SuperSpeed USB/USB 3.0

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USB 3.0: What it Means to You

An overview of characteristics

This white paper outlines the important characteristics of a new take on an existing technology, a revision of an interface that is certain to affect you in the future—USB 3.0.

While you might also hear USB 3.0 referred to as "SuperSpeed USB", in fact these terms are not quite interchangeable: USB 3.0 is actually a specification that encompasses both the USB 2.0 you are used to and the new, fast "SuperSpeed" side of USB 3.0.

This interface will not require you to change your thinking—it is evolutionary rather than revolutionary—but the advances it offers take it beyond USB 2.0, and will significantly add to the speed of storage technology and to the convenience of mobile computing, among other things.

The authors of the USB 3.0 Specification, Hewlett-Packard Company, Intel Corporation, Microsoft Corporation, NEC Corporation, ST-NXP Wireless, and Texas Instruments, and others have taken great care to make the USB 3.0 Specification a painless transition from USB 2.0. This white paper draws extensively on that specification.

Coming to a computer near you: USB 3.0

USB, an interface we are all familiar with, is changing (or changing again, if you remember USB 1.1). USB 2.0, which by now is as familiar as the electrical outlets on the wall, is getting a makeover that will bring it up to date with users' demands for increased bandwidth and peripheral support.

Turning the clock back, you might remember that the change from USB 1.1 to USB 2.0 entailed, most importantly, a forty-fold increase in speed from 12 Mbps to 480 Mbps. This speed increase put USB 2.0 in the ballpark with the FireWire of the time (400 Mbps IEEE 1394a), and made USB a practical interface for memory sticks, cameras, external USB drive enclosures, and so forth.

Nothing stands still for long however; FireWire 400 evolved to the faster FireWire 800 (IEEE 1394b), hard disk drive interfaces added the eSATA (external Serial ATA) interface, cameras started taking pictures with much larger megapixel counts, digital video overtook analog video, and everybody wanted to back up and transfer heaps of music and movies in digital form. USB 2.0 started to look old.

Enter USB 3.0. This specification adds a number of new features, most importantly:

- a new architecture with strong backward compatibility
- a much higher bandwidth with matching hardware
- greater speed from more efficient data and protocol signalling
- more sophisticated power management
- higher power output on the USB port

USB 3.0 Benefits

Backward Compatibility

- older USB devices plug into USB 3.0 ports
- newer USB devices plug into older USB ports
- software interfaces look the same

Ease of Use

- works just as previous versions of USB
- Plug and Play operation

Higher Speed

- SuperSpeed USB devices are about 10 times faster than USB 2.0 devices

Increased Efficiency

- more efficient protocols and device handling
- more efficient data handling

Sophisticated Power Management

- ability to quickly enter sleep & suspend modes to reduce power demands

Augmented Power Output

- up to six times more power output to SuperSpeed peripherals

USB 3.0 Architecture

USB 3.0, while an evolution from USB 2.0 in the sense that the user will see things as much the same, is at the same time revolutionary in its internal approach.

When USB started, it was in fact a two-speed interface: the "Low-Speed" USB, operating at 1.5 Mbps, and "Full-Speed" USB, operating at 12 Mbps. Low-Speed USB is the one everyone still uses all the time, and doesn't even notice (the best thing you can say about an interface). But look at your mouse: that skinny little cable that doesn't detach from the mouse (non-detaching cables are a characteristic of Low Speed USB) is what we are talking about. Full-Speed USB, arriving at the same time and with essentially the same wiring, was what put USB on the map. Later came USB 2.0, again running on the same wiring, but much faster; it is the standard today.

USB 3.0 breaks this pattern, because its new features are not actually implemented on the same bus as the older USB designs. Instead, USB 3.0 is really two buses in one, with two sets of wires and protocols. The USB 3.0 architecture diagram on the next page shows what I am talking about: the new stuff, SuperSpeed USB, is shown in red, and the old stuff, USB 2.0, is shown in blue. They co-exist in parallel.

Note however that the overall structure —host, hub, and peripheral—is the same for SuperSpeed USB and USB 2.0. Also note that although there are two buses coexisting in USB 3.0, they are passing through one set of "extended connectors" and "composite cables". And a final note: a USB peripheral cannot operate in both SuperSpeed and non-SuperSpeed modes simultaneously; this limitation is not explicit in the diagram but exists in fact.

