

USB 3.0

USB 3.0 is the third major version of the Universal Serial Bus (USB) standard for interfacing computers and electronic devices. Among other improvements, USB 3.0 adds the new transfer rate referred to as *SuperSpeed* USB (SS) that can transfer data at up to 5 Gbit/s (625 MB/s), which is about 10 times faster than the USB 2.0 standard. It is recommended that manufacturers distinguish USB 3.0 connectors from their USB 2.0 counterparts by using blue color for the Standard-A receptacles and plugs,^[2] and by the initials SS.^[3]

USB 3.1, released in July 2013, is the successor standard that replaces the USB 3.0 standard. USB 3.1 preserves the existing *SuperSpeed* transfer rate, giving it the new label *USB 3.1 Gen 1*,^{[4][5]} while defining a new *SuperSpeed+* transfer mode, called *USB 3.1 Gen 2*^[4] which can transfer data at up to 10 Gbit/s over the existing USB-type-A and USB-C connectors (1250 MB/s, twice the rate of USB 3.0).^{[6][7]}

USB 3.2, released in September 2017, replaces the USB 3.1 standard. It preserves existing USB 3.1 *SuperSpeed* and *SuperSpeed+* data modes and introduces two new *SuperSpeed+* transfer modes over the USB-C connector using two-lane operation, with data rates of 10 and 20 Gbit/s (1250 and 2500 MB/s).

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Overview

The USB 3.0 specification is similar to USB 2.0, but with many improvements and an alternative implementation. Earlier USB concepts such as endpoints and the four transfer types (bulk, control, isochronous and interrupt) are preserved but the protocol and electrical interface are different. The specification defines a physically separate channel to carry USB 3.0 traffic. The changes in this specification make improvements in the following areas:

- Transfer speed – USB 3.0 adds a new transfer type called SuperSpeed or SS, 5 Gbit/s (electrically, it is more similar to PCI Express 2.0 and SATA than USB 2.0)^[8]
- Increased bandwidth – USB 3.0 uses two unidirectional data paths instead of only one: one to receive data and the other to transmit
- Power management – U0 to U3 link power management states are defined
- Improved bus use – a new feature is added (using packets NRDY and ERDY) to let a device asynchronously notify the host of its readiness, with no need for polling
- Support for rotating media – the bulk protocol is updated with a new feature called Stream Protocol that allows a large number of logical streams within an Endpoint

USB 3.0 has transmission speeds of up to 5 Gbit/s, about ten times faster than USB 2.0 (480 Mbit/s) even without considering that USB 3.0 is full duplex whereas USB 2.0 is half duplex. This gives USB 3.0 a potential total bidirectional bandwidth twenty times greater than USB 2.0.^[9]

Architecture and features


In USB 3.0, dual-bus architecture is used to allow both USB 2.0 (Full Speed, Low Speed, or High Speed) and USB 3.0 (SuperSpeed) operations to take place simultaneously, thus providing backward compatibility. The structural topology is the same, consisting of a tiered star topology with a root hub at level 0 and hubs at lower levels to provide bus connectivity to devices.

Data transfer and synchronization

The SuperSpeed transaction is initiated by a host request, followed by a response from the device. The device either accepts the request or rejects it; if accepted, the device sends data or accepts data from the host. If the endpoint is halted, the device responds with a STALL handshake. If there is lack of buffer space or data, it responds with a Not Ready (NRDY) signal to tell the host that it is not able to process the request. When the device is ready, sends an Endpoint Ready (ERDY) to the host which then reschedules the transaction.

The use of unicast and the limited amount of multicast packets, combined with asynchronous notifications, enables links that are not actively passing packets to be put into reduced power states, which allows better power management.

Data encoding

USB 3.0	
<div></div> <div>SuperSpeed USB logo</div>	
Type	USB
Production history	
Designed	November 2010
Manufacturer	USB 3.0 Promoter Group (Hewlett-Packard, Intel, Microsoft, NEC, ST-Ericsson, and Texas Instruments) ^[1]
Superseded	USB 2.0 Hi-Speed
Superseded by	USB 3.1 (July 2013)
General specifications	
Width	12 mm (A plug), 8 mm (B plug), 12.2 mm (Micro-A & Micro-B plugs)
Height	4.5 mm (A plug), 10.44 mm (B plug), 1.8 mm (Micro-A & Micro-B plugs)
Pins	9
Electrical	
Max. current	900 mA
Data	
Data signal	Yes
Bitrate	5 Gbit/s (625 MB/s)

