

UNIVERSAL SERIAL BUS BACKGROUND

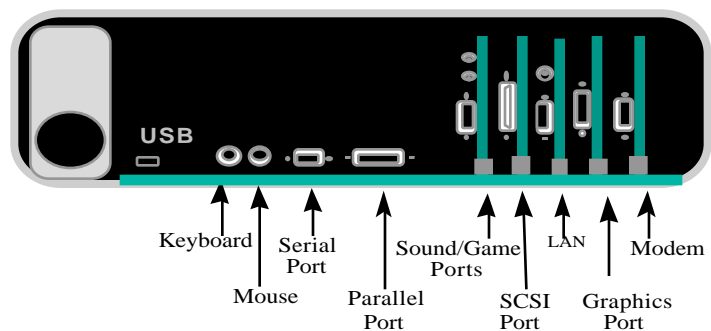
The concept of “plug and play” enables new cards to be easily added inside a computer but adding peripherals outside the actual case involves a mess of different cables, connectors and drivers. See diagram 1. The new Universal Serial Bus (USB) standard has been designed to solve this problem by providing a medium speed bus with a bandwidth of 12Mb per second so that mice, keyboards, monitors, loudspeakers, scanners, joysticks, set-top boxes, telephones, printers, etc. can all be simply connected to the PC using a standardised cabling system.

The core companies responsible for this concept are Intel, Microsoft, Digital, Compaq, Northern Telecom, NEC and IBM who have been joined by over 300 companies to form the USB Implementers Forum.

Diagram 1 PC connectivity vision

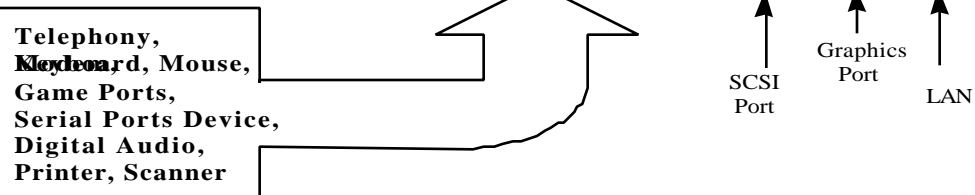
USB in 1996:

Initially introduced as an incremental connector for new applications.



USB Future:

The PC evolves into a simpler, easier to use appliance.



What are the limits to USB?

The only limit to USB is that it cannot handle the bandwidth required for uncompressed live video as no USB device can have more than 6Mbps (Megabits per second) total bandwidth for itself. Compressed video streams, such as for videoconferencing cameras (using H.320) and MPEG-1, do fit well within USB as.

course, do images from still cameras. MPEG-2, however, can only be handled when a system does not have too many active devices if a high end picture quality is required, i.e. it must be allocated 6Mbps. For smaller allocations of bit rate, the quality drops. The IEEE 1394 standard was devised to handle the requirement for higher throughput for MPEG-2 and DVD, and the IEEE standard for 100, 200, and 400 Mbps was approved by the IEEE in 1995. There is another version of 1394 that is being prepared for data rates of 1000Mbit per second data rates such as for high quality SVGA video. 1394 is not designed to replace USB but to work alongside it, i.e. USB handles the slow to medium speed applications whilst 1394 is reserved for high speed applications. Philips Semiconductors will have IEEE 1394 products sampling before the end of 1996.

USB is going to happen

From mid 1996, Intel is shipping all its new motherboards with a pair of USB connections on them, soon followed by leading OEM's and a host of Taiwanese motherboard suppliers. With such a large percentage of the world market in motherboards supporting USB as well as PC chipsets (which all have USB designed into them or announced), this means that USB will become the de facto standard very quickly ~ especially as the cost for OEMs of adding these connectors is very small because it only involves putting two small connectors onto the board with the rest of the USB implementation being done in software.

The commitment by Microsoft to supporting USB in Windows is also a big thrust for USB. Mike Glass at Microsoft recently said (EET, June 24, 1996), "The saturation rate of PCs in the home is about 35%. To tap the rest of the market, we have to make the PC more attractive in the home, which includes making it a sealed box (the Simply Interactive PC or SIPC) that doesn't have to be opened to add things on or upgrade it. That means using USB and the 1394 interface to provide digital I/O."