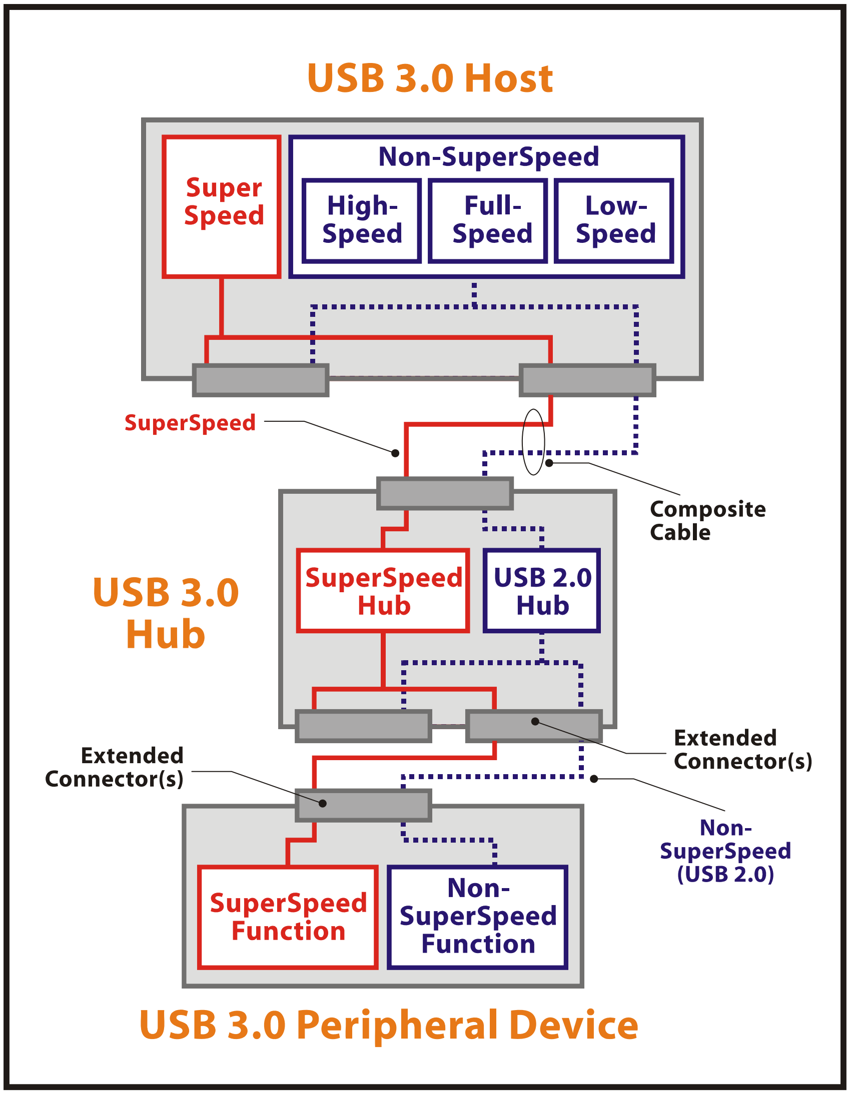
The upshot is that this design makes it possible for a great degree of forwards and backwards compatibility in USB 3.0. You won't have to get rid of old peripherals just because you have new USB 3.0 ports. Next we'll look more closely at the cables and connectors involved in delivering SuperSpeed USB to see just what is meant by the terms "extended connector" and "composite cable."

USB 3.0's higher bandwidth: SuperSpeed USB

USB 3.0's main claim to fame is more speed, and this speed has implications for cabling and connectors. These changes are the most evident physical manifestations of USB 3.0, and understanding why these changes are necessary goes a long way to understanding USB 3.0 as a whole.

The step up from USB 2.0 to USB 3.0 adds a ten-fold increase in raw speed, making USB 3.0 a 4.8 Gbps data bus. This is called "SuperSpeed" USB. But before you get too excited, remember that once protocol overhead is subtracted, a more realistic estimate of SuperSpeed USB is 3.2 Gbps. This is still a whole lot faster than the 480 Mbps of USB 2.0, which in any case did not add up to a full 480 Mbps once its protocol overhead was accounted for.

