SoC Individual Report

Intel Thunderbolt 4.0

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Content

1. Introduction

Thunderbolt is a high-speed protocol that delivers power, data, and a video signal at the same time, and it also can dynamically adjust data and video bandwidth depending on the device and/or application.

The Thunderbolt™ certification establishes mandatory minimum requirements for cables, PCs, and accessories to help ensure greater reliability and interoperability across devices and vendors. For end users, Thunderbolt™-based products deliver a great experience when connecting accessories.

Additionally, Thunderbolt is now the basis of the USB4 protocol specification. That is to say Thunderbolt 4 and USB 4 products will use the same underlying protocol specification to improve compatibility for USB-C based products. But Thunderbolt 4 will offer the most complete version of USB-C with a required superset of capabilities not required by USB4.

1.1History

1.1.1 A Brief of Thunderbolt History

Before we get into the new Thunderbolt 4 protocol, let's first back up and explain what Thunderbolt is and does.

Thunderbolt first showed up on a MacBook Pro in 2011. It has been developed by Intel, in collaboration with Apple. Thunderbolt 1 combines PCI Express (PCIe) and DisplayPort (DP) into two serial signals in one cable to drive high-resolution displays and high-speed data transfers with a top speed of 10Gbps. The physical form of the port was a mini DisplayPort connector with a little lightning-strike icon next to it.

Figure 1. Mini DisplayPort on a MacBook Pro

Thunderbolt 2 doubled the bandwidth to 20Gbps and added DisplayPort 1.2 support, giving the interface the ability to drive a video signal to a 4K display. The physical form of the port was a mini DisplayPort connector like the first generation.

Thunderbolt 3 doubled the data rate to 40Gbps. Another big change is it no longer used the mini DisplayPort connector as its physical interface, dropping it in favor of the USB Type-C port, with the technology piggybacking on that connector, in the same way that Thunderbolt 1 and 2 piggybacked on mini DisplayPort. It also added up to 100 watts of power via USB Power Delivery (USB PD), so we could use PC to charge our phone and other USB devices, or even charge a laptop over the port. The Thunderbolt 3 specification also introduced Thunderbolt networking with 10Gbps Ethernet. It provided enough video bandwidth that it led to a wide array of applications, from single-cable docks that could also charge devices, to external GPUs to supercharge a laptop’s graphics capabilities.

Thunderbolt 4 has been released in 2020, the detailed content will be introduced later.

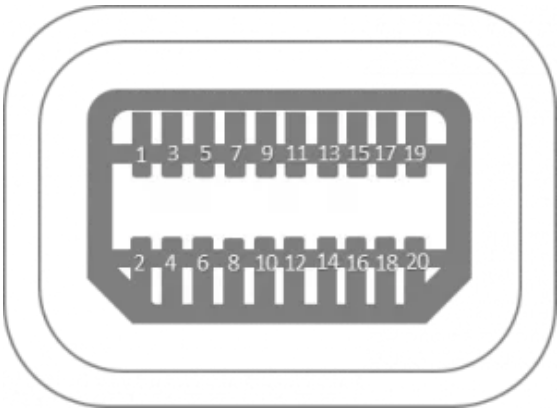


Figure 2. TBT1, 2 use Mini Display Port

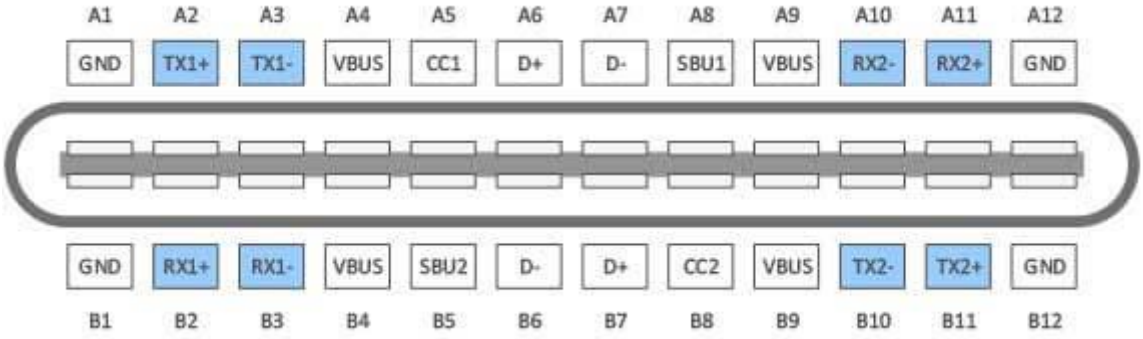


Figure 3. TBT3 4 use USB Type-C

Figure 4.

1.1.2 A Decade of Thunderbolt Innovation

Let’s review the development of Thunderbolt over the past ten years from the Figure 5.

