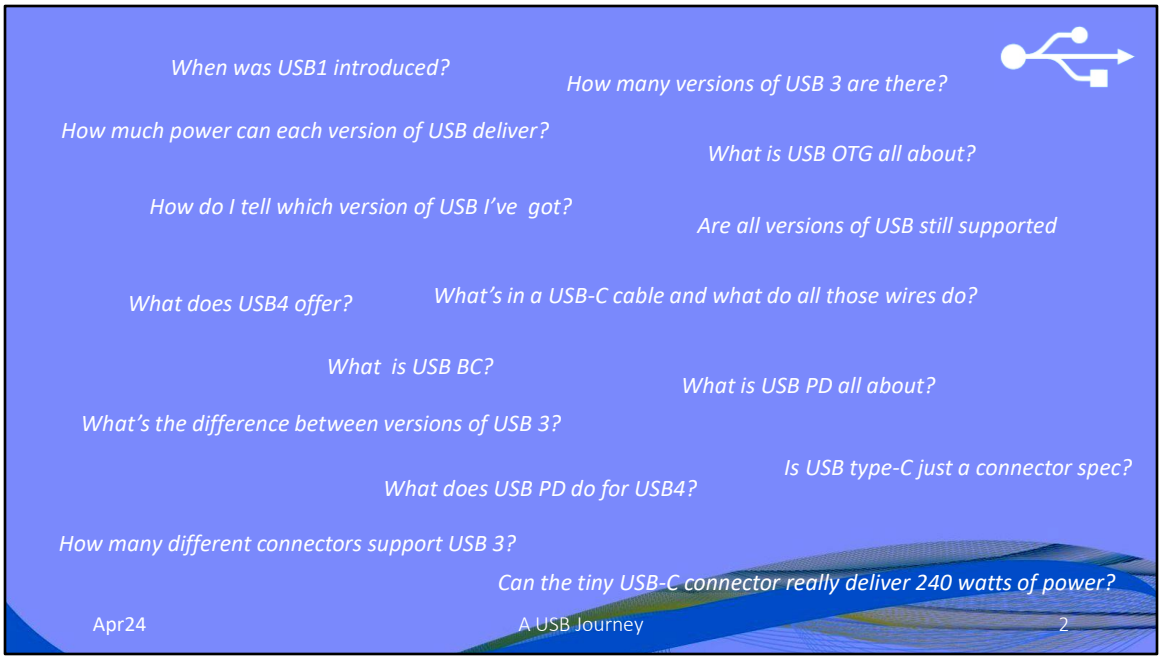

A USB Journey
It's History Evolution Insights & my Applications
VE3CZO



I began this presentation journey by wanting to create a breakout printed circuit board for USB-C adding it to my collection of USB breakout boards. I soon discovered that USB-C was not a protocol spec, its just a specification for a connector that can accommodate a series of communication and power delivery protocols.

If I wanted to create a USB-C breakout board I quickly came to realize its complexity. With it's 24 pins and multiple high speed data channels I'd probably need a fine pitch 6 layer PCB and that

wasn’t going to happen any time soon.
So I backed off the original idea and set out to determine what if anything I could build for USB-C with a 2 layer low cost board.
I began rummaging though specs and quickly came to grips with the realization that the USB family had evolved quite a bit past ***my*** understanding. I felt that this might also be true for a lot of folks and that lead to this presentation.

USB is over 30 years old!

USB was launched in 1993 by Intel to simplify computer peripheral attachments

In 1992 Intel's Ajay Bhatt formed a consortium with Compaq, Digital Equipment Corp. (DEC), IBM, Intel, Microsoft, NEC and Nortel to develop a plug-and-play scheme for PC peripheral connection

It took until 1996 to see wide adoption.

Key goals

Inexpensive

User-friendly

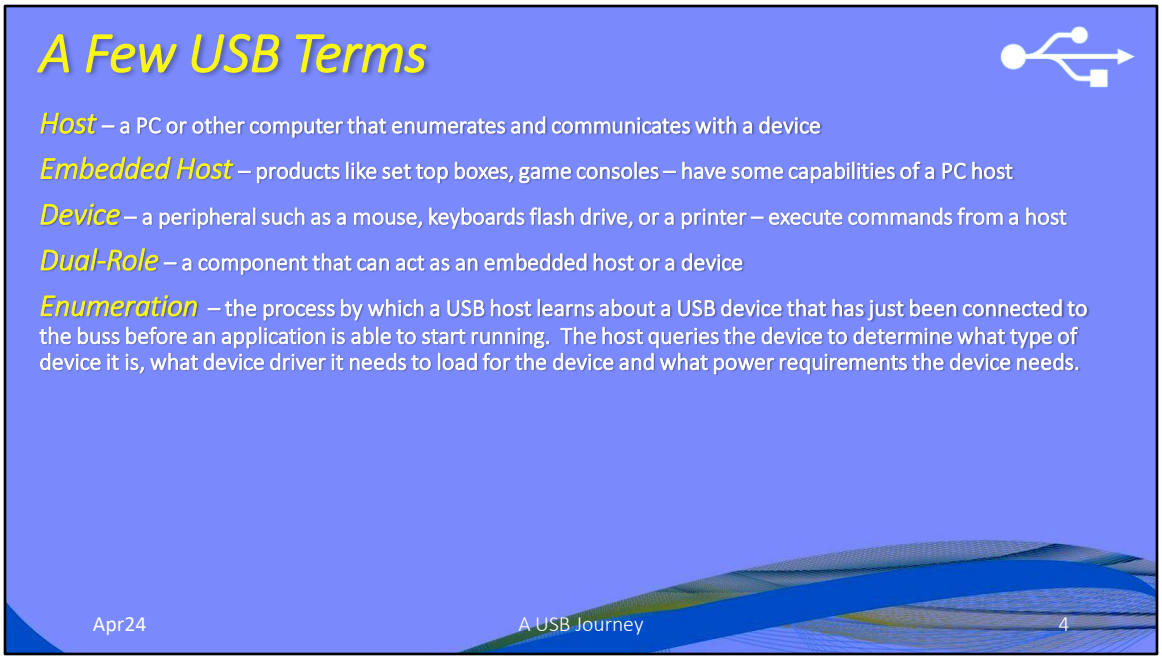
Lots of bandwidth

Able to power peripherals

I remember the era before USB. It was often a pain to connect computer peripherals. You typically had a choice between serial and parallel ports, and the computer most often didn't have enough of either so users often had to open their computer to add-in hardware to give them the communications port needed then arduously configure the port for use. Most often a wall wart power supply was also needed for the new device.

And then USB came along. It was conceived in

1992 by a group of 7 companies, was launched thirty one years ago in 1993 as an inexpensive, user friendly, high bandwidth solution to easily connect peripherals to a PC.



Throughout this presentation I'm not going to focus on any detail about ***how*** USB accomplishes it's tasks but rather only the features it provides. Here are a few USB terms that will pop-up.
A host

Embedded Hosts

A device

from a host.
Dual-Role are components that can act as either an embedded host or a device.
Enumeration is the process by which a USB host learns about a USB device that has just been connected to the buss before an application is able to start running.
The host queries the device to determine what type of device it is, what device driver it needs to load for the device and what power requirements the device needs.
You may notice a pop-up widow on a computer that identifies that a USB peripheral has been connected and offers the user options for accessing it.

USB 1.0 & USB 1.1

USB 1.0

- First design release 1995 commercial release 1996
- Data transfer 1.5 Mb/s half duplex
- Power delivery – 2.5Watts (5V 500mA)
- Maximum cable length 5 meters
- Connectors have white separator
- Cables used type A connectors for PC & type B for peripherals

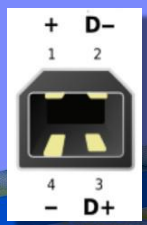
№	Pin	Wire Color		Description
1	V_{BUS}	Red	Orange	+5 V
2	D –	White	Gold	Data –
3	D +	Green		Data +
4	GND	Black	Navy	Ground

USB 1.1

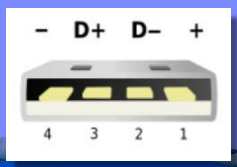
- Released in 1996 & saw widespread manuf in 1998
- Data transfer rate 12 Mb/s half duplex
- Same power delivery and cable lengths as USB 1.0

NB Plugs (m) are on cables, receptacles (f) are on hosts & devices
Pinouts throughout this presentation orient looking directly into plugs NOT receptacles!

USB type B Plug



USB type A Plug

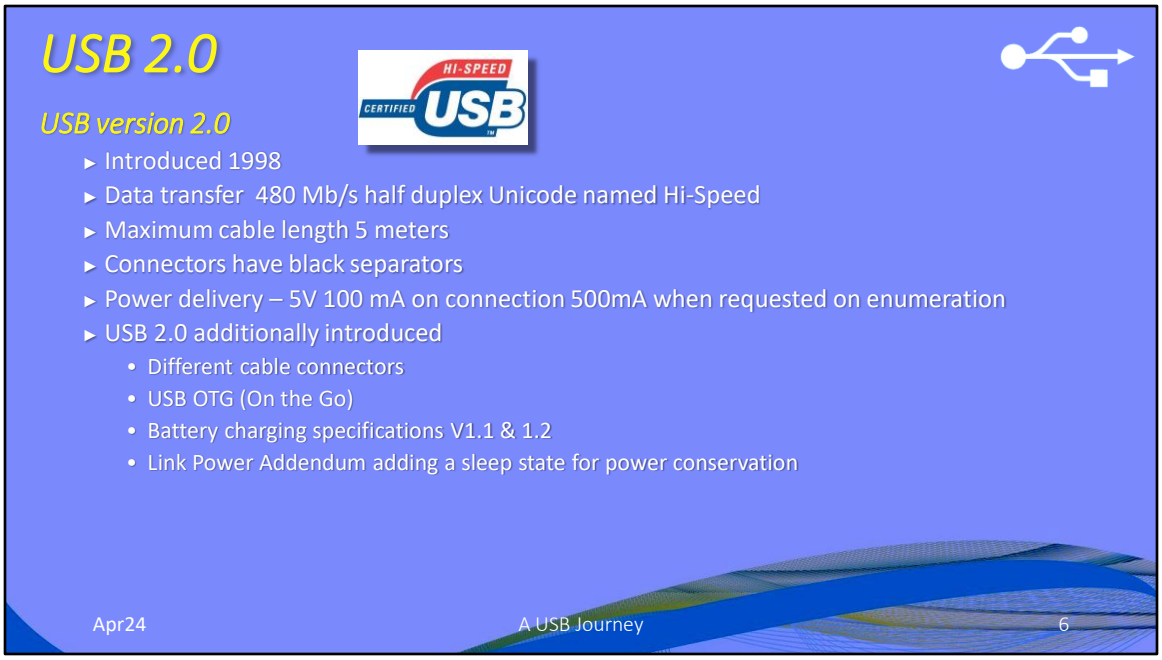


USB1.0's design was completed in 1995 and it saw commercial release in 1996. The data transfer rate was 1.5Mb/s half duplex and it could deliver power, 0.5A at 5V from host to device. The maximum cable length was 5 meters. Connectors have a white separator and typically used type A for the host and a type B for the device.
A 4 conductor cable delivered data and power between host and device. The wire colors in most cables became standard.

USB1.1 was released in 1996 but didn't see widespread use until 1998. It retains the white separator, delivers 12Mb/s half duplex data and has the same power delivery and cable lengths as version 1.0

Microsoft Windows 98 was the first operating system to support USB

Just so connector pinouts don't get reversed note that because the connectors are almost asexual, plugs are defined as being on cables, while receptacles are located on hosts & devices



USB 2.0 was introduced in 1998, had a data transfer speed of 480Mb/s so was known as USB HI-SPEED

The maximum cable length remained at 5m so was the same as USB1.

USB2 connectors have a black separator rather than the white used with USB1.

DC power delivered to a peripheral was reduced to

100mA @ 5V until enumeration was completed then increased to 500mA.

USB 2 also introduce several other things.
More cable connectors
USB OTG or On The Go
And Battery Charging specs
Let’s look into those…

Pin	Name	Cable color	Description
1	V_{BUS}	Red	+5 V
2	D−	White	Data −
3	D+	Green	Data +
4	ID	N/A	Permits distinction of a host connection from device connection: • host: connected to the signal ground • device: not connected
5	GND	Black	Signal ground

USB2 reuses USB1's type A and B connectors and additionally introduces the mini and micro connectors.