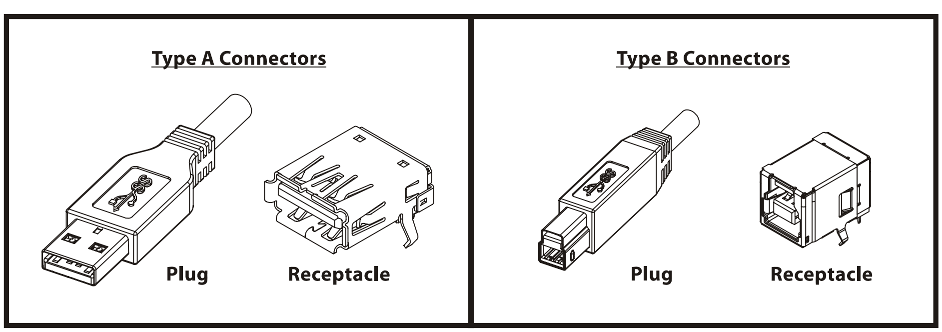
USB 3.0 is not strictly the same as SuperSpeed USB, in the same way that USB 2.0 is not strictly the same as High-Speed USB. That is, each of these versions of USB subsumes earlier versions of USB, and retains forward and backward compatibility.



Simply put, this means that a USB 3.0 port will act as a USB 2.0 port when a USB 2.0 peripheral is attached to it, or as a USB 1.1 port when you dust off the old hardware and decide to attach those antiques. All those earlier peripherals will work just the same when attached to a USB 3.0 port as they would when attached to a USB 2.0 port.

Fine. But how does USB 3.0 fit in its SuperSpeed mode? The answer is a clever design of connectors that will accept cabling from either a USB 2.0 device or a USB 3.0 SuperSpeed device.

The SuperSpeed USB interface differs from earlier USB in that it uses a separate and new set of wires to carry data within its cabling. Earlier USB used four wires to carry power and data, with the transmit data defined as a voltage difference between the ground line and the transmit line, and with the receive data defined as the voltage difference between the same ground line and the receive line. Power was the fourth line. Those familiar with RS-232 serial will recognize this TX/RX design.

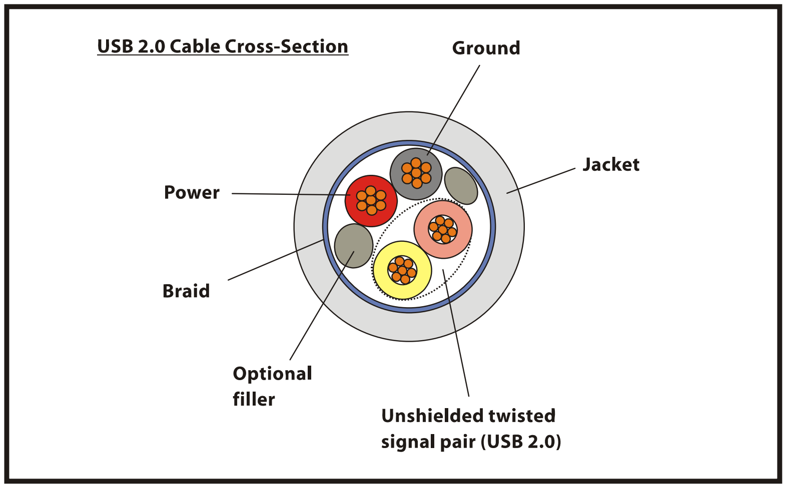


Cut a USB 2.0 cable in two and its cross-section looks like the drawing on the next page.

SuperSpeed USB handles its data lines differently: a transmit signal is now defined as a voltage difference between two transmit lines, and, similarly, a receive signal is defined as a voltage difference between two receive lines. Again, those familiar with RS-422 or RS-485 serial will feel at home.