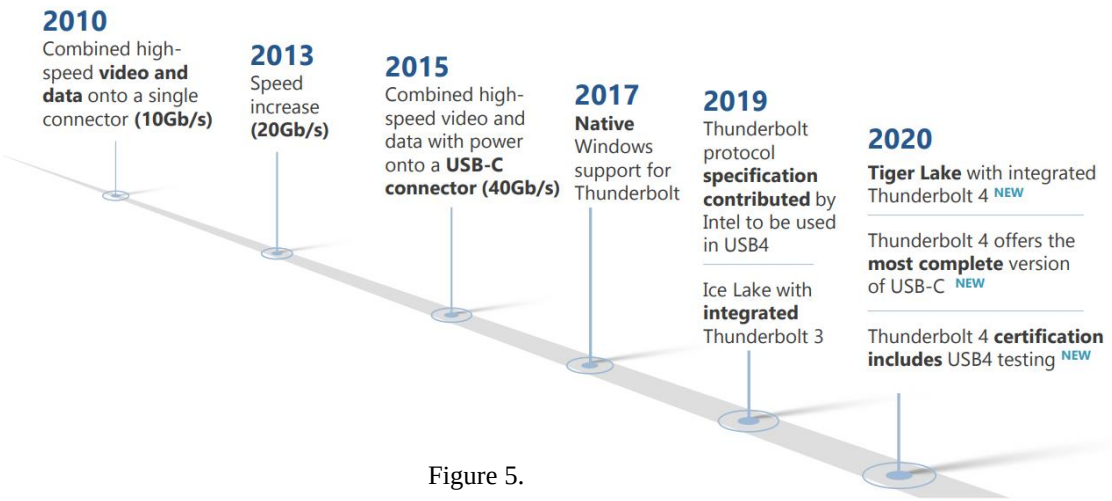


Figure 5.

1.2Key Features

Here are three of the most important features of Thunderbolt technology, and we will give a detailed description of the features of the fourth generation in the following chapters.

- Thunderbolt™ ports provide high bandwidth for connecting high-speed devices.
- Thunderbolt™ cables help to ensure a quality connection between the device and a PC.
- Thunderbolt™ accessories make it easy to expand the capabilities of your PC with docking options and external devices.

2. Technology Analysis

2.1Thunderbolt Protocol Architecture

Thunderbolt technology is based on a switched fabric architecture with full-duplex links. Unlike bus-based I/O architectures, each Thunderbolt port on a computer is capable of providing the full bandwidth of the link in both directions with no sharing of bandwidth between ports or between upstream and downstream directions. The Thunderbolt protocol architecture can be abstracted into four layers as shown in Figure 6.

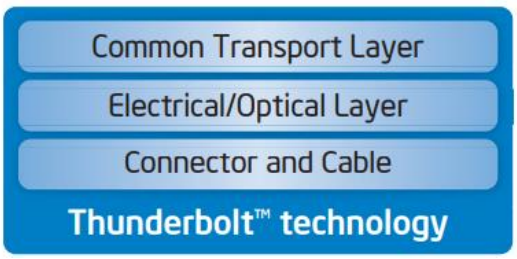


Figure 6. Thunderbolt Technology Architecture

Thunderbolt cables may be electrical or optical, both use the same Thunderbolt connector.

A Thunderbolt connector is capable of providing two full duplex channels. Each channel provides bi-directional 40Gbps of bandwidth. A Thunderbolt connector is ideal for Ultrabooks, plus it is enables connection to Thunderbolt products or to DisplayPort devices. Compatibility to DisplayPort devices is provided by an interoperability mode between host devices and DisplayPort products; if a DisplayPort device is detected, a Thunderbolt controller will drive compatibility mode DisplayPort signals to that device. Support for DisplayPort also enables easy connectivity to other display types, such as HDMI, with an adapter. In addition to Thunderbolt alternate mode and DisplayPort alternate mode, a

Thunderbolt also can dynamically detect the capabilities of other cables and devices plugged into it and then activates one (or a combination) of four connection modes. The first mode is USB only mode, for USB devices or cables that do not support Thunderbolt, the Thunderbolt port activates the USB controller to support USB 4 or 3.x or 2.0 signaling. The second mode is USB/DP combo mode, a combination of the USB and DP modes described above and the Thunderbolt port will share the four USB-C lanes between DisplayPort and USB. The third one is Thunderbolt Networking mode, allows two or more Thunderbolt-enabled computers to establish a direct Ethernet connection to share resources, and copy, transfer or print files. The last one, power delivery and charging of host and connected devices is supported by USB-PD.

The Thunderbolt protocol physical layer is responsible for link maintenance including hot-plug detection, and data encoding to provide highly efficient data transfer. The heart of the Thunderbolt protocol architecture is the transport layer. Some of the key innovations introduced by the transport layer include:

- A high-performance, low-power, switching architecture.
- A highly efficient, low-overhead packet format with flexible QoS support that allows multiplexing of bursty PCI Express transactions with isochronous DisplayPort communication on the same link.
- A time synchronization protocol that allows all the Thunderbolt products connected in a domain to synchronize their time within 8ns of each other.

