USB Standard?
USB Type-C® Connector?

- Features, Mechanism, and JAE Initiatives -

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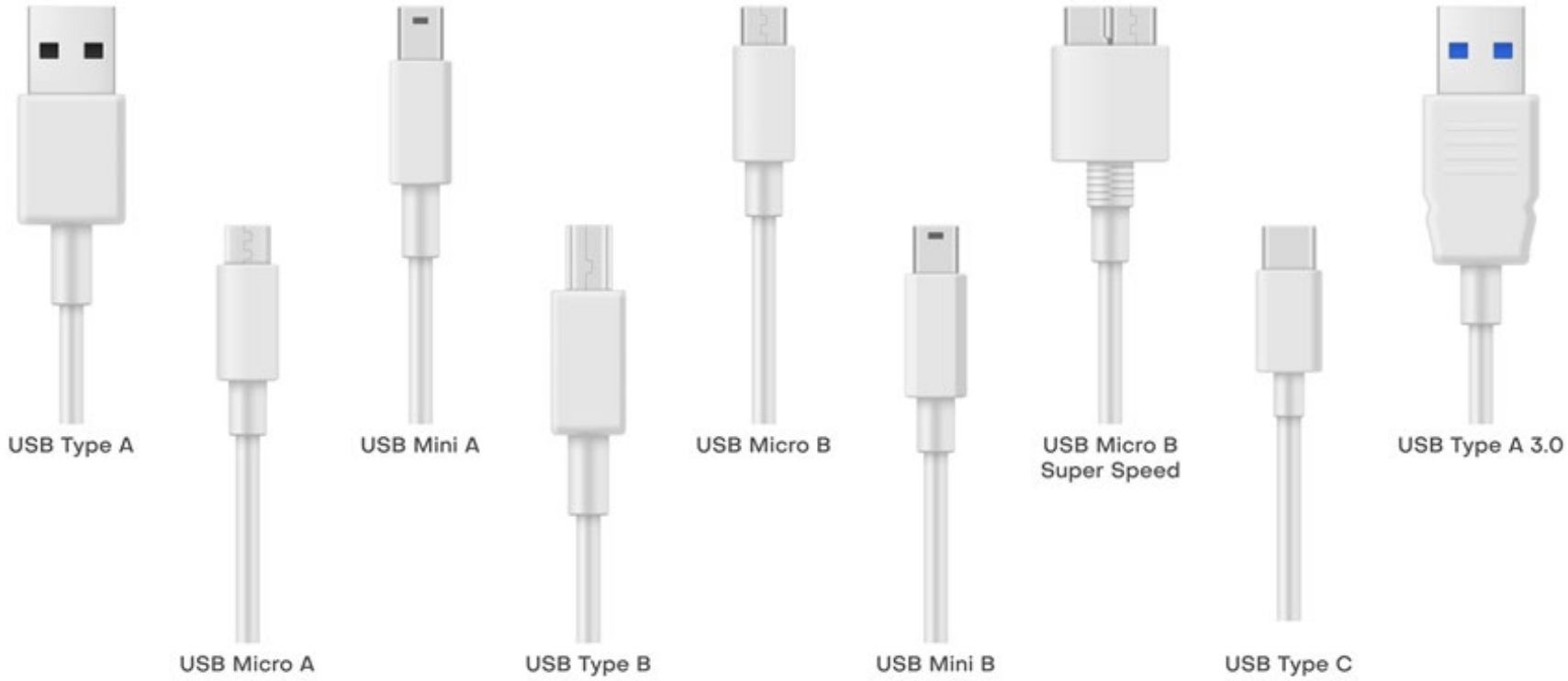
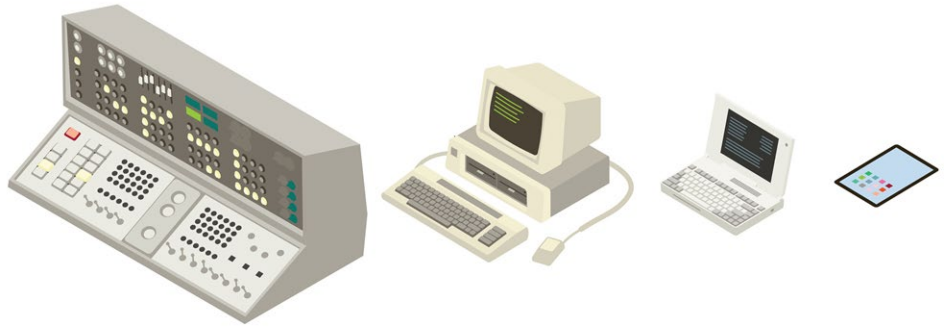


What is the USB Standard?

USB is an abbreviation of Universal Serial Bus, a standard for interconnecting electronic devices.

Specifications have been established by the USB Implementers Forum, Inc. (USB-IF), a non-profit corporation founded by a group of companies.

