USB: the most successful interface

that also brings power

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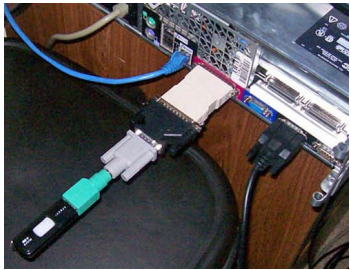
History

Quiz: what do you connect with this connector?

A a mouse
B a joystick
C a monitor
D computer network

Peripherals before USB

- special single-purpose ports
  - keyboard
  - Line Printer porT
  - game port
  - *serial port*
- reusing existing universal connectors
  - DIN a Mini-DIN (keyboard, mouse)
  - D-sub (monitor, printer, modem, mouse, joystick)
- many non-functional and dangerous combinations
- only plugging in off state supported



USB 2.0 and 3.x

Universal Serial Bus

- new interface for (some) peripherals
- new exclusive connectors and cables
- designed for hot-plugging
- **dangerous** and non-functional assemblies mitigated
- **supplying power** with power management
- economic and extensible
  - software-base host implementation
  - simple controllers in peripherals

Bus?

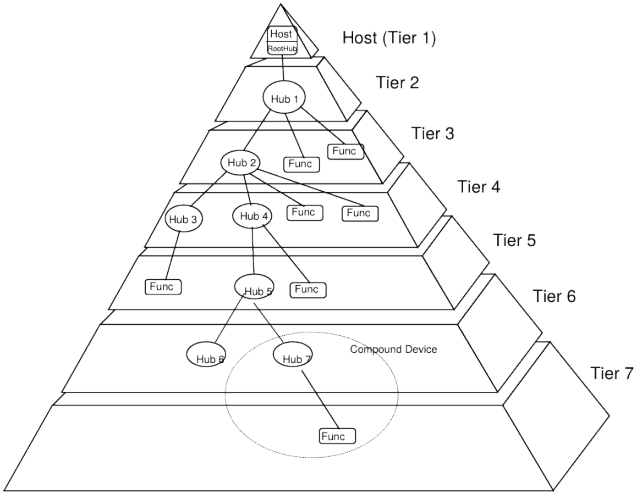
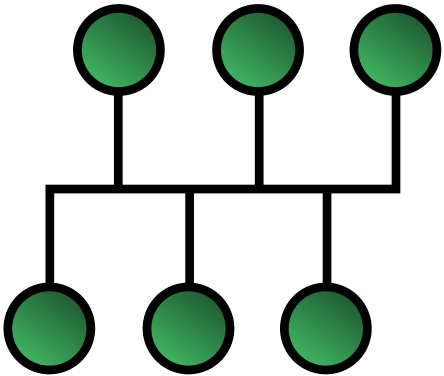


Figure 4-1. Bus Topology



USB topology

- tiered star
- only one *host* controlling everything
- up to 127 *devices*
  - *hubs* connecting other *devices*
  - *functions* = peripherials
  - *compound devices* = a combination of a *hub* and *functions*
- up to 4 daisy-chained *hubs*
- half-duplex operation controlled by the *host*

Hardware

- four wires
  - power: GND and VBUS (5 V)
  - data pair: D−, D+
- cables with connectors type A and B
  - A = Downstream-Facing Port
  - B = Upstream-Facing Port
- *captive cable* captivated in the peripheral
- maximum length of the cable ca. 5 meters

Transfer speeds (USB 2.0)

