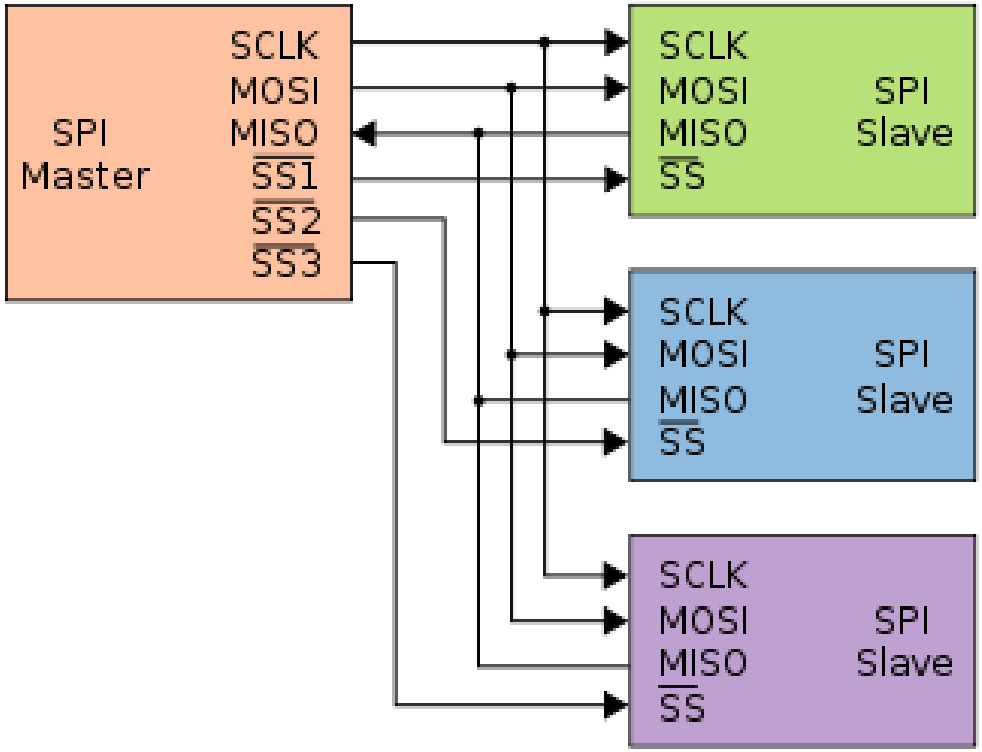
Serial Peripheral Interface (SPI) Bus

- It is a single master multi-slave serial bus communication by Motorola
- It uses a Slave Select (SS) line for master to indicate which slave to get the data
- The master must select only one slave at any time
- It is a full-duplex and synchronous communications
- It has 4 communication lines
  - SCLK: serial clock : Clock sent by master to synchronize the transmission
  - MOSI: Master Output, Slave Input: Data sent by master to slave
  - MISO: Master Input, Slave Output: Data sent by slave to master
  - SS: Slave Select: Sent by master to select designated slave to react

SERIAL PERIPHERAL INTERFACE (SPI)

Serial Peripheral Interface (SPI) Bus

- Typical SPI Bus Connections



SPI VS I^2C

SPI	I^2C
Uses 4 lines bus connections , more expensive	Uses 2 lines bus connections, cheaper
No addressing is required due to SS	Requires addressing to identify slave
Allowing only one master	Supports Multi-master mode
Supports full duplex communications	Supports half duplex communications
Higher Throughput	Lower Throughput

WIRED BACKEND DATA TRANSMISSION

Usual mode of Wired Backend Data Transmission

- UART
- USB
- Ethernet

Ethernet

- Ethernet was invented in 1973 by Xerox Corp
- Use for local area network (LAN)
- Ethernet made use of CSMA/CD to ensure that all PC on the LAN network have equal access to the network for communication purposes

ETHERNET

CSMA/CD (Carrier Sense Multiple Access with Collision Detection)

- **Carrier Sense :** Listens to the network's shared media to see if any other users are using the shared 'line' (i.e. shared media is 'busy').
- **Multiple Access :** If no transmission is sensed, (line is 'free') then anyone can access/use the media without any further permission.
- **Collision Detection :** If two PCs detected that line is free and access the shared media at the exact same time, a **collision** occurs and is **detected**.
- When a collision occurs, a **jamming signal** is sent out by the first PC to signal the collision.
- The PCs will then wait a certain random amount of time before retransmitting – since its random, chances of both PCs wait for the same amount of time is very small.