Because it is a connection standard, it guarantees problem-free data transmission and power delivery even between devices from differing manufacturers as long as they are compliant with this standard.
In order to transmit data, the connected devices must operate on the same transmission protocol.
When it comes to power, not only must voltage and current values be predetermined, but power delivery direction must be as well.
If connections are made that disregard these standard rules, this may result in the devices malfunctioning or in the worst case scenario, accidents such as the devices igniting and fires.
In this way, complying with the standards is extremely important when it comes to connection standards. Third party testing organizations certified by the USB-IF are used to determine whether a product meets USB standard specifications and permits use of the USB logo on passing products. This system enables the weeding out of non-compliant products.
Within the connection standard, one of the most important foundations are the connector specifications. Because you are connecting devices from different manufacturers, the connectors are made so that they can be mated to devices regardless of manufacturer. In addition, the connector shape has to be one where even if a general user who has no knowledge of the standard details uses it incorrectly, does not result in an accident.



USB Standard History

USB 1.0, the first standard, was released in 1996 and it was initially established for the purpose of connecting computers and their peripheral devices.

Computers started to be introduced in research organizations and in some departments at companies in order to execute complex numerical calculations. With the evolution of semiconductor technology, they spread among society when prices gradually came down to a range that individuals could afford.
USB became common with the popularization of the PC.
As time progressed, USB rapidly spread in the market when it was adopted as a charging interface for smartphones. It is now recognized as one of the most successful interface standards.

USB Standard Specifications

The USB standard is one that is used to interconnect electronic devices. These connection standards are established with three elements: “communication rules,” “power delivery rules,” and “connector shape.”

Because the USB standard was established as specifications to connect computers and peripheral devices, connector specifications were established with two types of basic shapes: USB Type-A for the parent device (computer side: host side) and USB Type-B for the child device (peripheral side: device side).
This concept also determines the direction of parent to child (A to B) for “communication rules” and “power delivery rules.”
By having each device comply with detailed rules (communication protocol, voltage/current specifications, post-connection communication, and power delivery initiation rules), USB became established in the market as a connection standard that could be used with peace of mind.

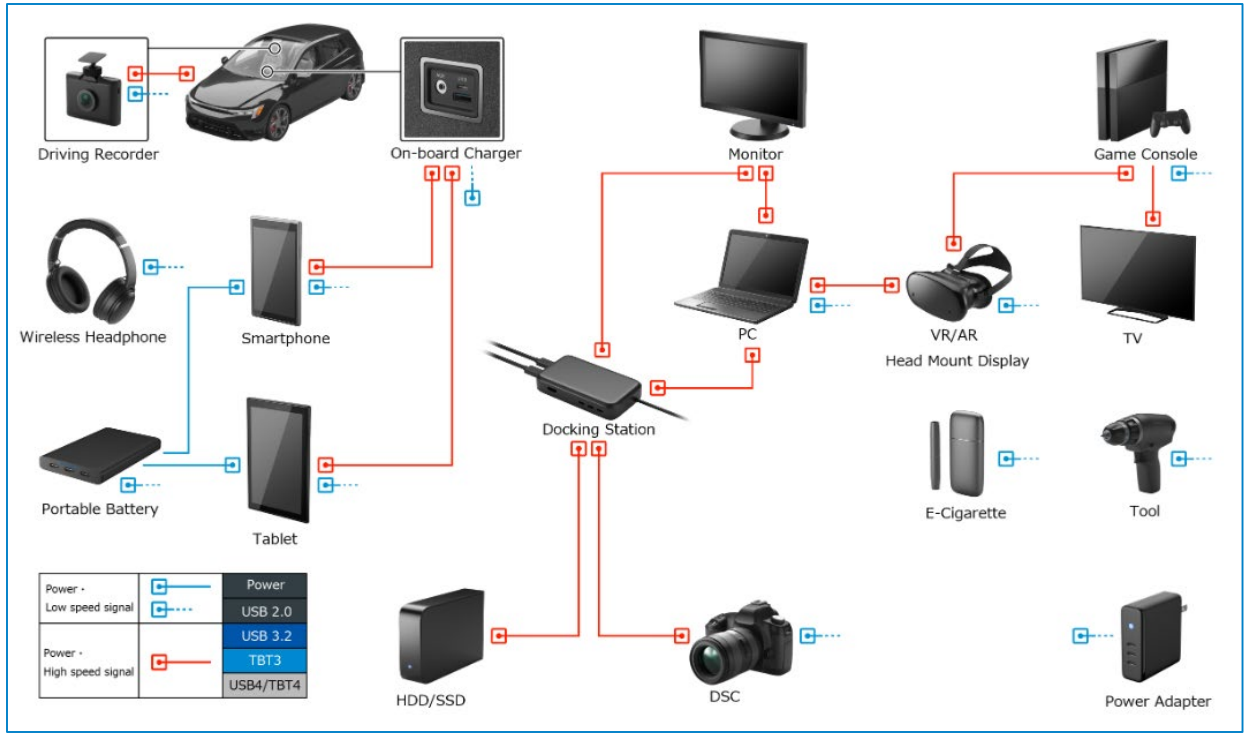
Evolution of the USB Standard

The number of devices that used the USB standard increased with the spread of the standard in the market. These devices evolved while competing with each other in terms of functionality and capabilities as well as becoming increasingly compact and better designed. As a demand of the times, there are also calls to enhance security features to eliminate the risk of data leaks.