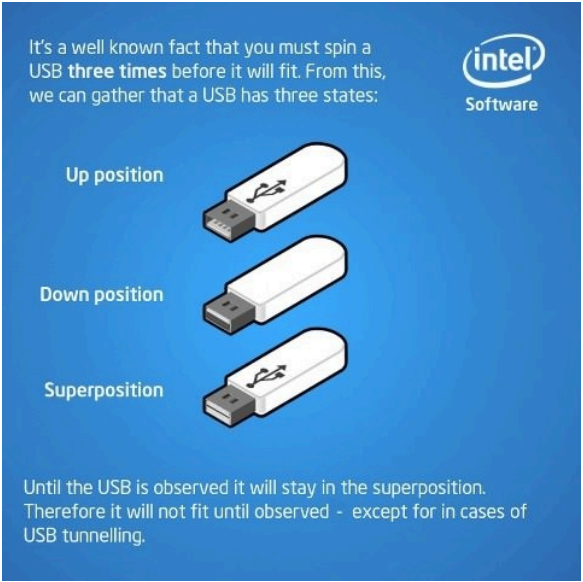
- Low-speed - 1,5 Mbps
  - simple cable can be used
  - only *captive* cables
  - transaction timeout limits cable length
- Full-speed - 12 Mbps
- High-speed - 480 Mbps (USB 2.0)
  - different voltage levels
  - impedance matching of the link

Non-functional assemblies mitigation

- oriented cables A -> B
- plug shapes very different

Forbidden (passive) cable assemblies

- USB extension cords (plug and socket of the same type)
  - can extend over allowed cable length and voltage drop
- cables with same plug type on both ends
  - dangerous when connecting two hosts
- low-speed cables with B plug
  - could be used with a high-speed device



- The USB Icon on the plugs **provides tactile feedback** making it easy to obtain proper orientation.
- The USB Icon is embossed, in a recessed area, on the topside of the USB plug.
- Receptacles should be oriented to allow the Icon on the plug to be **visible during the mating process**.

USB On-The-Go

- a feature of some *devices* to take over the *host* role
- uses the fifth pin of Mini-AB a Micro-AB connectors
- requires special cables and adapters
- limited *host* functionality
- extensively (ab)used by older Raspberry Pi computers

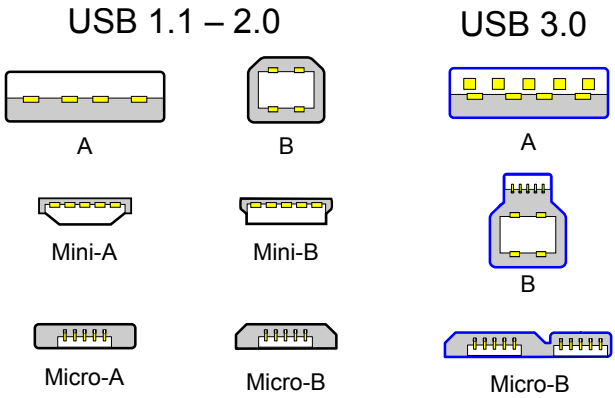
Software

- automatic addressing and enumeration - transparent to user
- generic device classes for driverless operation
  - Human Interface – keyboards, mice
  - Mass storage – block devices
  - Video – webcams and frame grabbers
  - Audio – headphones and microphones
  - Communications – modems and network adapters
  - Smart Card - readers
- devices identified by vendor and product ID
- direct access with *libusb*
  - with proper permissions to `/dev/bus/usb/*/*`
  - used by VirtualBox, GnuPG, FIDO, etc.

USB 3.x

- new SuperSpeed speed – 5 Gbps (USB 3.0, 3.1 Gen 1)
- two *extra* lanes for duplex transfer
- maximum length limited to 3 meters
- backwards compatible sockets and plugs of **type A** and type B sockets
- co-exists with **unaltered** USB 2.0
  - uses the original pair D- and D+
  - total capacity for all High- and Full-Speed devices stays 480 Mbps
- USB 3.1 Gen 2 with SuperSpeed+ (10 Gbps) speed
- USB 3.2 Gen $n \times k$ uses k pairs of links

Connectors



Author: Milos.bmx, Wikimedia Commons CC-BY-SA

USB as a power supply

Power mode

bus-powered devices powered only from the USB
self-powered devices with their own power supply
unit load 100 mA for USB 2.0, 150 mA for USB 3.x

- the *host* offers 5 volts, 5 load units
- *devices* before enumeration consume at most 1 unit
- hungry *devices* ask for 5 units
- bus-powered *hubs* offer only 1 unit to each connected device.

