Personal Computer

All about PC

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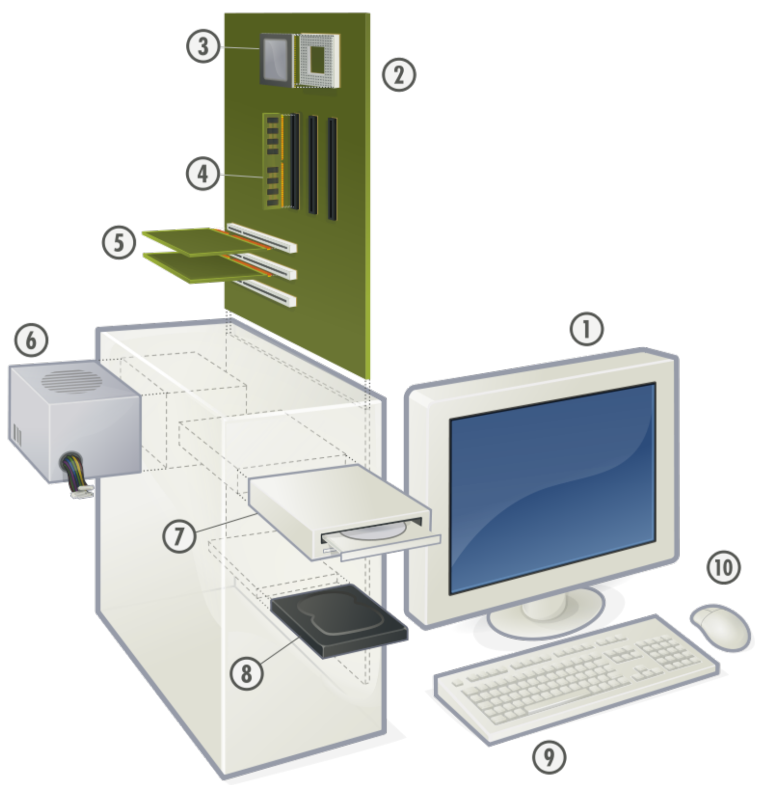
Articles

Parts of a Simple PC

Personal computer hardware

A personal computer is made up of multiple physical components of **computer hardware**, upon which can be installed an operating system and a multitude of software to perform the operator's desired functions.

Though a PC comes in many different forms, a typical personal computer consists of a case or chassis in a tower shape (desktop), containing components such as a motherboard.



Hardware of a modern Personal Computer.
1. Monitor
2. Motherboard
7. Optical disc drive
9. Keyboard
10. Mouse

Components

Motherboard

The motherboard is the main component inside the case. It is a large rectangular board with integrated circuitry that connects the rest of the parts of the computer including the CPU, the RAM, the disk drives (CD, DVD, hard disk, or any others) as well as any peripherals connected via the ports or the expansion slots.

Components directly attached to the motherboard include:

- The **central processing unit** (CPU) performs most of the calculations which enable a computer to function, and is sometimes referred to as the "brain" of the computer. It is usually cooled by a heat sink and fan.
- The **chip set** mediates communication between the CPU and the other components of the system, including main memory.
- **RAM** (Random Access Memory) stores all running processes (applications) and the current running OS.

Inside a custom-built computer: the power supply at the bottom has its own cooling zone.

- The **BIOS** includes boot firmware and power management. The **B**asic **I**nput **O**utput **S**ystem tasks are handled by operating system drivers.
- **Internal Buses** connect the CPU to various internal components and to expansion cards for graphics and sound.
  - **Current**
    - The north bridge memory controller, for RAM and PCI Express
      - PCI Express, for expansion cards such as graphics and physics processors, and high-end network interfaces
    - PCI, for other expansion cards
    - SATA, for disk drives
  - **Obsolete**
    - ATA (superseded by SATA)
    - AGP (superseded by PCI Express)
    - VLB VESA Local Bus (superseded by AGP)
    - ISA (expansion card slot format obsolete in PCs, but still used in industrial computers)
- **External Bus Controllers** support ports for external peripherals. These ports may be controlled directly by the south bridge I/O controller or based on expansion cards attached to the motherboard through the PCI bus.
  - USB
  - FireWire
  - eSATA
  - SCSI

Power supply

A power supply unit (PSU) is the component that supplies power to the other components in a computer. More specifically, a power supply unit is typically designed to convert general-purpose alternating current (AC) electric power from the mains (100-127V in North America, parts of South America, Japan, and Taiwan; 220-240V in most of the rest of the world) to usable low-voltage DC power for the internal components of the computer. Some power supplies have a switch to change between 230 V and 115 V. Other models have automatic sensors that switch input voltage automatically, or are able to accept any voltage between those limits. It converts high voltage into low voltage.

Power supply units often used in computers are SMPS (Switch Mode Power Supply). The SMPS provides +12, -12, +5, -5 and 3.* DC Volts for operation. When using the SMPS, it results in uninterrupted output within a wide range of input AC voltages. SMPS makes the power supply unit compact, rigid and reliable. The SMPS will switch over until it gets a negative loop from the computer's motherboard when switching ON the CPU. First, the SMPS converts the input AC voltage into corresponding DC voltage, which is then applied to a switching circuit at very high frequency. This high frequency (AC) is fed to a step down transformer with different tapings for various voltages required to run a computer. These AC voltages are then rectified and filtered. Finally, we get pure DC voltage of different levels.The power supply he si main of motherbord and then current motherbord for fan, process and SMPS of name hard wire of smps wire and power managment of process fan and other devisec of power supply

Video display controller

Produces the output for the computer monitor. This will either be built into the motherboard or attached in its own separate slot (PCI, PCI-E, PCI-E 2.0, or AGP), in the form of a graphics card.

Removable media devices

- CD (compact disc) - the most common type of removable media, suitable for music and data.
  - CD-ROM Drive - a device used for reading data from a CD.
  - CD Writer - a device used for both reading and writing data to and from a CD.
- DVD (digital versatile disc) - a popular type of removable media that is the same dimensions as a CD but stores up to 12 times as much information. It is the most common way of transferring digital video, and is popular for data storage.
  - DVD-ROM Drive - a device used for reading data from a DVD.
  - DVD Writer - a device used for both reading and writing data to and from a DVD.
  - DVD-RAM Drive - a device used for rapid writing and reading of data from a special type of DVD.
- Blu-ray Disc - a high-density optical disc format for data and high-definition video. Can store 70 times as much information as a CD.
  - BD-ROM Drive - a device used for reading data from a Blu-ray disc.
  - BD Writer - a device used for both reading and writing data to and from a Blu-ray disc.
- HD DVD - a discontinued competitor to the Blu-ray format.
- Floppy disk - an outdated storage device consisting of a thin disk of a flexible magnetic storage medium. Used today mainly for loading RAID drivers.
- Iomega Zip drive - an outdated medium-capacity removable disk storage system, first introduced by Iomega in 1994.
- USB flash drive - a flash memory data storage device integrated with a USB interface, typically small, lightweight, removable, and rewritable. Capacities vary, from hundreds of megabytes (in the same ballpark as CDs) to tens of gigabytes (surpassing, at great expense, Blu-ray discs).
- Tape drive - a device that reads and writes data on a magnetic tape, used for long term storage and backups.

Secondary storage

Hardware that keeps data inside the computer for later use and remains persistent even when the computer has no power.

- Hard disk - for medium-term storage of data.
- Solid-state drive - a device similar to hard disk, but containing no moving parts and stores data in a digital format.
- RAID array controller - a device to manage several internal or external hard disks and optionally some peripherals in order to achieve performance or reliability improvement in what is called a RAID array.

Sound card

Enables the computer to output sound to audio devices, as well as accept input from a microphone. Most modern computers have sound cards built-in to the motherboard, though it is common for a user to install a separate sound card as an upgrade. Most sound cards, either built-in or added, have surround sound capabilities.

Other peripherals

In addition, hardware devices can include external components of a computer system. The following are either standard or very common.

Includes various input and output devices, usually external to the computer system.

Wheel Mouse

Input

- Text input devices
  - Keyboard - a device to input text and characters by depressing buttons (referred to as keys), similar to a typewriter. The most common English-language key layout is the QWERTY layout.
- Pointing devices
  - Mouse - a pointing device that detects two dimensional motion relative to its supporting surface.
    - Optical Mouse - a newer technology that uses Light to track the surface under the mouse to determine the motion to be translated into cursor movements on the screen.
  - Trackball - a pointing device consisting of an exposed protruding ball housed in a socket that detects rotation about two axes.
  - Touchscreen
- Gaming devices
  - Joystick - a general control device that consists of a handheld stick that pivots around one end, to detect angles in two or three dimensions.
  - Gamepad - a general handheld game controller that relies on the digits (especially thumbs) to provide input.
  - Game controller - a specific type of controller specialized for certain gaming purposes.
- Image, Video input devices
  - Image scanner - a device that provides input by analyzing images, printed text, handwriting, or an object.
  - Webcam - a low resolution video camera used to provide visual input that can be easily transferred over the internet.
- Audio input devices
  - Microphone - an acoustic sensor that provides input by converting sound into electrical signals.

See also

- Glossary of computers

Input Device

Input device

An **input device** is any peripheral (piece of computer hardware equipment) used to provide data and control signals to an information processing system (such as a computer). Input and output devices make up the hardware interface between a computer as a scanner or 6DOF controller.

Many input devices can be classified according to:

- modality of input (e.g. mechanical motion, audio, visual, etc.)
- the input is discrete (e.g. keypresses) or continuous (e.g. a mouse's position, though digitized into a discrete quantity, is fast enough to be considered continuous)
- the number of degrees of freedom involved (e.g. two-dimensional traditional mice, or three-dimensional navigators designed for CAD applications)

Pointing devices, which are input devices used to specify a position in space, can further be classified according to:

- Whether the input is direct or indirect. With direct input, the input space coincides with the display space, i.e. pointing is done in the space where visual feedback or the cursor appears. Touchscreens and light pens involve direct input. Examples involving indirect input include the mouse and trackball.
- Whether the positional information is absolute (e.g. on a touch screen) or relative (e.g. with a mouse that can be lifted and repositioned)

Note that direct input is almost necessarily absolute, but indirect input may be either absolute or relative. For example, digitizing Graphics tablets that do not have an embedded screen involve indirect input and sense absolute positions and are often run in an absolute input mode, but they may also be setup to simulate a relative input mode where the stylus or puck can be lifted and repositioned.

Keyboards

A 'keyboard' is a human interface device which is represented as a layout of buttons. Each button, or key, can be used to either input a linguistic character to a computer, or to call upon a particular function of the computer. Traditional keyboards use spring-based buttons, though newer variations employ virtual keys, or even projected keyboards.

Examples of types of keyboards include:

- Computer keyboard
- Keyer
- Chorded keyboard
- LPFK

Pointing devices

A **pointing device** is any human interface device that allows a user to input spatial data to a computer. In the case of mice and touch screens, this is usually achieved by detecting movement across a physical surface. Analog devices, such as 3D mice, joysticks, or pointing sticks, function by reporting their angle of deflection. Movements of the pointing device are echoed on the screen by movements of the cursor, creating a simple, intuitive way to navigate a computer's GUI.

A computer mouse

High-degree of freedom input devices

Some devices allow many continuous degrees of freedom as input. These can be used as pointing devices, but are generally used in ways that don't involve pointing to a location in space, such as the control of a camera angle while in 3D applications. These kinds of devices are typically used in CAVEs, where input that registers 6DOF is required.

Composite devices

Input devices, such as buttons and joysticks, can be combined on a single physical device that could be thought of as a composite device. Many gaming devices have controllers like this. Technically mice are composite devices, as they both track movement and provide buttons for clicking, but composite devices are generally considered to have more than two different forms of input.

- Game controller
- Gamepad (or joypad)
- Paddle (game controller)
- Wii Remote

Wii Remote with attached strap

Imaging and Video input devices

Video input devices are used to digitize images or video from the outside world into the computer. The information can be stored in a multitude of formats depending on the user's requirement.

- digital camera
- Webcam
- Image scanner
- Fingerprint scanner
- Barcode reader
- 3D scanner
- Laser rangefinder

Medical Imaging

- Computed tomography
- Magnetic resonance imaging

- Positron emission tomography
- Medical ultrasonography

Audio input devices

In the fashion of video devices, audio devices are used to either capture or create sound. In some cases, an audio output device can be used as an input device, in order to capture produced sound.

- Microphone
- MIDI keyboard or other digital musical instrument

Keyboard (computing)

The PS/2's Model M keyboard from which modern PC keyboards are derived

Wireless multimedial media center German-layout keyboard with trackball

In computing, a **keyboard** is an input device, partially modeled after the typewriter keyboard, which uses an arrangement of buttons or keys, to act as mechanical levers or electronic switches. A keyboard typically has characters engraved or printed on the keys and each press of a key typically corresponds to a single written symbol. However, to produce some symbols requires pressing and holding several keys simultaneously or in sequence. While most keyboard keys produce letters, numbers or signs (characters), other keys or simultaneous key presses can produce actions or computer commands.

In normal usage, the keyboard is used to type text and numbers into a word processor, text editor or other program. In a modern computer, the interpretation of key presses is generally left to the software. A computer keyboard distinguishes each physical key from every other and reports all key presses to the controlling software. Keyboards are also used for computer gaming, either with regular keyboards or by using keyboards with special gaming features, which can expedite frequently used keystroke combinations. A keyboard is also used to give commands to the operating system of a computer, such as Windows' Control-Alt-Delete combination, which brings up a task window or shuts down the machine.

Types

Standard

Standard keyboards for desktop computers, such as the 101-key US traditional keyboards or the 104-key Windows keyboards, Include alphabetic characters, punctuation symbols, numbers and a variety of function keys. The internationally-common 102/105 key keyboards have a smaller 'left shift' key and an additional key with some more symbols between that and the letter to its right (usually Z or Y).[1] Computer keyboards are similar to electric-typewriter keyboards but contain additional keys.

Laptop-size

Keyboards on laptops and notebook computers usually have a shorter travel distance for the keystroke and a reduced set of keys. They may not have a numerical keypad, and the function keys may be placed in locations that differ from their placement on a standard, full-sized keyboard.

Multimedia

The keyboards on laptops have a shorter travel distance and (usually) a reduced set of keys.

Keyboards with extra keys, such as multimedia keyboards, have special keys for accessing music, web and other frequently used programs. For example, 'ctrl+marked on color-coded keys are used for some software applications and for specialized uses such as video editing.

Thumb-sized

Smaller keyboards have been introduced for laptops, PDAs, cellphones or users who have a limited workspace. The size of a standard keyboard is dictated by the practical consideration that the keys must be large enough to be easily pressed by fingers. To reduce the size of the keyboard, the numeric keyboard to the right of the alphabetic keyboard can be removed, or the size of the keys can be reduced, which makes it harder to enter text.

Another way to reduce the size of the keyboard is to reduce the number of keys and use chording keyer, i.e. pressing several keys simultaneously. For example, the GKOS keyboard has been designed for small wireless devices. Other two-handed alternatives more akin to a game controller, such as the AlphaGrip, are also used as a way to input data and text. Another way to reduce the size of a keyboard is to use smaller buttons and pack them closer together. Such keyboards, often called a "thumbboard" (thumbing) are used in some personal digital assistants such as the Palm Treo and BlackBerry and some Ultra-Mobile PCs such as the OQO.

Numeric

Numeric keyboards contain only numbers, mathematical symbols for addition, subtraction, multiplication, and division, a decimal point, and several function keys (e.g. End, Delete, etc.). They are often used to facilitate data entry with smaller keyboard-equipped laptops or with smaller keyboards that do not have a numeric keypad. A laptop does sometimes have a numeric pad, but not all the time. These keys are also known as, collectively, a numeric pad, numeric keys, or a numeric keypad, and it can consist of the following types of keys:

- arithmetic operators such as +, -, *, /
- numeric digits 0-9
- cursor arrow keys
- navigation keys such as Home, End, PgUp, PgDown, etc.
- Num Lock button, used to enable or disable the numeric pad
- enter key

Non-standard or special-use types

Chorded

While normal keyboards generally associate one action with each key, chorded keyboards associate actions with combinations of key presses. Since there are many combinations available, chorded keyboards can effectively produce more actions on a board with fewer keys. Court reporter's stenotype machines use chorded keyboards to enable them to enter text much faster by typing a syllable with each stroke instead of one letter at a time. Some chorded keyboards are also made for use in situations where fewer keys are preferable, such as on devices that can be used with only one hand, and on small mobile devices that don't have room for larger keyboards. Chorded keyboards are less desirable in many cases because it usually takes practice and memorization of the combinations to become proficient.

Software

Software keyboards or On-Screen Keyboards often take the form of computer programs that display an image of a keyboard on the screen. Another input device such as a mouse or a touchscreen can be used to each virtual key to enter text. Software keyboards have become very popular in touchscreen enabled cell phones, due to the additional cost and space requirements of other types of hardware keyboards. Microsoft Windows and Mac OS X both include on-screen keyboards that can be controlled with the mouse.

Foldable

Foldable (also called flexible) keyboards are made of soft plastic or silicone which can be rolled or folded on itself for travel.[2] When in use, these keyboards can conform to uneven surfaces, and are more resistant to liquids than standard keyboards. These can also be connected to portable devices and smartphones. Some models can be fully immersed in water, making them popular in hospitals and laboratories, as they can be disinfected.


A foldable keyboard.

Projection/Laser

Projection keyboards project an image of keys, usually with a laser, onto a flat surface. The device then uses a camera or infrared sensor to "watch" where your fingers move, and will count a key as being pressed when it "sees" your finger touch the projected image. Projection keyboards can simulate a full size keyboard from a very small projector. The keys cannot be felt when pressed, since they are just projected images. A flat, non-reflective surface is also required for the keys to be projected onto. Most projection keyboards are made for use with PDAs due to their small form factor.

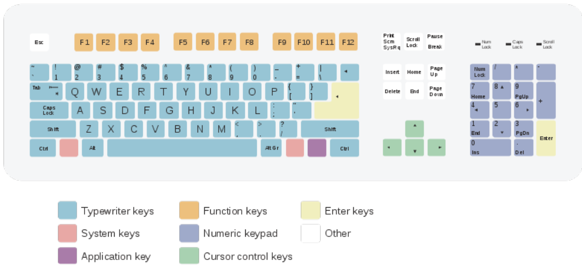
Optical Keyboard Technology

Also known as photo-optical keyboard, light responsive keyboard, Photo-electric keyboard and optical key actuation detection technology.

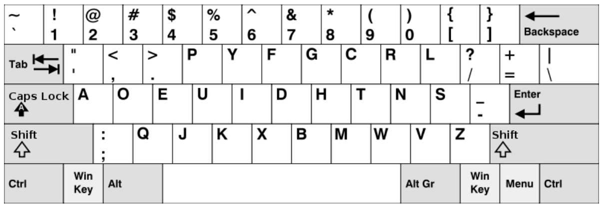
An optical keyboard technology utilizes light emitting devices and photo sensors to optically detect actuated keys. Most commonly the emitters and sensors are located in the perimeter, mounted on a small PCB. The light is directed from side to side of the keyboard interior and it can only be blocked by the actuated keys. Most optical keyboards require at least 2 beams (most commonly vertical beam and horizontal beam) to determine the actuated key. Some optical keyboards use a special key structure that blocks the light in a certain pattern, allowing only one beam per row of keys (most commonly horizontal beam).

Layout

Alphabetic



The 104-key PC US English QWERTY keyboard layout evolved from the standard typewriter keyboard, with extra keys for computing.



The Dvorak Simplified Keyboard layout arranges keys so that frequently used keys are easiest to press, which reduces muscle fatigue when typing common English.

There are a number of different arrangements of alphabetic, numeric, and punctuation symbols on keys. These different keyboard layouts arise mainly because different people need easy access to different symbols, either because they are inputting text in different languages, or because they need a specialized layout for mathematics, accounting, computer programming, or other purposes. Most of the more common keyboard layouts (QWERTY-based and similar) were designed in the era of the mechanical typewriters, so their ergonomics had to be slightly compromised in order to tackle some of the mechanical limitations of the typewriter.

As the letter-keys were attached to levers that needed to move freely, inventor Christopher Sholes developed the QWERTY layout to reduce the likelihood of jamming. With the advent of computers, lever jams are no longer an issue, but nevertheless, QWERTY layouts were adopted for electronic keyboards because they were widely used. Alternative layouts such as the Dvorak Simplified Keyboard are not in widespread use.

The QWERTZ layout is fairly widely used in Germany and much of Central Europe. The main difference between it and QWERTY is that Y and Z are swapped, and most special characters such as brackets are replaced by diacritical characters.

Another situation takes place with “national” layouts. Keyboards designed for typing in Spanish have some characters shifted, to release the space for Ñ ñ; similarly, those for French and other European languages may have a special key for the character Ç ç . The AZERTY layout is used in France, Belgium and some neighbouring countries. It differs from the QWERTY layout in that the A and Q are swapped, the Z and W are swapped, and the M is moved from the right of N to the right of L (where colon/semicolon is on a US keyboard). The digits 0 to 9 are on the same keys, but to be typed the shift key must be pressed. The unshifted positions are used for accented characters.

Keyboards in many parts of Asia may have special keys to switch between the Latin character set and a completely different typing system. In Japan, keyboards often can be switched between Japanese and the Latin alphabet, and the character ¥ (the Yen currency) is used instead of "\". In the Arab world, keyboards can often be switched between Arabic and Latin characters.

In bilingual regions of Canada and in the French-speaking province of Québec, keyboards can often be switched between an English and a French-language keyboard; while both keyboards share the same QWERTY alphabetic layout, the French-language keyboard enables the user to type accented vowels such as "é" or "à" with a single keystroke. Using keyboards for other languages leads to a conflict: the image on the key does not correspond to the character. In such cases, each new language may require an additional label on the keys, because the standard keyboard layouts do not share even similar characters of different languages (see the example in the figure above).

Key types

Alphanumeric

A Hebrew keyboard lets the user type in both Hebrew and the Latin alphabet.

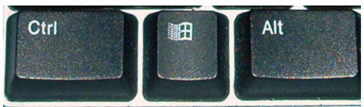
Alphabetical, numeric, and punctuation keys are used in the same fashion as a typewriter keyboard to enter their respective symbol into a word processing program, text editor, data spreadsheet, or other program. Many of these keys will produce different symbols when modifier keys or shift keys are pressed. The alphabetic characters become uppercase when the shift key or Caps Lock key is depressed. The numeric characters become symbols or punctuation marks when the shift key is depressed. The alphabetical, numeric, and punctuation keys can also have other functions when they are pressed at the same time as some modifier keys.

A Greek keyboard lets the user type in both Greek and the Latin alphabet(Macbook Pro).

The Space bar is a horizontal bar in the lowermost row, which is significantly wider than other keys. Like the alphanumeric characters, it is also descended from the mechanical typewriter. Its main purpose is to enter the space between words during typing. It is large enough so that a thumb from either hand can use it easily. Depending on the operating system, when the space bar is used with a modifier key such as the control key, it may have functions such as resizing or closing the current window, half-spacing, or backspacing. In computer games and other applications the key has myriad uses in addition to its normal purpose in typing, such as jumping and adding marks to check boxes. In certain programs for playback of digital video, the space bar is used for pausing and resuming the playback.

Modifiers

Modifier keys are special keys that modify the normal action of another key, when the two are pressed in combination. For example, <Alt> + <F4> in Microsoft Windows will close the program in an active window. In contrast, pressing just <F4> will probably do nothing, unless assigned a specific function in a particular program. By themselves, modifier keys usually do nothing.



The Ctrl and Alt keys are important modifier keys.

The most widely-used modifier keys include the Control key, Shift key and the Alt key. The AltGr key is used to access additional symbols for keys that have three symbols printed on them. On the Macintosh and Apple keyboards, the modifier keys are the Option key and Command key, respectively. On MIT computer keyboards, the Meta key is used as a modifier and for Windows keyboards, there is a Windows key. Compact keyboard layouts often use a Fn key. "Dead keys" allow placement of a diacritic mark, such as an accent, on the following letter (e.g., the Compose key).

The Enter/Return key typically causes a command line, window form or dialog box to operate its default function, which is typically to finish an "entry" and begin the desired process. In word processing applications, pressing the enter key ends a paragraph and starts a new one.

A Space-cadet keyboard has many modifier keys.

Navigation and typing mode

Navigation keys include a variety of keys which move the cursor to different positions on the screen. Arrow keys are programmed to move the cursor in a specified direction; page scroll keys, such as the 'Page Up and Page Down keys', scroll the page up and down. The Home key is used to return the cursor to the beginning of the line where the cursor is located; the End key puts the cursor at the end of the line. The Tab key advances the cursor to the next tab stop.

The Insert key is mainly used to switch between overtype mode, in which the cursor overwrites any text that is present on and after its current location, and insert mode, where the cursor inserts a character at its current position, forcing all characters past it one position further. The Delete key discards the character ahead of the cursor's position, moving all following characters one position "back" towards the freed place. On many notebook computer keyboards the key labeled Delete (sometimes Delete and Backspace are printed on the same key) serves the same purpose as a Backspace key. The Backspace key deletes the preceding character.

Lock keys lock part of a keyboard, depending on the settings selected. The lock keys are scattered around the keyboard. Most styles of keyboards have three LEDs indicating which locks are enabled, in the upper right corner above the numpad. The lock keys include Scroll lock, Num lock (which allows the use of the numeric keypad), and Caps lock.

System commands

The SysRq / Print screen commands often share the same key. SysRq was used in earlier computers as a "panic" button to recover from crashes. The Print screen command used to capture the entire screen and send it to the printer, but in the present it usually puts a screenshot in the clipboard. The Break key/Pause key no longer has a well-defined purpose. Its origins go back to teletype users, who wanted a key that would temporarily interrupt the communications line. The Break key can be used by software in several different ways, such as to switch between multiple login sessions, to terminate a program, or to interrupt a modem connection.

In programming, especially old DOS-style BASIC, Pascal and C, Break is used (in conjunction with Ctrl) to stop program execution. In addition to this, Linux and variants, as well as many DOS programs, treat this combination the same as Ctrl+C. On modern keyboards, the break key is usually labeled Pause/Break. In most Windows environments, the key combination Windows key+Pause brings up the system properties.

The Escape key (often abbreviated Esc) is used to initiate an escape sequence. As most computer users no longer are concerned with the details of controlling their computer's peripherals, the task for which the escape sequences were originally designed, the escape key was appropriated by application programmers, most often to mean Stop. This use continues today in Microsoft Windows's use of escape as a shortcut in dialog boxes for No, Quit, Exit, Cancel, or Abort.

A common application today of the Esc key is as a shortcut key for the Stop button in many web browsers. On machines running Microsoft Windows, prior to the implementation of the Windows key on keyboards, the typical practice for invoking the "start" button was to hold down the control key and press escape. This process still works in Windows 2000, XP, Windows Vista and Windows 7.

The Menu key or Application key is a key found on Windows-oriented computer keyboards. It is used to launch a context menu with the keyboard rather than with the usual right mouse button. The key's symbol is a small icon depicting a cursor hovering above a menu. This key was created at the same time as the Windows key. This key is normally used when the right mouse button is not present on the mouse. Some Windows public terminals do not have a Menu key on their keyboard to prevent users from right-clicking (however, in many windows applications, a similar functionality can be invoked with the Shift+F10 keyboard shortcut).

Miscellaneous

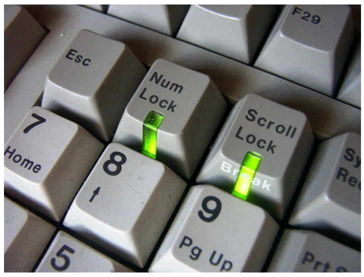
Many, but not all, computer keyboards have a numeric keypad to the right of the alphabetic keyboard which contains numbers, basic mathematical symbols (e.g., addition, subtraction, etc.), and a few function keys. On Japanese/Korean keyboards, there may be Language input keys. Some keyboards have power management keys (e.g., Power key, Sleep key and Wake key); Internet keys to access a web browser or E-mail; and/or multimedia keys, such as volume controls.

Multimedia buttons on some keyboards give quick access to the Internet or control the volume of the speakers.

Illumination

Keyboards and keypads may be illuminated from inside, especially on equipment for mobile use. Illumination facilitates the use of the keyboard or keypad in dark environments. Some gaming keyboards have lighted keys, to make it easier for gamers to find command keys while playing in a dark room. Some computers may have small LED lights in a few important function keys, to remind users that the function is activated (see photo).

Technology



Keys with integrated LED indicator lights

Key switches

In the first electronic keyboards in the early 1970s, the key switches were individual switches inserted into holes in metal frames. These keyboards cost from $80–$120 and were used in mainframe data terminals. The most popular switch types were reed switches (contacts enclosed in a vacuum in a glass capsule, affected by a magnet mounted on the switch plunger - from Clare-Pendar [3] in Post Falls Idaho, which became part of General Instrument, which used reedswitch capsules made by C.P. Clare Co. [4] in Illinois; and Key Tronic Corporation of Spokane, Washington), Hall-effect switches (using a Hall-effect semiconductor where a current is generated by a passing magnet - from Microswitch [5] in Illinois, which became part of Honeywell), and inductive core switches (again, activated by a magnet - from Cortron [6], which was part of ITW/Illinois Tool Works). These switches were rated to last for 100 million cycles and had 0.187-inch key travel (compared to 0.110-inch today).

In the mid 1970's, lower-cost direct-contact key switches were introduced, but their life in switch cycles was much shorter (rated 10 million cycles) because they open to the environment. However, this was getting acceptable for computer terminals at the time which were having increasingly shorter model lifespans as they were advancing.

In 1978, Key Tronic Corporation introduced keyboards with capacitive-based switches, one of the first keyboard technologies to not use self-contained switches. There was simply a sponge pad with a conductive-coated Mylar plastic sheet on the switch plunger, and two half-moon trace patterns on the printed circuit board below. As the key was depressed, the capacitance between the plunger pad and the patterns on the PCB below changed, which was detected by IC's/Integrated Circuits. These keyboards were claimed to have the same reliability as the other "solid-state switch" keyboards such as inductive and Hall-Effect, but competitive with direct-contact keyboards. Prices of $60 for keyboards were achieved and Key Tronic rapidly became the largest independent keyboard manufacturer.

Meanwhile, IBM made their own keyboards, using their own patented technology: Keys on older IBM keyboards were made with a "buckling spring" mechanism, in which a coil spring under the key buckles under pressure from the user's finger, pressing a rubber dome, whose inside is coated with conductive graphite, which connects two leads below, completing a circuit. This produces a clicking sound, and gives physical feedback for the typist indicating that the key has been depressed.[7] [8]

The first electronic keyboards had a typewriter key travel distance of 0.187 inches, keytops were a half-inch high, and keyboards were about two inches thick. Over time, less key travel was accepted in the market, finally landing on 0.110 inches. Coincident with this, Key Tronic was the first company to introduce a keyboard which was only about one inch thick. And now keyboards measure only about a half-inch thick.

Keytops are an important element of keyboards. In the beginning, keyboard keytops had a "dish shape" on top, like typewriters before them. Keyboard key legends must be extremely durable over tens of millions of depressions, since they are subjected to extreme mechanical wear from fingers and fingernails, and subject to hand oils and creams, so engraving and filling key legends with paint, as was done previously for individual switches, was never acceptable. So, for the first electronic keyboards, the key names/legends were produced by 2-shot molded by two-shot (or double-shot, or two-color) molding, where either the key shell or the inside of the key with the key legend was molded first, and then the other color molded second. But, to save cost, other methods were explored, such as sublimation printing and laser engraving, both methods which could be used to print a whole keyboard at the same time. Initially, sublimation printing, where a special ink is printed onto the keycap surface and the application of heat causes the ink molecules to penetrate and commingle with the plastic modules, had a problem because finger oils caused the molecules to disperse, but then a necessarily very hard clear coating was applied to prevent this. Coincident with sublimation printing, which was first used in high volume by IBM on their keyboards, was the introduction by IBM of single-curved-dish keycaps to facilitate quality printing of key legends by having a consistently-curved surface instead of a dish. But one problem with sublimation or laser printing was that the processes took too long and only dark legends could be printed on light-colored keys. On another note, IBM was unique in using separate shells, or "keycaps", on keytop bases. This might have made their manufacturing of different keyboard layouts more flexible, but the reason for doing this was that the plastic material that needed to be used for sublimation printing was different than standard ABS keytop plastic material.

Three final mechanical technologies brought keyboards to where they are today, driving the cost well under $10: 1) "Monoblock" keyboard designs were developed where individual switch housings were eliminated and a one-piece "monoblock" housing used instead. This was possible because of molding techniques that could provide very tight tolerances for the switch-plunger holes and guides across the width of the keyboard so that the key plunger-to-housing clearances were not too tight or too loose, either of which could cause the keys to bind. 2) The use of contact-switch membrane sheets under the monoblock. This technology came from flat-panel switch membranes, where the switch contacts are printed inside of a top and bottom layer, with a spacer layer in between, so that when pressure is applied to the area above, a direct electrical contact is made. The membrane layers can be printed by very-high volume, low-cost "reel-to-reel" printing machines, with each keyboard membrane cut and punched out afterwards. 3) The use of pad-printed keytops (called "Tampo printed" at the time because Tampo [9] was the most popular equipment manufacturer). Initially sublimation ink was used (see above), but very durable clear-coats are now printed over the key legends to protect them.

It should be noted that plastic materials played a very important part in the development and progress of electronic keyboards. Until "monoblocks" came along, GE's "self-lubricating" Delrin was the only plastic material for keyboard switch plungers that could withstand the beating over tens of millions of cycles of lifetime use. Greasing or oiling switch plungers was undesirable because it would attract dirt over time which would eventually affect the feel and even bind the key switches (although keyboard manufacturers would sometimes sneak this into their keyboards, especially if they could not control the tolerances of the key plungers and housings well enough to have a smooth key depression feel or prevent binding). But Delrin was only available in black and white, and was not suitable for keytops (too soft), so keytops use ABS plastic. However, as plastic molding advanced in maintaining tight tolerances, and as key travel length reduced from 0.187-inch to 0.110-inch, single-part keytop/plungers could be made of ABS, with the keyboard monolocks also made of ABS.

Control processor

Computer keyboards include control circuitry to convert key presses into key codes that the computer's electronics can understand. The key switches are connected via the printed circuit board in an electrical X-Y matrix where a voltage is provided sequentially to the Y lines and, when a key is depressed, detected sequentially by scanning the X lines.

The first computer keyboards were for mainframe computer data terminals and used discrete electronic parts. The first keyboard microprocessor was introduced in 1972 by General Instruments, but keyboards have been using the single-chip 8048 microcontroller variant since it became available in 1978. The keyboard switch matrix is wired to its inputs, it converts the keystrokes to key codes, and, for a detached keyboard, sends the codes down a serial cable (the keyboard cord) to the main processor on the computer motherboard. This serial keyboard cable communication is only bi-directional to the extent that the computer's electronics controls the illumination of the "caps lock", "num lock" and "scroll lock" lights.

One test for whether the computer has crashed is pressing the "caps lock" key. The keyboard sends the key code to the keyboard driver running in the main computer; if the main computer is operating, it commands the light to turn on. All the other indicator lights work in a similar way. The keyboard driver also tracks the shift, alt and control state of the keyboard.

Some lower-quality keyboards have multiple or false key entries due to inadequate electrical designs. These are caused by inadequate keyswitch "debouncing" or inadequate keyswitch matrix layout that don't allow multiple keys to be depressed at the same time, both circumstances which are explained below:

When pressing a keyboard key, the key contacts "bounce" against each other several times for several milliseconds before they settle into firm contact (although this was not true with early "solid-state" keyswitch keyboards that used Hall-effect, inductive, or capacitive keyswitch technologies). When released, they bounce some more until they revert to the uncontacted state. If the computer were watching for each pulse, it would see many keystrokes for what the user thought was just one. To resolve this problem, the processor in a keyboard (or computer) "debounces" the keystrokes, by aggregating them across time to produce one "confirmed" keystroke that (usually) corresponds to what is typically a solid contact.

Some low-quality keyboards also suffer problems with *rollover* (that is, when multiple keys pressed at the same time, or when keys are pressed so fast that multiple keys are down within the same milliseconds). Early "solid-state" keyswitch keyboards did not have this problem because the keyswitches are electrically isolated from each other, and early "direct-contact" keyswitch keyboards avoided this problem by having isolation diodes for every keyswitch. So, these early keyboards had "n-key" rollover, which means any number of keys can be depressed and the keyboard will still recognize the next key depressed. But when three keys are pressed (electrically closed) at the same time in a "direct contact" keyswitch matrix that doesn't have isolation diodes (diode are not practical with current membrane-switch based keyboards), the keyboard electronics can see a fourth "phantom" key which is the intersection (shorting out) of the X and Y lines of the three keys. Some types of keyboard circuitry will register a maximum number of keys at one time, such as "three-key" rollover maximum, also called "phantom key blocking" or "phantom key lockout", meaning that it will only register three keys and ignore all others until one of the three keys is lifted. This is of course undesirable, especially for fast typing (hitting new keys before the fingers can release previous keys, and undesirable for games (designed for multiple key presses).

As direct-contact membrane keyboards became popular, the available rollover of keys was optimized by analyzing the most common key sequences and placing these keys so that they do not potentially produce phantom keys in the electrical key matrix (for example, simply placing three or four keys that might be depressed simultaneously on the same X or same Y line, so that a phantom key intersection/short cannot happen), so that blocking a third key usually isn't a problem. But lower-quality keyboard designs and unknowledgeable engineers may not know these tricks, and it can still be a problem in games due to wildly different and/or configurable key/command layouts in different games.

Connection types

There are several ways of connecting a keyboard using cables, including the standard AT connector commonly found on motherboards, which was eventually replaced by the PS/2 and the USB connection. Prior to the iMac line of systems, Apple used the proprietary Apple Desktop Bus for its keyboard connector.

Wireless keyboards have become popular for their increased user freedom. A wireless keyboard often includes a required combination transmitter and receiver unit that attaches to the computer's keyboard port (see *Connection types* above). The wireless aspect is achieved either by radio frequency (RF) or by infrared (IR) signals sent and received from both the keyboard and the unit attached to the computer. A wireless keyboard may use an industry standard RF, called Bluetooth. With Bluetooth, the transceiver may be built into the computer. However, a wireless keyboard needs batteries to work and may pose a security problem due to the risk of data "eavesdropping" by hackers. An early example of a consumer wireless keyboard is that of the Olivetti Envision.

Alternative text-entering methods

An on-screen keyboard controlled with the mouse can be used by users with limited mobility.

Optical character recognition (OCR) is preferable to rekeying for converting existing text that is already written down but not in machine-readable format (for example, a Linotype-composed book from the 1940s). In other words, to convert the text from an image to editable text (that is, a string of character codes), a person could re-type it, or a computer could look at the image and deduce what each character is. OCR technology has already reached an impressive state (for example, Google Book Search) and promises more for the future.

Speech recognition converts speech into machine-readable text (that is, a string of character codes). The technology has already reached an impressive state and is already implemented in various software products. For certain uses (e.g., transcription of medical or legal dictation; journalism; writing essays or novels) it is starting to replace the keyboard; however, it does not threaten to replace keyboards entirely anytime soon. It can, however, interpret commands (for example, "close window" or "undo that") in addition to text. Therefore, it has theoretical potential to replace keyboards entirely (whereas OCR replaces them only for a certain kind of task). Pointing devices can be used to enter text or characters in contexts where using a physical keyboard would be inappropriate or impossible. These accessories typically present characters on a display, in a layout that provides fast access to the more frequently used characters or character combinations. Popular examples of this kind of input are Graffiti, Dasher and on-screen virtual keyboards.

Other issues

Keystroke hacking

Keystroke logging (often called keylogging) is a method of capturing and recording user keystrokes. While it is used legally to measure employee productivity on certain clerical tasks, or by law enforcement agencies to find out about illegal activities, it is also used by hackers for various illegal or malicious acts. Hackers use keyloggers as a means to obtain passwords or encryption keys and thus bypass other security measures.

Keystroke logging can be achieved by both hardware and software means. Hardware key loggers are attached to the keyboard cable or installed inside standard keyboards. Software keyloggers work on the target computer’s operating system and gain unauthorized access to the hardware, hook into the keyboard with functions provided by the OS, or use remote access software to transmit recorded data out of the target computer to a remote location. Some hackers also use wireless keylogger sniffers to collect packets of data being transferred from a wireless keyboard and its receiver, and then they crack the encryption key being used to secure wireless communications between the two devices.

Anti-spyware applications are able to detect many keyloggers and cleanse them. Responsible vendors of monitoring software support detection by anti-spyware programs, thus preventing abuse of the software. Enabling a firewall does not stop keyloggers per se, but can possibly prevent transmission of the logged material over the net if properly configured. Network monitors (also known as reverse-firewalls) can be used to alert the user whenever an application attempts to make a network connection. This gives the user the chance to prevent the keylogger from "phoning home" with his or her typed information. Automatic form-filling programs can prevent keylogging entirely by not using the keyboard at all. Most keyloggers can be fooled by alternating between typing the login credentials and typing characters somewhere else in the focus window.[10]

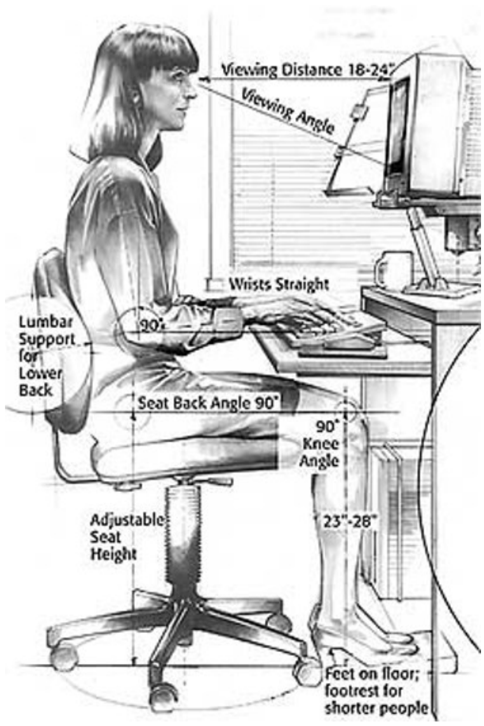
Wireless keystroke hacking

Also known as remote keylogging or wireless keylogging.

In their research “Compromising Electromagnetic Emanations of Wired Keyboard”[11] Vuagnoux and Pasini have provided evidence that modern keyboards radiate compromising electromagnetic emanations. The four techniques presented in their paper prove that these basic devices are generally not sufficiently protected against compromising emanations. Additionally, they showed that these emanations can be captured with relatively inexpensive equipment and keystrokes are recovered[12] not only in the semi-anechoic chamber but in practical environments as well (e.g office). The consequences of these attacks are that compromising electromagnetic emanations of keyboards still represent a security risk. PS/2, USB, laptop and wireless keyboards are vulnerable. Moreover, there is no software patch to avoid these attacks. Hardware has to be replaced in order to obtain safe devices. Due to cost pressure in the design and lack of knowledge, manufacturers do not systematically protect keyboards. Even in the practical space of an office with multiple keyboards, Vuagnoux and Pasini were able to deduce a specific fingerprint for every keyboard. When multiple keyboards are radiating at the same time, they are able to identify and differentiate them.

Physical injury

The use of any keyboard may cause serious injury (that is, carpal tunnel syndrome or other repetitive strain injury) to hands, wrists, arms, neck or back. The risks of injuries can be reduced by taking frequent short breaks to get up and walk around a couple of times every hour. As well, users should vary tasks throughout the day, to avoid overuse of the hands and wrists. When inputting at the keyboard, a person should keep the shoulders relaxed with the elbows at the side, with the keyboard and mouse positioned so that reaching is not necessary. The chair height and keyboard tray should be adjusted so that the wrists are straight, and the wrists should not be rested on sharp table edges. Wrist or palm rests should not be used while typing.



Proper ergonomic design of computer keyboard desks is necessary to prevent repetitive strain injuries, which can develop over time and can lead to long-term disability.[13]

Some Adaptive technology ranging from special keyboards, mouse replacements and pen tablet interfaces to speech recognition software can reduce the risk of injury. Pause software reminds the user to pause frequently. Switching to a much more ergonomic mouse, such as a vertical mouse or joystick mouse may provide relief. Switching from using a mouse to using a stylus pen with graphic tablet or a trackpad such as a Smart Cat trackpad can lessen the repetitive strain on the arms and hands.

See also

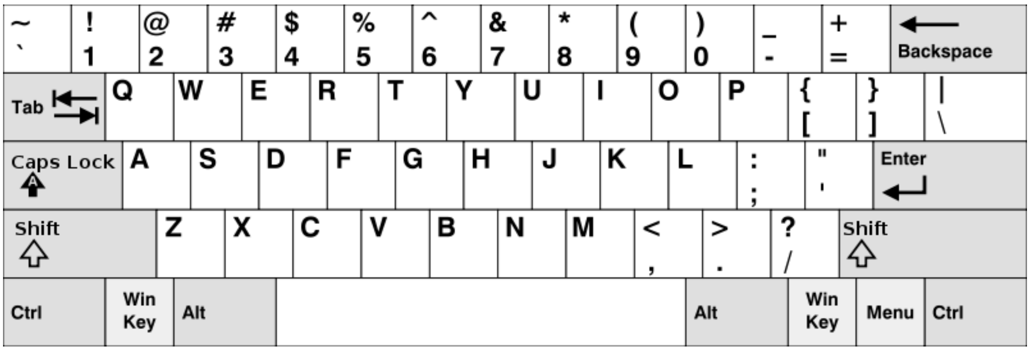
- Alphanumeric keyboard
- Enhanced keyboard
- Ergonomic keyboard
- Keyboard layout
- Keyboard technology
- Overlay keyboard
- Repetitive strain injury
- Scissor-switch technology (keyboard terminology)
- Table of keyboard shortcuts

External links

- How Computer Keyboards Work [14] at HowStuffWorks
- Art of Assembly Language: Chapter Twenty: The PC Keyboard [15]
- Keyboard matrix circuits [16]
- Large searchable database of keyboard shortcuts at Keyxl.com [17]
- PC World. "The 10 worst PC Keyboards of All Time [18]".
- IBM's 84-key PC keyboard. [19]

IBM/Windows keyboard (US layout)

Esc		F1	F2	F3	F4		F5	F6	F7	F8		F9	F10	F11	F12	PrtSc/ SysRq	ScrLk	Pause/ Break



Ins	Home	PgUp	NumLk	/	*	-
Del	End	PgDn	7	8	9	+
			4	5	6	
	↑		1	2	3	Ent
←	↓	→	0		.	

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[3] http://www.visualux.com/visualux2/clarependar.htm

[4] http://www.clare.com/

[5] http://content.honeywell.com/sensing/about/history.stm

[6] http://www.cortroninc.com/

[7] A Passion for the Keys: Particular About What You Type On? Relax -- You're Not Alone. (http://online.wsj.com/article/SB119578337324301744.html?mod=moj_columnists) LOOSE WIRE, By JEREMY WAGSTAFF, Wall Street Journal, November 23, 2007

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[9] http://www.tampo.co.uk/

[10] http://cups.cs.cmu.edu/soups/2006/posters/herley-poster_abstract.pdf

[11] http://lasecwww.epfl.ch/keyboard/

[12] http://www.newscientist.com/blogs/shortsharpscience/2008/10/a-spy-on-every-desk---keyboard.html

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[14] http://www.howstuffworks.com/keyboard.htm

[15] http://maven.smith.edu/~thiebaut/ArtOfAssembly/CH20/CH20-1.html

[16] http://www.dribin.org/dave/keyboard/one_html/

[17] http://www.keyxl.com/

[18] http://www.pcworld.com/article/139100/the_10_worst_pc_keyboards_of_all_time.html

[19] http://www.seasip.info/VintagePC/Images/6450225.jpg

Light pen

A **light pen** is a computer input device in the form of a light-sensitive wand used in conjunction with a computer's CRT TV set or monitor. It allows the user to point to displayed objects, or draw on the screen, in a similar way to a touch screen but with greater positional accuracy. A light pen can work with any CRT-based display, but not with LCD screens (though Toshiba and Hitachi displayed a similar idea at the "Display 2006" show in Japan[1]), projectors and other display devices.

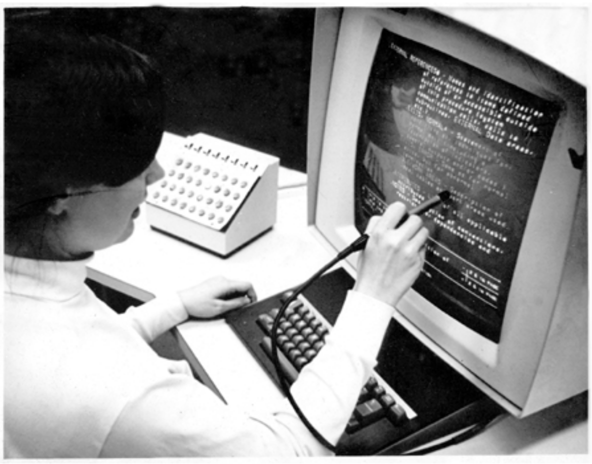

Photo of the Hypertext Editing System (HES) console in use at Brown University, circa October 1969. The photo shows HES on an IBM 2250 Mod 4 display station, including lightpen and programmed function keyboard, channel coupled to Brown's IBM 360 mainframe.

A light pen is fairly simple to implement. Just like a light gun, a light pen works by sensing the sudden small change in brightness of a point on the screen when the electron gun refreshes that spot. By noting exactly where the scanning has reached at that moment, the X,Y position of the pen can be resolved. This is usually achieved by the light pen causing an interrupt, at which point the scan position can be read from a special register, or computed from a counter or timer. The pen position is updated on every refresh of the screen.

The light pen became moderately popular during the early 1980s. It was notable for its use in the Fairlight CMI, and the BBC Micro. Even some consumer products were given light pens, in particular the Thomson MO5 computer family. Because the user was required to hold his or her arm in front of the screen for long periods of time, the light pen fell out of use as a general purpose input device.

The first light pen was created around 1952 as part of the Whirlwind project at MIT.[2] [3]

Since the current version of the game show *Jeopardy!* began in 1984, contestants have used a light pen to write down their wagers and responses for the *Final Jeopardy!* round.

Since light pens operate by detecting light emitted by the screen phosphors, some nonzero intensity level must be present at the coordinate position to be selected.

See also

- Pen computing

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Mouse (computing)

In computing, a **mouse** is a pointing device that functions by detecting two-dimensional motion relative to its supporting surface. Physically, a mouse consists of an object held under one of the user's hands, with one or more buttons. (Although traditionally a button is typically round or square, modern mice have spring-loaded regions of their top surface that operate switches when pressed down lightly.) It sometimes features other elements, such as "wheels", which allow the user to perform various system-dependent operations, or extra buttons or features that can add more control or dimensional input. The mouse's motion typically translates into the motion of a cursor on a display, which allows for fine control of a graphical user interface.

A computer mouse with the most common standard features: two buttons and a scroll wheel, which can also act as a third button

The name *mouse* originated at the Stanford Research Institute and derives from the resemblance of early models which had a cord attached to the rear part of the device (suggesting the idea of a tail) to the common mouse.[1]

The first marketed integrated mouse, shipped as a part of a computer and intended for personal computer navigation, came with the Xerox 8010 Star Information System in 1981. However, the mouse remained relatively obscure until the appearance of the Apple Macintosh. The use of mice with desktop computers is now ubiquitous and they are widely available for separate purchase.

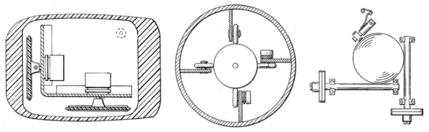
Naming

The first known publication of the term "*mouse*" as a pointing device is in Bill English's 1965 publication "Computer-Aided Display Control".[2]

The *Compact Oxford English Dictionary* (third edition) and the fourth edition of *The American Heritage Dictionary of the English Language* endorse both *computer mice* and *computer mouses* as correct plural forms for *computer mouse*. Some authors of technical documents may prefer either *mouse devices* or the more generic *pointing devices*. The plural *mouses* treats *mouse* as a "headless noun".

Two manuals of style in the computer industry—Sun Technical Publication's *Read Me First: A Style Guide for the Computer Industry* and *Microsoft Manual of Style for Technical Publications* from Microsoft Press—recommend that technical writers use the term *mouse devices* instead of the alternatives.