The USB standard evolved and variations started to appear in order to meet these demands. Connectors established with these new standards must be able to mate with connectors that use the previous standards and compatibility must be guaranteed. However, there are limitations with the conventional connector shape when trying to comply with the increases in transmission speeds and power delivery capabilities. Further, the USB standard became an extremely complex standard in light of the fact that it also had to be compatible with devices such as smartphones that could be both a “parent device” and a “child device.”
This resulted in a decline in user convenience. From these requirements, the USB Type-C connector was born to satisfy the increased demands associated with the further evolution of devices.

Background and Current State of the Spread of USB Type-C in Each Market

It is predicted that by 2023-2024, approximately 70% of devices that use USB will incorporate the USB Type-C connector.
(1) Over 80% of all PC/peripheral device connections are through USB Type-C.
(2) Because it is compatible with fast charging, it continues to replace conventional AC adapters for power delivery applications.
(3) From an SDGs perspective, there is a possibility of this replacement gaining speed with the trend in standardizing charging cables.
(4) It is spreading from the ICT market to the general market.
Considerations for replacement in industrial equipment (robots, CNC, servo amps, operations monitors, controllers, etc.) are also progressing.

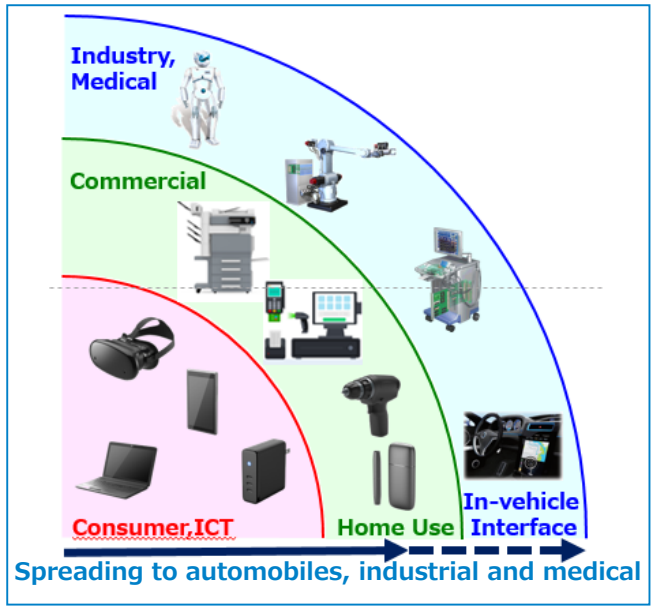


Topics

September 2021: The European Commission submits a law to standardize USB Type-C as the charging interface equipped on electronic devices.

June 2022: The European Union (EU) European Parliament and European Commission agree to implement the common charger proposed by the European Commission.

This EU regulation (standardization to USB Type-C connectors must be made by 2024) is expected to accelerate the trend of USB Type-C seeing common use as a power supply interface for electronic devices in the future.



What is a USB Type-C Connector?

The first version of the USB Type-C standard was released in 2013. It was one that revamped the USB standard up to that time in order to accommodate evolutions in devices and improve usability by users.

This chapter explains the features and mechanisms of USB Type-C.
Shown on the right are the features of USB Type-C, which revamped the USB standard.

Let’s now explain each feature.

Features

(1) Structure that allows mating regardless of orientation

(2) Same connector shape for both parent and child devices

(3) Increased data transmission speeds

(4) Improved power delivery capability

(5) Compatible with communication standards other than USB

Structure that Allows Mating Regardless of Orientation

This is the feature that was emphasized and explained the most when USB Type-C appeared. Perhaps this was because this was one feature that was easy to understand and that the general public could intuitively regard as a change despite numerous other important features.

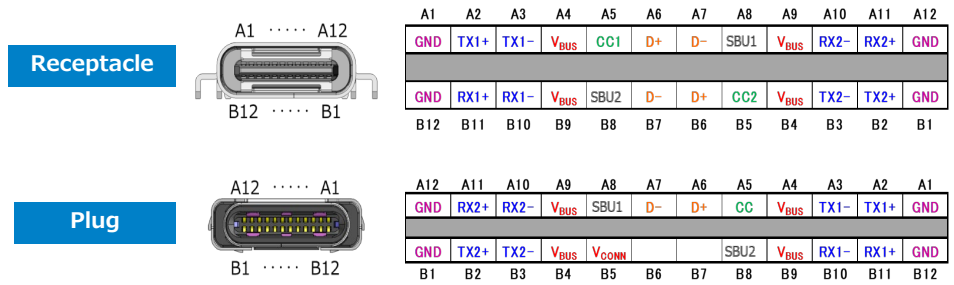
Let us explain the mechanism for this.

Figure 1 shows a drawing of the front view for the connector mating connection. The shape of both the receptacle connector and the plug connector is one where the structure is point-symmetrical around the mating opening. You can see that the structure is one that allows for mating regardless of physical orientation. Although it can physically be mated, would the electrical signals and power connections work correctly?