USB as a sole power supply

- fans, lamps, mug heaters,...
- Y-cables for external hard drives
- abuses leniency of many hosts

Picture source: Reichelt.com

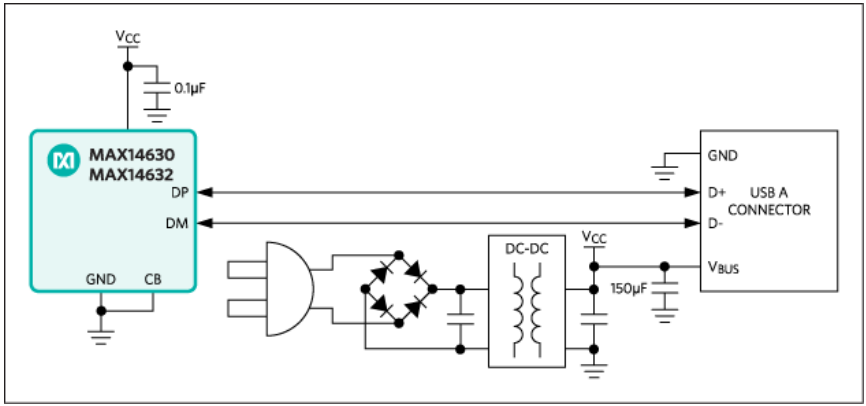
USB as a charger

- the need for more than 500 mA @ 5 V
- overloading legacy port might cause issuess
- signalling using D- a D+ wires
  - often incompatible with the USB protocol
  - proprietary **non-interoperable** solutions by each vendor
  - standardised as USB Battery Charging

USB Battery Charging 1.2

- 5 volts, at least 1 500 mA
- compatible with s USB protocol
- signalled connecting D- to D+ on the supply side

Building a USB charger



Source: Maxim tutorial 5801

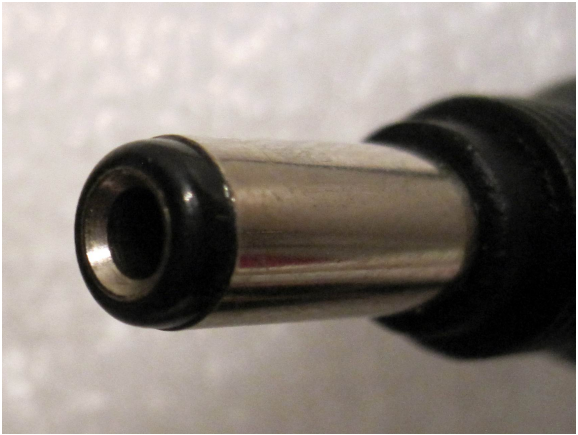
Advanced charging standards

- *well known:* Qualcomm Quick Charge
- changes even VBUS from 5 V up to 20 V
- QC 3.0 adds Programmable Power Supply (PPS)
  - charger's output adjusts to the battery voltage
  - no need for DC/DC conversion in the device
  - better efficiency, heat management
- standardisation effort with USB Power Delivery 1.0
  - compatible with USB protocol
  - 24MHz BFSK signalling on VBUS
  - not reliable, deprecated

Quiz: Which voltage does this connector supply?