The standard range of connections for the keyboard, serial output, parallel output, etc. will continue on the motherboard and then be phased out as the USB becomes dominant. As it is the operating system itself that recognises the devices connected over the USB, upgrades for Windows '95 and Windows NT are due to be released later in 1996, together with a host of USB peripherals from a variety of vendors.

Philips has been active with respect to USB from the very beginning and is still actively contributing to the standardisation process where Philips has responsibility for defining the generic standards for USB drivers for Audio and for Monitors, and, as a result, has established very close working links with the USB development team within Microsoft. A strong competence centre for USB has been developed at Philips' International Technology Centre Leuven (ITCL), which serves Philips directly and customers via Philips' global sales and applications support organisations.

Up to 127 devices can be connected to one PC

Hubs are used to provide branching with one upstream port and a number of downstream ports. The convention is that those ports going towards the computer are "upstream" whilst those going away are "downstream" with upstream type connectors being square to differentiate them from downstream connectors that are rectangular. All the interconnecting cables have a square upstream connector at one end and a rectangular downstream connector at the other so that it is impossible to connect things the wrong way round. Hubs can be either bus powered, in which case they can supply each of the downstream devices with up to 100mA each, or self powered, i.e. with their own power source, and can supply each downstream device with up to 500mA..

Philips Semiconductors' leading position in USB means that it will be the first company to launch a complete hub device, the PDIUSBH11, with samples available in September 1996. This can either be stand alone, in combination with a microcontroller of choice, or fitted into a monitor or keyboard. The monitor is the perfect place to build in a USB hub as the keyboard, mouse, printer, scanner, etc. can all be easily plugged into them as they are on the user's desk (unlike the PC which is usually on the floor). Having a USB-compliant monitor also enables all the controls on the monitor to be adjusted such as brightness, contrast, and colour balance, from the keyboard over the USB.