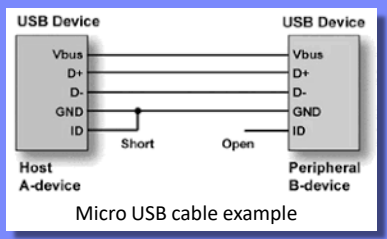
While mini-B and micro-B are still in wide use mini and micro A are not longer used

USB mini and micro cables add an ID pin and cable conductor for use with USB On the Go

USB On The Go

Referred to as USB OTG or just OTG

- Enables non PC host communication with peripherals (slave)
  - Printer hosts camera
  - Cell phone hosts memory stick, camera or a second cell phone
- USB On-The-Go and Embedded Host Supplement
  - Revision 2.0 added to USB 2.0 in 2001
  - Revision 1.1 added to USB 3.0 in 2012



Micro USB cable example

- Requires cable mode detect (ID, pin 4, on mini & uUSB), plus additional USB interface hardware & firmware in the host and peripheral
  - Cable ID pin is shorted to ground at one end (defines host) and open at the other (defines peripheral)
  - Enumeration with ID pin defines roles
  - Firmware in the standard supports host-peripheral role reversal

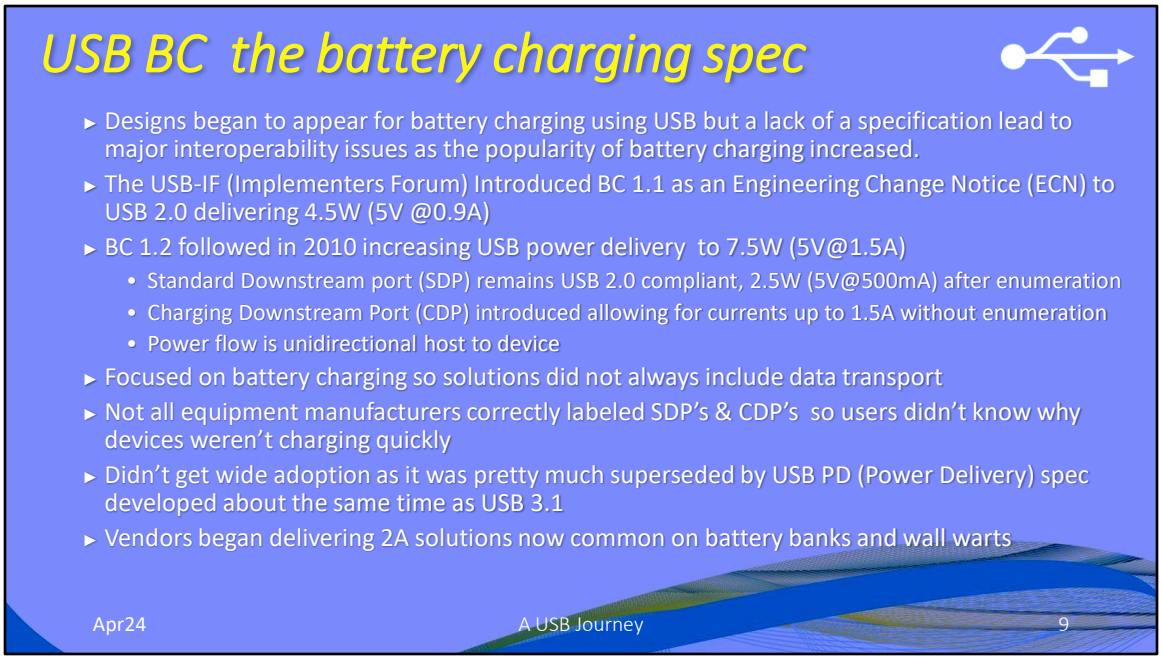
USB On The Go enables ***non*** PC host communication with peripherals.
For example a printer can host a camera to print pictures, a cell phone may host a memory stick, camera, or even a second cell phone.

USB OTG was added to the USB2 spec in 2001, and was included in the USB3 spec in 2012.

On The Go uses the ID wire, shorted to ground to define the host and the other end will be open to

define the device. Roles are determined during enumeration.

Host / Device role reversal capability is also incorporated into the spec.

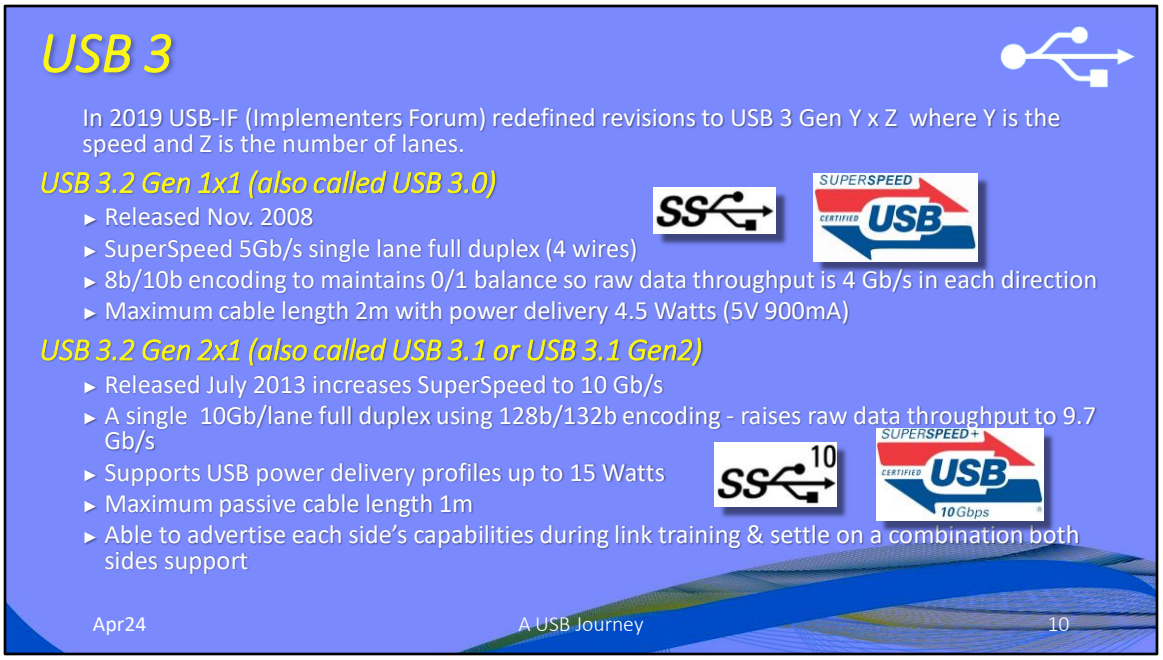


Designs began to appear for battery charging using USB but a lack of specifications lead to major interoperability issues as the popularity of charging increased.

The USB Implementers Forum introduced a battery charging spec version 1.1 providing for 5V @ .9A or 4.5 watts then shortly after introduced a version 1.2 spec enabling 5V @1.5A or 7.5W.

This resulted in 2 classes of hosts. A ***Standard*** Downstream Port retained the USB2's 0.5A or 2.5W spec. A ***Charging*** Downstream Port could

deliver 1.5A or 7.5 Watts without enumeration.
Power flow was unidirectional from host to device.
As the spec was focused on battery charging it did not always include data transport.
It’s downfall was that not all manufacturers correctly labeled Standard and Charging devices so users didn’t understand why their components weren’t charging quickly.
The Battery Charging option didn’t get wide adoption as it was superseded by the USB3 Power Delivery spec.
Many vendors settled on solutions delivering up to 2A to the device now commonly seen on may battery banks and wall wart supplies.

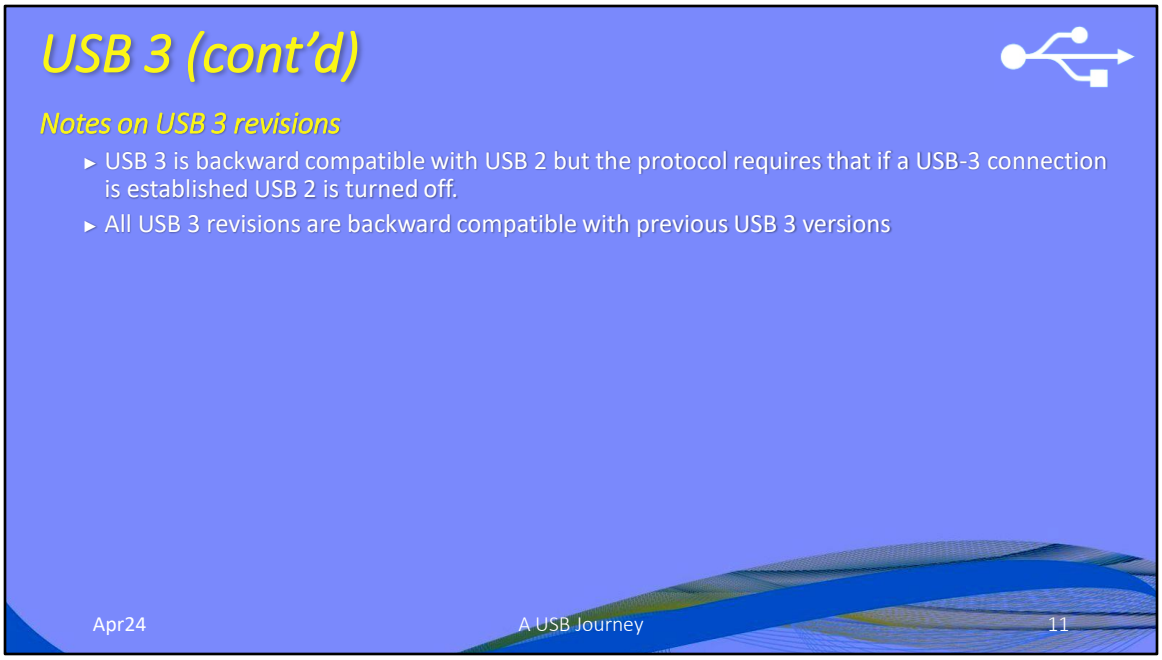


USB3's evolution got confusing, so to minimize it the implementers forum introduced the Gen Y by Z nomenclature in what I believe was a futile attempt to de-confuse things.

USB 3.0 later called USB3.2 Gen 1x1 was released in 2008 with a ***single full duplex*** data lane with a raw data speed of 5Gb/s. 8b/10b encoding maps 8-bit words into 10-bit symbols to achieve DC balance for a net throughput of about 4Gb/s in each direction.

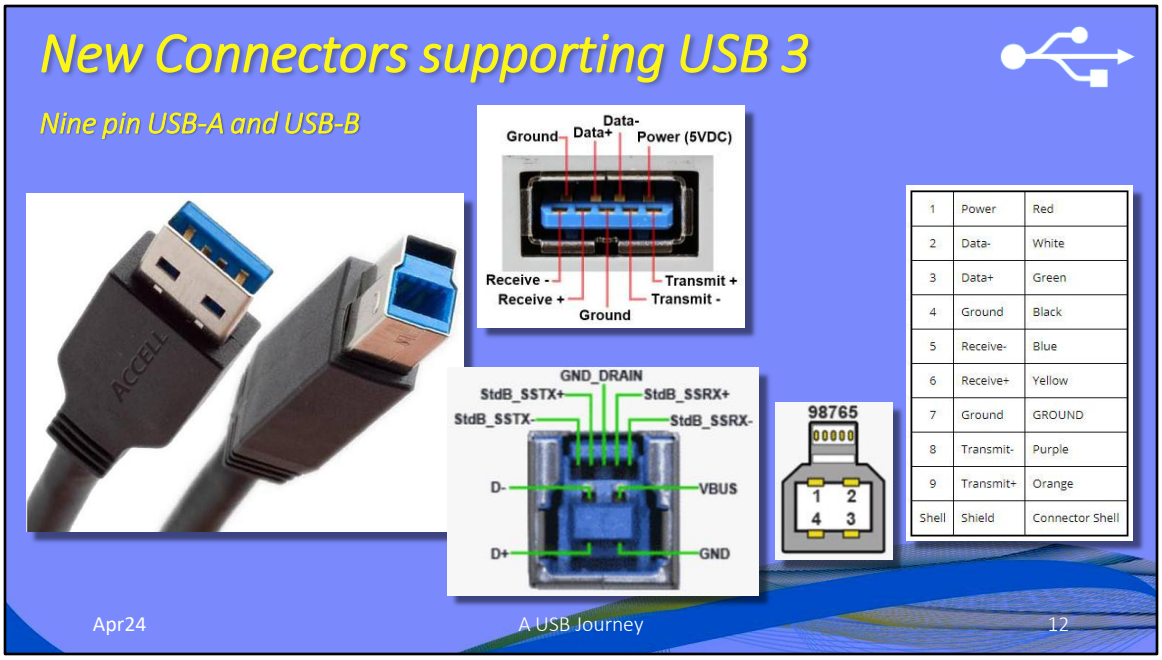
USB 3.2 Gen 2x1 released in 2013 introduced a

faster 10Gb/s full duplex lane using 128b/132b encoding realizing a raw data throughput of 9.7 Gb/s in each direction.
This version also supported the initial USB Power Delivery spec which was capable of delivering up to 15 Watts to devices.
The maximum cable length reduced to 1m
As there are now multiple speeds, for backward compatibility protocol and enumeration enhancements were added. These included the ability for a host and device to advertise capabilities so that the pair can settle on a combination that both sides can support.

