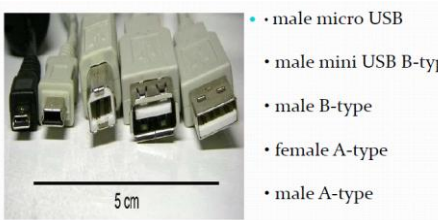
Lecture 9

3.7 Universal Serial Bus-USB:



Definition: USB, short for Universal Serial Bus, is an industry standard that defines cables, connectors and communications protocols for connection, communication, and power supply between computers and devices [1].

It connects peripheral devices such as digital cameras, mice, keyboards, printers, scanners, media devices, external hard drives and flash drives. Because of its wide variety of uses, including support for electrical power, the USB has replaced a wide range of interfaces like the parallel and serial port [2]. In 1995-96 Compaq, Digital Equipment Corporation (DEC), IBM, Intel, Microsoft and NEC, joined later by Hewlett-Packard, Lucent and, Philips got together and designed the USB [3].

Major Features of USB

- **Single connector type:** USB replaces all the different connectors with one well-defined, standardized USB connector for all USB peripheral devices.
- **Hot-swappable:** USB devices can be safely plugged and unplugged as needed while the computer is running. So there is no need to reboot.
- **Plug and Play:** Operating system software automatically identifies, configures, and loads the appropriate device driver when a user connects a USB device.
- **High performance:** USB offers low speed (1.5 Mbit/s), full speed (12 Mbit/s) and high speed (up to 480 Mbit/s) transfer rates that can support a variety of USB peripherals. USB 3.0 (SuperSpeed USB) achieves the throughput up to 5.0 Gbit/s.
- **Power supplied from the bus:** USB distributes the dc power to all connected devices eliminating the need for external power source for low-power devices.

3.7.1 The Standards:- USB 1.1 and USB 2.0

USB 1.0-1.1: Released in January 15, 1996-1998. Specified data rates of 1.5 Mb/s (Low-Bandwidth) and 12 Mb/s (Full-Bandwidth). Does not allow for extension cables or pass-through monitors (due to timing and power limitations). Few such devices actually made it to market.

USB 2.0: The USB 2.0 specification was released in April 27, 2000 and was ratified by the USB Implementers Forum (USB-IF) at the end of 2001. The major feature of revision 2.0 was the addition

of a high-speed transfer rate of 480 Mbit/s. USB 2.0 supports three speeds namely High Speed - 480Mbits/s, Full Speed - 12Mbits/s and Low Speed - 1.5Mbits/s with one host per bus (at a time).

USB 3.0:

- The USB 3.0 specification was published on 12 November 2008.
- Delivering data transfer rates up to ten times faster (the raw throughput is up to 5.0 Gbit/s) than Hi-Speed USB (USB 2.0), SuperSpeed USB is the next step in the continued evolution of USB technology.

Wireless USB:

Connections have the same personal security of wired USB 2.0.
• Released in May 12, 2005 which uses UWB (Ultra Wide Band) as the radio technology with speed 480 M bits/sec up to 3m.

USB On The Go (OTG):


The USB On-The-Go logo

USB On-The-Go, often abbreviated to USB OTG or just OTG, is a specification first used in late 2001 that allows USB devices, such as tablets or smartphones, to act as a host, allowing other USB devices, such as USB flash drives, digital cameras, mice or keyboards, to be attached to them. USB OTG is a new supplement to the USB 2.0 specification that arguments the capability of existing mobile devices and USB peripherals by adding host functionality for connection to USB peripherals.


A USB OTG setup involving a few devices

Features:

- A new standard for small form factor USB connectors and cables
- The addition of host capability to products that have traditionally been peripherals only, to enable point-to-point connection
- The ability to be either host or peripheral (dual role devices) and to dynamically switch between the two.

How USB works?

A typical USB connector, called an "A" connection

i. Know about Connectors:

The USB standard uses "A" and "B" connectors to avoid confusion:

- "A" connectors head "upstream" toward the computer.
- "B" connectors head "downstream" and connect to individual devices. [4]

ii. Know about Hubs:

The USB standard supports up to 127 devices

and USB hubs are a part of the standard.

Hub has two major roles: power management and signal distribution. Powered Hub; needed when connecting multiple unpowered devices such as mice or digital cameras. Un-powered hubs can be used with any number of high-power devices such as printers and scanners that have their own power supply, thus not requiring power from the bus.