Diagram 2 The physical configuration of USB

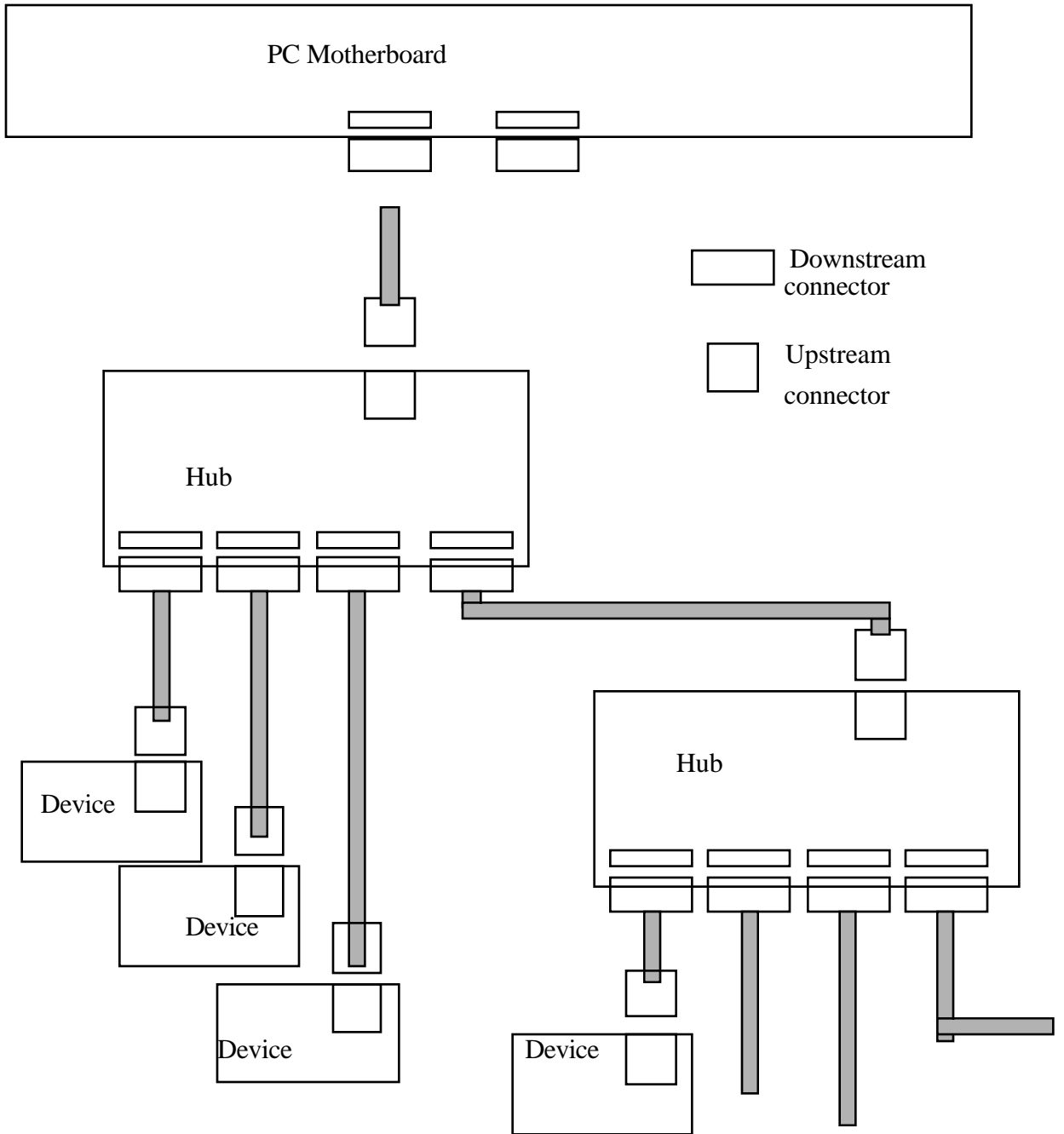
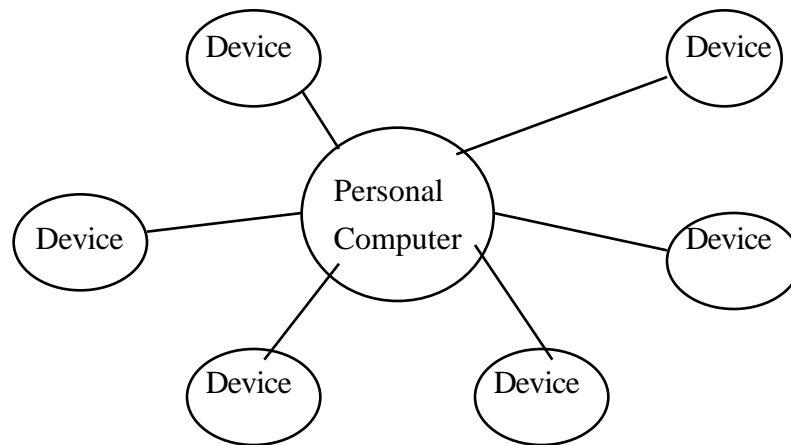


Diagram 3 The logical connection of USB



When the physical connections of devices and hubs are resolved down to the logical connection, every device has a direct route to the PC or host in what is called a tiered star topology, i.e. connections are always PC to device or device to PC and never device to device.

Types of cables

Each connector has four wires for V_{cc} , Ground, D+ and D-, providing power for low power devices and the two data connections. There are two types of cable. One is non-shielded capable of handling 1.5Mbps and designed for low demand applications such as keyboards, joysticks and mice, whilst the other is shielded twisted pair and capable of handling 12Mbps for all the other applications. These are differentiated electrically by using a static reporting mechanism whereby the high speed version has D+ high and the low speed version has D- high. The USB standard requires that the maximum cable length is five metres.

How does the PC work out all the addresses for all the devices connected over the USB? Whenever the PC is switched on, every device and hub connected to the USB assumes the address #0 and all downstream connections are disabled. The PC then interrogates the USB and finds the first device, say, a hub. It allocates the address #1 to this hub and activates the first of its downstream connectors. It then interrogates down this connection to find the next device or hub, which is still set at address #0, and allocates it address #2. The process continues with each device or hub being identified in turn and allocated a unique address number until they are all found or the limit of 127 is reached. At the same time as allocating an address number, the PC also determines what device drivers should be loaded for each device.

