CHAPTER 5 Communication Protocols

Contents:

- Modes of data communication: serial, parallel, synchronous and Asynchronous communication.
- Serial communication standards: RS232, MAX232 as a bidirectional level converter.
- Communication protocols & its types, Serial Communication: I2C, CAN, USB, SPI
- Features of **wireless** serial protocol IrDA, bluetooth, zigbee, WiFi.

1. Need of Communication Interface

- Essential for communicating with various subsystems of embedded systems.
- Device/board level communication interface.
- Product level communication interface.
- For sending data to host system and display it on GUI
- For communicating with other embedded systems.
- For networking and sharing data.
- For connecting embedded systems to internet.
- For interfacing with mobile devices.
- For software up-gradation via interfaces.

2. Serial and Parallel Communication

Computers transfer data in two ways:

□ Parallel

□ Often 8 or more lines (wire conductors) are used to transfer data to a device that is only a few feet away

□ Serial

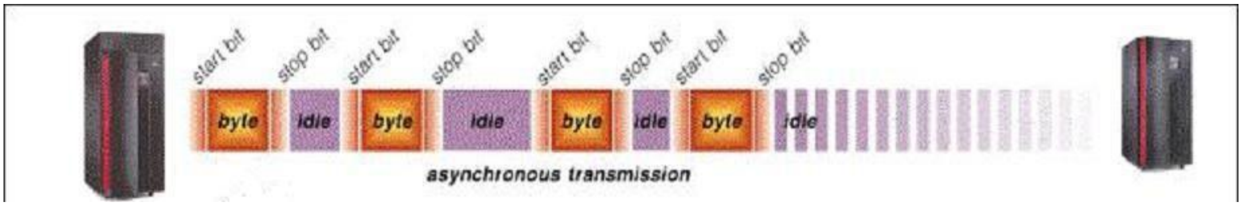
□ To transfer to a device located many meters away, the serial method is used

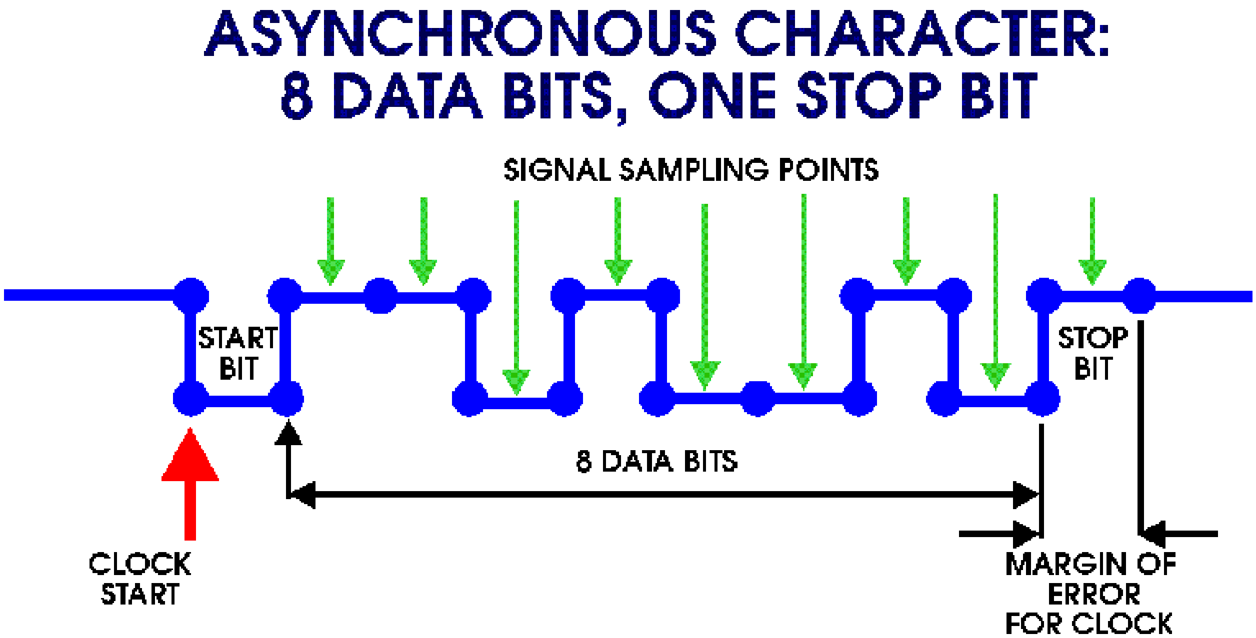
□ The data is sent one bit at a time

Serial Communication	Parallel Communication InstrumentationTools.com
Data transmitted serially, one bit at a time.	Data is transmitted parallelly, all bits at a time.
Low Speed	High Speed
It has single transmission line.	It has multiple transmission lines
Serial communication do not have any crosstalk problem.	Parallel communication may have crosstalk problem
Less expensive	More expensive
The bandwidth is higher	The bandwidth is lower
It is not affected with noise problems.	It may suffer with noise problems
Serial communication even works at high frequencies.	Parallel communication may not work properly at high frequencies
It covers long distance when compared to parallel communication.	It is used for short distances
Example: Serial communication between a computer and modem	Example: Parallel communication between a motherboard and hard disk

3. Asynchronous and Synchronous:

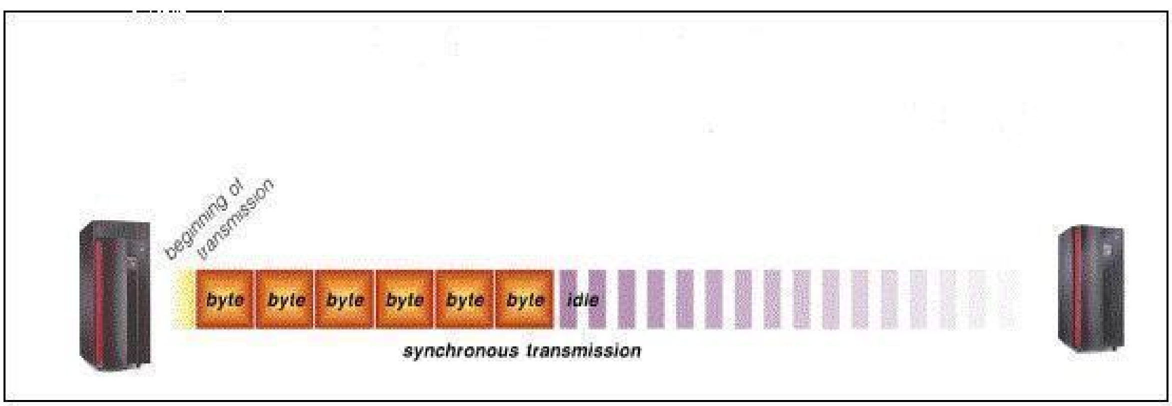
Asynchronous:

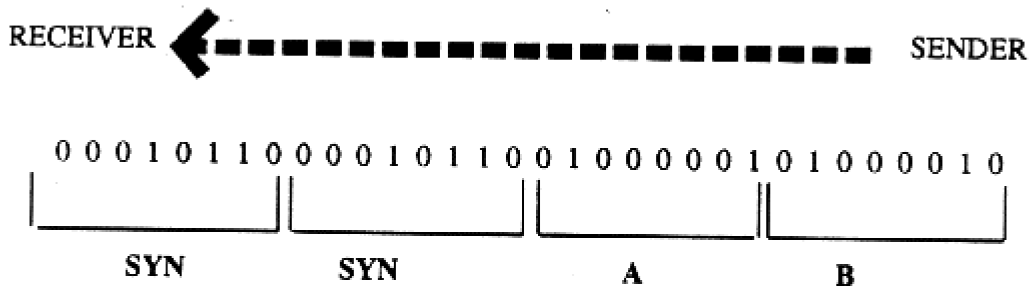




- The sender and receiver are not Synchronised.
- The sender sends only one character at a time.
- Each character needs a start bit and a stop bit.
- There can be idle time between each character.
- It is a slow and inefficient method of data transmission.
- It is an inexpensive method for low speed transmission.