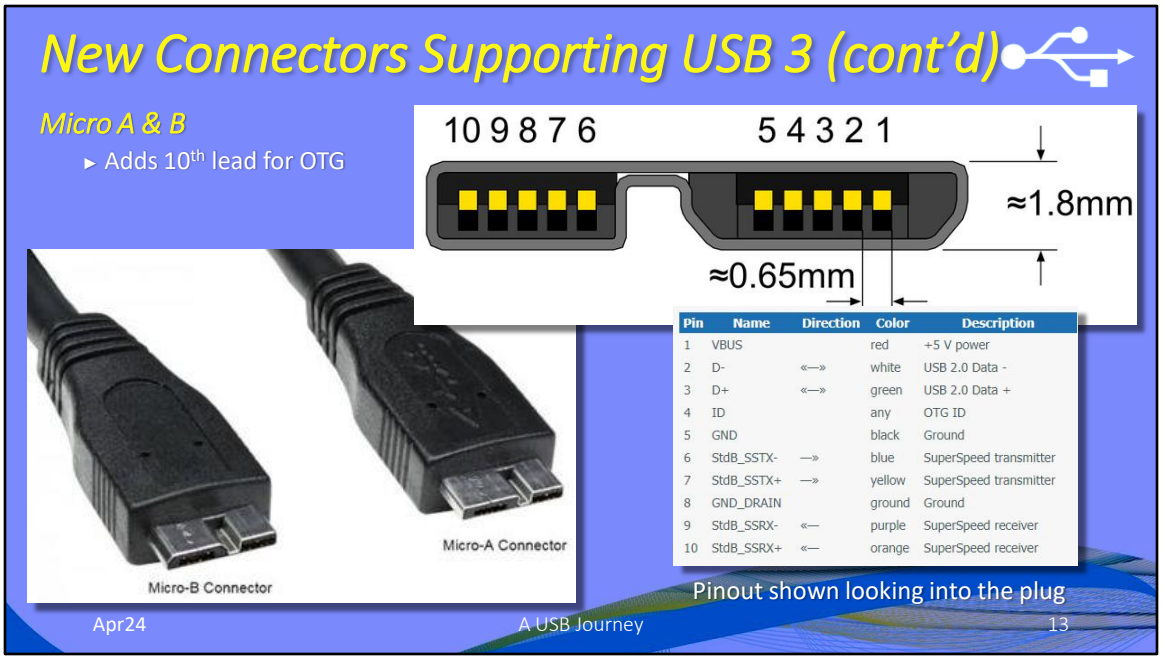


USB3 is backward compatible with USB 2 but the protocol requires that if a USB-3 connection is established USB 2 is turned off

All USB 3 revisions are backward compatible with previous USB 3 versions



New connectors are introduced to support USB3.
A blue separator typically identifies a cable as USB3 capable.
USB A and USB B plugs and receptacles add 5 pins for the full duplex super speed channel
The nine pin USB ‘A’ plug will mate correctly with a 4 pin USB ‘A’ receptacle but the ‘B’ plug has a higher nose to accommodate the additional 5 pins so will not mate with a USB2 ‘B’ receptacle.



Pin	Name	Direction	Color	Description
1	VBUS		red	+5 V power
2	D-	«—»	white	USB 2.0 Data -
3	D+	«—»	green	USB 2.0 Data +
4	ID		any	OTG ID
5	GND		black	Ground
6	StdB_SSTX-	—»	blue	SuperSpeed transmitter
7	StdB_SSTX+	—»	yellow	SuperSpeed transmitter
8	GND_DRAIN		ground	Ground
9	StdB_SSRX-	«—	purple	SuperSpeed receiver
10	StdB_SSRX+	«—	orange	SuperSpeed receiver

Micro A and B connectors are introduced although the micro A is not very common

These connectors support a tenth lead for On The Go applications using the same connection techniques developed for USB2 On The Go.

The pinout shown is a plug viewed looking into the connector, NOT the receptacle

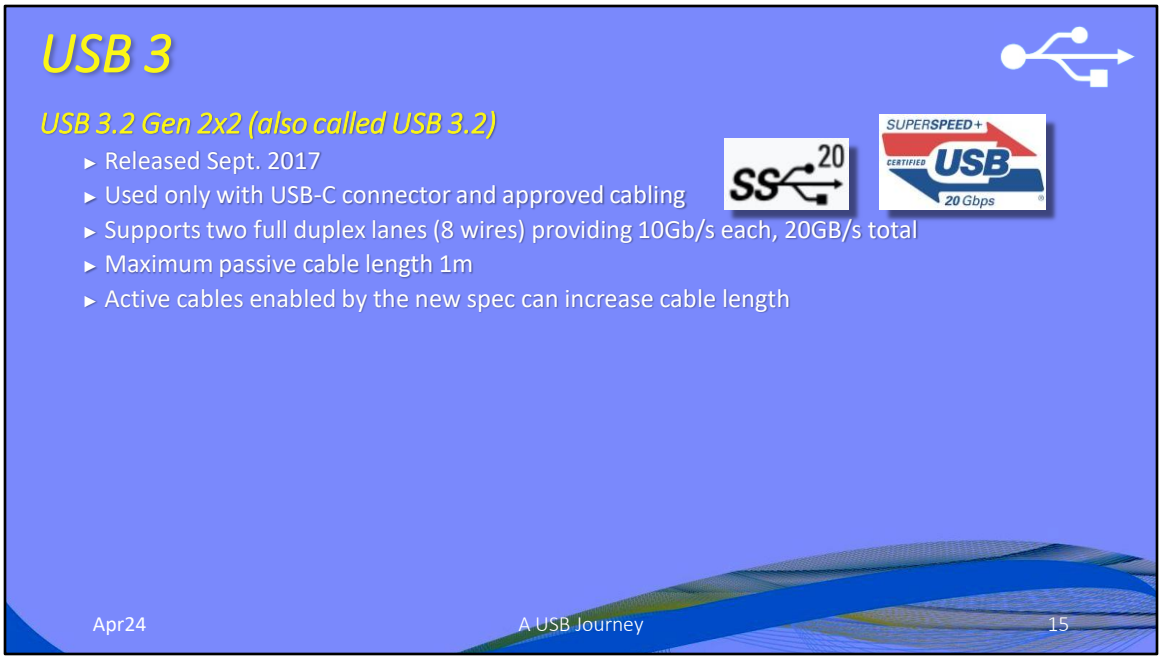
As we follow the USB development history, all subsequent releases of the USB spec incorporate three components simultaneously.

The adoption of a single connector, the USB-C

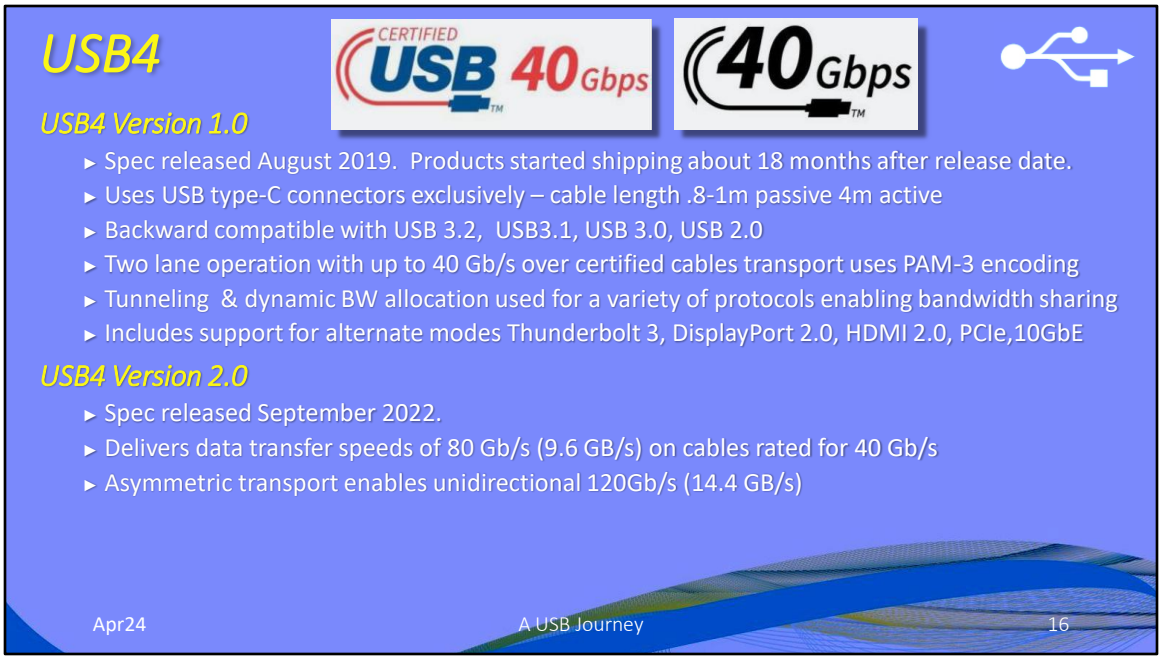
A set of standards for power delivery.

Transport protocol changes typically enhancing speed and enriching capability to perform additional functions

The USB-C plug and receptacle has remained unchanged since its introduction but the transport and power delivery specs are continuously evolving.
Well examine each aspect individually. Let’s begin by continuing with the protocol’s evolution.



USB3.2 Gen2x2 released in 2017 is the first point at which a USB-C connector becomes mandatory because the standard now supports two full duplex data lanes. The two data lanes can be bonded to provide a total 20Gb/s data transfer rate.
The maximum passive cable length is 1 meter. Active cables, enabled by the USB-C connector standard, can be used to increase that length.



USB4 was released in 2019 and product started appearing in 2021. Logos on packaging and cables no longer show version numbers just speed, a marketing change promoted by the USB Implementers Forum.

USB4 uses USB-C connectors exclusively Maximum cable length for full data rate is reduced slightly to 0.8 meters but more recent information indicates that 1 meter is possible and active cables can be as long as 4 m.

USB4 provides backward compatibility with USB

3.2, 3.1, 3.0 and 2
Feature two lane data transport using PAM3 encoding to enable transport speeds up to 40Gb/s when both lanes are bonded.
Tunneling and dynamic bandwidth allocation is introduced. Tunneling simply bundles up a protocol in a faster data stream for transport and is unpacked at the receiving end. This means that several protocols could be transported in the USB4 data stream and allocated a specific portion of the available bandwidth. Tunneling is now used for variety of protocols including USB3.2, DisplayPort, and PCIe. For example if a computer uses a USB4 dock to connect a display monitor and external drive, USB4 can allocate a portion of its 40Gb/s stream, say 10Gb/s to the display and 30Gb/s to the drive.
USB4 also supports the use of alternate modes, data streams that would not normally be handled by USB. For example Thunderbolt3, DisplayPort2 which is capable of 8k resolution at 60 frames per second, HDMI, PCIexpress, and 10 Gb Ethernet are all supported.

USB4 Version 2 increases the data delivery speed

to 80Gb/s over the same cable lengths.
It also introduces asymmetric data streams, so for example if streaming video, all lanes can be unidirectional to deliver up to 120Gb/s.

USB-C connector

USB Type – C

- Developed by the USB Implementer's Forum (USB-IF) introduced 2014
  - Evolved to provide a single form factor replacing many USB connectors
- The receptacle is symmetrical so the plug can be inserted either way
- Removes the need for different connectors on host & devices
- Supports all USB data standards from 2.0 to 4.
- Supports USB PD (power delivery) up to 240W
- Supports powered cables as part of USB PD standard
- Supports a variety of alternate modes.
- The standard receptacle has 24 pins but cables have fewer conductors depending on application

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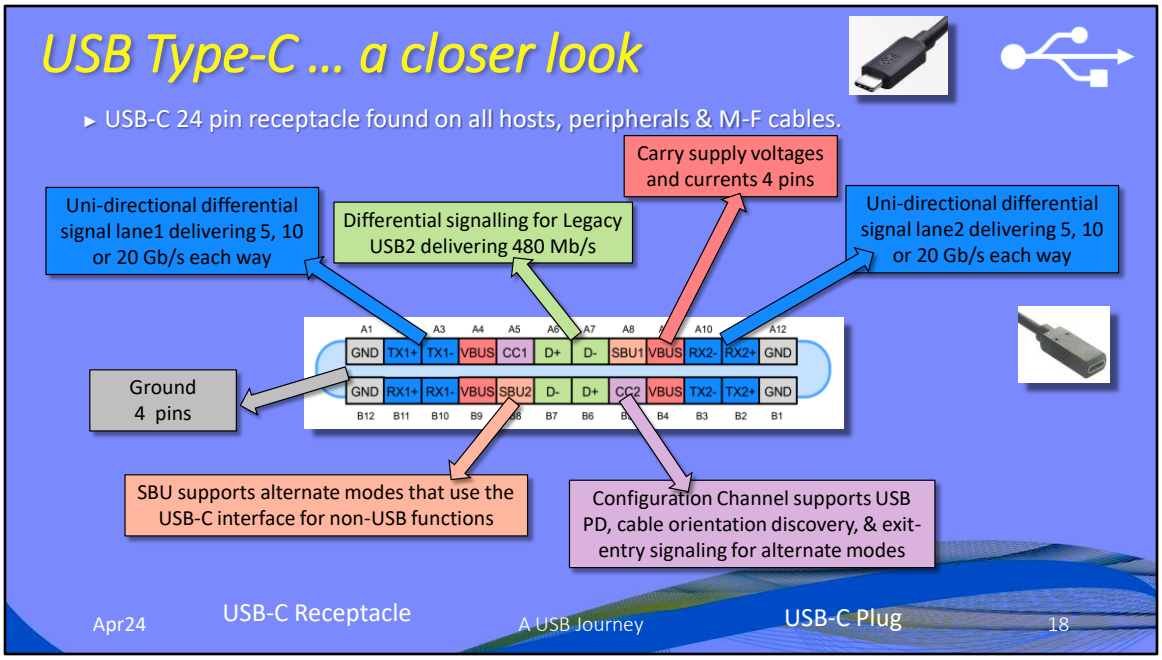
The USB-C connector was developed by the USB Implementers Forum and introduced in 2014 as an evolution to provide a single form factor replacing many USB connectors.

The receptacle pins are symmetrical so the plug can be flipped around and inserted in either orientation.

Its flexibility can remove the need for different connectors on host and devices

The connector supports all USB data standards, along with USB power delivery, powered cables,

and a variety of alternate modes.
The standard receptacle has 24 pins although cables have fewer conductors depending on application.
So let’s take a closer look at this connector.



USB 2 had 4 pins, USB3 nine 9, the USB-C connector sports 24. It certainly delivers more capability at the expense of cost and complexity.