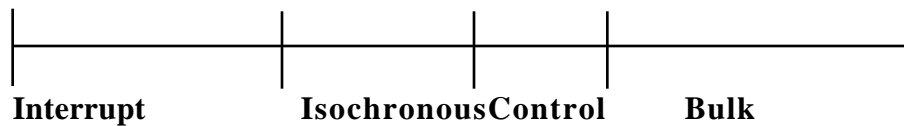
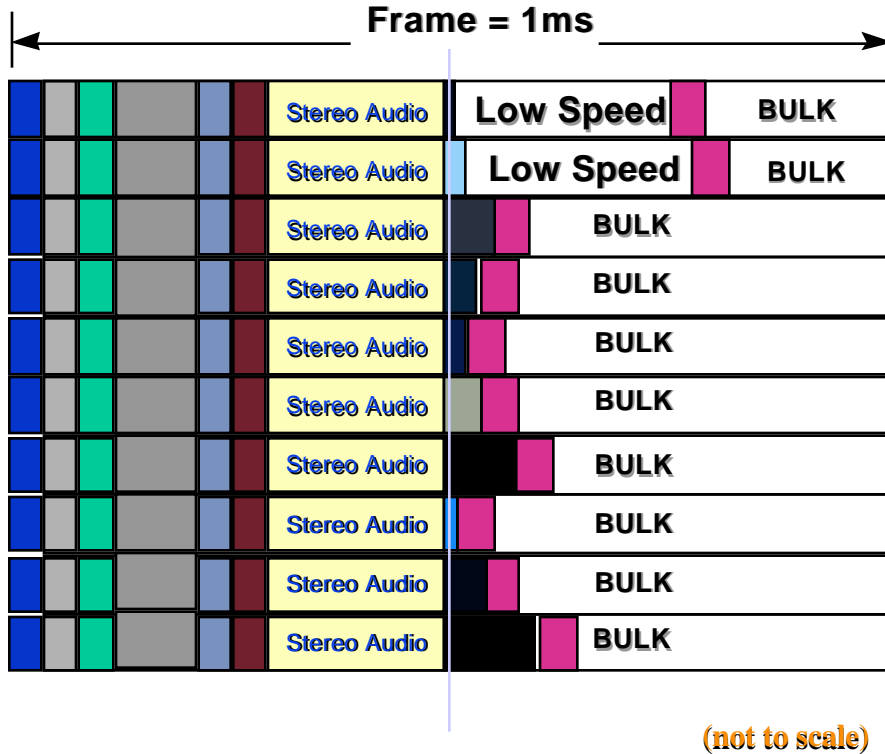
The beauty of this system is that it enables devices to be added or removed without turning off the PC or upsetting the existing configuration ~ so called “hot insertion”. A new device automatically has the address #0, as it has just been powered up, and the computer simply determines what it is, loads the appropriate drivers and allocates a previously unused address number. The removal of a device is noted by the computer as a non-responding device and its address number put back into the list of available ones for re-allocation.

Packets and transfers

Each packet contains a 7 bit address that identifies the device that it is going to. In addition, there is a 4 bit Endpoint address and an I/O bit, giving 16 in and 16 out Endpoints ~ each of which are addressable buffers within the device for, say, volume, overload warning, brightness, etc.

There are four types of transfer over the USB. The first is the Control, which is bi-directional, and is used to set up the USB structure and address allocation. The second is the Interrupt and provides a time critical, uni-directional link from the device to the host PC for mouse, keyboard or joystick. The third is Bulk and has a variable bandwidth, which is adjusted by the host PC depending on the amount of traffic on the USB, and is used for devices such as a scanner or printer where the delivery of the data is not time critical. The fourth is Isochronous and has a fixed bandwidth that is pre-negotiated with the host PC for devices that must have a certain bandwidth available at all times, such as an audio or MPEG-1 stream, and has bounded latency, i.e. there is a maximum permitted delay in the signal. The Bulk and Isochronous are again uni-directional but can be either from the computer to the device or vice versa.

Diagram 4 Frame build-up for each millisecond time frame



Control always has at least 10% of the frame so that it can perform control functions. Interrupt and Isochronous have fixed bandwidth allocation, whilst Bulk is dynamically reallocated depending on the job in hand. Each frame is 12K bits wide.