The "SuperSpeed" bus provides for a transfer mode at a nominal rate of 5.0 Gbit/s, in addition to the three existing transfer modes. Accounting for the encoding overhead, the raw data throughput is 4 Gbit/s, and the specification considers it reasonable to achieve 3.2 Gbit/s (400 MB/s) or more in practice.^[10]

All data is sent as a stream of eight-bit (one-byte) segments that are scrambled and converted into 10-bit symbols via 8b/10b encoding; this helps the receiver to decode correctly even in the presence of electromagnetic interference (EMI). Scrambling is implemented using a free-running linear feedback shift register (LFSR). The LFSR is reset whenever a COM symbol is sent or received.^[10]

Unlike previous standards, the USB 3.0 standard does not specify a maximum cable length, requiring only that all cables meet an electrical specification: for copper cabling with AWG 26 wires, the maximum practical length is 3 meters (9.8 ft).^[11]

Power and charging

As with earlier versions of USB, USB 3.0 provides power at 5 volts nominal. The available current for low-power (one unit load) SuperSpeed devices is 150 mA, an increase from the 100 mA defined in USB 2.0. For high-power SuperSpeed devices, the limit is six unit loads or 900 mA (4.5 W), almost twice USB 2.0's 500 mA.^{[10]:section 9.2.5.1 Power Budgeting}

The term "available current" can be misunderstood. It implies that if a low power device or a USB2 device is connected to a USB3 port it can only draw 150 mA or 500 mA from that port. However, the available current for **any** USB device plugged into a USB3 port is 900 mA (unless it is charging port compliant) as defined by the USB3 spec. The actual current draw is determined by the device capability. The Vbus, pin 1, and Ground, pin 4, are the same for USB 1, 2, or 3. A USB2 HDD with 2 USB2 connectors needing a total of 800 mA will draw full power from a single USB3 port. A USB2 phone will probably charge faster since 900 mA is "available" to it.

USB 3.0 ports may implement other USB specifications for increased power, including the USB Battery Charging Specification for up to 1.5 A or 7.5 W, or, in the case of USB 3.1, the USB Power Delivery Specification for charging the host device up to 100 W.^[12]

Availability

The USB 3.0 Promoter Group announced on 17 November 2008 that the specification of version 3.0 had been completed and had made the transition to the USB Implementers Forum (USB-IF), the managing body of USB specifications.^[13] This move effectively opened the specification to hardware developers for implementation in future products.

The first USB 3.0 consumer products were announced and shipped by Buffalo Technology in November 2009, while the first certified USB 3.0 consumer products were announced on 5 January 2010, at the Las Vegas Consumer Electronics Show (CES), including two motherboards by Asus and Gigabyte Technology.^{[14][15]}

Manufacturers of USB 3.0 host controllers include, but are not limited to, Renesas Electronics, Fresco Logic (<http://www.frescologic.com>), ASMedia, Etron, VIA Technologies, Texas Instruments, NEC and Nvidia. As of November 2010, Renesas and Fresco Logic^[16] have passed USB-IF certification. Motherboards for Intel's Sandy Bridge processors have been seen with Asmedia and Etron host controllers as well. On 28 October 2010, Hewlett-Packard released the HP Envy 17 3D featuring a Renesas USB 3.0 host controller several months before some of their competitors. AMD worked with Renesas to add its USB 3.0 implementation into its chipsets for its 2011 platforms. At CES2011, Toshiba unveiled a laptop called "Toshiba Qosmio X500" that included USB 3.0 and Bluetooth 3.0, and Sony released a new series of Sony VAIO laptops that would include USB 3.0. As of April 2011, the Inspiron and Dell XPS series were available with USB 3.0 ports, and, as of May 2012, the Dell Latitude laptop series were as well; yet the USB root hosts failed to work at SuperSpeed under Windows 8. On 11 June 2012, Apple announced new MacBook Airs and MacBook Pro with USB 3.0.

Adding to existing equipment

In laptop computers that lack USB 3.0 ports but have an ExpressCard slot, USB 3.0 ports can be added by using an ExpressCard-to-USB 3.0 adapter. Although the ExpressCard port itself is powered from a 3.3 V line, the connector also has a USB 2.0 port available to it (some express cards actually use the USB 2.0 interface rather than the true express card port). However, this USB 2.0 port is only capable of supplying the power for one USB 3.0 port. Where multiple ports are provided on the express card, additional power will need to be provided.