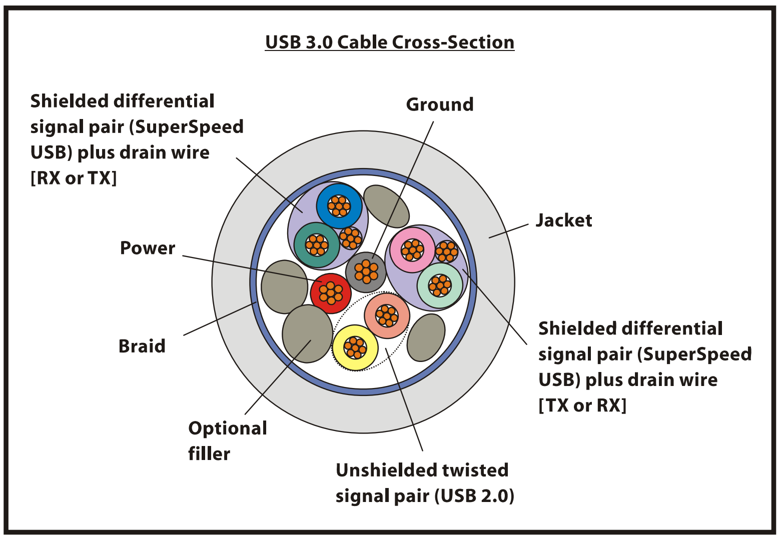
But because USB 3.0 remains backwards compatible, its earlier wires are retained for the older modes; new wires are added to carry the SuperSpeed USB transmit and receive signals. Also, throw in new ground wires for each SuperSpeed transmit and receive pair for drain wire termination, maintaining signal integrity, and improved EMI performance, and you now have a ten-wire USB 3.0 cable instead of a four-wire USB 2.0 cable. The drain wires merge so you end up with a nine-contact connector.

Cut a USB 3.0 cable in two and its cross-section looks like the diagram below.

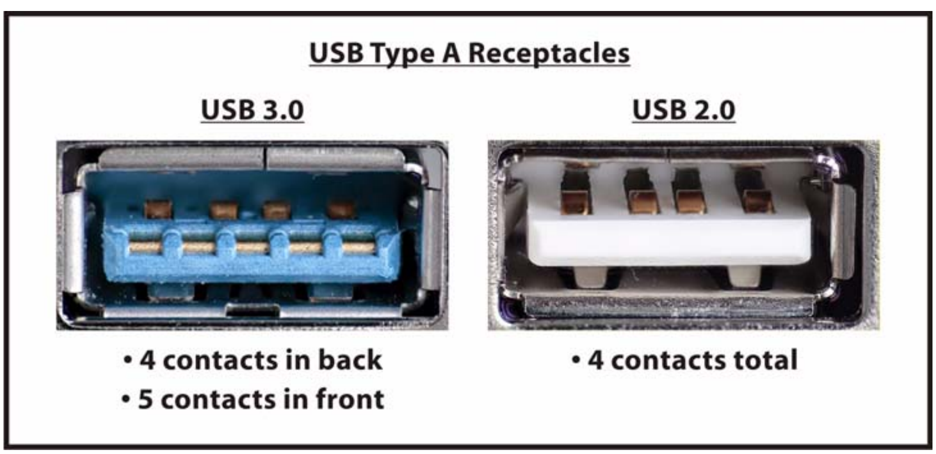


The bottom line is that, unlike the step up from USB 1.1 to USB 2.0, where the same cables could serve all needs, USB 3.0 requires new cables between peripheral and port if you intend to use a SuperSpeed peripheral. These new cables have a more rigorous shielding requirement also.

To cope with this new cabling, the connectors (shown on the previous page) have changed. The USB 3.0 Type A connectors (running upstream to the computer) are the same physical shape as the USB 2.0 Type A connectors, but with more electrical contacts. The contacts of the older USB 2.0 specification are all still there, in the same positions as always, don't worry, but the five new contacts to mate with the five new wires are there too. The old USB 2.0 contacts are towards the back of the receptacle, and the new SuperSpeed USB contacts are closer to the front. Correspondingly, the old contacts are towards the front of the plug, and the new contacts are further to the back. Unless you are manufacturing cables and connectors to meet this new specification, and need to keep things straight, it's best to believe that it all works, and that the wires don't get crossed when plugging and unplugging cables.



By contrast, the USB 3.0 Type B connectors (running downstream to the peripheral) are different between USB 2.0 and USB 3.0 in both physical shape and number of contacts. If you think about it, this makes sense. You don't want to plug a USB 3.0 cable into a USB 2.0 peripheral, both because you can't make a USB 2.0 device faster that way, and because you don't want to introduce the potentially higher USB 3.0 power levels to a USB 2.0 peripheral that wouldn't be prepared to handle them.



