The USB or Universal Serial Bus

In the latest PCs, many of the peripherals such as the keyboard, mouse, scanners, printers, modem and even external CD-ROM drives and CD-writers connect to the computer itself via a USB cable — either directly or via a 'hub' expander unit. Here's a brief introduction to the *Universal Serial Bus* or USB, which was developed expressly for this job.

As personal computers became more and more powerful and began to be used to handle photographic images, audio, video and other 'bulky' data, it became evident that existing communications buses were not going to be good enough to carry the data back and forth between the computers and their growing array of peripherals — especially as users wanted the data to be moved around *faster*, rather than more slowly. So a group of leading computer and telecom firms including IBM, Intel, Microsoft, Compaq, Digital Equipment, NEC and Northern Telecom got together and developed USB.

The USB is a medium-speed serial data bus designed to carry relatively large amounts of data over relatively short cables: up to about five metres long. It can support data rates of up to 12Mb/s (megabits per second), which is fast enough for most PC peripherals such as scanners, printers, keyboards, mice, joysticks, graphics tablets, low-res digital cameras, modems, digital speakers, low speed CD-ROM and CD-writer drives, external Zip disc drives and so on.

The USB is an addressible bus system, with a seven-bit address code so it can support up to 127 different devices or 'nodes' at once (the 'all zeroes' code is not a valid address). However it can have only one 'host': the PC itself. So a PC with its peripherals connected via the USB forms a 'star' local area network (LAN).

On the other hand any device connected to the USB can have a number of other nodes connected to it in daisy-chain fashion, so it can also form the 'hub' for a mini-star subnetwork. Similarly you can have a device which purely functions as a hub for other node devices, with no separate function of its own. This expansion via hubs is because the USB supports a *tiered star* topology, as shown in Fig.1. Each USB hub acts as a kind of 'traffic cop' for its part of the network, routing data from the host to its correct address and preventing 'bus contention' clashes between devices trying to send data at the same time.

On a USB hub device, the single port used to connect to the host PC — either directly or via another hub — is known as the 'upstream' port, while the ports used for connecting other devices to the USB are known as the 'downstream' ports. This is illustrated in Fig.2.

USB hubs work 'transparently' as far as the host PC and its operating system are concerned. Most hubs provide either four or seven downstream ports, or less if they already include a USB device of their own.

Another important feature of the USB is that it's designed to allow 'hot swapping': devices can be plugged into and unplugged from the bus without having to turn the power off and on again, re-boot the PC or even manually start a driver program. A new device can simply be connected to the USB, and the PC's operating system should recognise it and automatically set up the necessary driver to service it. Windows 98 and later versions of Windows 95 do this, as do the latest Macintosh operating systems.

Power and data

USB cables consist of two twisted pairs of wires, one pair used to carry the bidirectional serial data and the other pair 5V DC power. This makes it possible for low-powered peripherals such as a mouse, joystick or modem to be powered directly from the USB — or strictly from the host PC (or the nearest hub) upstream, via the USB.

Most modern PCs have two USB ports, and each can provide up to 500mA of 5V DC power for bus-powered peripherals. Individual peripheral devices (including hubs) can draw a maximum of 100mA from their upstream USB port, so if they require less than this figure for operation they can be bus powered. If they need more, they have to use their own power supply such as a plug-pack adaptor. Hubs should be able to supply up to 500mA at 5V from

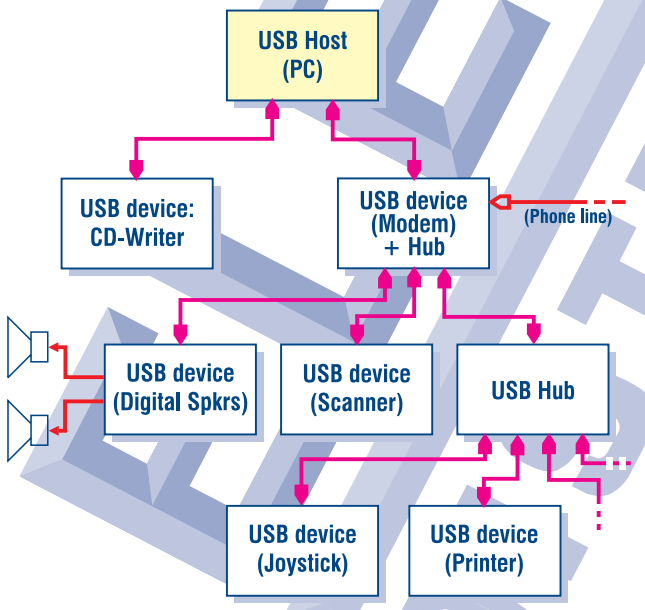


Fig.1: The USB is a medium speed serial bus used to transfer data between a PC and its peripherals. It uses a 'tiered star' configuration, with expansion via hubs (either separate, or in USB devices).

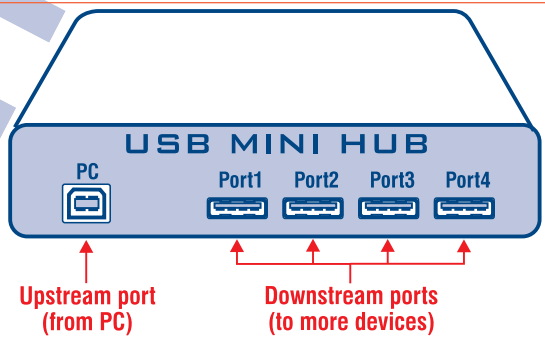
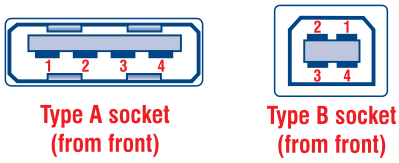


Fig.2: The port on a USB device or hub which connects to the PC host (either directly or via another hub) is known as the 'upstream' port, while hub ports which connect to additional USB devices are 'downstream' ports. Downstream ports use Type A sockets, while upstream ports use Type B sockets.