Additional power for multiple ports on a laptop PC may be derived in the following ways:

- Some ExpressCard-to-USB 3.0 adapters may connect by a cable to an additional USB 2.0 port on the computer, which supplies additional power.
- The ExpressCard may have a socket for an external power supply.
- If the external device has an appropriate connector, it can be powered by an external power supply.
- USB 3.0 port provided by an ExpressCard-to-USB 3.0 adapter may be connected to a separately-powered USB 3.0 hub, with external devices connected to that USB 3.0 hub.

On the motherboards of desktop PCs which have PCI Express (PCIe) slots (or the older PCI standard), USB 3.0 support can be added as a PCI Express expansion card. In addition to an empty PCIe slot on the motherboard, many "PCI Express to USB 3.0" expansion cards must be connected to a power supply such as a Molex adapter or external power supply, in order to power many USB 3.0 devices such as mobile phones, or external hard drives that have no power source other than USB; as of 2011, this is often used to supply two to four USB 3.0 ports with the full 0.9 A (4.5 W) of power that each USB 3.0 port is capable of (while also transmitting data), whereas the PCI Express slot itself cannot supply the required amount of power.

If faster connections to storage devices are the reason to consider USB 3.0, an alternative is to use eSATAp, possibly by adding an inexpensive expansion slot bracket that provides an eSATAp port; some external hard disk drives provide both USB (2.0 or 3.0) and eSATAp interfaces.^[15] To ensure compatibility between motherboards and peripherals, all USB-certified devices must be approved by the USB Implementers Forum (USB-IF). At least one complete end-to-end test system for USB 3.0 designers is available on the market.^[17]

Adoption



Front view of a Standard-A USB 3.0 connector, showing its front row of four pins for the USB 1.x/2.0 backward compatibility, and a second row of five pins for the new USB 3.0 connectivity. The plastic insert is in the USB 3.0 standard blue color known as Pantone 300C.



Internal circuitboard and connectors of a USB 3.0 four-port hub, using a VIA Technologies chipset



A USB 3.0 controller in form of a PCI Express expansion card



Side connectors on a laptop computer. Left to right: USB 3.0 host, VGA connector, DisplayPort connector, USB 2.0 host. Note the additional pins on the top side of the USB 3.0 port.

The USB Promoter Group announced the release of USB 3.0 on November 2008. On 5 January 2010, USB-IF announced the first two certified USB 3.0 motherboards, one by Asus and one by Gigabyte.^{[15][a]} Previous announcements included Gigabyte's October 2009 list of seven P55 chipset USB 3.0 motherboards,^[20] and an Asus motherboard that was cancelled before production.^[21]

Commercial controllers were expected to enter into volume production in the first quarter of 2010.^[22] On 14 September 2009, Freecom announced a USB 3.0 external hard drive.^[23] On 4 January 2010, Seagate announced a small portable HDD bundled with an additional USB 3.0 ExpressCard, targeted for laptops (or desktops with ExpressCard slot addition) at the CES in Las Vegas Nevada.^{[24][25]}

The Linux kernel mainline contains support for USB 3.0 since version 2.6.31, which was released in September 2009.^{[26][27][28]}

FreeBSD supports USB 3.0 since version 8.2, which was released in February 2011.^[29]

Windows 8 was the first Microsoft operating system to offer built in support for USB 3.0.^[30] In Windows 7 support was not included with the initial release of the operating system.^[31] However, drivers that enable support for Windows 7 are available through websites of hardware manufacturers.

Intel released its first chipset with integrated USB 3.0 ports in 2012 with the release of the Panther Point chipset. Some industry analysts have claimed that Intel was slow to integrate USB 3.0 into the chipset, thus slowing mainstream adoption.^[32] These delays may be due to problems in the CMOS manufacturing process,^[33] a focus to advance the Nehalem platform,^[34] a wait to mature all the 3.0 connections standards (USB 3.0, PCIe 3.0, SATA 3.0) before developing a new chipset,^{[35][36]} or a tactic by Intel to favor its new Thunderbolt interface.^[37] Apple, Inc. announced laptops with USB 3.0 ports on 11 June 2012, nearly four years after USB 3.0 was finalized.