This covers the higher-bandwidth capability of USB 3.0, and its implications for cables and connectors (did I mention the nice blue color used for the plugs and receptacles?); in addition, the USB 3.0 specification defines a set of micro connectors, that we won't cover here.

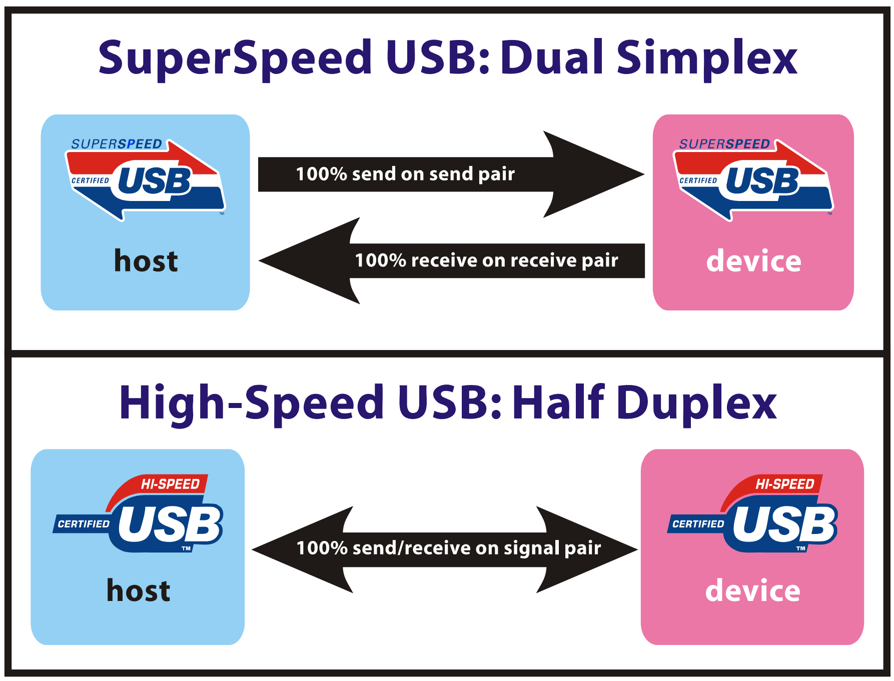
Speed: What makes SuperSpeed USB so fast?

Since the big deal about USB 3.0 is mainly that it is so much faster, it's worth asking what contributes to this speed. The answer boils down to a number of differences between SuperSpeed USB (the "fast" data path in USB 3.0) and USB 2.0. While SuperSpeed USB has a number of similarities to USB 2.0, including compatible connectors and the same host <==> hub <==> device architecture, the speed that SuperSpeed USB offers comes, not surprisingly, from its differences from USB 2.0.

The short answer is that the speed of the SuperSpeed portion of USB 3.0 comes from it being more electrically sophisticated than USB 2.0, and with improved channel performance.

Fundamental to that sophistication is the differential signalling that SuperSpeed USB uses. In SuperSpeed USB a transmit (or receive) signal is defined as the voltage difference between a pair of transmit lines (or a pair of receive lines), while in USB 2.0 a signal is defined as the voltage difference between a transmit (or receive) line and a ground line. For SuperSpeed USB, this leads to a number of benefits (at the expense of an increased cost for cabling). They are:

- the signalling is less affected by electrical noise. In SuperSpeed USB, because pairs of signal lines are approximately equally affected by electrical noise, the difference between them is less pronounced than when a single signal/ground pair is used. By contrast, in USB 2.0 the transmit and receive lines will be affected by electrical noise in ways the ground line is not, resulting in weakened signal robustness.
- because the transmit and receive line pairs are relatively unaffected by induced voltages on the lines, a smaller voltage difference can be used to indicate a valid signal. When the voltage difference is smaller, the signalling rate can be higher—leading in the case of SuperSpeed USB to a raw bandwidth of 5 Gbps.
- the differential signalling used for SuperSpeed USB means that there are discrete physical links for transmit and receive, enabling a port to simultaneously transmit and receive control and data information. This difference from USB 2.0, a difference between what is called "dual simplex" transmission in the case of SuperSpeed USB and "half duplex" transmission in the case of USB 2.0, permits additional bandwidth across the link. SuperSpeed USB therefore has simultaneous bi-directional data flows (although the data flow is unidirectional on a given signal pair); USB 2.0 has unidirectional data flow on its one signal pair, with negotiated directional bus transitions.



