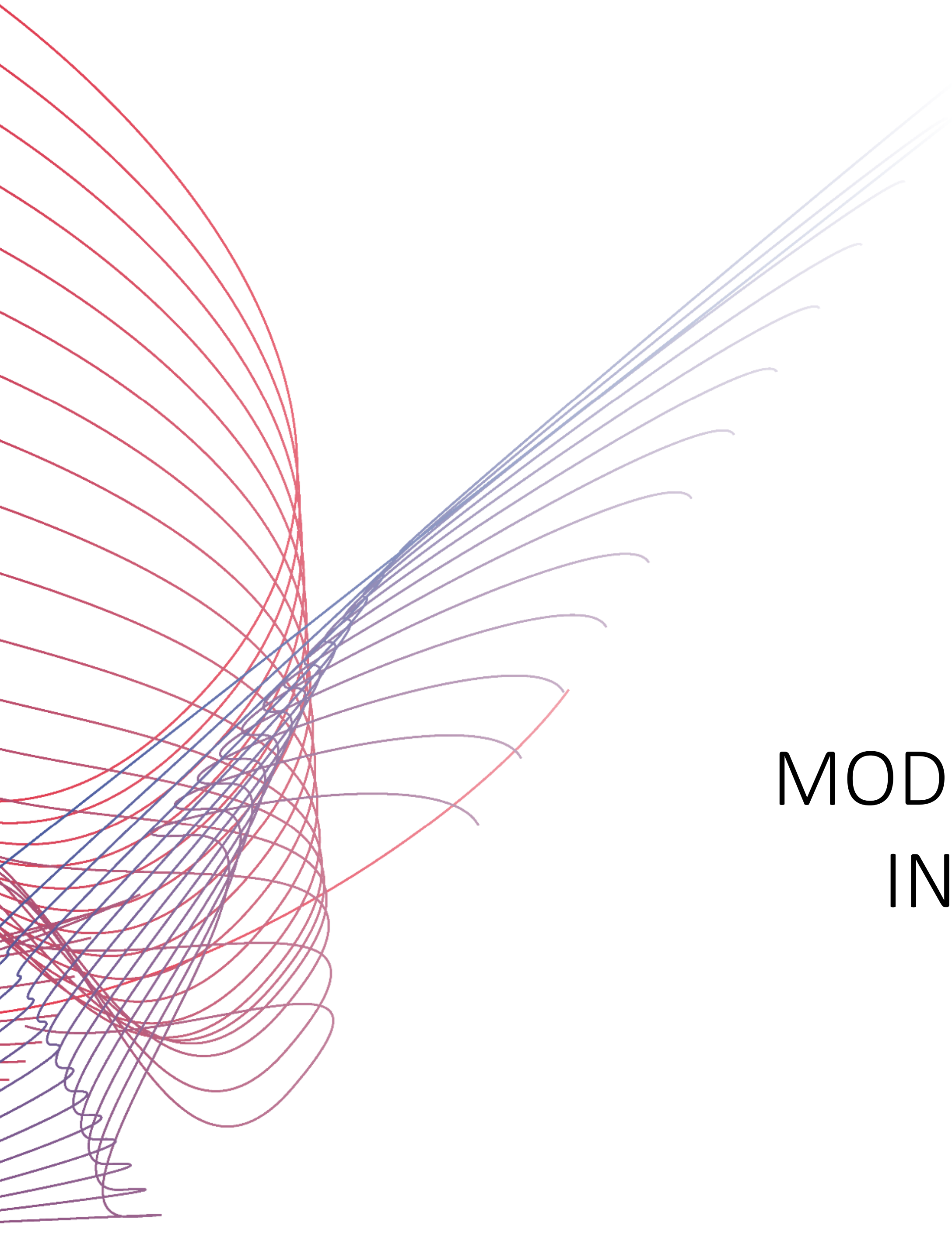
en cs de sk es

TECHpedia

MODERN DATA INTERFACES



IVAN PRAVDA

Title: Modern data interfaces

Author: Ivan Pravda

Published by: Czech Technical University of Prague
Faculty of electrical engineering

Contact address: Technicka 2, Prague 6, Czech Republic

Phone Number: +420 224352084

Print: (only electronic form)

Number of pages: 37

Edition: 1st Edition, 2017

ISBN 978-80-01-06267-8

TechPedia
European Virtual Learning Platform for
Electrical and Information Engineering

http://www.techpedia.eu

This project has been funded with support from the European Commission.
This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Explanatory Notes

Definition

Interesting

Note

Example

Summary

Advantage

Disadvantage

ANNOTATION

The new version of USB (USB 3.0), whose standards were issued in November 2008, has received over the previous version (USB 2.0) some significant improvements. The main advantages of the new interface is a high speed up to 5 Gbit/s, advanced power bus management and backward compatibility with previous USB versions. Thunderbolt technology is in these days another very perspective and competitive interface combining the features of PCI-Express Interface and Display Port. There is available an interesting comparison with USB 3.0 interface.

OBJECTIVES

Students will learn the basic principles and characteristics of perspective USB 3.0 and Thunderbolt interfaces. He obtains knowledge of the interface operation modes by describing of the various layer models. The main focus is on protocol layer. The module also describes the differences in comparison with previous versions of interfaces and backward compatibility with them.

LITERATURE

[1] HP, Intel, Microsoft, NEC, ST-Ericsson, Texas Instruments. *Universal Serial Bus 3.0 Specification* [online]. 2011, 2011-01-05 [cit. 2012-01-06]. Access from http://www.usb.org/. 531 pages.

[2] INTEL CORPORATION. Thunderbolt Technology [online]. Intel corp., 2011. [2013-01-16]. Access from http://download.intel.com/newsroom/kits/research/2011/pdfs/IntelThunderbolt_Overview.pdf

[3] Martínek, T.: Architektura sběrnic PCI, PCI-X a PCI Express. [online]. [2013-04-03]. Access from http://www.europen.cz/Proceedings/35/pci.pdf

[4] Thunderbolt Technology Community [online]. Intel corp. (2013) [2013-01-27] Access from https://thunderbolttechnology.net/

Index

1 Overview of perspective high-speed data interfaces

Data interfaces can be divided by physical media that transmit data between the host and the connected device into several categories. The most used categories are:

- metallic interfaces,
- optical interfaces
- and wireless interfaces.

Each of the above mentioned interface types has its advantages and disadvantages, which limit the predominant method of their utilization. In general, the main parameters for the selection of interface type are the **cost** (benefit of metallic interfaces), **speed** (advantage of optical interfaces) and **mobility** (advantage of wireless interface).

USB (*Universal Serial Bus*) interface is ranked among metallic interfaces and it is the most popular mainly due to its low cost and reachable high speed. Its main competitor, Firewire interface, has never reached such an extension, mainly due to the higher price at a similar speed.

Today, as the most serious competitor for USB 3.0 appears Thunderbolt interface in the current metallic version which offer higher transmission speeds with less overhead capacity and improved development capabilities for the future (optical version is being prepared). Thunderbolt interface is essentially a variant of an external PCI Express and it is already used in several Apple products (e.g. for connecting of monitors).

Advantages of Bluetooth consist mainly in the mobility of connected subscribers and in the speed of its implementation. Since it is a wireless interface, they are often mentioned just these two benefits in comparison with conventional "fixed" interfaces.