AMD began supporting USB 3.0 with its Fusion Controller Hubs in 2011. Samsung Electronics announced support of USB 3.0 with its ARM-based Exynos 5 Dual platform intended for handheld devices.

Issues

Speed and compatibility

Various early USB 3.0 implementations widely used the NEC/Renesas μD72020x family of host controllers,^[38] which are known to require a firmware update to function properly with some devices.^{[39][40][41]}

A factor affecting the speed of USB storage devices (more evident with USB 3.0 devices, but also noticeable with USB 2.0 ones) is that the USB Mass Storage Bulk-Only Transfer (BOT) protocol drivers are generally slower than the USB Attached SCSI protocol (UAS[P]) drivers.^{[42][43][44][45]}

On some old (2009–2010) Ibex Peak-based motherboards, the built-in USB 3.0 chipsets are connected by default via a 2.5 GT/s PCI Express lane of the PCH, which then did not provide full PCI Express 2.0 speed (5 GT/s), so it did not provide enough bandwidth even for a single USB 3.0 port. Early versions of such boards (e.g. the Gigabyte Technology P55A-UD4 or P55A-UD6) have a manual switch (in BIOS) that can connect the USB 3.0 chip to the processor (instead of the PCH), which did provide full-speed PCI Express 2.0 connectivity even then, but this meant using fewer PCI Express 2.0 lanes for the graphics card. However, newer boards (e.g. Gigabyte P55A-UD7 or the Asus P7P55D-E Premium) used a channel bonding technique (in the case of those boards provided by a PLX PEX8608 or PEX8613 PCI Express switch) that combines two PCI Express 2.5 GT/s lanes into a single PCI Express 5 GT/s lane (among other features), thus obtaining the necessary bandwidth from the PCH.^{[46][47][48]}

Radio frequency interference

USB 3.0 devices and cables may interfere with wireless devices operating in the 2.4 GHz ISM band. This may result in a drop in throughput or complete loss of response with Bluetooth and Wi-Fi devices.^[49] Various strategies can be applied to resolve the problem, ranging from simple solutions such as increasing the distance of USB 3.0 devices from Wi-Fi routers and Bluetooth devices, to applying additional shielding around internal computer components.^[50]

There were some devices (for example Vivo Xplay 3S) which were promised to come with USB 3.0, however, ultimately didn't ship with USB 3.0, because of manufacturers' inability to resolve the electromagnetic interference caused by USB 3.0.^[51]

Connectors

A USB 3.0 Standard-A receptacle accepts either a USB 3.0 Standard-A plug or a USB 2.0 Standard-A plug. Conversely, it is possible to plug a USB 3.0 Standard-A plug into a USB 2.0 Standard-A receptacle. This is a principle of backward compatibility. The Standard-A is used for connecting to a computer port, at the host side.

A USB 3.0 Standard-B receptacle accepts either a USB 3.0 Standard-B plug or a USB 2.0 Standard-B plug. Backward compatibility applies to connecting a USB 2.0 Standard-B plug into a USB 3.0 Standard-B receptacle. However, it is not possible to plug a USB 3.0 Standard-B plug into a USB 2.0 Standard-B receptacle, due to a physically larger connector. The Standard-B is used at the device side.

Since USB 2.0 and USB 3.0 ports may coexist on the same machine and they look similar, the USB 3.0 specification recommends that the Standard-A USB 3.0 receptacle have a blue insert (Pantone 300C color). The same color-coding applies to the USB 3.0 Standard-A plug.^{[10]:sections 3.1.1.1 and 5.3.1.3}

USB 3.0 also introduced a new Micro-B cable plug, which consists of a standard USB 1.x/2.0 Micro-B cable plug, with an additional 5-pin plug "stacked" inside it. That way, the USB 3.0 Micro-B host connector preserved its backward compatibility with the USB 1.x/2.0 Micro-B cable plugs, allowing devices with USB 3.0 Micro-B ports to run at USB 2.0 speeds on USB 2.0 Micro-B cables. However, it is not possible to plug a USB 3.0 Micro-B plug into a USB 2.0 Micro-B receptacle, due to a physically larger connector.

Pinouts

The connector has the same physical configuration as its predecessor but with five more pins.