DisplayPort, PCI Express and USB protocols are mapped onto the transport layer. The mapping function is provided by a protocol adapter which is responsible for efficient encapsulation of the mapped protocol information into transport layer

packets. Mapped protocol packets between a source device and a destination device may be routed over a path that may cross multiple Thunderbolt controllers. At the destination device, a protocol adapter recreates the mapped protocol in a way that is indistinguishable from what was received by the source device.

2.2Thunderbolt Controller

A Thunderbolt controller is the building block used to create Thunderbolt products. A basic Thunderbolt controller contains:

- A high-performance, cross-bar Thunderbolt protocol switch
- One or more Thunderbolt ports
- One or more DisplayPort protocol adapter ports
- One or more Thunderbolt ports
- A PCI Express switch with one or more PCI Express protocol adapter port

The external interfaces of a Thunderbolt controller that are connected in a system depend on the application for which the system is designed. Both peripherals and computers require a controller. An example implementation of Thunderbolt controller is shown in Figure 7. Host controllers have one or more DisplayPort input interfaces, a PCI Express interface along with one or more Thunderbolt technology interface. By integrating all the features necessary to implement Thunderbolt into a single chip, the host controller enables system vendors to easily incorporate Thunderbolt technology into their designs.

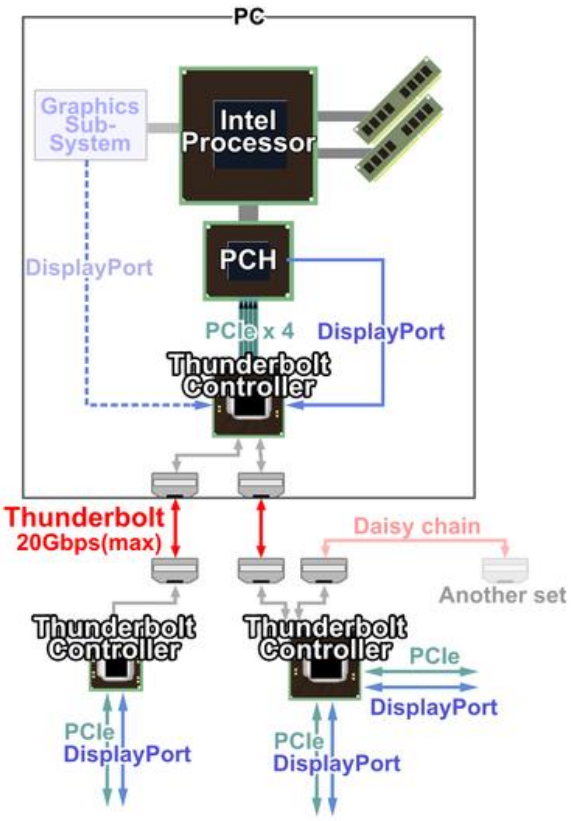


Figure 7. Block diagram of example PC system showing Thunderbolt controller connections

Thunderbolt technology leverages the native PCI Express, DisplayPort and USB device drivers available in most operating systems today. Native software support means no additional software development is required to use a Thunderbolt technology enabled product.

In terms of Thunderbolt 4, Intel® 8000 series Thunderbolt 4 controllers has come. JHL8540 and JHL8340 host controllers for computer makers and JHL8440 device controller for accessory makers. Both of the host controllers have the same features that always speed up 40Gbps and compatible with USB4. The device controller has the features include 40 Gbps speed, USB4 compliant (peripheral only), with 4x Thunderbolt 4 ports for branching hub topology. Tunnelling of DP1.4, USB 3 (10G), PCIe (32G). Has PCIe 3.0 x1 and USB 3 (10G) native

interfaces.

Additionally, Intel's upcoming mobile PC processors, code-named "Tiger Lake," will be the first to integrate Thunderbolt 4.

Figure 8.