Comparison of selected parameters of the current interfaces

Name	**Transfer Rate**	**Reachable Distance**	**Type**
USB 3.0	Up to 5 Gbit/s	circa 3 m	Metallic
USB 2.0	Up to 480 Mbit/s	5 m	Metallic
Firewire 800	Up to 3,2 Gbit/s	10 m	Metallic
Thunderbolt	Up to 10 Gbit/s	3 m	Metallic/Optical
Bluetooth 2.0	Up to 3 Mbit/s	10 m (base)	Wireless
HDMI 1.4	Up to 10,2 Gbit/s video	circa 10m	Metallic
Wi-Fi (802.11n)	Up to 600 Mbit/s	hundreds m	Wireless
PCI Express 3.0	Up to 256 Gbit/s for 16×link	-	Metallic
eSATA	Up to 3 Gbit/s	2 m	Metallic

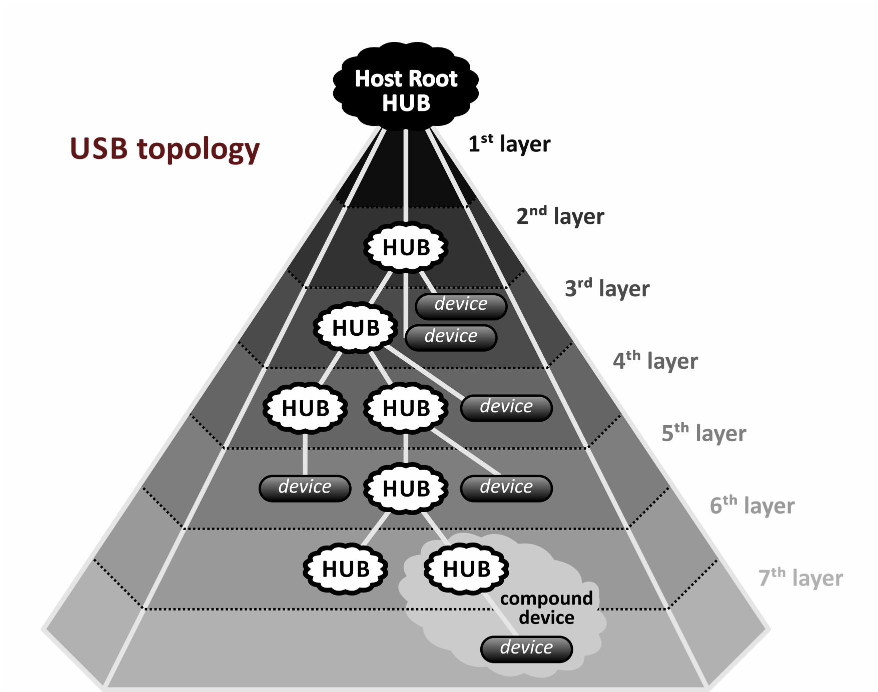
2 Interface USB 3.0 SuperSpeed

2.1 Introduction

USB interface is a serial bus interface type. Its key benefits include in particular:

- Low price
- Relatively high transfer rate (depends on the particular specification)
- Full support of audio and video data transfers realized in real time,
- Dynamic scalability (support of Plug&Play, i. e. without rebooting and driver installation)
- And transfer of power supply on bus (DC 5 V, consumption up to 100 mA (max. 500 mA)).

All devices connected to the USB interface share among themselves the entire bandwidth. USB bus is then controlled by one central facility (*Host Root HUB*), which coordinates transmission and reception of data, respectively cooperation of other USB devices. The path between the control (central) USB device, and any other USB device can contain in maximum five hubs. The maximum cable length between two USB devices is limited to 5 meters.



Classic USB bus topology

Connected USB devices are on the bus clearly identified by the USB address that is assigned immediately after connecting the USB device to the interface. It is possible to connect on the USB interface up to 127 devices.

The speed modes of data transfer

- Super Speed Mode – transfer rate up to 4,8 Gbit/s, specification USB 3.0
- High Speed Mode – transfer rate up to 480 Mbit/s, specification USB 2.0
- Full Speed Mode – transfer rate up to 12 Mbit/s, specification USB 1.1
- Low Speed Mode – transfer rate up to 1,5 Mbit/s, specification USB 1.1

The individual types of USB devices

- USB HUB – it is used for the extension of USB bus
- Terminal USB device (*USB function*) - devices using custom functionality of USB interface for data transfer, respectively for information exchange

2.2 Basic features of USB 3.0

The new version of USB 3.0, called as *SuperSpeed*, was created in November 2008. However its introduction into practice took almost three years. USB 3.0 is a follower of USB 2.0 and shares with previous versions of USB interface many characteristics. One of the main requirements for the development was the backward compatibility. So what are the advantages of new version of USB over previous versions?

- Higher transmission speed - up to 5 Gbit/s
- Full backward compatibility (with the exception of some connectors)
- Advanced power management
- 80% increase in potential power consumption from the bus
- Packets are routed over the bus (i.e. data are selectively routed to a particular device according to his address)

Obviously the new version of USB interface has not only advantages but these advantages prevail over disadvantages. The main disadvantages can be seen in:

- Increase in number of wires in the cable
- Increased susceptibility to electromagnetic interference **EMI** (*Electromagnetic Interference*), which is associated with the use of more wires in the cable and high speed modulation
- Certain types of connectors restrict backward compatibility

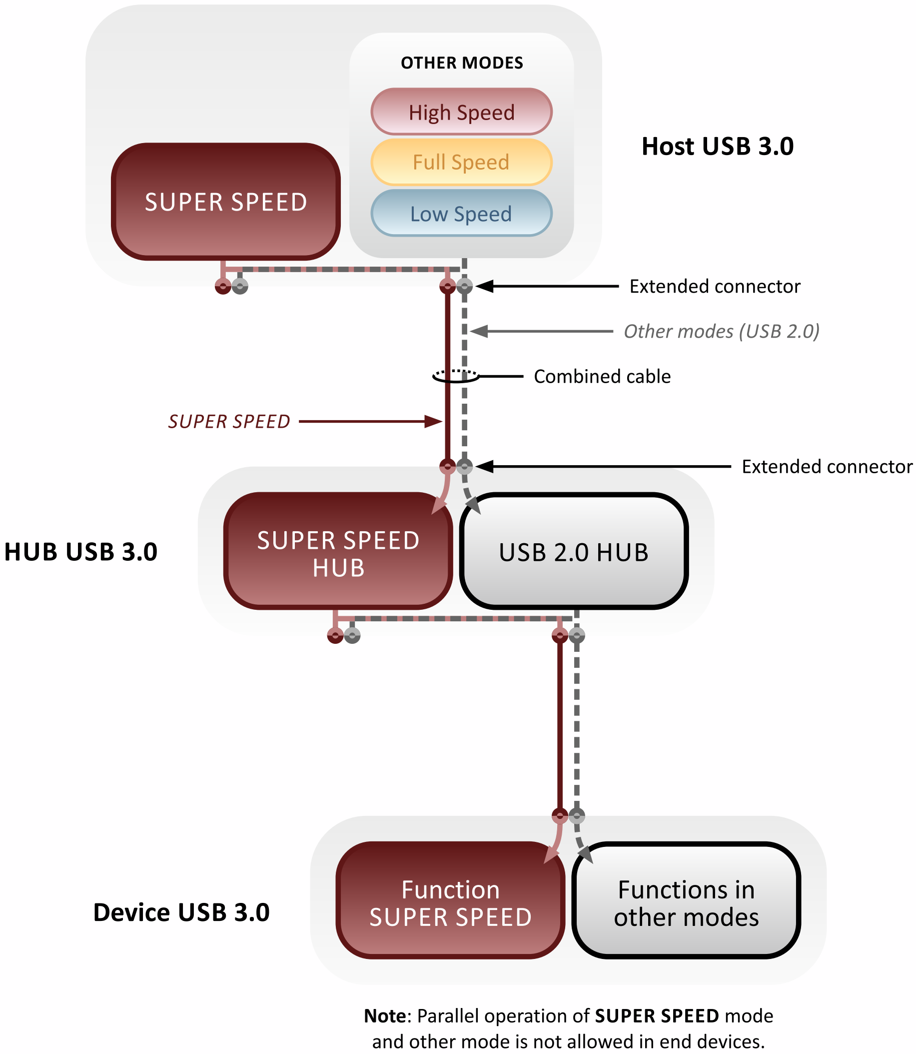
When we talk about the new version of USB bus, it should be noted that in essence, it is a standing side by side USB 2.0 and the new Super Speed USB bus. This phenomenon is described in details below.

USB version 3.0 greatly expands the possibilities and application of previous versions of USB interfaces.

Since July 2013, it is prepared a new version of USB interface in version 3.1 (USB 3.1 Gen 2). This version is also known as *SuperSpeed+*. The advantage of the new generation of USB interface has to be its speed (up to 10 Gbit/s) and reduced overhead during signal encoding. The interface has to be backward compatible with USB 3.0, i.e. you can use devices and hubs on standards USB 3.0 and USB 2.0.

2.3 The architecture of USB 3.0

Similarly host, hub and terminal equipment are fundamental elements of the architecture as on USB interface based on standard 2.0. The main difference compared to USB in version 3.0 is the parallel connection of two physical buses, specifically USB 2.0 and new *USB SuperSpeed*.



Architecture of USB 3.0 SuperSpeed

It is satisfied to the requirement for backward compatibility by selecting of this architecture, because host and hub enable simultaneous operation of both physical buses through a mixed cables and connectors. Then the terminal equipment according to their capabilities uses either of the USB 2.0 or *USB SuperSpeed*.