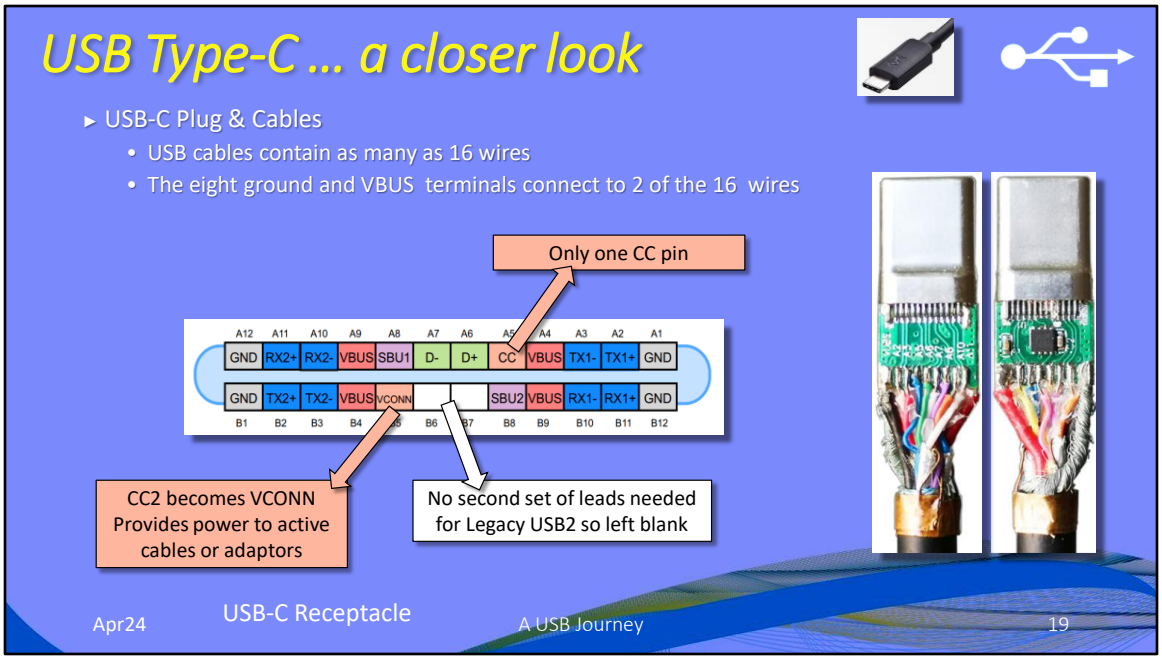
The 24 pin female ***receptacles*** are used on both hosts, devices, and in line cables. The USB-C male to male cable is a bit different.

The first thing to note is that the receptacle's pins are symmetrical so plugs can be inserted in either orientation.

Let's go around the connector and explore its pin functions starting on the upper left.

TX1+ TX1-, Rx1+ RX1- create a set of uni-directional differential signal lanes delivering 5, 10 or 20 Gb/s each way.
D+ & D- are differential signaling pins delivering legacy USB 2 at 480 Mb/s
Four VBUS pins carry supply voltages and currents delivering up to 240W. Basic cables are required to deliver 3A, that's 15 watts at 5 volts or 60 Watts at the highest voltage specified by the Power Delivery spec. Special cables with larger supply conductors are required if delivering more power.
Rx2- RX2+ TX2- and TX2+ form a second set of uni-directional differential signal lanes again capable of delivering 5, 10, or 20 Gb/s each way, and can be bonded with lane 1 to double throughput.
The configuration channel is one of the keys to USB-C's flexibility. It helps to determine cable orientation, defines overall data delivery rates, provides entry and exit signaling for alternate modes and supports USB Power Delivery.
The 'Sideband Use' pins SBU1 & SBU2 provide signaling that supports alternate modes. They use the USB-C interface to deliver non-USB protocols like DisplayPort, Thunderbolt, HDMI, PCI-e, 10Gb Ethernet.

And lastly there are 4 ground supply return pins.



USB-C cables use plugs that are a bit different than the receptacles.

There are 16 wires if a fully featured cable, the 4 Vbus and 4 ground pins are connected to two cable wires.

There is only one CC pin, CC1 becomes CC and only one CC wire runs in the cable. The other CC pin becomes VCONN. It's used to indicate a need for and can supply power to active cables or adapters.

Only two wires are needed for legacy USB2 so connections B6 and B7 are not used.

USB-C Configuration Channel (CC)

CC1, CC2 (receptacle) – CC, V_{CONN} (plug) pins are key to managing connections

- One CC pin and cable wire so the cable can be used to…
- Detect the attachment of a USB port
- Resolve the cable orientation and manage connection establishing data bus routing establishing lane 0 for the two data lanes specified for USB 3.2 and 4
  - Lane 0 determined as one closest to CC pin on the plug
- Discover and configure V_{CONN} - a plug is able to supply power (up to 1.5 Watts) for active cables to the "unused" CC1 or CC2 receptacle pin
- Establish data roles between two attached ports
- Establish source and sink roles between two attached ports
- Discover and configure optional alternate modes i.e. DisplayPort, Thunderbolt, HDMI etc.
- Discover and enter USB4 operation using USB PD protocol
- Discover, manage, and configure VBUS for power delivery
- No leading power pins on USB-C so by default VBUS power is off until authorized by CC

The configuration channel is a key part of USB-C.
In this presentation I'll not go into ***how*** tasks are accomplished but just highlight the number of functions performed.
As noted in the previous slide the cable has only one CC pin and CC2 becomes VCONN so the cable can be used to…
Detect cable insertion
Resolve the cable orientation, establishing data bus routing. Lane 0 of the two lanes will be the one closest to the CC pin on the plug.

Discover and configure V_{CONN} - active cables can be supplied with up to 1.5 Watts. Power is routed though the receptacle's "unused" CC1 or CC2 pin to cable's V_{CONN} PIN.

The configuration channel also establishes data roles between ports

It also establishes source and sink roles between two attached ports

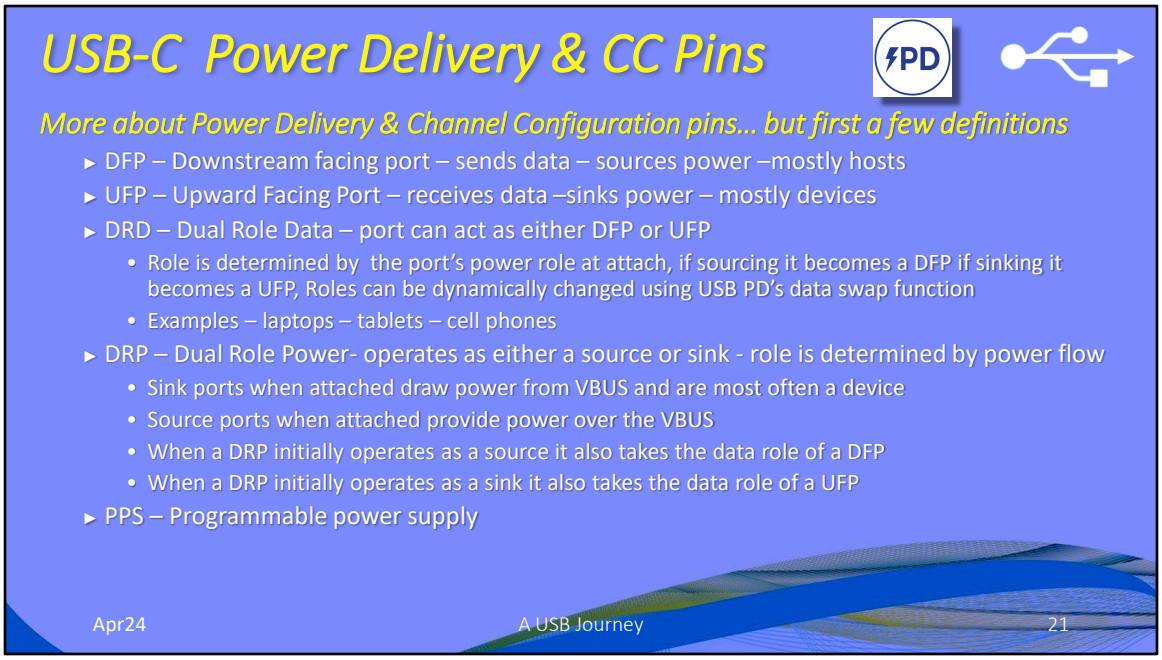
It discovers and configures optional alternate modes

It discovers and enters USB4 operation

It will also discover, manage, and configure VBUS for power delivery

The USB-C plug has no leading power pins as was used with previous USB connectors to insure power is applied first. So by default VBUS power is off until authorized by CC

Let's now take a look at USB-C Power Delivery



Before diving into power delivery here's are a few acronyms that we'll encounter.
DFP is the Downstream facing port. It sends data, sources power, and is associated mostly with hosts

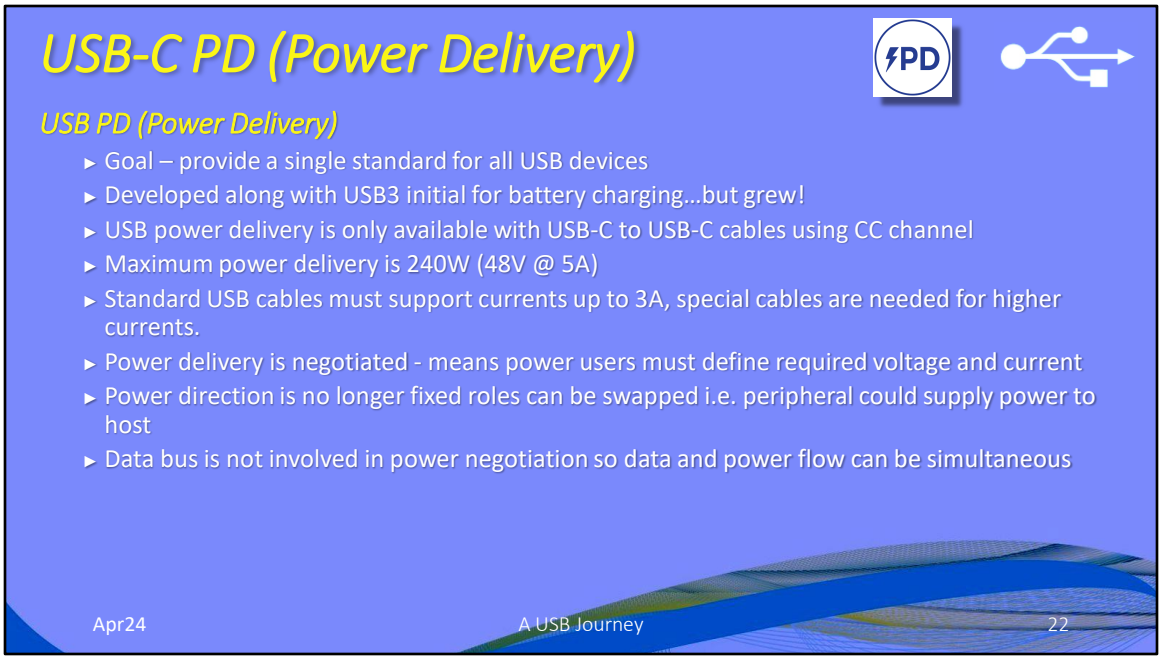
UFP is an Upward Facing Port. It receives data, sinks power, and is mostly associated with devices

DRD – Dual Role Data defines a port that can act as either Downstream Facing Port or Upward Facing Port

A role is determined by the port's power role at attach, if sinking it becomes a Upward Facing Port, if sourcing it becomes a Downward Facing Port. Roles can be dynamically changed using power delivery's power swap function

Dual Role Power means the port operates as either a source or sink. Its role is determined by power flow
Sink ports draw power from VBUS and are most often a device.
Source ports provide power over the VBUS.
When a Dual Role Power device initially operates as a source it also takes the data role of a Downward Facing Port
When a Dual Role Power device initially operates as a sink it also takes the data role of an Upward Facing Port

PPS is a programmable power supply

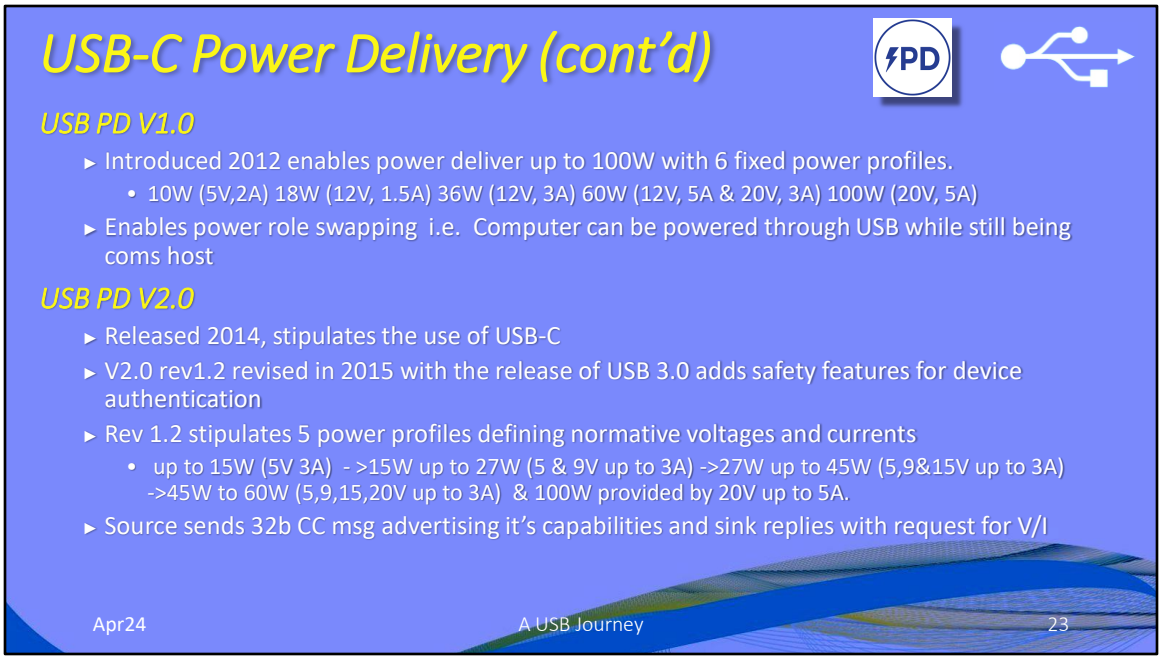


The original goal of USB power delivery was to provide a single standard that could be used across all USB devices.