Early mice



Early mouse patents. From left to right: Opposing track wheels by Engelbart, Nov. 1970, U.S. Patent 3541541 [3]. Ball and wheel by *Rider*, Sept. 1974, U.S. Patent 3835464 [4]. Ball and two rollers with spring by Opocensky, Oct. 1976, U.S. Patent 3987685 [5]

The trackball was invented by Tom Cranston, Fred Longstaff and Kenyon Taylor working on the Royal Canadian Navy's DATAR project in 1952. It used a standard Canadian five-pin bowling ball. It was not patented, as it was a secret military project.[6]

Independently, Douglas Engelbart at the Stanford Research Institute invented the first mouse prototype in 1963,[7] with the assistance of his colleague Bill English. Engelbart never received any royalties for it, as his patent ran out before it became widely used in personal computers.[8]

The invention of the mouse was just a small part of Engelbart's much larger project, aimed at augmenting human intellect.[9]

The first computer mouse, held by inventor Douglas Engelbart, showing the wheels that make contact with the working surface

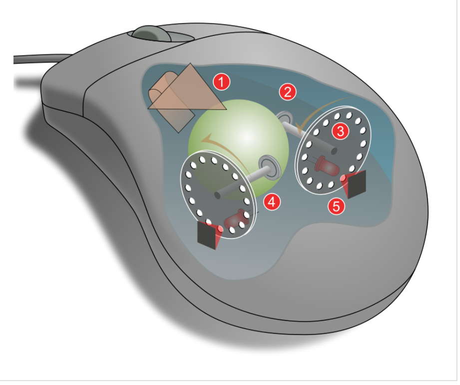
Several other experimental pointing-devices developed for Engelbart's oN-Line System (NLS) exploited different body movements – for example, head-mounted devices attached to the chin or nose – but ultimately the mouse won out because of its simplicity and convenience. The first mouse, a bulky device (pictured) used two gear-wheels perpendicular to each other: the rotation of each wheel translated into motion along one axis. Engelbart received patent US3541541 on November 17, 1970 for an "X-Y Position Indicator for a Display System".[10] At the time, Engelbart envisaged that users would hold the mouse continuously in one hand and type on a five-key chord keyset with the other.[11] The concept was preceded in the 19th century by the telautograph, which also anticipated the fax machine.

A Smaky mouse, as invented at the EPFL by Jean-Daniel Nicoud and André Guignard

The first marketed integrated mouse – shipped as a part of a computer and intended for personal computer navigation – came with the Xerox 8010 Star Information System in 1981. However, the mouse remained relatively obscure until the appearance of the Apple Macintosh; in 1984 PC columnist John C. Dvorak dismissively commented on the release of this new computer with a mouse: "There is no evidence that people want to use these things".[12] [13]

Variants

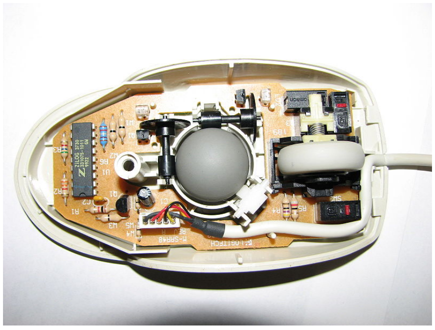
Mechanical mice



Operating an opto-mechanical mouse. moving the mouse turns the ball. X and Y rollers grip the ball and transfer movement Optical encoding disks include light holes. Infrared Light-emitting diodeLEDs shine through the disks. Sensors gather light pulses to convert to X and Y vectors.

Bill English, builder of Engelbart's original mouse,[14] invented the ball mouse in 1972 while working for Xerox PARC.[15]

The ball-mouse replaced the external wheels with a single ball that could rotate in any direction. It came as part of the hardware package of the Xerox Alto computer. Perpendicular chopper wheels housed inside the mouse's body chopped beams of light on the way to light sensors, thus detecting in their turn the motion of the ball. This variant of the mouse resembled an inverted trackball and became the predominant form used with personal computers throughout the 1980s and 1990s. The Xerox PARC group also settled on the modern technique of using both hands to type on a full-size keyboard and grabbing the mouse when required.



Mechanical mouse, shown with the top cover removed

The ball mouse has two freely rotating rollers. They are located 90 degrees apart. One roller detects the forward–backward motion of the mouse and other the left–right motion. Opposite the two rollers is a third one (white, in the photo, at 45 degrees) that is spring-loaded to push the ball against the other two rollers. Each roller is on the same shaft as an encoder wheel that has slotted edges; the slots interrupt infrared light beams to generate electrical pulses that represent wheel movement.

Each wheel's disc, however, has a pair of light beams, located so that a given beam becomes interrupted, or again starts to pass light freely, when the other beam of the pair is about halfway between changes. Simple logic circuits interpret the relative timing to indicate which direction the wheel is rotating. (This scheme is sometimes called "quadrature encoding" or some similar term by technical people.) The mouse sends these signals to the computer system via a data-formatting IC and the mouse cable. The driver software in the system converts the signals into motion of the mouse cursor along X and Y axes on the screen.

The ball is mostly steel, with a precision spherical rubber surface. The weight of the ball, given an appropriate working surface under the mouse, provides a reliable grip so the mouse's movement is transmitted accurately.

Ball mice and wheel mice were manufactured for Xerox by Jack Hawley, doing business as The Mouse House in Berkeley, California, starting in 1975.[16] [17]

Based on another invention by Jack Hawley, proprietor of the Mouse House, Honeywell produced another type of mechanical mouse.[18] [19] Instead of a ball, it had two wheels rotating at off axes. Keytronic later produced a similar product.[20]

Modern computer mice took form at the École polytechnique fédérale de Lausanne (EPFL) under the inspiration of Professor Jean-Daniel Nicoud and at the hands of engineer and watchmaker André Guignard.[21] This new design incorporated a single hard rubber mouseball and three buttons, and remained a common design until the mainstream adoption of the scroll-wheel mouse during the 1990s.[22] In 1985, René Sommer added a microprocessor to Nicoud's and Guignard's design.[23] Through this innovation, Sommer is credited with inventing a significant component of the mouse, which made it more "intelligent;"[23] though optical mice from Mouse Systems had incorporated microprocessors by 1984.[24]

Another type of mechanical mouse, the "analog mouse" (now generally regarded as obsolete), uses potentiometers rather than encoder wheels, and is typically designed to be plug-compatible with an analog joystick. The "Color Mouse", originally marketed by Radio Shack for their Color Computer (but also usable on MS-DOS machines equipped with analog joystick ports, provided the software accepted joystick input) was the best-known example.

Optical mice

An optical mouse uses a light-emitting diode and photodiodes to detect movement relative to the underlying surface, rather than moving some of its parts as in a mechanical mouse.

A wireless optical mouse on a mouse pad

Inertial and gyroscopic mice

Often called "air mice" since they do not require a surface to operate, inertial mice use a tuning fork or other accelerometer (US Patent 4787051 [25]) to detect rotary movement for every axis supported. The most common models (manufactured by Logitech and Gyration) work using 2 degrees of rotational freedom and are insensitive to spatial translation. The user requires only small wrist rotations to move the cursor, reducing user fatigue or "gorilla arm". Usually cordless, they often have a switch to deactivate the movement circuitry between use, allowing the user freedom of movement without affecting the cursor position. A patent for an inertial mouse claims that such mice consume less power than optically based mice, and offer increased sensitivity, reduced weight and increased ease-of-use.[26] In combination with a wireless keyboard an inertial mouse can offer alternative ergonomic arrangements which do not require a flat work surface, potentially alleviating some types of repetitive motion injuries related to workstation posture.

3D mice

Also known as bats,[27] flying mice, or wands,[28] these devices generally function through ultrasound and provide at least three degrees of freedom. Probably the best known example would be 3DConnexion/Logitech's SpaceMouse from the early 1990s.

In the late 1990s Kantek introduced the 3D RingMouse. This wireless mouse was worn on a ring around a finger, which enabled the thumb to access three buttons. The mouse was tracked in three dimensions by a base station.[29] Despite a certain appeal, it was finally discontinued because it did not provide sufficient resolution.

A recent consumer 3D pointing device is the Wii Remote. While primarily a motion-sensing device (that is, it can determine its orientation and direction of movement), Wii Remote can also detect its spatial position by comparing the distance and position of the lights from the IR emitter using its integrated IR camera (since the nunchuk accessory lacks a camera, it can only tell its current heading and orientation). The obvious drawback to this approach is that it can only produce spatial coordinates while its camera can see the sensor bar.

In February, 2008, at the Game Developers' Conference (GDC), a company called Motion4U introduced a 3D mouse add-on called "OptiBurst" for Autodesk's Maya application. The mouse allows users to work in true 3D with 6 degrees of freedom. The primary advantage of this system is speed of development with organic (natural) movement.

A mouse-related controller called the SpaceBall™ [30] has a ball placed above the work surface that can easily be gripped. With spring-loaded centering, it sends both translational as well as angular displacements on all six axes, in both directions for each.

Tactile mice

In 2000, Logitech introduced the "tactile mouse", which contained a small actuator that made the mouse vibrate. Such a mouse can augment user-interfaces with haptic feedback, such as giving feedback when crossing a window boundary. To surf by touch requires the user to be able to feel depth or hardness; this ability was realized with the first electrorheological tactile mice[31] but never marketed.

Connectivity and communication protocols

To transmit their input, typical cabled mice use a thin electrical cord terminating in a standard connector, such as RS-232C, PS/2, ADB or USB. Cordless mice instead transmit data via infrared radiation (see IrDA) or radio (including Bluetooth), although many such cordless interfaces are themselves connected through the aforementioned wired serial buses.

While the electrical interface and the format of the data transmitted by commonly available mice is currently standardized on USB, in the past it varied between different manufacturers. A bus mouse used a dedicated interface card for connection to an IBM PC or compatible computer.

Mouse use in DOS applications became more common after the introduction of the Microsoft mouse, largely because Microsoft provided an open standard for communication between applications and mouse driver software. Thus, any application written to use the Microsoft standard could use a mouse with a Microsoft compatible driver (even if the mouse hardware itself was incompatible with Microsoft's). An interesting footnote is that the Microsoft driver standard communicates mouse movements in standard units called "mickeys".

Serial interface and protocol

Standard PC mice once used the RS-232C serial port via a D-subminiature connector, which provided power to run the mouse's circuits as well as data on mouse movements. The Mouse Systems Corporation version used a five-byte protocol and supported three buttons. The Microsoft version used an incompatible three-byte protocol and only allowed for two buttons. Due to the incompatibility, some manufacturers sold serial mice with a mode switch: "PC" for MSC mode, "MS" for Microsoft mode.[32]

PS/2 interface and protocol

With the arrival of the IBM PS/2 personal-computer series in 1987, IBM introduced the eponymous PS/2 interface for mice and keyboards, which other manufacturers rapidly adopted. The most visible change was the use of a round 6-pin mini-DIN, in lieu of the former 5-pin connector. In default mode (called *stream mode*) a PS/2 mouse communicates motion, and the state of each button, by means of 3-byte packets.[33] For any motion, button press or button release event, a PS/2 mouse sends, over a bi-directional serial port, a sequence of three bytes, with the following format:

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Byte 1	YV	XV	YS	XS	1	MB	RB	LB
Byte 2	X movement							
Byte 3	Y movement							

Here, XS and YS represent the sign bits of the movement vectors, XV and YV indicate an overflow in the respective vector component, and LB, MB and RB indicate the status of the left, middle and right mouse buttons (1 = pressed). PS/2 mice also understand several commands for reset and self-test, switching between different operating modes, and changing the resolution of the reported motion vectors.

In Linux, a PS/2 mouse is detected as a /dev/psaux device.

A Microsoft IntelliMouse relies on an extension of the PS/2 protocol: the ImPS/2 or IMPS/2 protocol (the abbreviation combines the concepts of "IntelliMouse" and "PS/2"). It initially operates in standard PS/2 format, for backwards compatibility. After the host sends a special command sequence, it switches to an extended format in which a fourth byte carries information about wheel movements. The IntelliMouse Explorer works analogously, with the difference that its 4-byte packets also allow for two additional buttons (for a total of five).[34]

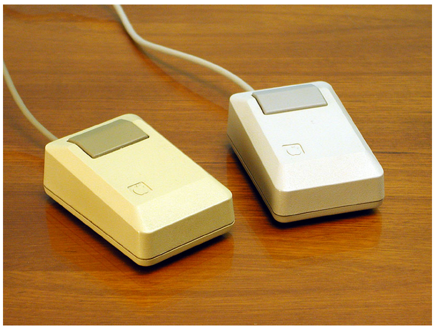
The Typhoon mouse uses 6-byte packets which can appear as a sequence of two standard 3-byte packets, such that an ordinary PS/2 driver can handle them.[35]

Mouse vendors also use other extended formats, often without providing public documentation.

For 3-D (or 6-degree-of-freedom) input, vendors have made many extensions both to the hardware and to software. In the late 90's Logitech created ultrasound based tracking which gave 3D input to a few millimeters accuracy, which worked well as an input device but failed as a profitable product. In 2008, Motion4U introduced its "OptiBurst" system using IR tracking for use as a Maya (graphics software) plugin.

Apple Desktop Bus

In 1986 Apple first implemented the Apple Desktop Bus allowing the daisy-chaining together of up to 16 devices, including arbitrarily many mice and other devices on the same bus with no configuration whatsoever. Featuring only a single data pin, the bus used a purely polled approach to computer/mouse communications and survived as the standard on mainstream models (including a number of non-Apple workstations) until 1998 when iMac began the industry-wide switch to using USB. Beginning with the "Bronze Keyboard" PowerBook G3 in May 1999, Apple dropped the external ADB port in favor of USB, but retained an internal ADB connection in the PowerBook G4 for communication with its built-in keyboard and trackpad until early 2005.



Apple Macintosh Plus mice, 1986

USB

The industry-standard USB protocol and its connector have become widely used for mice; it's currently among the most popular types.[36]

Operation

A mouse typically controls the motion of a cursor in two dimensions in a graphical user interface (GUI). Clicking or hovering (stopping movement while the cursor is within the bounds of an area) can select files, programs or actions from a list of names, or (in graphical interfaces) through small images called "icons" and other elements. For example, a text file might be represented by a picture of a paper notebook, and clicking while the cursor hovers this icon might cause a text editing program to open the file in a window. (See also point-and-click)

Users can also employ mice *gesturally*; meaning that a stylized motion of the mouse cursor itself, called a "gesture", can issue a command or map to a specific action. For example, in a drawing program, moving the mouse in a rapid "x" motion over a shape might delete the shape.

Gestural interfaces occur more rarely than plain pointing-and-clicking; and people often find them more difficult to use, because they require finer motor-control from the user. However, a few gestural conventions have become widespread, including the drag-and-drop gesture, in which:

1. The user presses the mouse button while the mouse cursor hovers over an interface object
2. The user moves the cursor to a different location while holding the button down
3. The user releases the mouse button

For example, a user might drag-and-drop a picture representing a file onto a picture of a trash can, thus instructing the system to delete the file.

Other uses of the mouse's input occur commonly in special application-domains. In interactive three-dimensional graphics, the mouse's motion often translates directly into changes in the virtual camera's orientation. For example, in the first-person shooter genre of games (see below), players usually employ the mouse to control the direction in which the virtual player's "head" faces: moving the mouse up will cause the player to look up, revealing the view above the player's head. A related function makes an image of an object rotate, so that all sides can be examined.

When mice have more than one button, software may assign different functions to each button. Often, the primary (leftmost in a right-handed configuration) button on the mouse will select items, and the secondary (rightmost in a right-handed) button will bring up a menu of alternative actions applicable to that item. For example, on platforms with more than one button, the Mozilla web browser will follow a link in response to a primary button click, will bring up a contextual menu of alternative actions for that link in response to a secondary-button click, and will often open the link in a new tab or window in response to a click with the tertiary (middle) mouse button.

Different ways of operating the mouse cause specific things to happen in the GUI:

- Click: pressing and releasing a button.
  - (left) Single-click: clicking the main button.
  - (left) Double-click: clicking the button two times in quick succession counts as a different gesture than two separate single clicks.
  - (left) Triple-click: clicking the button three times in quick succession.
  - Right-click: clicking the secondary button.
- Drag: pressing and holding a button, then moving the mouse without releasing. (Use the command "drag with the right mouse button" instead of just "drag" when you instruct a user to drag an object while holding the right mouse button down instead of the more commonly used left mouse button.)
- Button chording (a.k.a. Rocker navigation).
  - Combination of right-click then left-click.

  - Combination of left-click then right-click or keyboard letter.
  - Combination of left or right-click and the mouse wheel.
- Clicking while holding down a modifier key.

Standard semantic gestures include:

- Rollover
- Selection
- Menu traversal
- Drag and drop
- Pointing
- Goal crossing

Multiple-mouse systems

Some systems allow two or more mice to be used at once as input devices. 16-bit era home computers such as the Amiga used this to allow computer games with two players interacting on the same computer. The same idea is sometimes used in collaborative software, e.g. to simulate a whiteboard that multiple users can draw on without passing a single mouse around.

Microsoft Windows, since Windows 98, has supported multiple simultaneous pointing devices. Because Windows only provides a single screen cursor, using more than one device at the same time generally results in seemingly random movements of the cursor. However, the advantage of this support lies not in simultaneous use, but in simultaneous availability for *alternate* use: for example, a laptop user editing a complex document might use a handheld mouse for drawing and manipulation of graphics, but when editing a section of text, use a built-in trackpad to allow movement of the cursor while keeping his hands on the keyboard. Windows' multiple-device support means that the second device is available for use without having to disconnect or disable the first.

As of 2009, Linux distributions and other operating systems that use Xorg, such as OpenSolaris and FreeBSD, support unlimited numbers of cursors and keyboards.

There have also been propositions of having a single operator use two mice simultaneously as a more sophisticated means of controlling various graphics and multimedia applications.[37]

Buttons

Mouse buttons are microswitches which can be pressed ("clicked") in order to select or interact with an element of a graphical user interface.

The three-button scrollmouse has become the most commonly available design. As of 2007 (and roughly since the late 1990s), users most commonly employ the second button to invoke a contextual menu in the computer's software user interface, which contains options specifically tailored to the interface element over which the mouse cursor currently sits. By default, the primary mouse button sits located on the left-hand side of the mouse, for the benefit of right-handed users; left-handed users can usually reverse this configuration via software.

Mouse speed

The computer industry often measures mouse sensitivity in terms of counts per inch (CPI), commonly expressed less correctly as dots per inch (DPI) – the number of steps the mouse will report when it moves one inch. In early mice, this specification was called pulses per inch (ppi).[16] If the default mouse-tracking condition involves moving the cursor by one screen-pixel or dot on-screen per reported step, then the CPI does equate to DPI: dots of cursor motion per inch of mouse motion. The CPI or DPI as reported by manufacturers depends on how they make the mouse; the higher the CPI, the faster the cursor moves with mouse movement. However, software can adjust the mouse sensitivity, making the cursor move faster or slower than its CPI. Current software can change the speed of the cursor dynamically, taking into account the mouse's absolute speed and the movement from the last stop-point. In most software this setting is named "speed", referring to "cursor precision". However, some software names this setting "acceleration", but this term is in fact incorrect. The mouse acceleration, in the majority of mouse software, refers to the setting allowing the user to modify the cursor acceleration: the change in speed of the cursor over time while the mouse movement is constant.

For simple software, when the mouse starts to move, the software will count the number of "counts" received from the mouse and will move the cursor across the screen by that number of pixels (or multiplied by a rate factor, typically less than 1). The cursor will move slowly on the screen, having a good precision. When the movement of the mouse passes the value set for "threshold", the software will start to move the cursor more quickly, with a greater rate factor. Usually, the user can set the value of the second rate factor by changing the "acceleration" setting.

Operating systems sometimes apply acceleration, referred to as "ballistics", to the motion reported by the mouse. For example, versions of Windows prior to Windows XP doubled reported values above a configurable threshold, and then optionally doubled them again above a second configurable threshold. These doublings applied separately in the X and Y directions, resulting in very nonlinear response.[38] Starting with Windows XP and for many OS versions for Apple Macintosh, computers use a ballistics calculation that compensates for screen-resolution in a slightly different way, which affects the way the mouse feels. Ballistics are further affected by the choice of driver software.

Mousepads

Engelbart's original mouse did not require a mousepad;[39] the mouse had two large wheels which could roll on virtually any surface. However, most subsequent mechanical mice starting with the steel roller ball mouse have required a mousepad for optimal performance.

The mousepad, the most common mouse accessory, appears most commonly in conjunction with mechanical mice, because in order to roll smoothly, the ball requires more friction than common desk surfaces usually provide. So-called "hard mousepads" for gamers or optical/laser mice also exist.

Although most optical and laser mice do not require a pad, some users find that using a mousepad provides more comfort and less jitter of the cursor on the display. Whether to use a hard or soft mousepad with an optical mouse is largely a matter of personal preference. One exception occurs when the desk surface creates problems for the optical or laser tracking, for example, a transparent or reflective surface. Other cases may involve keeping desk or table surfaces free of scratches and deterioration; when the grain pattern on the surface causes inaccurate tracking of the cursor, or when the mouse-user desires a more comfortable mousing surface to work on and reduced collection of debris under the mouse.

In the marketplace

Around 1981 Xerox included mice with its Xerox Star, based on the mouse used in the 1970s on the Alto computer at Xerox PARC. Sun Microsystems, Symbolics, Lisp Machines Inc., and Tektronix also shipped workstations with mice, starting in about 1981. Later, inspired by the Star, Apple Computer released the Apple Lisa, which also used a mouse. However, none of these products achieved large-scale success. Only with the release of the Apple Macintosh in 1984 did the mouse see widespread use.

The Macintosh design, commercially successful and technically influential, led many other vendors to begin producing mice or including them with their other computer products (in 1985, Atari ST, Commodore Amiga, Windows 1.0, and GEOS for the Commodore 64). The widespread adoption of graphical user interfaces in the software of the 1980s and 1990s made mice all but indispensable for controlling computers.

In November 2008, Logitech built their billionth mouse.[40]

Use in gaming

Mice often function as an interface for PC-based computer games and sometimes for video game consoles.

First person shooters

Logitech G5 Laser Mouse designed for gaming

Due to the cursor-like nature of the crosshairs in first-person shooter (FPS), a combination of mouse and keyboard provides a popular way to play FPS games. Players use the X-axis of the mouse for looking (or turning) left and right, leaving the Y-axis for looking up and down. The left button usually controls primary fire. Many gamers prefer this primarily in FPS games over a gamepad or joypad because it allows them to look around easily, quickly and accurately. If the game supports multiple fire-modes, the right button often provides secondary fire from the selected weapon. The right button may also provide bonus options for a particular weapon, such as allowing access to the scope of a sniper rifle or allowing the mounting of a bayonet or silencer.

Gamers can use a scroll wheel for changing weapons, or for controlling scope-zoom magnification. On most FPS games, programming may also assign more functions to additional buttons on mice with more than three controls. A keyboard usually controls movement (for example, WASD, for moving forward, left, backward and right, respectively) and other functions such as changing posture. Since the mouse serves for aiming, a mouse that tracks movement accurately and with less lag (latency) will give a player an advantage over players with less accurate or slower mice.

An early technique of players, circle strafing, saw a player continuously strafing while aiming and shooting at an opponent by walking in circle around the opponent with the opponent at the center of the circle. Players could achieve this by holding down a key for strafing while continuously aiming the mouse towards the opponent.

Games using mice for input have such a degree of popularity that many manufacturers, such as Logitech, Cyber Snipa, Razer USA Ltd and SteelSeries, make peripherals such as mice and keyboards specifically for gaming. Such mice may feature adjustable weights, high-resolution optical or laser components, additional buttons, ergonomic shape, and other features such as adjustable DPI.

Many games, such as first- or third-person shooters, have a setting named "invert mouse" or similar (not to be confused with "button inversion", sometimes performed by left-handed users) which allows the user to look downward by moving the mouse forward and upward by moving the mouse backward (the opposite of non-inverted movement). This control system resembles that of aircraft control sticks, where pulling back causes pitch up and pushing forward causes pitch down; computer joysticks also typically emulate this control-configuration.

After id Software's *Doom*, the game that popularized FPS games but which did not support vertical aiming with a mouse (the y-axis served for forward/backward movement), competitor 3D Realms' *Duke Nukem 3D* became one of the first games that supported using the mouse to aim up and down. This and other games using the Build engine had an option to invert the Y-axis. The "invert" feature actually made the mouse behave in a manner that users now regard as non-inverted (by default, moving mouse forward resulted in looking down). Soon after, id Software released *Quake*, which introduced the invert feature as users now know it. Other games using the Quake engine have come on the market following this standard, likely due to the overall popularity of *Quake*.

Home consoles

In 1988 the educational video game system, the VTech Socrates, featured a wireless mouse with an attached mouse pad as an optional controller used for some games. In the early 1990s the Super Nintendo Entertainment System video game system featured a mouse in addition to its controllers. The Mario Paint game in particular used the mouse's capabilities, as did its successor on the Nintendo 64. Sega released official mice for their Genesis/Mega Drive, Saturn and Dreamcast consoles. NEC sold official mice for its PC Engine and PC-FX consoles. Sony Computer Entertainment released an official mouse product for the PlayStation console, and included one along with the Linux for PlayStation 2 kit. However, users can attach virtually any USB mouse to the PlayStation 2 console. In addition the PlayStation 3 also fully supports USB mice. Recently the Wii also has this latest development added on in a recent software update.

See also

- Computer accessibility
- Footmouse
- Graphics tablet
- Gesture recognition
- Human–computer interaction
- Mouse keys
- Pointer trails
- Pointing stick
- Repetitive strain injury
- Touchpad
- Rotational mouse

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External links

- Timeline of Mouse History (Macworld) [43]
- Interview with Doug Engelbart on 40th Anniversary of the Mouse [44]
- The Earliest Computer Mice [45]
- Xerox Alto ball mouse [46]
- Star optical mouse [47]
- Primary Material on the Apple Mouse [48]
- *Of Mice and Zen: Product Design and Invisible Innovation*, by Alex Soojung-Kim Pang [49]PDF (64.9 KiBapplication/pdf, 66545 bytes)
- MouseSite [50] including 1968 demonstration [51]
- Mouse Interrupts in DOS [52]
- The PS/2 mouse interface [53]: Detailed description of the data protocol, including the Microsoft Intellimouse wheel-and-five-buttons extensions
- Serial-port mouse protocols [54]
- howstuffworks.com article on how computer mice work [55]
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Microphone

A **microphone** (colloquially called a **mic** or **mike** (both pronounced English pronunciation: /ˈmaɪk/) is an acoustic-to-electric transducer or sensor that converts sound into an electrical signal. In 1876, Emile Berliner invented the first microphone used as a telephone voice transmitter. Microphones are used in many applications such as telephones, tape recorders, karaoke systems, hearing aids, motion picture production, live and recorded audio engineering, FRS radios, megaphones, in radio and television broadcasting and in computers for recording voice, speech recognition, VoIP, and for non-acoustic purposes such as ultrasonic checking or knock sensors.

A Neumann U87 condenser microphone with shock mount

Most microphones today use electromagnetic induction (dynamic microphone), capacitance change (condenser microphone), piezoelectric generation, or light modulation to produce an electrical voltage signal from mechanical vibration.

Varieties

The sensitive transducer element of a microphone is called its *element* or *capsule*. A complete microphone also includes a housing, some means of bringing the signal from the element to other equipment, and often an electronic circuit to adapt the output of the capsule to the equipment being driven. Microphones are referred to by their transducer principle, such as condenser, dynamic, etc., and by their directional characteristics. Sometimes other characteristics such as diaphragm size, intended use or orientation of the principal sound input to the principal axis (end- or side-address) of the microphone are used to describe the microphone.

Condenser microphone

Inside the Oktava 319 condenser microphone

In a **condenser microphone**,[1] also called a **capacitor microphone** or **electrostatic microphone**, the diaphragm acts as one plate of a capacitor, and the vibrations produce changes in the distance between the plates. There are two methods of extracting an audio output from the transducer thus formed: DC-biased and radio frequency (RF) or high frequency (HF) condenser microphones. With a DC-biased microphone, the plates are biased with a fixed charge (Q). The voltage maintained across the capacitor plates changes with the vibrations in the air, according to the capacitance equation ($C = Q / V$), where Q = charge in coulombs, C = capacitance in farads and V = potential difference in volts. The capacitance of the plates is inversely proportional to the distance between them for a parallel-plate capacitor. (See capacitance for details.) The assembly of fixed and movable plates is called an "element" or "capsule."

A nearly constant charge is maintained on the capacitor. As the capacitance changes, the charge across the capacitor does change very slightly, but at audible frequencies it is sensibly constant. The capacitance of the capsule (around 5–100 pF) and the value of the bias resistor (100 megohms to tens of gigohms) form a filter that is highpass for the audio signal, and lowpass for the bias voltage. Note that the time constant of an RC circuit equals the product of the resistance and capacitance.

Within the time-frame of the capacitance change (as much as 50 ms at 20 Hz audio signal), the charge is practically constant and the voltage across the capacitor changes instantaneously to reflect the change in capacitance. The voltage across the capacitor varies above and below the bias voltage. The voltage difference between the bias and the capacitor is seen across the series resistor. The voltage across the resistor is amplified for performance or recording.

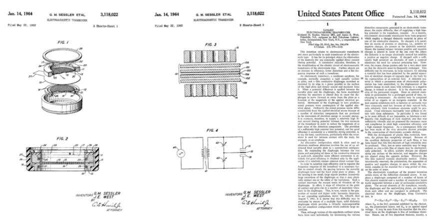
AKG C451B small-diaphragm condenser microphone

RF condenser microphones use a comparatively low RF voltage, generated by a low-noise oscillator. The oscillator may either be amplitude modulated by the capacitance changes produced by the sound waves moving the capsule diaphragm, or the capsule may be part of a resonant circuit that modulates the frequency of the oscillator signal. Demodulation yields a low-noise audio frequency signal with a very low source impedance. The absence of a high bias voltage permits the use of a diaphragm with looser tension, which may be used to achieve wider frequency response due to higher compliance. The RF biasing process results in a lower electrical impedance capsule, a useful byproduct of which is that RF condenser microphones can be operated in damp weather conditions that could create problems in DC-biased microphones with contaminated insulating surfaces. The Sennheiser "MKH" series of microphones use the RF biasing technique.

Condenser microphones span the range from telephone transmitters through inexpensive karaoke microphones to high-fidelity recording microphones. They generally produce a high-quality audio signal and are now the popular choice in laboratory and studio recording applications. The inherent suitability of this technology is due to the very small mass that must be moved by the incident sound wave, unlike other microphone types that require the sound wave to do more work. They require a power source, provided either via microphone outputs as phantom power or from a small battery. Power is necessary for establishing the capacitor plate voltage, and is also needed to power the microphone electronics (impedance conversion in the case of electret and DC-polarized microphones, demodulation or detection in the case of RF/HF microphones). Condenser microphones are also available with two diaphragms that can be electrically connected to provide a range of polar patterns (see below), such as cardioid, omnidirectional, and figure-eight. It is also possible to vary the pattern continuously with some microphones, for example the Røde

NT2000 or CAD M179.

Electret condenser microphone



First patent on foil electret microphone by G. M. Sessler et al. (pages 1 to 3)

An electret microphone is a relatively new type of capacitor microphone invented at Bell laboratories in 1962 by Gerhard Sessler and Jim West.[2] The externally applied charge described above under condenser microphones is replaced by a permanent charge in an electret material. An electret is a ferroelectric material that has been permanently electrically charged or *polarized*. The name comes from *electr*ostatic and magn*et*; a static charge is embedded in an electret by alignment of the static charges in the material, much the way a magnet is made by aligning the magnetic domains in a piece of iron.

Due to their good performance and ease of manufacture, hence low cost, the vast majority of microphones made today are electret microphones; a semiconductor manufacturer[3] estimates annual production at over one billion units. Nearly all cell-phone, computer, PDA and headset microphones are electret types. They are used in many applications, from high-quality recording and lavalier use to built-in microphones in small sound recording devices and telephones. Though electret microphones were once considered low quality, the best ones can now rival traditional condenser microphones in every respect and can even offer the long-term stability and ultra-flat response needed for a measurement microphone. Unlike other capacitor microphones, they require no polarizing voltage, but often contain an integrated preamplifier that does require power (often incorrectly called polarizing power or bias). This preamplifier is frequently phantom powered in sound reinforcement and studio applications. Microphones designed for personal computer (PC) use, sometimes called multimedia microphones, use a stereo 3.5 mm plug (though a mono source) with the ring receiving power via a resistor from (normally) a 5 V supply in the computer; unfortunately, a number of incompatible dynamic microphones are fitted with 3.5 mm plugs too. While few electret microphones rival the best DC-polarized units in terms of noise level, this is not due to any inherent limitation of the electret. Rather, mass production techniques needed to produce microphones cheaply don't lend themselves to the precision needed to produce the highest quality microphones, due to the tight tolerances required in internal dimensions. These tolerances are the same for all condenser microphones, whether the DC, RF or electret technology is used.

Dynamic microphone

Patti Smith singing into a Shure SM58 (dynamic cardioid type) microphone

Dynamic microphones work via electromagnetic induction. They are robust, relatively inexpensive and resistant to moisture. This, coupled with their potentially high gain before feedback makes them ideal for on-stage use.

Moving-coil microphones use the same dynamic principle as in a loudspeaker, only reversed. A small movable induction coil, positioned in the magnetic field of a permanent magnet, is attached to the diaphragm. When sound enters through the windscreen of the microphone, the sound wave moves the diaphragm. When the diaphragm vibrates, the coil moves in the magnetic field, producing a varying current in the coil through electromagnetic induction. A single dynamic membrane does not respond linearly to all audio frequencies. Some microphones for this reason utilize multiple membranes for the different parts of the audio spectrum and then combine the resulting signals. Combining the multiple signals correctly is difficult and designs that do this are rare and tend to be expensive. There are on the other hand several designs that are more specifically aimed towards isolated parts of the audio spectrum. The AKG D 112, for example, is designed for bass response rather than treble.[4] In audio engineering several kinds of microphones are often used at the same time to get the best result.

Edmund Lowe using a ribbon microphone

Ribbon Microphone

Ribbon microphones use a thin, usually corrugated metal ribbon suspended in a magnetic field. The ribbon is electrically connected to the microphone's output, and its vibration within the magnetic field generates the electrical signal. Ribbon microphones are similar to moving coil microphones in the sense that both produce sound by means of magnetic induction. Basic ribbon microphones detect sound in a bi-directional (also called figure-eight) pattern because the ribbon, which is open to sound both front and back, responds to the pressure gradient rather than the sound pressure. Though the symmetrical front and rear pickup can be a nuisance in normal stereo recording, the high side rejection can be used to advantage by positioning a ribbon microphone horizontally, for example above cymbals, so that the rear lobe picks up only sound from the cymbals. Crossed figure 8, or Blumlein pair, stereo recording is gaining in popularity, and the figure 8 response of a ribbon microphone is ideal for that application.

Other directional patterns are produced by enclosing one side of the ribbon in an acoustic trap or baffle, allowing sound to reach only one side. The classic RCA Type 77-DX microphone has several externally adjustable positions of the internal baffle, allowing the selection of several response patterns ranging from "Figure-8" to "Unidirectional". Such older ribbon microphones, some of which still provide high quality sound reproduction, were once valued for this reason, but a good low-frequency response could only be obtained when the ribbon was suspended very loosely, which made them relatively fragile. Modern ribbon materials, including new nanomaterials[5] have now been introduced that eliminate those concerns, and even improve the effective dynamic range of ribbon microphones at low frequencies. Protective wind screens can reduce the danger of damaging a vintage ribbon, and also reduce plosive artifacts in the recording. Properly designed wind screens produce negligible treble attenuation. In common with other classes of dynamic microphone, ribbon microphones don't require phantom power; in fact, this voltage can damage some older ribbon microphones. Some new modern ribbon microphone designs incorporate a preamplifier and, therefore, do require phantom power, and circuits of modern passive ribbon microphones, *i.e.*, those without the aforementioned preamplifier, are specifically designed to resist damage to the ribbon and transformer by phantom power. Also there are new ribbon materials available that are immune to wind blasts and phantom power.

Carbon microphone

A carbon microphone, also known as a carbon button microphone (or sometimes just a button microphone), use a capsule or button containing carbon granules pressed between two metal plates like the Berliner and Edison microphones. A voltage is applied across the metal plates, causing a small current to flow through the carbon. One of the plates, the diaphragm, vibrates in sympathy with incident sound waves, applying a varying pressure to the carbon. The changing pressure deforms the granules, causing the contact area between each pair of adjacent granules to change, and this causes the electrical resistance of the mass of granules to change. The changes in resistance cause a corresponding change in the current flowing through the microphone, producing the electrical signal. Carbon microphones were once commonly used in telephones; they have extremely low-quality sound reproduction and a very limited frequency response range, but are very robust devices. The Boudet Microphone of 1880 using carbon balls was a similar invention like the granule carbon button microphones.[6]

Unlike other microphone types, the carbon microphone can also be used as a type of amplifier, using a small amount of sound energy to control a larger amount of electrical energy. Carbon microphones found use as early telephone repeaters, making long distance phone calls possible in the era before vacuum tubes. These repeaters worked by mechanically coupling a magnetic telephone receiver to a carbon microphone: the faint signal from the receiver was transferred to the microphone, with a resulting stronger electrical signal to send down the line. One illustration of this amplifier effect was the oscillation caused by feedback, resulting in an audible squeal from the old "candlestick" telephone if its earphone was placed near the carbon microphone. The Boudet Microphone of 1881 using carbon balls was the offspring of the powdered carbon button microphones.

Piezoelectric microphone

A **crystal microphone** or **piezo microphone** uses the phenomenon of piezoelectricity — the ability of some materials to produce a voltage when subjected to pressure — to convert vibrations into an electrical signal. An example of this is Rochelle salt (potassium sodium tartrate), which is a piezoelectric crystal that works as a transducer, both as a microphone and as a slimline loudspeaker component. Crystal microphones were once commonly supplied with vacuum tube (valve) equipment, such as domestic tape recorders. Their high output impedance matched the high input impedance (typically about 10 megohms) of the vacuum tube input stage well. They were difficult to match to early transistor equipment, and were quickly supplanted by dynamic microphones for a time, and later small electret condenser devices. The high impedance of the crystal microphone made it very susceptible to handling noise, both from the microphone itself and from the connecting cable.

Piezoelectric transducers are often used as contact microphones to amplify sound from acoustic musical instruments, to sense drum hits, for triggering electronic samples, and to record sound in challenging environments, such as underwater under high pressure. Saddle-mounted pickups on acoustic guitars are generally piezoelectric devices that contact the strings passing over the saddle. This type of microphone is different from magnetic coil pickups commonly visible on typical electric guitars, which use magnetic induction, rather than mechanical coupling, to pick up vibration.

Fiber optic microphone

A fiber optic microphone converts acoustic waves into electrical signals by sensing changes in light intensity, instead of sensing changes in capacitance or magnetic fields as with conventional microphones.[7] [8]


The Optoacoustics 1140 fiber optic microphone

During operation, light from a laser source travels through an optical fiber to illuminate the surface of a tiny, sound-sensitive reflective diaphragm. Sound causes the diaphragm to vibrate, thereby minutely changing the intensity of the light it reflects. The modulated light is then transmitted over a second optical fiber to a photo detector, which transforms the intensity-modulated light into analog or digital audio for transmission or recording. Fiber optic microphones possess high dynamic and frequency range, similar to the best high fidelity conventional microphones.

Fiber optic microphones do not react to or influence any electrical, magnetic, electrostatic or radioactive fields (this is called EMI/RFI immunity). The fiber optic microphone design is therefore ideal for use in areas where conventional microphones are ineffective or dangerous, such as inside industrial turbines or in magnetic resonance imaging (MRI) equipment environments.

Fiber optic microphones are robust, resistant to environmental changes in heat and moisture, and can be produced for any directionality or impedance matching. The distance between the microphone's light source and its photo detector may be up to several kilometers without need for any preamplifier and/or other electrical device, making fiber optic microphones suitable for industrial and surveillance acoustic monitoring.

Fiber optic microphones are used in very specific application areas such as for infrasound monitoring and noise-canceling. They have proven especially useful in medical applications, such as allowing radiologists, staff and patients within the powerful and noisy magnetic field to converse normally, inside the MRI suites as well as in remote control rooms.[9]) Other uses include industrial equipment monitoring and sensing, audio calibration and measurement, high-fidelity recording and law enforcement.

Laser microphone

Laser microphones are often portrayed in movies as spy gadgets. A laser beam is aimed at the surface of a window or other plane surface that is affected by sound. The slight vibrations of this surface displace the returned beam, causing it to trace the sound wave. The vibrating laser spot is then converted back to sound. In a more robust and expensive implementation, the returned light is split and fed to an interferometer, which detects movement of the surface. The former implementation is a tabletop experiment; the latter requires an extremely stable laser and precise optics.

A new type of laser microphone is a device that uses a laser beam and smoke or vapor to detect sound vibrations in free air. On 25 August 2009, U.S. patent 7,580,533 issued for a Particulate Flow Detection Microphone based on a laser-photocell pair with a moving stream of smoke or vapor in the laser beam's path. Sound pressure waves cause disturbances in the smoke that in turn cause variations in the amount of laser light reaching the photo detector. A prototype of the device was demonstrated at the 127th Audio Engineering Society convention in New York City from 9 through 12 October 2009.

Liquid microphone

Early microphones did not produce intelligible speech, until Alexander Graham Bell made improvements including a variable resistance microphone/transmitter. Bell's liquid transmitter consisted of a metal cup filled with water with a small amount of sulfuric acid added. A sound wave caused the diaphragm to move, forcing a needle to move up and down in the water. The electrical resistance between the wire and the cup was then inversely proportional to the size of the water meniscus around the submerged needle. Elisha Gray filed a caveat for a version using a brass rod instead of the needle. Other minor variations and improvements were made to the liquid microphone by Majoranna, Chambers, Vanni, Sykes, and Elisha Gray, and one version was patented by Reginald Fessenden in 1903. These were the first working microphones, but they were not practical for commercial application. The famous first phone conversation between Bell and Watson took place using a liquid microphone.

MEMS microphone

The MEMS (MicroElectrical-Mechanical System) microphone is also called a microphone chip or silicon microphone. The pressure-sensitive diaphragm is etched directly into a silicon chip by MEMS techniques, and is usually accompanied with integrated preamplifier. Most MEMS microphones are variants of the condenser microphone design. Often MEMS microphones have built in analog-to-digital converter (ADC) circuits on the same CMOS chip making the chip a digital microphone and so more readily integrated with modern digital products. Major manufacturers producing MEMS silicon microphones are Wolfson Microelectronics (WM7xxx), Analog Devices, Akustica (AKU200x), Infineon (SMM310 product), Knowles Electronics, Memstech (MSMx), NXP Semiconductors, Sonion MEMS, AAC Acoustic Technologies,[10] and Omron.[11]

Speakers as microphones

A loudspeaker, a transducer that turns an electrical signal into sound waves, is the functional opposite of a microphone. Since a conventional speaker is constructed much like a dynamic microphone (with a diaphragm, coil and magnet), speakers can actually work "in reverse" as microphones. The result, though, is a microphone with poor quality, limited frequency response (particularly at the high end), and poor sensitivity. In practical use, speakers are sometimes used as microphones in applications where high quality and sensitivity are not needed such as intercoms, walkie-talkies or Video game voice chat peripherals, or when conventional microphones are in short supply.

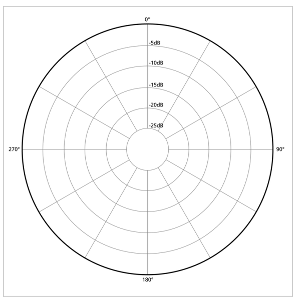
However, there is at least one other practical application of this principle: Using a medium-size woofer placed closely in front of a "kick" (bass drum) in a drum set to act as a microphone. The use of relatively large speakers to transduce low frequency sound sources, especially in music production, is becoming fairly common. A product example of this type of device is the Yamaha Subkick, a 12-inch (300 mm) woofer used in front of kick drums. Since a relatively massive membrane is unable to transduce high frequencies, placing a speaker in front of a kick drum is often ideal for reducing cymbal and snare bleed into the kick drum sound. Less commonly, microphones themselves can be used as speakers, almost always as tweeters. This is less common, since microphones are not designed to handle the power that speaker components are routinely required to cope with. One instance of such an application was the STC microphone-derived 4001 super-tweeter, which was successfully used in a number of high quality loudspeaker systems from the late 1960s to the mid-70s. A well-known example of this use was the Bowers & Wilkins DM2a model.

Capsule design and directivity

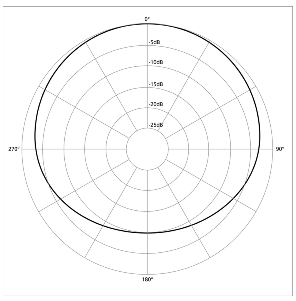
The inner elements of a microphone are the primary source of differences in directivity. A pressure microphone uses a diaphragm between a fixed internal volume of air and the environment, and responds uniformly to pressure from all directions, so it is said to be omnidirectional. A pressure-gradient microphone uses a diaphragm that is at least partially open on both sides. The pressure difference between the two sides produces its directional characteristics. Other elements such as the external shape of the microphone and external devices such as interference tubes can also alter a microphone's directional response. A pure pressure-gradient microphone is equally sensitive to sounds arriving from front or back, but insensitive to sounds arriving from the side because sound arriving at the front and back at the same time creates no gradient between the two. The characteristic directional pattern of a pure pressure-gradient microphone is like a figure-8. Other polar patterns are derived by creating a capsule that combines these two effects in different ways. The cardioid, for instance, features a partially closed backside, so its response is a combination of pressure and pressure-gradient characteristics.[12]

Microphone polar patterns

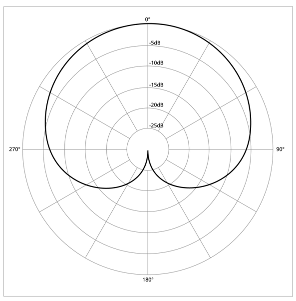
(Microphone facing top of page in diagram, parallel to page):



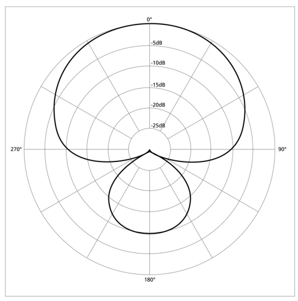
Omnidirectional



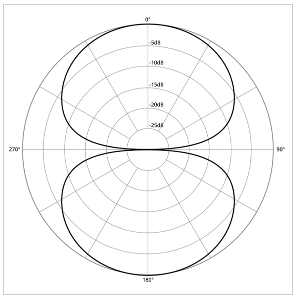
Subcardioid



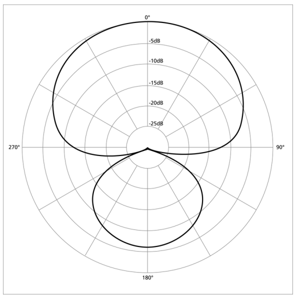
Cardioid



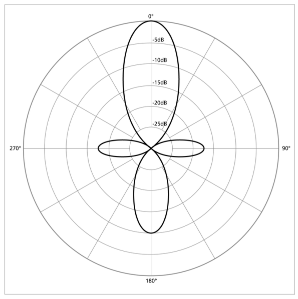
Supercardioid



Bi-directional or Figure of 8



Hypercardioid



Shotgun

A microphone's directionality or polar pattern indicates how sensitive it is to sounds arriving at different angles about its central axis. The polar patterns illustrated above represent the locus of points that produce the same signal level output in the microphone if a given sound pressure level is generated from that point. How the physical body of the microphone is oriented relative to the diagrams depends on the microphone design. For large-membrane microphones such as in the Oktava (pictured above), the upward direction in the polar diagram is usually perpendicular to the microphone body, commonly known as "side fire" or "side address". For small diaphragm microphones such as the Shure (also pictured above), it usually extends from the axis of the microphone commonly known as "end fire" or "top/end address".

Some microphone designs combine several principles in creating the desired polar pattern. This ranges from shielding (meaning diffraction/dissipation/absorption) by the housing itself to electronically combining dual membranes.

Omnidirectional

An omnidirectional (or nondirectional) microphone's response is generally considered to be a perfect sphere in three dimensions. In the real world, this is not the case. As with directional microphones, the polar pattern for an "omnidirectional" microphone is a function of frequency. The body of the microphone is not infinitely small and, as a consequence, it tends to get in its own way with respect to sounds arriving from the rear, causing a slight flattening of the polar response. This flattening increases as the diameter of the microphone (assuming it's cylindrical) reaches the wavelength of the frequency in question. Therefore, the smallest diameter microphone gives the best omnidirectional characteristics at high frequencies.

The wavelength of sound at 10 kHz is little over an inch (3.4 cm) so the smallest measuring microphones are often 1/4" (6 mm) in diameter, which practically eliminates directionality even up to the highest frequencies. Omnidirectional microphones, unlike cardioids, do not employ resonant cavities as delays, and so can be considered the "purest" microphones in terms of low coloration; they add very little to the original sound. Being pressure-sensitive they can also have a very flat low-frequency response down to 20 Hz or below. Pressure-sensitive microphones also respond much less to wind noise and plosives than directional (velocity sensitive) microphones.

An example of a nondirectional microphone is the round black *eight ball*.[13]

Unidirectional

A unidirectional microphone is sensitive to sounds from only one direction. The diagram above illustrates a number of these patterns. The microphone faces upwards in each diagram. The sound intensity for a particular frequency is plotted for angles radially from 0 to 360°. (Professional diagrams show these scales and include multiple plots at different frequencies. The diagrams given here provide only an overview of typical pattern shapes, and their names.)

Cardioids

US664A University Sound Dynamic Supercardioid Microphone

The most common unidirectional microphone is a cardioid microphone, so named because the sensitivity pattern is heart-shaped. A hyper-cardioid microphone is similar but with a tighter area of front sensitivity and a smaller lobe of rear sensitivity. A super-cardioid microphone is similar to a hyper-cardioid, except there is more front pickup and less rear pickup. These three patterns are commonly used as vocal or speech microphones, since they are good at rejecting sounds from other directions.

A cardioid microphone is effectively a superposition of an omnidirectional and a figure-8 microphone; for sound waves coming from the back, the negative signal from the figure-8 cancels the positive signal from the omnidirectional element, whereas for sound waves coming from the front, the two add to each other. A hypercardioid microphone is similar, but with a slightly larger figure-8 contribution. Since pressure gradient transducer microphones are directional, putting them very close to the sound source (at distances of a few centimeters) results in a bass boost. This is known as the proximity effect[14]

Bi-directional

"Figure 8" or bi-directional microphones receive sound from both the front and back of the element. Most ribbon microphones are of this pattern.

Shotgun

An Audio-Technica shotgun microphone

Shotgun microphones are the most highly directional. They have small lobes of sensitivity to the left, right, and rear but are significantly less sensitive to the side and rear than other directional microphones. This results from placing the element at the end of a tube with slots cut along the side; wave cancellation eliminates much of the off-axis sound. Due to the narrowness of their sensitivity area, shotgun microphones are commonly used on television and film sets, in stadiums, and for field recording of wildlife.

Boundary or "PZM"

Several approaches have been developed for effectively using a microphone in less-than-ideal acoustic spaces, which often suffer from excessive reflections from one or more of the surfaces (boundaries) that make up the space. If the microphone is placed in, or in very close proximity to, one of these boundaries, the reflections from that surface are not sensed by the microphone. Initially this was done by placing an ordinary microphone adjacent to the surface, sometimes in a block of acoustically transparent foam. Sound engineers Ed Long and Ron Wickersham developed the concept of placing the diaphragm parallel to and facing the boundary.[15] While the patent has expired, "Pressure

Zone Microphone" and "PZM" are still active trademarks of Crown International, and the generic term "boundary microphone" is preferred. While a boundary microphone was initially implemented using an omnidirectional element, it is also possible to mount a directional microphone close enough to the surface to gain some of the benefits of this technique while retaining the directional properties of the element. Crown's trademark on this approach is "Phase Coherent Cardioid" or "PCC," but there are other makers who employ this technique as well.

Application-specific designs

A lavalier microphone is made for hands-free operation. These small microphones are worn on the body. Originally, they were held in place with a lanyard worn around the neck, but more often they are fastened to clothing with a clip, pin, tape or magnet. The lavalier cord may be hidden by clothes and either run to an RF transmitter in a pocket or clipped to a belt (for mobile use), or run directly to the mixer (for stationary applications).