Synchronous:





SYNCHRONOUS SERIAL TRANSMISSION

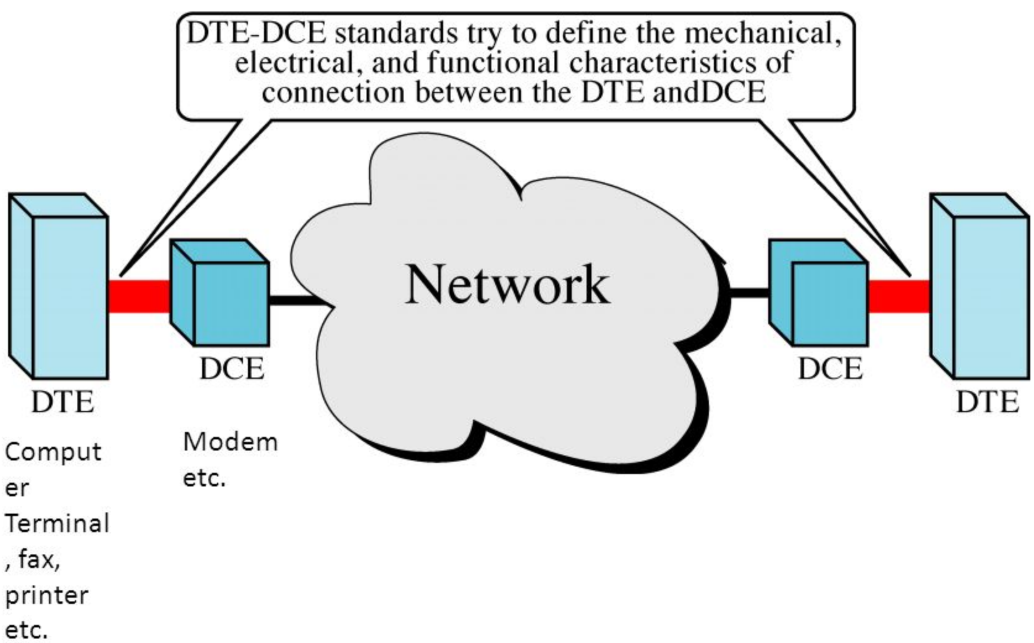
- The senders and the receivers clocks are synchronised.
- The sender sends a packet of data at a time.
- Synchronisation is achieved by sending a ‘start’ frame and a ‘stop’ frame.
- It is a more efficient method of transmission as only a start and stop frame are required with up to 8Kb of data in the packet of data.
- Asynchronous has a much higher overhead.

Sr. No.	Factor	Asynchronous	Synchronus
1.	Data send at one time	Usually 1 byte	Multiple bytes
2.	Start and Stop bit	Used	Not used
3.	Gap between Data units	Present	Not present
4.	Data transmission speed	Slow	Fast
5.	Cost	Low	High

4. **RS232**
   - o RS232 communication is between a DTE (computer) COM (communication) port and a DCE (modem) port. DTE stands for 'Data Terminal Equipment'. DCE stands for 'Data Communication Equipment'. RS232C is a standard for interfacing signals between DCE and DTE.
   - o RS-232 is a standard by which two serial devices communicate (recommended standard)

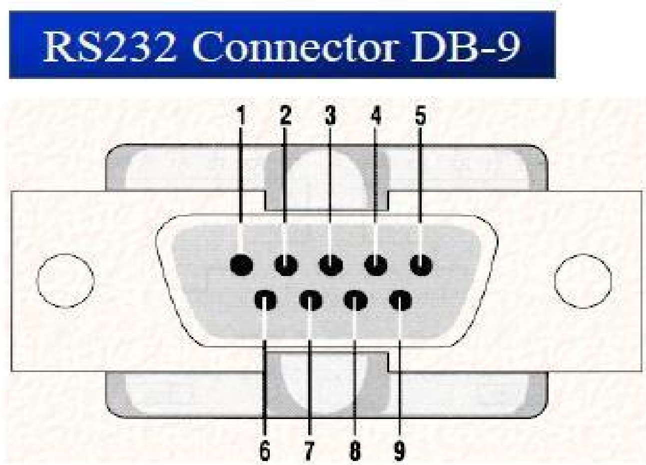
- The RS-232 interface is the Electronic Industries Association (EIA) standard for the interchange of serial binary data between two devices.
- It was initially developed by the EIA to standardize the connection of computers with telephone line modems
- The connection must be no longer than 50 feet.(15 m)
- Transmission voltages are –15V and +15V.
- It is designed around transmission of *characters*
- The max transfer rate is 20 kbps
- asynchronous form of communication.
- Logical 1 is -3 to –15VDC.
- Logical 0 is +3 to +15VDC.
- When the connection is idle, the hardware ties the connection to logical 1.

DTE-DCE interface



DTE is short for Data Terminal Equipment and DCE stands for Data Communications Equipment. DTE indicates this is a piece of device that ends a communication line, whereas the DCE provides a path for communication.
Let's say we have a computer on which wants to communicate with the Internet through a modem and a dial-up connection. To get to the Internet you tell your modem to dial the number of your provider. After your modems has dialed the number, the modem of the provider will answer your call and your will hear a lot of noise. Then it becomes quiet and you see your login prompt or your dialing program tells you the connection is established. Now you have a connection with the server from your provider and you can

wander the Internet.
In this example you PC is a Data Terminal (DTE). The two modems (yours and that one of your provider) are DCEs, they make the communication between you and your provider possible.
DB9 Connector:



RS232 DB-9 Pins

Pin	Description
1	Data carrier detect (-DCD)
2	Received data (RxD)
3	Transmitted data (TxD)
4	Data terminal ready (DTR)
5	Signal ground (GND)
6	Data set ready (-DSR)
7	Request to send (-RTS)
8	Clear to send (-CTS)
9	Ring indicator (RI)

Handshaking Signals:

Modem Cable - Straight Cable DB9 to DB9

DTE Device (Computer) DB9		DTE to DCE Connections	DCE Device (Modem) DB9	
Pin# DB9 RS-232 Signal Names		Signal Direction	Pin# DB9 RS-232 Signal Names	
#1 Carrier Detector (DCD)	CD	←	#1 Carrier Detector (DCD)	CD
#2 Receive Data (Rx)	RD	←	#2 Receive Data (Rx)	RD
#3 Transmit Data (Tx)	TD	→	#3 Transmit Data (Tx)	TD
#4 Data Terminal Ready	DTR	→	#4 Data Terminal Ready	DTR
#5 Signal Ground/Common (SG)	GND	—	#5 Signal Ground/Common (SG)	GND
#6 Data Set Ready	DSR	←	#6 Data Set Ready	DSR
#7 Request to Send	RTS	→	#7 Request to Send	RTS
#8 Clear to Send	CTS	←	#8 Clear to Send	CTS
#9 Ring Indicator	RI	←	#9 Ring Indicator	RI
Soldered to DB9 Metal - Shield	FGND	—	Soldered to DB9 Metal - Shield	FGND