The bus transaction protocol in SuperSpeed USB is more advanced too. The SuperSpeed USB protocol is host directed, with an asynchronous traffic flow. The USB 2.0 protocol is also host directed, but with a polled traffic flow and its associated overhead. In addition, SuperSpeed USB packet traffic is explicitly routed, whereas in USB 2.0 packet traffic is broadcast to all devices. These differences lead to SuperSpeed USB having a more efficient communication protocol, as well as having the potential for lower power consumption (a benefit we will discuss later).

A final difference between SuperSpeed USB and USB 2.0 is that in SuperSpeed USB, hardware detects "connect" events and then brings the port involved into an operational state; in USB 2.0 hardware also detects "connect" events but then system software is employed to bring the port into an operational state. Again, SuperSpeed USB is faster because of this difference.

All in all, the speed of USB 3.0 is a big part of what will lead to its adoption, facilitated by its high degree of familiarity and backward compatibility. Unlike the move from USB 1.1 to USB 2.0 however, this transition has necessitated hardware differences to cables and connectors to make it happen.

Power management in USB 3.0

While the higher-profile additional speed of SuperSpeed USB will be the thing that catches people's attention, the power saving aspect of USB will, I think, make just as much difference to people in practice, particularly if they are using portable devices.

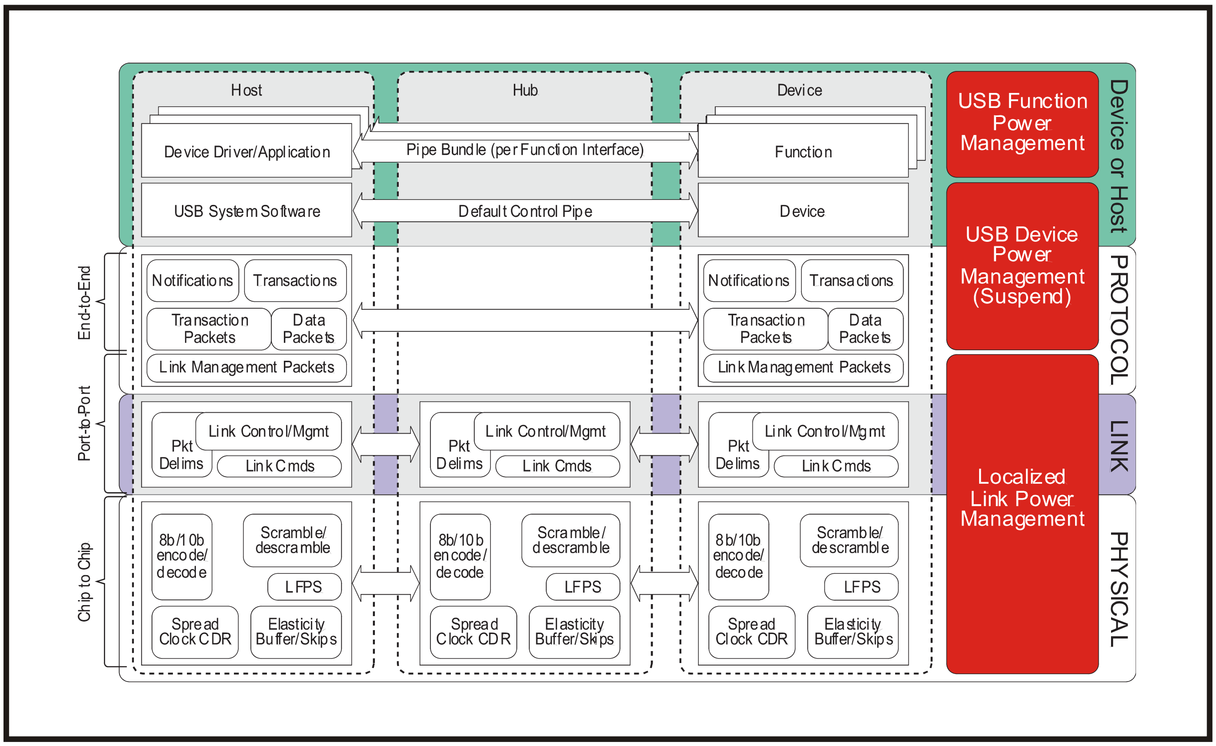
SuperSpeed USB has made great strides in power handling on two levels: it has far more sophisticated power management than USB 2.0, and it also delivers more power on the port to supply power to peripherals.