A wireless microphone transmits the audio as a radio or optical signal rather than via a cable. It usually sends its signal using a small FM radio transmitter to a nearby receiver connected to the sound system, but it can also use infrared waves if the transmitter and receiver are within sight of each other.

A contact microphone picks up vibrations directly from a solid surface or object, as opposed to sound vibrations carried through air. One use for this is to detect sounds of a very low level, such as those from small objects or insects. The microphone commonly consists of a magnetic (moving coil) transducer, contact plate and contact pin. The contact plate is placed directly on the vibrating part of a musical instrument or other surface, and the contact pin transfers vibrations to the coil. Contact microphones have been used to pick up the sound of a snail's heartbeat and the footsteps of ants. A portable version of this microphone has recently been developed. A throat microphone is a variant of the contact microphone that picks up speech directly from a person's throat, which it is strapped to. This lets the device be used in areas with ambient sounds that would otherwise make the speaker inaudible.

A parabolic microphone uses a parabolic reflector to collect and focus sound waves onto a microphone receiver, in much the same way that a parabolic antenna (e.g. satellite dish) does with radio waves. Typical uses of this microphone, which has unusually focused front sensitivity and can pick up sounds from many meters away, include nature recording, outdoor sporting events, eavesdropping, law enforcement, and even espionage. Parabolic microphones are not typically used for standard recording applications, because they tend to have poor low-frequency response as a side effect of their design.

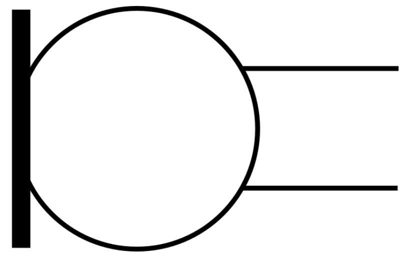
A stereo microphone integrates two microphones in one unit to produce a stereophonic signal. A stereo microphone is often used for broadcast applications or field recording where it would be impractical to configure two separate condenser microphones in a classic X-Y configuration (see microphone practice) for stereophonic recording. Some such microphones have an adjustable angle of coverage between the two channels.

A noise-canceling microphone is a highly directional design intended for noisy environments. One such use is in aircraft cockpits where they are normally installed as boom microphones on headsets. Another use is on loud concert stages for vocalists. Many noise-canceling microphones combine signals received from two diaphragms that are in opposite electrical polarity or are processed electronically. In dual diaphragm designs, the main diaphragm is mounted closest to the intended source and the second is positioned farther away from the source so that it can pick up environmental sounds to be subtracted from the main diaphragm's signal. After the two signals have been combined, sounds other than the intended source are greatly reduced, substantially increasing intelligibility. Other noise-canceling designs use one diaphragm that is affected by ports open to the sides and rear of the microphone, with the sum being a 16 dB rejection of sounds that are farther away. One noise-canceling headset design using a single diaphragm has been used prominently by vocal artists such as Garth Brooks and Janet Jackson.[16] A few noise-canceling microphones are throat microphones.

Connectors

The most common connectors used by microphones are:

- Male XLR connector on professional microphones
- ¼ inch (sometimes referred to as 6.5 mm) jack plug also known as 1/4 inch TRS connector on less expensive consumer microphones. Many consumer microphones use an unbalanced 1/4 inch phone jack. Harmonica microphones commonly use a high impedance 1/4 inch TS connection to be run through guitar amplifiers.
- 3.5 mm (sometimes referred to as 1/8 inch mini) stereo (wired as mono) mini phone plug on very inexpensive and computer microphones



Electronic symbol for a microphone

Some microphones use other connectors, such as a 5-pin XLR, or mini XLR for connection to portable equipment. Some lavalier (or 'lapel', from the days of attaching the microphone to the news reporters suit lapel) microphones use a proprietary connector for connection to a wireless transmitter. Since 2005, professional-quality microphones with USB connections have begun to appear, designed for direct recording into computer-based software.

Impedance-matching

Microphones have an electrical characteristic called impedance, measured in ohms (Ω), that depends on the design. Typically, the *rated impedance* is stated.[17] Low impedance is considered under 600 Ω. Medium impedance is considered between 600 Ω and 10 kΩ. High impedance is above 10 kΩ. Condenser microphones (after the built-in preamp) typically have an output impedance between 50 and 200 ohms.[18]

The output of a given microphone delivers the same power whether it is low or high impedance. If a microphone is made in high and low impedance versions, the high impedance version has a higher output voltage for a given sound pressure input, and is suitable for use with vacuum-tube guitar amplifiers, for instance, which have a high input impedance and require a relatively high signal input voltage to overcome the tubes' inherent noise. Most professional microphones are low impedance, about 200 Ω or lower. Professional vacuum-tube sound equipment incorporates a transformer that steps up the impedance of the microphone circuit to the high impedance and voltage needed to drive the input tube; the impedance conversion inherently creates voltage gain as well. External matching transformers are also available that can be used in-line between a low impedance microphone and a high impedance input.

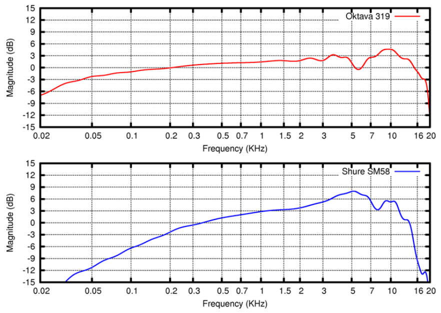
Low-impedance microphones are preferred over high impedance for two reasons: one is that using a high-impedance microphone with a long cable results in high frequency signal loss due to cable capacitance, which forms a low-pass filter with the microphone output impedance. The other is that long high-impedance cables tend to pick up more hum (and possibly radio-frequency interference (RFI) as well). Nothing is damaged if the impedance between microphone and other equipment is mismatched; the worst that happens is a reduction in signal or change in frequency response.

Most microphones are designed *not* to have their impedance matched by the load they are connected to.[19] Doing so can alter their frequency response and cause distortion, especially at high sound pressure levels. Certain ribbon and dynamic microphones are exceptions, due to the designers' assumption of a certain load impedance being part of the internal electro-acoustical damping circuit of the microphone.[20]

Digital microphone interface

The AES 42 standard, published by the Audio Engineering Society, defines a digital interface for microphones. Microphones conforming to this standard directly output a digital audio stream through an XLR male connector, rather than producing an analog output. Digital microphones may be used either with new equipment with appropriate input connections that conform to the AES 42 standard, or else via a suitable interface box. Studio-quality microphones that operate in accordance with the AES 42 standard are now available from a number of microphone manufacturers.

Measurements and specifications



A comparison of the far field on-axis frequency response of the Oktava 319 and the Shure SM58

Because of differences in their construction, microphones have their own characteristic responses to sound. This difference in response produces non-uniform phase and frequency responses. In addition, microphones are not uniformly sensitive to sound pressure, and can accept differing levels without distorting. Although for scientific applications microphones with a more uniform response are desirable, this is often not the case for music recording, as the non-uniform response of a microphone can produce a desirable coloration of the sound. There is an international standard for microphone specifications,[17] but few manufacturers adhere to it. As a result, comparison of published data from different manufacturers is difficult because different measurement techniques are used. The Microphone Data Website has collated the technical specifications complete with pictures, response curves and technical data from the microphone manufacturers for every currently listed microphone, and even a few obsolete models, and shows the data for them all in one common format for ease of comparison.[21]. Caution should be used in drawing any solid conclusions from this or any other published data, however, unless it is known that the manufacturer has supplied specifications in accordance with IEC 60268-4.

A frequency response diagram plots the microphone sensitivity in decibels over a range of frequencies (typically at least 0–20 kHz), generally for perfectly on-axis sound (sound arriving at 0° to the capsule). Frequency response may be less informatively stated textually like so: "30 Hz–16 kHz ±3 dB". This is interpreted as meaning a nearly flat, linear, plot between the stated frequencies, with variations in amplitude of no more than plus or minus 3 dB. However, one cannot determine from this information how *smooth* the variations are, nor in what parts of the spectrum they occur. Note that commonly made statements such as "20 Hz–20 kHz" are meaningless without a decibel measure of tolerance. Directional microphones' frequency response varies greatly with distance from the sound source, and with the geometry of the sound source. IEC 60268-4 specifies that frequency response should be measured in *plane progressive wave* conditions (very far away from the source) but this is seldom practical. *Close talking* microphones may be measured with different sound sources and distances, but there is no standard and therefore no way to compare data from different models unless the measurement technique is described.

The self-noise or equivalent noise level is the sound level that creates the same output voltage as the microphone does in the absence of sound. This represents the lowest point of the microphone's dynamic range, and is particularly important should you wish to record sounds that are quiet. The measure is often stated in dB(A), which is the equivalent loudness of the noise on a decibel scale frequency-weighted for how the ear hears, for example: "15 dBA SPL" (SPL means sound pressure level relative to 20 micropascals). The lower the number the better. Some microphone manufacturers state the noise level using ITU-R 468 noise weighting, which more accurately represents the way we hear noise, but gives a figure some 11–14 dB higher. A quiet microphone typically measures 20 dBA SPL or 32 dB SPL 468-weighted. Very quiet microphones have existed for years for special applications, such the Brüel & Kjaer 4179, with a noise level around 0 dB SPL. Recently some microphones with low noise specifications have been introduced in the studio/entertainment market, such as models from Neumann and Røde that advertise noise levels between 5–7 dBA. Typically this is achieved by altering the frequency response of the capsule and electronics to result in lower noise within the A-weighting curve while broadband noise may be increased.

The maximum SPL (sound pressure level) the microphone can accept is measured for particular values of total harmonic distortion (THD), typically 0.5%. This amount of distortion is generally inaudible, so one can safely use the microphone at this SPL without harming the recording. Example: "142 dB SPL peak (at 0.5% THD)". The higher the value, the better, although microphones with a very high maximum SPL also have a higher self-noise.

The clipping level is perhaps a better indicator of maximum usable level, as the 1% THD figure usually quoted under max SPL is really a very mild level of distortion, quite inaudible especially on brief high peaks. Harmonic distortion from microphones is usually of low-order (mostly third harmonic) type, and hence not very audible even at 3-5%. Clipping, on the other hand, usually caused by the diaphragm reaching its absolute displacement limit (or by the preamplifier), produces a harsh sound on peaks, and should be avoided if at all possible. For some microphones the clipping level may be much higher than the max SPL.

The dynamic range of a microphone is the difference in SPL between the noise floor and the maximum SPL. If stated on its own, for example "120 dB", it conveys significantly less information than having the self-noise and maximum SPL figures individually.

Sensitivity indicates how well the microphone converts acoustic pressure to output voltage. A high sensitivity microphone creates more voltage and so needs less amplification at the mixer or recording device. This is a practical concern but is not directly an indication of the mic's quality, and in fact the term sensitivity is something of a misnomer, 'transduction gain' being perhaps more meaningful, (or just "output level") because true sensitivity is generally set by the noise floor, and too much "sensitivity" in terms of output level compromises the clipping level. There are two common measures. The (preferred) international standard is made in millivolts per pascal at 1 kHz. A higher value indicates greater sensitivity. The older American method is referred to a 1 V/Pa standard and measured in plain decibels, resulting in a negative value. Again, a higher value indicates greater sensitivity, so −60 dB is more sensitive than −70 dB.

Measurement microphones

Some microphones are intended for testing speakers, measuring noise levels and otherwise quantifying an acoustic experience. These are calibrated transducers and are usually supplied with a calibration certificate that states absolute sensitivity against frequency. The quality of measurement microphones is often referred to using the designations "Class 1," "Type 2" etc., which are references not to microphone specifications but to sound level meters.[22] A more comprehensive standard[23] for the description of measurement microphone performance was recently adopted.

Measurement microphones are generally scalar sensors of pressure; they exhibit an omnidirectional response, limited only by the scattering profile of their physical dimensions. Sound intensity or sound power measurements require pressure-gradient measurements, which are typically made using arrays of at least two microphones, or with hot-wire anemometers.

Microphone calibration techniques

To take a scientific measurement with a microphone, its precise sensitivity must be known (in volts per pascal). Since this may change over the lifetime of the device, it is necessary to regularly calibrate measurement microphones. This service is offered by some microphone manufacturers and by independent certified testing labs. All microphone calibration is ultimately traceable to primary standards at a national measurement institute such as NPL in the UK, PTB in Germany and NIST in the USA, which most commonly calibrate using the reciprocity primary standard. Measurement microphones calibrated using this method can then be used to calibrate other microphones using comparison calibration techniques.

Depending on the application, measurement microphones must be tested periodically (every year or several months, typically) and after any potentially damaging event, such as being dropped (most such mikes come in foam-padded cases to reduce this risk) or exposed to sounds beyond the acceptable level.

Pistonphone apparatus

A pistonphone is an acoustical calibrator (sound source) using a closed coupler to generate a precise sound pressure for the calibration of instrumentation microphones. The principle relies on a piston mechanically driven to move at a specified cyclic rate, pushing on a fixed volume of that the tested microphone is exposed to. The air is assumed to be compressed adiabatically and the sound pressure level in the chamber can be calculated from internal physical dimensions of the device and the adiabatic gas law, which requires that PV^{γ} is a constant, where P is the pressure in the chamber, V is the volume of the chamber, and γ is the ratio of the specific heat of air at constant pressure to its specific heat at constant volume. The pistonphone method only works at low frequencies, but it can be accurate and yields an easily calculable sound pressure level. The standard test frequency is usually around 250 Hz.

Reciprocal method

This method relies on the reciprocity of one or more microphones in a group of 3 to be calibrated. It can be performed in a closed coupler or in the free field. Only one of the microphones need be reciprocal (exhibits equal response when used as a microphone or as a loudspeaker).

Microphone array and array microphones

A microphone array is any number of microphones operating in tandem. There are many applications:

- Systems for extracting voice input from ambient noise (notably telephones, speech recognition systems, hearing aids)
- Surround sound and related technologies
- Locating objects by sound: acoustic source localization, e.g. military use to locate the source(s) of artillery fire. Aircraft location and tracking.
- High fidelity original recordings
- 3D spatial beamforming for localized acoustic detection of subcutaneous sounds

Typically, an array is made up of omnidirectional microphones distributed about the perimeter of a space, linked to a computer that records and interprets the results into a coherent form.

Microphone windscreens

Windscreens[24] are used to protect microphones that would otherwise be buffeted by wind or vocal plosives from consonants such as "P", "B", etc. Most microphones have an integral windscreen built around the microphone diaphragm. A screen of plastic, wire mesh or a metal cage is held at a distance from the microphone diaphragm, to shield it. This cage provides a first line of defense against the mechanical impact of objects or wind. Some microphones, such as the Shure SM58, may have an additional layer of foam inside the cage to further enhance the protective properties of the shield. Beyond integral microphone windscreens, there are three broad classes of additional wind protection.

One disadvantage of all windscreen types is that the microphone's high frequency response is attenuated by a small amount, depending on the density of the protective layer.

Microphone covers

Microphone covers are often made of soft open-cell polyester or polyurethane foam because of the inexpensive, disposable nature of the foam. Optional windscreens are often available from the manufacturer and third parties. A visible example of an optional accessory windscreen is the A2WS from Shure, one of which is fitted over each of the two Shure SM57 microphones used on the United States president's lectern.[25] One disadvantage of polyurethane foam microphone covers is that they can deteriorate over time. Windscreens also tend to collect dirt and moisture in their open cells and must be cleaned to prevent high frequency loss, bad odor and unhealthy conditions for the person using the microphone. On the other hand, a major advantage of concert vocalist windscreens is that one can quickly change to a clean windscreen between users, reducing the chance of transferring germs. Windscreens of various colors can be used to distinguish one microphone from another on a busy, active stage.

Pop filters

Pop filters or pop screens are used in controlled studio environments to minimize plosives when recording. A typical pop filter is composed of one or more layers of acoustically transparent gauze-like material, such as woven nylon stretched over a circular frame and a clamp and a flexible mounting bracket to attach to the microphone stand. The pop shield is placed between the vocalist and the microphone. The need for a pop filter increases the closer a vocalist brings his lips the microphone. Singers can be trained either to soften their plosives or direct the air blast away from the microphone, in which cases they don't need a pop filter.

Pop filters also keep spittle off the microphone. Most condenser microphones can be damaged by spittle.

Blimps

Two recordings being made—A *blimp* is being used on the left. An open-cell foam windscreen is being used on the right.

Blimps (also known as Zeppelins) are large, hollow windscreens used to surround microphones for outdoor location audio, such as nature recording, electronic news gathering, and for film and video shoots. They can cut wind noise by as much as 25 dB, especially low-frequency noise. The blimp is essentially a hollow cage or basket with acoustically transparent material stretched over the outer frame. The blimp works by creating a volume of still air around the microphone. The microphone is often further isolated from the blimp by an elastic suspension inside the basket. This reduces wind vibrations and handling noise transmitted from the cage. To extend the range of wind speed conditions in which the blimp remains effective, many have the option of a secondary cover over the outer shell. This is usually an acoustically transparent, synthetic fur material with long, soft hairs (often called a "deadcat" or "windmuff"). The hairs act as shock absorbers to any wind turbulence hitting the blimp. A synthetic fur cover can reduce wind noise by an additional 10 dB.[26]

See also

- Loudspeaker (the inverse of a microphone)
- Hydrophone (microphone for underwater use)
- Geophone (microphone for use within the earth)
- Ionophone (plasma-based microphone)
- Microphone connector
- Microphone practice
- Microphone preamplifier
- A-weighting
- Button microphone
- ITU-R 468 noise weighting
- Nominal impedance — Information about impedance matching for audio components
- Sound pressure level

- Wireless microphone
- XLR connector — The 3-pin variant of which connects microphones
- Shock mount - Microphone mount that suspends the microphone in elastic straps

External links

- Info, Pictures and Soundbytes from vintage microphones [27]
- Microphone sensitivity conversion — dB re 1 V/Pa and transfer factor mV/Pa [28]
- Searchable database of specs and component info from 600+ microphones [29]
- Microphone construction and basic placement advice [30]
- Microphone for Computer [31]
- History of the Microphone [32]
- Large vs. Small Diaphragms in Omnidirectional Microphones [33]
- Guide to Condenser Microphones [34]
- Measurement/Engineering Grade Microphone Basics [35]

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[35] http://www.pcb.com/Linked_Documents/Vibration/Microphone_Handbook.pdf

Webcam

A **webcam** is a video capture device connected to a computer or computer network, often using a USB port or, if connected to a network, ethernet or Wi-Fi.

Typical low-cost webcam used with many personal computers

The most popular use is for videotelephony, permitting a computer to act as a videophone or video conferencing station. This can be used in messenger programs such as Windows Live Messenger, Skype and Yahoo! messenger services. Other popular uses, which include the recording of video files or even still-images, are accessible via numerous software programs, applications and devices.

Webcams are known for low manufacturing costs and flexibility,[1] making them the lowest cost form of videotelephony.

The term 'webcam' may also be used in its original sense of a video camera connected to the Web continuously for an indefinite time, rather than for a particular session, generally supplying a view for anyone who visits its web page over the Internet. Some of these, for example those used as online traffic cameras, are expensive, rugged professional video cameras.

History

First employed in 1991, a webcam was pointed at the Trojan room coffee pot in the computer science department of Cambridge University. The camera was finally switched off on August 22, 2001. The final image captured by the camera can still be viewed at its homepage.[2] [3] The oldest webcam still operating is FogCam at San Francisco State University, which has been running continuously since 1994.[4]

One of the most widely reported-on webcam sites was JenniCam, started in 1996, which allowed Internet users to constantly observe the life of its namesake, somewhat like reality TV series *Big Brother*, launched three years later.[5] More recently, the website Justin.tv has shown a continuous video and audio stream from a mobile camera mounted on the head of the site's star. Other cameras are mounted at bridges, public squares and other public places, their output made available on a public Web page in accordance with the original concept of a "webcam".

Around the turn of the century, computer hardware manufacturers began building webcams directly into laptop and desktop screens, thus eliminating the need to use an external USB or Firewire camera. Gradually webcams came to be used more for communication between two people, or among a few people, than for offering a view on a Web page for an unknown public.

Video calling and conferencing

Live birth: in July 2004 an armed services NCO was able to view the arrival of his new child via a webcam over the Internet

As webcam capabilities have been added to instant messaging, text chat services such as AOL Instant Messenger, one-to-one live video communication over the Internet has now reached millions of mainstream PC users worldwide. Improved video quality has helped webcams encroach on traditional video conferencing systems. New features such as automatic lighting controls, real-time enhancements (retouching, wrinkle smoothing and vertical stretch), automatic face tracking and autofocus assist users by providing substantial ease-of-use, further increasing the popularity of webcams.

Webcam features and performance can vary by program, computer operating system and also by the computer's processor capabilities. For example, *'high-quality video'* is principally available to users of certain Logitech webcams if their computers have dual-core processors meeting certain specifications. Video calling support has also been added to several popular instant messaging programs.

Some online video broadcasting sites have taken advantage of this technology to create Internet television programs centered around two (or more) people "diavlogging" with each other from different locations. Among others, BloggingHeads.tv uses this technology to enable conversations between prominent journalists, scientists, bloggers, and philosophers.

Sign language communications via webcam

Main articles: Video Relay Service, a telecommunication service for deaf, hard-of-hearing and speech-impaired (mute) individuals communicating with hearing persons at a different location, and Video Remote Interpreting, used where deaf/hard-of-hearing/mute persons are in the same location as their hearing parties

Video Interpreter sign used at VRS/VRI service locations

One of the first demonstrations of the ability for telecommunications to help sign language users communicate with each other occurred when AT&T's videophone (trademarked as the 'Picturephone') was introduced to the public at the 1964 New York World's Fair –two deaf users were able to freely communicate with each other between the fair and another city.[6] Various other organizations have also conducted research on signing via videotelephony.

A deaf or hard-of-hearing person at his workplace using a **VRS to communicate with a hearing person** in London.
Courtesy: SignVideo [7]

Using such video equipment, the deaf, hard-of-hearing and speech-impaired can communicate between themselves and with hearing individuals using sign language. The United States and several other countries compensate companies to provide 'Video Relay Services' (VRS). Telecommunication equipment can be used to talk to others via a sign language interpreter, who uses a conventional telephone at the same time to communicate with the deaf person's party. Video equipment is also used to do on-site sign language translation via Video Remote Interpreting (VRI). The relative low cost and widespread availability of 3G mobile phone technology with video calling capabilities have given deaf and speech-impaired users a greater ability to communicate with the same ease as others. Some wireless operators have even started free sign language gateways.

Sign language interpretation services via VRS or by VRI are useful in the present-day where one of the parties is deaf, hard-of-hearing or speech-impaired (mute). In such cases the interpretation flow is normally within the same principal language, such as French Sign Language (FSL) to spoken French, Spanish Sign Language (SSL) to spoken Spanish, British Sign Language (BSL) to spoken English, and American Sign Language (ASL) also to spoken English (since BSL and ASL are completely distinct), etc.... Multilingual sign language interpreters, who can also translate as well across principal languages (such as to and from SSL, to and from spoken English), are also available, albeit less frequently. Such activities involve considerable effort on the part of the translator, since sign languages are distinct natural languages with their own construction, semantics and syntax, different from the aural version of the same principal language.

A **Video Interpreter** (V.I.) assisting an on-screen client.

With video interpreting, sign language interpreters work remotely with live video and audio feeds, so that the interpreter can see the deaf or mute party, and converse with the hearing party, and vice versa. Much like telephone interpreting, video interpreting can be used for situations in which no on-site interpreters are available. However, video interpreting cannot be used for situations in which all parties are speaking via telephone alone. VRI and VRS interpretation requires all parties to have the necessary equipment. Some advanced equipment enables interpreters to remotely control the video camera, in order to zoom in and out or to point the camera toward the party that is signing.

Video security

Webcams are also used as security cameras. Software is available to allow PC-connected cameras to watch for movement and sound, recording both when they are detected; these recordings can then be saved to the computer, e-mailed or uploaded to the Internet. In one well-publicised case,[8] a computer e-mailed out images as the burglar stole it, allowing the owner to give police a clear picture of the burglar's face even after the computer had been stolen.

Input control device

Special software can use the video stream from a webcam to assist or enhance a user's control of applications and games. Video features, including faces, shapes, models and colors can be observed and tracked to produce a corresponding form of control. For example, the position of a single light source can be tracked and used to emulate a mouse pointer, a head mounted light would allow hands-free computing and would greatly improve computer accessibility. This can also be applied to games, providing additional control, improved interactivity and immersiveness.

FreeTrack is a free webcam motion tracking application for Microsoft Windows that can track a special head mounted model in up to six degrees of freedom and output data to mouse, keyboard, joystick and FreeTrack supported games. TrackIR is a commercial version of this technology utilising IR light, which has the advantage of being invisible to the naked eye, removing a distraction from the user.

The EyeToy for the PlayStation 2 (The updated PlayStation 3 equivalent is the PlayStation Eye) and similarly the Xbox Live Vision Camera and the Kinect AKA 'Project Natal' for the Xbox 360 and Xbox Live are color digital cameras that have been used as control input devices by some games.

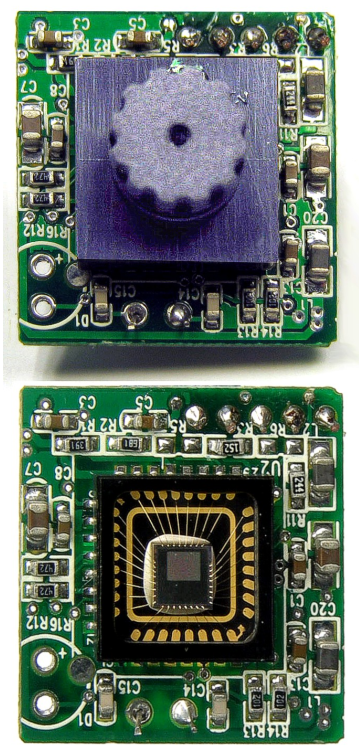
Small webcam-based PC games are available as either standalone executables or inside web browser windows using Adobe Flash.

Aggregators

Due to the increasing number of webcams throughout the world, aggregator websites have arisen, allowing users to find live video streams based on location or other criteria. Aggregators provide collections of thousands of live video streams or up-to-date still pictures.

Technology

Webcams typically include a lens, an image sensor, and some support electronics. Various lenses are available, the most common in consumer-grade webcams being a plastic lens that can be screwed in and out to set the camera's focus. Fixed focus lenses, which have no provision for adjustment, are also available. As a camera system's depth of field is greater for small imager formats and is greater for lenses with a large f-number (small aperture), the systems used in webcams have sufficiently large depth of field that the use of a fixed focus lens does not impact image sharpness much. Image sensors can be CMOS or CCD, the former being dominant for low-cost cameras, but CCD cameras do not necessarily outperform CMOS-based cameras in the low cost price range. Most consumer webcams are capable of providing VGA-resolution video at a frame rate of 30 frames per second. Many newer devices can produce video in multi-megapixel resolutions, and a few can run at high frame rates such as the PlayStation Eye, which can produce 320×240 video at 120 frames per second.



Webcams typically include a lens (shown at top), an image sensor (shown bottom), and supporting circuitry.

Support electronics are present to read the image from the sensor and transmit it to the host computer. The camera pictured to the right, for example, uses a Sonix SN9C101 to transmit its image over USB. Some cameras, such as mobile phone cameras, use a CMOS sensor with supporting electronics "on die", i.e. the sensor and the support electronics are built on a single silicon chip to save space and manufacturing costs. Most webcams feature built-in microphones to make video calling and videoconferencing more convenient.

The USB video device class (UVC) specification allows for interconnectivity of webcams to computers even without proprietary drivers installed. Microsoft Windows XP SP2, Linux[9] and Mac OS X (since October 2005) have UVC drivers built in and do not require extra drivers, although they are often installed in order to add additional features.

Privacy

Many users do not wish the continuous exposure for which webcams were originally intended, but rather prefer privacy. Such privacy is lost when 'Trojan horse' programs allow malicious hackers to activate the camera without the user's knowledge, providing hackers with a live video feed. Cameras such as Apple's older external iSight cameras include lens covers to thwart this. Most other webcams have a built-in LED that lights up whenever the camera is active (such as Apple's newer internal iSight).

In mid-January 2005 some search engine queries were published in an on-line forum[10] which allow anyone to find thousands of Panasonic- and Axis-made high-end web cameras, provided that they have a web-based interface for remote viewing. Many such cameras are running on default configuration, which does not require any password login or IP address verification, making them visible to anyone.

Effects on modern society

Webcams allow for inexpensive, real-time video chat and webcasting, in both amateur and professional pursuits. They are frequently used in online dating. YouTube is a popular website hosting many videos made using webcams. News websites such as the BBC can also produce professional live news videos.[11]

On 23 March 2007, a man named Kevin Whitrick committed cyber suicide live on the internet in front of viewers in a chat room website.[12]

Videotelephony descriptive names & terminology

Videophone calls (or *'videocalls'),* differ from **videoconferencing** in that they expect to serve individuals, not groups. However that distinction has becoming increasingly blurred with technology improvements such as increased bandwidth and sophisticated software clients that can allow for multiple parties on a call. In general everyday usage the term *videoconferencing* is now frequently used instead of *videocall* for point-to-point calls between two units. Both videophone calls and videoconferencing are also now commonly referred to as a *'video link'.*

Webcams are popular, relatively low cost devices which can provide live video and audio streams via personal computers, and can be used with many software clients for video calls.[13]

A **videoconference system** is generally higher cost than a videophone and deploys greater capabilities. A *videoconference* (also known as a videoteleconference) allows two or more locations to communicate via live, simultaneous two-way video and audio transmissions. This is often accomplished by the use of a multipoint control unit (a centralized distribution and call management system) or by a similar non-centralized multipoint capability embedded in each videoconferencing unit. Again, technology improvements have circumvented traditional definitions by allowing multiple party videoconferencing via web-based applications.[14] [15] A separate webpage article is devoted to videoconferencing.

A **telepresence system** is a high-end videoconferencing system and service usually employed by enterprise-level corporate offices. Telepresence conference rooms use state-of-the art room designs, video cameras, displays, sound-systems and processors, coupled with high-to-very-high capacity bandwidth transmissions.

Typical uses of the various technologies described above include videocalling or videoconferencing on a one-to-one, one-to-many or many-to-many basis for personal, business, educational, deaf Tele-Relay and tele-medical, diagnostic and rehabilitative use or services. New services utilizing videocalling and videoconferencing, such as personal videocalls to inmates incarcerated in penitentiaries, and videoconferencing to resolve airline engineering issues at maintenance facilities, are being created or evolving on an on-going basis.

See also

- List of digital camera brands
- List of video telecommunication services and product brands
- Video camera
- Videoconferencing
- Videophone
- Videotelephony
- Adult videochat

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Output Device

Output device

An **output device** is any piece of computer hardware equipment used to communicate the results of data processing carried out by an information processing system (such as a computer) to the outside world.

In computing, input/output, or I/O, refers to the communication between an information processing system (such as a computer), and the outside world. Inputs are the signals or data sent to the system, and outputs are the signals or data sent by the system to the outside.

Examples of output devices:

- Speaker
- Headphones
- Screen (Monitor)
- Printer

See also

- Graphical user interfaces
- CAD
- Computer-controlled milling machines
- Rapid prototyping
- Digital image processing
- Vector graphics vs. Raster graphics
- Graphics card
- Graphics chip
- Computer graphics

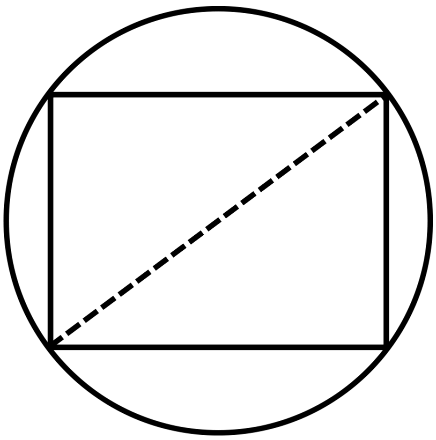
Computer monitor

A **monitor** or **display** (sometimes called a **visual display unit**) is an electronic visual display for computers. The monitor comprises the display device, circuitry, and an enclosure. The display device in modern monitors is typically a thin film transistor liquid crystal display (TFT-LCD), while older monitors use a cathode ray tube (CRT).


A 19-inch LG flat-panel LCD monitor.

Screen size

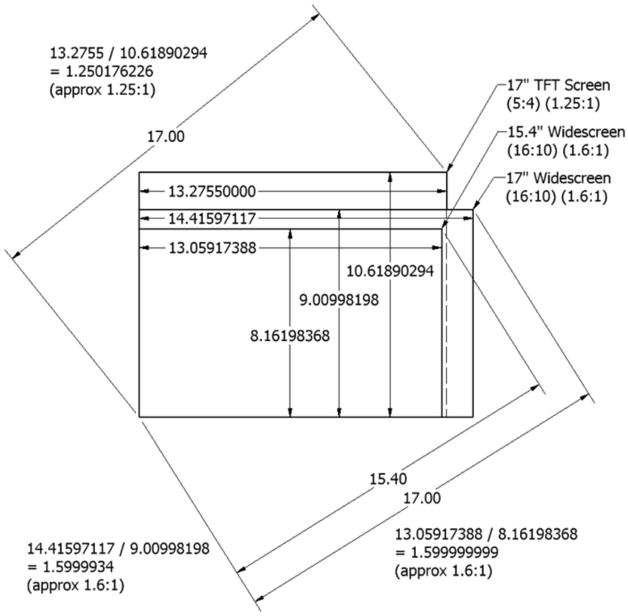
The size of an approximately rectangular display is usually given as the distance between two opposite screen corners, that is, the diagonal of the rectangle. One problem with this method is that it does take into account the fact that when a rectangle with a given length to its diagonal, becomes more rectangular, and less square (its aspect ratio increases), and at the same time its diagonal remains the same, then the area of the rectangle decreases. That is, given the same diagonal, the area of the display decreases if its aspect ratios increases. For example, a 4:3 21 in (53 cm) monitor has an area of about 211 sq in (1360 cm^2), while a 16:9 21-inch widescreen has about 188 sq in (1210 cm^2).


For any rectangular section on a round tube, the diagonal measurement is also the diameter of the tube

This method of measurement is inherited from the method used for the first generation of CRT television, when picture tubes with circular faces were in common use. Being circular, only their diameter was needed to describe their size. Since these circular tubes were used to display rectangular images, the diagonal measurement of the rectangle was equivalent to the diameter of the tube's face.

This method continued even when cathode ray tubes were manufactured as rounded rectangles.

Another problematic practice was using the size of a monitor's imaging element, rather than the size of its viewable image, when describing its size in publicity and advertising materials. Especially on CRT displays, a substantial portion of the imaging element is concealed behind the case's bezel or shroud in order to hide areas outside the monitor's safe area due to overscan. Seen as deceptive, widespread consumer objection and lawsuits eventually forced most manufacturers to instead measure viewable size.



The area of displays with identical diagonal measurements can vary substantially

Performance measurements

The performance of a monitor is measured by the following parameters:

- Luminance is measured in candelas per square meter.
- Viewable image size is measured diagonally. For CRTs, the viewable size is typically 1 in (25 mm) smaller than the tube itself.
- Aspect ratios is the ratio of the horizontal length to the vertical length. 4:3 is the standard aspect ratio, for example, so that a screen with a width of 1024 pixels will have a height of 768 pixels. If a widescreen display has an aspect ratio of 16:9, a display that is 1024 pixels wide will have a height of 576 pixels.
- Display resolution is the number of distinct pixels in each dimension that can be displayed. Maximum resolution is limited by dot pitch.
- Dot pitch is the distance between subpixels of the same color in millimeters. In general, the smaller the dot pitch, the sharper the picture will appear.
- Refresh rate is the number of times in a second that a display is illuminated. Maximum refresh rate is limited by response time.
- Response time is the time a pixel in a monitor takes to go from active (black) to inactive (white) and back to active (black) again, measured in milliseconds. Lower numbers mean faster transitions and therefore fewer visible image artifacts.
- Contrast ratio is the ratio of the luminosity of the brightest color (white) to that of the darkest color (black) that the monitor is capable of producing.
- Power consumption is measured in watts.
- Viewing angle is the maximum angle at which images on the monitor can be viewed, without excessive degradation to the image. It is measured in degrees horizontally and vertically.

Comparison

CRT

Pros:

- High dynamic range (up to around 15,000:1 [1],) excellent color, wide gamut and low black level.
- Can display natively in almost any resolution and refresh rate
- No input lag
- Sub-millisecond response times
- Near zero color, saturation, contrast or brightness distortion. Excellent viewing angle.
- Usually much cheaper than LCD or Plasma screens.

Cons:

- Large size and weight, especially for bigger screens (a 20-inch unit weighs about 50 lb (23 kg))
- High power consumption
- Geometric distortion caused by variable beam travel distances
- Older CRTs are prone to screen burn-in
- Produces noticeable flicker at low refresh rates

LCD

Pros:

- Very compact and light
- Low power consumption
- No geometric distortion
- Rugged
- Little or no flicker depending on backlight technology

Cons:

- Limited viewing angle, causing color, saturation, contrast and brightness to vary, even within the intended viewing angle, by variations in posture.
- Bleeding and uneven backlighting in some monitors, causing brightness distortion, especially toward the edges.
- Slow response times, which cause smearing and ghosting artifacts. Modern LCDs have response times of 8 ms or less.
- Only one native resolution. Displaying resolutions either requires a video scaler, lowering perceptual quality, or display at 1:1 pixel mapping, in which images will be physically too large or won't fill the whole screen.
- Fixed bit depth, many cheaper LCDs are incapable of truecolor.
- Input lag
- Dead pixels may occur either during manufacturing or through use.

Plasma

Pros:

- Compact and light.
- High contrast ratios (10,000:1 or greater,) excellent color, wide gamut and low black level.
- High speed response.
- Near zero color, saturation, contrast or brightness distortion. Excellent viewing angle.
- No geometric distortion.
- Highly scalable, with less weight gain per increase in size (from less than 30 in (760 mm) wide to the world's largest [2] at 150 in (3800 mm)).

Cons:

- Large pixel pitch, meaning either low resolution or a large screen.
- Noticeable flicker when viewed at close range
- High operating temperature and power consumption
- Only has one native resolution. Displaying other resolutions requires a video scaler, which degrades image quality at lower resolutions.
- Fixed bit depth
- Input lag
- Older PDPs are prone to burn-in
- Dead pixels are possible during manufacturing

Problems

Phosphor burn-in

Phosphor burn-in is localized aging of the phosphor layer of a CRT screen where it has displayed a static bright image for many years. This results in a faint permanent image on the screen, even when turned off. In severe cases, it can even be possible to read some of the text, though this only occurs where the displayed text remained the same for years.

This was once a common phenomenon in single purpose business computers. It can still be an issue with CRT displays when used to display the same image for years at a time, but modern computers aren't normally used this way anymore, so the problem is not a significant issue. The only systems that suffered the defect were ones displaying the same image for years, and with these the presence of burn-in was not a noticeable effect when in use, since it coincided with the displayed image perfectly. It only became a significant issue in three situations:

- when some heavily used monitors were reused at home,
- or re-used for display purposes
- in some high-security applications (but only those where the high-security data displayed did not change for years at a time).

Screen savers were developed as a means to avoid burn-in, but are unnecessary for CRTs today, despite their popularity.

Phosphor burn-in can be gradually removed on damaged CRT displays by displaying an all-white screen with brightness and contrast turned up full. This is a slow procedure, but is usually effective.

Plasma burn-in

Burn-in re-emerged as an issue with early plasma displays, which are more vulnerable to this than CRTs. Screen savers with moving images may be used with these to minimize localized burn. Periodic change of the color scheme in use also helps.

Glare

Glare is a problem caused by the relationship between lighting and screen, or by using monitors in bright sunlight. Matte finish LCDs and flat screen CRTs are less prone to reflected glare than conventional curved CRTs or glossy LCDs, and aperture grille CRTs, which are curved on one axis only and are less prone to it than other CRTs curved on both axes.

If the problem persists despite moving the monitor or adjusting lighting, a filter using a mesh of very fine black wires may be placed on the screen to reduce glare and improve contrast. These filters were popular in the late 1980s. They do also reduce light output.

A filter above will only work against reflective glare; direct glare (such as sunlight) will completely wash out most monitors' internal lighting, and can only be dealt with by use of a hood or transreflective LCD.

Color misregistration

With exceptions of correctly aligned video projectors and stacked LEDs, most display technologies, especially LCD, have an inherent misregistration of the color channels, that is, the centers of the red, green, and blue dots do not line up perfectly. Sub-pixel rendering depends on this misalignment; technologies making use of this include the Apple II from 1976[3] , and more recently Microsoft (ClearType, 1998) and XFree86 (X Rendering Extension).

Incomplete spectrum

RGB displays produce most of the visible color spectrum, but not all. This can be a problem where good color matching to non-RGB images is needed. This issue is common to all monitor technologies with three color channels.

Display interfaces

Computer terminals

Early CRT-based VDUs (Visual Display Units) such as the DEC VT05 without graphics capabilities gained the label *glass teletypes*, because of the functional similarity to their electromechanical predecessors.

Some historic computers had no screen display, using a teletype, modified electric typewriter, or printer instead.

Composite signal

Early home computers such as the Apple II and the Commodore 64 used a composite signal output to drive a CRT monitor or TV. This resulted in degraded resolution due to compromises in the broadcast TV standards used. This method is still used with video game consoles. The Commodore monitor had S-Video input to improve resolution.

Digital monitors

Early digital monitors are sometimes known as TTLs because the voltages on the red, green, and blue inputs are compatible with TTL logic chips. Later digital monitors support LVDS, or TMDS protocols.

TTL monitors

Monitors used with the MDA, Hercules, CGA, and EGA graphics adapters used in early IBM PC's (Personal Computer) and clones were controlled via TTL logic. Such monitors can usually be identified by a male DB-9 connector used on the video cable. The disadvantage of TTL monitors was the limited number of colors available due to the low number of digital bits used for video signaling.


IBM PC with green monochrome display.

Modern monochrome monitors use the same 15-pin SVGA connector as standard color monitors. They are capable of displaying 32-bit grayscale at 1024x768 resolution, making them able to interface with modern computers.

TTL Monochrome monitors only made use of five out of the nine pins. One pin was used as a ground, and two pins were used for horizontal/vertical synchronization. The electron gun was controlled by two separate digital signals, a video bit, and an intensity bit to control the brightness of the drawn pixels. Only four shades were possible; black, dim, medium or bright.

CGA monitors used four digital signals to control the three electron guns used in color CRTs, in a signaling method known as **RGBI**, or *Red Green and Blue, plus Intensity*. Each of the three RGB colors can be switched on or off independently. The intensity bit increases the brightness of all guns that are switched on, or if no colors are switched on the intensity bit will switch on all guns at a very low brightness to produce a dark grey. A CGA monitor is only capable of rendering 16 colors. The CGA monitor was not exclusively used by PC based hardware. The Commodore 128 could also utilize CGA monitors. Many CGA monitors were capable of displaying composite video via a separate jack.

EGA monitors used six digital signals to control the three electron guns in a signaling method known as **RrGgBb**. Unlike CGA, each gun is allocated its own intensity bit. This allowed each of the three primary colors to have four different states (off, soft, medium, and bright) resulting in 64 colors.

Although not supported in the original IBM specification, many vendors of clone graphics adapters have implemented backwards monitor compatibility and auto detection. For example, EGA cards produced by Paradise could operate as an MDA, or CGA adapter if a monochrome or CGA monitor was used in place of an EGA monitor. Many CGA cards were also capable of operating as MDA or Hercules card if a monochrome monitor was used.

Single color screens

Display colors other than white were popular on monochrome monitors in the 1980s. These colors were more comfortable on the eye. This was particularly an issue at the time due to the lower refresh rates in use at the time causing flicker, plus the use of less comfortable color schemes than used with most of today's software.

Green screens were the most popular color, with amber displays also available. "Paper white" was also in use, which was a warm white.

Modern technology

Analog monitors

Most modern computer displays can show the various colors of the RGB color space by changing red, green, and blue analog video signals in continuously variable intensities. These have been almost exclusively progressive scan since the middle 1980s. While many early plasma and liquid crystal displays have exclusively analog connections, all signals in such monitors pass through a completely digital section prior to display.

While many similar connectors (13W3, BNC, etc…) were used on other platforms, the IBM PC and compatible systems long ago standardized on the VGA connector.

Digital and analog combination

The first popular external digital monitor connectors, such as DVI-I and the various breakout connectors based on it, included both analog signals compatible with VGA and digital signals compatible with new flat-screen displays in the same connector.

Digital monitors

Newer connectors are being made which have digital only video signals. Many of these, such as HDMI and DisplayPort, also feature integrated audio and data connections. One less popular feature most of these connectors share are DRM encrypted signals.

Configuration and usage

Multiple monitors

More than one monitor can be attached to the same device. Each display can operate in two basic configurations:

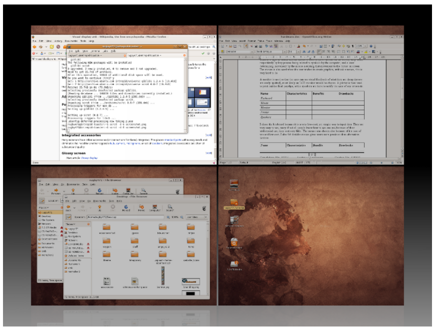
- The simpler of the two is **mirroring** (sometimes **cloning**,) in which at least two displays are showing the same image. It is commonly used for presentations. Hardware with only one video output can be tricked into doing this with an external splitter device, commonly built into many video projectors as a pass through connection.
- The more sophisticated of the two, **extension** allows each monitor to display a different image, so as to form a contiguous area of arbitrary shape. This requires software support and extra hardware, and may be locked out on "low end" products by crippleware.
- Primitive software is incapable of recognizing multiple displays, so **spanning** must be used, in which case a very large virtual display is created, and then pieces are split into multiple video outputs for separate monitors. Hardware with only one video output can be made to do this with an expensive external splitter device, this is most often used for very large composite displays made from many smaller monitors placed edge to edge.

Multiple video sources

Multiple devices can be connected to the same monitor using a video switch. In the case of computers, this usually takes the form of a "Keyboard Video Mouse switch" (KVM) switch, which is designed to switch all of the user interface devices for a workstation between different computers at once.

Virtual displays

Much software and video hardware supports the ability to create additional, virtual pieces of desktop, commonly known as **workspaces**. Spaces is Apple's implementation of virtual displays.



Screenshot of a user's 'workspaces' (virtual desktops) on Ubuntu GNU/Linux.

Additional features

Power saving

Most modern monitors will switch to a power-saving mode if no video-input signal is received. This allows modern operating systems to turn off a monitor after a specified period of inactivity. This also extends the monitor's service life.

Some monitors will also switch themselves off after a time period on standby.

Most modern laptops provide a method of screen dimming after periods of inactivity or when the battery is in use. This extends battery life and reduces wear.

Integrated accessories

Many monitors have other accessories (or connections for them) integrated. This places standard ports within easy reach and eliminates the need for another separate hub, camera, microphone, or set of speakers.

Glossy screen

Some displays, especially newer LCD monitors, replace the traditional anti-glare matte finish with a glossy one. This increases saturation and sharpness but reflections from lights and windows are very visible.

Directional screen

Narrow viewing angle screens are used in some security conscious applications.

Autopolyscopic screen

A directional screen which generates 3D images without headgear.

Touch screen

These monitors use touching of the screen as an input method. Items can be selected or moved with a finger, and finger gestures may be used to convey commands. The screen will need frequent cleaning due to image degradation from fingerprints.

Tablet screens

A combination of a monitor with a graphics tablet. Such devices are typically unresponsive to touch without the use of one or more special tools' pressure. Newer models however are now able to detect touch from any pressure and often have the ability to detect tilt and rotation as well.

Major manufacturers

- Acer
- AOC
- Apple Inc.
- Asus
- BenQ
- Dell
- Eizo
- Gateway
- Hewlett-Packard
- HannStar Display Corporation
- Iiyama Corporation
- LG
- NEC
- Samsung
- Sony
- Toshiba
- Tyco Electronics
- ViewSonic

See also

- Flat panel display
- Display examples

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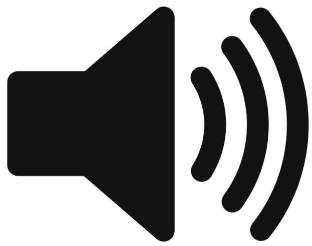
[3] GRC|The Origins of Sub-Pixel Font Rendering (http://grc.com/ctwho.htm)

Computer speaker


A common computer icon representing a speaker

Computer speakers, or **multimedia speakers**, are speakers external to a computer, that disable the lower fidelity built-in speaker. They often have a low-power internal amplifier. The standard audio connection is a 3.5mm (1/8 inch) stereo jack plug often colour-coded lime green (following the PC 99 standard) for computer sound cards. A plug and socket for a two-wire (signal and ground) coaxial cable that is widely used to connect analog audio and video components. Also called a "phono connector," rows of RCA sockets are found on the backs of stereo amplifier and numerous A/V products. The prong is 1/8" thick by 5/16" long. A few use an RCA connector for input. There are also USB speakers which are powered from the 5 volts at 200 milliamps provided by the USB port, allowing about half a watt of output power.

Computer speakers range widely in quality and in price. The computer speakers typically packaged with computer systems are small plastic boxes with mediocre sound quality. Some of the slightly better computer speakers have equalization features such as bass and treble controls, improving their sound quality somewhat.

The internal amplifiers require an external power source, known as a 'wall-wart'. More sophisticated computer speakers may have a 'subwoofer' unit, to enhance bass output, and these units usually include the power amplifiers both for the bass speaker, and the small 'satellite' speakers.

Some computer displays have rather basic speakers built-in. Laptops come with integrated speakers. Unfortunately the tight restriction on space inevitable in laptops means these speakers unavoidably produce low-quality sound.

For some users, a lead connecting computer sound output to an existing stereo system is practical. This normally yields much better results than small low-cost computer speakers. Computer speakers can also serve as an economy amplifier for MP3 player use for those who wish to not use headphones although some models of computer speakers have headphone jacks of their own.

Common features

Features vary by manufacturer, but may include the following:

- An LED power indicator.
- A 3.5-mm (1/8-inch) headphone jack.
- Controls for volume, and sometimes bass and treble
- A remote volume control.

Cost cutting measures and technical compatibility

In order to cut the cost of computer speakers (unless designed for premium sound performance), speakers designed for computers often lack an AM/FM tuner and other built-in sources of audio. However, the male 8th-inch plug can be jury rigged with "female 8th-inch to female stereo RCA" adapters to work with stereo system components such as CD/DVD-Audio/SACD players (although computers have CD-ROM drives of their own with audio CD support), Audio cassette players, turntables, etc.

Despite being designed for computers, computer speakers are electrically compatible with the aforementioned stereo components. There are even models of computer speakers that have stereo RCA in jacks.

Major computer speaker companies

- Altec Lansing
- Bose Corporation
- Creative Labs
- Cyber Acoustics
- Dell
- Edifier
- General Electric
- Harman Kardon
- Hewlett-Packard
- JBL
- Klipsch
- Logitech

The base of a Harman Kardon speaker.

See also

- PC speaker
- Loudspeaker
- Sound card
- Headphones
- Microphone

External links

- Wireless Speakers [1]

References

[1] http://www.wireless-speakers.org/

Printer (computing)

A Lexmark printer

An Epson MX-80

In computing, a **printer** is a peripheral which produces a hard copy (permanent readable text and/or graphics) of documents stored in electronic form, usually on physical print media such as paper or transparencies. Many printers are primarily used as local peripherals, and are attached by a printer cable or, in most newer printers, a USB cable to a computer which serves as a document source. Some printers, commonly known as network printers, have built-in network interfaces, typically wireless and/or Ethernet based, and can serve as a hard copy device for any user on the network. Individual printers are often designed to support both local and network connected users at the same time. In addition, a few modern printers can directly interface to electronic media such as memory cards, or to image capture devices such as digital cameras, scanners; some printers are combined with a scanners and/or fax machines in a single unit, and can function as photocopiers. Printers that include non-printing features are sometimes called multifunction printers (MFP), multi-function devices (MFD), or all-in-one (AIO) printers. Most MFPs include printing, scanning, and copying among their features.