- DTR (data terminal ready)

□ When terminal is turned on, it sends out signal DTR to indicate that it is ready for communication

⦿ DSR (data set ready)

□ When DCE is turned on and has gone through the self-test, it assert DSR to indicate that it is ready to communicate

⦿ RTS (request to send)

□ When the DTE device has byte to transmit, it assert RTS to signal the modem that it has a byte of data to transmit

⦿ CTS (clear to send)

□ When the modem has room for storing the data it is to receive, it sends out signal CTS to DTE to indicate that it can receive the data now

⦿ DCD (data carrier detect)

□ The modem asserts signal DCD to inform the DTE that a valid carrier has been detected and that contact between it and the other modem is established

⦿ RI (ring indicator)

□ An output from the modem and an input to a PC indicates that the telephone is ringing

□ It goes on and off in synchronous with the ringing sound

8051 connection to RS 232

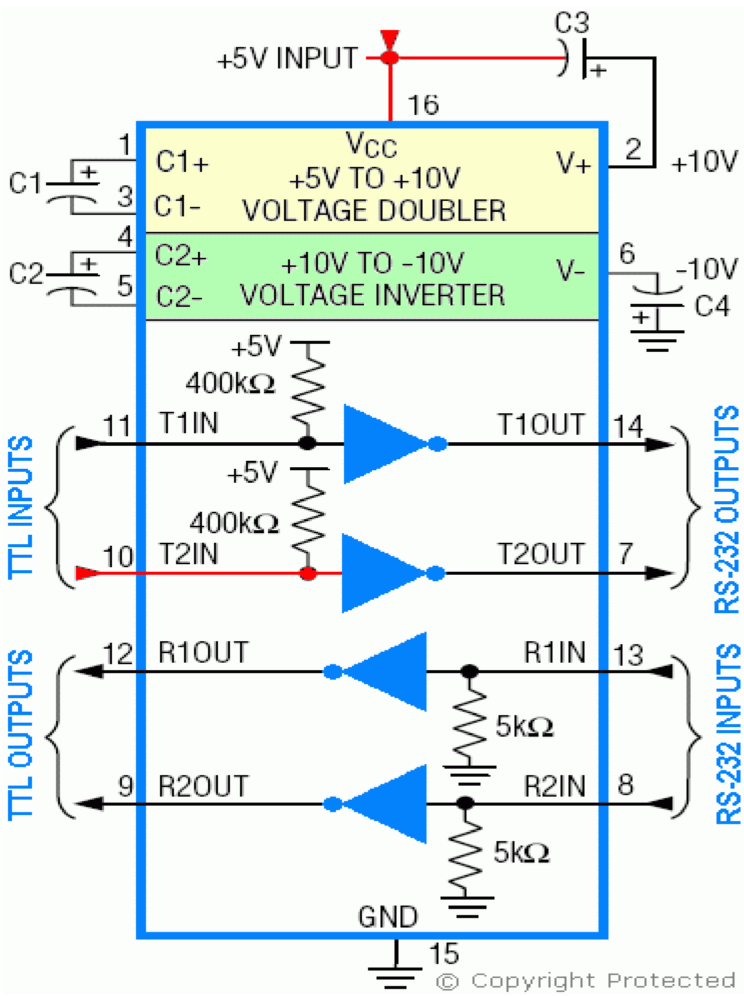
MAX 232

The MAX232 is a hardware layer *protocol converter* IC manufactured by the Maxim Corporation. Commonly known as a *RS-232 Transceiver*, it consists of a pair of drivers and a pair of receivers. The drivers convert between TTL and CMOS voltage levels (TIA/EIA-232-E), which is required for serial port communications. Utilized in embedded microcontroller systems, and computers, this IC has been one of the most popular components in production for many years. If you have a microcontroller circuit that requires communication through a serial port, then this is the IC to use.

The RS-232 serial communication protocol requires a voltage between -3 V to -15 V to represent binary 1, and a voltage between +3 V to +15 V to represent binary 0. For CMOS and TTL communication, this is incompatible since TTL uses +5 V to represent binary 1 and 0 V to represent binary 0. This chip therefore performs the necessary protocol conversion of the electrical voltage levels in both directions.

Since RS-232 requires higher voltage levels, the manufacturers thoughtfully incorporated switched-capacitor charge pump circuits within the IC to generate the required voltage levels. The doubler, as the name suggests, doubles the voltage

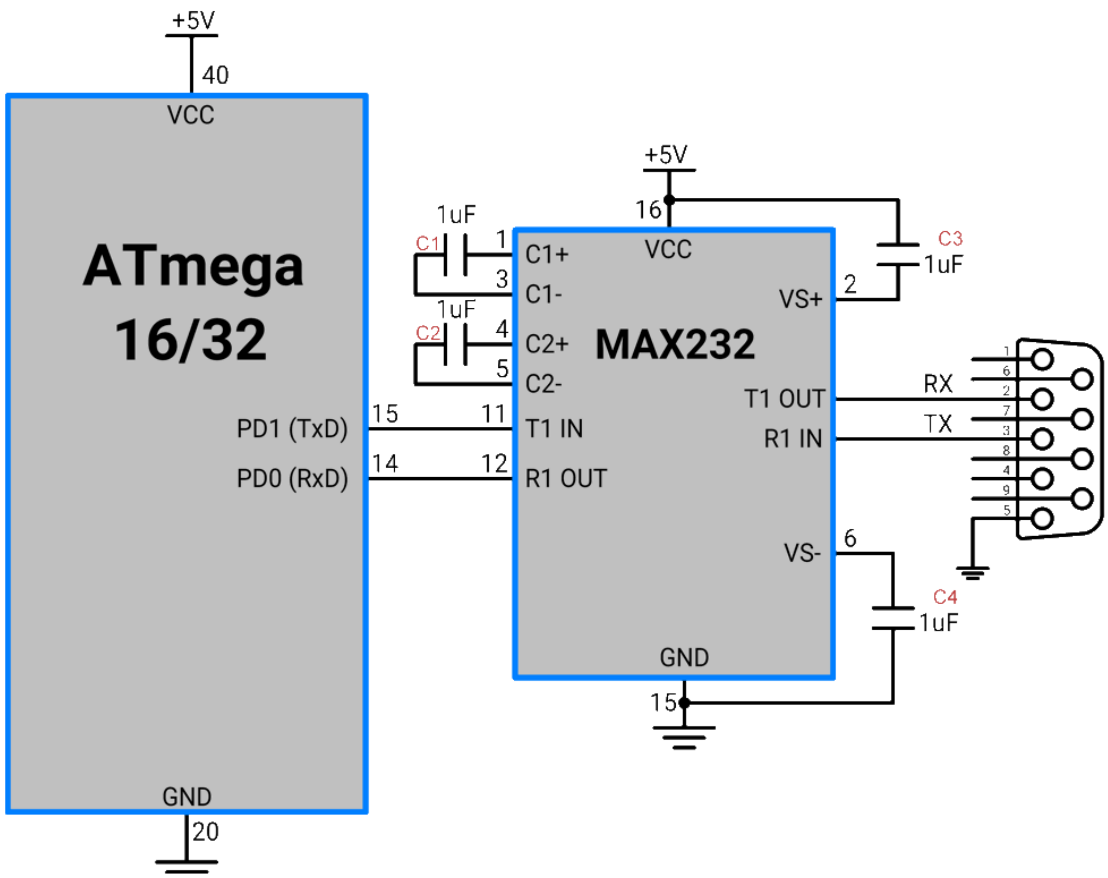
level to produce +10 V, whilst the inverter produces the negative voltage supply of
-10 V.
The external *support capacitors* C2 and C4 are part of the voltage inverter circuit that creates the negative voltage. However, C1 and C3 are part of the voltage doubler circuit.
As you can see, the proper operation of this IC relies on the correct value capacitors connected to it. There are many versions of this IC and they all have different requirements for their external support capacitors. For MAX232 all the capacitors value IS 1microFarad.