A 5 V
B 12 V
C 24 V
D 52 V

1 DC, center positive
2 DC, center negative
3 AC

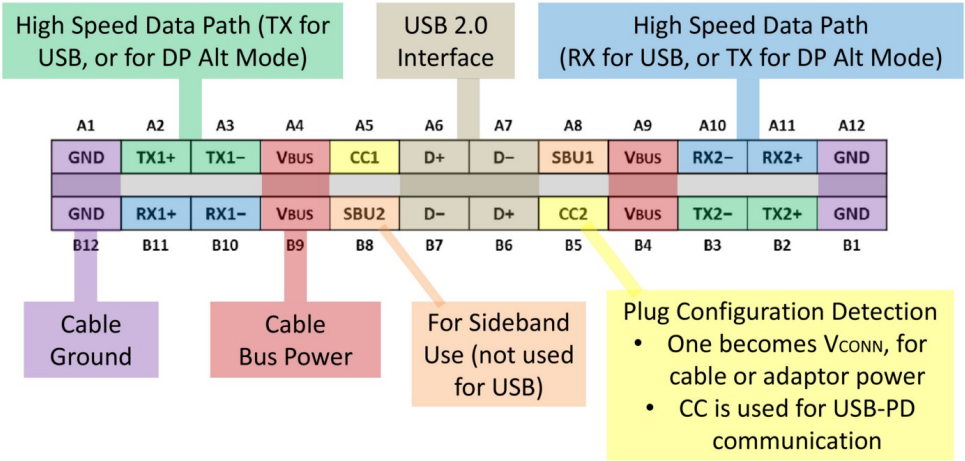


Type-C connector and Power Delivery

USB Type-C connector

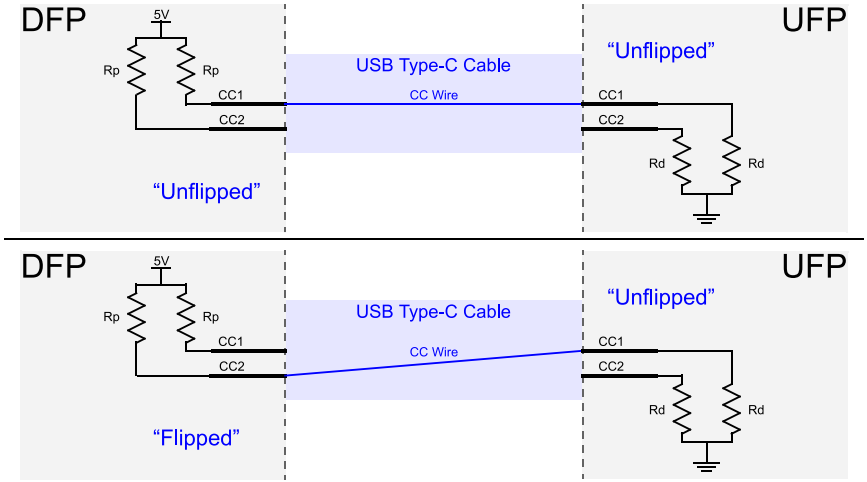
- new universal connector for both *host* and *device*
- four universal SuperSpeed lanes
- one USB 2.0 lane
- supports current up to 5 A
- separace Configuration Channel for plug and orientation detection
- supports alternative modes unrelated to USB
- elektronically marked cables

Type-C connector contacts



Source: Benson Leung

Cable orientation detection



Source: Microchip AN 1953

Powering by Type-C connector

- no voltage **before** connected device *detection*
- three current limits based on pull-up Rp value
  - USB default (5 V, 500/900 mA)
  - 5 V, 1 500 mA
  - 5 V, 3 000 mA
- other options available via USB Power Delivery 2.0+

USB Power Delivery

- using BMC on the Config Channel
- up to 20/48 V, 5 A = 100/240 W, Programmable Power Supply supported in PD 3.0
- source-sink exchange (eg. charging laptop from the monitor)
- can switch the connector to one of non-USB alternate modes

Common issues with lame Type-C devices

missing Rd resistors
: can be only charger with an A-C cable

one common Rd
: only the basic 3A USB 2.0 can be used

no mirrored D- D+ connection
: USB works only in one connector orientation

no SuperSpeed lane switch
: SuperSpeed USB works only in one connector orientation

Quiz

Which voltage is **not** a standard part of USB PD?