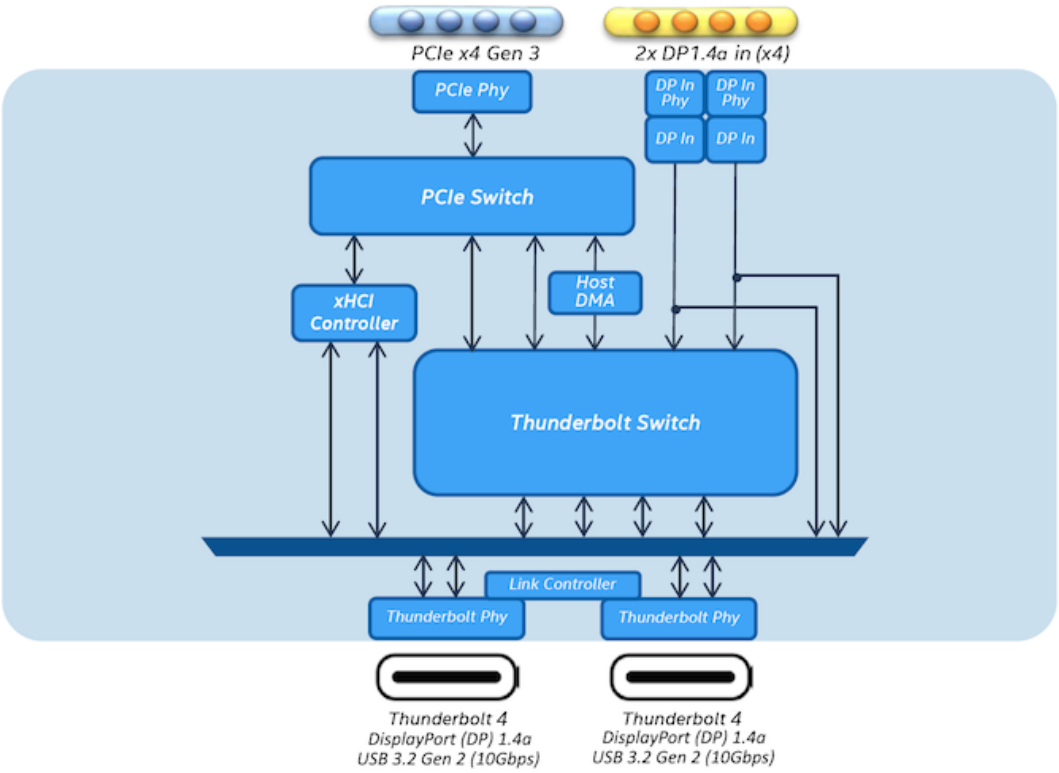


Figure 9. Thunderbolt 4 controller block diagram

2.3Features

Thunderbolt 4 technology is the next generation of the Thunderbolt protocol, following Thunderbolt 3 technology. Both of them support power charging, data transfer and video display in one interface and use the same USB-C connector type, but Thunderbolt 4 technology introduces higher minimum requirements and new capabilities for a best-in-class user experience that the detailed content is explained below.

2.3.1 Features Similar to Thunderbolt 3

- speed

Thunderbolt 3	Thunderbolt 4
Always provides a 40 Gbps connection in each direction	Same as left

- protocols

Thunderbolt 3	Thunderbolt 4
4 lanes of PCI Express Gen 3 - Great for the fastest storage, External Graphics (eGfx), 10 Gb Ethernet, and more - Provides the Lowest latency for PCI Express audio	Same as left
Supports 2 video streams, and DisplayPort 1.4: 8 lanes of HBR2, 4 lanes of HBR3	*Supports 2 video streams,* ***Display Port 2.0 UHBR*** *and DisplayPort 1.4: 8 lanes of HBR2, 4 lanes of*

- Supports two 4K displays - Allows connection of DVI, HDMI, and VGA displays via converters	*HBR3* - Supports **two 4K** displays or **one 8K** display - Allows connection of DVI, HDMI, and VGA displays via converters
Includes a USB 3 connection at up to 10 Gbs - Compatible with existing USB devices and cables	Same as left
Includes Thunderbolt Networking - Provides greater than 10 Gb Ethernet bandwidth connection between computers	Same as left

- Power :

  Delivers Power to Computer or Peripheral (based on USB power delivery)

  ✓ Up to 100W of power for laptop charging

  ✓ Up to 15W for computer-powered accessories charging

- Cross-Compatibility Between Thunderbolt and USB

  Various USB standards, including USB 3.2 and USB4, also use the USB-C connector type (Figure 10), and these cables and ports are cross-compatible both with Thunderbolt 4 and Thunderbolt 3. When devices with different capabilities are connected, the connection will only support the lowest

common data rate. For example, you can plug a USB 3.2 cable into a Thunderbolt 4 port, and the port will negotiate data, power, and video signal capabilities with the connected device at a USB 3.2 level.