First, let's consider what happens when terminal A1 on the receptacle and terminal A1 on the plug are mated.

When we check the pin assignments in Figure 1, we see that terminals with the same signal name are connected. Connections between different signal names are those between CC on the plug side and CC1 on the receptacle side as well as between VCONN on the plug side and CC2 on the receptacle side.

Figure 1 Mating Front View / Pin Assignment



Next, let's consider what happens when it is rotated 180 degrees and connected.

When connected after rotating it 180 degrees, connections between the same signal names still apply for GND, VBUS, and D+/-, but we see that other terminals are not: TX1 with TX2, RX1 with RX2, and SBU1 with SBU2. In addition CC on the plug side is connected to CC2 on the receptacle side and VCONN on the plug side to CC1 on the receptacle side.

The key point here is actually this CC terminal on the plug side.

Communication takes place as-is if the CC terminal is connected to CC1.

When the CC terminal is connected to CC2, the electronic circuit on the device side prescribes a rule that the transmitted signal is swapped (TX1↔2, RX1↔2, SBU1↔2).

In this way, while the user mates the connector without thinking about which side is up or down, the device side confirms orientation every time.

Ease of Use Through Reversible Insertion and Removal Regardless of Orientation Via Symmetrical Connector Shape and CC Pin Detection

Same Connector Shape for Both Parent and Child Devices

Connections between devices using USB Type-C can be made through cables with USB Type-C connectors on both ends. There was previously a rule that connectors on the parent side be Type-A and Type-B on the child side but with the advent of Type-C, users can make trouble-free cable connections. Again, this is thanks to the previously mentioned mechanism that uses the CC terminal.

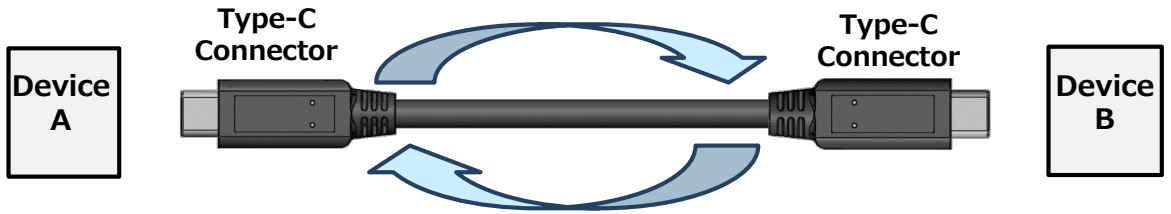
Devices connected with cables that have Type-C connectors on both ends communicate using the CC terminal.

Through this communication, devices define whether they will become the parent (or child) device and once defined, they start communicating or delivering power.

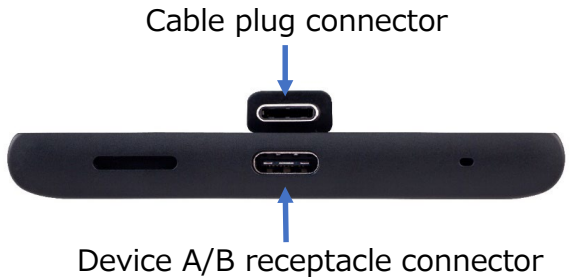
Because definitions are periodically redefined, a device can receive power as a child device until the battery has been charged to a certain level, for example, and can flexibly accommodate cases when the remaining charge on the parent device becomes low.

We explained on the previous page that the reason why a user can mate connectors without any concerns and without being conscious of orientation is because the device side performs a confirmation each time. This is because the device side accommodates this without the user realizing it.

Easy to Use Worry-Free Connections Regardless of Cable Orientation



Mating Possible Without Regard for Connector Orientation on Device A and B



Worry-free cable connections possible by mounting a symmetrical Type-C connector on both device A and B, and through CC pin detection

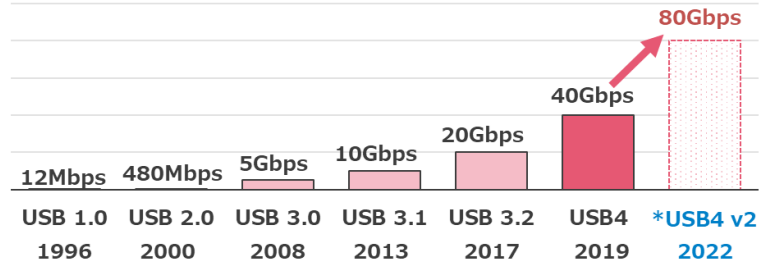
Increased Data Transmission Speeds

It is not an exaggeration to say that the USB standard has been updated with changes in transmission speeds.

This change is shown in the graph, and you can see that as technology evolves, transmission speeds double every couple of years. If the connector shape changed each time the standard is updated, cables and peripherals will become obsolete in a few years and will lead to financial and convenience problems for the user.
The USB standard supported backwards compatibility with existing connectors even after updates, but the USB Type-C connector was one that could not mate with existing connectors. This was a major change for the USB standard.