(source: https://www.petervis.com/electronics%20guides/MAX232/MAX232.html)

TTL	
LOGIC 0	0 V
LOGIC 1	5 V

RS232	
LOGIC 0	+3 to +25 V
LOGIC 1	-3 to -25 V



5. **I²C**

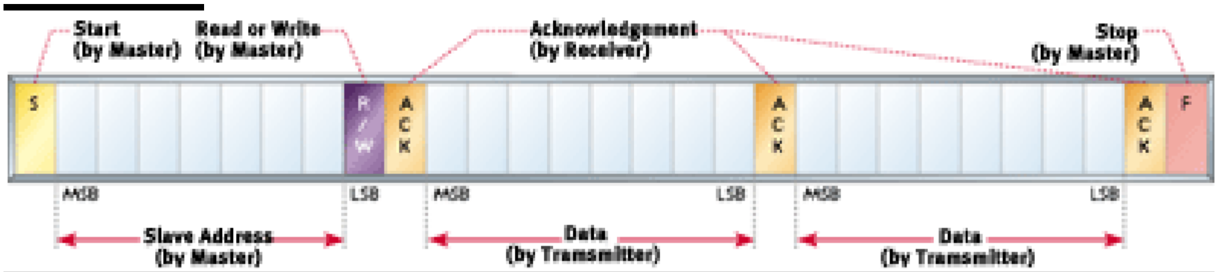
Shorthand for an "Inter-integrated circuit" bus
Developed by Philips Semiconductor for TV sets in the 1980's
I²C devices include EEPROMs, thermal sensors, and real-time clocks
Used as a control interface to signal processing devices that have separate data interfaces, e.g. RF tuners, video decoders and encoders, and audio processors.

<u>Features:</u>

1. I²C bus has three speeds:
   a. Slow (under 100 Kbps)
   b. Fast (400 Kbps)
   c. High-speed (3.4 Mbps) – I²C v.2.0
2. Limited to about 10 feet for moderate speeds.

3. 2-wire serial bus – Serial data (SDA) and Serial clock (SCL)
4. Half-duplex, synchronous, multi-master bus
5. No chip select or arbitration logic required
6. Lines pulled high via resistors, pulled down via open-drain drivers (wired- AND) If any single node writes a zero, the entire line is zero.

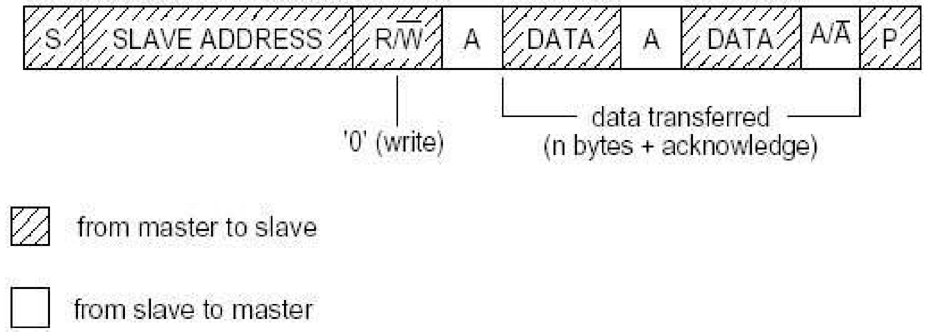
I^{2}C Protocol



1. Master sends start condition (S) and controls the clock signal
2. Master sends a unique 7-bit slave device address
3. Master sends read/write bit (R/W) – 0 - slave receive, 1 - slave transmit
4. Receiver sends acknowledge bit (ACK)
5. Transmitter (slave or master) transmits 1 byte of data
6. Receiver issues an ACK bit for the byte received
7. 7. Repeat 5 and 6 if more bytes need to be transmitted.
8. 8.a) For write transaction (master transmitting), master issues stop condition (P) after last byte of data.
9. 8.b) For read transaction (master receiving), master does not acknowledge final byte, just issues stop condition (P) to tell the slave the transmission is done.

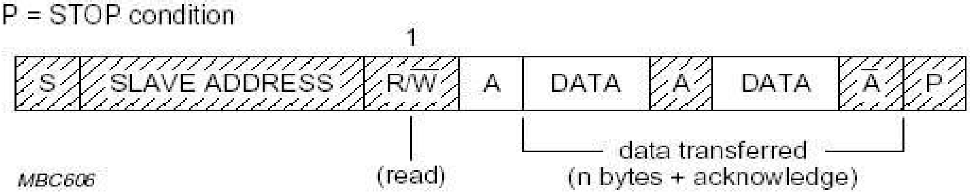
Frame format:

MASTER-TRANSMITTER:



A = acknowledge (SDA LOW)
$\overline{A}$ = not acknowledge (SDA HIGH)
S = START condition
P = STOP condition

MASTER-RECEIVER:



Advantages

1. 2 wire communication.
   - 2. ICs can be added or removed from system with out effecting any other circuit on the bus.
   - 3. Integrated addressing and data transfer protocol allow system to
   - be completely software dependent.
   - 4. Don’t require device drivers(plug and play).
   - 5. Low power consumption
   - 6. Cost Effective. Cost and complexity do not scale up with the number of devices
   - 7. Good for communication with on-board devices that are accessed occasionally.

Limitations

- 1. Get reflections at especially at high speeds. (To avoid this use dynamic resistor or current source)
- 2. Ghost signals may disturb transmission and corrupt the data.
- 3. Long lines present capacitive load.
- 4. No time outs in standard mode
- 5. The complexity of supporting software components can be higher than that of competing schemes

Comparison:

Name	Sync/ async	type	duplex	Max devices
RS232	Async	peer	full	2
I2C	Sync	Multi master	half	N

6. **CAN**

- Most widely used automotive networking Standard.
- Since very reliable, also used in other fields including Health Care
- Developed by the Robert Bosch Company in Germany.

Features

- A number of different data rates are defined, with 1Mbps (Bits per second) being the top end, and 10kbps the minimum rate.

- Simple transmission medium Twisted pair of wires
- Cable length depends on the data rate used. The maximum line length is 1Km, 40 meters at 1Mbps. Termination resistors are used at each end of the cable.
- The worst-case transmission time of an 8-byte frame with an 11-bit identifier is 134 bit times (that's 134 microseconds at the maximum baud rate of 1Mbits/sec).
- The CAN interface uses an asynchronous/ half duplex transmission scheme controlled by start and stop bits at the beginning and end of each character.
- Any node can access the bus when the bus is quiet
- Non-destructive bit-wise arbitration to allow 100% use of the bandwidth without loss of data
- Variable message priority based on 11-bit (or 29 bit) packet identifier
- Automatic error detection, signaling and retries
- Data packets 8 bytes long.