USB power delivery was developed in parallel with USB 3. Initially it was focused on battery charging but evolved to a more comprehensive power distribution scheme in a ‘green’ effort to eliminate multiple power supplies.

USB power delivery is only available with USB-C to USB-C cables as it requires the configuration channel.

Maximum power that can be delivered is 240W that's 48V @ 5A.
Standard USB cables must support currents up to 3A, special cables are needed for higher currents.
Power delivery is negotiated. This means power users can define their required voltage and current.
Power direction is no longer fixed, roles can be swapped i.e. a device could supply power to host.
The data bus is not involved in power negotiation so data and power flow can be simultaneous.



Let's begin with version 1 which was Introduced in 2012

It enables power deliver up to 100W and had 6 fixed voltage and current profiles.

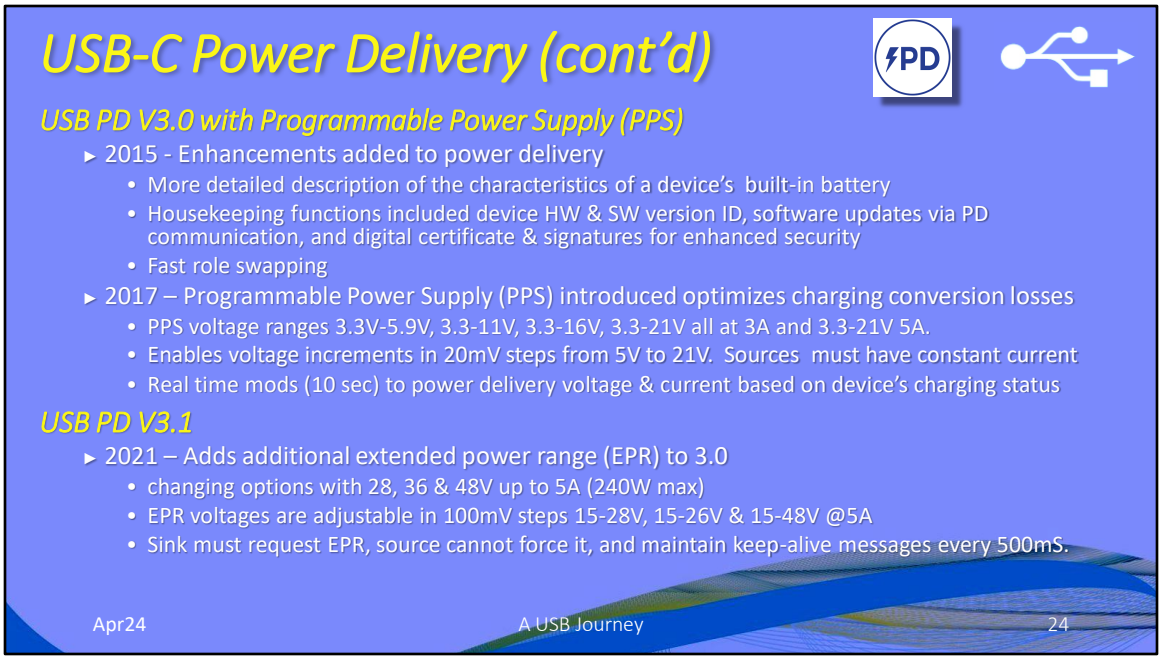
10W (5V,2A) 18W (12V, 1.5A) 36W (12V, 3A) 60W (12V, 5A & 20V, 3A) 100W (20V, 5A)

This version also enabled role swapping i.e. Computer can be powered through USB while still being communications host

Version 2 was released in 2014, must use the USB-

C connector
Subsequently Revision 2.2 of the spec released in 2015 adds device authentication and refines power delivery stipulating 5 power profiles. Sources providing up to 15 watts use 5V. Above that power supplies add additional voltages, for power delivery up to 27 watts 9 volts was added, up to 45 watts 15 volts was included and for 60 watts 20 volts was added. A provision was also made for up to 100 watts using 20 volts with up to 5 amps.

Power delivered from a source to a sink is negotiated. The source sends a 32 bit message over the configuration channel to the sink which responds with a message indicating its desired source voltage and current.

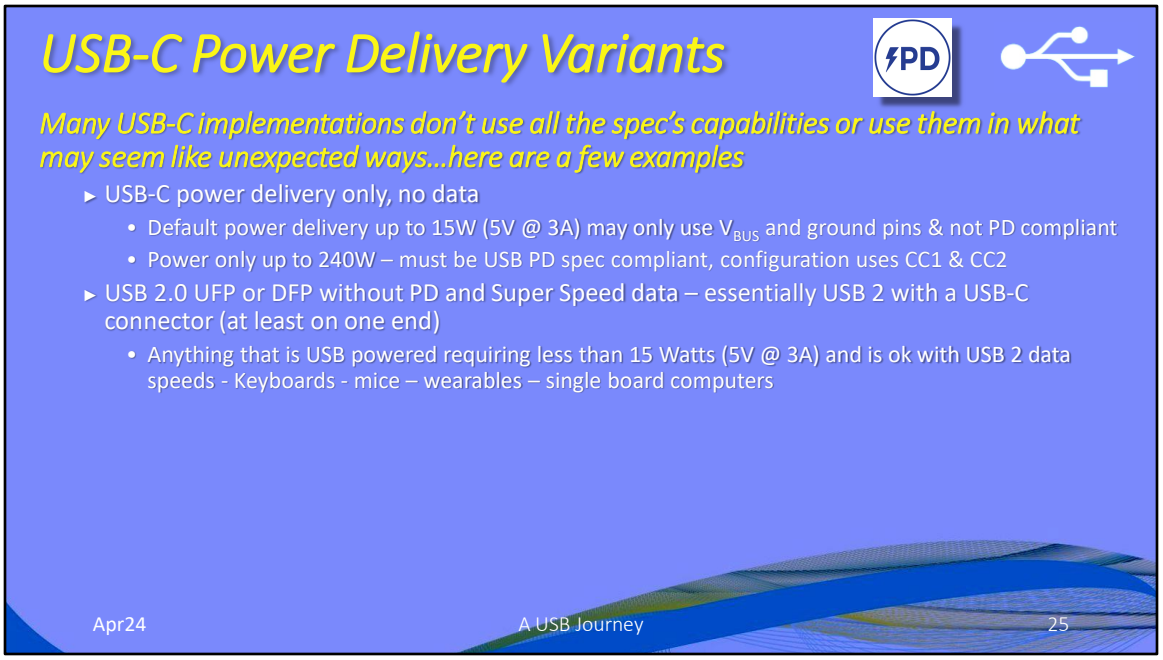


Power Delivery 3.0 introduced in 2015 provided a more detailed description of a device's built-in battery
Housekeeping functions included device HW & SW version ID, software update capability, and digital certificate & signatures for enhancing security
3.0 also introduced introduces fast role swapping

Power Delivery 3.0 PPS introduced in 2017 modifies the supported voltage ranges, and introduces the ability for the sourcing supply to

increment it’s output voltage in 20mV steps. Also if the supplied current exceeds that requested by the sink, the supply must enter a constant current mode and can change current in 50mA steps. Changes to the supply are made in real time about every ten seconds.

Power Delivery 3.1 introduced in 2021 adds Extended Power Range.
This provides additional changing options with higher voltages , 28, 36 and 48 volts with currents up to 5A for a maximum of 240 Watts.
Extended Power Range voltages are adjustable in 100mV steps from 15 to 48 volts
As a protection measure the sink must request the extended power range, the source cannot force it, and the sink must send a keep-alive messages to the source over the control channel every 500mS.



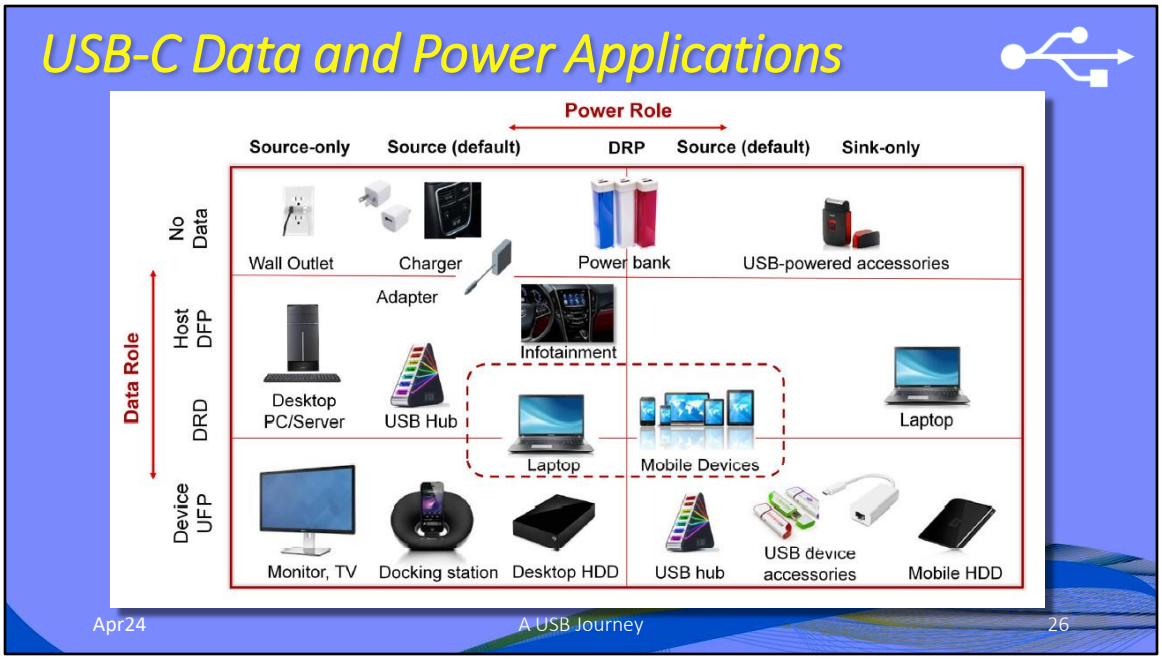
Many USB-C implementations don't use all the Power Delivery specs capabilities or use them in what may seem like unexpected ways. Here are a few examples.

A USB-C connector is used only for power delivery, no data. In this case the source may deliver up to 15 watts, 5V @ 3A without using the CC channel so only use the Vbus and ground pins. This type of application is commonly used for charging with cables that have USB-C on one end and the 4 pin

USB-A on the other.

Applications exist that deliver only power, and can deliver up to 240W. These applications will be USB Power Delivery spec compliant and will use the configuration channel to negotiate between source and sink.

Applications exist for a USB-C connection at USB2 speeds with a maximum of 15 watts power, so the application does not use the Power Delivery spec nor high speed data. Items that fit this category include mice, keyboards, wearables, and single board computers.



USB is now quite flexible so can fill a variety of data and power roles.

The slide shows a variety of devices having varying data and power roles.

DRP – dual role power

DRD - dual role data

UFP – upward or upstream facing port

DFP – downward facing port

Choosing USB Components

USB Chargers

- Before you buy define your specs and research
- Some things to watch for
  - If it's really cheap beware…100W charger with 4 USB-A ports will never deliver 100W
  - USB charger with multiple outlets
    - Total power is usually shared between ports, i.e. a 30W charger will deliver 30W shared between all outlets, not always equally
    - USB A outlets will deliver up to 3A
    - USB power delivery will NOT work with a USB-A plug, it doesn't have CC capability
- Look to products that are USB-IF certified

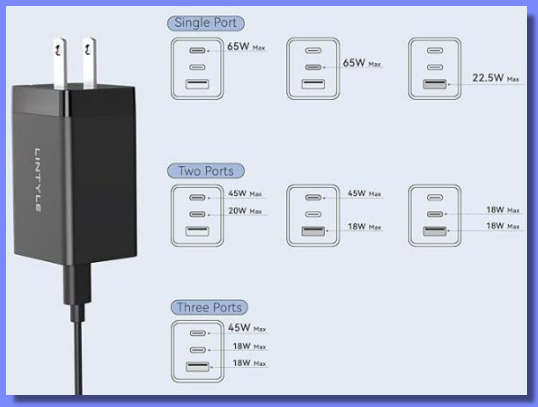
Input : AC 100-240V, 50/60Hz, 1.5A Max
Total Output : 30W
USB Port : 1x USB-C 1x USB-A
Output Current
USB-C : 3.3 - 11V 3A (PPS) / 5V 3A / 9V 3A / 12V 2.5A / 15V 2A / 20V 1.5A (30W Max)
USB-A : 5V 3A / 9V 2A / 12V 1.5A (QC 18W)

Let's take a look at two components that are often purchased, charging supplies and cables.
So here's a few examples of items that can't possibly deliver on advertised specs
A 100W 4 port USB-A phone charger with 4 at most 3A ports. (60W)
A dual USB-A USB-C charger that advertises Power Delivery voltages. You can't possibly do PD on a USB-A connector, it doesn't have the CC channel required to negotiate supply voltages and currents.