Consumer and some commercial printers are designed for low-volume, short-turnaround print jobs; requiring virtually no setup time to achieve a hard copy of a given document. However, printers are generally slow devices (30 pages per minute is considered fast; and many inexpensive consumer printers are far slower than that), and the cost per page is actually relatively high. However, this is offset by the on-demand convenience and project management costs being more controllable compared to an out-sourced solution. The printing press remains the machine of choice for high-volume, professional publishing. However, as printers have improved in quality and performance, many jobs which used to be done by professional print shops are now done by users on local printers; see desktop publishing. The world's first computer printer was a 19th century mechanically driven apparatus invented by Charles

Babbage for his Difference Engine.[1]

A virtual printer is a piece of computer software whose user interface and API resemble that of a printer driver, but which is not connected with a physical computer printer.

Printing technology

Printers are routinely classified by the technology they employ; numerous such technologies have been developed over the years. The choice of engine has a substantial effect on what jobs a printer is suitable for, as different technologies are capable of different levels of image/text quality, print speed, low cost, noise; in addition, some technologies are inappropriate for certain types of physical media, such as carbon paper or transparencies.

Another aspect of printer technology that is often forgotten is resistance to alteration: liquid ink such as from an inkjet head or fabric ribbon becomes absorbed by the paper fibers, so documents printed with a liquid ink sublimation printer [1] are more difficult to alter than documents printed with toner or solid inks, which do not penetrate below the paper surface.

Cheques should either be printed with liquid ink or on special cheque paper with toner anchorage.[2] For similar reasons carbon film ribbons for IBM Selectric typewriters bore labels warning against using them to type negotiable instruments such as cheques. The machine-readable lower portion of a cheque, however, must be printed using MICR toner or ink. Banks and other clearing houses employ automation equipment that relies on the magnetic flux from these specially printed characters to function properly.

Modern print technology

The following printing technologies are routinely found in modern printers:

Toner-based printers

A laser printer rapidly produces high quality text and graphics. As with digital photocopiers and multifunction printers (MFPs), laser printers employ a xerographic printing process but differ from analog photocopiers in that the image is produced by the direct scanning of a laser beam across the printer's photoreceptor.

Another toner-based printer is the LED printer which uses an array of LEDs instead of a laser to cause toner adhesion to the print drum.

Liquid inkjet printers

Inkjet printers operate by propelling variably-sized droplets of liquid or molten material (ink) onto almost any sized page. They are the most common type of computer printer used by consumers.

Solid ink printers

Solid ink printers, also known as phase-change printers, are a type of thermal transfer printer. They use solid sticks of CMYK-coloured ink, similar in consistency to candle wax, which are melted and fed into a piezo crystal operated print-head. The printhead sprays the ink on a rotating, oil coated drum. The paper then passes over the print drum, at which time the image is transferred, or transfixed, to the page. Solid ink printers are most commonly used as colour office printers, and are excellent at printing on transparencies and other non-porous media. Solid ink printers can produce excellent results. Acquisition and operating costs are similar to laser printers. Drawbacks of the technology include high energy consumption and long warm-up times from a cold state. Also, some users complain that the resulting prints are difficult to write on, as the wax tends to repel inks from pens, and are difficult to feed through automatic document feeders, but these traits have been significantly reduced in later models. In addition, this type of printer is only available from one manufacturer, Xerox, manufactured as part of their Xerox Phaser office printer line, it is also available by various Xerox concessionaires [3].[4] Previously, solid ink printers were manufactured by

Tektronix, but Tek sold the printing business to Xerox in 2001.

Dye-sublimation printers

A **dye-sublimation printer** (or **dye-sub printer**) is a printer which employs a printing process that uses heat to transfer dye to a medium such as a plastic card, paper or canvas. The process is usually to lay one colour at a time using a ribbon that has colour panels. Dye-sub printers are intended primarily for high-quality colour applications, including colour photography; and are less well-suited for text. While once the province of high-end print shops, dye-sublimation printers are now increasingly used as dedicated consumer photo printers.

Inkless printers

Thermal printers

Thermal printers work by selectively heating regions of special heat-sensitive paper. Monochrome thermal printers are used in cash registers, ATMs, gasoline dispensers and some older inexpensive fax machines. Colours can be achieved with special papers and different temperatures and heating rates for different colours. One example is the ZINK technology.

UV printers

Xerox is working on an inkless printer which will use a special reusable paper coated with a few micrometres of UV light sensitive chemicals. The printer will use a special UV light bar which will be able to write and erase the paper. As of early 2007 this technology is still in development and the text on the printed pages can only last between 16–24 hours before fading.[5]

Obsolete and special-purpose printing technologies

The following technologies are either obsolete, or limited to special applications though most were, at one time, in widespread use.

Impact printers rely on a forcible impact to transfer ink to the media, similar to the action of a typewriter. All but the dot matrix printer rely on the use of formed characters, letterforms that represent each of the characters that the printer was capable of printing. In addition, most of these printers were limited to monochrome printing in a single typeface at one time, although bolding and underlining of text could be done by "overstriking", that is, printing two or more impressions in the same character position. Impact printers varieties include, typewriter-derived printers, teletypewriter-derived printers, daisy wheel printers, dot matrix printers and line printers. Dot matrix printers remain in common use in businesses where multi-part forms are printed, such as car rental services. *An overview of impact printing* [6] contains a detailed description of many of the technologies used.

Pen-based plotters were an alternate printing technology once common in engineering and architectural firms. Pen-based plotters rely on contact with the paper, but not impact, per se, and special purpose pens that are mechanically run over the paper to create text and images.

Typewriter-derived printers

Several different computer printers were simply computer-controllable versions of existing electric typewriters. The Friden Flexowriter and IBM Selectric typewriter were the most-common examples. The Flexowriter printed with a conventional typebar mechanism while the Selectric used IBM's well-known "golf ball" printing mechanism. In either case, the letter form then struck a ribbon which was pressed against the paper, printing one character at a time. The maximum speed of the Selectric printer (the faster of the two) was 15.5 characters per second.

Teletypewriter-derived printers

The common teleprinter could easily be interfaced to the computer and became very popular except for those computers manufactured by IBM. Some models used a "typebox" that was positioned, in the X- and Y-axes, by a mechanism and the selected letter form was struck by a hammer. Others used a type cylinder in a similar way as the Selectric typewriters used their type ball. In either case, the letter form then struck a ribbon to print the letterform. Most teleprinters operated at ten characters per second although a few achieved 15 CPS.

Daisy wheel printers

Daisy-wheel printers operate in much the same fashion as a typewriter. A hammer strikes a wheel with petals, the "daisy wheel", each petal containing a letter form at its tip. The letter form strikes a ribbon of ink, depositing the ink on the page and thus printing a character. By rotating the daisy wheel, different characters are selected for printing. These printers were also referred to as *letter-quality printers* because, during their heyday, they could produce text which was as clear and crisp as a typewriter, though they were nowhere near the quality of printing presses. The fastest letter-quality printers printed at 30 characters per second.

Dot-matrix printers

In the general sense many printers rely on a matrix of pixels, or dots, that together form the larger image. However, the term dot matrix printer is specifically used for impact printers that use a matrix of small pins to create precise dots. The advantage of dot-matrix over other impact printers is that they can produce graphical images in addition to text; however the text is generally of poorer quality than impact printers that use letterforms (*type*).

A Tandy 1000 HX with a Tandy DMP-133 dot-matrix printer.

Dot-matrix printers can be broadly divided into two major classes:

- Ballistic wire printers (discussed in the dot matrix printers article)
- Stored energy printers

Dot matrix printers can either be character-based or line-based (that is, a single horizontal series of pixels across the page), referring to the configuration of the print head.

At one time, dot matrix printers were one of the more common types of printers used for general use, such as for home and small office use. Such printers would have either 9 or 24 pins on the print head. 24-pin print heads were able to print at a higher quality. Once the price of inkjet printers dropped to the point where they were competitive with dot matrix printers, dot matrix printers began to fall out of favor for general use.

Some dot matrix printers, such as the NEC P6300, can be upgraded to print in colour. This is achieved through the use of a four-colour ribbon mounted on a mechanism (provided in an upgrade kit that replaces the standard black ribbon mechanism after installation) that raises and lowers the ribbons as needed. Colour graphics are generally printed in four passes at standard resolution, thus slowing down printing considerably. As a result, colour graphics can take up to four times longer to print than standard monochrome graphics, or up to 8-16 times as long at high resolution mode.

Dot matrix printers are still commonly used in low-cost, low-quality applications like cash registers, or in demanding, very high volume applications like invoice printing. The fact that they use an impact printing method allows them to be used to print multi-part documents using carbonless copy paper, like sales invoices and credit card receipts, whereas other printing methods are unusable with paper of this type. Dot-matrix printers are now (as of 2005) rapidly being superseded even as receipt printers.

Line printers

Line printers, as the name implies, print an entire line of text at a time. Three principal designs existed. In drum printers, a drum carries the entire character set of the printer repeated in each column that is to be printed. In chain printers, also known as train printers, the character set is arranged multiple times around a chain that travels horizontally past the print line. In either case, to print a line, precisely timed hammers strike against the back of the paper at the exact moment that the correct character to be printed is passing in front of the paper. The paper presses forward against a ribbon which then presses against the character form and the impression of the character form is printed onto the paper.

Comb printers represent the third major design. These printers were a hybrid of dot matrix printing and line printing. In these printers, a comb of hammers printed a portion of a row of pixels at one time, such as every eighth pixel. By shifting the comb back and forth slightly, the entire pixel row could be printed, continuing the example, in just eight cycles. The paper then advanced and the next pixel row was printed. Because far less motion was involved than in a conventional dot matrix printer, these printers were very fast compared to dot matrix printers and were competitive in speed with formed-character line printers while also being able to print dot matrix graphics.

Line printers were the fastest of all impact printers and were used for bulk printing in large computer centres. They were virtually never used with personal computers and have now been replaced by high-speed laser printers.

Line printers, better known as line matrix printers are widely used in the automotive, logistic and banking world for high speed and barcode printing. They are known as robust and durable printers that have the lowest price per page, label or other item. Companies such as Printronix and TallyGenicom are the leading manufacturers today. The legacy of line printers lives on in many computer operating systems, which use the abbreviations "lp", "lpr", or "LPT" to refer to printers.

Pen-based plotters

A **plotter** is a vector graphics printing device which operates by moving a pen over the surface of paper. Plotters have been used in applications such as computer-aided design, though they are rarely used now and are being replaced with wide-format conventional printers, which nowadays have sufficient resolution to render high-quality vector graphics using a rasterized print engine. It is commonplace to refer to such wide-format printers as "plotters", even though such usage is technically incorrect. There are two types of plotters, flat bed and drum.

Sales

Since 2005, the world's top selling brand of inkjet and laser printers has been HP which now has 46% of sales in inkjet and 50.5% in laser printers.[7]

Other printers

A number of other sorts of printers are important for historical reasons, or for special purpose uses:

- Digital minilab (photographic paper)
- Electrolytic printers
- Spark printer
- Barcode printer multiple technologies, including: thermal printing, inkjet printing, and laser printing barcodes
- Billboard / sign paint spray printers
- Laser etching (product packaging) industrial printers
- Microsphere (special paper)

Printing mode

The data received by a printer may be:

- A string of characters
- A bitmapped image
- A vector image

Some printers can process all three types of data, others not.

- Character printers, such as daisy wheel printers, can handle only plain text data or rather simple point plots.
- Pen plotters typically process vector images. Inkjet based plotters can adequately reproduce all three.
- Modern printing technology, such as laser printers and inkjet printers, can adequately reproduce all three. This is especially true of printers equipped with support for PostScript and/or PCL; which includes the vast majority of printers produced today.

Today it is common to print everything (even plain text) by sending ready bitmapped images to the printer, because it allows better control over formatting. Many printer drivers do not use the text mode at all, even if the printer is capable of it.

Monochrome, colour and photo printers

A monochrome printer can only produce an image consisting of one colour, usually black. A monochrome printer may also be able to produce various tones of that color, such as a grey-scale. A colour printer can produce images of multiple colours. A photo printer is a colour printer that can produce images that mimic the colour range (gamut) and resolution of photographic methods of printing. Many can be used autonomously without a computer, with a memory card or USB connector.

The printer manufacturing business

Often the razor and blades business model is applied. That is, a company may sell a printer at cost, and make profits on the ink cartridge, paper, or some other replacement part. This has caused legal disputes regarding the right of companies other than the printer manufacturer to sell compatible ink cartridges. To protect their business model, several manufacturers invest heavily in developing new cartridge technology and patenting it.

Other manufacturers, in reaction to the challenges from using this business model, choose to make more money on printers and less on the ink, promoting the latter through their advertising campaigns. Finally, this generates two clearly different proposals: "cheap printer — expensive ink" or "expensive printer — cheap ink". Ultimately, the consumer decision depends on their reference interest rate or their time preference. From an Economics viewpoint, there is a clear trade-off between cost per copy and cost of the printer[8] .

Printing speed

The speed of early printers was measured in units of characters per second. More modern printers are measured in pages per minute. These measures are used primarily as a marketing tool, and are not as well standardised as toner yields. Usually pages per minute refers to sparse monochrome office documents, rather than dense pictures which usually print much more slowly, especially colour images. PPM are most of the time referring to A4 paper in Europe and letter paper in the United States, resulting in a 5-10% difference.

See also

- Cardboard engineering
- Dot matrix printer
- List of printer companies
- Print (command)
- Print job
- Print screen
- Print server
- Printable version
- Printer friendly
- Printer point
- Printer (publisher)
- Printing
- Printmaking
- Printer steganography

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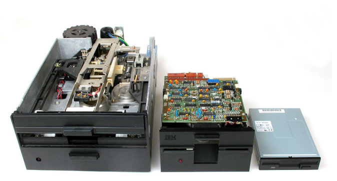
[8] Cost per Page versus Printer cost in currently available printers (http://www.officenet.com.ar/impresoras/)

Removable Data Storage

Floppy disk



8-inch, 5¼-inch (full height), and 3½-inch drives

Date invented	1969 (8-inch), 1976 (5¼-inch), 1982 (3½-inch)
Invented by	IBM team led by David L. Noble[1]
Connects to	Controller via: • Cable

A **floppy disk** is a data storage medium that is composed of a disk of thin, flexible ("floppy") magnetic storage medium encased in a square or rectangular plastic shell. Originally announced as the "Type 1 Diskette" by IBM in 1973, the industry then adopted the terms "floppy disk" or "floppy."[2]

8-inch, 5¼-inch, and 3½-inch floppy disks

Floppy disks are read and written by a **floppy disk drive** or **FDD**, the initials of which should not be confused with "fixed disk drive", which is another term for a (nonremovable) type of hard disk drive. Invented by the American information technology company IBM, floppy disks in 8 inch, 5¼ inch and 3½ inch forms enjoyed nearly three decades as a popular and ubiquitous form of data storage and exchange, from the mid-1970s to the late 1990s. While floppy disk drives still have some limited uses, especially with legacy industrial computer equipment,[3] they have now been superseded by USB flash drives, external hard disk drives, CDs, DVDs, and memory cards.

Usage

The flexible magnetic disk, commonly called **floppy disk** [4] , revolutionized computer disk storage for small systems and became ubiquitous in the 1980s and 1990s in their use with personal computers and home computers to distribute software, transfer data, and create backups.

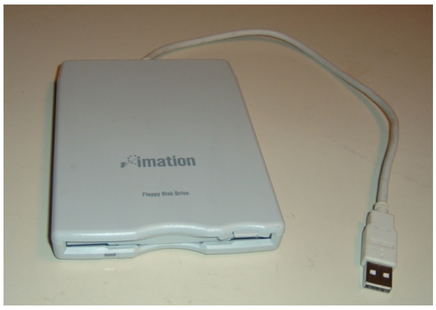
Before hard disks became affordable, floppy disks were often also used to store a computer's operating system (OS), in addition to application software and data. Most home computers had a primary OS (and often BASIC) stored permanently in on-board ROM, with the option of loading a more advanced disk operating system from a floppy, whether it be a proprietary system, CP/M, or later, DOS.

By the early 1990s, the increasing size of software meant that many programs demanded multiple diskettes; a large package like Windows or Adobe Photoshop could use a dozen disks or more. By 1996, there were an estimated 5 billion floppy disks in use.[5] Toward the end of the 1990s, distribution of larger packages therefore gradually switched to CD-ROM (or online distribution for smaller programs).

Mechanically incompatible higher-density formats were introduced (e.g. the Iomega Zip drive) and were briefly popular, but adoption was limited by the competition between proprietary formats, and the need to buy expensive drives for computers where the media would be used. In some cases, such as with the Zip drive, the failure in market penetration was exacerbated by the release of newer higher-capacity versions of the drive and media that were not backward compatible with the original drives, thus fragmenting the user base between new users and early adopters who were unwilling to pay for an upgrade so soon. A chicken or the egg scenario ensued, with consumers wary of making costly investments into unproven and rapidly changing technologies, with the result that none of the technologies were able to prove themselves and stabilize their market presence. Soon, inexpensive recordable CDs with even greater capacity, which were also compatible with an existing infrastructure of CD-ROM drives, made the new floppy technologies redundant. The last advantage of floppy disks, reusability, was countered by re-writable CDs. Later, advancements in flash-based devices and widespread adoption of the USB interface provided another alternative that, in turn, made even optical storage obsolete for some purposes.

An attempt to continue the traditional diskette was the SuperDisk (LS-120) in the late 1990s, with a capacity of 120 MB[6] which was backward compatible with standard 3½-inch floppies. For some time, PC manufacturers were reluctant to remove the floppy drive because many IT departments appreciated a built-in file transfer mechanism (dubbed Sneakernet) that always worked and required no device driver to operate properly. However, manufacturers and retailers have progressively reduced the availability of computers fitted with floppy drives and of the disks themselves. Widespread built-in operating system support for USB flash drives, and even BIOS boot support for such devices on most modern systems, has helped this process along.

External USB-based floppy disk drives are available for computers without floppy drives, and they work on any machine that supports USB Mass Storage Devices. Many modern systems even provide firmware support for booting to a USB-mounted floppy drive. However these drives can't handle anything but the common 80-track MFM format. Which means that formats used by C64, Amiga, Macintosh, etc. can't be read by these devices.



Imation USB Floppy Drive, model 01946. An external drive that accepts high-density disks.

Disk formats

Floppy sizes are almost universally referred to in imperial measurements, even in countries where metric is the standard, and even when the size is in fact defined in metric (for instance the 3½-inch floppy, which is actually 90 mm). Formatted capacities are generally set in terms of Kilobytes (1024 bytes, as 1 sector is generally 512 bytes), written as "KB". For more information see below.

Historical sequence of floppy disk formats, including the last format to be generally adopted — the "High Density" 3½-inch HD floppy, introduced 1987.

Disk format	Year introduced	Formatted Storage capacity in KB (1024 bytes) if not stated	Marketed capacity¹
8-inch - IBM 23FD (read-only)	1971	79.7[7]	?
8-inch - Memorex 650	1972	175 kB[8]	1.5 megabit[8] [unformatted]
8-inch - **SSSD** IBM 33FD / Shugart 901	1973	237.25[9] [10]	3.1 Mbits unformatted
8-inch - **DSSD** IBM 43FD / Shugart 850	1976	500.5[11]	6.2 Mbits unformatted
5¼-inch (35 track) Shugart SA 400	1976[12]	89.6 kB[13]	110 kB
8-inch **DSDD** IBM 53FD / Shugart 850	1977	980 (CP/M) - 1200 (MS-DOS FAT)	1.2 MB
5¼-inch DD	1978	360 or 800	360 KB
5¼-inch Apple Disk II (Pre-DOS 3.3)	1978	113.75 (256 byte sectors, 13 sectors/track, 35 tracks)	113 KB
5¼-inch Apple Disk II (DOS 3.3)	1980	140 (256 byte sectors, 16 sectors/track, 35 tracks)	140 KB
3½-inch HP single sided	1982	280	264 kB
3-inch	1982[14] [15]	360	125 kB (SS/SD), 500 kB (DS/DD)[15]
3½-inch (DD at release)	1983[16]	720 (400 SS, 800 DS on Macintosh, 880 DS on Amiga)	1 MB
5¼-inch QD		720	720 KB
5¼-inch HD	1982 YE Data YD380[17]	1,182,720 bytes	1.2 MB
3-inch DD	1984	720	?
3-inch Mitsumi Quick Disk	1985	128 to 256	?
2-inch	1985	720	?
2½-inch	1986[18]	?	?
5¼-inch Perpendicular	1986[18]	10 MB	?
3½-inch HD	**1987**	**1440**	**1.44 MB** (2.0 MB unformatted)
3½-inch ED	1987[19]	2880	2.88 MB
3½-inch Floptical (LS)	1991	21000	21 MB
3½-inch LS-120	1996	120.375 MB	120 MB
3½-inch LS-240	1997	240.75 MB	240 MB
3½-inch HiFD	1998/99	150/200 MB	150/200 MB

Abbreviations: **DD** = Double Density; **QD** = Quad Density; **HD** = High Density; **ED** = Extended Density; **LS** = Laser Servo; **HiFD** = High capacity Floppy Disk; **SS** = Single Sided; **DS** = Double Sided

¹ The formatted capacities of floppy disks frequently corresponded only vaguely to their capacities as marketed by drive and media companies, due to differences between formatted and unformatted capacities and also due to the non-standard use of binary prefixes in labeling and advertising floppy media. The erroneous "1.44 MB" value for the 3½-inch HD floppies is the most widely known example. See Ultimate capacity and speed.

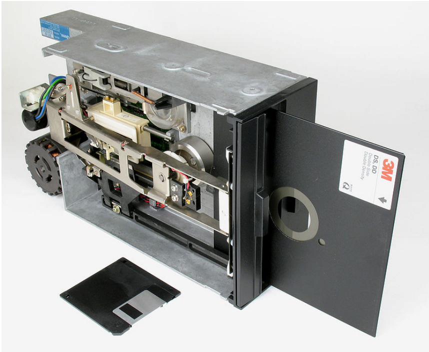
Dates and capacities marked ? are of unclear origin and need source information; other listed capacities refer to:
Formatted Storage Capacity is total size of all sectors on the disk:

- For 8-inch see Table of 8-inch floppy formats IBM 8-inch formats. Note that spare, hidden and otherwise reserved sectors are included in this number.
- For 5¼- and 3½-inch capacities quoted are from subsystem or system vendor statements.

Marketed Capacity is the capacity, typically unformatted, by the original media OEM vendor or in the case of IBM media, the first OEM thereafter. Other formats may get more or less capacity from the same drives and disks.

History

The earliest floppy disks, invented at IBM, were 8 inches in diameter. They became commercially available in 1971.[1] [20] Disks in this form factor were produced and improved upon by IBM and other companies such as Memorex, Shugart Associates, and Burroughs Corporation.[21]



8-inch disk drive with diskette (3½-inch disk for comparison)

In 1976 Shugart Associates introduced the first 5¼-inch FDD and associated media. By 1978 there were more than 10 manufacturers producing 5¼-inch FDDs, in competing disk formats: hard or soft sectored with various encoding schemes such as FM, MFM and GCR. The 5¼-inch formats quickly displaced the 8-inch for most applications, and the 5¼-inch hard-sectored disk format eventually disappeared.

A BASF double-density 5¼-inch diskette.

In 1984, IBM introduced the 1.2 megabyte dual sided floppy disk along with its AT model. Although often used as backup storage, the high density floppy was not often used by software manufacturers for interchangeability. In 1986, IBM began to use the 720 kB double density 3.5" microfloppy disk on its Convertible laptop computer. It introduced the so-called "1.44 MB" high density version with the PS/2 line. These disk drives could be added to existing older model PCs. In 1988 IBM introduced a drive for 2.88 MB "DSED" diskettes in its top-of-the-line PS/2 models; it was a commercial failure.

Throughout the early 1980s the limitations of the 5¼-inch format were starting to become clear. Originally designed to be smaller and more practical than the 8-inch format, the 5¼-inch system was itself too large, and as the quality of the recording media grew, the same amount of data could be placed on a smaller surface.

A number of solutions were developed, with drives at 2-inch, 2½-inch, 3-inch and 3½-inch (50, 60, 75 and 90 mm) all being offered by various companies. They all shared a number of advantages over the older format, including a small form factor and a rigid case with a sliding write protection tab. The almost-universal use of the 5¼-inch format made it very difficult for any of these new formats to gain any significant market share.

Sony introduced its own small-format 90.0 mm × 94.0 mm disk.; however, this format suffered from a fate similar to the other new formats: the 5¼-inch format simply had too much market share. A variant on the Sony design, introduced in 1982 by a large number of manufacturers, was then rapidly adopted. By 1988 the 3½-inch was outselling the 5¼-inch.[22]

3½-inch, high-density diskette affixed with a blank adhesive label.

By the end of the 1980s, the 5¼-inch disks had been superseded by the 3½-inch disks. Though 5¼-inch drives were still available, as were disks, they faded in popularity as the 1990s began. By the mid-1990s the 5¼-inch drives had virtually disappeared as the 3½-inch disk became the predominant floppy disk. One of the chief advantages of the 3½-inch disk, besides its smaller size which allows it to fit in a shirt pocket, is its plastic case, which gives it good protection from dust, liquids, fingerprints, scratches, sunlight, warping, and other environmental risks.

Standard floppy replacements

Through the early 1990s a number of attempts were made by various companies to introduce newer floppy-like formats based on the now-universal 3½-inch physical format. Most of these systems provided the ability to read and write standard DD and HD disks, while at the same time introducing a much higher-capacity format as well. There were a number of times where it was felt that the existing floppy was just about to be replaced by one of these newer devices, but a variety of problems ensured this never took place. None of these ever reached the point where it could be assumed that every current PC would have one, and they have now largely been replaced by CD and DVD burners and USB flash drives.

The main technological change was the addition of tracking information on the disk surface to allow the read/write heads to be positioned more accurately. Normal disks have no such information, so the drives use the tracks themselves with a feedback loop in order to center themselves. The newer systems generally used marks burned onto the surface of the disk to find the tracks, allowing the track width to be greatly reduced.

Flextra

As early as 1988, Brier Technology introduced the Flextra BR 3020, which boasted 21.4 MB (marketing, true size was 21,040 KB,[23] 25 MB unformatted). Later the same year it introduced the BR3225, which doubled the capacity. This model could also read standard 3½-inch disks.

It used 3½-inch standard disks which had servo information embedded on them for use with the Twin Tier Tracking technology.

Original Floptical

In 1991, Insite Peripherals introduced the "Floptical," which used an infra-red LED to position the heads over marks in the disk surface. The original drive stored 21 MB, while also reading and writing standard DD and HD floppies. In order to improve data transfer speeds and make the high-capacity drive usefully quick as well, the drives were attached to the system using a SCSI connector instead of the normal floppy controller. This made them appear to the operating system as a hard drive instead of a floppy, meaning that most PCs were unable to boot from them. This again adversely affected pickup rates.

Insite licenced their technology to a number of companies, who introduced compatible devices as well as even larger-capacity formats. The most popular of these, by far, was the LS-120, mentioned below.

Zip drive

In 1994, Iomega introduced the Zip drive. Although it was not true to the 3½-inch form factor (hence not compatible with the standard 1.44 MB floppies), it still became the most popular of the "super floppies". It boasted 100 MB, later 250 MB, and then 750 MB of storage. Though Zip drives gained in popularity for several years they never reached the same market penetration as standard floppy drives, since only some new computers were sold with the drives. Eventually the falling prices of CD-R and CD-RW media and USB flash drives, along with notorious hardware failures (the so-called "click of death"), reduced the popularity of the Zip drive.

A major reason for the failure of the Zip Drives is also attributed to the higher pricing they carried (partly because of royalties that 3rd-party manufacturers of drives and disks had to pay). However, hardware vendors such as Hewlett Packard, Dell and Compaq had promoted the same at a very high level. Zip drive media was primarily popular for the excellent storage density and drive speed they carried, but were always overshadowed by the price.

LS-120

Announced in 1995, the "SuperDisk" drive, often seen with the brand names Matsushita (Panasonic) and Imation, had an initial capacity of 120 MB (120.375 MB)[24] using even higher density "LS-120" disks.

It was upgraded (as the "LS-240") to 240 MB (240.75 MB). Not only could the drive read and write 1440 kB disks, but the last versions of the drives could write 32 MB onto a normal 1440 kB disk (see note below). Unfortunately, popular opinion held the Super Disk disks to be quite unreliable, though no more so than the Zip drives and SyQuest Technology offerings of the same period and there were also many reported problems moving standard floppies between LS-120 drives and normal floppy drives. This belief, true or otherwise, crippled adoption. The BIOS of many motherboards even to this day supports LS-120 drives as boot options.

LS-120 compatible drives were available as options on many computers, including desktop and notebook computers from Compaq Computer Corporation. In the case of the Compaq notebooks, the LS-120 drive replaced the standard floppy drive in a multibay configuration.

Sony HiFD

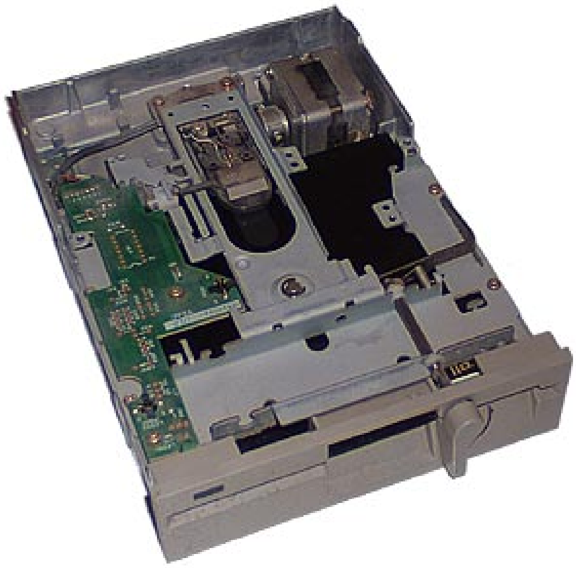
Sony introduced its own floptical-like system in 1997 as the "150 MB Sony HiFD" which could hold 150 megabytes (157.3 actual megabytes) of data. Although by this time the LS-120 had already garnered some market penetration, industry observers nevertheless confidently predicted the HiFD would be the real standard-floppy-killer and finally replace standard floppies in all machines.

After only a short time on the market the product was pulled, as it was discovered there were a number of performance and reliability problems that made the system essentially unusable. Sony then re-engineered the device for a quick re-release, but then extended the delay well into 1998 instead, and increased the capacity to "200 MB" (approximately 210 megabytes) while they were at it. By this point the market was already saturated by the Zip disk, so it never gained much market share.

Caleb Technology's UHD144

The UHD144 drive surfaced early in 1998 as the **it** drive, and provided 144 MB of storage while also being compatible with the standard 1.44 MB floppies. The drive was slower than its competitors but the media were cheaper, running about 8 US$ at introduction and 5 US$ soon after.

Structure



A user inserts the floppy disk, medium opening first, into a 5¼-inch floppy disk drive (pictured, an internal model) and moves the lever down (by twisting on this model) to close the drive and engage the motor and heads with the disk.

The 5¼-inch disk had a large circular hole in the center for the spindle of the drive and a small oval aperture in both sides of the plastic to allow the heads of the drive to read and write the data. The magnetic medium could be spun by rotating it from the middle hole. A small notch on the right hand side of the disk would identify that the disk was writable, detected by a mechanical switch or photo transistor above it. If this notch was not present, the disk was treated as read-only. (Punch devices were sold to convert read-only disks to writable ones. Tape could be used over the notch to effect protection of writable disks from unwanted writing.)

Another LED/photo-transistor pair located near the center of the disk could detect a small hole once per rotation, called the index hole, in the magnetic disk. It was used to detect the start of each track, and whether or not the disk rotated at the correct speed; some operating systems, such as Apple DOS, did not use index sync, and often the drives designed for such systems lacked the index hole sensor. Disks of this type were said to be *soft sector* disks. Very early 8-inch and 5¼-inch disks also had physical holes for each sector, and were termed *hard sector* disks.

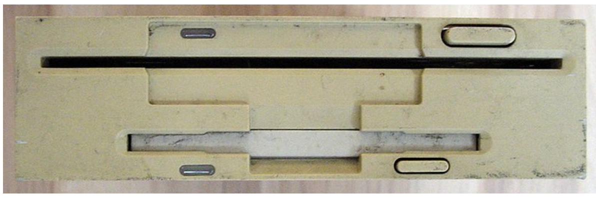
Inside the disk were two layers of fabric designed to reduce friction between the medium and the outer casing, with the medium sandwiched in the middle. The outer casing was usually a one-part sheet, folded double with flaps glued or spot-welded together. A catch was lowered into position in front of the drive to prevent the disk from emerging, as well as to raise or lower the spindle (and, in two-sided drives, the upper read/write head).

The 8-inch disk was very similar in structure to the 5¼-inch disk, with the exception that the read-only logic was in reverse: the slot on the side had to be taped over to allow writing.

The 3½-inch disk is made of two pieces of rigid plastic, with the fabric-medium-fabric sandwich in the middle to remove dust and dirt. The front has only a label and a small aperture for reading and writing data, protected by a spring-loaded metal or plastic cover, which is pushed back on entry into the drive.

The 5¼-inch 1.2 MB floppy disk drive

Newer 5¼-inch drives and all 3½-inch drives automatically engage when the user inserts a disk, and disengage and eject with the press of the eject button. On Apple Macintosh computers with built-in floppy drives, the disk is ejected by a motor (similar to a VCR) instead of manually; there is no eject button. The disk's desktop icon is dragged onto the Trash icon to eject a disk.



The 5¼-inch 3½-inch 1.2 MB 2.88 MB floppy disk drive

The 3½-inch 2.88 MB floppy disk drive

The reverse has a similar covered aperture, as well as a hole to allow the spindle to connect into a metal plate glued to the medium. Two holes, bottom left and right, indicate the write-protect status and high-density disk correspondingly, a hole meaning protected or high density, and a covered gap meaning write-enabled or low density. (Incidentally, the write-protect and high-density holes on a 3½-inch disk are spaced exactly as far apart as the holes in punched A4 paper (8 cm), allowing write-protected floppies to be clipped into standard ring binders.) A notch top right ensures that the disk is inserted correctly, and an arrow top left indicates the direction of insertion. The drive usually has a button that, when pressed, will spring the disk out at varying degrees of force. Some will barely make it out of the disk drive; others will shoot out at a fairly high speed. In a majority of drives, the ejection force is provided by the spring that holds the cover shut, and therefore the ejection speed is dependent on this spring. In PC-type machines, a floppy disk can be inserted or ejected manually at any time (evoking an error message or even lost data in some cases), as the drive is not continuously monitored for status and so programs can make assumptions that do not match actual status (e.g., disk 123 is still in the drive and has not been altered by any other agency).

With Apple Macintosh computers, disk drives are continuously monitored by the OS; a disk inserted is automatically searched for content, and one is ejected only when the software agrees the disk should be ejected. This kind of disk drive (starting with the slim "Twiggy" drives of the late Apple "Lisa") does not have an eject button, but uses a motorized mechanism to eject disks; this action is triggered by the OS software (e.g., the user dragged the "drive" icon to the "trash can" icon). Should this not work (as in the case of a power failure or drive malfunction), one can insert a straightened paper clip into a small hole at the drive's front, thereby forcing the disk to eject (similar to that found on CD–DVD drives). External 3.5" floppy drives from Apple were equipped with eject buttons. The button was ignored when the drive was plugged into a Mac, but would eject the disk if the drive was used with an Apple II, as ProDOS did not support or implement software-controlled eject. Some other computer designs (such as the Commodore Amiga) monitor for a new disk continuously but still have push-button eject mechanisms.

A 3″ floppy disk used on Amstrad CPC machines

The 3-inch disk, widely used on Amstrad CPC machines, bears much similarity to the 3½-inch type, with some unique and somewhat curious features. One example is the rectangular-shaped plastic casing, almost taller than a 3½-inch disk, but narrower, and more than twice as thick, almost the size of a standard compact audio cassette. This made the disk look more like a greatly oversized present day memory card or a standard PC card notebook expansion card rather than a floppy disk. Despite the size, the actual 3-inch magnetic-coated disk occupied less than 50% of the space inside the casing, the rest being used by the complex protection and sealing mechanisms implemented on the disks. Such mechanisms were largely responsible for the thickness, length and high costs of the 3-inch disks. On the Amstrad machines the disks were typically flipped over to use both sides, as opposed to being truly double-sided. Double-sided mechanisms were available but rare.

Legacy

The advent of other portable storage options, such as USB storage devices, SD Cards, recordable CDs and DVDs, and the rise of multi-megapixel digital photography encouraged the creation and use of files larger than most 3½-inch disks could hold. Additionally, the increasing availability of broadband and wireless Internet connections decreased the overall utility of removable storage devices (humorously named *sneakernet*).

In 1991, Commodore introduced the CDTV, which used a CD-ROM drive in place of the floppy drive. The majority of AmigaOS was stored in read-only memory, making it easier to boot from a CD-ROM rather than floppy.

In 1998, Apple introduced the iMac which had no floppy drive. This made USB-connected floppy drives a popular accessory for the early iMacs, since the basic model of iMac at the time had only a CD-ROM drive, giving users no easy access to writable removable media. This transition away from standard floppies was relatively easy for Apple, since all Macintosh models that were originally designed to use a CD-ROM drive were able to boot and install their operating system from CD-ROM early on.

In February 2003, Dell, Inc. announced that they would no longer include standard floppy drives on their Dell Dimension home computers as standard equipment, although they are available as a selectable option[25] [26] for around US$20 and can be purchased as an aftermarket OEM add-on anywhere from US$5–25.

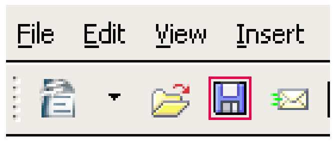
On 29 January 2007 the British computer retail chain PC World issued a statement saying that only 2% of the computers that they sold contained a built-in floppy disk drive and, once present stocks were exhausted, no more standard floppies would be sold.[27] [28] [29]

In 2009, Hewlett-Packard stopped supplying standard floppy drives on business desktops.

Floppies are still used for emergency boots in aging systems which lack support for other bootable media. They can also be used for BIOS updates since most BIOS and firmware programs can still be executed from bootable floppy disks. Furthermore, if a BIOS update fails or becomes corrupted somehow, floppy drives can be used to perform a recovery. The music and theatre industries still use equipment (i.e. synthesizers, samplers, drum machines, sequencers, and lighting consoles) that requires standard floppy disks as a storage medium.

Use as icon for saving

For more than two decades, the floppy disk was the primary external writable storage device used. Also, in a non-network environment, floppies were once the primary means of transferring data between computers. Floppy disks are also, unlike hard disks, handled and seen; even a novice user can identify a floppy disk. Because of all these factors, the image of the floppy disk has become a metaphor for saving data, and the floppy disk symbol is often seen in programs on buttons and other user interface elements related to saving files, even though such disks are obsolete.[30]



Screenshot of the toolbar in OpenOffice.org, highlighting the *Save* icon, a floppy disk.

Compatibility

In general, different physical sizes of floppy disks are incompatible by definition, and disks can be loaded only on the correct size of drive. There were some drives available with both 3½-inch and 5¼-inch slots that were popular in the transition period between the sizes.

However, there are many more subtle incompatibilities within each form factor. For example, all but the earliest models of Apple Macintosh computers that have built-in floppy drives included a disk controller that can read, write and format IBM PC-format 3½-inch diskettes. However, few IBM-compatible computers use floppy disk drives that can read or write disks in Apple's variable speed format. For details on this, see the section *More on floppy disk formats*.

3½-inch floppy disk

Within the world of IBM-compatible computers, the three densities of 3½-inch floppy disks are partially compatible. Higher density drives are built to read, write and even format lower density media without problems, provided the correct media are used for the density selected. However, if by whatever means a diskette is formatted at the wrong density, the result is a substantial risk of data loss due to magnetic mismatch between oxide and the drive head's writing attempts. Still, a fresh diskette that has been manufactured for high density use can theoretically be formatted as double density, but only if *no* information has ever been written on the disk using high density mode (for example, HD diskettes that are pre-formatted at the factory are out of the question). The magnetic strength of a high density record is stronger and will "overrule" the weaker lower density, remaining on the diskette and causing problems. However, in practice there are people who use downformatted (ED to HD, HD to DD) or even overformatted (DD to HD) without apparent problems. Doing so always constitutes a data risk, so one should weigh out the benefits (e.g. increased space or interoperability) versus the risks (data loss, permanent disk damage).

The holes on the right side of a 3½-inch disk can be altered as to 'fool' some disk drives or operating systems (others such as the Acorn Archimedes simply do not care about the holes) into treating the disk as a higher or lower density one, for backward compatibility or economical reasons . Possible modifications include:

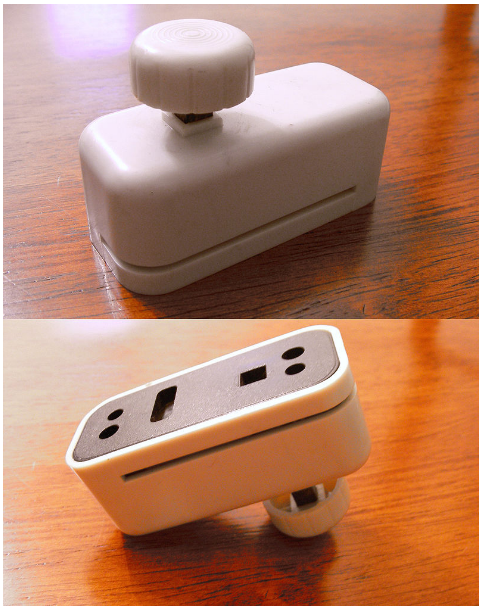
- Drilling or cutting an extra hole into the right-lower side of a 3½-inch DD disk (symmetrical to the write-protect hole) in order to format the DD disk into a HD one. This was a popular practice during the early 1990s, as most people switched to HD from DD during those days and some of them "converted" some or all of their DD disks into HD ones, for gaining an extra "free" 720 KB of disk space. There even was a special hole punch that was made to easily make this extra (square) hole in a floppy.
- Taping or otherwise covering the bottom right hole on a HD 3½-inch disk enables it to be 'downgraded' to DD format. This may be done for reasons such as compatibility issues with older computers, drives or devices that use DD floppies, like some electronic keyboard instruments and samplers[31] where a 'downgraded' disk can be useful, as factory-made DD disks have become hard to find after the mid-1990s. See the section *"Compatibility"* above.
  - Note: By default, many older HD drives will recognize ED disks as DD ones, since they lack the HD-specific holes and the drives lack the sensors to detect the ED-specific hole. Most DD drives will also handle ED (and some even HD) disks as DD ones.
- Similarly, drilling an HD-like hole (under the ED one) into an ED (2880 kB) disk for 'downgrading' it to HD (1440 kB) format if there are many unusable ED disks due to the lack of a specific ED drive, which can now be used as normal HD disks.
- Even if such a format was hardly officially supported on any system, it is possible to "force" a 3½-inch floppy disk drive to be recognized by the system as a 5¼-inch 360 kB or 1200 kB one (on PCs and compatibles. This can be done by simply changing the CMOS BIOS settings) and thus format and read non-standard disk formats, such as a double sided 360 kB 3½-inch disk. Possible applications include data exchange with obsolete CP/M systems, for example with an Amstrad CPC.

5¼-inch floppy disk

The situation was even more complex with 5¼-inch diskettes. The head gap of an 80-track high-density (1.2 MB in the MFM format) drive is shorter than that of a 40-track double-density (360 kB) drive, but will format, read and write 40 track diskettes with apparent success provided the controller supports double stepping (or the manufacturer fitted a switch to do double stepping in hardware). A blank 40 track disk formatted and written on an 80 track drive can be taken to a 40 track drive without problems, similarly a disk formatted on a 40 track drive can be used on an 80 track drive. But a disk written on a 40 track drive and updated on an 80 track drive becomes permanently unreadable on any 360 kB drive, owing to the incompatibility of the track widths (special, very slow programs could have been used to overcome this problem). There are several other bad scenarios.

Prior to the problems with head and track size, there was a period when just trying to figure out which side of a "single sided" diskette was the right side was a problem. Both Radio Shack and Apple used 180 kB single-sided 5¼-inch disks, and both sold disks labeled "single sided" that were certified for use on only one side, even though they in fact were coated in magnetic material on both sides. The irony was that the disks would work on both Radio Shack and Apple machines, yet the Radio Shack TRS-80 Model I computers used one side and the Apple II machines used the other, regardless of whether there was software available which could make sense of the other format.

For quite a while in the 1980s, users could purchase a special tool called a disk notcher which would allow them to cut a second write-unprotect notch in these diskettes and thus use them as "flippies" (either inserted as intended or upside down): both sides could now be written on and thereby the data storage capacity was doubled. Other users made do with a steady hand and a hole punch or scissors. For re-protecting a disk side, one would simply place a piece of opaque tape over the notch or hole in question. These "flippy disk procedures" were followed by owners of practically every home-computer with single sided disk drives. Proper disk labels became quite important for such users. Flippies were eventually adopted by some manufacturers, with a few programs being sold in this medium (they were also widely used for software distribution on systems that could be used with both 40 track and 80 track drives but lacked the software to read a 40 track disk in an 80 track drive). The practice eventually faded with the increased use of double-sided drives capable of accessing both sides of the disk without the need for flipping.



A disk notcher used to convert single-sided 5.25-inch diskettes to double-sided.

More on floppy disk formats

Efficiency of disk space usage

In general, data is written to floppy disks in a series of sectors, angular blocks of the disk, and in tracks, concentric rings at a constant radius, e.g. the HD format of 3½-inch floppy disks uses 512 bytes per sector, 18 sectors per track, 80 tracks per side and two sides, for a total of 1,474,560 bytes per disk. (Some disk controllers can vary these parameters at the user's request, increasing the amount of storage on the disk, although these formats may not be able to be read on machines with other controllers; e.g. Microsoft applications were often distributed on Distribution Media Format (DMF) disks, a hack that allowed 1.68 MB (1680 kB) to be stored on a 3½-inch floppy by formatting it with 21 sectors instead of 18, while these disks were still properly recognized by a standard controller.) On the IBM PC and also on the MSX, Atari ST, Amstrad CPC, and most other microcomputer platforms, disks are written using a Constant Angular Velocity (CAV)—Constant Sector Capacity format. This means that the disk spins at a constant speed, and the sectors on the disk all hold the same amount of information on each track regardless of radial location.

However, this is not the most efficient way to use the disk surface, even with available drive electronics. Because the sectors have a constant angular size, the 512 bytes in each sector are packed into a smaller length near the disk's center than nearer the disk's edge. A better technique would be to increase the number of sectors/track toward the outer edge of the disk, from 18 to 30 for instance, thereby keeping constant the amount of physical disk space used for storing each 512 byte sector (see *zone bit recording*). Apple implemented this solution in the early Macintosh computers by spinning the disk slower when the head was at the edge while keeping the data rate the same, allowing them to store 400 kB per side, amounting to an extra 160 kB on a double-sided disk. This higher capacity came with a serious disadvantage, however: the format required a special drive mechanism and control circuitry not used by other manufacturers, meaning that Mac disks could not be read on any other computers. Apple eventually gave up on the format and used constant angular velocity with HD floppy disks on their later machines; these drives were still unique to Apple as they still supported the older variable-speed format.

Commodore 64/128

Commodore started its tradition of special disk formats with the 5¼-inch disk drives accompanying its PET/CBM, VIC-20 and Commodore 64 home computers, the same as the 1540 and 1541 drives used with the later two machines. The standard Commodore Group Code Recording (GCR) scheme used in 1541 and compatibles employed four different data rates depending upon track position (see *zone bit recording*). Tracks 1 to 17 had 21 sectors, 18 to 24 had 19, 25 to 30 had 18, and 31 to 35 had 17, for a disk capacity of 170 kB (170.75 KB). Unique among personal computer architectures, the operating system on the computer itself was unaware of the details of the disk and filesystem; disk operations were handled by Commodore DOS instead, which was implemented with an extra MOS-6502 processor on the disk drive. Many programs such as GEOS removed Commodore's DOS completely, and replaced it with "fast loading" programs in the 1541 drive.

Eventually Commodore gave in to disk format standardization, and made its last 5¼-inch drives, the 1570 and 1571, compatible with Modified Frequency Modulation (MFM), to enable the Commodore 128 to work with CP/M disks from several vendors. Equipped with one of these drives, the C128 was able to access both C64 and CP/M disks, as it needed to, as well as MS-DOS disks (using third-party software), which was a crucial feature for some office work.

Commodore also offered its 8-bit machines a 3½-inch 800 kByte disk format with its 1581 disk drive, which used only MFM.

The GEOS operating system used a disk format that was largely identical to the Commodore DOS format with a few minor extensions; while generally compatible with standard Commodore disks, certain disk maintenance operations could corrupt the filesystem without proper supervision from the GEOS Kernel.

Atari 8-bit line

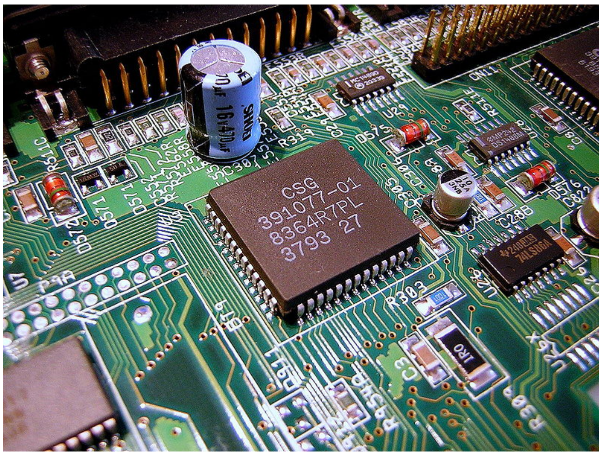
The combination of DOS and hardware (810, 1050 and XF551 disk drives) for Atari 8-bit floppy usage allowed sectors numbered from 1 to 720. The DOS' 2.0 disk bitmap provides information on sector allocation, counts from 0 to 719. As a result, sector 720 could not be written to by the DOS. Some companies used a copy protection scheme where "hidden" data was put in sector 720 that could not be copied through the DOS copy option. Another more-common early copy-protected scheme simply did not record important sectors as "used" in the FAT, so the DOS Utility Package (DUP) did not duplicate them. All of these early techniques were thwarted by the first program that simply duplicated all 720 sectors.

Later DOS versions (3.0 and later 2.5) and DOS systems by third parties (i.e. OSS) accepted (and formatted) disks with up to 960 and 1020 sectors, resulting in 127KB storage capacity per disk side on drives equipped with double-density heads (*i.e.* not the Atari 810) vs. previous 90KB. That unusual 127K format allowed sectors 1-720 to still be read on a single-density 810 disk drive, and was introduced by Atari with the 1050 drive with the introduction of DOS 3.0 in 1983.

A true 180K double-density Atari floppy format used 128 byte sectors for sectors 1-3, then 256 byte sectors for 4-720. The first three sectors typically contain boot code as used by the onboard ROM OS; it's up to the resulting boot program (such as SpartaDOS) to recognize the density of the formatted disk structure. While this 180K format was developed by Atari for their DOS 2.0D and their (canceled) Atari 815 Floppy Drive, that double-density DOS was never widely released and the format was generally used by third-party DOS products. Under the Atari DOS scheme, sector 360 was the FAT sector map, and sectors 361-367 contained the file listing. The Atari-brand DOS versions and compatible used three bytes per sector for housekeeping and to link-list to the next sector.

Third-party DOS systems added features such as double-sided drives, subdirectories, and drive types such as 1.2 MByte and 8". Well-known 3rd party Atari DOS products included SmartDOS (distributed with the Rana disk drive), TopDos, MyDos and SpartaDOS.

Commodore Amiga



The pictured chip, codenamed *Paula*, controlled floppy access on all revisions of the Commodore Amiga as one of its many functions.

The Commodore Amiga computers used an 880 kByte format (11×512-byte sectors per track) on a 3½-inch floppy. Because the entire track is written at once, inter-sector gaps could be eliminated, saving space. The Amiga floppy controller was basic but much more flexible than the one on the PC: it was free of arbitrary format restrictions, encoding such as MFM and GCR could be done in software, and developers were able to create their own proprietary disc formats. Because of this, foreign formats such as the IBM PC-compatible could be handled with ease (by use of CrossDOS, which was included with later versions of AmigaOS). With the correct filesystem driver, an Amiga could theoretically read any arbitrary format on the 3½-inch floppy, including those recorded at a slightly different rotation rate. On the PC, however, there is no way to read an Amiga disk without special hardware, such as a CatWeasel, or a second floppy drive,[32] which is also a crucial reason for an emulator being technically unable to access real Amiga disks inserted in a standard PC floppy disk drive.