USB Process:

Enumeration- the computer would decide which kind of data the device uses

- Interrupt - low data transfer - keyboard or mouse
- Bulk - large amounts of data - printer or external hard drive
- Isochronous - streamed data - microphones or speakers

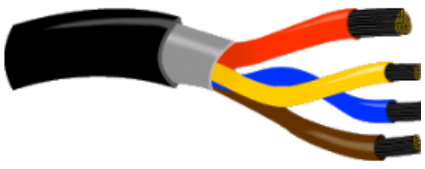
Encoding- the process of recoding or modifying information into a desired format or pattern

Transmission- Convey information from the device to another location.

Receiving-Recognizes and accepts information from transition and collects the inputs and readies them for storage

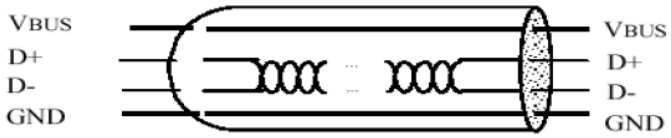
3.7.2 Signals, Throughput & Protocol

Signals



Inside a USB cable: There are two wires for power -- +5 volts (red) and ground (brown) -- and a twisted pair (yellow and blue) of wires to carry the data. The cable is also shielded.

Howstuffwork.com



Pin	Color	Name	Description
1	Red	Vcc	+5V dc
2	White	D-	Data-
3	Green	D+	Data+
4	Black	GND	Ground

Fig: USB electrical signals

Throughput: Throughput is the actual output of any device, USB's actual throughput is a function of many variables:

- Target device's ability to source or sink data
- Bandwidth consumption by other devices in the bus
- Efficiency of host's USB ports
- Types of data [5]

USB Protocols:

USB is host controlled. The USB host is responsible for undertaking all transactions and scheduling bandwidth. Data can be sent by various transaction methods using a token-based protocol. [6]

USB Topology: Star topology

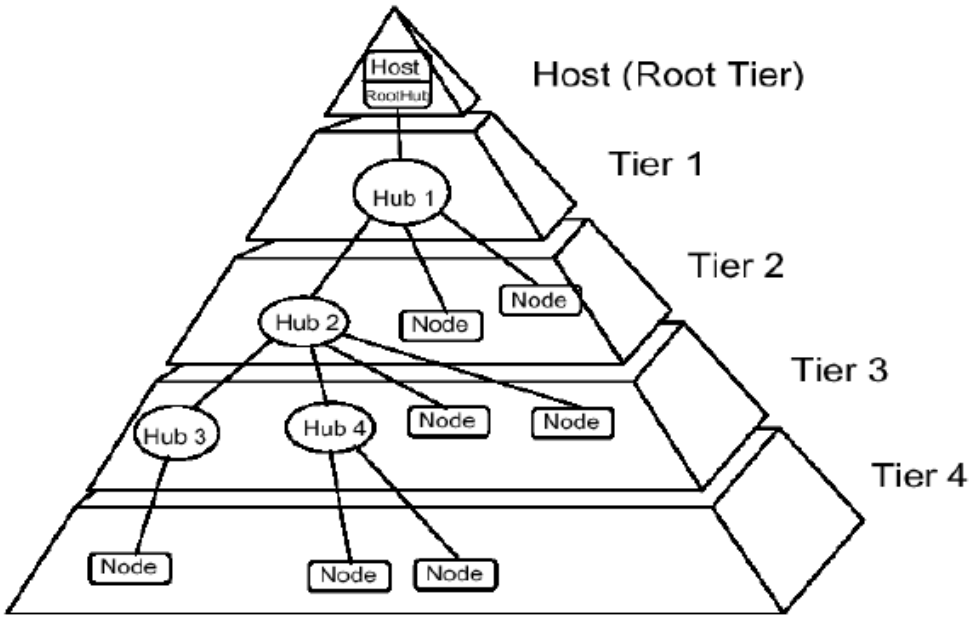


Fig: USB network protocol architecture

The USB is based on a so-called 'tiered star topology' in which there is a single host controller and up to 127 'slave' devices. A device can be plugged into a hub, and that hub can be plugged into another

hub and so on. However the maximum number of tiers permitted is six. The length of any cable is limited to 5 metres. This means that a device cannot be further than 30 metres from the PC, and even to achieve that will involve 5 external hubs, of which at least 2 will need to be self-powered.

USB packet types used in USB protocol:

- Token packets - indicate the type of transaction to follow (header defining)
- Data packets - contain the payload.
- Handshake packets - are used for acknowledging data or reporting errors.
- Start of frame packets - indicate the start of a new frame.

i. **Token Packets**: There are three types of token packets,

- In - Informs the USB device that the host wishes to read information.
- Out - Informs the USB device that the host wishes to send information.
- Setup - Used to begin control transfers.
- Packet format:

used to synchronize the clock of the receiver with that of the transmitter

used to identify the type of packet that is being sent.

address field specifies which device the packet is designated for, 7 bits long that means 127 devices can be supported.

made up of 4 bits, allowing 16 possible endpoints.