Choosing a USB Components

USB Chargers

- Look for chargers that clearly spell out their total power and shared power capabilities.



Look for chargers that clearly spell out their total power delivery and individual outlet capabilities
This Lintyle charger is a good example. It's advertised as 65 watts and shows how much power can be delivered to each outlet when multiple outlets are in use.
Note that the USB-A can't deliver more than 3.6A (18W)

Choosing a USB Components

USB Cables

- USB 3 and USB4 speeds range from 5 to 120 Gb/s, power delivery complexity, accommodating alternate modes, CC communications - all mean USB is more complex and costly.
- Some things to watch for
  - Not all cables with a USB-C plug will support speeds greater than USB 2
  - USB cables advertised for power delivery may not deliver data
  - USB cables with a USB A connectors will at most deliver around 15 watts
    - For data Black separator = 480Mb/s blue separator = 5-10Gb/s
  - Look to products that are USB-IF certified

40Gbps

USB4 cable certification label

CERTIFIED USB 40Gbps

USB4 device certification label

USB 3 and USB4 open a whole new world of cable selection.

Meeting USB's 40-100Gb/s data speeds and high power PD delivery specs is costly.

If a cable is cheap it is so for a reason…so here are some things to watch for

Not all cables with a USB-C plug will support speeds greater than USB2…here's a picture of a cable that proudly advertises it can deliver up to 480Mb/s…well at least it's likely honest.

USB cables advertise for power delivery may not

deliver data.
Cables with USB-A connectors won't deliver more than about 15 Watts power. Data delivery will depend on the A connector. If it's USB2, (black separator) expect 480Mb/s, if it's got a blue separator it will have USB 3 capabilities with one duplex high speed lane, so between 5 and 10Gb/s. Look to cables that support USB Implementers Forum certification logos

Choosing USB Components

A bit more about USB-C cables

- Connecting a USB-C cable between two components will work in most cases but performance may not be optimum
- Mixing cables & chargers can drastically alter charging speeds. Keep chargers and cables that were shipped with a device together
- For optimum performance know the capabilities of the UFP, DFP, and cable
- A list of USB IF certified products can be searched here: https://www.usb.org/products
- Certified cables now typically sport speed and power info on connectors

Transport rate stamped on connector Superspeed 10Gb/s

Club3D CAC1576
1M cable

Connecting a USB-C cable between two components will work in most cases but performance may not be optimum

Mixing cables and chargers can drastically alter charging speeds. Keep chargers and cables that were shipped with a device together

For optimum performance know the capabilities of the UFP, DFP, and cable

A list of USB IF certified products can be searched here: https://www.usb.org/products

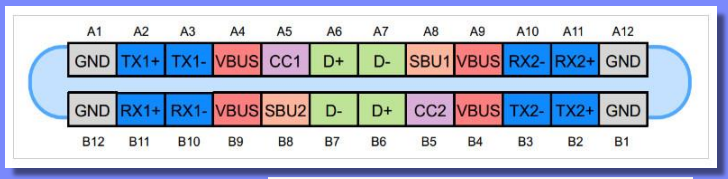
Certified cables now typically sport speed and

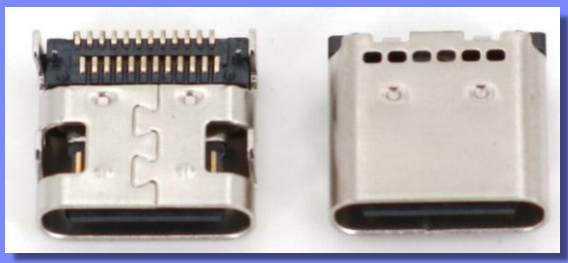
power info on connectors. Here's an example of a USB IF certified cable manufactured by Club3D available at many vendors including Canada computers, Walmart, Amazon. Staples, New Egg and others.

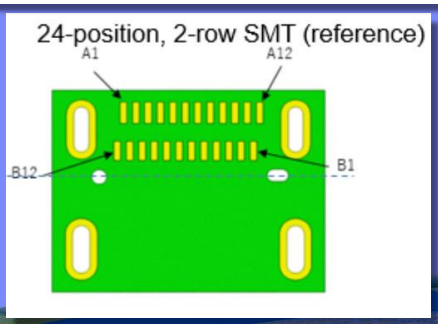
USB-C Receptacle Variants

Three Common USB-C receptacles

- 24 Pin for full power and data delivery







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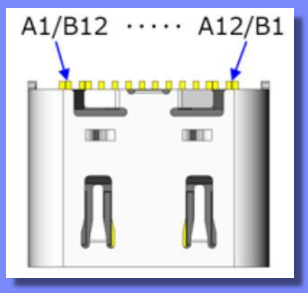
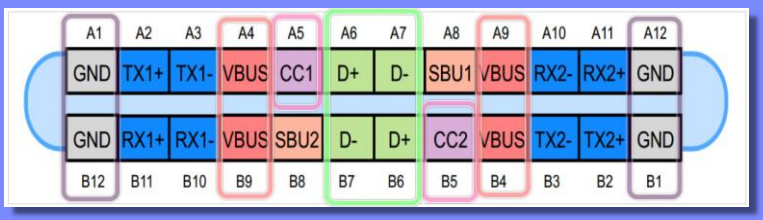
There are three common USB-C receptacle types. The 24 pin receptacle has two rows of SMD pads A1 to A12 closest to the rear of the connector and B12 to B1 closest to the front.
Variants of this 24 pin connector have through-hole mounting pins for B12 to B1. Mid mount versions are also made for PCB edge mount applications with 12 pads each side of a PCB.

USB-C Receptacle Variants

Three Common USB-C receptacles

- 16 Pin for Power Delivery along with a USB2 data channel
- Removes pins for the two high speed lanes and SBU buss





Pin No.	1 & 2	3 & 4	5	6	7	8	9	10	11	12	13 & 14	15 & 16
Pin ID	A1/B12	A4/B9	A5	B8	B7	A6	B6	A7	B5	A8	B4/A9	A12/B1
Pin Function	GND	VBUS	CC1	SBU2	D-	D+	D+	D-	CC2	SBU1	VBUS	GND

The 16 pin USB-C receptacle variant enables full power delivery, but limits data to a single USB-2 lane.

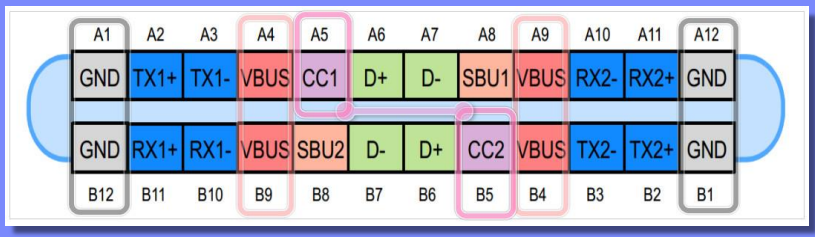
The connector eliminates pins associated with both high speed channels and the SBU bus.

It's easier to solder than the 24 pin devices, and can be successfully designed using single or double layer PCB's

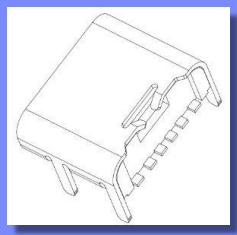
USB-C Receptacle Variants

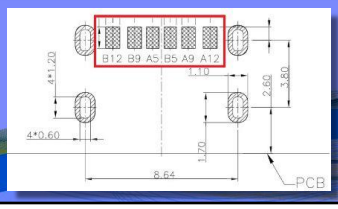
Three Common USB-C receptacles

- 6 Pin for power delivery only
- No data transport



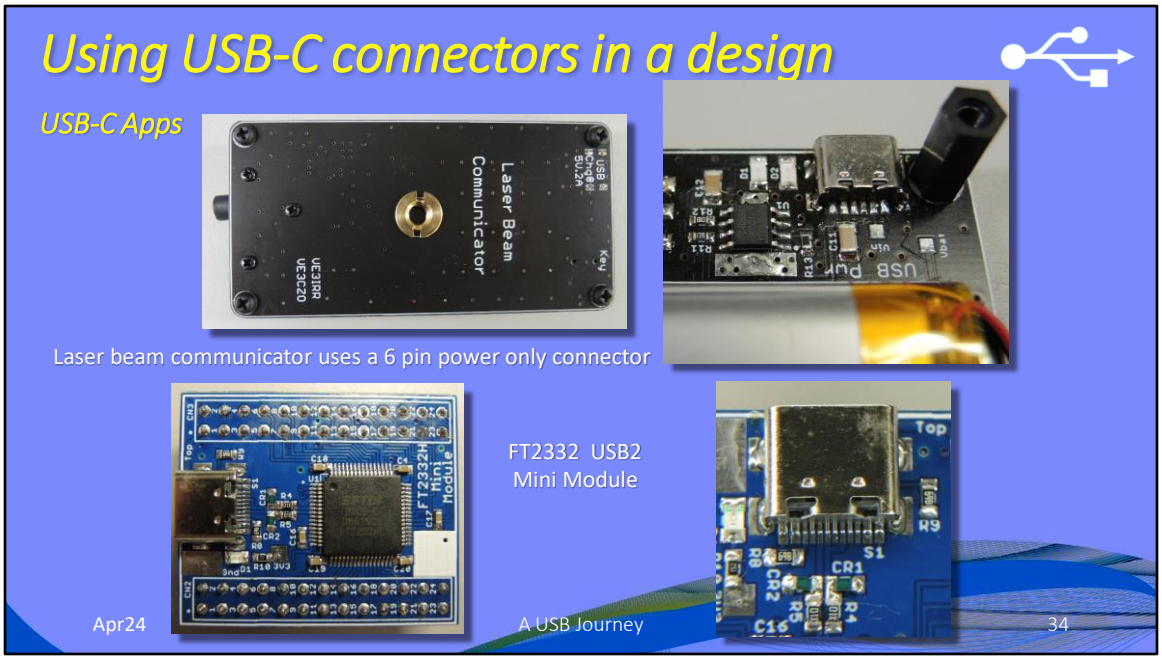
Pin No.	1	2	3	4	5	6
Pin ID	A1/B12	A4/B9	A5	B5	B4/A9	A12/B1
Pin Function	GND	VBUS	CC1	CC2	VBUS	GND





The USB-C six pin version is used only for power delivery, as it eliminates all data channels and the SBU bus

The six wider leads make it the easiest USB-C connector to solder.

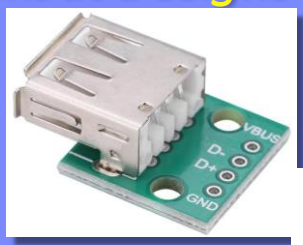


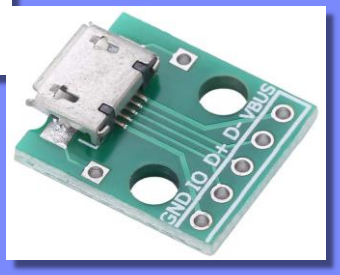
Here are a couple examples of projects I've done with 6 and 16 pin versions of the USB-C connector.

A bit a bout USB Breakout Designs

Typical Commercial offerings

- Single USB connector with header pins
- Ok for testing continuity through a connector but lacked pass-through capability so can't be used to measure terminated pass-thru signal voltages or VBUS currents
- So I made a set for USB2

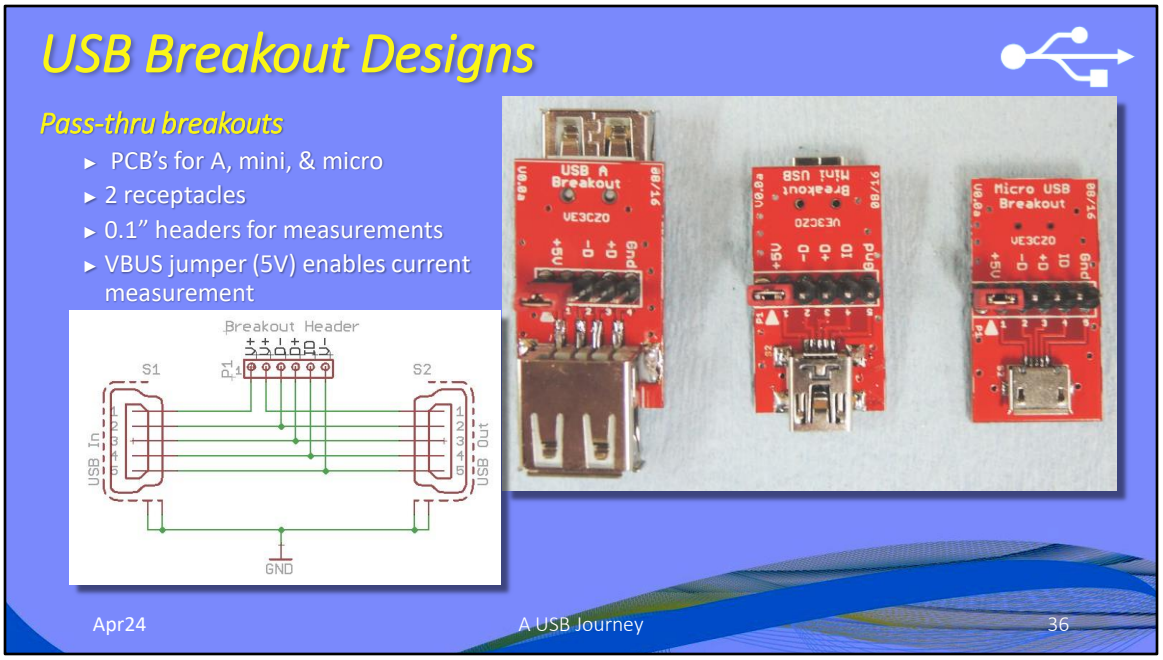




I started this journey wanting to add a USB-C breakout board to my collection so let's talk a bit about breakout boards.