Commodore never upgraded the Amiga chip set to support high-density floppies, but sold a custom drive (made by Chinon) that spun at half speed (150 RPM) when a high-density floppy was inserted, enabling the existing floppy controller to be used. This drive was introduced with the launch of the Amiga 3000, although the later Amiga 1200 was only fitted with the standard DD drive. The Amiga HD disks could handle 1760 kByte, but using special software programs it could hold even more data. A company named Kolff Computer Supplies also made an external HD floppy drive (KCS Dual HD Drive) available which could handle HD format diskettes on all Amiga computer systems.[33]

Because of storage reasons, the use of emulators and preserving data, many disks were packed into disk-images. Currently popular formats are `.ADF` (Amiga Disk File), `.DMS` (DiskMasher) and `.IPF` (Interchangeable Preservation Format) files. The DiskMasher format is copyright-protected and has problems storing particular sequences of bits due to bugs in the compression algorithm, but was widely used in the pirate and demo scenes. ADF has been around for almost as long as the Amiga itself though it was not initially called by that name. Only with the advent of the Internet and Amiga emulators has it become a popular way of distributing disk images. The proprietary IPF files were created to allow preservation of commercial games which have copy protection, which is something that ADF and DMS unfortunately cannot do.

Acorn Electron, BBC Micro, and Acorn Archimedes

The British company Acorn used non-standard disk formats in their 8-bit BBC Micro and Acorn Electron, and their successor the 32-bit Acorn Archimedes. Acorn however used standard disk controllers — initially FM, though they quickly transitioned to MFM. The original disk implementation for the BBC Micro stored 100 KB (40 track) or 200 KB (80 track) per side on 5¼-inch disks in a custom format using the Disc Filing System (DFS).

Because of the incompatibility between 40 and 80 track drives, much software was distributed on combined 40/80 track discs. These worked by writing the same data in pairs of consecutive tracks in 80 track format, and including a small loader program on track 1 (which is in the same physical position in either format). The loader program detected which type of drive was in use, and loaded the main software program straight from disc bypassing the DFS, double-stepping for 80 track drives and single-stepping for 40 track. This effectively achieved downgraded capacity to 100 KB from either disk format, but enabled distributed software to be effectively compatible with either drive.

For their Electron floppy disk add-on added, Acorn picked 3½-inch disks and developed the Advanced Disc Filing System (ADFS). It used double-density recording and added the ability to treat both sides of the disk as a single drive. This offered three formats: S (small) — 160 KB, 40-track single-sided; M (medium) — 320 KB, 80-track single-sided; and L (large) — 640 KB, 80-track double-sided. ADFS provided hierarchical directory structure, rather than the flat model of DFS. ADFS also stored some metadata about each file, notably a load address, an execution address, owner and public privileges, and a "lock" bit. Even on the eight-bit machines, load addresses were stored in 32-bit format, since those machines supported 16 and 32-bit coprocessors.

The ADFS format was later adopted into the BBC line upon release of the BBC Master. The BBC Master Compact marked the move to 3½-inch disks, using the same ADFS formats.

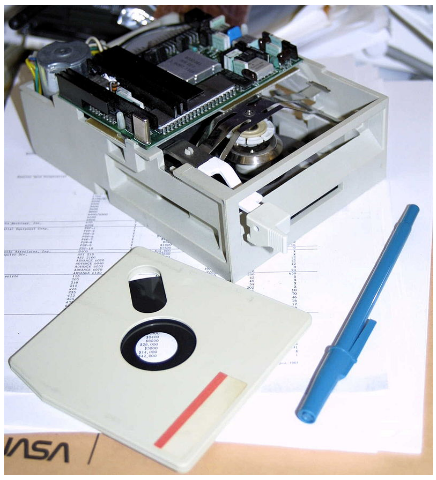
The Acorn Archimedes added D format, which increased the number of objects per directory from 44 to 77 and increased the storage space to 800 KB. The extra space was obtained by using 1024 byte sectors instead of the usual 512 bytes, thus reducing the space needed for inter-sector gaps. As a further enhancement, successive tracks were offset by a sector, giving time for the head to advance to the next track without missing the first sector, thus increasing bulk throughput. The Archimedes used special values in the ADFS load/execute address metadata to store a 12-bit filetype field and a 40-bit timestamp.

RISC OS 2 introduced E format, which retained the same physical layout as D format, but supported file fragmentation and auto-compaction. Post-1991 machines including the A5000 and Risc PC added support for high-density disks with F format, storing 1600 KB. However, the PC combo IO chips used were unable to format disks with sector skew, losing some performance. ADFS and the PC controllers also support extended-density disks as G format, storing 3200 KB, but ED drives were never fitted to production machines.

With RISC OS 3, the Archimedes could also read and write disk formats from other machines, for example the Atari ST and the IBM PC. With third party software it could even read the BBC Micro's original single density 5¼-inch DFS disks. The Amiga's disks could not be read as they used unusual sector gap markers.

The Acorn filesystem design was interesting because all ADFS-based storage devices connected to a module called FileCore which provided almost all the features required to implement an ADFS-compatible filesystem. Because of this modular design, it was easy in RISC OS 3 to add support for so-called image filing systems. These were used to implement completely transparent support for IBM PC format floppy disks, including the slightly different Atari ST format. Computer Concepts released a package that implemented an image filing system to allow access to high density Macintosh format disks.

IBM DemiDiskettes



IBM DemiDiskette media and drive

In the early 80s, IBM Rochester developed a 4-inch floppy diskette, the DemiDiskette. This program was driven by aggressive cost goals, but missed the pulse of the industry. The prospective users, both inside and outside IBM, preferred standardization to what by release time were small cost reductions, and were unwilling to retool packaging, interface chips and applications for a proprietary design. The product never appeared in the light of day, and IBM wrote off several hundred million dollars of development and manufacturing facility. IBM obtained patent number 4482929 on the media and the drive for the DemiDiskette. At trade shows, the drive and media were labeled "Brown" and "Tabor".

Auto-loaders

IBM developed, and several companies copied, an autoloader mechanism that could load a stack of floppies one at a time into a drive unit. These were very bulky systems, and suffered from media hangups and chew-ups more than standard drives, but they were a partial answer to replication and large removable storage needs. The smaller 5¼- and 3½-inch floppy made this a much easier technology to perfect.

Floppy mass storage

A number of companies, including IBM and Burroughs, experimented with using large numbers of unenclosed disks to create massive amounts of storage. The Burroughs system used a stack of 256 12-inch disks, spinning at a high speed. The disk to be accessed was selected by using air jets to part the stack, and then a pair of heads flew over the surface as in any standard hard disk drive. This approach in some ways anticipated the Bernoulli disk technology implemented in the Iomega Bernoulli Box, but head crashes or air failures were spectacularly messy. The program did not reach production.

2-inch floppy disks

2-inch Video Floppy Disk from Canon.

A small floppy disk was also used in the late 1980s to store video information for still video cameras such as the Sony Mavica (not to be confused with later Digital Mavica models) and the Ion and Xapshot cameras from Canon. It was officially referred to as a Video Floppy (or VF for short).

VF was not a digital data format; each track on the disk stored one video field in the analog interlaced composite video format in either the North American NTSC or European PAL standard. This yielded a capacity of 25 images per disk in frame mode and 50 in field mode.

The same media were used digitally formatted - 720 kB, 245TPI, 80 tracks/side, double-sided, double-density - in the Zenith Minisport laptop computer circa 1989. Although the media exhibited nearly identical performance to the 3½-inch disks of the time, they were not successful. This was due in part to the scarcity of other devices using this drive making it impractical for software transfer, and high media cost which was much more than 3½-inch and 5¼-inch disks of the time.

Ultimate capacity and speed

Floppy disk drive and floppy media manufacturers specify an unformatted capacity, which is, for example, 2.0 MB for a standard 3½-inch HD floppy. It is implied that this data capacity should not be exceeded since exceeding such limitations will most likely degrade the design margins of the floppy system and could result in performance problems such as inability to interchange or even loss of data. However the Distribution Media Format was later introduced permitting 1680 KB to fit onto an otherwise standard 3½-inch disk. Utilities then appeared allowing disks to be formatted to this capacity.

The nominal formatted capacity printed on labels is "1.44 MB" which uses an incorrect definition of the megabyte that combines decimal (base 10) with binary (base 2) to yield 1.44×1000×1024 bytes (approximately 1.47 million bytes). This usage of the "Mega-" prefix is not compatible with the International System of Units prefixes. Using SI-compliant definitions, the capacity of a 3½-inch HD floppy is properly written as 1.47 MB (base 10) or 1.41 MiB (base 2).

User available data capacity is a function of the particular disk format used which in turn is determined by the FDD controller manufacturer and the settings applied to its controller. The differences between formats can result in user data capacities ranging from approximately 1300 KB up to 1760 KB (1.80 MB) on a "standard" 3½-inch High Density floppy (and even up to near 2 MB with utilities like 2MGUI). The highest capacity techniques require much tighter matching of drive head geometry between drives; this is not always possible and cannot be relied upon. The LS-240 drive supports a (rarely used) 32 MB capacity on standard 3½-inch HD floppies —it is, however, a write-once technique, and cannot be used in a read/write/read mode. All the data must be read off, changed as needed and rewritten to the disk. The format also requires an LS-240 drive to read.

Double-sided Extended-density (DSED) 3½″ floppy disks, introduced by Toshiba in 1987 and adopted by IBM on the PS/2 in 1994,[19] operate at twice the data rate and have twice the capacity of DSHD 3½″ FDDs.[34] The only serious attempt to speed up a 3½" floppy drive beyond 2x was the X10 accelerated floppy drive. It used a combination of RAM and 4x spindle speed to read a floppy in less than six seconds versus the more than one minute of a conventional drive.

3½-inch HD floppy drives typically have a maximum transfer rate of 1000 kilobits/second (minus overhead such as error correction and file handling). (For comparison, a 1x CD transfers at 1200 kilobits per second (maximum), and a 1x DVD transfers at approximately 11,000 kilobits per second.) While the floppy's data rate cannot be easily changed, overall performance can be improved by optimizing drive access times, shortening some BIOS introduced delays (especially on the IBM PC and compatible platforms), and by changing the **sector:shift** parameter of a disk. Because of overhead and these additional delays, the average sequential read speed is rather 30–70 KB/s than 125 KB/s.

The **sector:shift** parameter controls the order in which sectors are located on each track of the disk. Naively, one could place the sectors consecutively - 1, 2, 3, 4,... - but when multiple sectors are being read or written, this requires the disk controller and the CPU to handle the data from each sector, or prepare the data for the next sector, in the very short time that it takes the disk to rotate from the end of one sector to the beginning of the next. For example, when reading, if sector 2 reaches the drive heads before processing of the data from sector 1 has been completed, it is too late, and the disk must rotate one full revolution before sector 2 can be handled, resulting in a catastrophic loss of overall throughput. If the sectors are placed so that consecutively numbered sectors are further apart - for example, 1, 9, 2, 10, 3, 11,... - then a much longer time is available for processing the data from sector 1 before sector 2 arrives and needs to be processed.

Usability

One of the chief usability problems of the floppy disk is its vulnerability. Even inside a closed plastic housing, the disk medium is still highly sensitive to dust, condensation and temperature extremes. As with any magnetic storage, it is also vulnerable to magnetic fields. Blank disks have usually been distributed with an extensive set of warnings, cautioning the user not to expose it to conditions which can endanger it. It should be noted that the disk must not be roughly treated, or removed from the drive if the access light is switched on and the magnetic media is still spinning, since doing so is likely to cause damage to the disk, drive head and/or render the data on it inaccessible.

Users damaging floppy disks (or their contents) were once a staple of "stupid user" folklore among computer technicians. These stories poked fun at users who stapled floppies to papers, made faxes or photocopies of them when asked to "copy a disk," or stored floppies by holding them with a magnet to a file cabinet. The flexible 5¼-inch disk could also (apocryphally) be abused by rolling it into a typewriter to type a label, or by removing the disk medium from the plastic enclosure, the same way a record is removed from its slipsleeve. Also, these same users were, conversely, often the victims of technicians' hoaxes. Stories of them being carried on Subway/Underground systems wrapped in tin-foil to protect them from the magnetic fields of the electric power supply were common (for an explanation of why this is plausible, see Faraday cage).

On the other hand, the 3½-inch floppy has also been lauded for its mechanical usability by HCI expert Donald Norman:

> A simple example of a good design is the 3½-inch magnetic diskette for computers, a small circle of "floppy" magnetic material encased in hard plastic. Earlier types of floppy disks did not have this plastic case, which protects the magnetic material from abuse and damage. A sliding metal cover protects the delicate magnetic surface when the diskette is not in use and automatically opens when the diskette is inserted into the computer. The diskette has a square shape: there are apparently eight possible ways to insert it into the machine, only one of which is correct. What happens if I do it wrong? I try inserting the disk sideways. Ah, the designer thought of that. A little study shows that the case really isn't square: it's rectangular, so you can't insert a longer side. I try backward. The diskette goes in only part of the way. Small protrusions, indentations, and cutouts, prevent the diskette from being inserted backward or upside down: of the eight ways one might try to insert the diskette, only one is correct, and only that one will fit. An excellent design.[35]

If a floppy drive is used very infrequently, dust may accumulate on the drive's read/write head and cause damage to floppy disks. This rarely happens on floppy drives that are used frequently. In order to overcome this, the user can first put in the drive a cleaning disk or an already useless disk and run the drive. Thus dust would be cleaned off from the read/write head.

See also

- Floppy disk controller
- Floppy disk format
- RaWrite2 (a floppy disk image file writer/creator)
- On Unix or Unix-like systems the dd program can be used to write an image to a floppy.
- Don't Copy That Floppy
- Semi-virtual diskette
- USB
- USB flash drive
- Compact Disc
- DVD

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- Hewlett Packard: 9121D/S Disc Memory Operator's Manual; Printed 1 September 1982; Part No. 09121-90000 [37]

External links

- Programming Floppy Disk Controllers [38]
- HowStuffWorks: How Floppy Disk Drives Work [39] – By Gary Brown.
- Computer Hope: Information about computer floppy drives [40] – Including abbreviated history, physical parameters and cable pin specifications.
- NCITS [41] (mention of ANSI X3.162 (5¼-inch) and X3.171 (90 mm) floppy standards)
- Tandon Floppy Disk Drive Manuals [42]
- Persci Floppy Disk Drive Manuals [43]
- Floppy Drive Tech Info [44]

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[3] The Floppy Disk Drive Engineering Design Challenge SSD to FDD (http://www.jimwarholic.com/docs/Floppy-Disk-Drive-Solid-State-Drive.pdf)

[4] Originally announced as the "Type 1 Diskette" by IBM in 1973, the industry then adopted the terms "floppy disk" or "floppy." The hard shelled 3.5" version was called a "stiffy" principally in South Africa (Victor, Terry; Partridge, Eric; Dalzell, Tom (2006). *The new Partridge dictionary of slang and unconventional English*. New York: Routledge. ISBN 0-415-25938-X.) .

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[11] The IBM Diskette and Diskette Drive (http://www.research.ibm.com/journal/rd/255/ibmrd2505ZE.pdf), James T. Engh, 1981 - "This would double the capacity to approximately 0.5 megabytes (Mbytes)."

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[13] Shugart SA 400 Datasheet (http://www.swtpc.com/mholley/SA400/SA400_Index.htm) Formatted with 256 byte sectors and 10 sectors per track the capacity is 89.6 Kbytes (256 x 10 x 35 = 89,600)

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> A new, compact floppy disk, with dimensions of 80 × 100 × 5 millimeters (about 3 × 4 inches), has been jointly announced by Maxell, Hitachi, and Matsushita. (...) we expect that various disk drives using 3-inch disks will begin to appear in the latter part of 1982. The capacity of the new disk is 125K bytes for the single-sided, single-density version and 500K bytes for the double-sided, double-density version.
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[19] Mueller, S: "Upgrading and Repairing PCs," p.656, Que Publishing, 2002.

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[22] 1991 Disk/Trend Report, Flexible Disk Drives, Figure 2

[23] 2 sides × 526 cyl × 40 tracks × 512 bytes

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[32] Jonguin, Vincent; Sonia Joguin (2004). "Disk2FDI Homepage" (http://www.oldskool.org/disk2fdi). . Retrieved 2006-05-25.

[33] KCS Dual HD Drive for Amiga computers (http://www.amiga-hardware.com/showhardware.cgi?HARDID=773)

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[44] http://retrotechnology.com/herbs_stuff/drive.html

CD-RW

Compact Disc ReWritable (CD-RW) logo/trademark

Optical discOptical disc driveOptical disc authoringOptical disc authoring softwareAuthoring softwareOptical disc recording technologiesRecording technologiesOptical disc recording modesRecording modesPacket writing
Optical media types
Blu-ray Disc (BD): Blu-ray Disc recordableBD-R, BD-REDVD: DVD-R, DVD+R, DVD-R DL, DVD+R DL, DVD-RW, DVD+RW, DVD-RAM, DVD-D, High-Definition Versatile DiscHVD, EcoDiscCompact Disc (CD): Red Book (audio Compact Disc standard)Red Book, CD-ROM, CD-R, CD-RW, 5.1 Music Disc, Super Audio CDSACD, PhotoCD, CD Video (CDV), Video CD (VCD), SVCD, CD+G, CD-Text, CD-ROM XA, CD-iUniversal Media Disc (UMD) Enhanced Versatile Disc (EVD) Forward Versatile Disc (FVD) Holographic Versatile Disc (HVD) China Blue High-definition Disc (CBHD) HD DVD: HD DVD-R, HD DVD-RW, HD DVD-RAMHigh definition Versatile Multilayer Disc (HD VMD) VCDHDGD-ROMMiniDisc (MD) (Hi-MD) Laserdisc (LD) Video Single Disc (VSD) Ultra Density Optical (UDO) Stacked Volumetric Optical Disk (SVOD) 5D DVDFive dimensional discs (5D DVD) Nintendo optical disc (NOD)
Standards
Rainbow BooksFile systems ISO 9660Joliet (file system)JolietRock Ridge / SUSP El Torito (CD-ROM standard)El ToritoApple ISO 9660 ExtensionsUniversal Disk Format (UDF) Mount Rainier (packet writing)Mount Rainier
See also
History of optical storage mediaHigh definition optical disc format war

A **CD-RW** (Compact Disc-ReWritable)is a rewritable optical disc format. Known as CD-Erasable (CD-E) during its development, CD-RW was introduced in 1997, and was preceded by the CD-MO, which was never officially released, in 1988.

CD-RW discs require a more sensitive laser optics. Also, CD-RWs cannot be read in some CD-ROM drives built prior to 1997. This is why CD-ROM drives of the age must bear a "MultiRead" certification to show compatibility. CD-RW discs need to be blanked before reuse. Different blanking methods can be used, including "full" blanking in which the entire surface of the disc is cleared, and "fast" blanking in which only meta-data areas are cleared: PMA, TOC and pregap, comprising a few percent of the disc. Fast blanking will obviously be much quicker, and is usually sufficient to allow rewriting the disc. Full blanking removes traces of the former data, often for confidentiality. It may be possible to recover data from full-blanked CD-RWs with specialty data recovery equipment; however, this is generally not used except by government agencies due to cost.

CD-RW also have a shorter rewriting cycles life (ca. 1,000) compared to virtually all of the previously exposed types storage of media (typically well above 10,000 or even 100,000), something which however is less of a drawback considering that CD-RWs are usually written and erased in their totality, and not with repeated small scale changes, so normally wear leveling is not an issue.

Their ideal usage field is in the creation of test disks, temporary short or mid-term backups, and in general, where an intermediate solution between online and offline storage schemes is required.

CD-MO

Prior to the introduction of the CD-RW technology, a standard for magneto-optical recordable and erasable CDs called CD-MO was introduced in 1988 and set in the Orange Book, part 1, and was basically a CD with a magneto-optical recording layer. The CD-MO standard also allowed for an optional non-erasable zone on the disk, which could be read by normal CD-ROM reader units.

Data recording (and erasing) was achieved by heating the magneto-optical layer's material (eg. DyFeCo or less often TbFeCo or GdFeCo) up to its Curie point thus erasing all previous data and then using a magnetic field to write the new data, in a manner essentially identical to Sony's MiniDisc and other magneto-optical formats. Reading of the discs relied on the Kerr effect. This was also the first major flaw of this format: it could only be read in special drives and was physically incompatible with non magneto-optical enabled drives, in a much more radical way than the later CD-RWs.

The format was never released commercially, mostly because of its inherent incompatibility with standard CD reading units. A similar situation was also present for early CD-R media, which suffered from either physical or logical incompatibilities.

Since the CD-MO was otherwise physically identical to "normal" CDs, it still adopted their spiral-groove recording scheme, which would have rendered it hard to use as a removable medium for repeated, small scale deletions and recordings (not unlike CD-RW). There were (and are) however some magneto-optical drives and media with the same form factor that don't have this limitation. Unlike modern CD-RWs, CD-MO allowed for hybrid disks containing both an unmodifiable, pressed section, readable in standard drives and a recordable MO section.

This early introduction along with the lack of standards for disk recording software, file systems and formats, physical incompatibility as well as the introduction of the relatively more economical CD-R disks essentially caused the format to be abandoned before commercialization [1][2], and the whole idea of a rewritable CD medium to be almost forgotten until modern phase change CD-RWs appeared. Other kinds of magneto-optical media, unbound by the limitations of the typical CD-ROM filesystems, took the place intended for CD-MO.

Speed specifications

Spec[3]	Speed
(Original) "slow"	1x - 4x
High Speed	4x - 10x
Ultra Speed	12x - 24x
Ultra Speed+	32x

Like CD-R, CD-RW have hardcoded speed specifications which limit the allowable recording speeds to certain fairly restrictive ranges, but unlike the former they also have a **minimum** writing speed under which the disks cannot be reliably recorded, something dictated by the phase change material's heating and cooling time constants, and the required laser energy levels.

Philips created the "High-Speed" CD-RW logo for media that supports writing speeds above 4x.

Since the CD-RW discs need to be blanked either entirely or "on the fly" before recording actual data, writing too slowly or with too low energy on a high speed unblanked disc will cause the phase change layer to cool off before blanking has been achieved, preventing the actual data from being reliably written.

Similarly, using inappropriately high amounts of laser energy will cause the material to get overheated and become "insensitive" to the actual data, a situation which is typical of slower discs used in a higher powered faster spec drive.

For these reasons, in general older CD-RW drives lacking appropriate firmware and hardware cannot handle newer, high speed CD-RW discs (poor forward compatibility), while newer drives can generally record to older CD-RW discs, provided their firmware can set the correct speed, delay and power settings for the task.

The actual reading speed of CD-RW disks however is not directly correlated or bound to its speed spec, but depends first and foremost on the reading drive's capabilities, as with CD-R discs.

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[3] http://www.cdrfaq.org/faq04.html

- Bennett, Hugh. "CD-E: Call it Erasable, Call it Rewritable, but will it Fly?" *CD-ROM Professional* Sept. 1996: 28+
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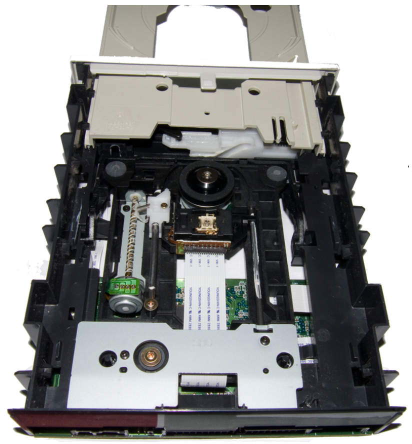
- Steinmetz, Ralf and Nahrstedt Klara. "Multimedia Fundamentals Volume 1: Media Coding and Content Processing", ISBN 0-13-031399-8.

External links

- The CD-R FAQ (http://www.cdrfaq.org/)
- Understanding CD-R & CD-RW (http://www.osta.org/technology/cdqa.htm)

Optical disc drive

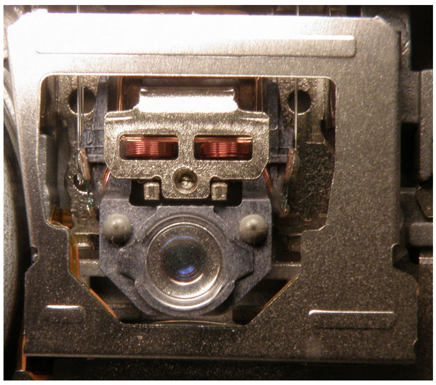
A CD-ROM Drive



A CD-ROM Drive (without case)

Optical discOptical disc driveOptical disc authoringOptical disc authoring softwareAuthoring softwareOptical disc recording technologiesRecording technologiesOptical disc recording modesRecording modesPacket writing
Optical media types
Blu-ray Disc (BD): Blu-ray Disc recordableBD-R, BD-REDVD: DVD-R, DVD+R, DVD-R DL, DVD+R DL, DVD-RW, DVD+RW, DVD-RAM, DVD-D, High-Definition Versatile DiscHVD, EcoDiscCompact Disc (CD): Red Book (audio Compact Disc standard)Red Book, CD-ROM, CD-R, CD-RW, 5.1 Music Disc, Super Audio CDSACD, PhotoCD, CD Video (CDV), Video CD (VCD), SVCD, CD+G, CD-Text, CD-ROM XA, CD-iUniversal Media Disc (UMD) Enhanced Versatile Disc (EVD) Forward Versatile Disc (FVD) Holographic Versatile Disc (HVD) China Blue High-definition Disc (CBHD) HD DVD: HD DVD-R, HD DVD-RW, HD DVD-RAMHigh definition Versatile Multilayer Disc (HD VMD) VCDHDGD-ROMMiniDisc (MD) (Hi-MD) Laserdisc (LD) Video Single Disc (VSD) Ultra Density Optical (UDO) Stacked Volumetric Optical Disk (SVOD) 5D DVDFive dimensional discs (5D DVD) Nintendo optical disc (NOD)
Standards
Rainbow BooksFile systems ISO 9660Joliet (file system)JolietRock Ridge / SUSP El Torito (CD-ROM standard)El ToritoApple ISO 9660 ExtensionsUniversal Disk Format (UDF) Mount Rainier (packet writing)Mount Rainier
See also
History of optical storage mediaHigh definition optical disc format war

In computing, an **optical disc drive** (**ODD**) is a disk drive that uses laser light or electromagnetic waves near the light spectrum as part of the process of reading or writing data to or from optical discs. Some drives can only read from discs, but recent drives are commonly both **readers** and **recorders**. Recorders are sometimes called **burners** or **writers**. Compact discs, DVDs, HD DVDs and Blu-ray discs are common types of optical media which can be read and recorded by such drives.



The CD/DVD drive lens on an Acer laptop

Optical disc drives are an integral part of stand-alone consumer appliances such as CD players, DVD players and DVD recorders. They are also very commonly used in computers to read software and consumer media distributed in disc form, and to record discs for archival and data exchange. Optical drives—along with flash memory—have mostly displaced floppy disk drives and magnetic tape drives for this purpose because of the low cost of optical media and the near-ubiquity of optical drives in computers and consumer entertainment hardware.

Disc recording is generally restricted to small-scale backup and distribution, being slower and more materially expensive per unit than the moulding process used to mass-manufacture pressed discs.

Laser and optics

The most important part of an optical disc drive is an *optical path*, placed in a *pickup head* (*PUH*),[1] usually consisting of semiconductor laser, a lens for guiding the laser beam, and photodiodes detecting the light reflection from disc's surface.[2]

Initially, CD lasers with a wavelength of 780 nm were used, being within infrared range. For DVDs, the wavelength was reduced to 650 nm (red color), and the wavelength for Blu-Ray Disc was reduced to 405 nm (violet color).

Two main servomechanisms are used, the first one to maintain a correct distance between lens and disc, and ensure the laser beam is focused on a small *laser spot* on the disc. The second servo moves a head along the disc's radius, keeping the beam on a *groove*, a continuous spiral data path.

On *read only media* (ROM), during the manufacturing process the groove, made of *pits*, is pressed on a flat surface, called *land*. Because the depth of the pits is approximately one-quarter to one-sixth of the laser's wavelength, the reflected beam's phase is shifted in relation to the incoming reading beam, causing mutual destructive interference and reducing the reflected beam's intensity. This is detected by photodiodes that output electrical signals.

A recorder encodes (or *burns*) data onto a recordable CD-R, DVD-R, DVD+R, or BD-R disc (called a *blank*) by selectively heating parts of an organic dye layer with a laser. This changes the reflectivity of the dye, thereby creating marks that can be read like the pits and lands on pressed discs. For recordable discs, the process is permanent and the media can be written to only once. While the reading laser is usually not stronger than 5 mW, the writing laser is considerably more powerful. The higher writing speed, the less time a laser has to heat a point on the media, thus its power has to increase proportionally. DVD burner's laser often peaks at about 100 mW in continuous wave, and 225 mW pulsed.

For rewritable CD-RW, DVD-RW, DVD+RW, DVD-RAM, or BD-RE media, the laser is used to melt a crystalline metal alloy in the recording layer of the disc. Depending on the amount of power applied, the substance may be allowed to melt back (change the phase back) into crystalline form or left in an amorphous form, enabling marks of varying reflectivity to be created.

Double-sided media may be used, but they are not easily accessed with a standard drive, as they must be physically turned over to access the data on the other side.

Double layer (DL) media have two independent data layers separated by a semi-reflective layer. Both layers are accessible from the same side, but require the optics to change the laser's focus. Traditional *single layer* (SL) writable media are produced with a spiral groove molded in the protective polycarbonate layer (not in the data recording layer), to lead and synchronize the speed of recording head. Double-layered writable media have: a first polycarbonate layer with a (shallow) groove, a first data layer, a semi-reflective layer, a second (spacer) polycarbonate layer with another (deep) groove, and a second data layer. The first groove spiral usually starts on the inner edge and extends outwards, while the second groove starts on the outer edge and extends inwards.

Some drives support Hewlett-Packard's LightScribe photothermal printing technology for labeling specially coated discs.

Rotational mechanism

Optical drives' rotational mechanism differs considerably from hard disk drives', in that the latter keep a constant angular velocity (CAV), in other words a constant number of revolutions per minute (RPM). With CAV, a higher throughput is generally achievable at an outer disc area, as compared to inner area.

On the other hand, optical drives were developed with an assumption of achieving a constant throughput, in CD drives initially equal to 150 KiB/s. It was a feature important for streaming audio data that always tend to require a constant bit rate. But to ensure no disc capacity is wasted, a head had to transfer data at a maximum linear rate at all times too, without slowing on the outer rim of disc. This had led to optical drives—until recently—operating with a constant linear velocity (CLV). The spiral *groove* of the disc passed under its *head* at a constant speed. Of course the implication of CLV, as opposed to CAV, is that disc *angular* velocity is no longer constant, and spindle motor need to be designed to vary speed between 200 RPM on the outer rim and 500 RPM on the inner rim.

Later CD drives kept the CLV paradigm, but evolved to achieve higher rotational speeds, popularly described in multiples of a *base speed*. As a result, a 4X drive, for instance, would rotate at 800-2000 RPM, while transferring data steadily at 600 KiB/s, which is equal to 4 x 150 KiB/s.

For DVD base speed, or "1x speed", is 1.385 MB/s, equal to 1.32 MiB/s, approximately 9 times faster than CD's base speed. For Blu-ray drive base speed is 6.74 MB/s, equal to 6.43 MiB/s.

There are mechanical limits to how quickly a disc can be spun. Beyond a certain rate of rotation, around 10000 RPM, centrifugal stress can cause the disc plastic to creep and possibly shatter. On the outer edge of the CD disc, 10000 RPM limitation roughly equals to 52x speed, but on the inner edge only to 20x. Some drives further lower their maximum read speed to around 40x on the reasoning that blank discs will be clear of structural damage, but that discs inserted for reading may not be. Without higher rotational speeds, increased read performance may be attainable by simultaneously reading more than one point of a data groove [3] , but drives with such mechanisms are more expensive, less compatible, and very uncommon.

The Z-CLV recording strategy is easily visible after burning a DVD-R.

Because keeping a constant transfer rate for the whole disc is not so important in most contemporary CD uses, to keep the rotational speed of the disc safely low while maximizing data rate, a pure CLV approach needed to be abandoned. Some drives work in *partial CLV* (PCLV) scheme, by switching from CLV to CAV only when a rotational limit is reached. But switching to CAV requires considerable changes in hardware design, so instead most drives use the zoned constant linear velocity (Z-CLV) scheme. This divides the disc into several zones, each having its own different constant linear velocity. A Z-CLV recorder rated at "52X", for example, would write at 20X on the innermost zone and then progressively increase the speed in several *discrete* steps up to 52X at the outer rim.

Loading mechanisms

Current optical drives use either a *tray-loading* mechanism, where the disc is loaded onto a motorised or manually operated tray, or a *slot-loading* mechanism, where the disc is slid into a slot and drawn in by motorized rollers. Slot-loading drives have the disadvantage that they cannot usually accept the smaller 80 mm discs or any non-standard sizes; however, the Wii and PlayStation 3 video game consoles seem to have defeated this problem, for they are able to load standard size DVDs and 80 mm discs in the same slot-loading drive.

A small number of drive models, mostly compact portable units, have a *top-loading* mechanism where the drive lid is opened upwards and the disc is placed directly onto the spindle.[4] These sometimes have the advantage of using spring-loaded ball bearings to hold the disc in place, minimizing damage to the disc if the drive is moved while it is spun up.

Some early CD-ROM drives used a mechanism where CDs had to be inserted into special cartridges or caddies, somewhat similar in appearance to a 3.5" floppy diskette. This was intended to protect the disc from accidental damage by enclosing it in a tougher plastic casing, but did not gain wide acceptance due to the additional cost and compatibility concerns—such drives would also inconveniently require "bare" discs to be manually inserted into an openable caddy before use.

Computer interfaces

Digital audio output, analog audio output, and parallel ATA interface.

Most internal drives for personal computers, servers and workstations are designed to fit in a standard 5.25" drive bay and connect to their host via an ATA or SATA interface. Additionally, there may be digital and analog outputs for Red Book audio. The outputs may be connected via a header cable to the sound card or the motherboard. External drives usually have USB or FireWire interfaces. Some portable versions for laptop use power themselves off batteries or off their interface bus.

Drives with SCSI interface exist, but are less common and tend to be more expensive, because of the cost of their interface chipsets and more complex SCSI connectors.

When the optical disc drive was first developed, it was not easy to add to computer systems. Some computers such as the IBM PS/2 were standardizing on the 3.5" floppy and 3.5" hard disk, and did not include a place for a large internal device. Also IBM PCs and clones at first only included a single ATA drive interface, which by the time the CDROM was introduced, was already being used to support two hard drives. Early laptops simply had no built-in high-speed interface for supporting an external storage device.

This was solved through several techniques:

- Early sound cards could include a second ATA interface, though it was often limited to supporting a single optical drive and no hard drives. This evolved into the modern second ATA interface included as standard equipment
- A parallel port external drive was developed that connected between a printer and the computer. This was slow but an option for laptops
- A PCMCIA optical drive interface was also developed for laptops
- A SCSI card could be installed in desktop PCs for an external SCSI drive enclosure, though SCSI was typically much more expensive than other options

Compatibility

Most optical drives are backwards compatible with their ancestors up to CD, although this is not required by standards.

Compared to a CD's 1.2 mm layer of polycarbonate, a DVD's laser beam only has to penetrate 0.6 mm in order to reach the recording surface. This allows a DVD drive to focus the beam on a smaller spot size and to read smaller pits. DVD lens supports a different focus for CD or DVD media with same laser.

	Pressed CD	CD-R	CD-RW	Pressed DVD	DVD-R	DVD+R	DVD-RW	DVD+RW	DVD+R DL	Pressed BD	BD-R	BD-RE	BD-R DL	BD-RE DL
Audio CD player	Read	Read [1]	Read [2]	None	None	None	None	None	None	None	None	None	None	None
CD-ROM drive	Read	Read [1]	Read [2]	None	None	None	None	None	None	None	None	None	None	None
CD-R recorder	Read	Write	Read	None	None	None	None	None	None	None	None	None	None	None
CD-RW recorder	Read	Write	Write	None	None	None	None	None	None	None	None	None	None	None
DVD-ROM drive	Read	Read [3]	Read [3]	Read	Read [4]	Read [4]	Read [4]	Read [4]	Read [5]	None	None	None	None	None
DVD-R recorder	Read	Write	Write	Read	Write	Read [6]	Read [7]	Read [6]	Read [5]	None	None	None	None	None
DVD-RW recorder	Read	Write	Write	Read	Write	Read [7]	Write [8]	Read [6]	Read [5]	None	None	None	None	None
DVD+R recorder	Read	Write	Write	Read	Read [6]	Write	Read [6]	Read [9]	Read [5]	None	None	None	None	None
DVD+RW recorder	Read	Write	Write	Read	Read [6]	Write	Read [6]	Write	Read [5]	None	None	None	None	None
DVD±RW recorder	Read	Write	Write	Read	Write	Write	Write	Write	Read [5]	None	None	None	None	None
DVD±RW/DVD+R DL recorder	Read	Write	Write	Read	Write [10]	Write	Write [10]	Write	Write	None	None	None	None	None
BD-ROM	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read	Read
BD-R recorder	Read [11]	Write [11]	Write [11]	Read	Write	Write	Write	Write	Write	Read	Write	Read	Read	Read
BD-RE recorder	Read [11]	Write [11]	Write [11]	Read	Write	Write	Write	Write	Write	Read	Write	Write	Read	Read
BD-R DL recorder	Read [11]	Write [11]	Write [11]	Read	Write	Write	Write	Write	Write	Read	Write	Read	Write	Read
BD-RE DL recorder	Read [11]	Write [11]	Write [11]	Read	Write	Write	Write	Write	Write	Read	Write	Write	Write	Write

- **1** Some types of CD-R media with less-reflective dyes may cause problems.
- **2** May not work in non MultiRead-compliant drives.
- **3** May not work [5] in some early-model DVD-ROM drives.
- **4** A large-scale compatibility test [6] conducted by cdrinfo.com in July 2003 found DVD-R discs playable by 96.74%, DVD+R by 87.32%, DVD-RW by 87.68% and DVD+RW by 86.96% of consumer DVD players and DVD-ROM drives.
- **5** Read compatibility with existing DVD drives may vary greatly] with the brand of DVD+R DL media used.
- **6** Need information on read compatibility.

- **7** May not work in non DVD Multi-compliant drives.
- **8** Recorder firmware may blacklist or otherwise refuse to record to some brands of DVD-RW media.
- **9** Need information on read compatibility.
- **10** As of April 2005, all DVD+R DL recorders on the market are Super Multi-capable.
- **11** As of October 2006, recently released BD drives are able to read and write CD media.

Recording performance

Optical recorder drives are often marked with three different speed ratings. In these cases, the first speed is for write-once (R) operations, second for re-write (RW or RE) operations, and one for read-only (ROM) operations. For example a 12x/10x/32x CD drive is capable of writing to CD-R discs at 12x speed (1.76 MB/s), write to CD-RW discs at 10x speed (1.46 MB/s), and read from any CD discs at 32x speed (4.69 MB/s).

In the late 1990s, *buffer underruns* became a very common problem as high-speed CD recorders began to appear in home and office computers, which—for a variety of reasons—often could not muster the I/O performance to keep the data stream to the recorder steadily fed. The recorder, should it run short, would be forced to halt the recording process, leaving a truncated track that usually renders the disc useless.

In response, manufacturers of CD recorders began shipping drives with "buffer underrun protection" (under various trade names, such as Sanyo's "BURN-Proof", Ricoh's "JustLink" and Yamaha's "Lossless Link"). These can suspend and resume the recording process in such a way that the gap the stoppage produces can be dealt with by the error-correcting logic built into CD players and CD-ROM drives. The first of these drives were rated at 12X and 16X.

Recording schemes

CD recording on personal computers was originally a batch-oriented task in that it required specialised authoring software to create an "image" of the data to record, and to record it to disc in the one session. This was acceptable for archival purposes, but limited the general convenience of CD-R and CD-RW discs as a removable storage medium.

Packet writing is a scheme in which the recorder writes incrementally to disc in short bursts, or packets. Sequential packet writing fills the disc with packets from bottom up. To make it readable in CD-ROM and DVD-ROM drives, the disc can be *closed* at any time by writing a final table-of-contents to the start of the disc; thereafter, the disc cannot be packet-written any further. Packet writing, together with support from the operating system and a file system like UDF, can be used to mimic random write-access as in media like flash memory and magnetic disks.

Fixed-length packet writing (on CD-RW and DVD-RW media) divides up the disc into padded, fixed-size packets. The padding reduces the capacity of the disc, but allows the recorder to start and stop recording on an individual packet without affecting its neighbours. These resemble the block-writable access offered by magnetic media closely enough that many conventional file systems will work as-is. Such discs, however, are not readable in most CD-ROM and DVD-ROM drives or on most operating systems without additional third-party drivers.

The DVD+RW disc format goes further by embedding more accurate timing hints in the data groove of the disc and allowing individual data blocks to be replaced without affecting backwards compatibility (a feature dubbed "lossless linking"). The format itself was designed to deal with discontinuous recording because it was expected to be widely used in digital video recorders. Many such DVRs use variable-rate video compression schemes which require them to record in short bursts; some allow simultaneous playback and recording by alternating quickly between recording to the tail of the disc whilst reading from elsewhere.

Mount Rainier aims to make packet-written CD-RW and DVD+RW discs as convenient to use as that of removable magnetic media by having the firmware format new discs in the background and manage media defects (by automatically mapping parts of the disc which have been worn out by erase cycles to reserve space elsewhere on the disc). As of February 2007, support for Mount Rainier is natively supported in Windows Vista. All previous versions of Windows require a third-party solution, as does Mac OS X.

Recorder Unique Identifier

Owing to pressure from the music industry, as represented by the IFPI and RIAA, Philips developed the *Recorder Identification Code* (RID) to allow media to be uniquely associated with the recorder that has written it. This standard is contained in the Rainbow Books. The RID-Code is the opposite of the Source Identification Code (SID), an eight character supplier code that is placed on every CD-ROM.

The RID-Code consists of a supplier code (e.g. "PHI" for Philips), a model number and the unique ID of the recorder.

See also

- Computer hardware
- Ripping
- Cue sheet (music software)
- CD shattering
- Optical disc authoring
- List of optical disc authoring software
- ISO image
- Optical disc recording technologies
- MultiLevel Recording
- Phase-change Dual
- Receiver (radio)

External links

- How CD Burners Work [7] at HowStuffWorks
- Understanding CD-R & CD-RW [8]
- Guide to CD Writing and writing standards [9]
- CD-Recordable FAQ [10]
- CD/DVD/Blu-ray news and reviews [11]
- Why Audio CD-R Discs Won't Always Play [12]
- How to Fix a Faulty CD Burner Driver [13]
- An IDE ODD (Top) and a SATA ODD (Bottom). Both are designed for laptops. [14]
- An IDE ODD. It is 5.25-inch in form factor. [15]
- A SATA ODD. It is 5.25-inch in form factor. [16]

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[2] Stan, Sorin G. (1998), *The CD-ROM Drive: A Brief System Description* (http://books.google.com/?id=Gs3pdRb83VcC&pg=PA14), Springer, pp. 13, ISBN 079238167X,

[3] Page, M., *Kenwood 72X CD-ROM Review* (http://www.pcstats.com/articleview.cfm?articleid=339&page=2), pp. 2, , retrieved 2007-10-08

[4] *CD-210PU USB interface portable CD-ROM drive* (http://www.teac.co.jp/dspd/product/optical/cd-210pu.html), TEAC, , retrieved 2007–10–08

[5] http://www2.osta.org/osta/html/cddvd/intro.html

[6] http://www.cdrinfo.com/Sections/Reviews/Specific.aspx?ArticleId=7664

[7] http://www.howstuffworks.com/cd-burner.htm

[8] http://www.osta.org/technology/cdqa.htm

[9] http://www.pcnineoneone.com/howto/cdburnadv1.html

[10] http://www.cdrfaq.org

[11] http://www.cdfreaks.com

[12] http://www.oggfrog.com/howto/cds-wont-play/

[13] http://www.windows-media-player-updates.com/fixafaultycdburnerdriver.html

[14] http://www.newmodeus.com/pics/OBHD/OBHD-SATA-Compare.jpg

[15] http://www.hardwarezone.com/img/data/articles/2005/1500/rear_view.jpg

[16] http://www.pcstats.com/articleimages/200708/LGGSAH62N_sata2.jpg

USB flash drive

A **USB flash drive** is an consists of a flash memory data storage device integrated with a USB (Universal Serial Bus) 1.1 or 2.0 interface. USB flash drives are typically removable and rewritable, and physically much smaller than a floppy disk. Most weigh less than 30 g (1 oz).[1] Storage capacities in 2010 can be as large as 256 GB[2] with steady improvements in size and price per capacity expected. Some allow 1 million write or erase cycles and have a 10-year data retention cycle.[3] [4]

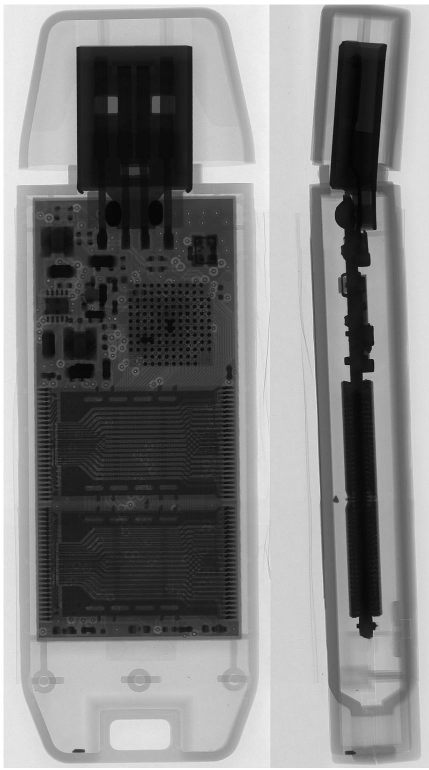
A 16 GB USB retractable flash drive.

USB flash drives are often used for the same purposes as floppy disks were. They are smaller, faster, have thousands of times more capacity, and are more durable and reliable because of their lack of moving parts. Until approximately 2005, most desktop and laptop computers were supplied with floppy disk drives, but most recent equipment has abandoned floppy disk drives in favor of USB ports.

Flash drives use the USB mass storage standard, supported natively by modern operating systems such as Windows, Mac OS X, Linux, and other Unix-like systems. USB drives with USB 2.0 support can store more data and transfer faster than a much larger optical disc drive and can be read by most other systems such as the PlayStation 3.

Nothing moves mechanically in a flash drive; the term *drive* persists because computers read and write flash-drive data using the same system commands as for a mechanical disk drive, with the storage appearing to the computer operating system and user interface as just another drive. Flash drives are very robust mechanically.

A flash drive consists of a small printed circuit board carrying the circuit elements and a USB connector, insulated electrically and protected inside a plastic, metal, or rubberized case which can be carried in a pocket or on a key chain, for example. The USB connector may be protected by a removable cap or by retracting into the body of the drive, although it is not likely to be damaged if unprotected. Most flash drives use a standard type-A USB connection allowing plugging into a port on a personal computer, but drives for other interfaces also exist.


X-ray of a broken 32GB USB stick by Intenso

Most USB flash drives draw their power from the USB connection, and do not require a battery. Some devices that combine the functionality of a digital audio player with flash-drive-type storage require a battery for the player function.

Technology

Flash memory combines a number of older technologies, with lower cost, lower power consumption and small size made possible by recent advances in microprocessor technology. The memory storage was based on earlier EPROM and EEPROM technologies. These had very limited capacity, were very slow for both reading and writing, required complex high-voltage drive circuitry, and could only be re-written after erasing the entire contents of the chip.

Hardware designers later developed EEPROMs with the erasure region broken up into smaller "fields" that could be erased individually without affecting the others. Altering the contents of a particular memory location involved copying the entire field into an off-chip buffer memory, erasing the field, modifying the data as required in the buffer, and re-writing it into the same field. This required considerable computer support, and PC-based EEPROM flash memory systems often carried their own dedicated microprocessor system. Flash drives are more or less a miniaturized version of this.

The development of high-speed serial data interfaces such as USB made semiconductor memory systems with serially accessed storage viable, and the simultaneous development of small, high-speed, low-power microprocessor systems allowed this to be incorporated into extremely compact systems. Serial access requires far fewer electrical connections for the memory chips than does parallel access, which has simplified the manufacture of multi-gigabyte drives.

Computers access modern flash memory systems very much like hard disk drives, where the controller system has full control over where information is actually stored. The actual EEPROM writing and erasure processes are, however, still very similar to the earlier systems described above.

Many low-cost MP3 players simply add extra software and a battery to a standard flash memory control microprocessor so it can also serve as a music playback decoder. Most of these players can also be used as a conventional flash drive, for storing files of any type.

History

First commercial product

Trek Technology and IBM began selling the first USB flash drives commercially in 2000. The Singaporean Trek Technology sold a model under the brand name "ThumbDrive", and IBM marketed the first such drives in North America with its product named the "DiskOnKey" -which was developed and manufactured by the Israeli company M-Systems.[5] IBM's USB flash drive became available on December 15, 2000,[6] and had a storage capacity of 8 MB, more than five times the capacity of the then-common floppy disks.

In 2000 Lexar introduced a Compact Flash (CF) card with a USB connection, and a companion card read/writer and USB cable that eliminated the need for a USB hub.

In 2002 Netac Technology, a Shenzen consumer electronics company which claims to have invented the USB flash drive in the late 1990s,[7] was granted a Chinese patent for the device.[8]

Both Trek Technology and Netac Technology have tried to protect their patent claims. Trek won a Singaporean suit,[9] but a court in the United Kingdom revoked one of Trek's UK patents.[10] While Netac Technology has brought lawsuits against PNY Technologies,[8] Lenovo,[11] aigo,[12] Sony,[13] [14] [15] and Taiwan's Acer and Tai Guen Enterprise Co,[15] most companies that manufacture USB flash drives do so without regard for Trek and Netac's patents.

Phison Electronics Corporation claims to have produced the earliest "USB flash removable disk" dubbed the "Pen Drive" in May 2001.[16] [17]

Second generation

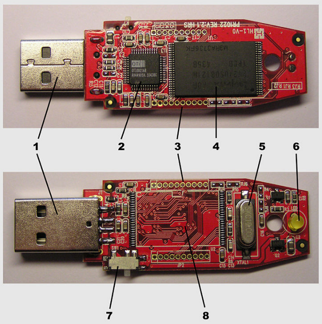
Modern flash drives have USB 2.0 connectivity. However, they do not currently use the full 480 Mbit/s (60MB/s) the USB 2.0 Hi-Speed specification supports because of technical limitations inherent in NAND flash. The fastest drives currently available use a dual channel controller, although they still fall considerably short of the transfer rate possible from a current generation hard disk, or the maximum high speed USB throughput.

File transfer speeds vary considerably, and should be checked before purchase. Speeds may be given in Mbyte per second, Mbit per second, or optical drive multipliers such as "180X" (180 times 150 KiB per second). Typical fast drives claim to read at up to 30 megabytes/s (MB/s) and write at about half that, about 20 times faster than older "USB full speed" devices, which are limited to a maximum speed of 12 Mbit/s (1.5 MB/s).

Design and implementation

One end of the device is fitted with a single male type-A USB connector. Inside the plastic casing is a small printed circuit board. Mounted on this board is some power circuitry and a small number of surface-mounted integrated circuits (ICs). Typically, one of these ICs provides an interface to the USB port, another drives the onboard memory, and the other is the flash memory.

Drives typically use the USB mass storage device class to communicate with the host.



Internals of a typical USB flash drive

1	USB connector
2	USB mass storage controller device
3	Test points
4	Flash memory chip
5	Crystal oscillator
6	LED
7	Write-protect switch (Optional)
8	Space for second flash memory chip

Essential components

There are typically four parts to a flash drive:

- Male type-A USB connector – provides an interface to the host computer.
- USB mass storage controller – implements the USB host controller. The controller contains a small microcontroller with a small amount of on-chip ROM and RAM.
- NAND flash memory chip – stores data. NAND flash is typically also used in digital cameras.
- Crystal oscillator – produces the device's main 12 MHz clock signal and controls the device's data output through a phase-locked loop.