FRAME TYPES

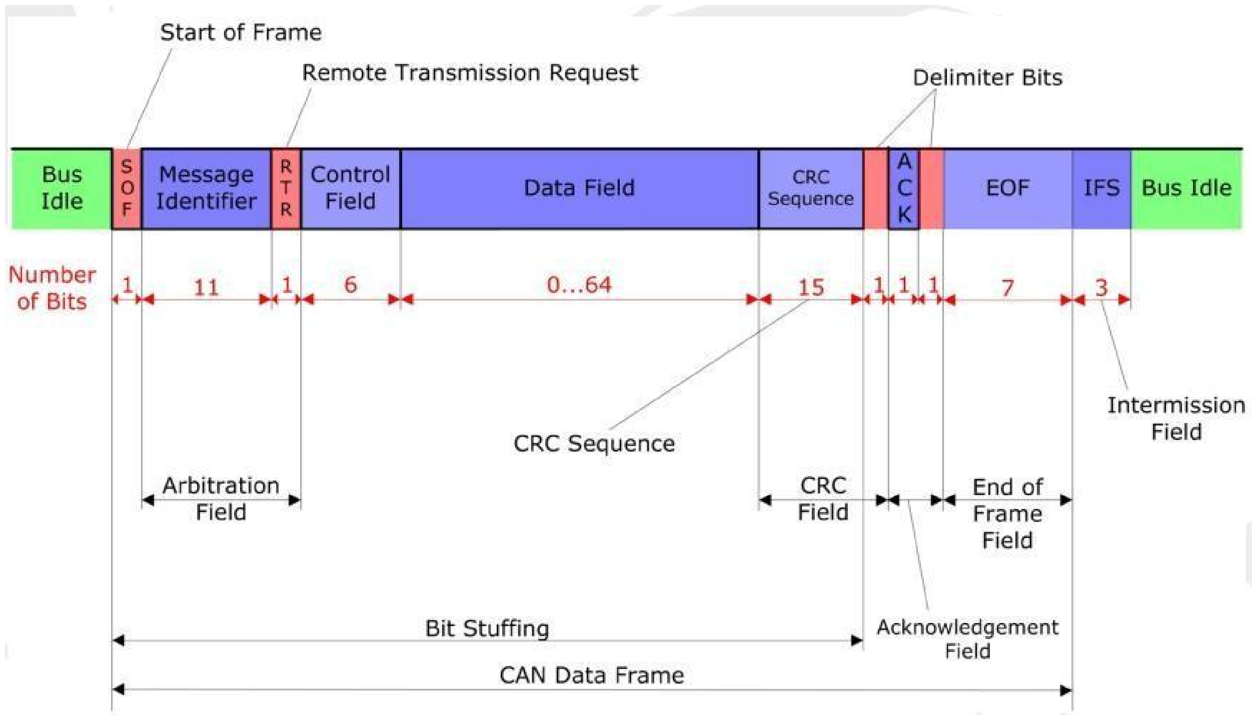
Message transfer is manifested and controlled by four different frame types: A DATA FRAME carries data from a transmitter to the receivers.

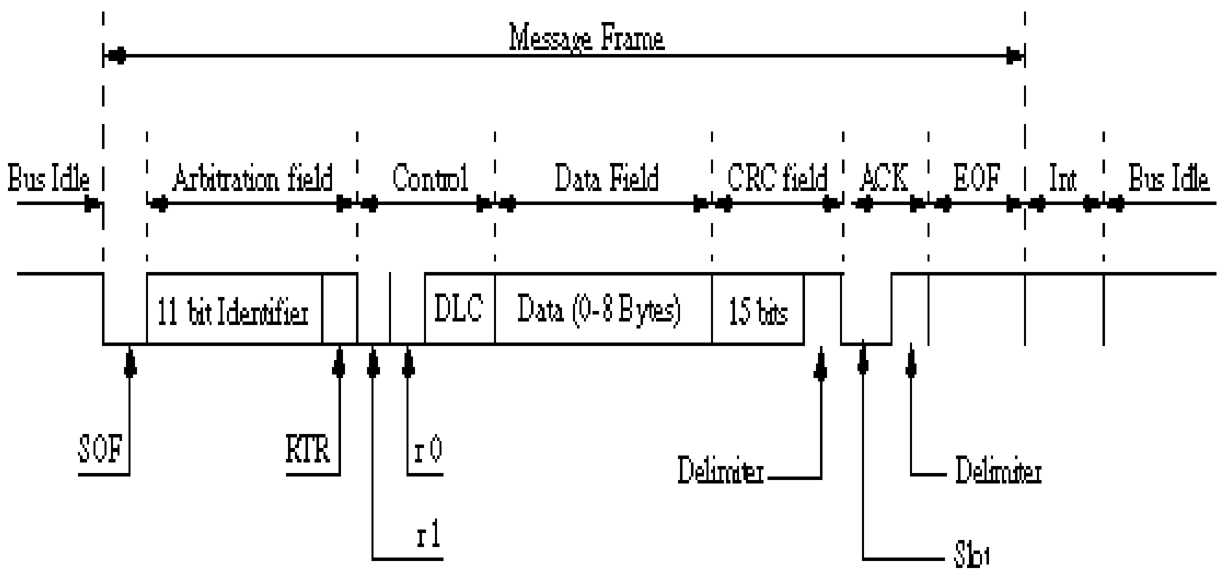
A REMOTE FRAME is transmitted by a bus unit to request the transmission of the DATA FRAME with the same IDENTIFIER.

An ERROR FRAME is transmitted by any unit on detecting a bus error.

An OVERLOAD FRAME is used to provide for an extra delay between the preceding and the succeeding DATA or REMOTE FRAMEs.

DATA FRAME FORMAT





A DATA FRAME is composed of seven different bit fields:

START OF FRAME, ARBITRATION FIELD, CONTROL FIELD, DATA FIELD, CRC FIELD, ACK FIELD, END OF FRAME.
The DATA FIELD can be of length zero.

START OF FRAME

- marks the beginning of DATA FRAMES and REMOTE Frames. It consists of a single ’dominant’ bit.
- A station is only allowed to start transmission when the bus is idle . All stations have to synchronize to the leading edge caused by START OF FRAME of the station starting transmission first

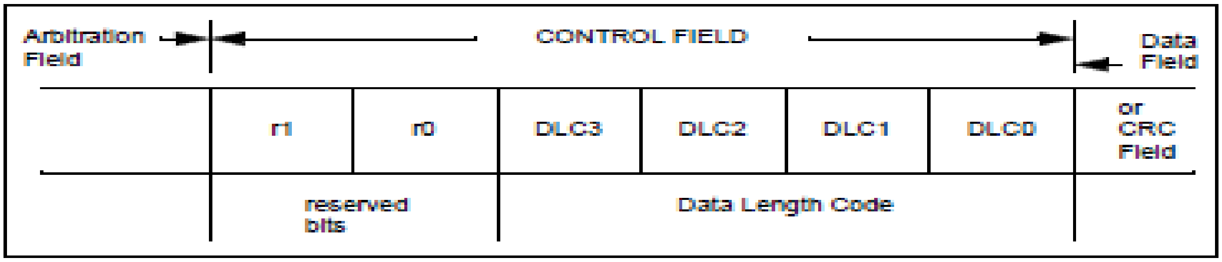
ARBITRATION FIELD

- The ARBITRATION FIELD consists of the IDENTIFIER and the RTR-BIT
- The IDENTIFIER’s length is 11 bits. These bits are transmitted in the order from ID-10 to ID-0. The least significant bit is ID-0. The 7 most significant bits (ID-10 - ID-4) must not be all ’recessive’.
- Remote Transmission Request BIT

In DATA FRAMEs the RTR BIT has to be ’dominant’. Within a REMOTE FRAME the RTR BIT has to be ’recessive’.