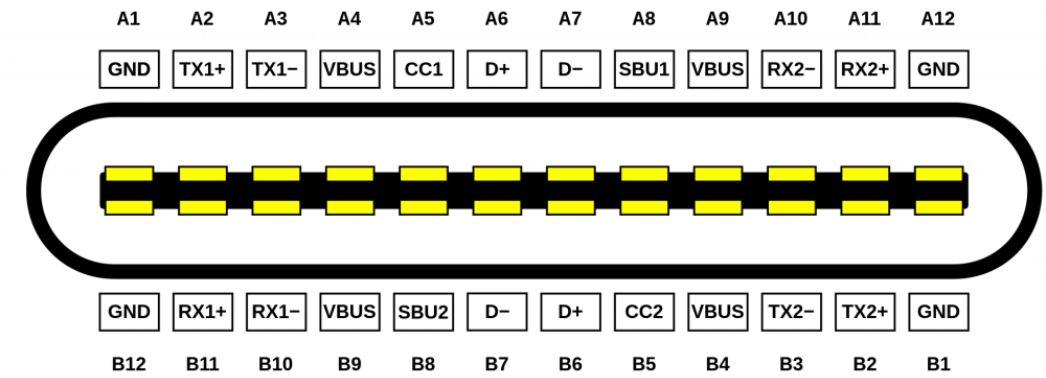


Figure 10. USB-C connector

Pin	Description	Pin	Description
A1	Ground	B12	Ground
A2	SuperSpeed differential pair 1, TX, positive	B11	SuperSpeed differential pair 2, RX, positive
A3	SuperSpeed differential pair 1, TX, negative	B10	SuperSpeed differential pair 2, RX, negative
A4	Bus power	B9	Bus power
A5	Configuration channel	B8	Side Band Use (SBU)
A6	Differential pair 1, positive	B7	Differential pair 2, negative
A7	Differential pair 1, negative	B6	Differential pair 2, positive
A8	Side Band Use (SBU)	B5	Configuration channel
A9	Bus power	B4	Bus power
A10	SuperSpeed differential pair 4, RX, negative	B3	SuperSpeed differential pair 3, TX, negative
A11	SuperSpeed differential pair 4, RX, positive	B2	SuperSpeed differential pair 3, TX, positive
A12	Ground	B1	Ground

- One brand, one logo, and one icon to simplify purchases

Name	Logo	Icon	Port	Cable
Thunderbolt™ 4	THUNDERBOLT			

2.3.2 New Features in Thunderbolt 4

- Required Support for Dual 4K Monitors or One 8K Monitor
- Higher Minimum Data Transfer Speed – PCIe at 32 Gb/s for storage speeds up to 3000MB/s

  Although Thunderbolt 4 ports have the same high-speed 40Gbps bandwidth as Thunderbolt 3, however minimum PCIe data requirements have increased from 16Gbps to 32Gbps. This means that high-speed external PCIe devices like storage and external graphics could see significant increases in transfer rates and performance.
- At least one computer port for PC charging
- USB4 specification compliant
- Enhanced Security – Intel VT-d based direct memory access (DMA) protection

  Memory isolation is a key security capability that helps protect computers from data loss and attacks like memory snooping. Thunderbolt 4 technology now requires Intel VT-d based direct memory access (DMA) protection. DMA protection helps ensure that accessories connected through a Thunderbolt port can only access the data for their specific workloads by isolating data in memory.

- Wake from Sleep Mode

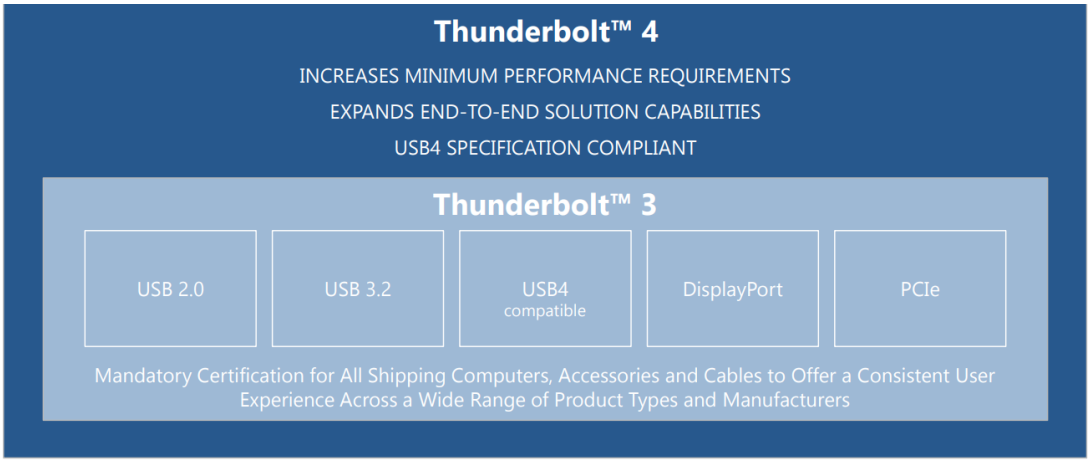
  A computer with a Thunderbolt port connected to a Thunderbolt dock wakes up with a touch of keyboard or mouse even when the computer lid is closed. This feature provides the convenience of quickly waking up a computer so they can get back to their work, game, or creation in seconds.

- Supports up to four Thunderbolt ports per accessory

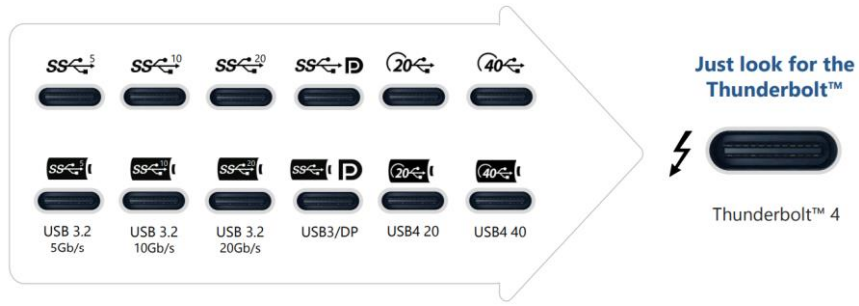
  More ports mean more connected accessories and monitors. Thunderbolt 4 technology now supports up to four ports per accessory, compared to two ports with Thunderbolt™ 3 technology.