Additional components

The typical device may also include:

- Jumpers and test pins – for testing during the flash drive's manufacturing or loading code into the microprocessor.
- LEDs – indicate data transfers or data reads and writes.
- Write-protect switches – Enable or disable writing of data into memory.
- Unpopulated space – provides space to include a second memory chip. Having this second space allows the manufacturer to use a single printed circuit board for more than one storage size device.
- USB connector cover or cap – reduces the risk of damage, prevents the ingress of fluff or other contaminants, and improves overall device appearance. Some flash drives use retractable USB connectors instead. Others have a swivel arrangement so that the connector can be protected without removing anything.
- Transport aid – the cap or the body often contains a hole suitable for connection to a key chain or lanyard. Connecting the cap, rather than the body, can allow the drive itself to be lost.
- Some drives offer expandable storage via an internal memory card slot, much like a memory card reader.[18] [19]

Size and style of packaging

Some manufacturers differentiate their products by using elaborate housings, which are often bulky and make the drive difficult to connect to the USB port. Because the USB port connectors on a computer housing are often closely spaced, plugging a flash drive into a USB port may block an adjacent port. Such devices may only carry the USB logo if sold with a separate extension cable.

Flash drives come in various, sometimes bulky or novelty, shapes and sizes, in this case ikura sushi

USB flash drives have been integrated into other commonly carried items such as watches, pens, and even the Swiss Army Knife; others have been fitted with novelty cases such as toy cars or LEGO bricks. The small size, robustness and cheapness of USB flash drives make them an increasingly popular peripheral for case modding.

Heavy or bulky flash drive packaging can make for unreliable operation when plugged directly into a USB port; this can be relieved by a USB extension cable. Such cables are USB-compatible but do not conform to the USB standard.[20] [21]

File system

Most flash drives ship preformatted with the FAT or FAT 32 file system. The ubiquity of this file system allows the drive to be accessed on virtually any host device with USB support. Also, standard FAT maintenance utilities (e.g. ScanDisk) can be used to repair or retrieve corrupted data. However, because a flash drive appears as a USB-connected hard drive to the host system, the drive can be reformatted to any file system supported by the host operating system.

Defragmenting: Flash drives can be defragmented, but this brings little advantage as there is no mechanical head that moves from fragment to fragment. Flash drives often have a large internal sector size, so defragmenting means accessing fewer sectors. Defragmenting shortens the life of the drive by making many unnecessary writes.[22]

Even Distribution: Some file systems are designed to distribute usage over an entire memory device without concentrating usage on any part (e.g. for a directory); this even distribution prolongs the life of simple flash memory devices. Some USB flash drives have this functionality built into the software controller to prolong device life, while others do not, therefore the end user should check the specifications of his device prior to changing the file system for this reason.[23]

Hard Drive: Sectors are 512 bytes long, for compatibility with hard drives, and first sector can contain a Master Boot Record and a partition table. Therefore USB flash units can be partitioned as hard drives.

Longevity

Barring physical destruction of the drive, the memory or USB connector of a flash drive will eventually fail. SLC based memory is good for around 100,000 writes; more commonly used MLC for around 10,000. The USB connector can withstand approximately 1,500 connect/disconnect cycles.[24]

Fake products

Fake USB flash drives are fairly common. These are typically low capacity USB drives which are modified so that they emulate larger capacity drives (e.g. a 2 GB drive being marketed as an 8 GB drive). When plugged into a computer, they report themselves as being the larger capacity they were sold as, but when data is written to them, either the write fails, the drive freezes up, or it overwrites existing data. Software tools exist to check and detect fake USB drives.

Uses

Personal data transport

USB flash drive with an Ubuntu-branded lanyard.

The most common use of flash drives is to transport and store personal files such as documents, pictures and videos. Individuals also store medical alert information on MedicTag flash drives for use in emergencies and for disaster preparation.

Secure storage of data, application and software files

With wide deployment(s) of flash drives being used in various environments (secured or otherwise), the issue of data and information security remains of the utmost importance. The use of biometrics and encryption is becoming the norm with the need for increased security for data; OTFE systems such as FreeOTFE and TrueCrypt are particularly useful in this regard, as they can transparently encrypt large amounts of data. In some cases a Secure USB Drive may use a hardware-based encryption mechanism that uses a hardware module instead of software for strongly encrypting data. IEEE 1667 is an attempt to create a generic authentication platform for USB drives and enjoys the support of Microsoft with support in Windows 7.

System administration

Flash drives are particularly popular among system and network administrators, who load them with configuration information and software used for system maintenance, troubleshooting, and recovery. They are also used as a means to transfer recovery and antivirus software to infected PCs, allowing a portion of the host machine's data to be archived. As the drives have increased in storage space, they have also replaced the need to carry a number of CD ROMs and installers which were needed when reinstalling or updating a system.

Application carriers

Flash drives are used to carry applications that run on the host computer without requiring installation. While any standalone application can in principle be used this way, many programs store data, configuration information, etc. on the hard drive and registry of the host computer

The U3 company works with drive makers (parent company SanDisk as well as others) to deliver custom versions of applications designed for Microsoft Windows from a special flash drive; U3-compatible devices are designed to autoload a menu when plugged into a computer running Windows. Applications must be modified for the U3 platform not to leave any data on the host machine. U3 also provides a software framework for independent software vendors interested in their platform.

Ceedo is an alternative product with the key difference that it does not require Windows applications to be modified in order for them to be carried and run on the drive.

Similarly, other application virtualization solutions and portable application creators, such as VMware ThinApp (for Windows) or RUNZ (for Linux) can be used to run software from a flash drive without installation.

A wide range of portable applications which are all free of charge, and able to run off a computer running Windows without storing anything on the host computer's drives or registry, can be found in the list of portable software.

Computer forensics and law enforcement

A recent development for the use of a USB Flash Drive as an application carrier is to carry the Computer Online Forensic Evidence Extractor (COFEE) application developed by Microsoft. COFEE is a set of applications designed to search for and extract digital evidence on computers confiscated from suspects.[25] Forensic software should not alter the information stored on the computer being examined in any way; other forensic suites run from CD-ROM or DVD-ROM, but cannot store data on the media they are run from (although they can write to other attached devices such as external drives or memory sticks).

Booting operating systems

Most current PC firmware permits booting from a USB drive, allowing the launch of an operating system from a bootable flash drive. Such a configuration is known as a Live USB.

While a Live USB could be used for general-purpose applications, size and memory wear make them poor choices compared to alternatives. They are more suited to special-purpose or temporary tasks, such as:

- Loading a minimal, hardened kernel for embedded applications (e.g. network router, firewall).
- Bootstrapping an operating system install or disk cloning operation, often across a network.
- Maintenance tasks, such as virus scanning or low-level data repair, without the primary host operating system loaded.

Windows Vista and Windows 7 ReadyBoost

In Windows Vista and Windows 7, the ReadyBoost feature allows use of flash drives (up to 4 GB in the case of Windows Vista) to augment operating system memory[26]

Audio players

Many companies make small solid-state digital audio players, essentially producing flash drives with sound output and a simple user interface. Examples include the Creative MuVo, Philips GoGear and the iPod shuffle(First generation). Some of these players are true USB flash drives as well as music players; others do not support general-purpose data storage.

Many of the smallest players are powered by a permanently fitted rechargeable battery, charged from the USB interface.

Music storage and marketing

Digital audio files can be transported from one computer to another like any other file, and played on a compatible media player (with caveats for DRM-locked files). In addition, many home Hi-Fi and car stereo head units are now equipped with a USB port. This allows a USB flash drive containing media files in a variety of formats to be played directly on devices which support the format.

Artists have sold or given away USB flash drives, with the first instance believed to be in 2004 when the German band WIZO released the "Stick EP", only as a USB drive. In addition to five high-bitrate MP3s, it also included a video, pictures, lyrics, and guitar tablature. Subsequently artists including Kanye West,[27] Nine Inch Nails, Kylie Minogue[28] and Ayumi Hamasaki [29] have released music and promotional material on USB flash drives. In 2009 a USB drive holding fourteen remastered Beatles albums in both FLAC and MP3 was released.

In arcades

In the arcade game *In the Groove* and more commonly *In The Groove 2*, flash drives are used to transfer high scores, screenshots, dance edits, and combos throughout sessions. As of software revision 21 (R21), players can also store custom songs and play them on any machine on which this feature is enabled. While use of flash drives is common, the drive must be Linux compatible.

In the arcade games *Pump it Up NX2* and *Pump it Up NXA*, a special produced flash drive is used as a "save file" for unlocked songs, as well as progressing in the WorldMax and Brain Shower sections of the game.

In the arcade game *Dance Dance Revolution X*, an exclusive USB flash drive was made by Konami for the purpose of the link feature from its Sony PlayStation 2 counterpart. However, any USB flash drives can be used in this arcade game.

Brand and product promotion

The availability of inexpensive flash drives has enabled them to be used for promotional and marketing purposes, particularly within technical and computer-industry circles (e.g. technology trade shows). They may be given away for free, sold at less than wholesale price, or included as a bonus with another purchased product.

Usually, such drives will be custom-stamped with a company's logo, as a form of advertising to increase mind share and brand awareness. The drive may be a blank drive, or preloaded with graphics, documentation, web links, Flash animation or other multimedia, and free or demonstration software. Some preloaded drives are read-only; others are configured with a read-only and a writeable partition. Dual-partition drives are more expensive.

Flash drives can be set up to automatically launch stored presentations, websites, articles, and any other software immediately on insertion of the drive using the Microsoft Windows AutoRun feature.[30] Autorunning software this way does not work on all computers, and is normally disabled by security-conscious users.

Backup

Some value-added resellers are now using a flash drive as part of small-business turnkey solutions (e.g. point-of-sale systems). The drive is used as a backup medium: at the close of business each night, the drive is inserted, and a database backup is saved to the drive. Alternatively, the drive can be left inserted through the business day, and data regularly updated. In either case, the drive is removed at night and taken offsite.

- This is simple for the end-user, and more likely to be done;
- The drive is small and convenient, and more likely to be carried off-site for safety;
- The drives are less fragile mechanically and magnetically than tapes;
- The capacity is often large enough for several backup images of critical data;
- And flash drives are cheaper than many other backup systems.

It is also easy to lose these small devices, and easy for people without a right to data to take illicit backups.

Advantages and disadvantages

Advantages

Data stored on flash drives is impervious to scratches and dust, and flash drives are mechanically very robust making them suitable for transporting data from place to place and keeping it readily at hand. Most personal computers support USB as of 2009.

Flash drives also store data densely compared to many removable media. In mid-2009, 256 GB drives became available, with the ability to hold many times more data than a DVD or even a Blu-ray disc.

Compared to hard drives, flash drives use little power, have no fragile moving parts, and for low capacities are small and light.

Flash drives implement the USB mass storage device class so that most modern operating systems can read and write to them without installing device drivers. The flash drives present a simple block-structured logical unit to the host operating system, hiding the individual complex implementation details of the various underlying flash memory devices. The operating system can use any file system or block addressing scheme. Some computers can boot up from flash drives.

Some flash drives retain their memory even after being submerged in water,[31] even through a machine wash, although this is not a design feature and not to be relied upon. Leaving the flash drive out to dry completely before allowing current to run through it has been known to result in a working drive with no future problems. Channel Five's *Gadget Show* cooked a flash drive with propane, froze it with dry ice, submerged it in various acidic liquids, ran over it with a jeep and fired it against a wall with a mortar. A company specializing in recovering lost data from computer drives managed to recover all the data on the drive.[32] All data on the other removable storage devices tested, using optical or magnetic technologies, were destroyed.

Disadvantages

Like all flash memory devices, flash drives can sustain only a limited number of write and erase cycles before failure.[33] [34] This should be a consideration when using a flash drive to run application software or an operating system. To address this, as well as space limitations, some developers have produced special versions of operating systems (such as Linux in Live USB)[35] or commonplace applications (such as Mozilla Firefox) designed to run from flash drives. These are typically optimized for size and configured to place temporary or intermediate files in the computer's main RAM rather than store them temporarily on the flash drive.

Most USB flash drives do not include a write-protect mechanism, although some have a switch on the housing of the drive itself to keep the host computer from writing or modifying data on the drive. Write-protection makes a device suitable for repairing virus-contaminated host computers without risk of infecting the USB flash drive itself.

A drawback to the small size is that they are easily misplaced, left behind, or otherwise lost. This is a particular problem if the data they contain are sensitive (see data security). As a consequence, some manufacturers have added encryption hardware to their drives—although software encryption systems achieve the same thing, and are universally available for all USB flash drives. Others just have the possibility of being attached to keychains, necklaces and lanyards. To protect the USB plug from possible damage or contamination by the contents of a pocket or handbag, and to cover the sharp edge, it is usually fitted with a removable protective cap, or is retractable.

Compared to other portable storage devices such as external hard drives, USB flash drives still have a high price per unit of storage and were, until recently, only available in comparatively small capacities. This balance is changing, but the rate of change is slowing. Hard drives have a higher minimum price, so in the smaller capacities (16 GB and less), USB flash drives are much less expensive than the smallest available hard drives.[36] [37]

Comparison with other portable storage

Tape

The applications of current data tape cartridges hardly overlap those of flash drives: cost per gigabyte is very low, the drives and media are expensive, have very high capacity and very fast transfer speeds, and store data sequentially. While disk-based backup is the primary medium of choice for most companies, tape backup is still popular for taking data off-site for worst-case scenarios. See LTO tapes.

Floppy disk

Floppy disk drives are rarely fitted to modern computers and are obsolete for normal purposes, although internal and external drives can be fitted if required. Floppy disks may be the method of choice for transferring data to and from very old computers without USB or booting from floppy disks, and so they are sometimes used to change the firmware on, for example, BIOS chips. Devices with removable storage like older Yamaha music keyboards are also dependent on floppy disks, which require computers to process them. Newer devices are built with USB flash drive support.

Size comparison of a flash drive and a 3.5-inch floppy disk

Optical media

The various writable and rewritable forms of CD and DVD are portable storage media supported by the vast majority of computers as of 2008. CD-R, DVD-R, and DVD+R can be written to only once, RW varieties up to about 1,000 erase/write cycles, while modern NAND-based flash drives often last for 500,000 or more erase/write cycles.[38] DVD-RAM discs are the most suitable optical discs for data storage involving much rewriting.

Optical storage devices are among the cheapest methods of mass data storage after the hard drive. They are slower than their flash-based counterparts. Standard 12 cm optical discs are larger than flash drives and more subject to damage. Smaller optical media do exist, such as business card CD-Rs which have the same dimensions as a credit card, and the slightly less convenient but higher capacity 8 cm recordable CD/DVDs. The small discs are more expensive than the standard size, and do not work in all drives.

Universal Disk Format (UDF) version 1.50 and above has facilities to support rewritable discs like sparing tables and virtual allocation tables, spreading usage over the entire surface of a disc and maximising life, but many older operating systems do not support this format. Packet-writing utilities such as DirectCD and InCD are available but produce discs that are not universally readable (although based on the UDF standard). The Mount Rainier standard addresses this shortcoming in CD-RW media by running the older file systems on top of it and performing defect management for those standards, but it requires support from both the CD/DVD burner and the operating system. Many drives made today do not support Mount Rainier, and many older operating systems such as Windows XP and below, and Linux kernels older than 2.6.2, do not support it (later versions do). Essentially CDs/DVDs are a good way to record a great deal of information cheaply and have the advantage of being readable by most standalone players, but they are poor at making ongoing small changes to a large collection of information. Flash drives' ability to do this is their major advantage over optical media.

Flash memory cards

Flash memory cards, e.g. Secure Digital cards, are available in various formats and capacities, and are used by many consumer devices. However, while virtually all PCs have USB ports, allowing the use of USB flash drives, memory card readers are not commonly supplied as standard equipment (particularly with desktop computers). Although inexpensive card readers are available that read many common formats, this results in two pieces of portable equipment (card plus reader) rather than one.

Some manufacturers, aiming at a "best of both worlds" solution, have produced card readers that approach the size and form of USB flash drives (e.g. Kingston MobileLite,[39] SanDisk MobileMate.[40]) These readers are limited to a specific subset of memory card formats (such as SD, microSD, or Memory Stick), and often completely enclose the card, offering durability and portability approaching, if not quite equal to, that of a flash drive. Although the combined cost of a mini-reader and a memory card is usually slightly higher than a USB flash drive of comparable capacity, the reader + card solution offers additional flexibility of use, and virtually "unlimited" capacity.

An additional advantage of memory cards is that many consumer devices (e.g. digital cameras, portable music players) cannot make use of USB flash drives (even if the device has a USB port) whereas the memory cards used by the devices can be read by PCs with a card reader.

External hard disk

Particularly with the advent of USB, external hard disks have become widely available and inexpensive. External hard disk drives currently cost less per gigabyte than flash drives and are available in larger capacities. Some hard drives support alternative and faster interfaces than USB 2.0 (e.g. IEEE 1394 and eSATA). For writes and consecutive sector reads (for example, from an unfragmented file) most hard drives can provide a much higher sustained data rate than current NAND flash memory.

Unlike solid-state memory, hard drives are susceptible to damage by shock, e.g., a short fall, vibration, have limitations on use at high altitude, and although they are shielded by their casings, they are vulnerable when exposed to strong magnetic fields. In terms of overall mass, hard drives are usually larger and heavier than flash drives; however, hard disks sometimes weigh less per unit of storage. Hard disks also suffer from file fragmentation which can reduce access speed.

Obsolete devices

Audio tape cassettes are no longer used for data storage. High-capacity floppy disks (e.g. Imation SuperDisk), and other forms of drives with removable magnetic media such as the Iomega Zip and Jaz drives are now largely obsolete and rarely used. There are products in today's market which will emulate these legacy drives for both tape & disk (SCSI1/SCSI2, SASI, Magneto optic, Ricoh ZIP, Jaz, IBM3590/ Fujitsu 3490E and Bernoulli for example) in state of the art Compact Flash storage devices - CF2SCSI.

Encryption

As highly portable media, USB flash drives are easily lost or stolen. All USB flash drives can have their contents encrypted using third party disk encryption software such as FreeOTFE and TrueCrypt or programs which can use encrypted archives such as ZIP and RAR. Some of these programs can be used without installation. The executable files can be stored on the USB drive, together with the encrypted file image. The encrypted partition can then be accessed on any computer running the correct operating system, although it may require the user to have administrative rights on the host computer to access data. Some vendors have produced USB flash drives which use hardware based encryption as part of the design, thus removing the need for third-party encryption software.

Other flash drives allow the user to configure secure and public partitions of different sizes, and offer hardware encryption.

Newer flash drives support biometric fingerprinting to confirm the user's identity. As of mid-2005, this was a costly alternative to standard password protection offered on many new USB flash storage devices. Most fingerprint scanning drives rely upon the host operating system to validate the fingerprint via a software driver, often restricting the drive to Microsoft Windows computers. However, there are USB drives with fingerprint scanners which use controllers that allow access to protected data without any authentication.[41]

Some manufacturers deploy physical authentication tokens in the form of a flash drive. These are used to control access to a sensitive system by containing encryption keys or, more commonly, communicating with security software on the target machine. The system is designed so the target machine will not operate except when the flash drive device is plugged into it. Some of these "PC lock" devices also function as normal flash drives when plugged into other machines.

Security threats

Flash drives present a significant security challenge for large organizations. Their small size and ease of use allows unsupervised visitors or employees to store and smuggle out confidential data with little chance of detection. Both corporate and public computers are vulnerable to attackers connecting a flash drive to a free USB port and using malicious software such as keyboard loggers or packet sniffers.

For computers set up to be bootable from a USB drive it is possible to use a flash drive containing a bootable portable operating system to access the files of a computer even if the computer is password protected. The password can then be changed; or it may be possible to crack the password with a password cracking program, and gain full control over the computer. Encrypting files provides considerable protection against this type of attack.

USB flash drives may also be used deliberately or unwittingly to transfer malware and autorun worms onto a network.

Some organizations forbid the use of flash drives, and some computers are configured to disable the mounting of USB mass storage devices by users other than administrators; others use third-party software to control USB usage. The use of software allows the administrator to not only provide a USB lock but also control the use of CD-RW, SD cards and other memory devices. This enables companies with policies forbidding the use of USB flash drives in the workplace to enforce these policies. In a lower-tech security solution, some organizations disconnect USB ports inside the computer or fill the USB sockets with epoxy.

Security breaches

Examples of security breaches as a result of using USB drives include:

- In the United States:
  - A USB drive was stolen with names, grades, and social security numbers of 6,500 former students. [42]

Naming

By August 2008, "USB flash drive" had emerged as a common term for these devices, and most major manufacturers [43] use similar wording on their packaging, although potentially confusing alternatives (such as Memory Stick or *USB memory key*) still occur.

The myriad different brand names and terminology used, in the past and currently, make USB flash drives more difficult for manufacturers to market and for consumers to research. Some commonly-used names actually represent trademarks of particular companies, such as Cruzer, TravelDrive, ThumbDrive, and Disgo.

Current and future developments

Semiconductor corporations have worked to reduce the cost of the components in a flash drive by integrating various flash drive functions in a single chip, thereby reducing the part-count and overall package-cost.

Flash drive capacities on the market increase continually. As of 2008 few manufacturers continue to produce models of 256 MB and smaller; and many have started to phase out 512 MB capacity flash memory. High speed has become a standard for modern flash drives and capacities of up to 256 GB have come on the market, as of 2009.

Lexar is attempting to introduce a USB FlashCard,[44] [45] which would be a compact USB flash drive intended to replace various kinds of flash memory cards. Pretec introduced a similar card, which also plugs into every USB port, but is just one quarter the thickness of the Lexar model.[46] Until 2008, SanDisk manufactured a product called SD Plus, which was a SecureDigital card with a USB connector.[47]

SanDisk has also introduced a new technology to allow controlled storage and usage of copyrighted materials on flash drives, primarily for use by students. This technology is termed FlashCP.

Flash drives for non-USB interfaces

The majority of flash drives use USB, but some flash drives use other interfaces, such as IEEE1394 (FireWire),[48] [49] one of their theoretical advantages when compared to USB drives being the minimal latency and CPU utilisation that the IEEE1394 protocol provides, but in practice because of the prevalence of the USB interfaces all IEEE1394-based flash drives that have appeared used old slow flash memory chips[50] and no manufacturer sells IEEE1394 flash drives with modern fast flash memory as of 2009, and the currently available models go up only to 4 GB,[51] 8 GB [49] or 16 GB, depending on the manufacturer. FireWire flash drives that needs to be connected to FireWire 400 port cannot be connected to a FireWire 800 port and vice-versa.

In late 2008, flash drives that utilize the eSATA interface became available. One advantage that an eSATA flash drive claims over a USB flash drive is increased data throughput, thereby resulting in faster data read and write speeds.[52] However, using eSATA for flash drives also has some disadvantages. The eSATA connector was designed primarily for use with external hard disk drives that often include their own separate power supply. Therefore, unlike USB, an eSATA connector does not provide any usable electrical power other than what is required for signaling and data transfer purposes. This means that an eSATA flash drive still requires an available USB port or some other external source of power to operate it. Additionally, as of September 2009, eSATA is still a fairly uncommon interface on most home computers, therefore very few systems can currently make use of the increased performance offered via the eSATA interface on such-equipped flash drives. Finally, with the exception of eSATA-equipped laptop computers, most home computers that include one or more eSATA connectors usually locate the ports on the back of the computer case, thus making accessibility difficult in certain situations and complicating insertion and removal of the flash drive.

See also

- Computer storage
- USB Flash Drive Alliance

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Memory card

A **memory card** or **flash card** is an electronic flash memory data storage device used for storing digital contents. They are commonly used in many electronic devices, including digital cameras, mobile phones, laptop computers, MP3 players, and video game consoles. They are small, re-recordable, and they can retain data without power.

Miniaturization is evident in memory card creation; over time, the physical card sizes grow smaller while their respective logical sizes grow larger. The memory cards listed from left to right are: Compact flash (32 MB), SD (128 MB), miniSD (1.0 GB), and microSD (2.0 GB).

The most common type of memory card in use today is the SD card,[1] which comes in capacities of up to 64 Gigabytes. In addition to these and other types of memory cards, there are also non-solid-state memory cards that do not use flash memory, and there are different types of flash memory. Many cards incorporate wear leveling algorithms in their design.

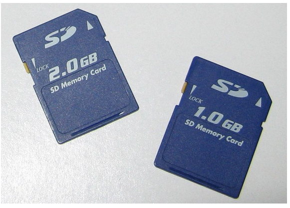
History

PC Cards (PCMCIA) were among first commercial memory card formats (type I cards) to come out in the 1990s, but are now mainly used in industrial applications and to connect I/O devices such as modems. In 1990s, a number of memory card formats smaller than PC Card arrived, including CompactFlash, SmartMedia, and Miniature Card. The desire for smaller cards for cell-phones, PDAs, and compact digital cameras drove a trend that left the previous generation of "compact" cards looking big. In digital cameras SmartMedia and CompactFlash had been very successful, in 2001 SM alone captured 50% of the digital camera market and CF had a stranglehold on professional digital cameras. By 2005 however, SD/MMC had nearly taken over SmartMedia's spot, though not to the same level and with stiff competition coming from Memory Stick variants, as well as CompactFlash. In industrial fields, even the venerable PC card (PCMCIA) memory cards still manage to maintain a niche, while in cell-phones and PDAs, the memory card market is highly fragmented.

Data table of selected memory card formats

Name	Acronym	Form factor	DRM free
PC Card	PCMCIA	85.6 × 54 × 3.3 mm	Yes
CompactFlash I	CF-I	43 × 36 × 3.3 mm	Yes
CompactFlash II	CF-II	43 × 36 × 5.5 mm	Yes
SmartMedia	SM / SMC	45 × 37 × 0.76 mm	Yes
Memory Stick	MS	50.0 × 21.5 × 2.8 mm	No (MagicGate)
Memory Stick Duo	MSD	31.0 × 20.0 × 1.6 mm	No (MagicGate)
Memory Stick PRO Duo	MSPD	31.0 × 20.0 × 1.6 mm	No (MagicGate)
Memory Stick PRO-HG Duo	MSPDX	31.0 × 20.0 × 1.6 mm	No (MagicGate)
Memory Stick Micro M2	M2	15.0 × 12.5 × 1.2 mm	No (MagicGate)
Miniature Card		37 x 45 x 3.5 mm	Yes
Multimedia Card	MMC	32 × 24 × 1.5 mm	Yes
Reduced Size Multimedia Card	RS-MMC	16 × 24 × 1.5 mm	Yes
MMCmicro Card	MMCmicro	12 × 14 × 1.1 mm	Yes

Secure Digital card	SD	32 × 24 × 2.1 mm	No (CPRM)
SxS	SxS		
Universal Flash Storage	UFS		
miniSD card	miniSD	21.5 × 20 × 1.4 mm	No (CPRM)
microSD card	microSD	15 × 11 × 0.7 mm	No (CPRM)
xD-Picture Card	xD	20 × 25 × 1.7 mm	Yes
Intelligent Stick	iStick	24 x 18 x 2.8 mm	Yes
Serial Flash Module	SFM	45 x 15 mm	Yes
µ card	µcard	32 x 24 x 1 mm	Unknown
NT Card	NT NT+	44 x 24 x 2.5 mm	Yes



Secure Digital card (SD)

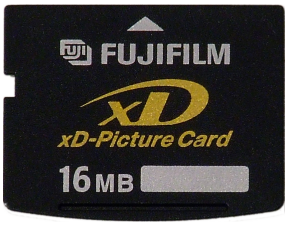
MiniSD Card

CompactFlash (CF-I)

Memory Stick

MultiMediaCard (MMC)

SmartMedia



xD-Picture Card (xD)

Overview of all memory card types

- PCMCIA ATA Type I Flash Memory Card (PC Card ATA Type I)
  - PCMCIA Type II, Type III cards
- CompactFlash Card (Type I), CompactFlash High-Speed
- CompactFlash Type II, CF+(CF2.0), CF3.0
  - Microdrive
- MiniCard (Miniature Card) (max 64 MB (64 MiB))
- SmartMedia Card (SSFDC) (max 128 MB) (3.3 V,5 V)
- xD-Picture Card, xD-Picture Card Type M
- Memory Stick, MagicGate Memory Stick (max 128 MB); Memory Stick Select, MagicGate Memory Stick Select ("Select" means: 2x128 MB with A/B switch)
- SecureMMC
- Secure Digital (SD Card), Secure Digital High-Speed, Secure Digital Plus/Xtra/etc (SD with USB connector)
  - miniSD card
  - microSD card (aka Transflash, T-Flash)
  - SDHC

- MU-Flash (Mu-Card) (Mu-Card Alliance of OMIA)
- C-Flash
- SIM card (Subscriber Identity Module)
- Smart card (ISO/IEC 7810, ISO/IEC 7816 card standards, etc.)
- UFC (USB FlashCard) [2] (uses USB)
- FISH Universal Transportable Memory Card Standard (uses USB)
- Disk memory cards:
  - Clik! (PocketZip), (40 MB PocketZip)
  - Floppy disk (32MB, LS120 and LS240, 2-inch, 3.5-inch, etc.)
- Intelligent Stick (iStick, a USB-based flash memory card with MMS)
- SxS (S-by-S) memory card, a new memory card specification developed by Sandisk and Sony. SxS complies to the ExpressCard industry standard. [3]
- Nexflash Winbond [4] Serial Flash Module (SFM) cards, size range 1 mb, 2 mb and 4 mb.

Memory cards in video game consoles

PlayStation memory card.

Many game consoles have used proprietary solid-state memory cards to store data. In recent years read-only optical discs have replaced these memory cards in most current home console systems. However most portable gaming systems still rely on custom memory cartridges, due to their low power consumption, smaller physical size and reduced mechanical complexity.

The sizes in parenthesis are those of the official, first-party memory cards.

- Microsoft Xbox line:
  - Xbox Memory Unit (8 MB)
  - Xbox 360 Memory Unit (64 MB, 256 MB, and 512 MB versions)
- Nintendo line:
  - Nintendo 64 Controller Pak (256 kbit/32 KB), divided into 123 *pages*
  - Nintendo GameCube Memory Card 59 block (4 Mbit/512 KB), 251 block (16 Mbit/2 MB), and 1019 block (64 Mbit/8 MB) versions
  - Wii Nintendo GameCube Memory Card compatible (see above) and Secure Digital card compatible
  - Nintendo DSi Secure Digital card compatible
- Sega Dreamcast Visual Memory Unit (VMU) (128 KB divided in 200 blocks)
- Sega Saturn memory unit can hold 20 blocks of save games.
- Sony PlayStation line:
  - PlayStation Memory Card (1 Mb/128 KB divided in 15 *blocks*)
  - The PocketStation can act as PlayStation Memory Card
  - The PlayStation 2 used 8MB cards for its own content and supported PlayStation Memory Cards for backward compatibility. Larger capacity memory cards were made available by 3rd parties but these were not officially supported.
  - Early models of the PlayStation 3 featured integrated CompactFlash, Secure Digital, and Memory Stick PRO Duo support. External attachments allow the import and export of PlayStation and PlayStation 2 Memory Cards.
  - PlayStation Portable uses Memory Stick PRO Duo, while its successor, the PSP Go uses Memory Stick Micro
- GP2X GNU/Linux based portable games console, uses SD/MMC.
- Neo Geo AES, released in 1990 by SNK, was the first video game console able to use a memory card. AES memory cards are also compatible with Neo-Geo MVS arcade cabinets.

See also

- Hot swapping

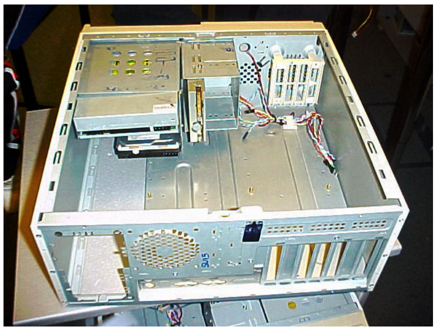
References

[1] Secure Digital (SD) memory card (http://www.allmemorycards.com/sd.htm)
[2] http://www.lexar.com/ufc/
[3] http://www.dpreview.com/news/0704/07041601sxsmemorycardformat.asp
[4] http://www.winbond-usa.com/en/component/option,com_staticxt/Itemid,553/xt_item,1/staticfile,Nexflash~press_011000.htm

Computer Case

Computer case

A **computer case** (also known as a **computer chassis**, **cabinet**, **box**, **tower**, **enclosure**, **housing**, '''system unit''' or simply **case**) is the enclosure that contains the main components of a computer. A computer case is sometimes incorrectly referred to metonymously as a CPU or hard drive referring to components housed within the case. CPU was a more common term in the earlier days of home computers, when peripherals other than the motherboard were usually housed in their own separate cases.



A stripped ATX desktop case. The motherboard will lie flat on the bottom, against the right panel, with peripheral connectors protruding through the rear panel, drive bays at the top and front, and the power supply at the top and rear.

Cases are usually constructed from steel (often SECC—Steel, Electrically Chromate Coated) or aluminium. Plastic is sometimes used, and other materials such as wood and even Lego blocks have appeared in home-built cases.

Sizes

Cases can come in many different sizes (known as *form factors*). The size and shape of a computer case is usually determined by the form factor of the motherboard, since it is the largest component of most computers. Consequently, personal computer form factors typically specify only the *internal* dimensions and layout of the case. Form factors for rack-mounted and blade servers may include precise *external* dimensions as well, since these cases must themselves fit in specific enclosures.

For example, a case designed for an ATX motherboard and power supply may take on several external forms, such as a vertical *tower* (designed to sit on the floor, height > width) or a flat *desktop* (height < width) or *pizza box* (height ≤ 2 inches) (designed to sit on the desk under the computer's monitor). Full-size tower cases are typically larger in volume than desktop cases, with more room for drive bays and expansion slots. Desktop cases—and *mini-tower* cases designed for the reduced microATX form factor—are popular in business environments where space is at a premium.[1] 1

Currently, the most popular form factor for desktop computers is ATX, although microATX and small form factors have also become very popular for a variety of uses. Companies like Shuttle Inc. and AOpen have popularized small cases, for which FlexATX is the most common motherboard size. Apple Inc. has also produced the Mac Mini computer, which is similar in size to a standard CD-ROM drive.

Tower cases come in mini-tower, mid-tower, and big-tower/full-tower sizes. Full tower cases are typically 22 inches or more in height and intended to stand on the floor. They have anywhere from six to ten externally accessible drive bays, with more bays only internally accessible. The ratio of external to internal bays is shifting, however, as computing technology moves from floppy disks and CD-ROMs to large capacity hard drives, USB flash drives, and network-based solutions. Midtower cases are smaller, about 18" high with two to four external bays. A minitower case will typically have only one or two external bays and stand from 14" to 16" tall.

Layout

Computer cases usually include sheet metal enclosures for a power supply unit and drive bays, as well as a rear panel that can accommodate peripheral connectors protruding from the motherboard and expansion slots. Most cases also have a power button or switch, a reset button, and LEDs to indicate power status as well as hard drive and network activity. Some cases include built-in I/O ports (such as USB and headphone ports) on the front of the case. Such a case will also include the wires needed to connect these ports, switches and indicators to the motherboard.

Major component locations

- The motherboard is usually screwed to the case along its largest face, which could be the bottom or the side of the case depending on the form factor and orientation.
- Form factors such as ATX provide a back panel with cut-out holes to expose I/O ports provided by integrated peripherals, as well as expansion slots which may optionally expose additional ports provided by expansion cards.
- The power supply unit is often housed at the top rear of the case; it is usually attached with four screws to support its weight.
- Most cases include drive bays on the front of the case; a typical ATX case includes both 5.25" and 3.5" bays. In modern computers, the former are used mainly for optical drives, while the latter are used for hard drives, floppy drives, and card readers.
- Buttons and LEDs are typically located on the front of the case; some cases include additional I/O ports, temperature and/or processor speed monitors in the same area.
- Vents are often found on the front, back, and sometimes on the side of the case to allow cooling fans to be mounted via surrounding threaded screw holes.

Internal access

Tower cases have either a single side panel which may be removed in order to access the internal components or a large cover that saddles the chassis. Traditionally, most computer cases required screws to hold components and panels in place (i.e. motherboard, PSU, drives, and expansion cards). Recently there is a trend toward "screwless" cases, in which components are held together with snap-in plastic rails, thumbscrews, and other methods that do not require tools; this facilitates quick assembly and modification of computer hardware.

Appearance


Apple's iMac computer models released from 2004 on have all of their internal components integrated behind an LCD screen. Save for the base, the iMac is about 1.25 inches thick. This miniaturization is achieved using parts designed for notebook computers.

Through the 1990s, most computer cases had simple rectangular shapes, and were often painted beige. Beige box designs are still found on a large number of budget computers assembled from generic components.

Case modding is the artistic styling of computer cases, often to draw attention to the use of advanced or unusual components. Since the early 2000s, some cases have included clear side panels or acrylic windows so that users can look inside while it is operating. Modded cases may also include internal lighting, custom paint, or liquid cooling systems. Some hobbyists build custom cases from raw materials like aluminum, steel, acrylic, or wood.

Case manufacturers

Prominent after-market case manufacturers include Ahanix, Antec, AOpen, Asus, Chenbro, Chieftec, Cooler Master, Ever Case, Foxconn, Gigabyte Technology, HEC Compucase, IXIUM, Lian Li, Lin Chi, CIRCLE, FRONTECH, ODYSSEY, ZEBRONICS, NZXT, OrigenAE, Raidmax, Shuttle Inc., SilverStone Technology, Thermaltake, Xclio, Yue Lin, and Zalman.

Intrusion detection

Some computer cases include a biased switch (push-button) which connects to the motherboard. When the case is opened, the switch position changes and the system records this change. The system's firmware or BIOS may be configured to report this event the next time it is powered on.

This physical intrusion detection system may help computer owners detect tampering with their computer. However, most such systems are quite simple in construction; a knowledgeable intruder can open the case or modify its contents without triggering the switch.

Gallery

Computer cases


A black mid or midi tower case (ATX form factor)


A beige mini tower case (microATX form factor)


Three of the Wikimedia servers in 1U rackmount cases

Enthusiast case featuring translucent panel casemod

Micro ATX Desktop case beside standard ATX tower case

Antec Fusion V2 home theater PC case with VFD display, volume control and some ports on front.

See also

- System unit
- Computer case screws
- List of computer hardware manufacturers

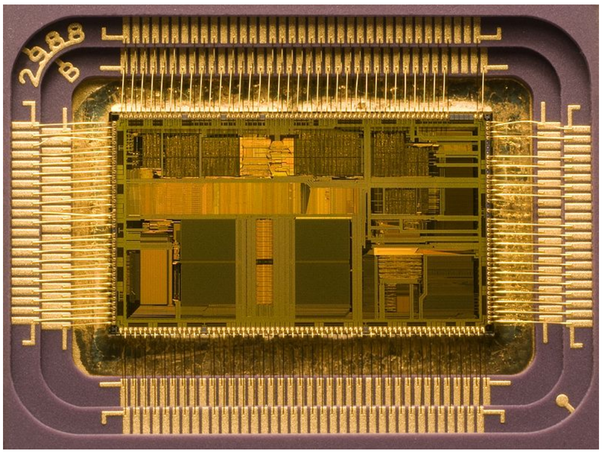
External links

- Chassis Form Factors [2]
- Alex Turovsky's Computer Case Hebrew Encyclopedia [3]
- Taiwan Joyance Rackmount Chassis [4]
- Taiwan Computer Case Manufacturers [5]

References

[1] PCGuide - Reference Guide - Case - Styles (http://www.pcguide.com/ref/case/styles.htm)
[2] http://www.formfactors.org/formfactor.asp
[3] http://www.iopanel.net/forum/thread13606.html
[4] http://www.b2brackmount-server.com/
[5] http://www.manufacturers.com.tw/computers/Computer-Case-Manufacturers.html

Central processing unit

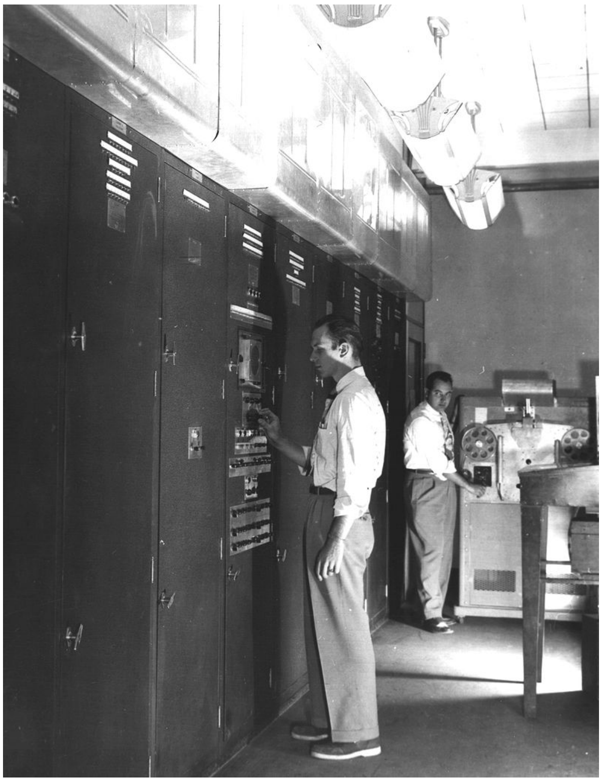


Die of an Intel 80486DX2 microprocessor (actual size: 12×6.75 mm) in its packaging.

The **Central Processing Unit** (**CPU**) or the **processor** is the portion of a computer system that carries out the instructions of a computer program, and is the primary element carrying out the computer's functions. This term has been in use in the computer industry at least since the early 1960s [1] . The form, design and implementation of CPUs have changed dramatically since the earliest examples, but their fundamental operation remains much the same.

Early CPUs were custom-designed as a part of a larger, sometimes one-of-a-kind, computer. However, this costly method of designing custom CPUs for a particular application has largely given way to the development of mass-produced processors that are made for one or many purposes. This standardization trend generally began in the era of discrete transistor mainframes and minicomputers and has rapidly accelerated with the popularization of the integrated circuit (IC). The IC has allowed increasingly complex CPUs to be designed and manufactured to tolerances on the order of nanometers. Both the miniaturization and standardization of CPUs have increased the presence of these digital devices in modern life far beyond the limited application of dedicated computing machines. Modern microprocessors appear in everything from automobiles to cell phones and children's toys.

History


EDVAC, one of the first electronic stored program computers.

Computers such as the ENIAC had to be physically rewired in order to perform different tasks, these machines are "fixed-program computers." Since the term "CPU" is generally defined as a software (computer program) execution device, the earliest devices that could rightly be called CPUs came with the advent of the stored-program computer.

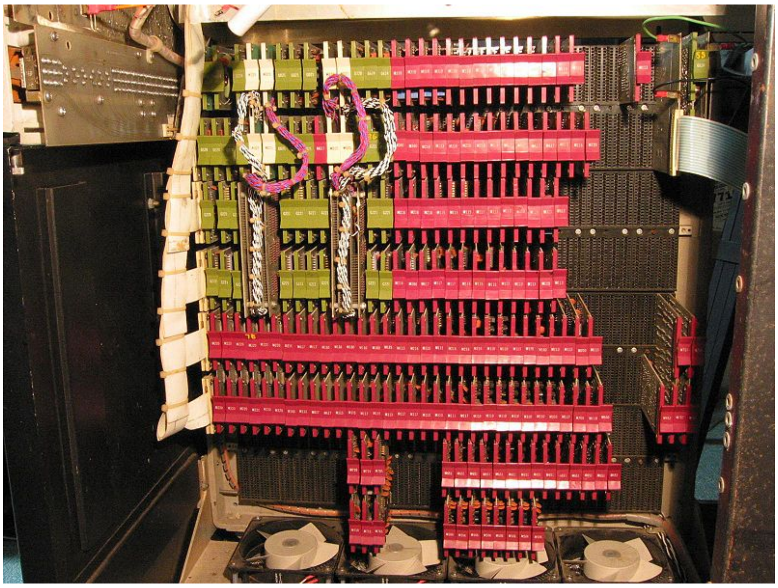
The idea of program computer was already present in the design of J. Presper Eckert and John William Mauchly's ENIAC, but was initially omitted so the machine could be finished sooner. On June 30, 1945, before ENIAC was even completed, mathematician John von Neumann distributed the paper entitled "First Draft of a Report on the EDVAC." It outlined the design of a stored-program computer that would eventually be completed in August 1949 [2] . EDVAC was designed to perform a certain number of instructions (or operations) of various types. These instructions could be combined to create useful programs for the EDVAC to run. Significantly, the programs written for EDVAC were stored in high-speed computer memory rather than specified by the physical wiring of the computer. This overcame a severe limitation of ENIAC, which was the considerable time and effort required to reconfigure the computer to perform a new task. With von Neumann's design, the program, or software, that EDVAC ran could be changed simply by changing the contents of the computer's memory.[3]

While von Neumann is most often credited with the design of the stored-program computer because of his design of EDVAC, others before him, such as Konrad Zuse, had suggested and implemented similar ideas. The so-called Harvard architecture of the Harvard Mark I, which was completed before EDVAC, also utilized a stored-program design using punched paper tape rather than electronic memory. The key difference between the von Neumann and Harvard architectures is that the latter separates the storage and treatment of CPU instructions and data, while the former uses the same memory space for both. Most modern CPUs are primarily von Neumann in design, but elements of the Harvard architecture are commonly seen as well.

As a digital device, a CPU is limited to a set of discrete states, and requires some kind of switching elements to differentiate between and change states. Prior to commercial development of the transistor, electrical relays and vacuum tubes (thermionic valves) were commonly used as switching elements. Although these had distinct speed advantages over earlier, purely mechanical designs, they were unreliable for various reasons. For example, building direct current sequential logic circuits out of relays requires additional hardware to cope with the problem of contact bounce. While vacuum tubes do not suffer from contact bounce, they must heat up before becoming fully operational, and they eventually cease to function due to slow contamination of their cathodes that occurs in the course of normal operation. If a tube's vacuum seal leaks, as sometimes happens, cathode contamination is accelerated. Usually, when a tube failed, the CPU would have to be diagnosed to locate the failed component so it could be replaced. Therefore, early electronic (vacuum tube based) computers were generally faster but less reliable than electromechanical (relay based) computers.

Tube computers like EDVAC tended to average eight hours between failures, whereas relay computers like the (slower, but earlier) Harvard Mark I failed very rarely [1] . In the end, tube based CPUs became dominant because the significant speed advantages afforded generally outweighed the reliability problems. Most of these early synchronous CPUs ran at low clock rates compared to modern microelectronic designs (see below for a discussion of clock rate). Clock signal frequencies ranging from 100 kHz to 4 MHz were very common at this time, limited largely by the speed of the switching devices they were built with.

Discrete transistor and Integrated Circuit CPUs



CPU, core memory, and external bus interface of a DEC PDP-8/I. made of medium-scale integrated circuits

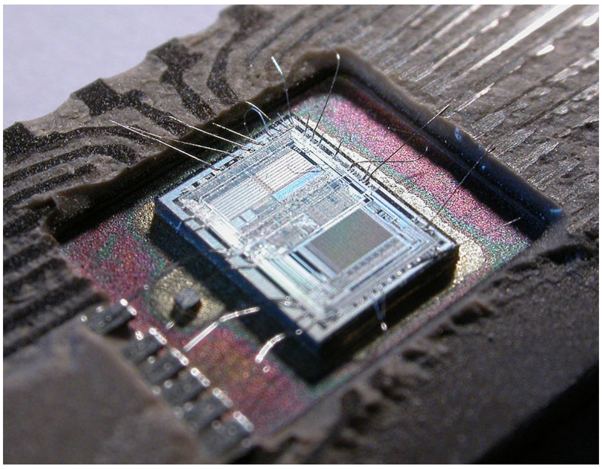
The design complexity of CPUs increased as various technologies facilitated building smaller and more reliable electronic devices. The first such improvement came with the advent of the transistor. Transistorized CPUs during the 1950s and 1960s no longer had to be built out of bulky, unreliable, and fragile switching elements like vacuum tubes and electrical relays. With this improvement more complex and reliable CPUs were built onto one or several printed circuit boards containing discrete (individual) components.

During this period, a method of manufacturing many transistors in a compact space gained popularity. The integrated circuit (**IC**) allowed a large number of transistors to be manufactured on a single semiconductor-based die, or "chip." At first only very basic non-specialized digital circuits such as NOR gates were miniaturized into ICs. CPUs based upon these "building block" ICs are generally referred to as "small-scale integration" (**SSI**) devices. SSI ICs, such as the ones used in the Apollo guidance computer, usually contained transistor counts numbering in multiples of ten. To build an entire CPU out of SSI ICs required thousands of individual chips, but still consumed much less space and power than earlier discrete transistor designs. As microelectronic technology advanced, an increasing number of transistors were placed on ICs, thus decreasing the quantity of individual ICs needed for a complete CPU. **MSI** and **LSI** (medium- and large-scale integration) ICs increased transistor counts to hundreds, and then thousands.

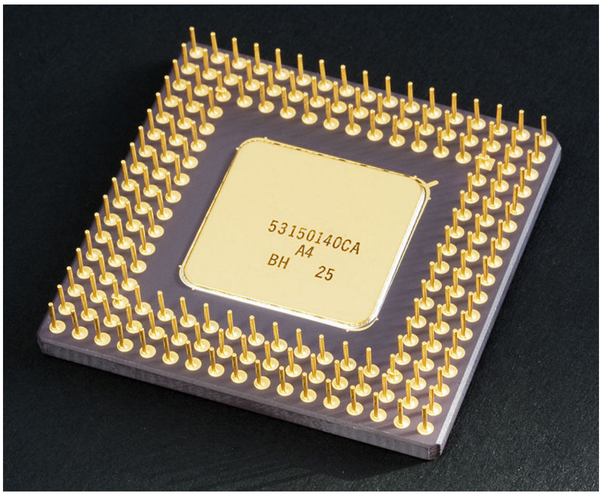
In 1964 IBM introduced its System/360 computer architecture which was used in a series of computers that could run the same programs with different speed and performance. This was significant at a time when most electronic computers were incompatible with one another, even those made by the same manufacturer. To facilitate this improvement, IBM utilized the concept of a microprogram (often called "microcode"), which still sees widespread usage in modern CPUs [4] . The System/360 architecture was so popular that it dominated the mainframe computer market for decades and left a legacy that is still continued by similar modern computers like the IBM zSeries. In the same year (1964), Digital Equipment Corporation (DEC) introduced another influential computer aimed at the scientific and research markets, the PDP-8. DEC would later introduce the extremely popular PDP-11 line that originally was built with SSI ICs but was eventually implemented with LSI components once these became practical. In stark contrast with its SSI and MSI predecessors, the first LSI implementation of the PDP-11 contained a CPU composed of only four LSI integrated circuits [5] .

Transistor-based computers had several distinct advantages over their predecessors. Aside from facilitating increased reliability and lower power consumption, transistors also allowed CPUs to operate at much higher speeds because of the short switching time of a transistor in comparison to a tube or relay. Thanks to both the increased reliability as well as the dramatically increased speed of the switching elements (which were almost exclusively transistors by this time), CPU clock rates in the tens of megahertz were obtained during this period. Additionally while discrete transistor and IC CPUs were in heavy usage, new high-performance designs like SIMD (Single Instruction Multiple Data) vector processors began to appear. These early experimental designs later gave rise to the era of specialized supercomputers like those made by Cray Inc.

Microprocessors



The die from an Intel 8742.



Intel 80486DX2 microprocessor in a ceramic PGA package.

The introduction of the microprocessor in the 1970s significantly affected the design and implementation of CPUs. Since the introduction of the first commercially available microprocessor (the Intel 4004) in 1970 and the first widely used microprocessor (the Intel 8080) in 1974, this class of CPUs has almost completely overtaken all other central processing unit implementation methods. Mainframe and minicomputer manufacturers of the time launched proprietary IC development programs to upgrade their older computer architectures, and eventually produced instruction set compatible microprocessors that were backward-compatible with their older hardware and software. Combined with the advent and eventual vast success of the now ubiquitous personal computer, the term "CPU" is now applied almost exclusively to microprocessors.