CONTROL FIELD

- The CONTROL FIELD consists of six bits. It includes the DATA LENGTH CODE and two bits reserved for future expansion. The reserved bits have to be sent ’dominant’.
- The number of bytes in the DATA FIELD is indicated by the DATA LENGTH CODE.
- This DATA LENGTH CODE is 4 bits wide and is transmitted within the CONTROL FIELD.



Coding of the number of data bytes by the DATA LENGTH CODE

abbreviations: d 'dominant'
r 'recessive'

Number of Data Bytes	Data Length Code			
	DLC3	DLC2	DLC1	DLC0
0	d	d	d	d
1	d	d	d	r
2	d	d	r	d
3	d	d	r	r
4	d	r	d	d
5	d	r	d	r
6	d	r	r	d
7	d	r	r	r
8	r	d	d	d

DATA FRAME: admissible numbers of data bytes: {0,1,....,7,8}.
Other values may not be used.

<u>CRC FIELD</u>

The CRC field consists of CRC sequence and CRC delimiter.CRC sequence is a code generated for error checking. The CRC delimiter consists of single recessive bit.

<u>ACK FIELD</u>

- The ACK FIELD is two bits long and contains the ACK SLOT and the ACK DELIMITER. In the ACK FIELD the transmitting station sends two ’recessive’ bits.

- A RECEIVER which has received a valid message correctly, reports this to the TRANSMITTER by sending a ’dominant’ bit during the ACK SLOT (it sends ’ACK’).
- The ACK DELIMITER is the second bit of the ACK FIELD and has to be a ’recessive’ bit.

END OF FRAME:

- Each DATA FRAME and REMOTE FRAME is delimited by a flag sequence consisting of seven ’recessive’ bits

Bus Arbitration In CAN

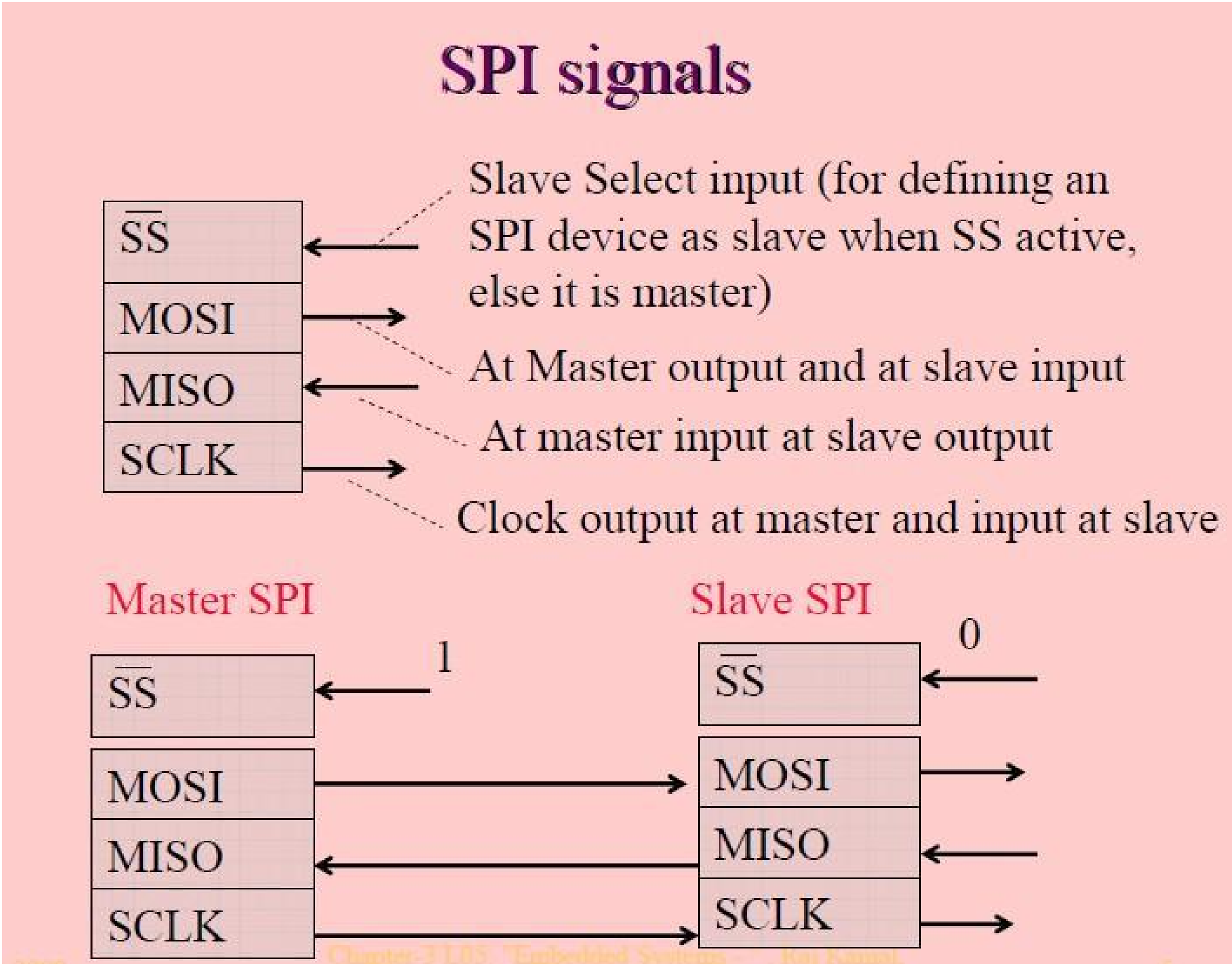
To avoid data collisions, CAN performs a bitwise and nondestructive arbitration on the bus. The lower the value of the identifier, the higher the priority of the frame.
Whenever the bus is free (recessive level), any station can start to transmit data.
If two messages are simultaneously sent over the CAN bus, the bus takes the bit wise “logical AND” of all them starting from most significant bit. Hence, the messages identifiers with the lowest binary number gets the highest priority. Every device listens on the channel and backs off as and when it notices a mismatch
between the bus’s bit and its identifier’s bit.

Comparison

	CAN	I2C
FORMAT	SERIAL, ASYNCHRONOUS	SERIAL, synchronous
Identifier	Message based, 7 bit address	Device based,11 bit address
LENGTH(MAX)	1 KM, 40 Meters at 1Mbps	Upto 10 feet for moderate speed
SPEED(MAX)	1 Mbps	3.4mbps
Developed by	Robert Bosch Company	Phillips semiconductors

APPLICATION	Most widely used in vehicle networking	designed specifically for communication between ICs
Transmission Lines	Uses balanced line interface	Single line interface
Noise	Uses maximum bandwidth, hence data loss less	More data loss

7. **SPI : Serial Peripheral Interface**
   - Developed by Motorola
   - Also known as MicroWire (National Semiconductor), QSPI (Queued),MicrowirePlus
   - Primarily used for serial communication between a host processor and peripherals.
   - Can also connect 2 processors via SPI
   - SPI works in a master slave configuration with the master being the host microcontroller for example and the slave being the peripheral
   - Full-duplex
   - Synchronous communication.
   - SCLK, MOSI and MISO signals for serial clock from master, output from master and input to master, respectively.
   - Device selection as master or slave can be done by a signal to hardware input SS. (Slave select when 0) pin



- SPI protocol specifies 4 signal wires.
- Master Out Slave In (MOSI) - MOSI signal is generated by Master, recipient is the Slave.
- Master In Slave Out (MISO) - Slaves generate MISO signals and recipient is the Master.
- 3. Serial Clock (SCLK or SCK) - SCLK signal is generated by the Master to synchronize data transfers between the master and the slave.
- 4. Slave Select (SS) from master to Chip Select (CS) of slave - SS signal is generated by Master to select individual slave/peripheral devices. The SS/CS is an active low signal.