REVIEW QUESTIONS

REVIEW QUESTION

Name the various communication interfaces of GPIO pins

Answer:

- Digital Input/Output (DIO)
- Analog Input
- Universal Asynchronous Receiver Transmitter (UART)
- Pulse Width Modulation (PWM)
- Inter-Integrated Circuit (I2C)
- Serial Peripheral Interface (SPI)

REVIEW QUESTION

(a) What does UART stands for.

(b) With the aid of a diagram, explain the process of data communications between 2 processors using UART.

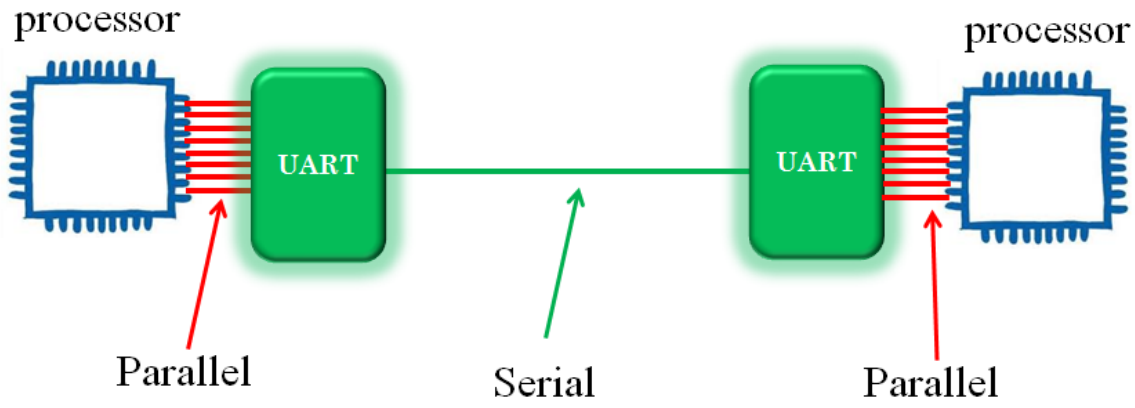
See Next Page for answer

ANSWER

(a) UART stands for Universal Asynchronous Receiver Transmitter

(b)

- Computer processor operates at byte level but serial transmission channel is in bit level.
- The UART breaks data bytes(Parallel) from processor into data bits (serial) for transmission through the serial channel.
- The UART receives data bits (Serial) from channel and convert them back into bytes (parallel) to be processed by processor.



REVIEW QUESTION

In UART communication, you need to connect the communications lines correctly and configure the 4 communications parameters.

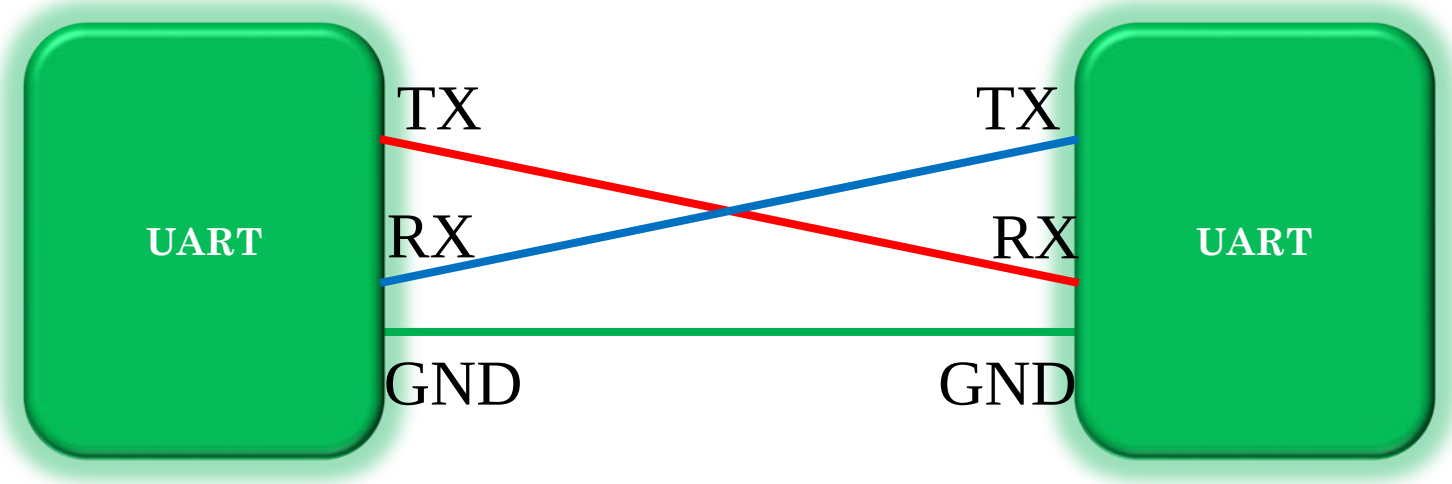
(a) Name the 3 communication lines
(b) Draw the connection diagram for these 3 lines
(c) List down the 4 communications parameters
(d) Write down the functions of the parameters
(e) Provide 1 possible value for each of the communications parameter.?