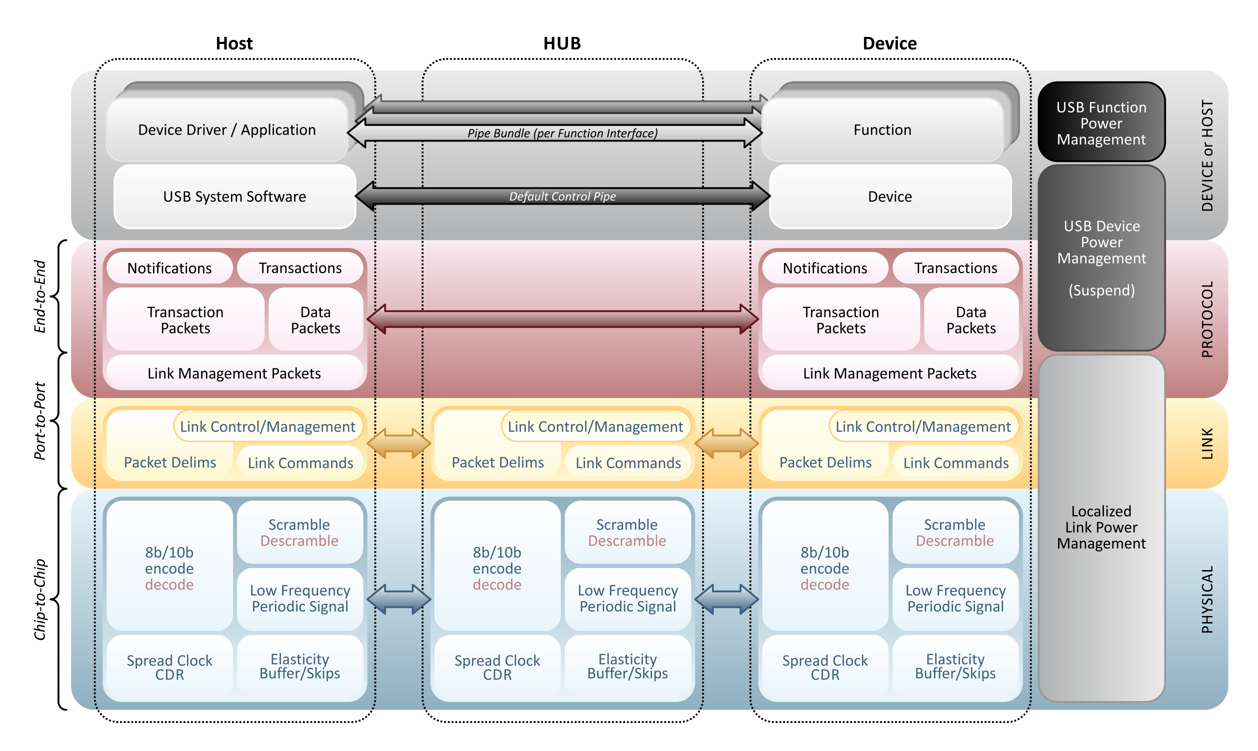
Similarly the physical bus topology respectively tree structure is preserved, where is located in the root the host, which can be connected to a larger number of terminals or hubs.

The hubs can further provide connection to other terminal devices or other hubs.

Comparison of USB SuperSpeed and USB 2.0

Feature	USB SuperSpeed	USB 2.0
Data Channels	two simplex – simultaneous bidirectional data flow, the two conductors on the direction (4 in total)	poloduplex – unidirectional data flow with negotiating a change in direction, the two conductors
Transfer Rate	SuperSpeed – 5 Gbit/s	according to mode 1,5 – 480 Mbit/s
Transmission Protocol	Asynchronous data flow driven by the host, packets routing	the host allocates data rate (polling), packet broadcasting
Power Management	At the level of the connection, devices and functions, several states	At the level of the connection and devices, only the Suspend state
Bus Power Supply	Like on USB 2.0, higher limits (50% for unconfigured devices and 80% for configured devices)	Low and high power devices, the lower limit for unconfigured devices

Each connection among the host and the devices (or the hubs) can be represented by communication layers. The following figure shows a diagram that describes each layer interconnection (see lines) and their elements in different parts of the topology (see left three columns) and the influence of power management (see right column).



Communication layers of SuperSpeed bus

USB 3.0 is a dual bus (*Dual Bus Architecture*), which is a parallel connection of USB 2.0 and the new USB SuperSpeed. This concept allows the usage of USB 2.0 terminal equipments on USB 3.0 controllers. However, there is one fundamental restriction. It is not possible to use both buses simultaneously at one terminal device.

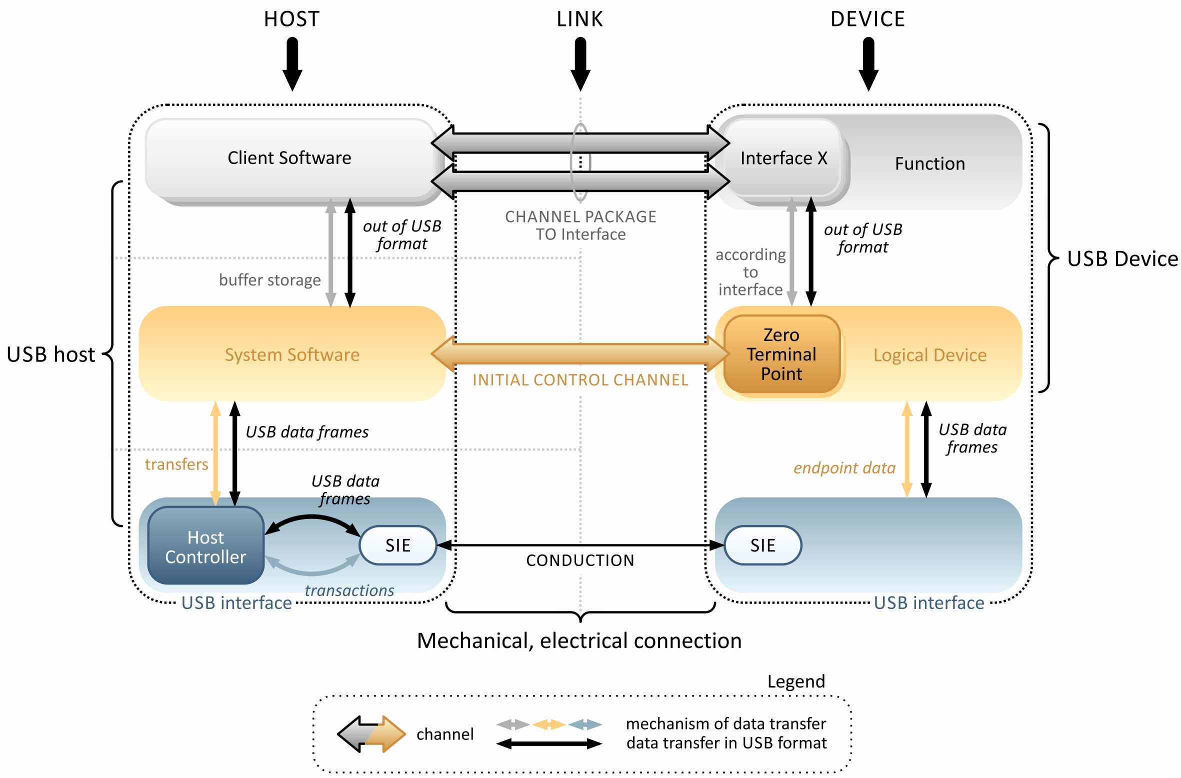
2.4 Models of data transfers

USB SuperSpeed takes the models of data transfers from USB 2.0. Data exchange between the terminal and the host proceeds through channels also called as pipes. Thus data transfers are realized between terminal devices associated to the function and host software.

Obviously we are talking about logical connections, physical connection consists of a single cable only.

All channels and endpoints are created during system configuration besides the initial control channel and the zero terminal point and support one of the four types of transmissions - bulk transmission, control transmission, synchronous transmission and transmission with interruption.

There are two types of channels as on USB 2.0 interface - stream channels (the structure is out of the USB format) and message channels (the format is defined by the USB interface).



Model of USB data transfers

It is possible to conclude, that the communication on the USB bus proceeds between the host software and terminal devices through virtual channels.

2.5 Burst data transmission

Burst data transmission is a new feature USB SuperSpeed, increasing transmission efficiency by removing the time that we wait for confirmation of each data packet. Each endpoint of SuperSpeed device indicates on its descriptor maximum number of packets that can be send or receive without waiting for their confirmation.