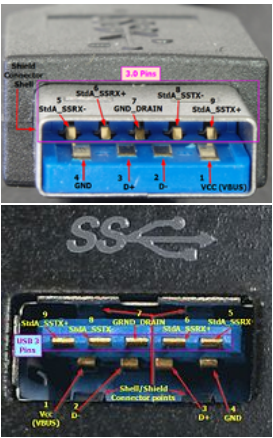
The VBUS, D[−], D⁺, and GND pins are required for USB 2.0 communication. The additional USB 3.0 pins are two differential pairs and one ground (GND_DRAIN). The two additional differential pairs are for SuperSpeed data transfer; they are used for full duplex SuperSpeed signaling. The GND_DRAIN pin is for drain wire termination and to control EMI and maintain signal integrity.



USB 3.0 Standard-A receptacle (top, in the blue color "Pantone 300C"), Standard-B plug (middle), and Micro-B plug (bottom)

USB 3.0 connector pinouts^[52]

Pin	Color	Signal name		Description
		A connector	B connector	
Shell	N/A	Shield		Metal housing
1	Red	VBUS		Power
2	White	D−		USB 2.0 differential pair
3	Green	D+		
4	Black	GND		Ground for power return
5	Blue	StdA_SSRX−	StdB_SSTX−	SuperSpeed receiver differential pair
6	Yellow	StdA_SSRX+	StdB_SSTX+	
7	N/A	GND_DRAIN		Ground for signal return
8	Purple	StdA_SSTX−	StdB_SSRX−	SuperSpeed transmitter differential pair
9	Orange	StdA_SSTX+	StdB_SSRX+	
The USB 3.0 <i>Powered-B</i> connector has two additional pins for power and ground supplied to the device. ^[53]				
10	N/A		DPWR	Power provided to device (Powered-B only)
11			DGND	Ground for DPWR return (Powered-B only)



USB 3.0 Standard-A plug (top) and receptacle (bottom), with annotated pins

Backward compatibility



USB Micro-B USB 2.0 vs USB Micro-B SuperSpeed (USB 3.0)

USB 3.0 and USB 2.0 (or earlier) Type-A plugs and receptacles are designed to interoperate.

USB 3.0 Type-B receptacles, such as those found on peripheral devices, are larger than in USB 2.0 (or earlier versions), and accept both the larger USB 3.0 Type-B plug and the smaller USB 2.0 (or earlier) Type-B plug. USB 3.0 Type B plugs are larger than USB 2.0 (or earlier) Type-B plugs; therefore, USB 3.0 Type-B plugs cannot be inserted into USB 2.0 (or earlier) Type-B receptacles.

Micro USB 3.0 (Micro-B) plug and receptacle are intended primarily for small portable devices such as smartphones, digital cameras and GPS devices. The Micro USB 3.0 receptacle is backward compatible with the Micro USB 2.0 plug.

A receptacle for eSATAp, which is an eSATA/USB combo, is designed to accept USB Type-A plugs from USB 2.0 (or earlier), so it also accepts USB 3.0 Type-A plugs.

USB 3.1

In January 2013 the USB group announced plans to update USB 3.0 to 10 Gbit/s (1.25 GB/s).^[54] The group ended up creating a new USB specification, USB 3.1, which was released on 31 July 2013,^[55] replacing the USB 3.0 standard. The USB 3.1 specification takes over the existing USB 3.0's *SuperSpeed USB* transfer rate, also referred to as *USB 3.1 Gen 1*, and introduces a faster transfer rate called *SuperSpeed USB 10 Gbps*, referred to as *USB 3.1 Gen 2*,^[56] putting it on par with a single first-generation Thunderbolt channel. The new mode's logo features a caption stylized as *SUPER SPEED+*.^[57] The USB 3.1 Gen 2 standard increases the maximum data signaling rate to 10 Gbit/s (1.25 GB/s), double that of SuperSpeed USB, and reduces line encoding overhead to just 3% by changing the encoding scheme to 128b/132b.^[58] The first USB 3.1 Gen 2 implementation demonstrated real-world transfer speeds of 7.2 Gbit/s.^[59]

The USB 3.1 standard is backward compatible with USB 3.0 and USB 2.0. It defines the following transfer modes:

- **USB 3.1 Gen 1** – SuperSpeed, 5 Gbit/s (0.500 GB/s) data signaling rate over 1 lane using 8b/10b encoding; the same as USB 3.0.
- **USB 3.1 Gen 2** – SuperSpeed+, new 10 Gbit/s (1.212 GB/s) data rate over 1 lane using 128b/132b encoding.