This section will discuss the important power management aspects of USB 3.0; the next section will look at power distribution.

On the power management front, much of USB 3.0's power efficiency comes from its ability to quickly and selectively drop to a low power consumption mode. A SuperSpeed link is considered idle when a port is connected but no signalling is occurring. In this state, low frequency periodic signaling (LFPS) monitors the port and will signal initialization and pass power management information. In this mode the port uses very little power.

USB 2.0 can also enter idle mode, and is able to suspend power at the port level with two tiers of entry/exit latency. In essence, if nothing is happening USB 2.0 can shut down power to a port. USB 2.0 also has a basic degree of device-level power management.

By contrast, SuperSpeed USB has the ability to suspend power with multiple levels, and supports idle, sleep, and suspend states. SuperSpeed USB also has the ability to manage power at the link, device, and function levels, not just at the device level, as shown in the diagram below.



For those who are familiar with the OSI layer model for networking, this might be old hat, but the important point, illustrated by the red blocks of the diagram, is that power management is implemented across all layers of SuperSpeed USB's operation (Device, Protocol, Link, and Physical layers). This also makes it possible for requests for low power operation to come from either end of a link—host or device—instead of just from the host as in USB 2.0.

Because power management is implemented across all layers of the communication model, SuperSpeed USB can do things such as ensure that synchronization packets are not sent to ports in a low power state. Similarly, because SuperSpeed data packets are targeted to their destinations rather than broadcast (as was discussed earlier), SuperSpeed USB is able to selectively and quickly power down unused portions of the SuperSpeed network. Lower power consumption and more efficient (and consequently faster) communications go hand in hand.

While there is a lot to say on the specifics of SuperSpeed power management, it might just be enough to say that this power management design is fairly intelligent. For example, a SuperSpeed hub with all its downstream ports in a low power state will automatically also put its upstream port into a low power state.

SuperSpeed devices are also capable of indicating their latency requirements to the system, making it possible for the system to determine when or how often to put a device into low power mode. There is after all no point in putting to sleep a slow-waking device unless it is likely to sleep for a while.

All of these refinements make USB 3.0 a big step forward in interface technology.

Power distribution in USB 3.0

The new USB 3.0 interface, or to be specific the SuperSpeed USB portion of it, can deliver more current to peripherals than the earlier USB 2.0 interface. This will matter to many users as peripherals develop to take advantage of this capability. I can see POS devices, external storage drives, and printers as the first adopters of this potential, as they eliminate external power supplies and unnecessary wires. Other applications will surely follow.

On the power distribution front, USB 3.0 has "increased supply budgets for devices operating at SuperSpeed". This means that some USB peripherals that in the past would have needed a separate power supply might not need one in the future. A good example is the power requirement for a USB 3.0 drive enclosure with a 2.5" hard drive (a laptop-sized drive). In this case either a "wall wart" or another clumsy solution is currently sometimes used: the peripheral draws power from two USB 2.0 ports, but data only from one. You see this sort of cable, a big waste of USB ports, on the right.

A clever solution to a problem that will go away.

As the USB 3.0 specification notes, USB power is a limited resource. We already knew that from USB 2.0: many devices need to be self-powered rather than bus powered. The good news is that SuperSpeed USB devices can now receive more power than was provided by USB 2.0, as long as they are operating as SuperSpeed USB devices. If they are operating as USB 2.0 devices, then only USB 2.0 levels of power are available on the bus.