Host enables to dynamically change the number of packets in a burst for each transaction according to its requirements (but cannot exceed the maximum burst size for given endpoint). The host reduces the burst size easily in the case of OUT transactions, in the case of IN transactions sets the burst size using the field in the **ACK** (*ACKnowledge*) packets.

Burst data transmission is a function of the SuperSpeed bus enabling to send multiple packets at once without waiting for confirmation of their receipt.

1. IN TRANSMISSIONS

The terminal device sends data to the host at IN transmissions. The host initiates these transmissions by sending of confirmation IN packet to terminal device that is by using of the included information routed to the terminal device. It also includes information about the expected sequential number of the packet and about the number of expected packets. In response to host the terminal device sends data packets with corresponding sequence numbers.

Although the host must acknowledge the confirmation **ACK** packet each received data packet, terminal device can send all the requested data packets without waiting for their confirmation.

SuperSpeed IN transmission consists of one or more IN transactions containing one or more packets. It is terminated when all the data was successfully received, the endpoint sends a packet whose size is less than the maximum for given endpoint or endpoint responds with an error.

2. OUT TRANSMISSIONS

The host sends data to the terminal device at OUT transmissions. The host initiates OUT transmission by sending a continuous stream of data packets to the terminal device. Each data packet contains the information required for routing of the packet and the sequence number of the packet. Terminal device answers by the confirmation **ACK** packet containing the sequence number of the next expected packet, which also confirms the successful reception of the previous packet.

Like at IN transmissions the terminal equipment must send a confirmation **ACK** packet for each incoming data packet, but the host on these confirmations **ACK** packets does not have to wait.

SuperSpeed OUT transmission consists of one or more IN transactions containing one or more packets. It is terminated when all the data was successfully received, the host sends a packet whose size is less than the maximum for given endpoint or endpoint responds with an error.

2.6 Packets of USB SuperSpeed Interface

All packets begin on SuperSpeed USB interface by 16-bit header, which can form the entire packet. The packet header starts with packet type information, which is used to determine the method of packet handling. The packet header is protected by a 16-bit **CRC** (*Cyclic Redundancy Check*) and it ends by two bytes control word. Most types of packets also comprises the routing information used for routing of the packet from the host.

There are four types of packets on USB SuperSpeed interface:

- Link Management Packet **LMP** is sent only between two directly connected ports and it is designed to link control of this connection
- Transaction Packet **TP** passes through all the links on the direct route between the device and the host, it is used for control of the flow of data packets, configuration and hubs, it consists only from the header
- Data Packet **DP** passes through all the links on a direct route between the device and the host, it has two parts - a data packet header (similar to the transaction packet) and user data in a data packet (it contains data block and 32-bit **CRC**)
- Isochronous Timestamp Packet **ITP** is a packet that it sends by the multicast to all connections in the active state

USB SuperSpeed interface uses four kinds of packets - Link Management Packet **LMP**, Transaction Packet **TP**, Data Packet **DP** and Isochronous Timestamp Packet **ITP**.

2.7 Type of data transmissions

Data transmissions are composed of one or more transactions which are implemented using packet. Individual types of data transmissions then correspond to the used packet types.

1. CONTROL TRANSMISSIONS

The purpose and function of the control transmissions are practically identical to the USB 2.0 interface, it enables communication between the host software and terminal device for configuration, control and status.

The control transmissions use message channels, each device must support the default control channel. The control transmissions have the highest priority on the bus, similarly to the USB 2.0 interface cannot request a specific bandwidth. The maximum payload is 512 bytes, and it cannot utilize the bursting.

2. BULK TRANSMISSIONS

The bulk transmissions operate like on USB 2.0 interface similarly to control transmissions. They are designed for peripheral devices that need to move relatively large volumes of data. They use any available bandwidth (with low priority), such as copying data to an external drive.

Bulk transmission guarantees delivery of data, but does not guarantee bandwidth and delay. It uses stream channels, so there are no requirements on data structure. Stream channels are unidirectional, bidirectional data flow requires two channels (IN and OUT). Bulk transmission may be divided into more transactions.

3. BULK TRANSMISSIONS WITH STREAMS

This is a completely new type of transmission on USB SuperSpeed interface. Standard channel for bulk transmission represents the ability of transfer of one stream data type **FIFO** (*First In First Out*) between the host and the terminal devices via the memory stack of host and terminal devices. SuperSpeed Streams provide support for a multistream model at the protocol level. The streams between the host and terminal device are managed by stream protocol. Stream ID **SID** is assigned to each stream.

Stream protocol defines status messages, which allow for a host or a terminal device to establish the current stream ID **CSID** of endpoint. Host uses the **CSID** to select data buffers of endpoint which will be used for subsequent transmissions on the channel. The terminal device uses the **CSID** to select data buffers for function.

SuperSpeed streams allow the usage of more host data buffers for the terminal device (by default only one). SuperSpeed streams are interrupted in case of failure of standard bulk channel, which SuperSpeed streams use. SuperSpeed streams extend the possibilities of bulk transmissions with minimal changes in the hardware. This function may be used for example for USB Mass Storage devices.

4. TRANSMISSIONS WITH INTERRUPTION

Similar to USB 2.0 interface transmission with interruption is dedicated for terminal devices that require high reliability transfer of small volume of data in a limited operating range, such as a mouse or keyboard. The host periodically requests data and terminal device according to their possibilities it provides.

Transmissions with interruption guarantee maximum operating range (delay of data). It uses stream channels, so the data may not have a defined format and the channel is unidirectional. Up to 90% of the available bandwidth may be allocated for transmissions with interruption. Endpoint can in its handler operating interval in multiples of 125 µs. It enables retransmission of three packets per operating interval.

5. SYNCHRONOUS TRANSMISSIONS

Synchronous transmission and its purpose compared to USB 2.0 remains unchanged. It is used for data streaming, i.e. for periodic transmissions with limited service interval and the error margin enabling continuous data flow. USB SuperSpeed interface uses for synchronization timing isochronous packets **ITP**.

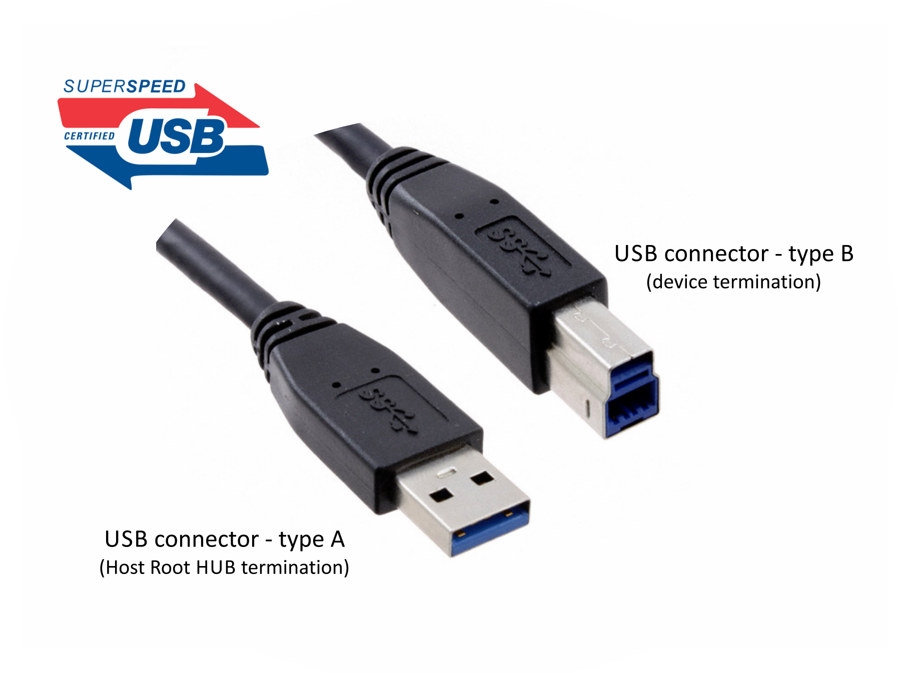
Synchronous transmission guarantees bandwidth for traffic with limited delay and required bandwidth is also guaranteed and it is given in descriptor. Synchronous channels are streams with unidirectional data flow. Host before starting synchronous transmission sends to terminal device a packet transaction (*PING*) due to possible delays in transfer caused by bus power management and this transaction activate all links on bus to active state. Maximum bandwidth and service intervals are consistent with transmission with interruption. Synchronous transmission allows up to three burst transactions after 16 packets per operating interval.