Configuration:

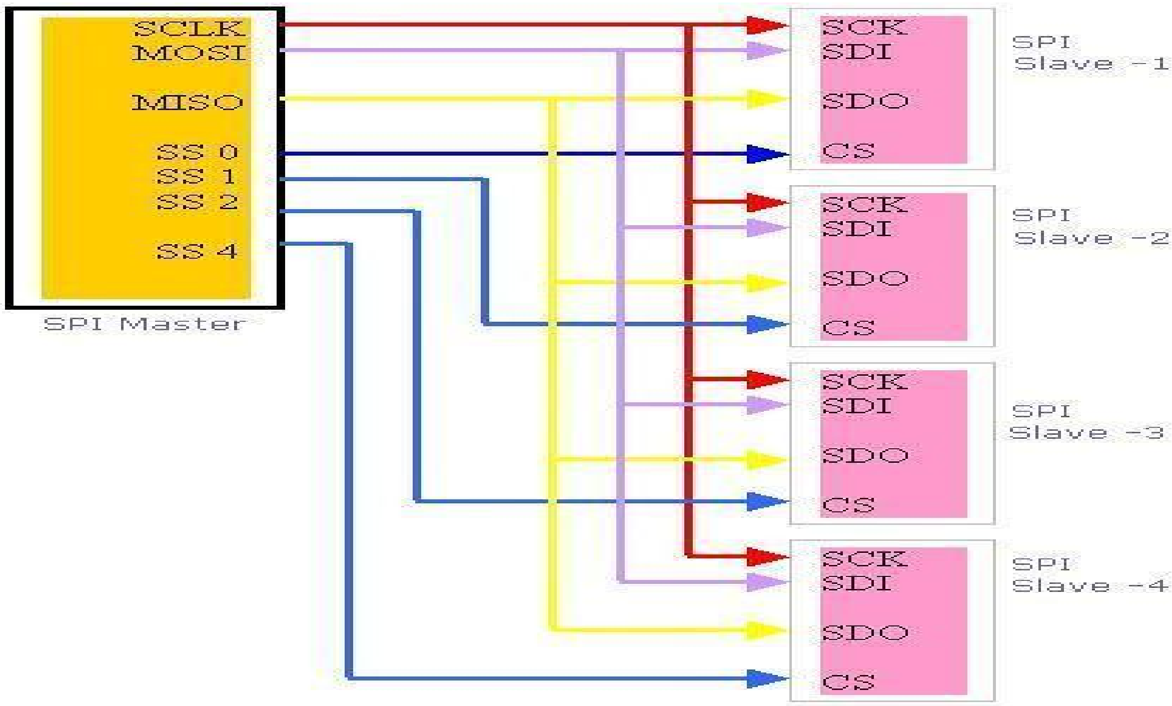


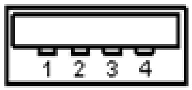
Fig – 4 (SPI bus in independent slave configuration)

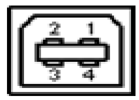
- In SPI-bus communication there can be one master with multiple slaves.
- In single-master protocol, usually one SPI device acts as the SPI Master and controls the data flow by generating the clock signal (SCLK) and activating the slave it wants to communicate with slave-select signal (SS),
- Then it receives and or transmits data via the two data lines.
- A master, usually the host micro controller, always provides clock signal to all devices on a bus whether it is selected or not.
- The slaves on the bus that has not been activated by the master using its slave select signal will disregard the input clock and MOSI signals from the master, and must not drive MISO.

8. Universal Serial Bus(USB)

- It is Host Polled bus .
- Device responds in a "speak when spoken to" arrangement.
- The plug and play capability of the USB is one of its advantages over other serial buses (hot pluggable)
- Power management :- devices can automatically power down when not in use
- Data Transmission Rate
    - USB1.0 : Up to 1.5 Mb/s
    - USB1.1 : Up to 12 Mb/s
    - USB 2.0 : Up to 480 Mb/s

connectors





Pin Number	Cable Colour	Function
1	Red	V_{BUS} (5 volts)
2	White	D-
3	Green	D+
4	Black	Ground

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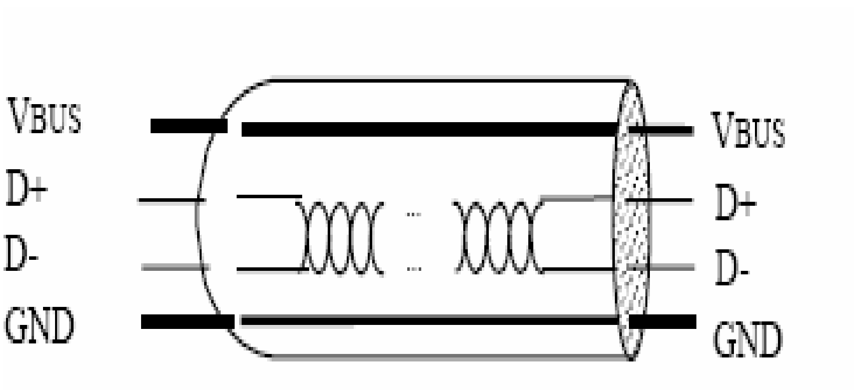
Electrical Characteristics:

- USB uses a differential transmission pair for data

- On low and full speed devices, a differential ‘1’ is transmitted by pulling D+ over 2.8V and D- under 0.3V with appropriate pull up/pull down registers.
- A differential ‘0’ on the other hand is a D- greater than 2.8V and a D+ less than 0.3V with the same appropriate pull down/up resistors
- Physical wire consists of 4 pins
- Two wires D+ and D- are used to carry the signal
- Vbus is normally +5V at the source.
- USB cable connectors have power pins longer than signal pins so that power is applied before the signals



- Each USB transaction consists of a
    - Token Packet (Header defining what it expects to follow), an
    - Optional Data Packet, (Containing the payload) and a
    - Status Packet (Used to acknowledge transactions and to provide a means of error correction)

9. **Wireless Communication Protocols**

a. **Infrared Data Association(IrDA)**

The Infrared Data Association (IrDA) was established in 1993 to create and maintain international standards for the hardware and software used in infrared communication links.

- A focused ray of light in the infrared frequency spectrum - is modulated with information and sent from a transmitter to a receiver. The communication between the devices requires that each has a transceiver (a combination of a transmitter and a receiver) in order to communicate. However, devices may also require further, specialized software allowing communication to be synchronized.

The IrDA 1.1 standard has following features

- a maximum data transmission size of 2,048 bytes
- a maximum transmission rate of 4Mbps.
- interconnection of products of up to 1m in distance
- At 5m data transfer rate will be up to 75kbps.