This USB Type-C connector was released alongside the USB 3.1 specification, which increased transmission speeds to 10Gbps, double that of USB 3.0. However, because Type-A and Type-B connectors were also supported at this stage, there were many cables on the market that had a Type-A connector on one end and Type-C on the other. With the release of USB 3.2, which further increased speeds, cables that had USB Type-C connectors on both ends were required to support data transfer rates up to 20Gbps. The USB4© specification was released just two years later, doubling the maximum speed to 40Gbps. In view of greater communication data requirements in the future, the USB-IF is considering further increases in transmission speeds.

USB Standard Data Transmission Speeds



*The USB4® Version 2.0 specification announced by USB-IF on October 18, 2022 has been added to page 10 of this document (Updated December 2022)

High-speed data transmission using USB Type-C is explained here, and we will try to do so in as simple terms as possible so that it can be understood by persons without electronic engineering knowledge.

Please take look at the pin assignments shown below.
Each of the 24 pins is assigned various signals. Among these, the TX terminals and RX terminals, boxed in red, are the terminals used for high-speed data transmission. TX is for sending and RX for receiving. There are 2 sets of TX and RX terminals, with each further having a + and -. Think of the + and - as being a pair. Signals are sent and received using these two terminals as a pair. A method known as differential transmission is used to transmit signals by identifying the difference in voltage between the terminals. The TX and RX pairs are required on both devices in order to perform bidirectional communication between devices. As for the 1 and 2, as you probably realized, USB Type-C has two sets of high-speed data transmission lines.

USB Type-C Pin Assignment

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
GND	TX1+	TX1−	V_{BUS}	CC1	D+	D−	SBU1	V_{BUS}	RX2−	RX2+	GND
GND	RX1+	RX1−	V_{BUS}	SBU2	D−	D+	CC2	V_{BUS}	TX2−	TX2+	GND
B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1

About Pin Assignments for Purposes Other Than High-Speed Data Transmission

・VBUS: Power delivery terminal
・GND: Grounding terminal
・D+/-: For USB 2.0 communications
・SBU1, 2: Side Band Use (for functional extensions)
・CC1, 2: Configuration Channel (for connection configurations and settings)

Increased Data Transmission Speeds

Please take a look at the table below on the understanding that USB Type-C has two pairs of lanes to conduct high-speed data communication. When you compare the revision and data rate columns, you can see the mechanism relating to the number of lanes and transmission speeds.

With USB 3.2 Gen 2 (“Gen” is an abbreviation of “Generation”), the maximum data rate is 10Gbps when using one lane, and 20Gbps with two lanes.
Although there was a need to support transmission using one lane when connecting from conventional Type-A or Type-B, this became two lanes only as it became mandatory to use two lanes with the USB4 and later standards.

While the “x1” and “x2” have been removed from the brand name for better user understanding, you will be able to understand how transmission speeds have increased when you read into the revision versions.

USB Type-C-Compatible USB Standards

Revision	Marketing Name	Data Rate
USB 3.2 Gen 1x1	SuperSpeed USB 5Gbps	5Gbps
USB 3.2 Gen 2x1	SuperSpeed USB 10Gbps	10Gbps
USB 3.2 Gen 2x2	SuperSpeed USB 20Gbps	20Gbps
USB4 Gen 2x2	USB4 20Gbps	20Gbps
USB4 Gen 3x2	USB4 40Gbps	40Gbps

USB4® Version 2.0 Specifications Overview

The main features of the USB4® Version 2.0 specification announced by the USB-IF on October 18, 2022 are described in ① to ⑥ below.
Of these features, ①, ④, and ⑤ are a little difficult to understand, and supplementary explanations are also provided, so please check them as well.

① **Supports 80Gbps with PAM3 signal encoding**
② **80Gbps operation is possible with existing USB4 Gen3 (40Gbps) standard receptacles, passive cables, and newly-defined active cables**
③ **Supports DisplayPort™ 2.1 and PCI Express® 4.0**
④ **USB 3.2 by tunneling will be enable 20Gbps communication**
⑤ **Asymmetric mode (3 TX / 1 RX) allows configuration of 120 Gbps transmission/40 Gbps reception**
⑥ **Retains compatibility with all previous versions of USB**

① What is PAM3 signal encoding?

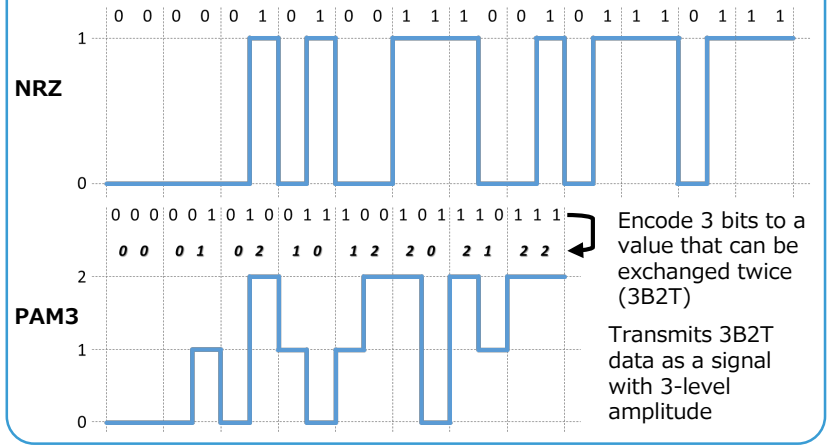
PAM (Pulse Amplitude Modulation) is a method of transmitting digital signals depending on the amplitude (voltage) of the signal.In particular, the method of transmitting 1 bit (binary values of 1 and 0) is called NRZ (Non Return to Zero).PAM3 means that three values are transmitted depending on the voltage level.Compared to transmitting binary data per hour, ternary data can be sent 1.5 times as much data, so speed can be increased without increasing the frequency.However, since the voltage difference is small, it is necessary to consider that data transmission may become difficult due to the effects of noise, etc. if appropriate measures are not taken.