Most commercial breakout PCB's feature a single connector tracked to a header. This type of board can be used to measure pin voltages or continuity from the breakout through a connector on a PCB.

I wanted a pass-through design that not only enables continuity measurements but would also have the capability of measuring VBUS supply current as well as supply and signal voltages.



I built pass-through PCB's for USB A, mini, & micro connectors

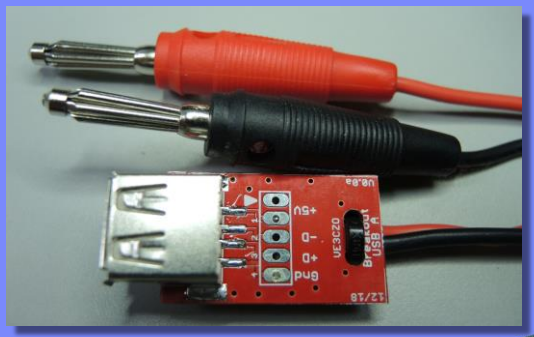
They featured a row of 0.1" header pins placed between an input and output receptacle that allowed voltage measurements, and also featured a jumper on the VBUS line that could be used to monitor supply current. When not used, a jumper shorts the VBUS input to output.

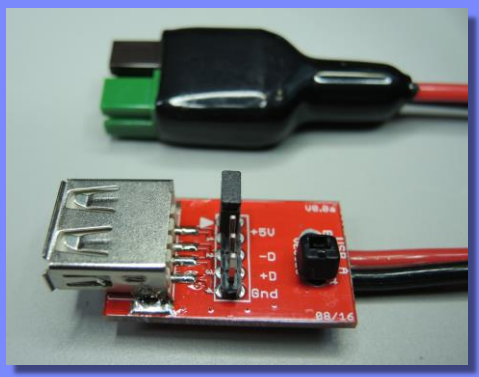
The data line is not impedance matched but is quite short.

USB Breakout Designs

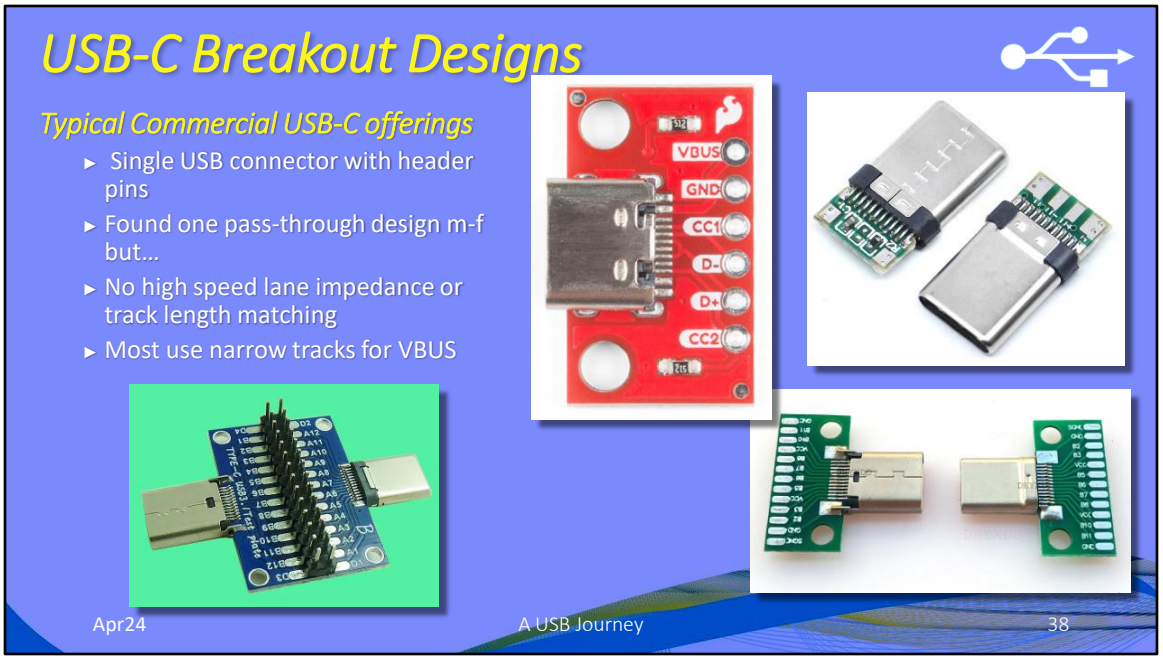
Other useful breakout implementations

- USB to banana plug
  - For changing devices from regulated supplies
- USB to power pole
  - For powering devices from 5V sources



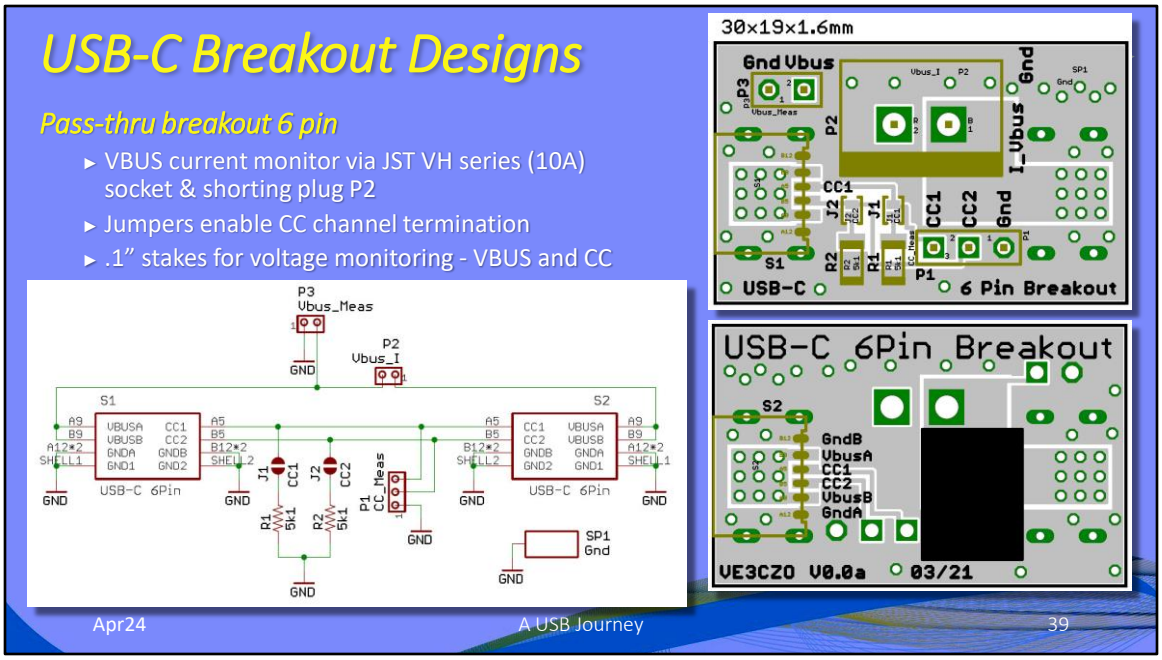


I've also used this PCB to provide power only connections using both banana plugs and Powerpole connectors. Note that the Powerpole connector is green (5) and black in an attempt to tell me not to connect it to supply higher than five volts. So far it's worked.



The USB-C breakout designs I've come across are primarily single connector types that again, provide the ability to measure continuity. The SparkFun PCB, (the one in red), uses a receptacle, has terminating resistors for the CC bus and wider tracks for higher current for the VBUS.

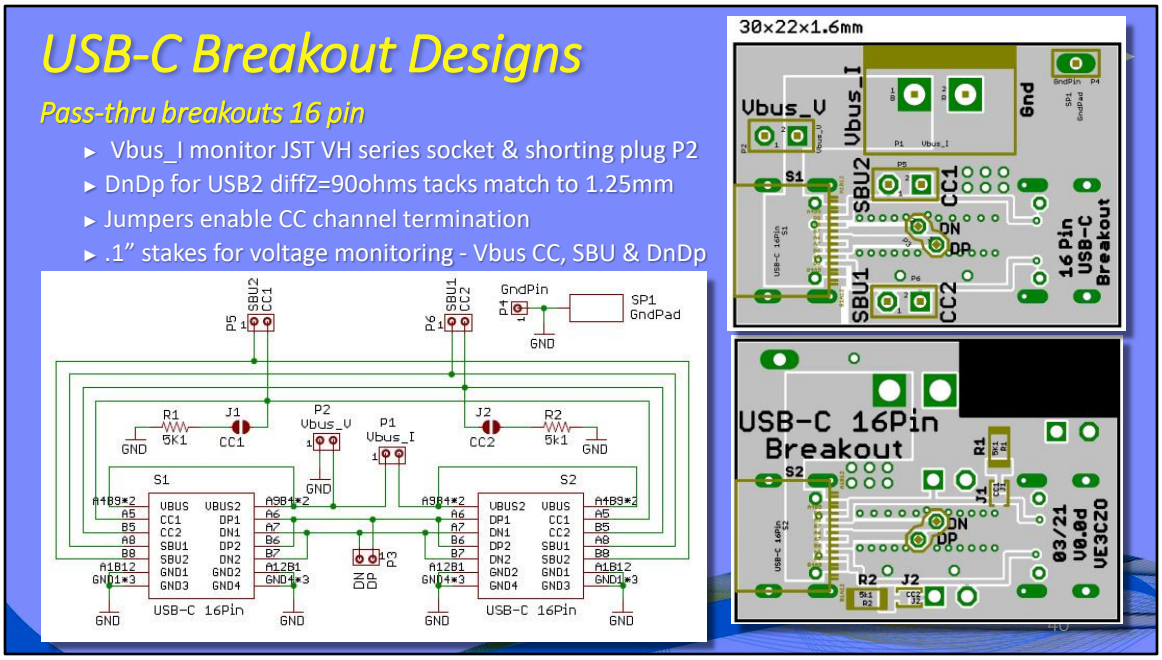
The only thru connector I have found has a plug on one side and receptacle on the other. It treats all leads alike, so does not consider super speed lane track length or impedance matching and has narrow tracks for the VBUS.



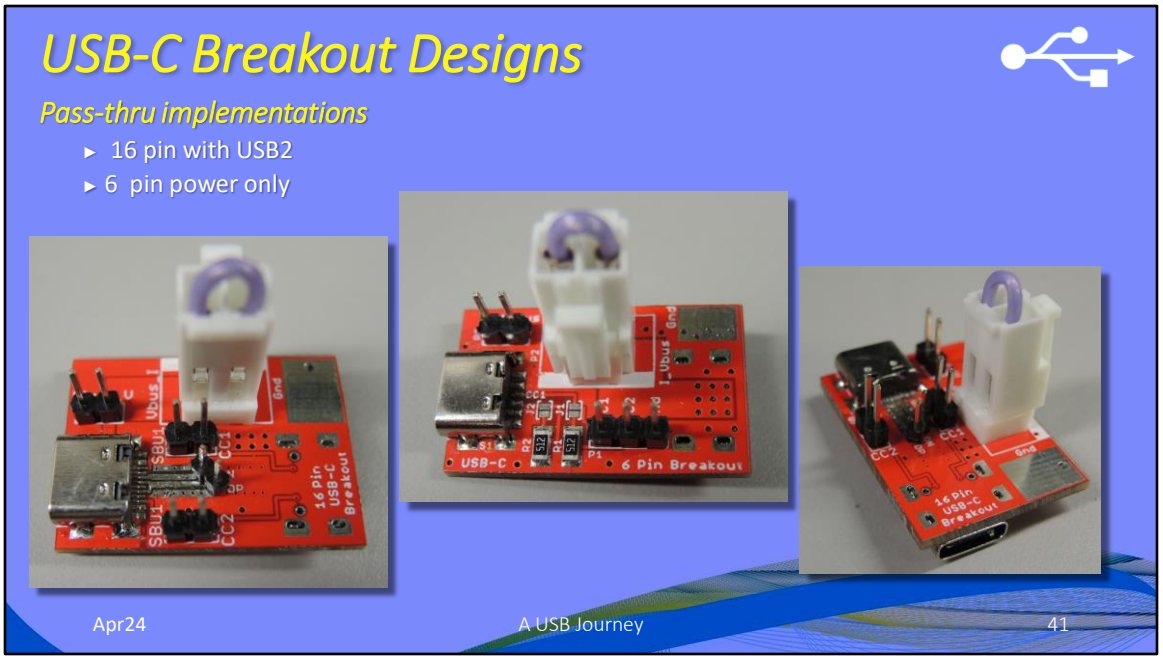
USB C breakouts get a little more complex. This six pin pass-through connector has no data lanes so is used only for power delivery, and works well for a two sided PCB.

This breakout is capable or monitoring the VBUS current using a JST VH series plug and socket. This connector is capable of handling 10A, and a shorting plug is used to provide continuity when not monitoring current. the PCB tracks are quite wide for negligible voltage drop at high currents. Solder jumpers are provided to terminate the CC

channel for applications where no device is attached.