ANWERS

(a) The 3 communication lines

- Transmit (TX)
- Receive (RX)
- GND

(b) Connection diagram of the 3 lines



ANSWERS

(c) (d) (e)

Communication Parameters	Functions	Possible values
Baud Rate	Rate (or speed) of data transmission (in Bits per sec, BPS)	9600
Stop Bits	Stop bits serve to bring the receiving device to rest in preparation for reception of next data	1
Data Bits	Number of data bits in each character transmitted	8
Parity	Bit that is added to data stream for error detection.	Odd

REVIEW QUESTION

Pulse Width Modulation (PWM) is one of common the General Purpose Input/Output (GPIO) pins present in a micro-controller.

(a) Draw and label a diagram of a PWM.

(b) Define the formula for Duty Cycle.

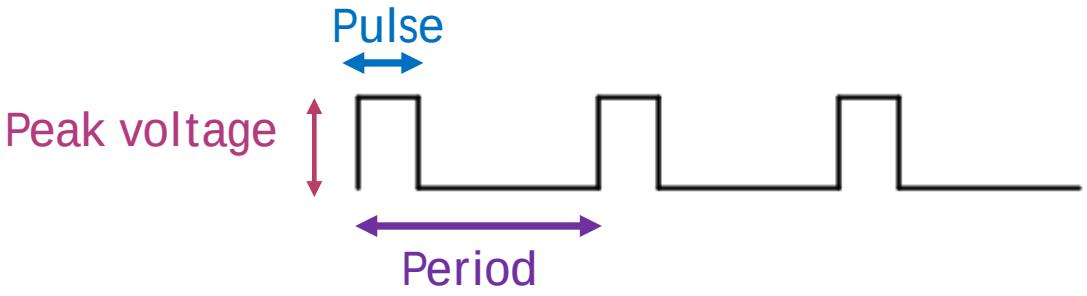
(c) Define the formula of PWM Average Voltage.

(d) Calculate the duty cycle required to output 3.75V from a 5V peak voltage PWM.

ANSWER

(a) Diagram of a labelled PWM

- The time duration of 1 cycle is known as <u>period</u>
- The time duration within the cycle where output state is high is known as the <u>pulse</u>

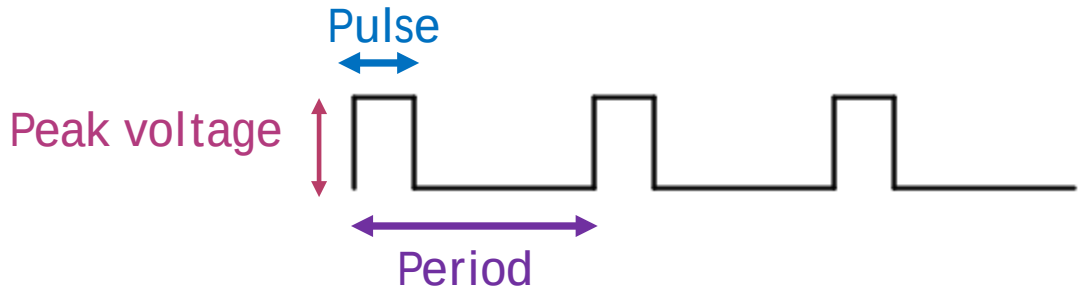


(b)

$$\text{Duty cycle} = \frac{\text{pulse}}{\text{period}} \times 100\ \%$$

ANSWER

(c) PWM Average Voltage



$$\text{Avg Voltage} = \frac{\text{Duty Cycle}}{100} \times \text{Peak Voltage}$$

(d)

- $3.75 = \frac{\text{Duty Cycle}}{100} \times 5$

Therefore Duty Cycle = 75 %

REVIEW QUESTION

Some sensors in the market operates using Inter-Integrated Circuit (I2C) messaging.

(a) Define the operating principle of I2C.

(b) Define its mode of operations.

See Next Page for answer

ANSWER

(a) I2C operating principle

- It is a multi-master multi-slave serial bus used for communication between low-speed devices
- Each device connected to the bus must have a unique address
- It uses a addressing scheme (7 bits or 10 bits) for master to indicate which slave to get the data
- It uses two bidirectional lines
  - Serial Data Line (SDA) : Used to transmit data or address
  - Serial Clock (SCL) : Used to synchronised data transmission
- It is a half-duplex and synchronous communications

ANSWER

(b) I2C Mode of operation

- Four possible modes of operation for the device
  - Master transmit : Master node is sending data to a slave
  - Master receive : Master node is receiving data from a slave
  - Slave transmit : Slave node is sending data to the master
  - Slave receive : Slave node is receiving data from the master

REVIEW QUESTION

Some sensors in the market operates using Serial Peripheral Interface (SPI) messaging.