④ What is USB 3.2 by tunneling will be enable 20Gbps communication?

With the advent of USB4 Version 2.0, the transmission rate of 10Gbps was improved to 20Gbps with conventional USB4.Please refer to page 13 of this document for an explanation of the concept of tunneling.

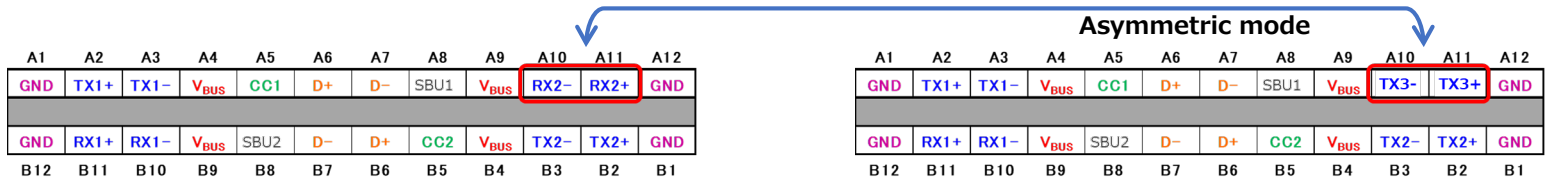
NRZ and PAM3

For example, when transmitting data 000001010011100101110111



⑤ What is Asymmetric mode (3 TX / 1 RX) allows configuration of 120 Gbps transmission/40 Gbps reception?

On page 8 of this document, we explained that high-speed data transmission is performed with the “TX” and “RX” terminals using the USB Type-C pin assignment.
The configuration consists of two pairs of "TX" terminals on the transmitting side and two pairs of "RX" terminals on the receiving side. However, in USB4 Version 2.0, by assigning the RX2 terminal to the transmitting side as the TX3 terminal, the configuration of 120 Gbps transmission / 40 Gbps reception. is now possible



Improved Power Delivery Capabilities

Power delivery is one USB function that you should remember. This power delivery function evolved into a standard dedicated to power delivery as the USB standard was revised.

The graph on the right shows the current, voltage, and power value compatible with each standard.
Because it is difficult to understand all of these changes, we will be explaining USB Power Delivery, a high power standard that requires the use of USB Type-C.
The first thing to focus on is that power delivery increased significantly with this USB Power Delivery standard. Because handling large amounts of power also generates heat, safety must be guaranteed in order to prevent major accidents such as burns and fires.

USB Standard Power Delivery Capabilities

Standard		Current	Voltage	Power
USB 2.0		0.5A	5V	2.5W
USB 3.2		0.9A		4.5W
USB4		1.5A		7.5W
USB BC 1.2				
USB Type-C Current@1.5A				
USB Type-C Current@3A		3A		15W
USB Power Delivery 3.1	SPR	3A	20V	～60W
		5A	20V	～100W
	EPR	5A	～48V	～240W

Power Delivery Mechanism for USB Power Delivery

We previously mentioned the role of the CC terminal on the “Structure that Allows Mating Regardless of Orientation” and “Same Connector Shape for Both Parent and Child Devices” pages but the CC terminal also plays a major role in power delivery as well.

In order to safely deliver a large amount of power the entire cable assembly that connects the devices must have sufficient power delivery capabilities.
For example, a device that can only receive 5V will break if a voltage of 20V is applied. It may even result in a fire…

As such, there is a mechanism in place where communication is made via the CC terminal between the two connected devices to determine the power delivery capabilities of the connected cable assembly. Once the checks have been made, power delivery is started at the appropriate specification.

Storing information about the cable assembly capabilities can be done using an IC chip known as the E-Marker that is incorporated inside the cable assembly. The E-Marker is like a business card and is a memory chip that contains information such as cable assembly specifications. If checks cannot be made through communication, or if the cable assembly does not incorporate an E-Marker, the Power Delivery standard is not applied and minimal power is delivered.