Type A socket (from front)

Type B socket (from front)

Pin connections	
Pin No.	Signal
1	+5V Power
2	– Data
3	+ Data
4	Ground

Fig.3: Pin connections for the two different types of USB socket, as viewed from the front.

each downstream port, if they're not bus powered.

Serial data is sent along the USB in differential or 'push-pull' mode, with opposite polarities on the two signal lines. This improves the signal-to-noise ratio (SNR), by doubling the effective signal amplitude and also allowing the cancellation of any common-mode noise induced into the cable. The data is sent in non-return-to-zero (NRTZ) format, with signal levels of 3.3V peak (i.e., 6.6V peak differential).

USB cables use two different types of connector: 'Type A' plugs for the upstream end, and 'Type B' plugs for the downstream end. Hence the USB ports of PCs are provided with matching Type A sockets, as are the

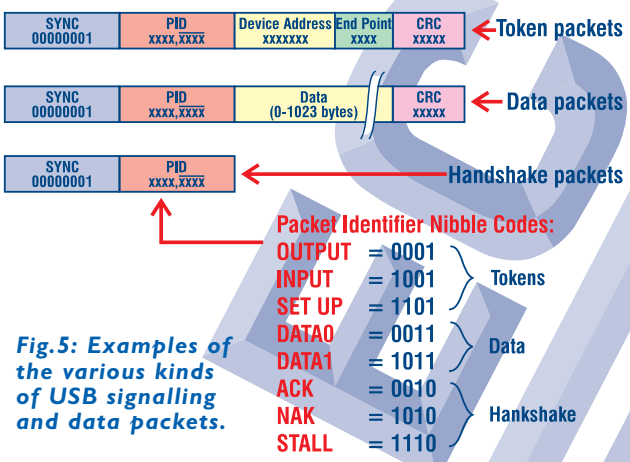


Fig.5: Examples of the various kinds of USB signalling and data packets.

downstream ports of hubs, while the upstream ports of USB devices (including hubs) have Type B sockets. Type A plugs and sockets are flat in shape and have the four connections in line, while Type B plugs and sockets are much squarer in shape and have two connections on either side of the centre spigot. (Fig.3)

Both types of connector are polarised so they cannot be inserted the wrong way around. Fig.3 shows the pin connections for both type of connector, with sockets shown and viewed from the front.

Note that although USB cables having a Type A plug at each end are available, they should never be used to connect two PCs together, via their USB ports. This is because a USB network can only have one host, and both would try to claim that role. In any case, the cable would also short their 5V power rails together, which could cause a damaging current to flow. USB is not designed for direct data transfer between PCs.

All normal USB connections should be made using

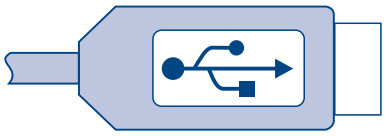


Fig.4: Most USB plugs have this distinctive marking symbol.

cables with a Type A plug at one end and a Type B plug at the other, although extension cables with a Type A plug at one end and a Type A socket at the other can also be used, providing the total extended length of a cable doesn't exceed 5m.

By the way, USB cables are usually easy to identify as the plugs have a distinctive symbol moulded into them — see Fig.4.

Data formats

USB data transfer is essentially in the form of 'packets' of data, sent back and forth between the host and peripheral devices. However because USB is designed to handle many different types of data, it can use four different data formats as appropriate.

One of the two main formats is *bulk asynchronous* mode, which is used for transferring data that isn't time critical. This is the format used to transmit data from a scanner or digital scanner for example, or to a printer. The packets can be interleaved on the USB with others being sent to or from other devices.

The other main format is *isochronous* mode, used to transfer data that is time critical — such as audio data to digital speakers, or to/from a modem. These packets must not be delayed by those from other devices.

The two other data formats are *interrupt* format, used by devices to request servicing from the PC/host, and *control* format, used by the PC/host to send *token* packets to control bus operation, and by all devices to send *handshake* packets to indicate whether the data they have just just received was OK ('ACK') or had errors ('NAK').

Some of the data formats are illustrated in Fig.5. Note that all data packets begin with a 'sync' byte (01hex), used to synchronise the PLL (phase-locked loop) in the receiving device's USB controller. This is followed by the packet identifier (PID), containing a four-bit nibble (sent in both normal and inverted form) which indicates the type of data and the direction it's going in (i.e., to or from the host). Token packets then have the 7-bit address of the destination device and a 4-bit 'end point' field to indicate which of that device's registers it's to be sent to.

On the other hand data packets have a data field of up to 1023 bytes of data following the PID field, while 'Start of Frame' (SOF) packets have an 11-bit frame identifier instead and handshake packets have no other field. Most packets end with a cyclic redundancy check (CRC) field of either five or 16 bits, for error checking, except handshake packets which rely on the redundancy in the PID field. All USB data is sent serially, of course, and least-significant-bit (LSB) first.

Luckily all of the fine details of USB handshaking and data transfer are looked after by the driver software in the PC and the firmware built into the USB controller inside each USB peripheral device and hub — so normally all you have to do is hook it all together and perhaps supply a driver for a new device, when the PC's operating system can't find it. Most USB peripherals come with their driver on a floppy disk or CD-ROM.