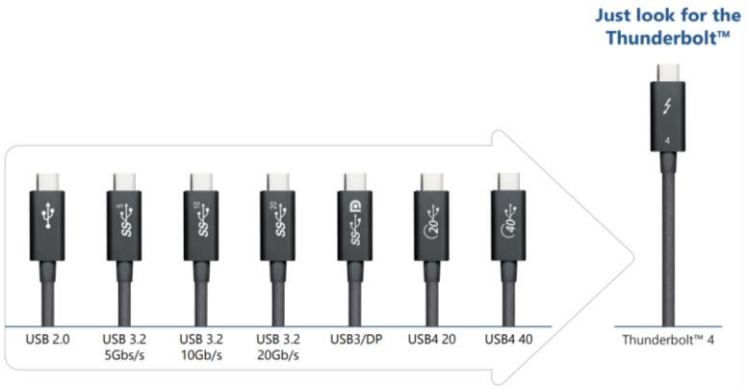
- Backward Compatibility

  Thunderbolt 4 technology is backwards compatible with Thunderbolt 3 as well as millions of USB 3 and USB4 products.



- Computer port & Cable simplification





2.4Applications

Thunderbolt 4 is available on a lot of modern computers and supports broad OS platform like Windows, Mac, Linux, and Chrome OS.

2.4.1 Apple device

Apple started to include Thunderbolt 4 on some of their devices, starting in 2021 with MacBook Pro.

List of Apple devices featuring Thunderbolt 4 ports include:

- MacBook Pro (14-inch, 2021)
- MacBook Pro (16-inch, 2021)
- Mac Studio (2022)

Figure 11. Macbook Pro 2021

2.4.2 Laptop

All Intel® Evo™ laptops and all Intel® Core™ vPro® processor-enabled laptops.

Figure 12.

2.4.3 Accessories

Thunderbolt 4 computers and cables are a fully compatible extension to existing Thunderbolt 3 accessories and cables.

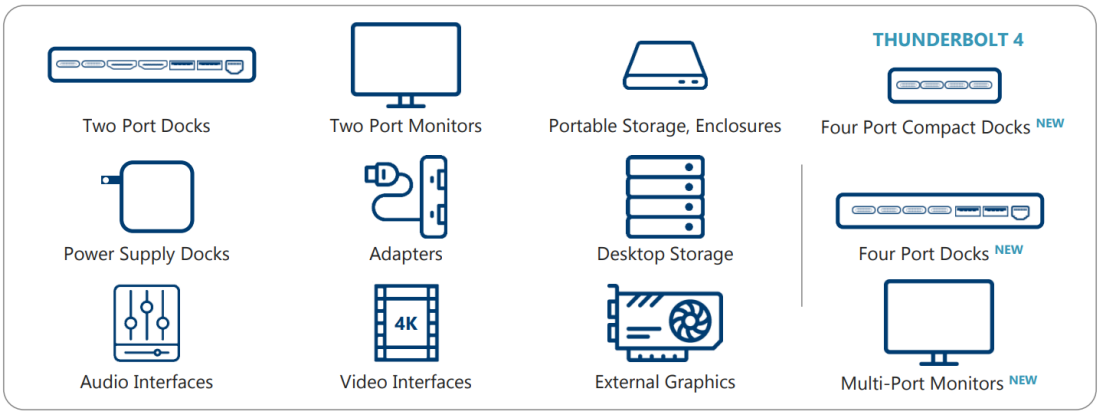


Figure 13.

Figure 14. Thunderbolt 4 four ports dock

3. Comparison

3.1Thunderbolt 4 And Thunderbolt 3

	Thunderbolt™ 4 Technology	Thunderbolt™ 3 Technology
Connector type	USB-C	USB-C
Total bandwidth	40 Gbps	40 Gbps
Minimum bandwidth available for data transfer	32 Gbps	16 Gbps
Display	Up to two 4K monitors or one 8K monitor	One 4K monitor
Thunderbolt™ ports per accessory	Up to four ports	Up to two ports

Laptop charging	Up to 100W on at least one computer port	Supported, but not required
System wake from sleep from connected accessory	Required	Supported, but not required
Intel® VT-d-based direct memory access (DMA) protection	Required	Supported, but not required
USB4 specification	Compliant	Compatible