The E-Marker is incorporated in the cable assembly

Use Specific to Power Delivery and USB 2.0 Communication

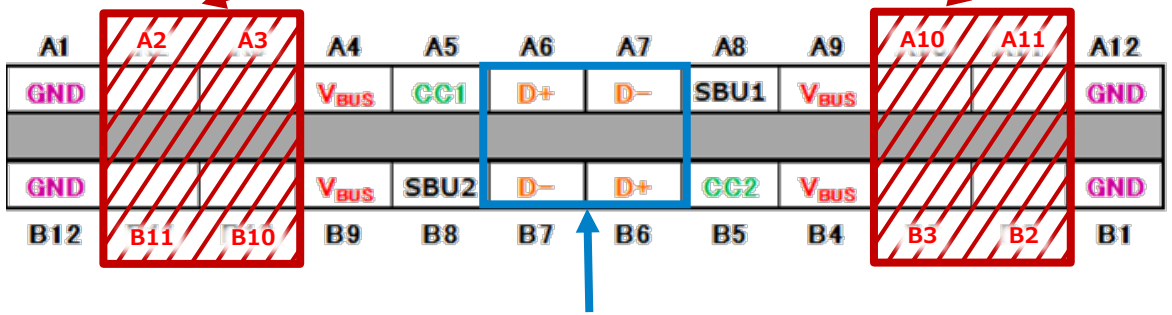
With the advent of USB Type-C, power delivery capabilities for the USB standard drastically increased. Along with this, there was wider use of the USB Type-C connector as a device's power supply. The USB standard presumes use for power (no high-speed data transmission) and defines connector specification for that purpose.

As shown in the figure below, the receptacle connector provides for pin assignments that remove the terminals used for high-speed data transmission (the previously mentioned TX and RX terminals). Although the connector shape is the same, the number of terminals is reduced from 24 to 16. Using 16 pins has the advantage of easier design and mounting for the PCB the connector will be mounted on.

JAE also offers 16 pin connectors in our lineup. Please see the JAE website for details.

16 Pin Receptacle Connector Pin Assignment Specific to Power Delivery and USB 2.0 Communication

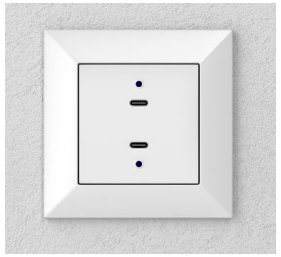
All eight TX and RX terminals are removed



Data transmission at 480Mbps possible as there are D+/- terminals for USB 2.0

Examples of Uses Specific to Power Delivery

Mobile Battery
Wall Outlet Adapter
Wall Outlet



Compatible with Communication Standards Other Than USB

A feature of USB Type-C is that communication standards other than the USB can be supported.

Compatible communication standards include Thunderbolt™, DisplayPort, and PCIe® (optional).

When USB Type-C was first released, this function was called Alternate Mode.

With Alternate Mode, the mechanism was one where inter-device negotiations were first made using the CC terminal and communication was started once the negotiation to determine which communication standard to use is completed.

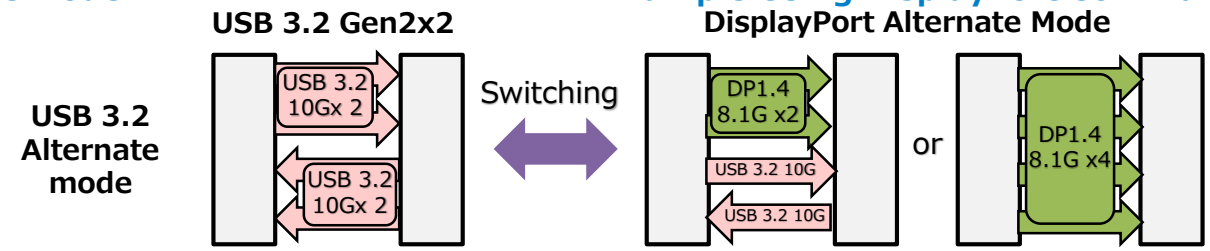
While the idea of negotiation between devices using the CC terminal remains the same, there was a change in the mechanism with the latest USB standard (USB4). A new concept known as tunneling was introduced as a method to further improve transmission efficiency.

Alternate Mode and Tunneling Concepts

With conventional Alternate Mode, one communication protocol occupies the transmission path, making the available bandwidth fixed. However, tunneling allows for signals other than USB to be carried on USB4 packets on the same transmission path by efficiently allocating bandwidth based on the requirements of each individual signal within the total available bandwidth.