2.8 USB 3.0 connectors

USB 3.0 connectors have been developed on the bases of the requirements of the higher transfer rate, limitation of the influence of electromagnetic interference, support for mobility and low price. All features while maintaining of maximum compatibility with USB 2.0. USB 3.0 specification defines the same types of connectors such as USB 2.0, up to a new one - powered connector type B.

1. Standard connector type A – probably the most widely used connector, host connector, shape and dimensions are identical to the corresponding USB 2.0, but with additional contacts for two additional data pairs and ground; it provides full backward compatibility.

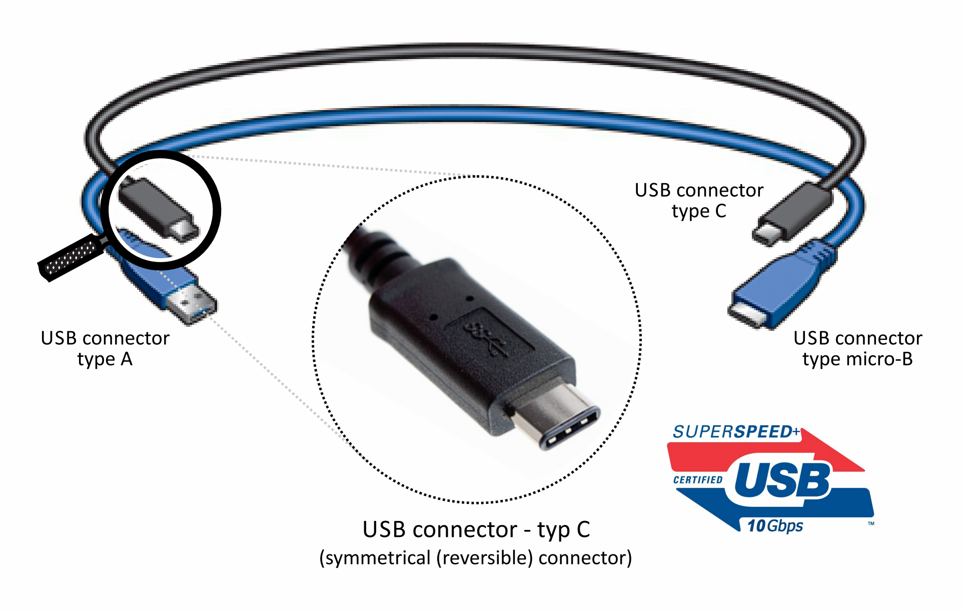
2. Standard and powered connector type B – designed for use with large stationary equipments, do not provide complete backward compatibility and the connector is larger due to the added contacts. It is possible to connect USB 2.0 plug into a USB 3.0 connector, but the reverse connection is not possible. Powered connector is different only in two other added contacts enabling the device to provide power supply.



Standard connector type A and B

3. Micro connectors type A and B – designed for relatively small and lightweight device, which corresponds to their size and therefore the same as B-type connectors do not provide complete backward compatibility; There plugs type B and type AB, to plug type AB can engage connector type A and B to plug type B, then just connector type A.

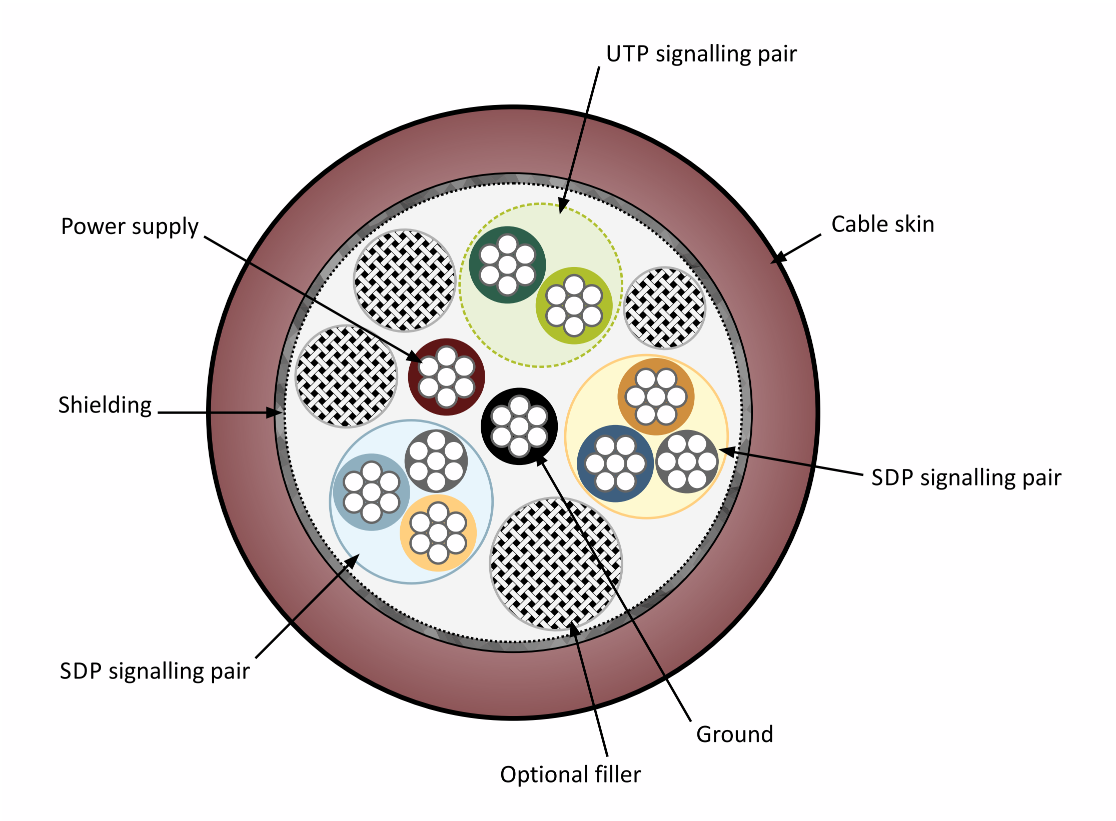
4. Reversible connector type C – it is a new universal connector for USB interface, which is mechanically symmetrical (i.e. it is not necessary to differentiate the direction of the link). There are arranged inside the cable 24 wires for power, USB 2.0 data, 2× USB 3.0 data, configuration poles and poles for other purposes. Active cable is an optional possibility (includes a chip). Power supply is classic 5 V with a current up to 3 A (maximum is up to 20 V with a current of 5 A). The dimensions of the connector are 8.4 × 2.6 mm. The new connector implicitly supports alternative transport protocols.



Reversible USB connector type C

2.9 USB 3.0 cabling

The following figure shows cross section of cable in USB 3.0 specification. There are three visible groups of wires - signaling pair **UTP** (*Unshielded Twisted Pair*), crossed pairs (shielded differential pairs **SDP** (*Shielded Differential Pairs*)) and the power and ground wires.



Cross section of cable in USB 3.0 specification

UTP is designed for transmission of signals USB 2.0, **SDP** are for USB SuperSpeed specification. It is evident from the name, **SDP** pairs have their own shielding for signal integrity and limitation of **EMI**. Additionally, each shielded pair of has additional wire, called as *DRAIN*, which is connected to the grounded pin connector (different from the ground power supply, denoted as *GND_DRAIN*).

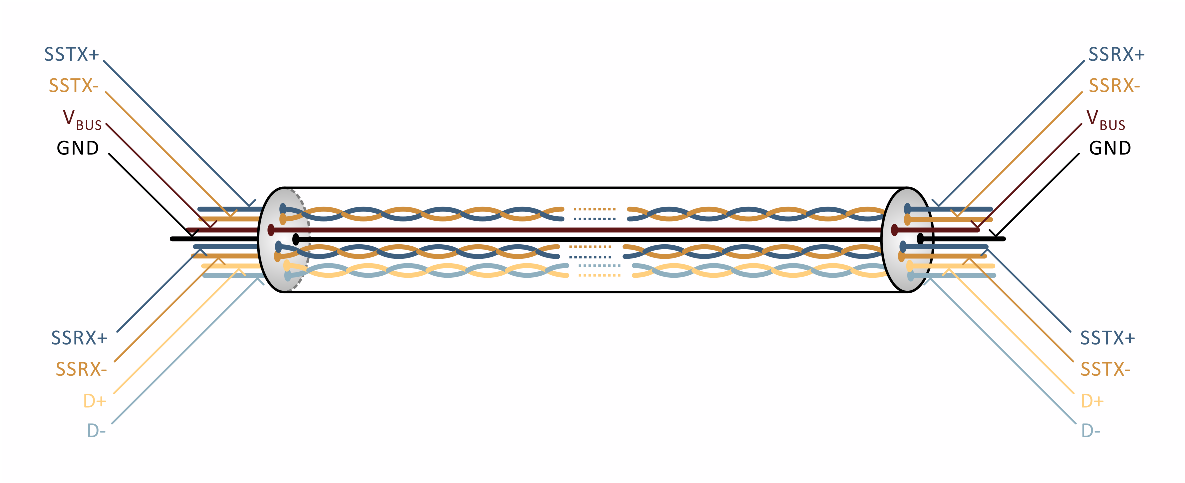


Diagram of cable in USB 3.0 specification

Shielding closing all cable wires is realized by a metallic braiding connected to a metal part of the connector and it serves to eliminate the **EMI** disturbance. The colors in the images match with the colors of insulated wires.