The USB protocol contains error recovery and correction techniques to ensure that all data transfers over the USB are correct with an acknowledge signal sent back if a packet is received safely. There is also guaranteed delivery, i.e. the system keeps trying to send a packet until it is received correctly or this operation is timed out and a fault is reported on screen.

The exception to this is Isochronous traffic which, by its very nature, is time determined, for example resending a packet of sound data would put it out of sync so a faulty transmission is ignored. In reality, this is such a rare occurrence that it is not a problem and for an audio stream unlikely to be noticed, especially with the necessary error detection and correction mechanisms in place

High quality digital audio sounds the end of PC sound cards

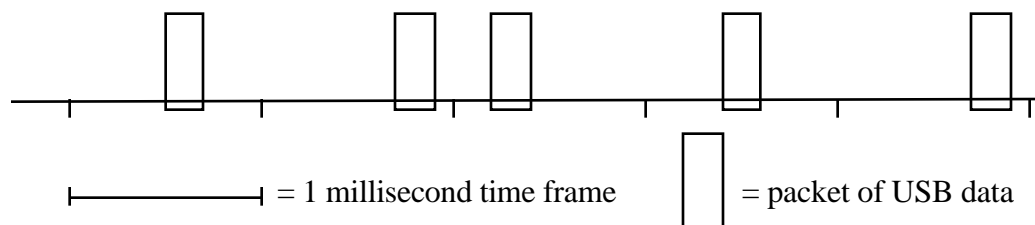
One of the design aims behind the USB concept is that it enables sound processing to be taken outside of the PC case, which is inherently an electrically noisy environment and likely to cause interference. With USB, the sound data is kept in digital format right up to the last Digital to Analog Converter (DAC) in the external amplifier. This goes directly to the loudspeaker, giving the extremely high quality hi-fi sound that will further assist the PC in its move into the home environment. Some companies, such as Philips, are already working on speakers with built-in amplifiers that will take a direct USB connection. As well as resulting in the lack of need for PC sound cards or audio design burden on the motherboard and the associated extra cost, this approach also provides for more than the two channels to which PC sound cards are constrained. Therefore multiple channel surround sound is now possible as all the required data is stored in the digital data stream. Last but not least, PC-audio system costs will be reduced because a big part of the functionality of the sound card will be emulated on the host by the USB audio driver that Microsoft will provide.

The sound information is sent over the USB through an Isochronous channel, which guarantees the bandwidth on the USB in order to deliver the necessary amount of audio samples in time to a USB audio device, e.g. a USB digital speaker. (see "Packets and transfers"). In an Isochronous channel, a packet of audio samples is sent to the receiving USB audio device every millisecond. On average, each packet contains a number of samples according to the sampling frequency of the signal that is being played. For example, a CD quality signal at 44.1 KHz (i.e. 44100 samples per second) will use packets of 44 samples during 90% of the time and 45 samples during 10% of the time to match the exact sample rate: ~

$$[44 \text{ samples/packet} \times 0.9] + [45 \text{ samples/packet} \times 0.1] = 44.1 \text{ samples per millisecond}$$

or 44100 samples per second

Diagram 5 Packet positions within each time frame can vary



The receiving USB audio device decodes the incoming USB stream, distributes the "bursty" (i.e. all information concentrated in a packet) incoming audio data stream to a continuous datastream and converts this stream to a high quality analog audio signal.

Philips is the first company that has proved high quality audio over USB. A prototype USB "Audio Demonstrator" board has been built and demonstrated at the USB Developers Conference earlier in 1996 as well as during the keynote address of Microsoft Chairman and CEO Mr. Bill Gates at WinHEC '96. Philips Semiconductors is now integrating the Audio Integrator board into a single USB DAC, the UDA1321T. This IC takes in the USB signal at the input side and produces a high quality stereo signal at its output. Further, it will be possible to control audio features such as volume, bass and treble from the PC through the same USB signal

while servicing all the other USB devices at the same time. Philips Audio also has available pairs of USB demonstration digital speakers, including drivers and support, that enable hardware and software customers to test their USB audio developments.