Alternate Mode

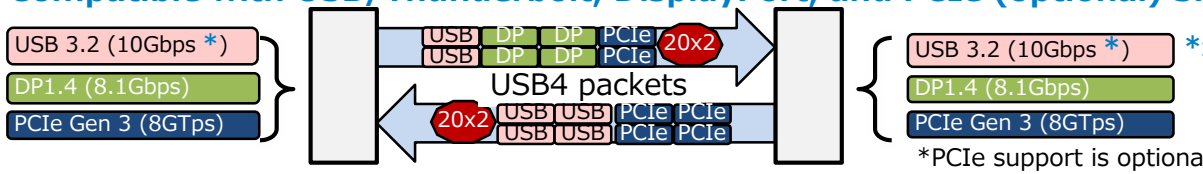
Example Using DisplayPort Communication



Each signal occupies a transmission path and bandwidth is fixed

Tunneling

Compatible with USB/Thunderbolt, DisplayPort, and PCIe (optional) Signals



*Improved from 10Gbps to 20Gbps with USB4® Version 2.0

*PCIe support is optional

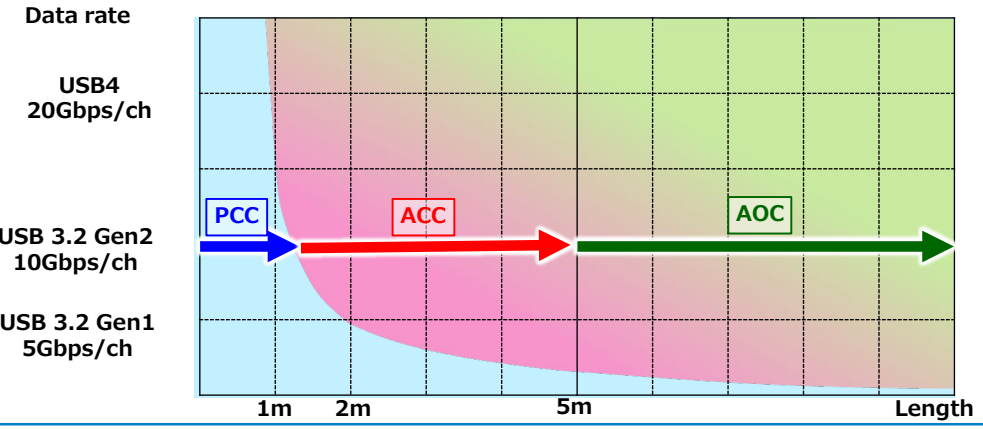
USB 3.2, DisplayPort, and PCIe signals are efficiently distributed within the 40Gbps bandwidth according to data volume and transmitted on USB4 packets.
With USB4, bandwidth is doubled at 40Gbps and efficient transmission is possible

Compatibility Status with Long Cable Assemblies (Optional)

While the USB standard allows for high-speed data transmission, there is an inconvenience that arises with connections using regular passive copper cables (PCC) where transmission distances have to be short.

As shown in the figure below, when connecting USB4 with a PCC, the maximum length for that cable is around 1m.
ACC and AOC transmission methods can be used to resolve this issue, as shown in the table below.
ACC is a cable type where signals are electrically regenerated and transmitted, and AOC is a cable type where electrical signals are converted to optical signals.

Cable Assembly Transmission Methods and Transmission Distance/Speed



Cable Assembly Transmission Methods

PCC	Passive Copper Cable	Electrical signal → Wire
ACC	Active Copper Cable	Electrical signal → Redriver / Retimer → Wire
AOC	Active Optical Cable	Electrical signal → VCSEL/PD Driver/TIA → Optical fiber Optical signal

JAE is developing both ACC and AOC.
Please contact us if you are interested.

Contact Us ：
https://www.jae.com/en/contact/

Lastly, USB Type-C and JAE

JAE participates in the USB-IF working group that establishes USB Type-C standards and has contributed to the development of the connector standards.

The JAE plug connector has also been adopted as the Golden Plug incorporated on official test fixtures (the only certified testing tool specified by the USB-IF) used for USB4 receptacle connector certification tests.

We have prepared this white paper based upon this experience and track record in order for everyone to gain a correct understanding of USB Type-C.

This white paper also uses concise wording in order for readers to understand the content even if they do not have specialized knowledge.
Please feel free to contact us if you would like to gain an even deeper understanding of if you have any questions.

Contact Us ： https://www.jae.com/en/contact/

The following page lists links to related information featured on the JAE website.
Please refer to these as well.

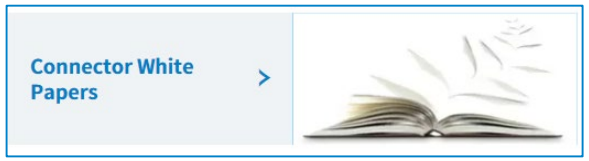
Related Information

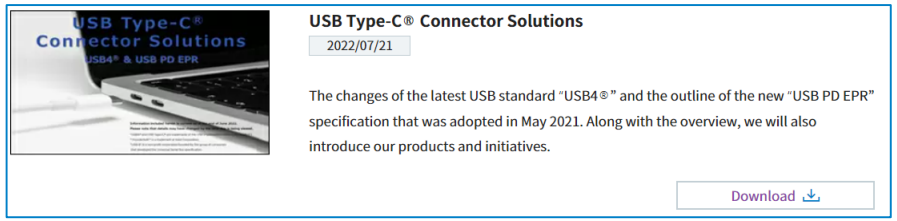
Please refer to the following links if you would like to know more details about USB Type-C products.

Introduction to USB Type-C Products

Introduction to USB Type-C USB4-Compatible Products

White Papers Explaining the Latest Standards (USB4, USB PD EPR)





Introduction to USB Type-C and Other Products for Compact Devices

Product Series by Type Introduction Pages (Individual catalogs can be downloaded from each page)

USB Type-C Receptacle Connector

USB Type-C Plug Connector

USB Type-C Cable Assembly

Technology to Inspire Innovation

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Please feel free to contact us if you would like to consult with us or have any questions concerning our products.

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