A 9 V

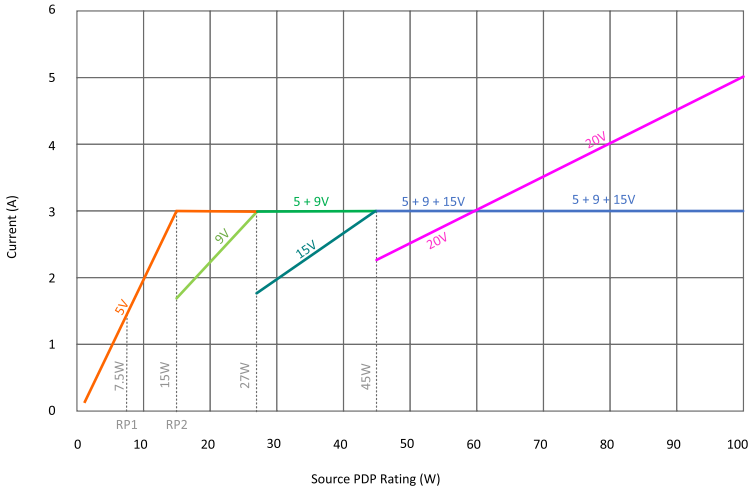
B 12 V

C 15 V

D 20 V

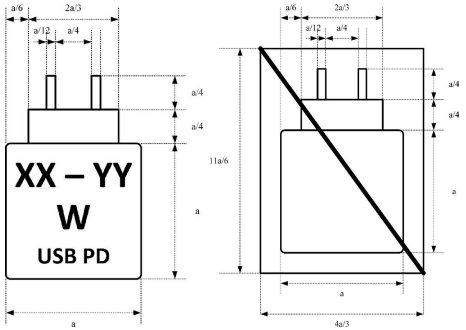
Supported USB PD voltages

Figure 10.1 SPR Source Power Rule Illustration for Fixed Supply PDOs



EU Directive 2022/2380

- **USB Type-C** socket mandtory for small portable devices
- **USB PD mandatory** for voltage/current higher than 5 V/3 A
- standard pictograms signalling charger presence and required power range



USB Type-C cables

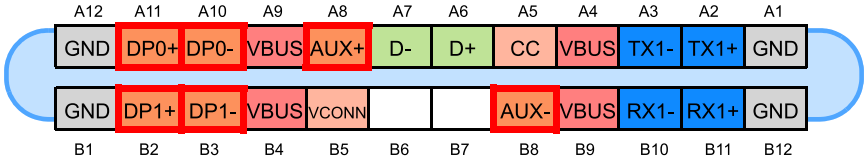
Basic Type-C cables

- High-speed, 3A (most common)
- High-speed, 5A (charging cable)
- SuperSpeed, 3A (3 subtypes based on revision)
- SuperSpeed, 5A (3 subtypes based on revision)

- cables with Type-A or Type-B plug support only limited functionality
- proprietary charinging standards that change VBUS are **forbidden**
- chargers should support USB BC for legacy devices
- passive assemblies with Type-C sockets are **forbidden**

DisplayPort Alternate Mode

- most common way of connecting a screen
- SuperSpeed lanes used for DisplayPort
- **coexists with USB and PD** in one cable
- 4K@60Hz + SuperSpeed USB requires DP 1.4



Zdroj: Microchip AN 1953

Thunderbolt 3

- proprietary interface with speed up to 40 Gbps
- uses Type-C connectors
- reuses USB *Power Delivery*
- **link capacity sharing** by multiple devices
- can connect two monitors or even a PCIe device
- **authentication and authorisation** of connected devices
- TB 3 is backwards compatible with SuperSpeed USB + DP alt mode
- standard **has been opened** and became **USB4** in 2019
  - mandatory Type-C and USB PD
  - tunnels USB 3.2, PCIe and DP

Wrap up

Takeaways

- many issues with USB are caused by cables, adapters and devices, which based on the spec **should not exist**
- type-C connector is **the only fast charging standard**
- if you play with USB on Raspberry Pi, the majority of texts about the OTG mode are wrong. You **disable OTG** to make it act like a device
- all **cables are not the same**; proper marking is sometimes missing

Thank you!

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The slides can be downloaded from my website.