Previous generations of CPUs were implemented as discrete components and numerous small integrated circuits (ICs) on one or more circuit boards. Microprocessors, on the other hand, are CPUs manufactured on a very small number of ICs; usually just one. The overall smaller CPU size as a result of being implemented on a single die means faster switching time because of physical factors like decreased gate parasitic capacitance. This has allowed synchronous microprocessors to have clock rates ranging from tens of megahertz to several gigahertz. Additionally, as the ability to construct exceedingly small transistors on an IC has increased, the complexity and number of transistors in a single CPU has increased dramatically. This widely observed trend is described by Moore's law, which has proven to be a fairly accurate predictor of the growth of CPU (and other IC) complexity to date.

While the complexity, size, construction, and general form of CPUs have changed drastically over the past sixty years, it is notable that the basic design and function has not changed much at all. Almost all common CPUs today can be very accurately described as von Neumann stored-program machines. As the aforementioned Moore's law continues to hold true, concerns have arisen about the limits of integrated circuit transistor technology. Extreme miniaturization of electronic gates is causing the effects of phenomena like electromigration and subthreshold leakage to become much more significant. These newer concerns are among the many factors causing researchers to investigate new methods of computing such as the quantum computer, as well as to expand the usage of parallelism and other methods that extend the usefulness of the classical von Neumann model.

Operation

The fundamental operation of most CPUs, regardless of the physical form they take, is to execute a sequence of stored instructions called a program. The program is represented by a series of numbers that are kept in some kind of computer memory. There are four steps that nearly all CPUs use in their operation: **fetch**, **decode**, **execute**, and **writeback**.

The first step, **fetch**, involves retrieving an instruction (which is represented by a number or sequence of numbers) from program memory. The location in program memory is determined by a program counter (PC), which stores a number that identifies the current position in the program. In other words, the program counter keeps track of the CPU's place in the current program. After an instruction is fetched, the PC is incremented by the length of the instruction word in terms of memory units.[6] Often the instruction to be fetched must be retrieved from relatively slow memory, causing the CPU to stall while waiting for the instruction to be returned. This issue is largely addressed in modern processors by caches and pipeline architectures (see below).

The instruction that the CPU fetches from memory is used to determine what the CPU is to do. In the **decode** step, the instruction is broken up into parts that have significance to other portions of the CPU. The way in which the numerical instruction value is interpreted is defined by the CPU's instruction set architecture (**ISA**).[7] Often, one group of numbers in the instruction, called the opcode, indicates which operation to perform. The remaining parts of the number usually provide information required for that instruction, such as operands for an addition operation. Such operands may be given as a constant value (called an immediate value), or as a place to locate a value: a register or a memory address, as determined by some addressing mode. In older designs the portions of the CPU responsible for instruction decoding were unchangeable hardware devices. However, in more abstract and complicated CPUs and ISAs, a microprogram is often used to assist in translating instructions into various configuration signals for the CPU. This microprogram is sometimes rewritable so that it can be modified to change the way the CPU decodes instructions even after it has been manufactured.

After the fetch and decode steps, the **execute** step is performed. During this step, various portions of the CPU are connected so they can perform the desired operation. If, for instance, an addition operation was requested, an arithmetic logic unit (**ALU**) will be connected to a set of inputs and a set of outputs. The inputs provide the numbers to be added, and the outputs will contain the final sum. The ALU contains the circuitry to perform simple arithmetic and logical operations on the inputs (like addition and bitwise operations). If the addition operation produces a result too large for the CPU to handle, an arithmetic overflow flag in a flags register may also be set.

The final step, **writeback**, simply "writes back" the results of the execute step to some form of memory. Very often the results are written to some internal CPU register for quick access by subsequent instructions. In other cases results may be written to slower, but cheaper and larger, main memory. Some types of instructions manipulate the program counter rather than directly produce result data. These are generally called "jumps" and facilitate behavior like loops, conditional program execution (through the use of a conditional jump), and functions in programs.[8] Many instructions will also change the state of digits in a "flags" register. These flags can be used to influence how a program behaves, since they often indicate the outcome of various operations. For example, one type of "compare" instruction considers two values and sets a number in the flags register according to which one is greater. This flag could then be used by a later jump instruction to determine program flow.

After the execution of the instruction and writeback of the resulting data, the entire process repeats, with the next instruction cycle normally fetching the next-in-sequence instruction because of the incremented value in the program counter. If the completed instruction was a jump, the program counter will be modified to contain the address of the instruction that was jumped to, and program execution continues normally. In more complex CPUs than the one described here, multiple instructions can be fetched, decoded, and executed simultaneously. This section describes what is generally referred to as the "Classic RISC pipeline", which in fact is quite common among the simple CPUs used in many electronic devices (often called microcontroller). It largely ignores the important role of CPU cache, and therefore the **access** stage of the pipeline.

Design and implementation

Integer range

The way a **CPU** represents numbers is a design choice that affects the most basic ways in which the device functions. Some early digital computers used an electrical model of the common decimal (base ten) numeral system to represent numbers internally. A few other computers have used more exotic numeral systems like ternary (base three). Nearly all modern CPUs represent numbers in binary form, with each digit being represented by some two-valued physical quantity such as a "high" or "low" voltage.[9]

MOS 6502 microprocessor in a dual in-line package, an extremely popular 8-bit design.

Related to number representation is the size and precision of numbers that a CPU can represent. In the case of a binary CPU, a **bit** refers to one significant place in the numbers a CPU deals with. The number of bits (or numeral places) a CPU uses to represent numbers is often called "word size", "bit width", "data path width", or "integer precision" when dealing with strictly integer numbers (as opposed to floating point). This number differs between architectures, and often within different parts of the very same CPU. For example, an 8-bit CPU deals with a range of numbers that can be represented by eight binary digits (each digit having two possible values), that is, 2^8 or 256 discrete numbers. In effect, integer size sets a hardware limit on the range of integers the software run by the CPU can utilize.[10]

Integer range can also affect the number of locations in memory the CPU can **address** (locate). For example, if a binary CPU uses 32 bits to represent a memory address, and each memory address represents one octet (8 bits), the maximum quantity of memory that CPU can address is 2^{32} octets, or 4 GiB. This is a very simple view of CPU address space, and many designs use more complex addressing methods like paging in order to locate more memory than their integer range would allow with a flat address space.

Higher levels of integer range require more structures to deal with the additional digits, and therefore more complexity, size, power usage, and general expense. It is not at all uncommon, therefore, to see 4- or 8-bit microcontrollers used in modern applications, even though CPUs with much higher range (such as 16, 32, 64, even 128-bit) are available. The simpler microcontrollers are usually cheaper, use less power, and therefore dissipate less heat, all of which can be major design considerations for electronic devices. However, in higher-end applications, the benefits afforded by the extra range (most often the additional address space) are more significant and often affect design choices. To gain some of the advantages afforded by both lower and higher bit lengths, many CPUs are designed with different bit widths for different portions of the device. For example, the IBM System/370 used a CPU that was primarily 32 bit, but it used 128-bit precision inside its floating point units to facilitate greater accuracy and range in floating point numbers [4] . Many later CPU designs use similar mixed bit width, especially when the processor is meant for general-purpose usage where a reasonable balance of integer and floating point capability is required.

Clock rate

Most CPUs, and indeed most sequential logic devices, are synchronous in nature.[11] That is, they are designed and operate on assumptions about a synchronization signal. This signal, known as a **clock signal**, usually takes the form of a periodic square wave. By calculating the maximum time that electrical signals can move in various branches of a CPU's many circuits, the designers can select an appropriate period for the clock signal.

This period must be longer than the amount of time it takes for a signal to move, or propagate, in the worst-case scenario. In setting the clock period to a value well above the worst-case propagation delay, it is possible to design the entire CPU and the way it moves data around the "edges" of the rising and falling clock signal. This has the advantage of simplifying the CPU significantly, both from a design perspective and a component-count perspective. However, it also carries the disadvantage that the entire CPU must wait on its slowest elements, even though some portions of it are much faster. This limitation has largely been compensated for by various methods of increasing CPU parallelism. (see below)

However, architectural improvements alone do not solve all of the drawbacks of globally synchronous CPUs. For example, a clock signal is subject to the delays of any other electrical signal. Higher clock rates in increasingly complex CPUs make it more difficult to keep the clock signal in phase (synchronized) throughout the entire unit. This has led many modern CPUs to require multiple identical clock signals to be provided in order to avoid delaying a single signal significantly enough to cause the CPU to malfunction. Another major issue as clock rates increase dramatically is the amount of heat that is dissipated by the CPU. The constantly changing clock causes many components to switch regardless of whether they are being used at that time. In general, a component that is switching uses more energy than an element in a static state. Therefore, as clock rate increases, so does heat dissipation, causing the CPU to require more effective cooling solutions.

One method of dealing with the switching of unneeded components is called clock gating, which involves turning off the clock signal to unneeded components (effectively disabling them). However, this is often regarded as difficult to implement and therefore does not see common usage outside of very low-power designs. One notable late CPU design that uses clock gating is that of the IBM PowerPC-based Xbox 360. It utilizes extensive clock gating in order to reduce the power requirements of the aforementioned videogame console it is used in. [12] Another method of addressing some of the problems with a global clock signal is the removal of the clock signal altogether. While removing the global clock signal makes the design process considerably more complex in many ways, asynchronous (or clockless) designs carry marked advantages in power consumption and heat dissipation in comparison with similar synchronous designs. While somewhat uncommon, entire asynchronous CPUs have been built without utilizing a global clock signal. Two notable examples of this are the ARM compliant AMULET and the MIPS R3000 compatible MiniMIPS. Rather than totally removing the clock signal, some CPU designs allow certain portions of the device to be asynchronous, such as using asynchronous ALUs in conjunction with superscalar pipelining to achieve some arithmetic performance gains. While it is not altogether clear whether totally asynchronous designs can perform at a comparable or better level than their synchronous counterparts, it is evident that they do at least excel in simpler math operations. This, combined with their excellent power consumption and heat dissipation properties, makes them very suitable for embedded computers [13] .

Parallelism

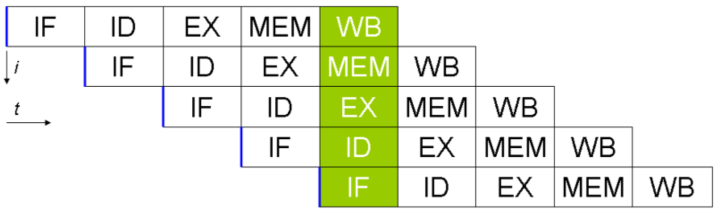
The description of the basic operation of a CPU offered in the previous section describes the simplest form that a CPU can take. This type of CPU, usually referred to as **subscalar**, operates on and executes one instruction on one or two pieces of data at a time.

Model of a subscalar CPU. Notice that it takes fifteen cycles to complete three instructions.

This process gives rise to an inherent inefficiency in subscalar CPUs. Since only one instruction is executed at a time, the entire CPU must wait for that instruction to complete before proceeding to the next instruction. As a result the subscalar CPU gets "hung up" on instructions which take more than one clock cycle to complete execution. Even adding a second execution unit (see below) does not improve performance much; rather than one pathway being hung up, now two pathways are hung up and the number of unused transistors is increased. This design, wherein the CPU's execution resources can operate on only one instruction at a time, can only possibly reach **scalar** performance (one instruction per clock). However, the performance is nearly always subscalar (less than one instruction per cycle).

Attempts to achieve scalar and better performance have resulted in a variety of design methodologies that cause the CPU to behave less linearly and more in parallel. When referring to parallelism in CPUs, two terms are generally used to classify these design techniques. Instruction level parallelism (ILP) seeks to increase the rate at which instructions are executed within a CPU (that is, to increase the utilization of on-die execution resources), and thread level parallelism (TLP) purposes to increase the number of threads (effectively individual programs) that a CPU can execute simultaneously. Each methodology differs both in the ways in which they are implemented, as well as the relative effectiveness they afford in increasing the CPU's performance for an application.[14]

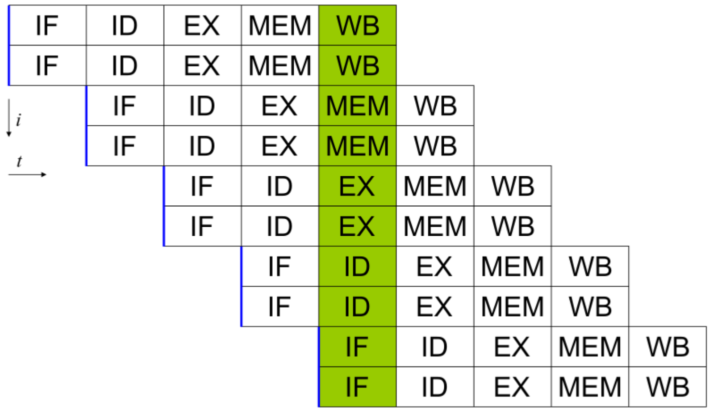
Instruction level parallelism



Basic five-stage pipeline. In the best case scenario, this pipeline can sustain a completion rate of one instruction per cycle.

One of the simplest methods used to accomplish increased parallelism is to begin the first steps of instruction fetching and decoding before the prior instruction finishes executing. This is the simplest form of a technique known as **instruction pipelining**, and is utilized in almost all modern general-purpose CPUs. Pipelining allows more than one instruction to be executed at any given time by breaking down the execution pathway into discrete stages. This separation can be compared to an assembly line, in which an instruction is made more complete at each stage until it exits the execution pipeline and is retired.

Pipelining does, however, introduce the possibility for a situation where the result of the previous operation is needed to complete the next operation; a condition often termed data dependency conflict. To cope with this, additional care must be taken to check for these sorts of conditions and delay a portion of the instruction pipeline if this occurs. Naturally, accomplishing this requires additional circuitry, so pipelined processors are more complex than subscalar ones (though not very significantly so). A pipelined processor can become very nearly scalar, inhibited only by pipeline stalls (an instruction spending more than one clock cycle in a stage).



Simple superscalar pipeline. By fetching and dispatching two instructions at a time, a maximum of two instructions per cycle can be completed.

Further improvement upon the idea of instruction pipelining led to the development of a method that decreases the idle time of CPU components even further. Designs that are said to be **superscalar** include a long instruction pipeline and multiple identical execution units. [15] In a superscalar pipeline, multiple instructions are read and passed to a dispatcher, which decides whether or not the instructions can be executed in parallel (simultaneously). If so they are dispatched to available execution units, resulting in the ability for several instructions to be executed simultaneously. In general, the more instructions a superscalar CPU is able to dispatch simultaneously to waiting execution units, the more instructions will be completed in a given cycle.

Most of the difficulty in the design of a superscalar CPU architecture lies in creating an effective dispatcher. The dispatcher needs to be able to quickly and correctly determine whether instructions can be executed in parallel, as well as dispatch them in such a way as to keep as many execution units busy as possible. This requires that the instruction pipeline is filled as often as possible and gives rise to the need in superscalar architectures for significant amounts of CPU cache. It also makes hazard-avoiding techniques like branch prediction, speculative execution, and out-of-order execution crucial to maintaining high levels of performance. By attempting to predict which branch (or path) a conditional instruction will take, the CPU can minimize the number of times that the entire pipeline must wait until a conditional instruction is completed. Speculative execution often provides modest performance increases by executing portions of code that may or may not be needed after a conditional operation completes. Out-of-order execution somewhat rearranges the order in which instructions are executed to reduce delays due to data dependencies. Also in case of Single Instructions Multiple Data - a case when a lot of data from the same type has to be processed, modern processors can disable parts of the pipeline so that when a single instruction is executed many times, the CPU skips the fetch and decode phases and thus greatly increasing performance on certain occasions, especially in highly monotonous program engines such as video creation software and photo processing.

In the case where a portion of the CPU is superscalar and part is not, the part which is not suffers a performance penalty due to scheduling stalls. The Intel P5 Pentium had two superscalar ALUs which could accept one instruction per clock each, but its FPU could not accept one instruction per clock. Thus the P5 was integer superscalar but not floating point superscalar. Intel's successor to the P5 architecture, P6, added superscalar capabilities to its floating point features, and therefore afforded a significant increase in floating point instruction performance.

Both simple pipelining and superscalar design increase a CPU's ILP by allowing a single processor to complete execution of instructions at rates surpassing one instruction per cycle (**IPC**).[16] Most modern CPU designs are at least somewhat superscalar, and nearly all general purpose CPUs designed in the last decade are superscalar. In later years some of the emphasis in designing high-ILP computers has been moved out of the CPU's hardware and into its software interface, or ISA. The strategy of the very long instruction word (VLIW) causes some ILP to become implied directly by the software, reducing the amount of work the CPU must perform to boost ILP and thereby reducing the design's complexity.

Thread level parallelism

Another strategy of achieving performance is to execute multiple programs or threads in parallel. This area of research is known as parallel computing. In Flynn's taxonomy, this strategy is known as Multiple Instructions-Multiple Data or MIMD.

One technology used for this purpose was multiprocessing (MP). The initial flavor of this technology is known as symmetric multiprocessing (SMP), where a small number of CPUs share a coherent view of their memory system. In this scheme, each CPU has additional hardware to maintain a constantly up-to-date view of memory. By avoiding stale views of memory, the CPUs can cooperate on the same program and programs can migrate from one CPU to another. To increase the number of cooperating CPUs beyond a handful, schemes such as non-uniform memory access (NUMA) and directory-based coherence protocols were introduced in the 1990s. SMP systems are limited to a small number of CPUs while NUMA systems have been built with thousands of processors. Initially, multiprocessing was built using multiple discrete CPUs and boards to implement the interconnect between the processors. When the processors and their interconnect are all implemented on a single silicon chip, the technology is known as a multi-core microprocessor.

It was later recognized that finer-grain parallelism existed with a single program. A single program might have several threads (or functions) that could be executed separately or in parallel. Some of earliest examples of this technology implemented input/output processing such as direct memory access as a separate thread from the computation thread. A more general approach to this technology was introduced in the 1970s when systems were designed to run multiple computation threads in parallel. This technology is known as multi-threading (MT). This approach is considered more cost-effective than multiprocessing, as only a small number of components within a CPU is replicated in order to support MT as opposed to the entire CPU in the case of MP. In MT, the execution units and the memory system including the caches are shared among multiple threads. The downside of MT is that the hardware support for multithreading is more visible to software than that of MP and thus supervisor software like operating systems have to undergo larger changes to support MT. One type of MT that was implemented is known as block multithreading, where one thread is executed until it is stalled waiting for data to return from external memory. In this scheme, the CPU would then quickly switch to another thread which is ready to run, the switch often done in one CPU clock cycle, such as the UltraSPARC Technology. Another type of MT is known as simultaneous multithreading, where instructions of multiple threads are executed in parallel within one CPU clock cycle.

For several decades from the 1970s to early 2000s, the focus in designing high performance general purpose CPUs was largely on achieving high ILP through technologies such as pipelining, caches, superscalar execution, out-of-order execution, etc. This trend culminated in large, power-hungry CPUs such as the Intel Pentium 4. By the early 2000s, CPU designers were thwarted from achieving higher performance from ILP techniques due to the growing disparity between CPU operating frequencies and main memory operating frequencies as well as escalating CPU power dissipation owing to more esoteric ILP techniques.

CPU designers then borrowed ideas from commercial computing markets such as transaction processing, where the aggregate performance of multiple programs, also known as throughput computing, was more important than the performance of a single thread or program.

This reversal of emphasis is evidenced by the proliferation of dual and multiple core CMP (chip-level multiprocessing) designs and notably, Intel's newer designs resembling its less superscalar P6 architecture. Late designs in several processor families exhibit CMP, including the x86-64 Opteron and Athlon 64 X2, the SPARC UltraSPARC T1, IBM POWER4 and POWER5, as well as several video game console CPUs like the Xbox 360's triple-core PowerPC design, and the PS3's 7-core Cell microprocessor.

Data parallelism

A less common but increasingly important paradigm of CPUs (and indeed, computing in general) deals with data parallelism. The processors discussed earlier are all referred to as some type of scalar device.[17] As the name implies, vector processors deal with multiple pieces of data in the context of one instruction. This contrasts with scalar processors, which deal with one piece of data for every instruction. Using Flynn's taxonomy, these two schemes of dealing with data are generally referred to as SISD (single instruction, single data) and SIMD (single instruction, multiple data), respectively. The great utility in creating CPUs that deal with vectors of data lies in optimizing tasks that tend to require the same operation (for example, a sum or a dot product) to be performed on a large set of data. Some classic examples of these types of tasks are multimedia applications (images, video, and sound), as well as many types of scientific and engineering tasks. Whereas a scalar CPU must complete the entire process of fetching, decoding, and executing each instruction and value in a set of data, a vector CPU can perform a single operation on a comparatively large set of data with one instruction. Of course, this is only possible when the application tends to require many steps which apply one operation to a large set of data.

Most early vector CPUs, such as the Cray-1, were associated almost exclusively with scientific research and cryptography applications. However, as multimedia has largely shifted to digital media, the need for some form of SIMD in general-purpose CPUs has become significant. Shortly after floating point execution units started to become commonplace to include in general-purpose processors, specifications for and implementations of SIMD execution units also began to appear for general-purpose CPUs. Some of these early SIMD specifications like HP's Multimedia Acceleration eXtensions (MAX) and Intel's MMX were integer-only. This proved to be a significant impediment for some software developers, since many of the applications that benefit from SIMD primarily deal with floating point numbers. Progressively, these early designs were refined and remade into some of the common, modern SIMD specifications, which are usually associated with one ISA. Some notable modern examples are Intel's SSE and the PowerPC-related AltiVec (also known as VMX).[18]

Performance

The *performance* or *speed* of a processor depends on e.g. the clock rate and the Instructions Per Clock (IPC), which together are the factors for the Instructions Per Second (IPS) that the CPU can perform.[19] Many reported IPS values have represented "peak" execution rates on artificial instruction sequences with few branches, whereas realistic workloads consist of a mix of instructions and applications, some of which take longer to execute than others. The performance of the memory hierarchy also greatly affects processor performance, an issue barely considered in MIPS calculations. Because of these problems, various standardized tests such as SPECint have been developed to attempt to measure the real effective performance in commonly used applications.

Processing performance of computers is increased by using multi-core processors, which essentially is plugging two or more individual processors (called *cores* in this sense) into one integrated circuit.[20] Ideally, a dual core processor would be nearly twice as powerful as a single core processor. In practice, however, the performance gain is far less, only about fifty percent[20] , due to, e.g. imperfect software algorithms and implementation.

See also

- Accelerated Processing Unit
- Addressing mode
- CISC
- Computer bus
- Computer engineering
- CPU cooling
- CPU core voltage
- CPU design
- CPU power dissipation
- CPU socket
- Digital signal processor
- Floating point unit
- Instruction pipeline
- Instruction set
- List of CPU architectures
- Ring (computer security)
- RISC
- Stream processing
- True Performance Index
- Wait state

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[1] Weik, Martin H. (1961). *A Third Survey of Domestic Electronic Digital Computing Systems* (http://ed-thelen.org/comp-hist/BRL61.html). Ballistic Research Laboratories. .

[2] von Neumann, John (1945). *First Draft of a Report on the EDVAC* (http://www.virtualtravelog.net/entries/2003-08-TheFirstDraft.pdf). Moore School of Electrical Engineering, University of Pennsylvania. .

[3] While EDVAC was designed a few years before ENIAC was built, ENIAC was actually retrofitted to execute stored programs in 1948, somewhat before EDVAC was completed. Therefore, ENIAC became a stored-program computer before EDVAC was completed, even though stored-program capabilities were originally omitted from ENIAC's design due to cost and schedule concerns.

[4] Amdahl, G. M., Blaauw, G. A., & Brooks, F. P. Jr. (1964). *Architecture of the IBM System/360* (http://www.research.ibm.com/journal/rd/441/amdahl.pdf). IBM Research. .

[5] Digital Equipment Corporation (November 1975). "LSI-11 Module Descriptions" (http://www.classiccmp.org/bitsavers/pdf/dec/pdp11/1103/EK-LSI11-TM-002.pdf). *LSI-11, PDP-11/03 user's manual* (2nd ed.). Maynard, Massachusetts: Digital Equipment Corporation. pp. 4–3. .

[6] Since the program counter counts *memory addresses* and not *instructions,* it is incremented by the number of memory units that the instruction word contains. In the case of simple fixed-length instruction word ISAs, this is always the same number. For example, a fixed-length 32-bit instruction word ISA that uses 8-bit memory words would always increment the PC by 4 (except in the case of jumps). ISAs that use variable length instruction words,increment the PC by the number of memory words corresponding to the last instruction's length.

[7] Because the instruction set architecture of a CPU is fundamental to its interface and usage, it is often used as a classification of the "type" of CPU. For example, a "PowerPC CPU" uses some variant of the PowerPC ISA. A system can execute a different ISA by running an emulator.

[8] Some early computers like the Harvard Mark I did not support any kind of "jump" instruction, effectively limiting the complexity of the programs they could run. It is largely for this reason that these computers are often not considered to contain a CPU proper, despite their close similarity as stored program computers.

[9] The physical concept of voltage is an analog one by its nature, practically having an infinite range of possible values. For the purpose of physical representation of binary numbers, set ranges of voltages are defined as one or zero. These ranges are usually influenced by the circuit designs and operational parameters of the switching elements used to create the CPU, such as a transistor's threshold level.

[10] While a CPU's integer size sets a limit on integer ranges, this can (and often is) overcome using a combination of software and hardware techniques. By using additional memory, software can represent integers many magnitudes larger than the CPU can. Sometimes the CPU's ISA will even facilitate operations on integers larger than it can natively represent by providing instructions to make large integer arithmetic relatively quick. While this method of dealing with large integers is somewhat slower than utilizing a CPU with higher integer size, it is a

reasonable trade-off in cases where natively supporting the full integer range needed would be cost-prohibitive. See Arbitrary-precision arithmetic for more details on purely software-supported arbitrary-sized integers.

[11] In fact, all synchronous CPUs use a combination of sequential logic and combinational logic. (See boolean logic)

[12] Brown, Jeffery (2005). "Application-customized CPU design" (http://www-128.ibm.com/developerworks/power/library/pa-fpfxbox/?ca=dgr-lnxw07XBoxDesign). IBM developerWorks. . Retrieved 2005-12-17.

[13] Garside, J. D., Furber, S. B., & Chung, S-H (1999). *AMULET3 Revealed* (http://www.cs.manchester.ac.uk/apt/publications/papers/async99_A3.php). University of Manchester Computer Science Department. .

[14] Neither ILP nor TLP is inherently superior over the other; they are simply different means by which to increase CPU parallelism. As such, they both have advantages and disadvantages, which are often determined by the type of software that the processor is intended to run. High-TLP CPUs are often used in applications that lend themselves well to being split up into numerous smaller applications, so-called "embarrassingly parallel problems". Frequently, a computational problem that can be solved quickly with high TLP design strategies like SMP take significantly more time on high ILP devices like superscalar CPUs, and vice versa.

[15] Huynh, Jack (2003). "The AMD Athlon XP Processor with 512KB L2 Cache" (http://courses.ece.uiuc.edu/ece512/Papers/Athlon.pdf). University of Illinois - Urbana-Champaign. pp. 6–11. . Retrieved 2007-10-06.

[16] Best-case scenario (or peak) IPC rates in very superscalar architectures are difficult to maintain since it is impossible to keep the instruction pipeline filled all the time. Therefore, in highly superscalar CPUs, average sustained IPC is often discussed rather than peak IPC.

[17] Earlier the term scalar was used to compare the IPC (instructions per cycle) count afforded by various ILP methods. Here the term is used in the strictly mathematical sense to contrast with vectors. See scalar (mathematics) and Vector (geometric).

[18] Although SSE/SSE2/SSE3 have superseded MMX in Intel's general purpose CPUs, later IA-32 designs still support MMX. This is usually accomplished by providing most of the MMX functionality with the same hardware that supports the much more expansive SSE instruction sets.

[19] "CPU Frequency" (http://www.cpu-world.com/Glossary/C/CPU_Frequency.html). *CPU World Glossary*. CPU World. 25 March 2008. . Retrieved 1 January 2010.

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- [a] MIPS Technologies, Inc. (2005). *MIPS32 Architecture For Programmers Volume II: The MIPS32 Instruction Set* (http://www.mips.com/content/Documentation/MIPSDocumentation/ProcessorArchitecture/doclibrary). MIPS Technologies, Inc..
- [a] Smotherman, Mark (2005). "History of Multithreading" (http://www.cs.clemson.edu/~mark/multithreading.html). Retrieved 2005-12-19.

External links

Microprocessor designers

- Advanced Micro Devices (http://www.amd.com/) - Advanced Micro Devices, a designer of primarily x86-compatible personal computer CPUs.
- ARM Ltd (http://www.arm.com/) - ARM Ltd, one of the few CPU designers that profits solely by licensing their designs rather than manufacturing them. ARM architecture microprocessors are among the most popular in the world for embedded applications.
- Freescale Semiconductor (http://www.freescale.com/) (formerly of Motorola) - Freescale Semiconductor, designer of several embedded and SoC PowerPC based processors.
- IBM Microelectronics (http://www-03.ibm.com/chips/) - Microelectronics division of IBM, which is responsible for many POWER and PowerPC based designs, including many of the CPUs utilized in late video game consoles.
- Intel Corp (http://www.intel.com/) - Intel, a maker of several notable CPU lines, including IA-32 and IA-64. Also a producer of various peripheral chips for use with their CPUs.

- Microchip Technology Inc. (http://www.microchip.com/) - Microchip, developers of the 8 and 16-bit short pipleine RISC and DSP microcontrollers.
- MIPS Technologies (http://www.mips.com/) - MIPS Technologies, developers of the MIPS architecture, a pioneer in RISC designs.
- NEC Electronics (http://www.am.necel.com/) - NEC Electronics (http://www.am.necel.com/), developers of the 78K0 8-bit Architecture (http://www.am.necel.com/micro/product/all_8_general.html/), 78K0R 16-bit Architecture (http://www.am.necel.com/micro/product/all_16_general.html/), and V850 32-bit Architecture (http://www.am.necel.com/micro/product/all_32_general.html/).
- Sun Microsystems (http://www.sun.com/) - Sun Microsystems, developers of the SPARC architecture, a RISC design.
- Texas Instruments (http://www.ti.com/home_p_allsc) - Texas Instruments semiconductor division. Designs and manufactures several types of low-power microcontrollers among their many other semiconductor products.
- Transmeta (http://www.transmeta.com/) - Transmeta Corporation. Creators of low-power x86 compatibles like Crusoe and Efficeon.
- VIA Technologies (http://www.viatech.com/) - Taiwanese maker of low-power x86-compatible CPUs.

Further reading

- How Microprocessors Work (http://www.howstuffworks.com/microprocessor.htm) at HowStuffWorks
- 25 Microchips that shook the world (http://spectrum.ieee.org/25chips) - an article by the Institute of Electrical and Electronics Engineers

Random-access memory

Example of writable volatile random-access memory: Synchronous Dynamic RAM modules, primarily used as main memory in personal computers, workstations, and servers.

Computer memory types
Volatile

• DRAM, e.g. DDR SDRAM
• SRAM
• Upcoming
  • T-RAM
  • Z-RAM
  • TTRAM
• Historical
  • Delay line memory
  • Selectron tube
  • Williams tube

Non-volatile

• ROM
  • PROM
  • EPROM
  • EEPROM
• Flash memory
• FeRAM
• MRAM
• PRAM
• Upcoming
  • CBRAM
  • SONOS
  • RRAM
  • Racetrack memory
  • NRAM
  • Millipede
• Historical
  • Drum memory
  • Magnetic core memory
  • Plated wire memory
  • Bubble memory
  • Twistor memory

Random-access memory (**RAM**) is a form of computer data storage. Today, it takes the form of integrated circuits that allow stored data to be accessed in any order (i.e., at random). "Random" refers to the idea that any piece of data can be returned in a constant time, regardless of its physical location and whether or not it is related to the previous piece of data.[1]

By contrast, storage devices such as magnetic discs and optical discs rely on the physical movement of the recording medium or a reading head. In these devices, the movement takes longer than data transfer, and the retrieval time varies based on the physical location of the next item.

The word RAM is often associated with volatile types of memory (such as DRAM memory modules), where the information is lost after the power is switched off. Many other types of memory are RAM, too, including most types of ROM and a type of flash memory called *NOR-Flash*.

History

An early type of widespread *writable* random-access memory was the magnetic core memory, developed from 1949 to 1952, and subsequently used in most computers up until the development of the static and dynamic integrated RAM circuits in the late 1960s and early 1970s. Before this, computers used relays, delay line/delay memory, or various kinds of vacuum tube arrangements to implement "main" memory functions (i.e., hundreds or thousands of bits), some of which were *random access*, some not. Latches built out of vacuum tube triodes, and later, out of discrete transistors, were used for smaller and faster memories such as random-access register banks and registers. Prior to the development of integrated ROM circuits, *permanent* (or *read-only*) random-access memory was often constructed using semiconductor diode matrices driven by address decoders.

Overview

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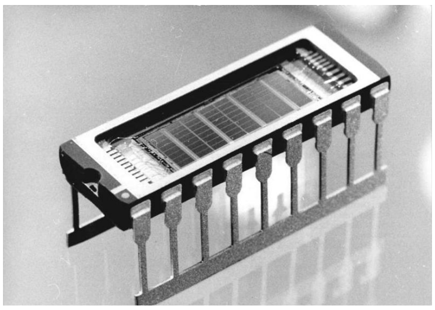
Types of RAM

Top L-R, DDR2 with heat-spreader, DDR2 without heat-spreader, Laptop DDR2, DDR3, DDR, Laptop DDR


1 Megabit chip - one of the last models developed by VEB Carl Zeiss Jena in 1989

Modern types of *writable* RAM generally store a bit of data in either the state of a flip-flop, as in SRAM (static RAM), or as a charge in a capacitor (or transistor gate), as in DRAM (dynamic RAM), EPROM, EEPROM and Flash. Some types have circuitry to detect and/or correct random faults called *memory errors* in the stored data, using parity bits or error correction codes. RAM of the *read-only* type, ROM, instead uses a metal mask to permanently enable/disable selected transistors, instead of storing a charge in them. Of special consideration is SIMM and DIMM memory modules.

SRAM and DRAM are *volatile*, other forms of computer storage, such as disks and magnetic tapes, have been used as persistent storage in traditional computers. Many newer products instead rely on flash memory to maintain data when not in use, such as PDAs or small music players. Certain personal computers, such as many rugged computers and netbooks, have also replaced magnetic disks with flash drives. With flash memory, only the NOR type is capable of true random access, allowing direct code execution, and is therefore often used instead of ROM; the lower cost NAND type is commonly used for bulk storage in memory cards and solid-state drives.

Similar to a microprocessor, a memory chip is an integrated circuit (IC) made of millions of transistors and capacitors. In the most common form of computer memory, dynamic random access memory (DRAM), a transistor and a capacitor are paired to create a memory cell, which represents a single bit of data. The capacitor holds the bit of information — a 0 or a 1 . The transistor acts as a switch that lets the control circuitry on the memory chip read the capacitor or change its state.

Memory hierarchy

Many computer systems have a memory hierarchy consisting of CPU registers, on-die SRAM caches, external caches, DRAM, paging systems, and virtual memory or swap space on a hard drive. This entire pool of memory may be referred to as "RAM" by many developers, even though the various subsystems can have very different access times, violating the original concept behind the *random access* term in RAM. Even within a hierarchy level such as DRAM, the specific row, column, bank, rank, channel, or interleave organization of the components make the access time variable, although not to the extent that rotating storage media or a tape is variable. The overall goal of using a memory hierarchy is to obtain the higher possible average access performance while minimizing the total cost of the entire memory system (generally, the memory hierarchy follows the access time with the fast CPU registers at the top and the slow hard drive at the bottom).

In many modern personal computers, the RAM comes in an easily upgraded form of modules called memory modules or DRAM modules about the size of a few sticks of chewing gum. These can quickly be replaced should they become damaged or when changing needs demand more storage capacity. As suggested above, smaller amounts of RAM (mostly SRAM) are also integrated in the CPU and other ICs on the motherboard, as well as in hard-drives, CD-ROMs, and several other parts of the computer system.

Swapping

If a computer becomes low on RAM during intensive application cycles, many CPU architectures and operating systems are able to perform an operation known as "swapping". Swapping uses a *paging file*, an area on a hard drive temporarily used as additional working memory. Excessive use of this mechanism is called thrashing and is generally undesirable because it lowers overall system performance, mainly because hard drives are far slower than RAM. However, if a program attempts to allocate memory and fails, it may crash.

Other uses of the "RAM" term

Other physical devices with read–write capability can have "RAM" in their names: for example, DVD-RAM. "Random access" is also the name of an indexing method: hence, disk storage is often called "random access" (Wiki:PowerOfPlainText, Fortran language features#Direct-access files, MBASIC#Files and input/output, Java Platform, Standard Edition#Random access, indexed file) because the reading head can move relatively quickly from one piece of data to another, and does not have to read all the data in between. However the final "M" is crucial: "RAM" (provided there is no additional term as in "DVD-RAM") always refers to a solid-state device.

Often, RAM is a shorthand in on-line conversations for referring to the computer's main working memory.

RAM disks

Software can "partition" a portion of a computer's RAM, allowing it to act as a much faster hard drive that is called a RAM disk. Unless the memory used is non-volatile, a RAM disk loses the stored data when the computer is shut down. However, volatile memory can retain its data when the computer is shut down if it has a separate power source, usually a battery.

Shadow RAM

Sometimes, the contents of a ROM chip are copied to SRAM or DRAM to allow for shorter access times (as ROM may be slower). The ROM chip is then disabled while the initialized memory locations are switched in on the same block of addresses (often write-protected). This process, sometimes called *shadowing*, is fairly common in both computers and embedded systems.

As a common example, the BIOS in typical personal computers often has an option called “use shadow BIOS” or similar. When enabled, functions relying on data from the BIOS’s ROM will instead use DRAM locations (most can also toggle shadowing of video card ROM or other ROM sections). Depending on the system, this may or may not result in increased performance, and may cause incompatibilities. For example, some hardware may be inaccessible to the operating system if shadow RAM is used. On some systems the benefit may be hypothetical because the BIOS is not used after booting in favor of direct hardware access. Of course, somewhat less free memory is available when shadowing is enabled.[2]

Recent developments

Several new types of *non-volatile* RAM, which will preserve data while powered down, are under development. The technologies used include carbon nanotubes and approaches utilizing the magnetic tunnel effect. Amongst the 1st generation MRAM, a 128 KiB (128×2^{10} bytes) magnetic RAM (MRAM) chip was manufactured with 0.18 µm technology in the summer of 2003. In June 2004, Infineon Technologies unveiled a 16 MiB (16×2^{20} bytes) prototype again based on 0.18 µm technology. There are two 2nd generation techniques currently in development: Thermal Assisted Switching (TAS)[3] which is being developed by Crocus Technology, and Spin Torque Transfer (STT) on which Crocus, Hynix, IBM, and several other companies are working[4] . Nantero built a functioning carbon nanotube memory prototype 10 GiB (10×2^{30} bytes) array in 2004. Whether some of these technologies will be able to eventually take a significant market share from either DRAM, SRAM, or flash-memory technology, however, remains to be seen.

Since 2006, "Solid-state drives" (based on flash memory) with capacities exceeding 64 gigabytes and performance far exceeding traditional disks have become available. This development has started to blur the definition between traditional random access memory and "disks", dramatically reducing the difference in performance. There is also active research in the field of plastic magnets, which switch magnetic polarities based on light.

Some kinds of random-access memory, such as "EcoRAM", are specifically designed for server farms, where low power consumption is more important than speed. [5]

Memory wall

The "memory wall" is the growing disparity of speed between CPU and memory outside the CPU chip. An important reason for this disparity is the limited communication bandwidth beyond chip boundaries. From 1986 to 2000, CPU speed improved at an annual rate of 55% while memory speed only improved at 10%. Given these trends, it was expected that memory latency would become an overwhelming bottleneck in computer performance. [6]

Currently, CPU speed improvements have slowed significantly partly due to major physical barriers and partly because current CPU designs have already hit the memory wall in some sense. Intel summarized these causes in their Platform 2015 documentation (PDF) [7]

> “First of all, as chip geometries shrink and clock frequencies rise, the transistor leakage current increases, leading to excess power consumption and heat... Secondly, the advantages of higher clock speeds are in part negated by memory latency, since memory access times have not been able to keep pace with increasing clock frequencies. Third, for certain applications, traditional serial architectures are becoming less efficient as processors get faster (due to the so-called Von Neumann bottleneck), further undercutting any gains that frequency increases might otherwise buy. In addition, partly due to limitations in the means of producing inductance within solid state devices, resistance-capacitance (RC) delays in signal transmission are growing as feature sizes shrink, imposing an additional bottleneck that frequency increases don't address.”

The RC delays in signal transmission were also noted in Clock Rate versus IPC: The End of the Road for Conventional Microarchitectures [8] which projects a maximum of 12.5% average annual CPU performance improvement between 2000 and 2014. The data on Intel Processors [9] clearly shows a slowdown in performance improvements in recent processors. However, Intel's new processors, Core 2 Duo (codenamed Conroe) show a significant improvement over previous Pentium 4 processors; due to a more efficient architecture, performance increased while clock rate actually decreased.

Security concerns

Contrary to simple models (and perhaps common belief), the contents of modern SDRAM modules are not lost immediately when the computer is shut down; instead, the contents fade away, a process that takes only seconds at room temperatures, but which can be extended to minutes at low temperatures. It is therefore possible to recover any data stored in ordinary working memory (i.e. the SDRAM modules).[10] This is sometimes referred to as a cold boot attack or ice-man attack.

See also

- CAS latency (CL)
- Dual-channel architecture
- Triple-channel architecture
- ECC (Error-correcting code)
- Registered/buffered memory
- RAM parity
- List_of_device_bit_rates#Memory_Interconnect.2FRAM_buses

External links

- Memory Prices (1957-2010) [11]

References

[1] *Strictly speaking, modern types of DRAM are therefore not truly (or technically) random access, as data are read in burst, although the name DRAM / RAM has stuck. However, many types of SRAM, ROM, OTP, and NOR flash are still random access even in a strict sense.*
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[4] http://www.eetimes.com/news/latest/showArticle.jhtml?articleID=218000269
[5] "EcoRAM held up as less power-hungry option than DRAM for server farms" (http://blogs.zdnet.com/green/?p=1165) by Heather Clancy 2008
[6] The term was coined in Hitting the Memory Wall: Implications of the Obvious (PDF) (http://www.cs.virginia.edu/papers/Hitting_Memory_Wall-wulf94.pdf).
[7] http://download.intel.com/technology/computing/archinnov/platform2015/download/RMS.pdf
[8] http://www.cs.utexas.edu/users/cart/trips/publications/isca00.pdf
[9] http://www.intel.com/pressroom/kits/quickreffam.htm
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[11] http://www.jcmit.com/memoryprice.htm

Video card

Connects to	Motherboard via one of: • ISA • MCA • VLB • PCI • AGP • PCI-X • PCI Express • PCI Express 2.0 • Others Display via one of: • VGA connector • Digital Visual Interface • Composite video • S-Video • Component video • HDMI • DMS-59 • DisplayPort • Others

A **video card**, **video adapter**, **graphics-accelerator card**, **display adapter** or **graphics card** is an expansion card whose function is to generate and output images to a display. Many video cards offer added functions, such as accelerated rendering of 3D scenes and 2D graphics, video capture, TV-tuner adapter, MPEG-2/MPEG-4 decoding, FireWire, light pen, TV output, or the ability to connect multiple monitors (multi-monitor). Other modern high performance video cards are used for more graphically demanding purposes, such as PC games.

Video hardware can be integrated on the motherboard, often occurring with early machines. In this configuration it is sometimes referred to as a *video controller* or *graphics controller*. Modern low-end to mid-range motherboards often include a graphics chipset developed by the developer of the northbridge (i.e. an nForce chipset with nVidia graphics or an Intel chipset with Intel graphics) on the motherboard. This graphics chip usually has a small quantity of embedded memory and takes some of the system's main RAM, reducing the total RAM available. This is usually called *integrated graphics* or *on-board graphics*, and is low-performance and undesirable for those wishing to run 3D applications. Almost all of these motherboards allow the disabling of the integrated graphics chip in BIOS, and have an AGP or PCI Express slot for adding a higher-performance graphics card in its stead.

History

	Year	Text Mode (columns/lines)	Graphics Mode (resolution/colors)	Memory
MDA	1981	80×25	-	4 KB
CGA	1981	80×25	640×200 / 4	16 KB
HGC	1982	80×25	720×348 / 2	64 KB
PGA	1984	80×25	640×480 / 256	320 KB
EGA	1984	80×25	640×350 / 16	256 KB
8514	1987	80×25	1024×768 / 256	-
MCGA	1987	80×25	320×200 / 256	-
VGA	1987	80×25	640×480 / 16	256 KB
SVGA (VBE 1.x)	1989	80×25	800×600 / 256	512 KB
			640×480+ / 256+	512 KB+
XGA	1990	80×25	1024×768 / 256	1 MB
XGA-2	1992	80×25	1024×768 / 65,536	2 MB
SVGA (VBE 3.0)	1998	132×60	1280×1024 / 16.7M	-

The first IBM PC video card, which was released with the first IBM PC, was developed by IBM in 1981. The MDA (*Monochrome Display Adapter*) could only work in text mode representing 80 columns and 25 lines (80x25) in the screen. It had a 4KB video memory and just one color.[1]

Starting with the MDA in 1981, several video cards were released, which are summarized in the attached table.[2] [3] [4] [5]

VGA was widely accepted, which led some corporations such as ATI, Cirrus Logic and S3 to work with that video card, improving its resolution and the number of colours it used. This developed into the SVGA (*Super VGA*) standard, which reached 2 MB of video memory and a resolution of 1024x768 at 256 color mode.

In 1995 the first consumer 2D/3D cards were released, developed by Matrox, Creative, S3, ATI and others. These video cards followed the SVGA standard, but incorporated 3D functions. In 1997, 3dfx released the **Voodoo** graphics chip, which was more powerful compared to other consumer graphics cards, introducing 3D effects such as mip mapping, Z-buffering and anti-aliasing into the consumer market. After this card, a series of 3D video cards were released, such as **Voodoo2** from 3dfx, **TNT** and **TNT2** from NVIDIA. The bandwidth required by these cards was approaching the limits of the PCI bus capacity. Intel developed the AGP (*Accelerated Graphics Port*) which solved the bottleneck between the microprocessor and the video card. From 1999 until 2002, NVIDIA controlled the video card market (taking over 3dfx) with the GeForce family.[6] The improvements carried out at this time were focused in 3D algorithms and graphics processor clock rate. Video memory was also increased to improve their data rate; DDR technology was incorporated, improving the capacity of video memory from 32 MB with GeForce to 128 MB with GeForce 4.

Since 2003, ATI and Nvidia have dominated the video card market with their Radeon and Geforce lines (respectively), sharing around 90% of the independent graphics card market and forcing other manufacturers into smaller, niche markets.[7]

Components

A modern video card consists of a printed circuit board on which the components are mounted. These include:

Graphics processing unit (GPU)

A GPU is a dedicated processor optimized for accelerating graphics. The processor is designed specifically to perform floating-point calculations, which are fundamental to 3D graphics rendering. The main attributes of the GPU are the core clock frequency, which typically ranges from 250 MHz to 4 GHz and the number of pipelines (*vertex* and *fragment* shaders), which translate a 3D image characterized by vertices and lines into a 2D image formed by pixels.

Video BIOS

The video BIOS or firmware contains the basic program, which is usually hidden, that governs the video card's operations and provides the instructions that allow the computer and software to interact with the card. It may contain information on the memory timing, operating speeds and voltages of the graphics processor, RAM, and other information. It is sometimes possible to change the BIOS (e.g. to enable factory-locked settings for higher performance), although this is typically only done by video card overclockers and has the potential to irreversibly damage the card.

Video memory

Type	Memory clock rate (MHz)	Bandwidth (GB/s)
DDR	166 - 950	1.2 - 30.4
DDR2	533 - 1000	8.5 - 16
GDDR3	700 - 2400	5.6 - 156.6
GDDR4	2000 - 3600	128 - 200
GDDR5	3400 - 5600	130 - 230

The memory capacity of most modern video cards ranges from 128 MB to 4 GB, though very few cards actually go over 1 GB.[8] [9] Since video memory needs to be accessed by the GPU and the display circuitry, it often uses special high-speed or multi-port memory, such as VRAM, WRAM, SGRAM, etc. Around 2003, the video memory was typically based on DDR technology. During and after that year, manufacturers moved towards DDR2, GDDR3, GDDR4, and even GDDR5 utilized most notably by the ATI Radeon HD 4870. The effective memory clock rate in modern cards is generally between 400 MHz and 3.8 GHz.

Video memory may be used for storing other data as well as the screen image, such as the Z-buffer, which manages the depth coordinates in 3D graphics, textures, vertex buffers, and compiled shader programs.

RAMDAC

The RAMDAC, or Random Access Memory Digital-to-Analog Converter, converts digital signals to analog signals for use by a computer display that uses analog inputs such as CRT displays. The RAMDAC is a kind of RAM chip that regulates the functioning of the graphics card. Depending on the number of bits used and the RAMDAC-data-transfer rate, the converter will be able to support different computer-display refresh rates. With CRT displays, it is best to work over 75 Hz and never under 60 Hz, in order to minimize flicker.[10] (With LCD displays, flicker is not a problem.) Due to the growing popularity of digital computer displays and the integration of the RAMDAC onto the GPU die, it has mostly disappeared as a discrete component. All current LCDs, plasma displays and TVs work in the digital domain and do not require a RAMDAC. There are few remaining legacy LCD and plasma displays that feature analog inputs (VGA, component, SCART etc.) *only*. These require a RAMDAC, but they reconvert the analog signal back to digital before they can display it, with the unavoidable loss of quality stemming from this digital-to-analog-to-digital conversion.

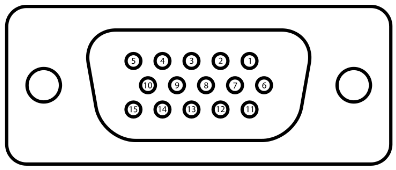
Outputs

9-pin VIVO for S-Video (TV-out), DVI for HDTV, and DE-15 for VGA outputs.

The most common connection systems between the video card and the computer display are:

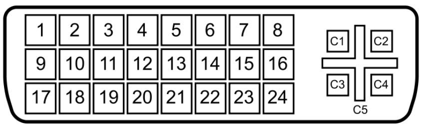
Video Graphics Array (VGA) (DE-15)

Analog-based standard adopted in the late 1980s designed for CRT displays, also called VGA connector. Some problems of this standard are electrical noise, image distortion and sampling error evaluating pixels.



Video Graphics Array (VGA) (DE-15).

Digital Visual Interface (DVI)

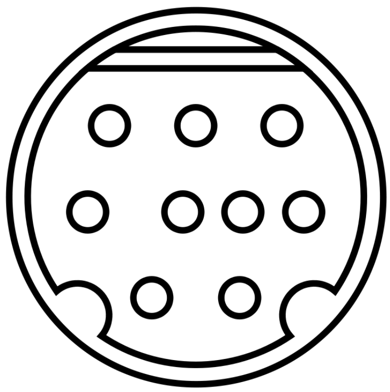


Digital Visual Interface (DVI).

Digital-based standard designed for displays such as flat-panel displays (LCDs, plasma screens, wide high-definition television displays) and video projectors. It avoids image distortion and electrical noise, corresponding each pixel from the computer to a display pixel, using its native resolution.

Video In Video Out (VIVO) for S-Video, Composite video and Component video

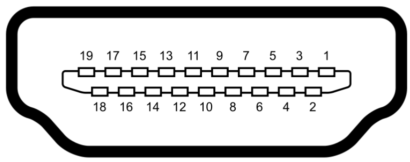
Included to allow the connection with televisions, DVD players, video recorders and video game consoles. They often come in two 9-pin Mini-DIN connector variations, and the VIVO splitter cable generally comes with either 4 connectors (S-Video in and out + composite video in and out), or 6 connectors (S-Video in and out + component P_B out + component P_R out + component Y out [also composite out] + composite in).



9 Pin Mini DIN Connector, Frequently Used for VIVO Connections.

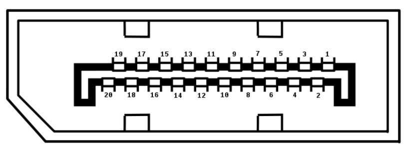
High-Definition Multimedia Interface (HDMI)

An advanced digital audio/video interconnect released in 2003 and is commonly used to connect game consoles and DVD players to a display. HDMI supports copy protection through HDCP.