3.2Thunderbolt 4 And USB4

The most obvious difference is in the minimum spec requirements

	Thunderbolt™ 4	USB4
Interface	USB-C	USB-C
Minimum Supported Bandwidth	40Gbps	20Gbps
Maximum Supported Bandwidth	40Gbps	40Gbps
Minimum Display Output Requirements	Double 4K Display Output	Single Display Output
DisplayPort Tunneling	DisplayPort 1.4a	DisplayPort 1.4a
DisplayPort Alt Mode	DisplayPort 2.0	DisplayPort 2.0
Minimum Data Transfer Speed	PCIe – 32Gbps USB 3.2 – 10Gbps	USB 3.2 – 10Gbps
PCIe	PCIe Gen3x4	Optional
Wake Function Support	Yes	Optional
Minimum Power Supply	15W	7.5W
Maximum Power Supply	240W	240W
Intel VT-d DMA Protection	Yes	No
USB4 Specification	In Compliance	In Compliance

3.3Thunderbolt 4 And Others

		Thunderbolt™ 4	Thunderbolt™ 3	USB4	USB3/DP
Unrivaled Simplicity	One universal computer port	•	•		
	Universal 40Gb/s cables up to 2 meters in length	•			
	Accessories with four Thunderbolt ports	•			
Maximum Performance	Minimum PC speed requirements	40Gb/s	40Gb/s	20Gb/s	10Gb/s
	Minimum PC video requirements	Two 4K displays	One 4K display	One display (No Minimum)	One display (No Minimum)
	Minimum PC data requirements	PCIe 32 Gb/s USB 3.2 - 10Gb/s	PCIe 16 Gb/s USB 3.2 - 10Gb/s	USB 3.2 - 10Gb/s	USB 3.2 - 5Gb/s
	Required PC charging on at least one computer port[1]	•			
	Required PC wake from sleep when computer is connected to a Thunderbolt dock	•			
	Minimum PC port power for accessories	15W	15W	7.5W	4.5W
	Thunderbolt Networking	•	•		
Reliable Connectivity	Mandatory certification for all shipping computers, accessories and cables	•	•		
	Cable testing and cable quality audits for Thunderbolt cable manufacturers	•	•		
	Required Intel VT-d based DMA protection	•			
	USB4 Specification	Compliant	Compatible	Compliant	Compatible

4. Industrial Analysis

4.1Market Analysis

- Though Thunderbolt offers great capability, its impact in the interface world is uncertain. We can see in Figure 11, the proportion of Thundebolt is the smallest from 2015 to 2021 and in Figure 12, the Thunderbolt products only have 5% in 2021. But the total market for Thunderbolt-enabled devices in terms of unit shipments grow at a CAGR of around 51 percent from 2016 to 2021, basically driven by Thunderbolt alternate mode specifications and Intel’s plan to bake Thunderbolt technology into its core processors.