The nominal data rate in bytes accounts for bit-encoding overhead. The physical SuperSpeed bit rate is 5 Gbit/s. Since transmission of every byte takes 10 bit times, the raw data overhead is 20%, so the byte rate is 500 MB/s, not 625. Similarly, at SS+ rate the encoding is 128/132, so transmission of 16 bytes physically takes 16.5 bytes, or 3% overhead. Therefore the byte-rate at SS+ is 1.25 * 0.97 GB/s=1.212 GB/s. In reality the SS bus has some additional service overhead (link management, protocol response, host latencies), so the best-case achievable data rates are about 10% smaller.

This rebranding of USB 3.0 as "USB 3.1 Gen 1" allows manufacturers to advertise products with transfer rates of only 5 Gbit/s as "USB 3.1," omitting the generation.^[60]

USB 3.2

On 25 July 2017, a press release from the USB 3.0 Promoter Group detailed a pending update to the USB Type-C specification, defining the doubling of bandwidth for existing USB-C cables. Under the USB 3.2 specification, released 22 September 2017,^[61] existing SuperSpeed certified USB-C 3.1 Gen 1 cables will be able to operate at 10 Gbit/s (up from 5 Gbit/s), and SuperSpeed+ certified USB-C 3.1 Gen 2 cables will be able to operate at 20 Gbit/s (up from 10 Gbit/s). The increase in bandwidth is a result of multi-lane operation over existing wires that were intended for flip-flop capabilities of the USB-C connector.^{[62][63]}

The USB 3.2 standard is backward compatible with USB 3.1/3.0 and USB 2.0. It defines the following transfer modes:




- **USB 3.2 Gen 1x1** – SuperSpeed, 5 Gbit/s (0.500 GB/s) data signaling rate over 1 lane using 8b/10b encoding, the same as USB 3.1 Gen 1 and USB 3.0.
- **USB 3.2 Gen 1x2** – SuperSpeed+, new 10 Gbit/s (1.00 GB/s) data rate over 2 lanes using 8b/10b encoding.
- **USB 3.2 Gen 2x1** – SuperSpeed+,^[57] 10 Gbit/s (~1.2 GB/s) data rate over 1 lane using 128b/132b encoding, the same as USB 3.1 Gen 2.
- **USB 3.2 Gen 2x2** – SuperSpeed+, new 20 Gbit/s (~2.4 GB/s) data rate over 2 lanes using 128b/132b encoding.

As with the previous version, the same considerations around encoding and effective data rates apply. Although both Gen 1x2 and 2x1 signal at 10 Gbit/s, Gen 1x2's use of the older, less efficient coding gives it less byte-rate.

In May 2018, Synopsys demonstrated the first USB 3.2 Gen 2x2 connection, where a Windows PC was connected to a storage device, reaching an average speed of 1.6 GB/s.^{[64][65]}

USB 3.2 is supported with the default Windows 10 USB drivers and in Linux Kernel 4.18.^{[64][65][66]}

USB 3.2 transfer modes

USB-IF recommended marketing name ^[67]	Logo ^[57]	USB 3.2 transfer mode	Older specifications		Dual-lane	Encoding	Nominal speed		Connectors	
			USB 3.1	USB 3.0			Gbit/s	GB/s	USB-A, B, micro B (SuperSpeed) ^[68]	USB-C
SuperSpeed USB		USB 3.2 Gen 1x1	USB 3.1 Gen 1	USB 3.0	No	8b/10b	5	0.500	Yes	Yes
SuperSpeed USB 10 Gbit/s		USB 3.2 Gen 1x2	N/A	N/A	Yes	8b/10b	10	1.0	No	Yes
SuperSpeed USB 10 Gbit/s		USB 3.2 Gen 2x1	USB 3.1 Gen 2	N/A	No	128b/132b	10	1.2	Yes	Yes
SuperSpeed USB 20 Gbit/s		USB 3.2 Gen 2x2	N/A	N/A	Yes	128b/132b	20	2.4	No	Yes

See also

- Computer bus
- Extensible Host Controller Interface (XHCI)
- List of computer peripheral bus bit rates
- Mobile High-Definition Link

Notes

a. Both Gigabyte and Asus^[18] claimed the "first" USB 3.0 motherboard, while the official announcement credits both companies.^[19]

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