Applications

- PDAs
- Phones
- Organizer
- Printers
- Digital Cameras
- Laptops and Notebooks, Keyboards, Mouse
- TV,AC,LCD projectors.

Advantages

- Point-to-point
- Transfer data up to 1m
- Security
- Low power consumption

- Low

cost Disadvantages

- o IR uses a line-of-sight transmission. Thus, it is sensitive to atmospheric conditions and bad weather, particularly fog.
- o One device at a time
- o Transfer rate 4Mbps
- o Have to keep the device stable when transferring data

b. Bluetooth

- The Bluetooth special interest Group founded by Ericsson, IBM, Intel, Nokia, and Toshiba in 1998. It was created to develop an open specification for short-range wireless connectivity between laptops, computers, cellular telephones and other electronic devices.Bluetooth is a wireless technology standard for exchanging data over short distances (using short- wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz[3]) from fixed and mobile devices.

Features:

- Short range Radio Frequency at 2.4 GHz
- Point-to-point or point-to-multiple points
- Voice and Data
- Transmit through walls up to 10m
- Supports both synchronous and asynchronous services
- Bluetooth 1.x supports data rate up to 1Mbps.
- Bluetooth 2.0 enhanced maximum data rate of 3Mbps over 100m.
- Bluetooth devices use a protocol called (FHSS) Frequency-Hopping Spread Spectrum .

Applications:

- Wireless Head Sets
- Cell Phones
- Laptops and Notebooks
- PDA’s
- Printers
- Car manufactures Industry
- E-Mail / Internet / Intranet Access

Advantage:

Advantages

- No line of Sight
- Lower power consumption
- 2.5 GHz radio frequency ensures worldwide operation
- Very adaptive

c. ZIGBEE

- ZigBee is a worldwide open standard for wireless radio networks in the monitoring and control fields. The standard was developed by the ZigBee Alliance (an association of international companies) .

Features

- low cost
- ultra-low power consumption
- use of unlicensed radio bands
    - The unlicensed RF bands are not the same in all territories of the world, but IEEE 802.15.4 employs three possible bands, at least one of which should be available in a given territory.

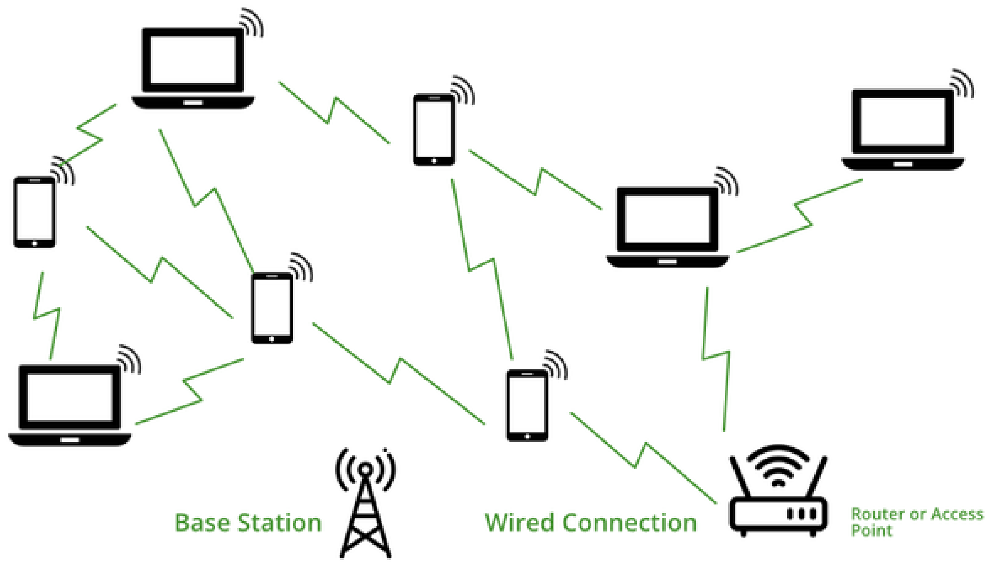
    - The three bands are centred on the following frequencies: **868**, **915** and **2400 MHz**.
- cheap and easy installation
- flexible and extendable networks
- integrated intelligence for network set-up and message routing
- In an open area, a range of over 200 metres can typically be achieved , in a building, a range of 30 metres can typically be achieved.

d. WiFi

- **WiFi technology is a wireless technology that allows devices access to the internet without the need for cables**. Depending on the router and the connection, it has a range of around 100 meters.
- The connection **is possible through infrared and radiofrequency waves**. In this way, the information can be transmitted. In addition, having a WiFi technology router allows several devices to connect to the internet at the same time.
- Due to the development of more and more devices and technologies, we not only have smartphones or PCs connected to the internet but also tablets or smart TVs.
- For the Wi-Fi connection to work properly, **a router is necessary**. This is a device connected by cables to the Internet. Through infrared and radiofrequency waves, **the router is capable of sending information to the devices** and for them to connect to the Internet.
- For a good internet connection, **the devices must be in the range of the router**, and the closer to the router, the better the connectivity.
- Once the router is installed, **we need its identification name and the password through which we can connect** the devices to the internet. For example, when you activate the Wi-Fi option on your smartphone and it is the first time you connect to that router, it will ask the name and password.
- Once this action is done, the device will already be connected to the internet. Also, this step does not need to be done every time but is done the first time you connect to a particular router. Thus, the device remembers the router and its password.

For transmitting Wi-Fi signal there is three medium,

- **Base station network or an Ethernet(802.3) connection:** It is the main host network from where the network connection is provided to the router.
- **Access point or router:** it is a bridge between a wired network and a wireless network. It accepts a wired Ethernet connection and converts the wired connection to a wireless connection and spreads the connection as a radio wave.
- **Accessing devices:** It is our mobile, computer, etc from where we use the Wi-Fi and surfing internet.



IEEE 802.11 is the set of technical guidelines used for implementing Wi-Fi

Standards	Year of Release	Description
Wi-Fi-1 (802.11b)	1999	This version has a link speed from 2Mb/s to 11 Mb/s over a 2.4 GHz frequency band
Wi-Fi-2 (802.11a)	1999	After a month of release previous version, 802.11a was released and it provide up to 54 Mb/s link speed over 5 Ghz band
Wi-Fi-3 (802.11g)	2003	In this version the speed was increased up to 54 to 108 Mb/s over 2.4 GHz
802.11i	2004	This is the same as 802.11g but only the security mechanism was increased in this version

802.11e	2004	This is also the same as 802.11g, only Voice over Wireless LAN and multimedia streaming are involved
Wi-Fi-4 (802.11n)	2009	This version supports both 2.4 GHz and 5 GHz radio frequency and it offers up to 72 to 600 Mb/s speed
Wi-Fi-5 (802.11ac)	2014	It supports a speed of 1733 Mb/s in the 5 GHz band

A new version is released in 2020 named *802.11ax* developed by Huawei, which can support, a maximum of 3.5 Gb/s. it is known as WiFI6

Features

- Wi-Fi uses radio waves to transmit information between your device and a router via frequencies. The radio-wave frequencies can be used, depending on the amount of data being sent: 2.4 GHz or 4 GHz (802.11b) or 5 GHZ (802.11 a)
- The Wi-Fi Alliance is a global, non-profit organization that helps to make sure standards and interoperability for wireless networks
- Most routers operate at 54 Mbps (megabits per second)
- It uses a star/mesh network during which all nodes send/receive data through access points