The cable length is not limited by specification, but it is limited by losses to build of connection and voltage drop on the whole cable length. These losses for the cable must not exceed the limit of 20 dB. This corresponds to the maximum recommended cable length up to 3 m.

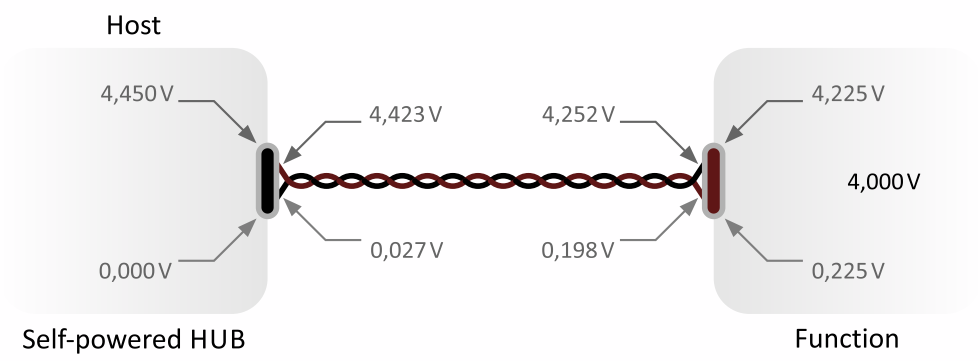
2.10 Power management

USB 3.0 provides the power supply via two connectors - a standard connector "type A" and powered connector "type B". Power supply via standard connector type A has similar properties as the USB 2.0 interface. There is for simplicity defined the equivalent load, in case of USB SuperSpeed interface is current of unit increased to 150 mA. USB interface contains several types of sources and appliances:

- Host Root HUB – is connected directly to the USB Host Controller, host ports connected to the power supply must supply at least 6 units of load, respectively host ports, whose source is a battery, may allow only one load unit
- Self-powered HUB – does not consume the energy required for the operation and downlink ports from V_{BUS} wire, but it can take up to one unit load for function and uplink port in case of switch off the rest of the hub, each downlink port then provides up to 6 load units
- Low-power Device – takes all necessary power supply from the V_{BUS} wire, consumption up to 1 unit load
- High-performance Device – takes power supply from the V_{BUS} wire, after device switching on can take up to 1 unit load, then after configuring up to 6 units load
- Self-powered Device – takes a maximum of 1 unit load from V_{BUS} wires to ensure the port functionality, and even if the rest of the device is shutdown

No device can realize power supply on V_{BUS} wire at uplink port. Similarly as on the USB 2.0 interface to be the host and self-powered hubs provide protection against current overload. Restore of the normal functionality is possible without user intervention.

The highest allowable voltage drops within the bus topology are shown in the following figure.



Bus topology under the maximum acceptable voltage drop

Powered connector type B was introduced to allow for another device, such as e.g. printers, connection and power supply of other devices (e.g. adapters Wireless USB). This option eliminates the need for external power adapter. Power plug type B must be able to provide 5 volts in full current scale up to 1 A, provide protection against current overload, to deliver maximum energy regardless of the state of the terminal equipment. Terminal device providing the power supply through this connector must be low power and a terminal device, which is powered by a connector can not provide any standard plugs type A.

2.11 Bus inventory

When you connect or disconnect a terminal device from the USB, the host uses a process called as bus inventory to identify and manage the state of the terminal device. This process consists of several following steps:

1. The hub, where the terminal device is connected, inform the host about this event through a special channel (terminal device is at this moment after the *RESET* command in the default state, i.e. it cannot take more than 150 mA from V_{BUS} wire and responds to the default address.)
2. Then the host determines the exact nature of the event by request to the hub. If the host knows the port to which the terminal device is connected, it can reactivate *RESET* command for terminal device.
3. Subsequently, the host assign to terminal device a unique address and it informs the terminal device about synchronous delay and several other parameters.
4. There will be also realized reading of all configurations of terminal device by host and it will be realized eventual timer settings U_1/U_2 for downlink port which is occupied by the terminal device.
5. The host determines values required to set the terminal device on the basis of information about configurations and how to use the terminal device. Terminal device will come on state *CONFIGURED* and it is now ready for use.

In case of a disconnection of terminal device is sent the notice message to the hub and the host can update the local topology information.

2.12 USB 3.0 terminal device

All USB 3.0 terminal devices supports a common set of general operations. Let us here at least their review: dynamic connection and disconnection, address assignment, configuration, data transmission, power management, processing of the request and error request.

Terminal devices notify their properties using descriptors. Descriptor is a data structure in predefined format. Each descriptor begins with a single byte field containing the number of bytes of the descriptor, followed by a single byte field that determines the type of descriptor.

Each configuration may use descriptors or their parts from other configurations. Terminal devices may also have a special descriptors according to their class or manufacturer.

There are several types of descriptors - Device Descriptor, Configuration Descriptor, Descriptor of associated interfaces, Interface Descriptor, Endpoint Descriptor, SuperSpeed Endpoint Descriptor, String Descriptor and Binary Device Object Store **BOS**.

Descriptor **BOS** defines the Root Descriptor, which is similar to the Configuration Descriptor and it is the starting point for access to a set of related descriptors. These descriptors are then further divided into several types. Wireless USB describes the capabilities of the device for wireless USB interface. Extension of USB 2.0 is the descriptor indicating the possibility of extended power management and high speed mode in USB 2.0. The ability of SuperSpeed USB devices describing for example the support of different speed modes or periods of transition from U_1 and U_2 to the state U_0. The last descriptor is the containers ID containing an identification number enabling to the host identification of the terminal device regardless of the mode in which the terminal device is working.

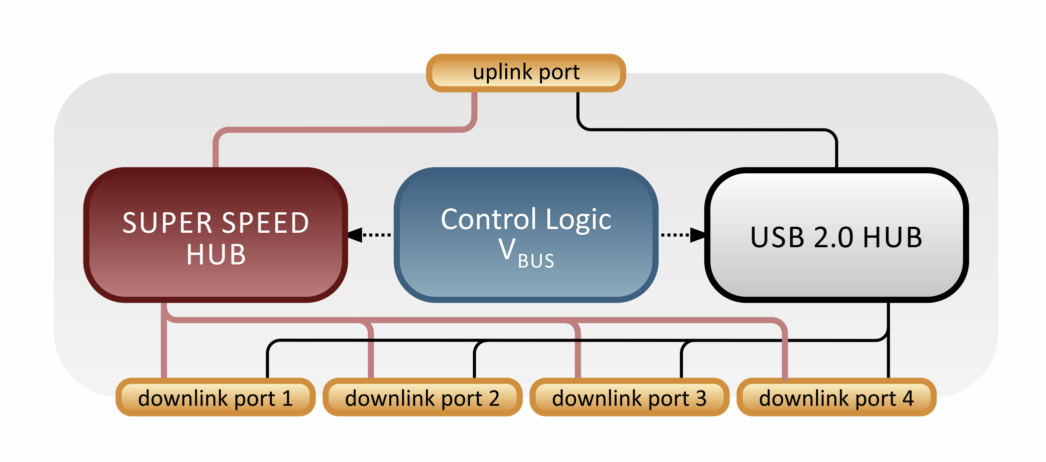
2.13 USB 3.0 HUB

Hub of interfaces provides the electrical connection between the host and terminal devices. It enables USB interface to be easier to use for common users. They take care about the behavior of connectivity, power management, bus failure detection and recovery of bus and support facilities in all speed modes.