Low speed devices have only 4 possible endpoint max.

Cyclic Redundancy Checks are performed on the data within the packet

End of packet is Signaled by a Single Ended Zero

ii. **Data Packets:** There are two types of data packets each capable of transmitting up to 1024 bytes of data-Data0 & Data1. High Speed mode defines another two data PIDs, DATA2 and MDATA.

Maximum data payload size for low-speed devices is 8 bytes. Maximum data payload size for full-speed devices is 1023 bytes. Maximum data payload size for high-speed devices is 1024 bytes.

iii. **Status / Handshake Packets:** There are three type of handshake packets which consist simply of the PID

- **ACK** - Acknowledgment that the packet has been successfully received.
- **NAK** - Reports that the device temporary cannot send or received data. Also used during interrupt transactions to inform the host there is no data to send.
- **STALL** - The device finds its in a state that it requires intervention from the host.

iv. **Start of Frame Packets:** The SOF packet consisting of an 11-bit frame number is sent by the host every 1ms +-500ns on a full speed bus or every 125 μs +- 0.0625 μs on a high speed bus.

Frame number is 11-bit field that is incremented by the host on a per-frame. Max number is 7FF H (2047). It is sent only in SOF tokens at the start of each frame.

3.7.4 Interface Chips: USB Device and USB Host

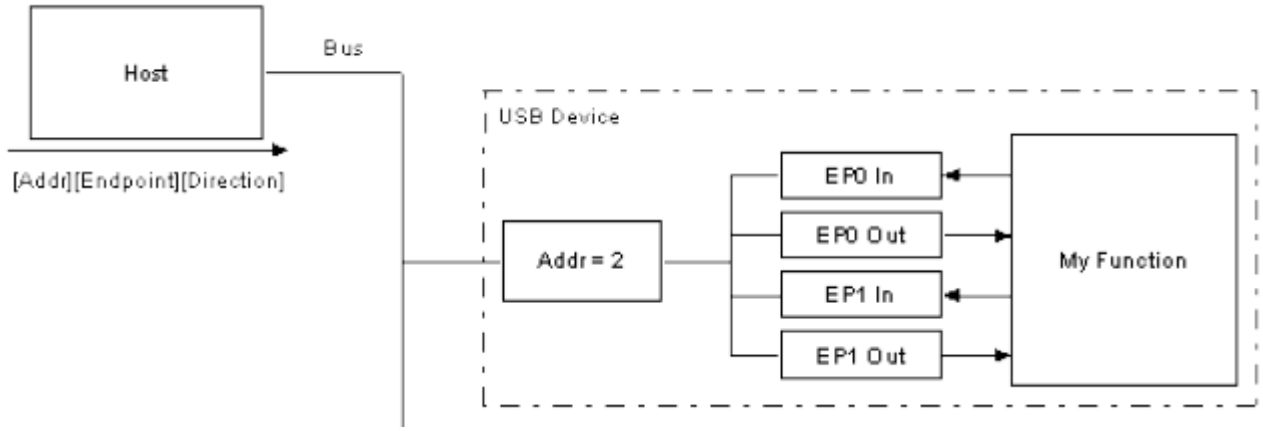


Fig: Relation between host and device [6]

- USB devices which provide a capability or function such as a Printer, Zip Drive, Scanner, Modem or other peripheral called a function. Most functions will have a series of buffers, Each buffer will belong to an endpoint. Endpoint is where data and control or status request enters or leaves the USB system. EP0 is for control and status request flowing. EP1 is for data flowing. *Endpoints can also be seen as the interface between the hardware of the function device and the firmware running on the function device.*
  For eg: Data transmission process from host to device:
- The host sends a device descriptor request via EP0 Out.
- The device will send the description data via EP1 In.
- The function hardware will read the setup packet and copy the payload of the following data packet to the EP1 Out.
- It will then send a handshake packet to acknowledge the reception of the byte via EP0 In

References

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[4] howstuffworks, "How USB ports work," 2017. [Online]. Available: https://computer.howstuffworks.com/usb1.htm.

[5] H. Aryal, "Course Hands Out of Instrumentation II," Pulchowk Stationary, Pulchowk, Lalitpur, 2015.

[6] M. El-koumy, "USB," slideshare.net, 2017.