The 16pin breakout adds a USB2 data lane. Attempts were made to control the differential impedance, to 90 ohms and match the track lengths to under 1.25mm to minimize data skew. VBUS current is monitored using a two pin JST VH socket and plug. The plug just shorts the VBUS track between input and output when current isn't measured. The tracks are quite wide for negligible voltage drop at high currents.



And here's the way they look. The picture on the left shows the 16 pin breakout, the one in the middle the 6 pin and the picture on the right shows the 16 pin from a slightly different angle to show the input and output receptacles.

USB Summary

USB-C

- USB 3 and USB4 speeds range from 5 to 120 Gb/s, power delivery complexity, accommodating alternate modes, CC communications - all mean USB is more complex and costly.
  - Not all USB-C computer ports will have full USB 3 or 4 capabilities
  - Expect to live with a range of data speeds of 5Gb/s up
  - Not all cables with a USB-C plug will support speeds greater than USB 2
  - USB power delivery capabilities will vary widely, and some charging cables won't deliver data
- How to deal with the variety and complexity
  - Research to become aware of the data and power needs for your specific application
  - Read product specs carefully, if you need a specific power or speed and the manufacturer does not specifically advertise it it's probably not on offer
  - Don't buy more performance than you need (unless you're filthy rich)
  - Look to products that are USB-IF certified

USB4 cable certification label

USB4 device certification label

USB 3 and USB4 speeds range from 5 to 120 Gb/s on one or two data lanes, power delivery has become very versatile and as a result complex. Accommodating alternate modes, and configuration channel and sideband communications all mean USB has become significantly more complex and therefor costly. Supported data rates range all the way from 480mB/s to 120Gb/s on dual lane unidirectional devices.

Power delivery started off with a simple 5 volt

supply providing half an amp to a much more sophisticated programmable voltage and current supply capable of being set from 5v to 48v handling currents up to 5 amps.
Will all features and capabilities be available on all ports? Of course not, it would be too costly. Will suppliers try and cut features and performance corners to reduce cost without telling consumers? Guess you can easily answer that question.
Not all USB-C computer ports will have all USB4 capabilities
Expect to live with a range of data speeds of 480Mb/s up
Not all cables with a USB-C plug will support speeds greater than USB 2
USB power delivery capabilities will vary widely

So what does a consumer do?
Before you buy, do a bit of research and become aware of what your application needs and the options available.
Read product specs carefully, if you need a specific speed or power and a product doesn't advertise it, it's probably not on offer.
Don't buy more performance than you need unless

you’re filthy rich.
Look for products that are USB-Implementers Forum certified. Both cables and devices are beginning to sport labels that spell out their capabilities.

Questions?

ve3czo @ gmail.com

Link to USB-A mini & micro breakouts

- https://drive.google.com/file/d/1bbADurxjXE143yGZ6FTew1h8s1q81dXm/view?usp=drive_link

Link to USB-C 6 and 16 pin breakouts

- https://drive.google.com/drive/folders/1oSOIzrGtlikaQA1oGeggclL9SGAhX4t-?usp=sharing

Other stuff that maybe of interest

Improving your chances of inserting a USB connector the right way the first time

- USB A and mini and micro connectors are going to be around for sometime
- Every plug and receptacle has (or is supposed to have) one side labeled with the USB symbol
  - Plug pins should be exposed towards the labeled side
  - Devices with horizontal USB ports should have receptacles oriented so that the symbol points up
  - Receptacles should be labeled so when inserted, plug and device symbols are on the same side
- It's often useful to look at the receptacle and plug before inserting
  - Note the orientation of the separator in USB-A connectors
  - Look to match the widest flats on USB mini and micro connectors

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As we're going to be living with legacy USB connectors for some time so here's a bit of a guide to help insert the connector the right way the first time.

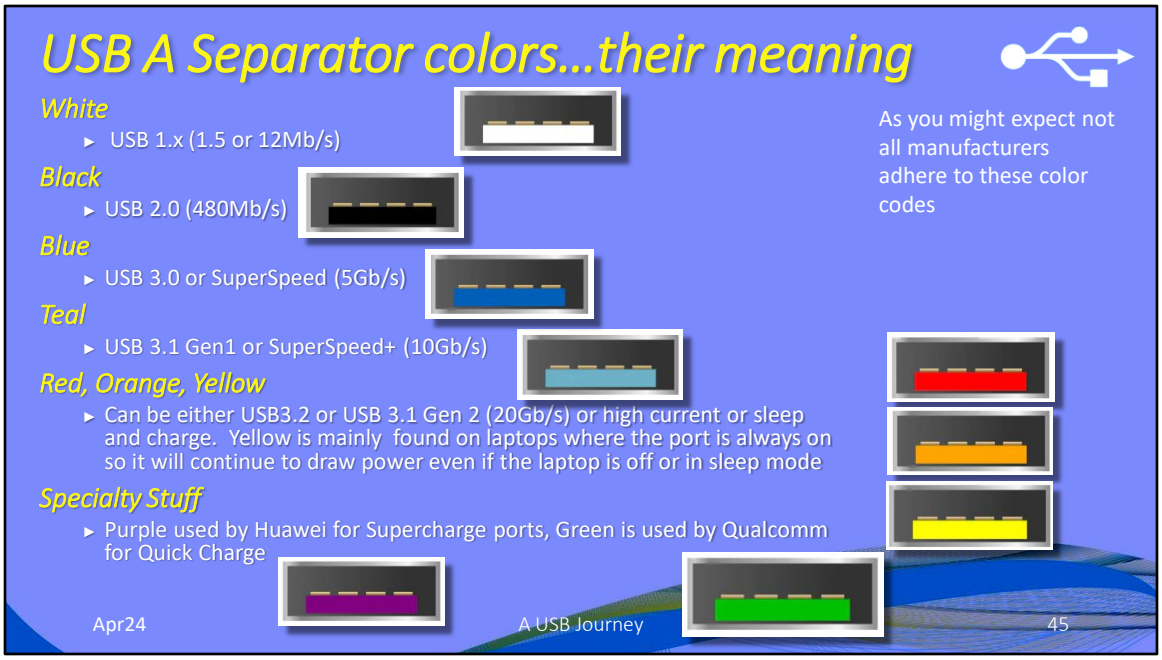
Every plug and receptacle has (or is supposed to have one side labeled with the USB symbol

Plug pins should be exposed towards the labeled side

Devices with horizontal USB ports should have receptacle oriented so that the symbol points up

Receptacles should be labeled so when inserted,

plug and device symbols are on the same side
It’s often useful to look at the receptacle and plug before inserting
Note the orientation of the separator in USB-A connectors
Look to match the widest flats on USB mini and micro connectors



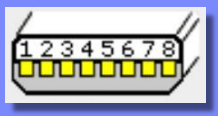
The separator color on a USB – A connector can often indicate it's speed and function.
White was almost universally used for USB 1 versions and black for USB2.
USB 3 is typically blue, but the faster 3.1 gen 1 or superspeed+ is often teal.
Red, Orange, and Yellow are often used with high current or sleep and charge ports, but have also been used to represent USB3.2 or USB3.1 Gen2.
The yellow version is mostly found on laptops that can feed power even if the laptop is off or in sleep

mode.

USB Non-Standard Connectors

Mini-USB 8 Pin

- Used on many digital cameras
- Pins other than USB signals may vary depending on camera model



Pin Number	Pin Name
8	GND
7	Video Out
6	Audio Out L
5	GND
4	USB Data +
3	Audio Out R
2	USB Data -
1	USB Vcc

Before ending it should be mentioned that there are several non-standard USB connectors that have become common. Here's an example of one used by many digital cameras.

Thunderbolt

Thunderbolt 1

- Developed by Intel adopted by Apple introduced with MacBook Pro 2011
- Transfer speed 10Gb/s DC power transfer up to 10W (5V@2A)
- Mini DisplayPort connector

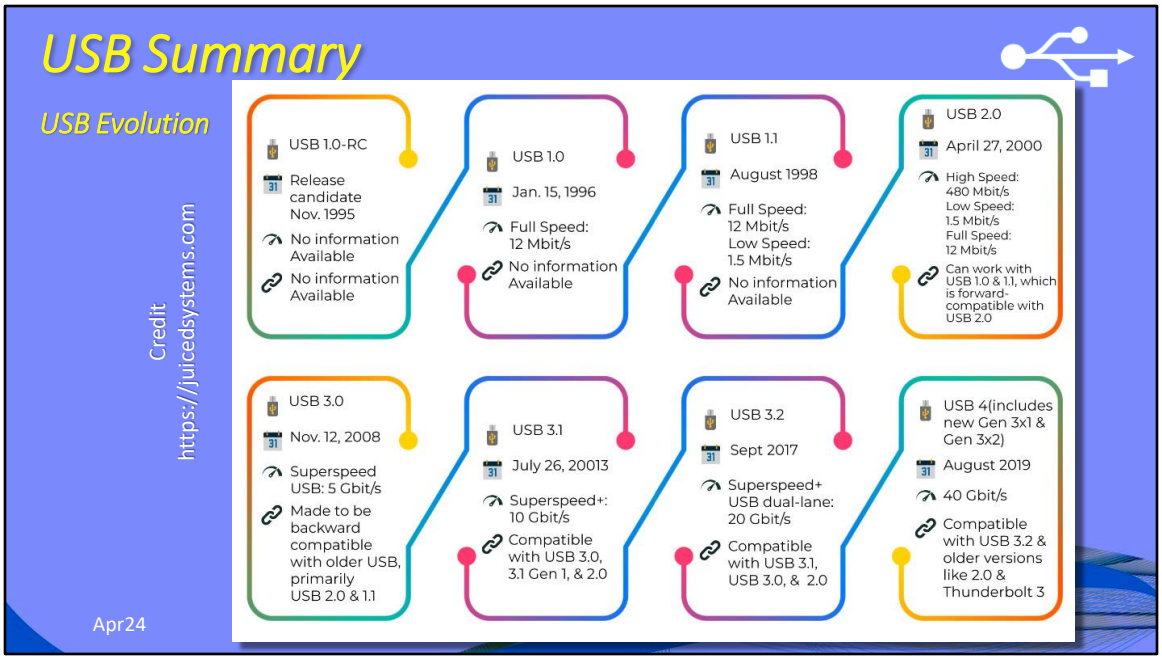
Thunderbolt 2

- Introduced in 2013 & is backward compatible with Thunderbolt 1
- Offers 20Gb/s transfer rate using 2 full duplex channels
- Continues use of Mini DisplayPort connector

Thunderbolt 3

- Developed by Intel & released 2015
- Adopts USB-C connector so not backward compatible with previous versions
- Transfer rates of 40Gb/s and power delivery up to 100 watts with approved cables
- Will not work in a USB3 Gen2x2 port; host & peripherals need Thunderbolt firmware/software

I mentioned Thunderbolt several times as one of the USB-C supported alternate modes Here's a short summary of its evolution
Lower adoption rates plague this format as only Apple support it so lower manufacturing volumes result in higher peripheral price points.
Intel gave the USB implementers forum the full spec so that they can implement Thunderbolt as a alternate mode.

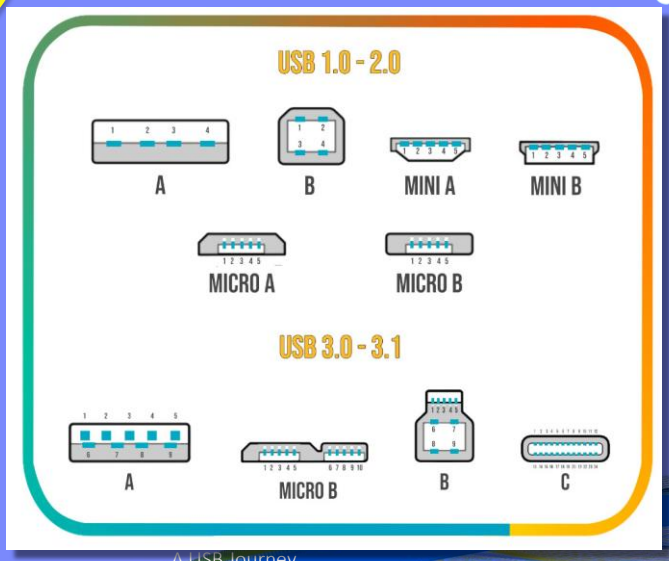


Very nice chart showing USB Evolution Credit https://juicedsystems.com/

USB Summary

USB Connector Gallery

Credit
https://juicedsystems.com



Very nice chart showing USB connectors Credit https://juicedsystems.com/

Bibliography

For further reading…

- USB Overview – better than reading the spec but does not include anything beyond USB OTG https://www.beyondlogic.org/usbnutshell/usb2.shtml
- USB-IF library www.usb.org/developers/docs/devclass_docs/
- USB-Implementers Forum www.usb.org
- Battery charging overview https://www.maximintegrated.com/en/design/technical-documents/tutorials/5/5936.html
- USB-C overview https://www.allaboutcircuits.com/technical-articles/introduction-to-usb-type-c-which-pins-power-delivery-data-transfer/
- USB-C cable info https://www.pshinecable.com/article/usb-c-cable-wiring-diagram.html
- USB Alternative Modes TI Slly021 app note.
- USB overview & a source for certified products https://juicedsystems.com/en-ca/blogs/news/know-your-usb-a-practical-guide-to-the-universal-serial-bus

- Have fun exploring but… pay attention to the date information was published… things change!