USB 3.0 hub includes an USB 2.0 hub and SuperSpeed hub. SuperSpeed hub further consists of a Repeater and Hub Controller:

- Repeater serves to handling of connections, detection of connection and disconnection of terminal device, error detection and recovery.
- Hub Controller supports communication between the hub and the host that allows to set up the hub and its downlink ports.

SuperSpeed Hub also takes care about packet routing as it is described in previous chapters. USB 3.0 Hub is a logical combination of USB 2.0 hub and SuperSpeed hub. Control logic for V_{BUS} is only one shared part of the logic, as it is shown in the following figure.



USB 3.0 HUB

2.14 The possibility of using USB 3.0 interface

USB 3.0 compared to the previous older version of **USB** has undergone significant improvements. Probably the most significant difference is of course the transfer rate, which increased approximately ten times compared to the previous USB 2.0 interface. Theoretically USB bus brings transfer rates up to 5 Gbit/s, as it is seen from the characteristics of the physical layer interface.

Of course this transfer rate at the end of data transfer interfaces cannot be reached. After counting the losses caused by 8B/10B encoding (20%) and data encapsulation in a data link protocol layer (about 2.4%), we obtain the highest possible transfer rate circa 3.88 Gbit/s.

The specification USB 3.0 indicates really achieved transfer rates above 400 MB/s (i.e. 3.2 Gbit/s).

Nowadays, even transfer rate 3.2 Gbit/s is relatively high transfer rate that USB 3.0 can compete with most existing high-speed interfaces. One of many examples of practical use could be connecting devices using Flash memories such as memory cards, flash drives or hard drives currently popular **SSD** (*Solid State Drives*), which are capable of at least partially take advantage of the offered transfer rate.

Application of USB 3.0 will therefore especially when we transfer large amounts of data. More simultaneously performed OUT transactions together with one IN transaction then it also means the possibility of simultaneous utilization of the bus by multiple devices even send data to a host can actively only one of them. In the data rate can better compete with interfaces such as **eSATA** (*external Serial Advanced Technology Attachment*), which had so far in the transmission of data on top.

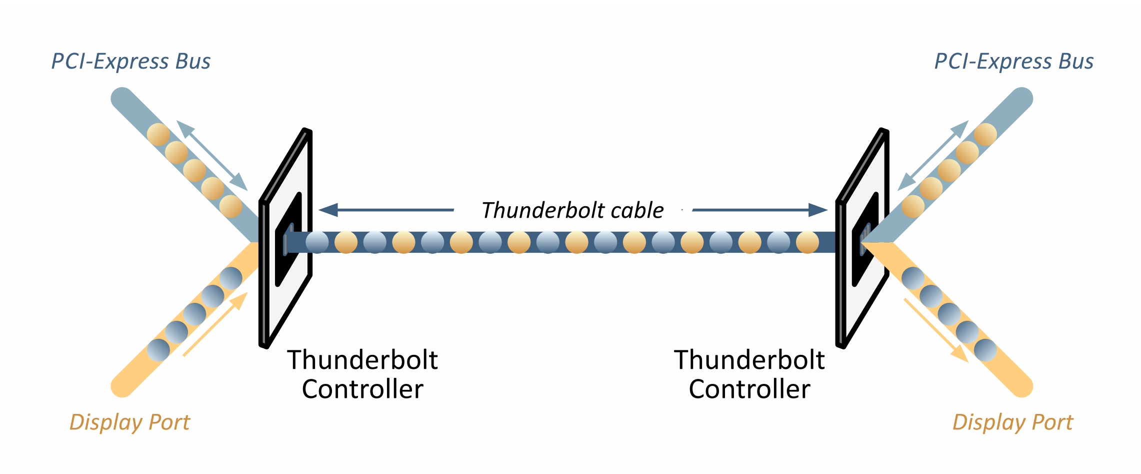
Currently, the only serious competitor to USB 3.0 interface appears Thunderbolt interface, which it is in essence an external **PCI-E** (*Peripheral Component Interconnect - Express*). It offers even faster than USB 3.0 and it allows in addition the possibility of chaining devices. Currently Thunderbolt interface is used practically exclusively for the products of the firm Apple.

3 Thunderbolt interface

3.1 Interface characteristics

Thunderbolt interface **TB** is an interface which brings to the world computer industry a number of new designs, solutions, features and enhancements. Thunderbolt interface is being developed in cooperation of Intel and Apple. The first prototype of the interface was presented to the public in 2009. It was called at that time as Light Peak. The first standardly produced device with Thunderbolt interface was in 2011 the notebook MacBook Pro of the firm Apple.

Difference of Thunderbolt interface compared with other interfaces is particularly in the structural design. It consists of a combination of two different interfaces - external **PCI-E** bus and port **DP** (*Display Port*). Communication is bidirectional and connection works in full duplex mode. The packets of both protocols are transmitted simultaneously over a single session. Thunderbolt controller multiplexes these packets at the transmitter side into a single data stream and the receiver at opposite side switches between the different protocols.



Principle of communication on Thunderbolt interface

Advantage and objective of **TB** interface is a high-speed connection of various devices and support for multiple types of data transfers via one unified connector.

It was used a modified *Mini DisplayPort* connector for this purpose.

The **TB** interface exceeds standards such as **eSATA**, **USB** and Firewire With a theoretical transfer rate of up to 10 Gbit/s per channel. Its transfer rate is almost twice higher (depending on the specific hardware and software) in comparison with the bus USB 3.0 and requires less overhead. However, the real transfer rate is around the border of 6.4 Gbit/s per channel.

It can be connected to one **TB** connector up to seven **TB** devices. One **TB** port can also manage simultaneously transmit the data for two displays with **DP** ports in high resolution **HD** (*High Definition*).

Copper wires were in spite of initial plans of optical cables (technology of *Silicon Photonics Link*) used for data transmission and power supply.

The advantage of copper pairs is managing of sufficient transmission speed, cost price is in comparison with optical conductors substantially lower and it is possible to realize through them the power supply of the connected devices up to 10 W of power.

Their great disadvantage is limitation of cable length, which can be only up to three meters.

It is still counted with optical cables for the future use, especially due to their potential in the area of increasing of transfer rates up to values in the order of 100 Gbit/s and can be used much longer lengths of cables under constant transmission conditions.

Intel Corporation promises to transfer a two-hour video in Full **HD** resolution in 30 seconds, and transfer of records in **MP3** format with time duration one year for 10 minutes.

3.2 Interface architecture

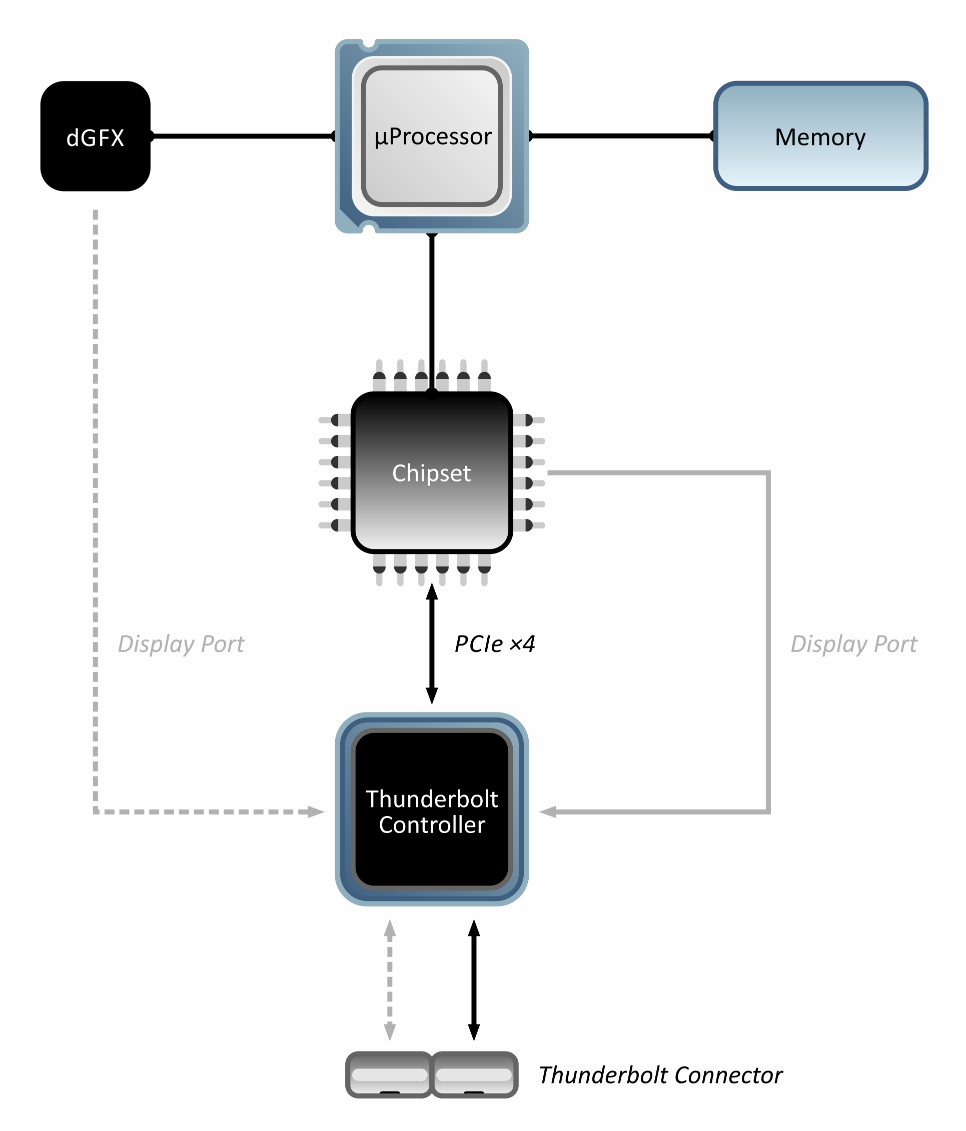
Architecture of Thunderbolt interface is based in two perspective standards. The first is the standard **PCI-E** and the second is standard **DP**.