Define the operating principle of SPI.

See Next Page for answer

ANSWER

Serial Peripheral Interface (SPI) Bus

- It is a single master multi-slave serial bus communication
- It uses a Slave Select (SS) line for master to indicate which slave to get the data
- The master must select only one slave at any time
- It is a full-duplex and synchronous communications
- It has 4 communication lines
  - SCLK: serial clock : Clock sent by master to synchronize the transmission
  - MOSI: Master Output, Slave Input: Data sent by master to slave
  - MISO: Master Input, Slave Output: Data sent by slave to master
  - SS: Slave Select: Sent by master to select designated slave to react

REVIEW QUESTIONS

Many micro-controller in the fields offer both Serial Peripheral Interface (SPI) and Inter-Integrated Circuit (I2C) messaging.

Use a table to describe five differences between the SPI and I2C.

See Next Page for answer

ANSWER

SPI	I^2C
Uses 4 lines bus connections , more expensive	Uses 2 lines bus connections, cheaper
No addressing is required due to SS	Requires addressing to identify slave
Allowing only one master	Supports Multi-master mode
Supports full duplex communications	Supports half duplex communications
Higher Throughput	Lower Throughput

REVIEW QUESTION

Which type of data communication always requires a clock signal?

A. Synchronous
B. Asynchronous
C. Half Duplex
D. Full Duplex

Answers => A

REVIEW QUESTION

Radio Broadcasting is type of _____ communication?

A. Simplex
B. Quarter Duplex
C. Half Duplex
D. Full Duplex

Answers => A

REVIEW QUESTION

Walkie-Talkie is type of _____ communication?

A. Simplex
B. Quarter Duplex
C. Half Duplex
D. Full Duplex

Answers => C

REVIEW QUESTION

Phone conversation is type of _____ communication?

A. Simplex
B. Quarter Duplex
C. Half Duplex
D. Full Duplex

Answers => D

REVIEW QUESTION

A push button switch is usually connected to which General Purpose Input/Output (GPIO)?

A. Digital Input
B. I2C Input
C. Analog Input
D. Pulse Width Modulation Input

Answers => A

REVIEW QUESTION

A potentiometer is usually connected to which General Purpose Input/Output (GPIO)?

A. Digital Input
B. I2C Input
C. Analog Input
D. Pulse Width Modulation Input

Answers => C

REVIEW QUESTION

The process of sending data one bit at a time, sequentially over a communication channel is known as _____ communication?

A. Simplex
B. Duplex
C. Serial
D. Parallel

Answers => C

REVIEW QUESTION

Which General Purpose Input/Output (GPIO) uses the technique where durations of high and low state of digital output are varied to form digital pulses?

A. Ethernet
B. Pulse Width Modulation (PWM)
C. Serial Peripheral Interface (SPI)
D. Inter-Integrated Circuit (I2C)

Answers => B

REVIEW QUESTION

Which of the following is added to data stream for error detection?

A. Stop bit
B. Parity bit
C. Serial Clock (SCL) bit
D. Slave Select (SS) bit

Answers => B

REVIEW QUESTION

Inter-Integrated Circuit (I2C) is a type of _____ serial bus?

A. Single-Master Single-Slave
B. Single-Master Multi-Slave
C. Multi-Master Single-Slave
D. Multi-Master Multi-Slave

Answers => D

REVIEW QUESTION

Serial Peripheral Interface (SPI) is a type of _____ serial bus?

A. Single-Master Single-Slave
B. Single-Master Multi-Slave
C. Multi-Master Single-Slave
D. Multi-Master Multi-Slave

Answers => B

REVIEW QUESTION

In Carrier Sense Multiple Access with Collision Detection (CSMA/CD), what signal is sent when collision occurs?

A. Collision signal
B. Jamming signal
C. Stop signal
D. Backoff signal

Answers => B

STRUCTURED QUESTIONS

Quantum Sensor Pte Ltd is developing an attendance clocking system that deals with a Radio Frequency Identification (RFID) reader. The micro-controller is required to interface with the reader over a UART.

(a) What does UART stands for.

(b) With the aid of a diagram, explain the process of data communications between 2 processors using UART.

(c) What are the 3 communications line of a UART.

(d) Draw the connection diagram for these 3 lines.

(e) Use a Table to list down and describe the 4 communications parameters of a UART and provide a valid setting for each of them.