Simple way to prototype control software for USB devices

As USB is so new, device manufacturers need to develop the software drivers for their devices. Again, Philips Semiconductors pioneering position in USB means that the company was the first to be able to offer a PC-based USB Prototyping Tool, the PDIUSBP11, in mid 1996 for USB development partners. The key part of the PDIUSBP11 is an ISA card that fits into a PC turning it into a development platform where the software to control a new USB device can be developed and de-bugged, prior to being embedded into an ASIC. It also contains a library of software routines that cover all the USB interface requirements, leaving the developers free to concentrate on the device driver and application parts of the software.

The PDIUSBP11 is incorporating the PDIUSBP11, which is Philips Semiconductors' one chip generic USB transceiver IC that can be used to implement a USB function in any PC peripheral device. As the first USB transceiver on the market, it will help bring the USB standard closer to reality as peripheral makers do not have to re-invent the wheel and can introduce new peripherals to the market faster. Samples are already available.

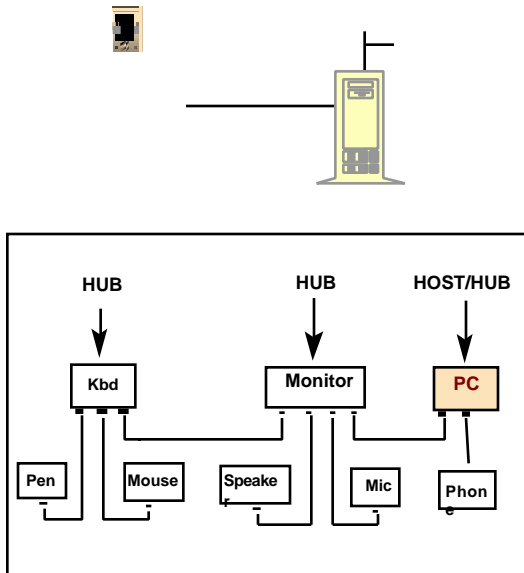
Conclusion

Philips has been pioneering the development of USB with a number of world firsts that will help manufacturers of USB-related products deliver products rapidly to market and Philips Semiconductors is now in the process of introducing USB ICs to drive this process. USB is set to take off over the second part of 1996 as major PC OEMs will ship PCs with USB connectors and as Microsoft ships the necessary upgrades to the Windows '95 and NT operating systems. Microsoft envisages the creation of the Simply Interactive PC (SIPC), which is a sealed box containing all the ICs and processor with digital I/O using USB. The SIPC would require no boot routine as users want an instant response.

This would be achieved actually having the PC always active but in a deep sleep mode for the OFF mode and going active virtually instantaneously when switched ON. The aim is to make PCs very easy to use, extending the "plug and play" concept of inside the PC to everything outside the PC case. The PC becomes the centre of an easy-to-use home entertainment system connecting together games controllers, telephones, telephone answering machines, set-top boxes, hi-fi system, etc. to form an integrated system and Philips Semiconductors is one of the leaders in providing the devices and tools to make this happen. See diagram 6.

Diagram 6 USB connection

USB Hardware Overview



Topology

- ✓ Tiered Star (Distributes Connectivity P
- ✓ 127 logical connections (up to 5 metre segment)
- ✓ Up to 6 tiers

Bus transactions

- ✓ Speed: 12Mbps aggregate
 - ✓ 1.5Mbps sub-channel
- ✓ Isochronous and
- ✓ ~~Asynchronous~~ **Mass storage** controlled by host

Configuration

- ✓ Dynamic insertion-removal
- ✓ Autoconfiguration on change

Physical Layer

- ✓ 2-wire differential signalling, NRZI code, bit stuffing
- ✓ Supply sourcing +5V
- ✓ Signalling at CMOS 3.3V
- ✓ 4 Pin connector, 4 Wire cable

Philips Semiconductors, a division of Philips Electronics NV, headquartered in Eindhoven, The Netherlands, is the eleventh largest semiconductor supplier in the world. Philips Semiconductors' innovations in digital audio, video, and mobile technology position the company as a leader in the consumer, multimedia and wireless communications markets. Sales offices are located in all major markets around the world and are supported by regional systems labs.