The advantage of **PCI-E** bus is its universality, a wide application in existing computers like **PC** (*Personal Computer*), a large number of technologies designed especially for the connection and cooperation with the **PCI-E** bus and possibility of direct connection with the **PCI-E** bus located on motherboard of **PC**.

The advantage of **DP** port is ability to achieve even higher than Full **HD** resolution (for example *4K* or *5K*) with still increasing frame rate. The image can be simultaneously transmitted with 8-channel audio too.

Physical *Mini DP* connector is backward compatible with the standard **DP** port. The maximum transfer rate of **DP** port is 5.4 Gbit/s using four links. The transfer rate is increased up to 10 Gbit/s when we connects our traffic to device with **TB** interface. The total transfer rate of the bidirectional two-channel transmission is therefore 20 Gbit/s.

Block diagram of the architecture of Thunderbolt interface is shown below.



Architecture of Thunderbolt interface

Data from **DP** port and **PCI-E** bus come into **TB** controller. **TB** controller combines the data into packets which are transmitted together via a single active **TB** cable.

–

However utilization of active cables have unfavorable thermal effects. We can measure on connected idle connector the temperature around 43°C. The temperature in the active state may quickly rise up to 50°C. The temperature on the cable between connectors is not different from the surrounding environment.

i

Heating of cable ends, i.e. connectors, is caused by mounting of the chip *Gennum GN2033* directly into the connectors. This chip despite its very small size can provide conditions for high-speed and error-free data transmission via a thin copper pair. The chip is not directly necessary for the **TB** technology, but its presence improves transfer rates and the transmission characteristics of the interface. Its integration is not necessary when moving the interface into the optical cables.

Raised temperatures are not harmful to the user, but certainly contribute to the overall heating of the device and thus to higher demands on its cooling. For example, connectors for USB 3.0 interface don't have a similar problem, because their temperature is only slightly different from the temperature of surrounding environment.

The utilization of active cables have for the user much greater impact, besides a large heating, which is a higher purchase price compared to competing types of interfaces.

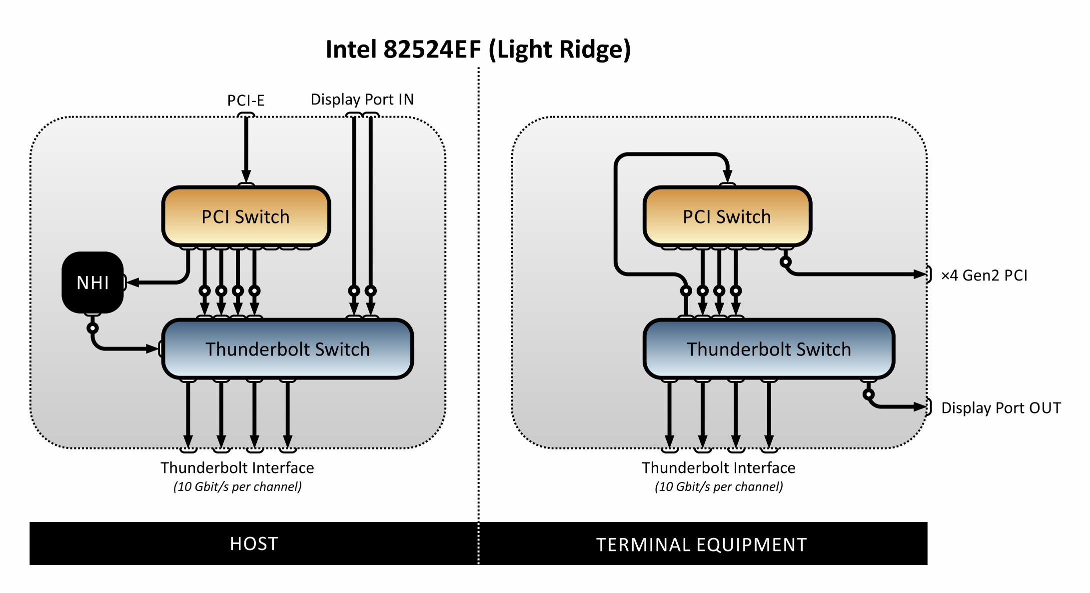
3.3 Data transfer

The controller is a key component for data transfer. The controller is part of transmitting and receiving equipment. The controller is designed for communication with very little delay and with the support **QoS** (*Quality of Service*) requests.

One of the many features of **QoS** is the ability of a network to provide prior information about the bandwidth/delay and according to priority to reserve and manage data flow. Each packet has determined a priority within the packet header called as TLP Header.

Synchronization of clock with the connected device via **TB** interface will be realized into 8 ns.

TB controller located on the motherboard of **PC** is always in *Host mode* (see figure below). The controller includes the independent input for the data from ports **PCI-E** and **DP**. **PCI-E** controller (PCI-E Switch) is inside **TB** controller which controls the connected terminal device and **NHI** (*Native Host Interface*) element, which is used for detection of the connected device (support Plug&Play). The last element is a Thunderbolt Switch, which combines both types of data into a single data stream.



Controller of Thunderbolt interface

One **TB** port requires two channels. Each consists of two paths for bidirectional transmission and it has a channel capacity of 10 Gbit/s. One channel is used for image data and another for other data. Because the performance of **TB** interface is not given as sum of performance of each channels, the official mentioned throughput is of 10 Gbit/s per port. Thus the controller has four outputs according to given solution.

TB controller for terminal equipments connected to the **PC** is in terminal mode (*Endpoint*). There are available four inputs respectively outputs according to the type of operation. Received data come into the Thunderbolt switch, which is a very powerful protocol switch. Data is distributed in it according to their protocol. Data of **DP** port get off from the controller (*DP out*) and data of **PCI-E** bus come into the PCI-E switch. Then it divides the data according to the specifications of the 4-channel **PCI-E** 2.0. It is possible to connect one (4-channel), two (2-channel) or four (1-channel) equipments. PCI-E switch, which is located in front of the equipment, controls data routing in serial connection of more devices. Each element connected in the serial connection must include two ports. If it contains only one port, it is unable to transfer data to other devices and is therefore connected to the chain end. Typical example is a monitor. The device has the smallest delay, when it is in topology diagram in the first place. The data are subsequently divided and come into microchip **PCH** (*Platform Controller Hub*), which determines the data path and controls the auxiliary function in cooperation with a **CPU** (*Central Processing Unit*) (e.g. the system clock) and the memory. The connection between the controller and the **PCH** includes **FDI** (*Flexible Display Interface*) interface that realize a separate band for transferring of image data.

When applying fiber optic technology it won't be necessary to change the current devices with **TB** interface. These devices are already capable of transmitting data over both copper and fiber optic cables. The cables may have in the case of the optics reachable range up to several tens of meters while power using metallic conductors. Without the need to the power supply of the remote device is calculated with the transmission of the optical signal up to hundreds of meters.