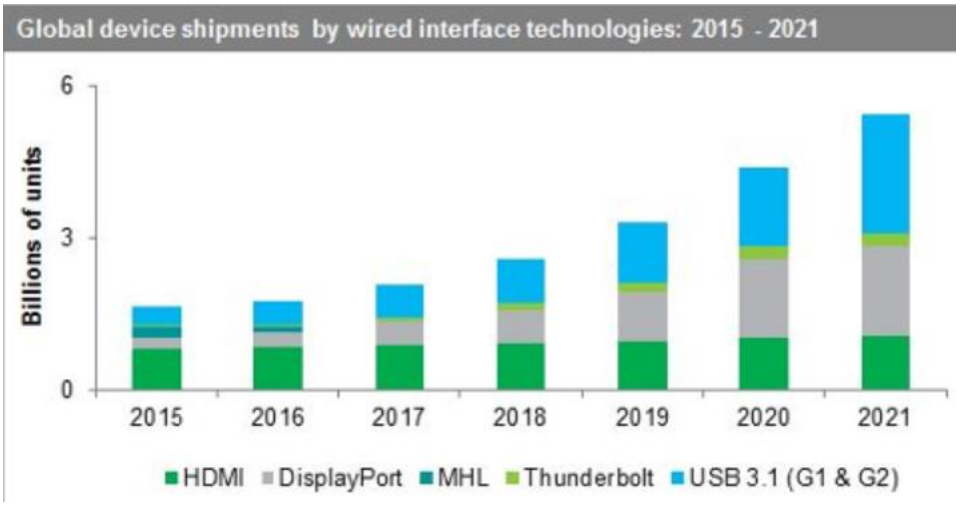


Figure 15. Global device shipments by wired interface technologies 2015 ~ 2021

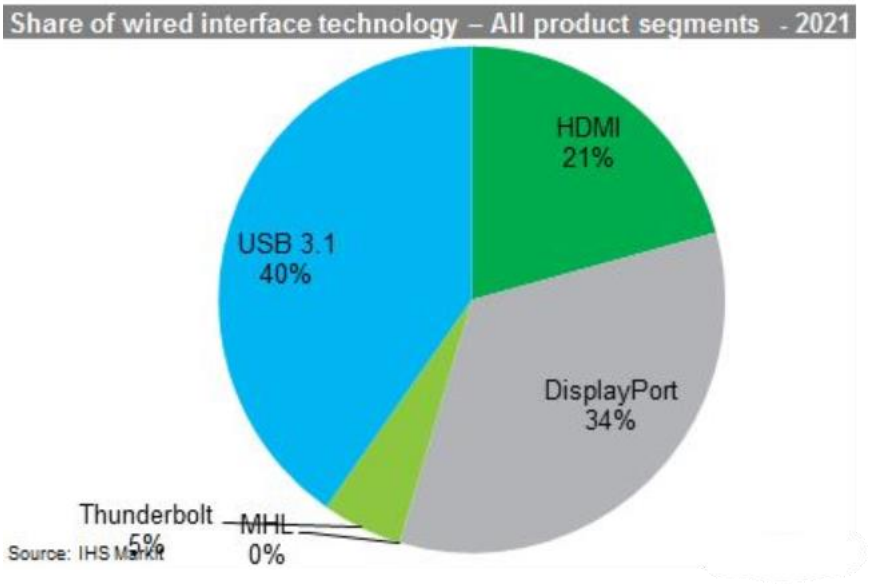


Figure 16. All product segments in 2021

- Thunderbolt Devices Manufacturer
  - ✓ Apple
  - ✓ Belkin
  - ✓ Dell
  - ✓ HP
  - ✓ OWC

- ✓ Anker
- ✓ Plugable
- ✓ And so on

4.2SWOT Analysis

- Strengths
  - ✓ High performance
  - ✓ Compatibility
  - ✓ Simplicity

- Weaknesses
  - ✓ Small product ecosystem
  - ✓ Expensive

- Opportunities
  - ✓ Develop the market of high performance devices (such as a high-speed SSD)
- Threats
  - ✓ USB products

5. Future Trend

- Thunderbolt 5

  On October 19, 2022, Intel previewed Thunderbolt 5, aligned to the USB Implementers Forum's (USB-IF) release of the USB4 2.0 specification.

  It delivers up to 80 Gbps of bi-directional bandwidth, allowing for up to two

times faster data transfer speeds between future host device and external storage drives that support the standard, compared to current Thunderbolt 4 speeds. It will also have a mode allowing up to 120 Gbit/s bandwidth for external displays (three times Thunderbolt 4 speed), allowing a host device to support up to dual 8K displays at 60Hz.

While a release date is not available, Intel advised those interested to look for more detail on next-generation Thunderbolt's official brand name, features, and capabilities in 2023.

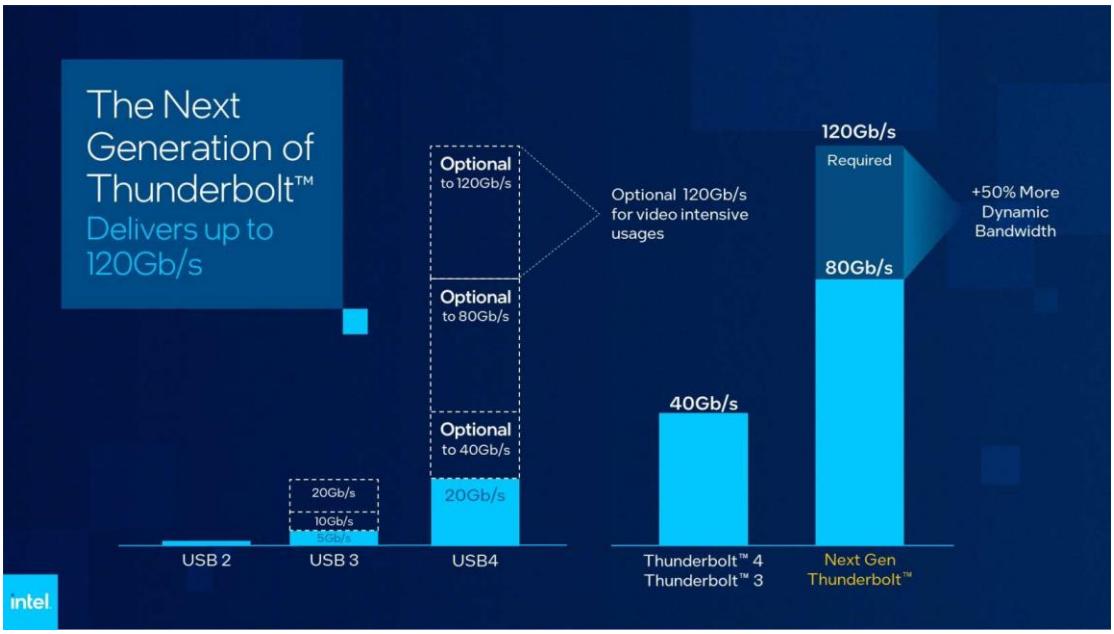


Figure 17. Next generation of Thunderbolt

6. Conclusion

- Thunderbolt 4 is the latest generation of cable technology from Intel.
- Thunderbolt 4 is a fast, simple, reliable solution.
- Thunderbolt 4 offers greater performance and an expansive set of capabilities, while fully compatible with all USB Type-C solutions.
- Thunderbolt 4 ports are available on many modern computers, we can easily use it.

7. Reference

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