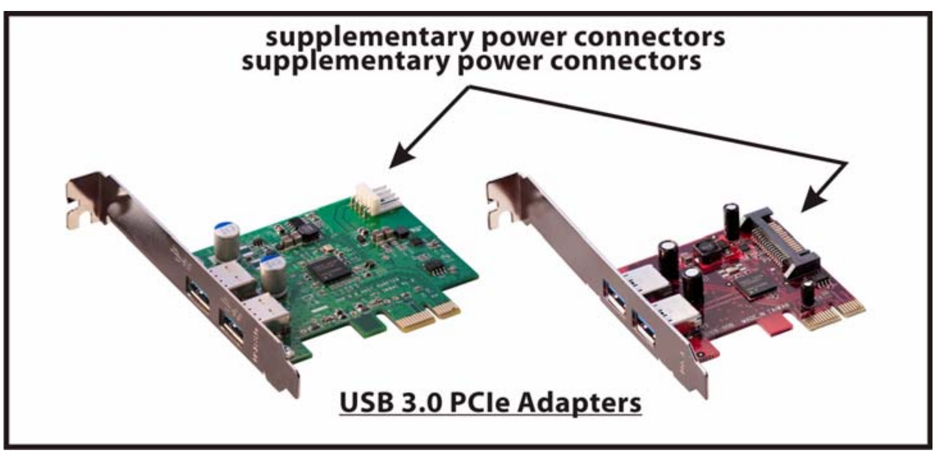
A SuperSpeed USB device must draw no more than USB 2.0 levels of power until it is configured as a USB 3.0 device and it has provided its power budget requirements to the system. At that point the system will adjust to meet to device's needs, if possible, or leave it to power itself.

How much more power is available to SuperSpeed USB devices? Six times more than USB 2.0. The maximum allowable current draw on a USB 2.0 port is 150 mA at 5.0 volts; SuperSpeed USB devices are allowed up to 900 mA at 5.0 volts, assuming of course that they are in a fully USB 3.0 stream from host through any hubs in the path.

Power delivery is efficient and intelligent. For example, if there is no data going to a hub's port there will be no power going to that port, unless the hub supports the USB Implementer Forum's Battery Charging Specification. In other words, you will still be able to plug your cell phone into USB to charge, with no data interface needed. The new power potential available in USB 3.0 won't power a hair drier but it's ok for your mini USB fan.

PCIe add-in host adapter cards need to compensate for this additional potential power draw, particularly since the power that the PCIe bus will deliver to a card is less than that expected by the USB 3.0 specification. These cards meet this need by adding a connector to supply the added power needed. The images below show a couple of PCIe-to-USB 3.0 host adapters, one with a four-pin power jack, one with a SATA connector to supplement the power coming from the bus.

USB 3.0's power handling will make a significant difference to real life. For one thing, it is much more efficient: laptops with USB 3.0 ports and peripherals will last longer on a given battery and charge, for an equivalent or greater ability to process data. In addition, SuperSpeed USB data transactions will finish more quickly than those of USB 2.0, allowing devices, ports, hubs, and so on to return to low-power operation more quickly. Finally, in the case where a peripheral is drawing power at the newer, higher levels you will at times not need a supplemental power brick (although the additional power draw will drain batteries faster than USB 2.0 in this case, of course). All in all, the advances in power management and distribution of USB 3.0 will lead to major improvement in the usefulness of USB 3.0.



Summary

As you can see, USB 3.0 and particularly its SuperSpeed portion, move USB forward significantly, addressing increasing demands for faster data speed, lower power consumption, and greater power output. SuperSpeed USB will initially matter most where speed is paramount, such as with digital video recorders and external storage devices, but its lower power consumption will soon provide benefits to users of devices such as laptop computers. Finally, as makers of USB peripherals adapt, some will revamp the power demands of their devices to make it viable to power those devices directly through the USB bus, and so eliminate the need for external power supplies.

About LAVA

LAVA designs and manufactures hardware that provides system integrators and end users with simple serial-to-PC, serial-to-Ethernet, and USB-to-serial connectivity. The LAVA product line includes multi-port serial and parallel boards, Ethernet-to-serial device servers, links for legacy payment terminals, and headquarters-to-store links for cash register polling.

We serve customers around the globe in a wide array of industries, including Point of Sale, Telecommunications, Light Industrial Automation, Payment Processing, Building Automation, Gaming, and Restaurant & Hospitality. Our connectivity hardware suits any design needing more COM ports or remote monitoring and control of serial equipment over IP (Internet Protocol).

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