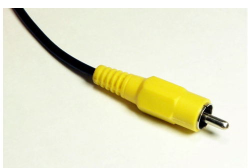


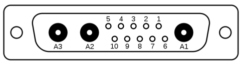
DisplayPort

An advanced license- and royalty-free digital audio/video interconnect released in 2007. DisplayPort intends to replace VGA and DVI for connecting a display to a computer.



Other types of connection systems

Composite video 	Analog system with lower resolution; it uses the RCA connector.

Component video 	It has three cables, each with RCA connector (YC_BC_R for digital component, or YP_BP_R for analogue component); it is used in projectors, DVD players and some televisions.
DB13W3 	An analog standard once used by Sun Microsystems, SGI and IBM.
DMS-59 	A connector that provides two DVI outputs on a single connector.

Motherboard interface

Chronologically, connection systems between video card and motherboard were, mainly:

- S-100 bus: designed in 1974 as a part of the Altair 8800, it was the first industry-standard bus for the microcomputer industry.
- ISA: Introduced in 1981 by IBM, it became dominant in the marketplace in the 1980s. It was an 8 or 16-bit bus clocked at 8 MHz.
- NuBus: Used in Macintosh II, it was a 32-bit bus with an average bandwidth of 10 to 20 MB/s.
- MCA: Introduced in 1987 by IBM it was a 32-bit bus clocked at 10 MHz.
- EISA: Released in 1988 to compete with IBM's MCA, it was compatible with the earlier ISA bus. It was a 32-bit bus clocked at 8.33 MHz.
- VLB: An extension of ISA, it was a 32-bit bus clocked at 33 MHz.
- PCI: Replaced the EISA, ISA, MCA and VESA buses from 1993 onwards. PCI allowed dynamic connectivity between devices, avoiding the jumpers manual adjustments. It is a 32-bit bus clocked 33 MHz.
- UPA: An interconnect bus architecture introduced by Sun Microsystems in 1995. It had a 64-bit bus clocked at 67 or 83 MHz.
- USB: Mostly used for other types of devices, but there are USB displays.
- AGP: First used in 1997, it is a dedicated-to-graphics bus. It is a 32-bit bus clocked at 66 MHz.
- PCI-X: An extension of the PCI bus, it was introduced in 1998. It improves upon PCI by extending the width of bus to 64-bit and the clock frequency to up to 133 MHz.
- PCI Express: Abbreviated PCIe, it is a point to point interface released in 2004. In 2006 provided double the data-transfer rate of AGP. It should not be confused with PCI-X, an enhanced version of the original PCI specification.

In the attached table[11] is a comparison between a selection of the features of some of those interfaces.

Bus	Width (bits)	Clock rate (MHz)	Bandwidth (MB/s)	Style
ISA XT	8	4,77	8	Parallel
ISA AT	16	8,33	16	Parallel
MCA	32	10	20	Parallel
EISA	32	8,33	32	Parallel
VESA	32	40	160	Parallel
PCI	32 - 64	33 - 100	132 - 800	Parallel
AGP 1x	32	66	264	Parallel
AGP 2x	32	66	528	Parallel
AGP 4x	32	66	1000	Parallel
AGP 8x	32	66	2000	Parallel
PCIe x1	1	2500 / 5000	250 / 500	Serial
PCIe x4	1 × 4	2500 / 5000	1000 / 2000	Serial
PCIe x8	1 × 8	2500 / 5000	2000 / 4000	Serial
PCIe x16	1 × 16	2500 / 5000	4000 / 8000	Serial
PCIe x16 2.0	1 × 16	5000 / 10000	8000 / 16000	Serial

Cooling devices

Video cards may use a lot of electricity, which is converted into heat. If the heat isn't dissipated, the video card could overheat and be damaged. Cooling devices are incorporated to transfer the heat elsewhere. Three types of cooling devices are commonly used on video cards:

- Heat sink: a heat sink is a passive-cooling device. It conducts heat away from the graphics card's core, or memory, by using a heat-conductive metal (most commonly aluminum or copper); sometimes in combination with heat pipes. It uses air (most common), or in extreme cooling situations, water (see water block), to remove the heat from the card. When air is used, a fan is often used to increase cooling effectiveness.
- Computer fan: an example of an active-cooling part. It is usually used with a heat sink. Due to the moving parts, a fan requires maintenance and possible replacement. The fan speed or actual fan can be changed for more efficient or quieter cooling.
- Water block: a water block is a heat sink suited to use water instead of air. It is mounted on the graphics processor and has a hollow inside. Water is pumped through the water block, transferring the heat into the water, which is then usually cooled in a radiator. This is the most effective cooling solution without extreme modification.

Power demand

As the processing power of video cards has increased, so has their demand for electrical power. Present fast video cards tend to consume a great deal of power. While CPU and power supply makers have recently moved toward higher efficiency, power demands of GPUs have continued to rise, so the video card may be the biggest electricity user in a computer.[12] [13] Although power supplies are increasing their power too, the bottleneck is due to the PCI-Express connection, which is limited to supplying 75 Watts.[14] Modern video cards with a power consumption over 75 Watts usually include a combination of six-pin (75W) or eight-pin (150W) sockets that connect directly to the power supply via a Molex connector to supplement power.

See also

- Computer display standards - detailed list of standards like SVGA, WXGA, WUXGA, etc.
- List of manufacturers
- ATI, NVIDIA - duopoly of 3D chip GPU and graphics card designers
- GeForce, Radeon – Examples of GPUs.
- Framebuffer - The computer memory used to store a screen image
- 3D computer graphics
- Z-buffering – A means of determining visibility.
- Texture mapping - A means of adding image details to a 3D scene
- Graphics hardware and FOSS
- Scalable Link Interface - NVIDIA's proprietary mechanism for scaling graphics performance
- ATI Crossfire - ATI's proprietary mechanism for scaling graphics performance
- Mini-DIN connector
- Video In Video Out (VIVO)
- GPGPU
- CUDA

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- Mueller, Scott (2005) *Upgrading and Repairing PCs*. 16th edition. Que Publishing. ISBN 0-7897-3173-8

External links

- How Graphics Cards Work (http://www.howstuffworks.com/graphics-card.htm) at HowStuffWorks
- http://www.gpureview.com

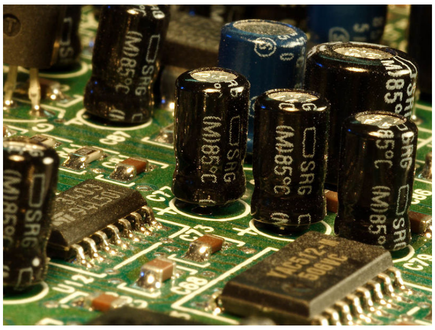
Sound card

A Sound Blaster Live! Value card, a typical (circa 2000) PCI sound card.

Connects to	Motherboard via one of: • PCI • ISA • USB • IEEE 1394 • IBM PC Parallel Port • PCI-E • MCA (rare) • PCMCIA interfaces (PC Card, Expresscard) Line in or out: via one of: • Analogue - TRS, RCA or DIN connector • Digital - RCA, TOSLink or AES/EBU Microphone via one of: • TRS connector • DIN connector
Common manufacturers	Creative Labs (and subsidiary E-mu Systems) Realtek C-Media M-Audio Turtle Beach

A **sound card** (also known as an **audio card**) is a computer expansion card that facilitates the input and output of audio signals to and from a computer under control of computer programs. Typical uses of sound cards include providing the audio component for multimedia applications such as music composition, editing video or audio, presentation, education, and entertainment (games). Many computers have sound capabilities built in, while others require additional expansion cards to provide for audio capability.

General characteristics

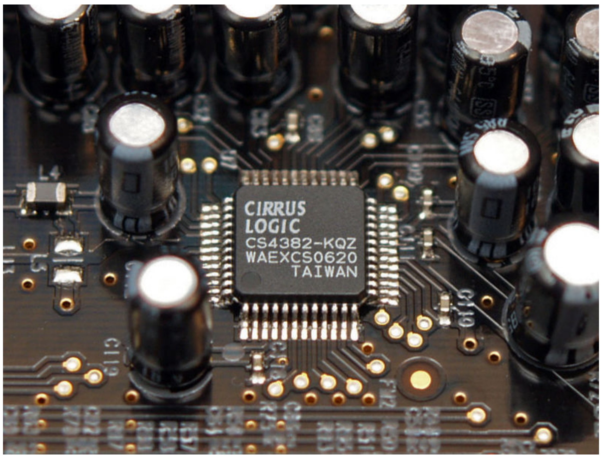


Close-up of a sound card PCB, showing electrolytic capacitors, SMT capacitors and resistors, and a YAC512 [1] two-channel 16-bit DAC.

Sound cards usually feature a digital-to-analog converter (DAC), which converts recorded or generated digital data into an analog format. The output signal is connected to an amplifier, headphones, or external device using standard interconnects, such as a TRS connector or an RCA connector. If the number and size of connectors is too large for the space on the backplate the connectors will be off-board, typically using a breakout box, or an auxiliary backplate. More advanced cards usually include more than one sound chip to provide for higher data rates and multiple simultaneous functionality, eg between digital sound production and synthesized sounds (usually for real-time generation of music and sound effects using minimal data and CPU time). Digital sound reproduction is usually done with multi-channel DACs, which are capable of multiple digital samples simultaneously at different pitches and volumes, or optionally applying real-time effects like filtering or distortion. Multi-channel digital sound playback can also be used for music synthesis when used with a compliance, and even multiple-channel emulation. This approach has become common as manufacturers seek to simplify the design and the cost of sound cards.

Most sound cards have a **line in** connector for signal from a cassette tape recorder or similar sound source. The sound card digitizes this signal and stores it (under control of appropriate matching computer software) on the computer's hard disk for storage, editing, or further processing. Another common external connector is the **microphone** connector, for use by a microphone or other low level input device. Input through a microphone jack can then be used by speech recognition software or for Voice over IP applications.

Sound channels and polyphony



8-channel DAC Cirrus Logic **CS4382** placed on Sound Blaster X-Fi Fatal1ty.

An important characteristic of sound cards is polyphony, which is more than one distinct voice or sound playable *simultaneously* and *independently*, and the number of simultaneous channels. These are intended as the number of distinct *electrical* audio outputs, which may correspond to a speaker configuration such as 2.0 (stereo), 2.1 (stereo and sub woofer), 5.1 etc. Sometimes, the terms "voices" and "channels" are used interchangeably to indicate the degree of polyphony, not the output speaker configuration.

For example, many older sound chips could accommodate three voices, but only one audio channel (ie, a single mono output) for output, requiring all voices to be mixed together. Later cards, such as the AdLib sound card, had a 9 voice polyphony and 1 mono channel as a combined output.

For some years, most PC sound cards have had multiple FM synthesis voices (typically 9 or 16) which were usually used for MIDI music. The full capabilities of advanced cards aren't often completely used; only one (mono) or two (stereo) voice(s) and channel(s) are usually dedicated to playback of digital sound samples, and playing back more than one digital sound sample usually requires a software downmix at a fixed sampling rate. Modern low-cost integrated soundcards (ie, those built into motherboards) such as audio codecs like those meeting the AC'97 standard and even some budget expansion soundcards still work that way. They may provide more than two sound output channels (typically 5.1 or 7.1 surround sound), but they usually have no actual hardware polyphony for either sound effects or MIDI reproduction, these tasks are performed entirely in software. This is similar to the way inexpensive softmodems perform modem tasks in software rather than in hardware).

Also, in the early days of wavetable synthesis, some sound card manufacturers advertised polyphony solely on the MIDI capabilities alone. In this case, the card's output channel is irrelevant (and typically, the card is only capable of two channels of digital sound). Instead, the polyphony measurement solely applies to the amount of MIDI instruments the sound card is capable of producing at one given time.

Today, a sound card providing actual hardware polyphony, regardless of the number of output channels, is typically referred to as a "hardware audio accelerator", although actual voice polyphony is not the sole (or even a necessary) prerequisite, with other aspects such as hardware acceleration of 3D sound, positional audio and real-time DSP effects being more important.

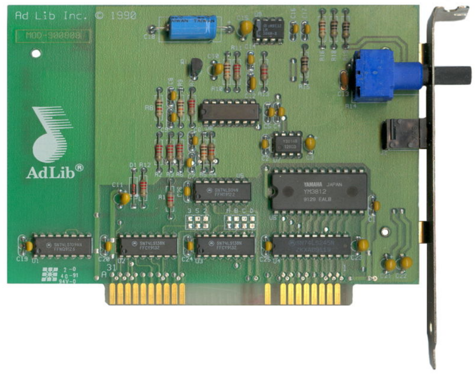
Since digital sound playback has become available and provided better performance than synthesis, modern soundcards with hardware polyphony don't actually use DACs with as many channels as voices. Instead, they perform voice mixing and effects processing in hardware (eventually performing digital filtering and conversions to and from the frequency domain for applying certain effects) inside a dedicated DSP. The final playback stage is performed by an external (in reference to the DSP chip(s)) DAC with significantly fewer channels than voices (e.g., 8 channels for 7.1 audio, which can be divided among 32, 64 or even 128 voices).

Color codes

Connectors on the sound cards are colour coded as per the PC System Design Guide. They will also have symbols with arrows, holes and soundwaves that are associated with each jack position, the meaning of each is given below:

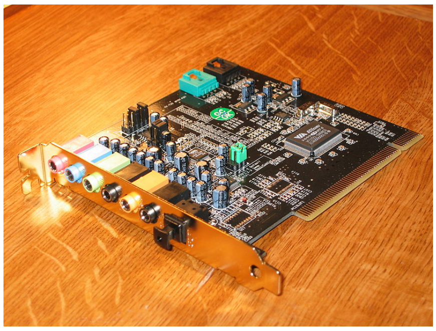
Colour	Function	Connector	symbol
Pink	Analog microphone audio input.	3.5 mm TRS	A microphone
Light blue	Analog line level audio input.	3.5 mm TRS	An arrow going into a circle
Lime green	Analog line level audio output for the main stereo signal (front speakers or headphones).	3.5 mm TRS	Arrow going out one side of a circle into a wave
Brown/Dark	Analog line level audio output for a special panning,'Right-to-left speaker'.	3.5 mm TRS	
Black	Analog line level audio output for surround speakers, typically rear stereo.	3.5 mm TRS	
Orange	Analog line level audio output for center channel speaker and subwoofer	3.5 mm TRS	
Gold/Grey	Game port / MIDI	15 pin D	Arrow going out both sides into waves

History of sound cards for the IBM PC architecture



The AdLib Music Synthesizer Card, was one of the first sound cards circa 1990. Note the manual volume adjustment knob.

Sound cards for computers compatible with the IBM PC were very uncommon until 1988, which left the single internal PC speaker as the only way early PC software could produce sound and music. The speaker hardware was typically limited to square waves, which fit the common nickname of "beeper". The resulting sound was generally described as "beeps and boops". Several companies, most notably Access Software, developed techniques for digital sound reproduction over the PC speaker; the resulting audio, while baldly functional, suffered from distorted output and low volume, and usually required all other processing to be stopped while sounds were played. Other home computer models of the 1980s included hardware support for digital sound playback, or music synthesis (or both), leaving the IBM PC at a disadvantage to them when it came to multimedia applications such as music composition or gaming.



A sound card based on VIA Envy chip.

It is important to note that the initial design and marketing focuses of sound cards for the IBM PC platform were not based on gaming, but rather on specific audio applications such as music composition (AdLib Personal Music System, Creative Music System, IBM Music Feature Card) or on speech synthesis (Digispeech *DS201*, Covox Speech Thing, Street Electronics *Echo*). Not until Sierra and other game companies became involved in 1988 was there a switch toward gaming.

Hardware manufacturers

Echo Digital Audio Corporation's Indigo IO — PCMCIA card 24-bit 96 kHz stereo in/out sound card.

One of the first manufacturers of sound cards for the IBM PC was AdLib, who produced a card based on the Yamaha YM3812 sound chip, also known as the OPL2. The AdLib had two modes: A 9-voice mode where each voice could be fully programmed, and a less frequently used "percussion" mode with 3 regular voices producing 5 independent percussion-only voices for a total of 11. (The percussion mode was considered inflexible by most developers; it was used mostly by AdLib's own composition software.)

Creative Labs also marketed a sound card about the same time called the Creative Music System. Although the *C/MS* had twelve voices to AdLib's nine, and was a stereo card while the AdLib was mono, the basic technology behind it was based on the Philips SAA 1099 chip which was essentially a square-wave generator. It sounded much like twelve simultaneous PC speakers would have, and failed to sell well, even after Creative renamed it the Game Blaster a year later, and marketed it through Radio Shack in the US. The Game Blaster retailed for under $100 and included the hit game Silpheed.

A large change in the IBM PC compatible sound card market happened with Creative Labs' introduced the Sound Blaster card. The Sound Blaster cloned the AdLib, and added a sound coprocessor for recording and play back of digital audio (likely to have been an Intel microcontroller relabeled by Creative). It was incorrectly called a "DSP" (to suggest it was a digital signal processor), a game port for adding a joystick, and capability to interface to MIDI equipment (using the game port and a special cable). With more features at nearly the same price, and compatibility as well, most buyers chose the Sound Blaster. It eventually outsold the AdLib and dominated the market.

The Sound Blaster line of cards, together with the first inexpensive CD-ROM drives and evolving video technology, ushered in a new era of multimedia computer applications that could play back CD audio, add recorded dialogue to computer games, or even reproduce motion video (albeit at much lower resolutions and quality in early days). The widespread decision to support the Sound Blaster design in multimedia and entertainment titles meant that future sound cards such as Media Vision's Pro Audio Spectrum and the Gravis Ultrasound had to be Sound Blaster compatible if they were to sell well. Until the early 2000s (by which the AC'97 audio standard became more widespread and eventually usurped the SoundBlaster as a standard due to its low cost and integration into many motherboards), Sound Blaster compatibility is a standard that many other sound cards still support to maintain compatibility with many games and applications released.

Industry adoption

When game company Sierra On-Line opted to support add-on music hardware (instead of built-in hardware such as the PC speaker and built-in sound capabilities of the IBM PCjr and Tandy 1000), what could be done with sound and music on the IBM PC changed dramatically. Two of the companies Sierra partnered with were Roland and Adlib, opting to produce in-game music for King's Quest 4 that supported the Roland MT-32 and Adlib Music Synthesizer. The MT-32 had superior output quality, due in part to its method of sound synthesis as well as built-in reverb. Since it was the most sophisticated synthesizer they supported, Sierra chose to use most of the MT-32's custom features and unconventional instrument patches, producing background sound effects (eg, chirping birds, clopping horse hooves, etc.) before the Sound Blaster brought playing real audio clips to the PC entertainment world. Many game companies also supported the MT-32, but supported the Adlib card as an alternative because of the latter's higher market base. The adoption of the MT-32 led the way for the creation of the MPU-401/Roland Sound Canvas and General MIDI standards as the most common means of playing in-game music until the mid-1990s.

Feature evolution

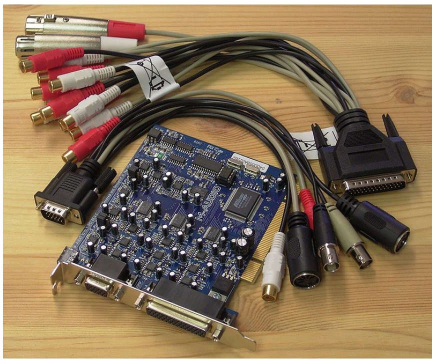
Early ISA bus soundcards were half-duplex, meaning they couldn't record and play digitized sound simultaneously, mostly due to inferior card hardware (eg, DSPs). Later, ISA cards like the SoundBlaster AWE series and Plug-and-play Soundblaster clones eventually became full-duplex and supported simultaneous recording and playback, but at the expense of using up two IRQ and DMA channels instead of one, making them no different from having two half-duplex sound cards in terms of configuration. Towards the end of the ISA bus' life, ISA soundcards started taking advantage of IRQ sharing, thus reducing the IRQs needed to one, but still needed two DMA channels. Many PCI bus cards do not have these limitations and are mostly full-duplex. It should also be noted that many modern PCI bus cards also do not require free DMA channels to operate.

Also, throughout the years, soundcards have evolved in terms of digital audio sampling rate (starting from 8-bit 11.025 kHz, to 32-bit, 192 kHz that the latest solutions support). Along the way, some cards started offering wavetable synthesis, which provides superior MIDI synthesis quality in relative to the earlier OPL-based solutions, which uses FM-synthesis. Also, some higher end cards started having its own RAM and processor for user-definable sound samples and MIDI instruments as well as to offload audio processing from the CPU.

For years, soundcards had only one or two channels of digital sound (most notably the Sound Blaster series and their compatibles) with the exception of the E-MU card family, which had hardware support for up to 32 independent channels of digital audio. Early games and MOD-players needing more channels than a card could support had to resort to mixing multiple channels in software. Even today, the tendency is still to mix multiple sound streams in software, except in products specifically intended for gamers or professional musicians, with a sensible difference in price from "software based" products. Also, in the early era of wavetable synthesis, soundcard companies would also sometimes boast about the card's polyphony capabilities in terms of MIDI synthesis. In this case polyphony solely refers to the amount of MIDI notes the card is capable of synthesizing simultaneously at one given time and not the amount of digital audio streams the card is capable of handling.

In regards to physical sound output, the number of physical sound channels has also increased. The first soundcard solutions were mono. Stereo sound was introduced in the early 90s, and quadraphonic sound came in the late 90s. This was shortly followed by 5.1 channel audio. The latest soundcards support up to 8 physical audio channels in the 7.1 speaker setup.

Professional soundcards (audio interfaces)


An M-Audio professional sound card with its breakout cables.

Professional soundcards are special soundcards optimized for real time (or at least low latency) multichannel sound recording and playback, including studio-grade fidelity. Their drivers usually follow the Audio Stream Input Output protocol for use with professional sound engineering and music software, although ASIO drivers are also available for a range of consumer-grade soundcards.

Professional soundcards are usually described as "audio interfaces", and sometimes have the form of external rack-mountable units using USB 2.0, Firewire, or an optical interface, to offer sufficient data rates. The emphasis in these products is, in general, on multiple input and output connectors, direct hardware support for multiple input and output sound channels, as well as higher sampling rates and fidelity as compared to the usual consumer soundcard. In that respect, their role and intended purpose is more similar to a specialized multi-channel data recorder and real-time audio mixer and processor, roles which are possible only to a limited degree with typical consumer soundcards.

On the other hand, certain features of consumer soundcards such as support for environmental audio extensions, optimization for hardware acceleration in video games, or real-time ambience effects are secondary, nonexistent or even undesirable in professional soundcards, and as such audio interfaces are not recommended for the typical home user.

The typical "consumer-grade" soundcard is intended for generic home, office, and entertainment purposes with an emphasis on playback and casual use, rather than catering to the needs of audio professionals. In response to this, Steinberg (the creators of audio recording and sequencing software, Cubase and Nuendo) developed a protocol that specified the handling of multiple audio inputs and outputs.

In general, consumer grade soundcards impose several restrictions and inconvenieces that would be unacceptable to an audio professional. One of a modern soundcard's purposes is to provide an AD/DA converter (analog to digital/digital to analog). However, in professional applications, there is usually a need for enhanced recording (analog to digital) conversion capabilities.

One of the limitations of consumer soundcards is their comparatively large sampling latency; this is the time it takes for the AD Converter to complete conversion of a sound sample and transfer it to the computer's main memory.

Consumer soundcards are also limited in the *effective* sampling rates and bit depths they can actually manage (compare analog versus digital sound) and have lower numbers of less flexible input channels: professional studio recording use typically requires more than two channels which consumer soundcards provide, and more accessible connectors, unlike the variable mixture of internal—and sometimes virtual—and external connectors found in consumer-grade soundcards.

Sound devices other than expansion cards

Integrated sound hardware on PC motherboards

In 1984, the first IBM PCjr had only a rudimentary 3-voice sound synthesis chip (the SN76489) which was capable of generating three square-wave tones with variable amplitude, and a pseudo white noise channel that could generate primitive percussion sounds. The Tandy 1000, initially a clone of the PCjr, duplicated this functionality, with the Tandy TL/SL/RL models adding digital sound recording/playback capabilities.

In the late 1990s, many computer manufacturers began to replace plug-in soundcards with a "codec" chip (actually a combined audio AD/DA-converter) integrated into the motherboard. Many of these used Intel's AC97 specification. Others used inexpensive ACR slot accessory cards.

From the mid 2000s most motherboards were manufactured with integrated "real" (non-codec) soundcards, usually in the form of a custom chipset providing something akin to full Soundblaster compatibility; this saves an expansion slot while providing the user with a (relatively) high quality soundcard.

Integrated sound on other platforms

Various non-IBM PC compatible computers, such as early home computers like the Commodore C64 and Amiga or Apple's Macintosh, and workstations from manufacturers like Sun have had their own motherboard integrated sound devices. In some cases, most notably in those of the Commodore Amiga and the C64, they provide very advanced capabilities (as of the time of manufacture), in others they are only minimal capabilities. Some of these platforms have also had sound cards designed for their bus architectures that cannot be used in a standard PC.

The custom sound chip on Amiga, named Paula, had four digital sound channels (2 for the left speaker and 2 for the right) with 8 bit resolution (although with patches, 14/15bit was accomplishable at the cost of high CPU usage) for each channel and a 6 bit volume control per channel. Sound Play back on Amiga was done by reading directly from the chip-RAM without using the main CPU.

Sound cards on other platforms

The earliest known soundcard used by computers was the Gooch Synthetic Woodwind, A music device for PLATO terminals, and is widely hailed as the precursor to sound cards and MIDI. It was invented in 1972.

While many of Apple's machines come with on-board sound capabilities, their bestselling Apple II series suffered from a lack of more than minimal sound devices, all but the last model containing only a beeper that was even more limited than the one in the PC. To get around the problem, the Sweet Micro Systems company developed the Mockingboard (a name-play on mockingbird), which was essentially a sound card for the Apple II. Early Mockingboard models ranged from 3 voices in mono, while some later designs were 6 voices in stereo. Some software supported use of two Mockingboard cards which allowed 12 voice music and sound. A 12 voice, single card clone of the Mockingboard called the Phasor was also made by Applied Engineering. In late 2005 a company called ReactiveMicro.com produced a 6 voice clone called the Mockingboard v1 and also has plans to clone the Phasor and produce a hybrid card which will be user selectable between Mockingboard and Phasor modes plus support both the SC-01 or SC-02 speech synthesizers.

MSX computers also relied on sound cards to produce better quality audio. The card, known as Moonsound, uses a Yamaha OPL4 sound chip. Prior to the Moonsound, there were also soundcards called *MSX Music* and *MSX Audio*, which uses OPL2 and OPL3 chipsets, for the system.

USB sound "cards"

USB sound "cards" are actually external boxes that plug into the computer via USB. They are more accurately called audio interfaces rather than sound cards.

The USB specification defines a standard interface, the USB audio device class, allowing a single driver to work with the various USB sound devices on the market. Cards meeting the USB 2.0 specification have sufficient data transfer capacity to support high quality sound operation if their circuit design permits.


USB sound "card"

Other outboard sound devices

.USB Sound Cards are far from the first external devices allowing a computer to record or synthesize sound. For example, devices such as the Covox Speech Thing were attached to the parallel port of an IBM PC and fed 6- or 8-bit PCM sample data to produce audio. Also, many types of professional soundcards (audio interfaces) have the form of an external Firewire or USB unit, usually for convenience and improved fidelity.

Soundcards using the PCMCIA cardbus interface were popular in the early days of portable computing when laptops and notebooks did not have onboard sound. Even today, while rare, these cardbus audio solutions are still used in some setups in which the onboard sound solution of the notebook or laptop is not up to par with the owners' expectations or requirements, and are particularly targeted at mobile DJs, with units providing separated outputs usually allow both playback and monitoring from one system.

Driver architecture

To use a sound card, the operating system typically requires a specific device driver. This is a low-level program that handles the data connections between the physical hardware and the operating system. Some operating systems include the drivers for some or all cards available, in other cases the drivers are supplied with the card itself, or are available for download.

- DOS programs for the IBM PC often had to use universal middleware driver libraries (such as the HMI Sound Operating System, the Miles Audio Interface Libraries (AIL), the Miles Sound System etc.) which had drivers for most common sound cards, since DOS itself had no real concept of a sound card. Some card manufacturers provided (sometimes inefficient) middleware TSR-based drivers for their products. Often the driver is a SoundBlaster emulator designed to allow their products to emulate a SoundBlaster and to allow games that could only use SoundBlaster sound to work with the card. finally, some programs simply had driver/middleware source code incorporated into the program itself for the sound cards that were supported.
- Microsoft Windows uses proprietary drivers generally written by the sound card manufacturers. Many device manufacturers supply the drivers on their own discs or to Microsoft for inclusion on Windows installation disc. Sometimes drivers are also supplied by the individual vendors for download and installation. Bug fixes and other improvements are likely to be available faster via downloading, since CDs cannot be updated as frequently as a web or FTP site. USB audio device class support is present from Windows 98 SE onwards.[2] Since Microsoft's Universal Audio Architecture (UAA) initiative which supports the HD Audio, FireWire and USB audio device class standards, a universal class driver by Microsoft can be used. The driver is included with Windows Vista. For Windows XP, Windows 2000 or Windows Server 2003, the driver can be obtained by contacting Microsoft support.[3] Almost all manufacturer-supplied drivers for such devices also include this class driver.

- A number of versions of UNIX make use of the portable Open Sound System (OSS). Drivers are seldom produced by the card manufacturer.
- Most present day Linux-based distributions make use of the Advanced Linux Sound Architecture (ALSA). Up until Linux kernel 2.4, OSS was the standard sound architecture for Linux, although ALSA can be downloaded, compiled and installed separately for kernels 2.2 or higher). But from kernel 2.5 onwards, ALSA was integrated into the kernel and the OSS native drivers were deprecated. Backwards compatibility with OSS-based software is maintained, however, by the use of the ALSA-OSS compatibility API and the OSS-emulation kernel modules.
- Mockingboard support on the Apple II is usually incorporated into the programs itself as many programs for the Apple II boot directly from disk.

See also

- Computer hardware
- OMAP (TI)
- EAX
- ASIO
- Sound chip
- Audio signal processing
- Guitar effects unit
- Sound effect
- Audio / Video connectors (template)
  - MIDI
  - Jack
  - Mini-RCA
  - S/PDIF
  - Game port
  - Mute button
- Audio Libraries (Categories)
- Codec
  - Virtual Studio Technology (VST)
  - Cross-platform Audio Creation Tool (XACT)
- DirectSound
- DirectMusic
- OpenAL
- Stereo
- Dolby Digital (EX, Surround EX)
- S Logic
- SNR
- Texture (music)
- Audio Compression
- AdLib
- C-Media
- Creative Labs (A3D)
- Realtek
- Sensaura
- Turtle Beach
- USB

- VIA Envy
- Video Games
- MIDI Manufacturers Association
- Japan MIDI Standards Committee
- texture (template)

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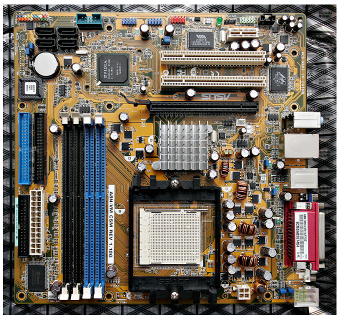
[1] http://www.datasheetarchive.com/pdf/3761230.pdf
[2] Microsoft USB FAQ (http://www.microsoft.com/whdc/system/bus/USB/USBFAQ_intro.mspx#E2DAC)
[3] Universal Audio Architecture (UAA) High Definition Audio class driver version 1.0a available (http://support.microsoft.com/kb/888111)

External links

- Jumper settings for Sound/Multimedia Card (http://th99.80x86.ru)
- A History of PC Sound Hardware (http://www.crossfire-designs.de/link/soundcards)
- Soundcards Museum (http://www.yvan256.net/soundcards/)
- How Stuff Works - Sound Cards (http://computer.howstuffworks.com/sound-card.htm)
- Sound card driver download category (http://www.driverindirin.com/kategori/ses-karti)

Motherboard


The ASUS A8N VM CSM

Connects to	Microprocessors via one of: • Sockets • Slots (on older motherboards) • Direct soldering (on dedicated and embedded system mainboards Main memory via one of: • Slots • Sockets for EXTERNEL chips (on old motherboards) • Direct soldering of individual chips (on special purpose motherboards) Peripherals via one of: • External ports • Internal cables Expansion cards via one of: • PCI Express bus • PCI bus • AGP bus • ISA bus (on older motherboards) • Others
Form factors	ATX microATX AT (on older motherboards) Baby AT (on older motherboards) Others
Common manufacturers	ASUS Gigabyte Technology Intel MSI Foxconn Others

A **motherboard** is the central printed circuit board (PCB) in many modern computers and holds many of the crucial components of the system, while providing connectors for other peripherals. The motherboard is sometimes alternatively known as the **main board**, **system board**, or, on Apple computers, the logic board.[1] It is also sometimes casually shortened to **mobo**.[2]

History

Prior to the advent of the microprocessor, a computer was usually built in a card-cage case or mainframe with components connected by a backplane consisting of a set of slots themselves connected with wires; in very old designs the wires were discrete connections between card connector pins, but printed circuit boards soon became the standard practice. The Central Processing Unit, memory and peripherals were housed on individual printed circuit boards which plugged into the backplane.

During the late 1980s and 1990s, it became economical to move an increasing number of peripheral functions onto the motherboard (see below). In the late 1980s, motherboards began to include single ICs (called Super I/O chips) capable of supporting a set of low-speed peripherals: keyboard, mouse, floppy disk drive, serial ports, and parallel ports. As of the late 1990s, many personal computer motherboards supported a full range of audio, video, storage, and networking functions without the need for any expansion cards at all; higher-end systems for 3D gaming and computer graphics typically retained only the graphics card as a separate component.

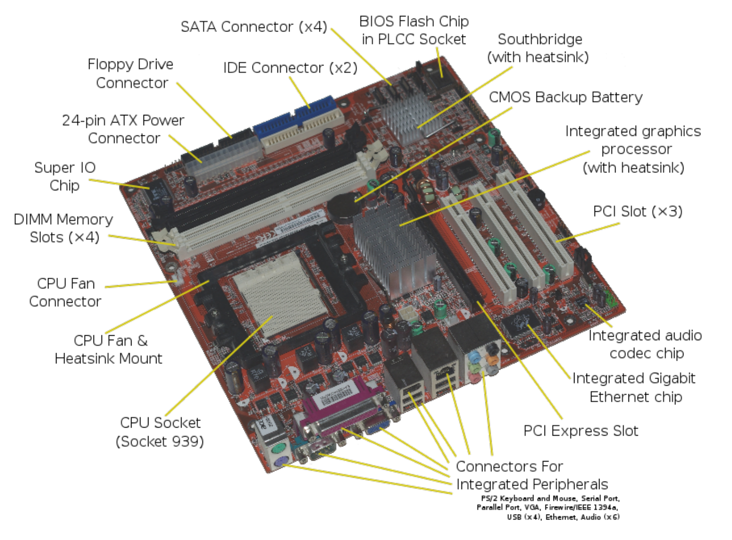
The early pioneers of motherboard manufacturing were Micronics, Mylex, AMI, DTK, Hauppauge, Orchid Technology, Elitegroup, DFI, and a number of Taiwan-based manufacturers.

The most popular computers such as the Apple II and IBM PC had published schematic diagrams and other documentation which permitted rapid reverse-engineering and third-party replacement motherboards. Usually intended for building new computers compatible with the exemplars, many motherboards offered additional performance or other features and were used to upgrade the manufacturer's original equipment.

The term mainboard is archaically applied to devices with a single board and no additional expansions or capability. In modern terms this would include embedded systems and controlling boards in televisions, washing machines, etc. A motherboard specifically refers to a printed circuit with the capability to add/extend its performance.

Overview

Most computer motherboards produced today are designed for IBM-compatible computers, which currently account for around 90% of global PC sales. A motherboard, like a backplane, provides the electrical connections by which the other components of the system communicate, but unlike a backplane, it also connects the central processing unit and hosts other subsystems and devices.



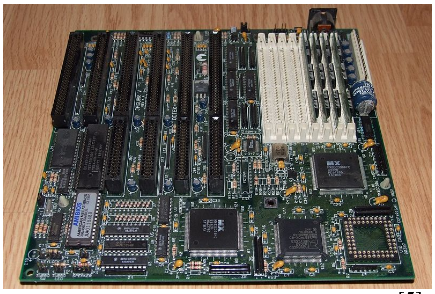
An Acer E360 motherboard made by Foxconn, from 2005, with a large number of integrated peripherals. This board's nForce3 chipset lacks a traditional northbridge.

A typical desktop computer has its microprocessor, main memory, and other essential components connected to the motherboard. Other components such as external storage, controllers for video display and sound, and peripheral devices may be attached to the motherboard as plug-in cards or via cables, although in modern computers it is increasingly common to integrate some of these peripherals into the motherboard itself.

An important component of a motherboard is the microprocessor's supporting chipset, which provides the supporting interfaces between the CPU and the various buses and external components. This chipset determines, to an extent, the features and capabilities of the motherboard.

Modern motherboards include, at a minimum:

- sockets (or slots) in which one or more microprocessors may be installed[3]
- slots into which the system's main memory is to be installed (typically in the form of DIMM modules containing DRAM chips)
- a chipset which forms an interface between the CPU's front-side bus, main memory, and peripheral buses
- non-volatile memory chips (usually Flash ROM in modern motherboards) containing the system's firmware or BIOS
- a clock generator which produces the system clock signal to synchronize the various components
- slots for expansion cards (these interface to the system via the buses supported by the chipset)
- power connectors, which receive electrical power from the computer power supply and distribute it to the CPU, chipset, main memory, and expansion cards.[4]



The Octek Jaguar V motherboard from 1993.[5] This board has 6 ISA slots but few onboard peripherals, as evidenced by the lack of external connectors.

Additionally, nearly all motherboards include logic and connectors to support commonly used input devices, such as PS/2 connectors for a mouse and keyboard. Early personal computers such as the Apple II or IBM PC included only this minimal peripheral support on the motherboard. Occasionally video interface hardware was also integrated into the motherboard; for example, on the Apple II and rarely on IBM-compatible computers such as the IBM PC Jr. Additional peripherals such as disk controllers and serial ports were provided as expansion cards.

Given the high thermal design power of high-speed computer CPUs and components, modern motherboards nearly always include heat sinks and mounting points for fans to dissipate excess heat.

CPU sockets

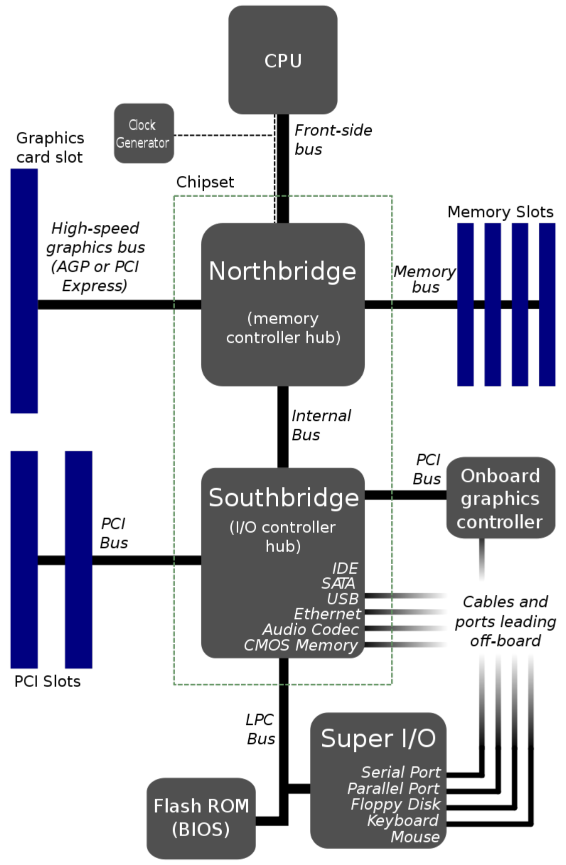
A CPU socket or slot is an electrical component that attaches to a printed circuit board (PCB) and is designed to house a CPU (also called a microprocessor). It is a special type of integrated circuit socket designed for very high pin counts. A CPU socket provides many functions, including a physical structure to support the CPU, support for a heat sink, facilitating replacement (as well as reducing cost), and most importantly, forming an electrical interface both with the CPU and the PCB. CPU sockets can most often be found in most desktop and server computers (laptops typically use surface mount CPUs), particularly those based on the Intel x86 architecture on the motherboard. A CPU socket type and motherboard chipset must support the CPU series and speed. Generally, with a newer AMD microprocessor, you need only select a motherboard that supports the CPU and not be concerned with the chipset.

Integrated peripherals

With the steadily declining costs and size of integrated circuits, it is now possible to include support for many peripherals on the motherboard. By combining many functions on one PCB, the physical size and total cost of the system may be reduced; highly integrated motherboards are thus especially popular in small form factor and budget computers.

For example, the ECS RS485M-M,[6] a typical modern budget motherboard for computers based on AMD processors, has on-board support for a very large range of peripherals:

- disk controllers for a floppy disk drive, up to 2 PATA drives, and up to 6 SATA drives (including RAID 0/1 support)
- integrated ATI Radeon graphics controller supporting 2D and 3D graphics, with VGA and TV output
- integrated sound card supporting 8-channel (7.1) audio and S/PDIF output
- Fast Ethernet network controller for 10/100 Mbit networking
- USB 2.0 controller supporting up to 12 USB ports
- IrDA controller for infrared data communication (e.g. with an IrDA-enabled cellular phone or printer)
- temperature, voltage, and fan-speed sensors that allow software to monitor the health of computer components



Block diagram of a modern motherboard, which supports many on-board peripheral functions as well as several expansion slots.

Expansion cards to support all of these functions would have cost hundreds of dollars even a decade ago; however, as of April 2007 such highly integrated motherboards are available for as little as $30 in the USA.

Peripheral card slots

A typical motherboard of 2009 will have a different number of connections depending on its standard.

A standard ATX motherboard will typically have one PCI-E 16x connection for a graphics card, two conventional PCI slots for various expansion cards, and one PCI-E 1x (which will eventually supersede PCI). A standard EATX motherboard will have one PCI-E 16x connection for a graphics card, and a varying number of PCI and PCI-E 1x slots. It can sometimes also have a PCI-E 4x slot. (This varies between brands and models.)

Some motherboards have two PCI-E 16x slots, to allow more than 2 monitors without special hardware, or use a special graphics technology called SLI (for Nvidia) and Crossfire (for ATI). These allow 2 graphics cards to be linked together, to allow better performance in intensive graphical computing tasks, such as gaming and video editing.

As of 2007, virtually all motherboards come with at least four USB ports on the rear, with at least 2 connections on the board internally for wiring additional front ports that may be built into the computer's case. Ethernet is also included. This is a standard networking cable for connecting the computer to a network or a modem. A sound chip is always included on the motherboard, to allow sound output without the need for any extra components. This allows computers to be far more multimedia-based than before. Some motherboards often have their graphics chip built into the motherboard rather than needing a separate card. A separate card may still be used.

Temperature and reliability

Motherboards are generally air cooled with heat sinks often mounted on larger chips, such as the Northbridge, in modern motherboards. If the motherboard is not cooled properly, it can cause the computer to crash. Passive cooling, or a single fan mounted on the power supply, was sufficient for many desktop computer CPUs until the late 1990s; since then, most have required CPU fans mounted on their heat sinks, due to rising clock speeds and power consumption. Most motherboards have connectors for additional case fans as well. Newer motherboards have integrated temperature sensors to detect motherboard and CPU temperatures, and controllable fan connectors which the BIOS or operating system can use to regulate fan speed. Some computers (which typically have high-performance microprocessors, large amounts of RAM, and high-performance video cards) use a water-cooling system instead of many fans.

Some small form factor computers and home theater PCs designed for quiet and energy-efficient operation boast fan-less designs. This typically requires the use of a low-power CPU, as well as careful layout of the motherboard and other components to allow for heat sink placement.

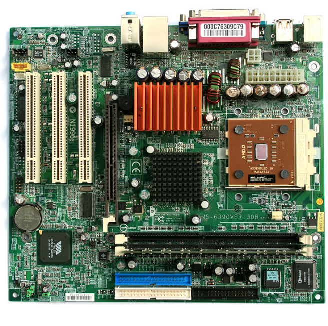
A 2003 study[7] found that some spurious computer crashes and general reliability issues, ranging from screen image distortions to I/O read/write errors, can be attributed not to software or peripheral hardware but to aging capacitors on PC motherboards. Ultimately this was shown to be the result of a faulty electrolyte formulation.[8]

For more information on premature capacitor failure on PC motherboards, see capacitor plague.

Motherboards use electrolytic capacitors to filter the DC power distributed around the board. These capacitors age at a temperature-dependent rate, as their water based electrolytes slowly evaporate. This can lead to loss of capacitance and subsequent motherboard malfunctions due to voltage instabilities. While most capacitors are rated for 2000 hours of operation at 105 °C,[9] their expected design life roughly doubles for every 10 °C below this. At 45 °C a lifetime of 15 years can be expected. This appears reasonable for a computer motherboard. However, many manufacturers have delivered substandard capacitors, which significantly reduce life expectancy. Inadequate case cooling and elevated temperatures easily exacerbate this problem. It is possible, but tedious and time-consuming, to find and replace failed capacitors on PC motherboards.

Form factor

Motherboards are produced in a variety of sizes and shapes called computer form factor, some of which are specific to individual computer manufacturers. However, the motherboards used in IBM-compatible commodity computers have been standardized to fit various case sizes. As of 2007, most desktop computer motherboards use one of these standard form factors—even those found in Macintosh and Sun computers, which have not traditionally been built from commodity components. The current desktop PC form factor of choice is ATX. A case's, motherboard and PSU form factor must all match, though some smaller form factor motherboards of the same family will fit larger cases. For example, an ATX case will usually accommodate a microATX motherboard.



microATX form factor motherboard

Laptop computers generally use highly integrated, miniaturized and customized motherboards. This is one of the reasons that laptop computers are difficult to upgrade and expensive to repair. Often the failure of one laptop component requires the replacement of the entire motherboard, which is usually more expensive than a desktop motherboard due to the large number of integrated components.

Bootstrapping using the BIOS

Motherboards contain some non-volatile memory to initialize the system and load an operating system from some external peripheral device. Microcomputers such as the Apple II and IBM PC used ROM chips, mounted in sockets on the motherboard. At power-up, the central processor would load its program counter with the address of the boot ROM and start executing ROM instructions, displaying system information on the screen and running memory checks, which would in turn start loading memory from an external or peripheral device (disk drive). If none is available, then the computer can perform tasks from other memory stores or display an error message, depending on the model and design of the computer and version of the BIOS.

Most modern motherboard designs use a BIOS, stored in an EEPROM chip soldered to the motherboard, to bootstrap the motherboard. (Socketed BIOS chips are widely used, also.) By booting the motherboard, the memory, circuitry, and peripherals are tested and configured. This process is known as a computer Power-On Self Test (POST) and may include testing some of the following devices:

- floppy drive
- network controller
- CD-ROM drive
- DVD-ROM drive
- SCSI hard drive
- IDE, EIDE, or SATA hard disk
- External USB memory storage device

Any of the above devices can be stored with machine code instructions to load an operating system or program.

See also

- Backplane
- Computer case
- BIOS
- Chipset
- Front-side bus
- List of motherboard manufacturers
- Offboard
- Conventional PCI
- PCI Express
- Accelerated Graphics Port (AGP)
- Central Processing Unit
- Industry Standard Architecture (ISA)
- Single-board computer
- Overclocking

External links

- List of motherboard manufacturers and links to BIOS updates [10]
- What is a motherboard? [11]
- The Making of a Motherboard: ECS Factory Tour [12]
- The Making of a Motherboard: Gigabyte Factory Tour [13]
- Motherboard reviews [14]
- Motherboards [15] at the Open Directory Project
- Motherboard forums [16]
- Jumper settings for motherboard [17]
- Front Panel I/O Connectivity Design Guide [18] - v1.3 (pdf file) (February 2005)
- Laptop Repair & Maintenance : How to Change a Laptop Video Card [19]

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[2] "mobo" (http://www.webopedia.com/TERM/M/mobo.html). Webopedia. . Retrieved 2008-10-23.
[3] In the case of CPUs in BGA packages, such as the VIA C3, the CPU is directly soldered to the motherboard.
[4] As of 2007, some graphics cards (e.g. GeForce 8 and Radeon R600) require more power than the motherboard can provide, and thus dedicated connectors (http://www.techpowerup.com/articles/overclocking/psu/116) have been introduced to attach them directly to the power supply. (Note that most disk drives also connect to the power supply via dedicated connectors.)
[5] "Golden Oldies: 1993 mainboards" (http://redhill.net.au/b/b-93.html). . Retrieved 2007-06-27.
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[7] *c't Magazine*, vol. 21, pp. 216-221. 2003.
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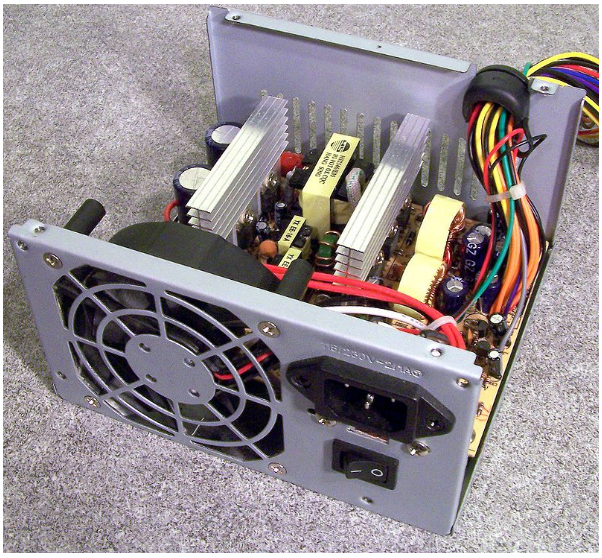
[9] See the capacitor lifetime formula at (http://www.low-esr.com/endurance.html-ssi).
[10] http://www.wimsbios.com/biosupdates.jsp
[11] http://www.pcreview.co.uk/articles/Hardware/What_is_a_Motherboard/
[12] http://www.hardcoreware.net/reviews/review-335-1.htm
[13] http://www.hardcoreware.net/reviews/review-217-1.htm
[14] http://www.hardcoreware.net/reviews.htm
[15] http://www.dmoz.org/Computers/Hardware/Components/Motherboards/
[16] http://www.motherboardpoint.com
[17] http://th99.80x86.ru
[18] http://www.formfactors.org/developer/specs/A2928604-005.pdf
[19] http://laptopcomputerrepair.bigvane.com/general/laptop-repair-maintenance-how-to-change-a-laptop-video-card.html

Power supply unit (computer)

This article is about the common off-line switching power supplies used in desktop IBM PC compatible computers. There are many other kinds of computers with differing power supplies.


The top cover has been removed to show the internals of a computer Power supply unit.

A **power supply unit** (**PSU**) is the component that supplies power to the other components in a computer. More specifically, a power supply unit is typically designed to convert general-purpose alternating current (AC) electric power from the mains (100-127V in North America, parts of South America, Japan, and Taiwan; 220-240V in most of the rest of the world) to usable low-voltage DC power for the internal components of the computer. Some power supplies have a switch to change between 230 V and 115 V. Other models have automatic sensors that switch input voltage automatically, or are able to accept any voltage between those limits.

The most common computer power supplies are built to conform to the ATX form factor. This enables different power supplies to be interchangeable with different components inside the computer. ATX power supplies also are designed to turn on and off using a signal from the motherboard, and provide support for modern functions such as the standby mode available in many computers. The most recent specification of the ATX standard PSU as of mid-2008 is version 2.31.

Power rating

Computer power supplies are rated based on their maximum output power. Typical power ranges are from 500 W to lower than 300 W for small form factor systems intended as ordinary home computers, the use of which is limited to Internet-surfing and burning and playing DVDs. Power supplies used by gamers and enthusiasts mostly range from 450 W to 1400 W. Typical gaming PCs feature power supplies in the range of 500-800 W, with higher-end PCs demanding 800-1400 W supplies. The highest-end units are up to 2 kW strong and are intended mainly for servers and, to a lesser degree, extreme performance computers with multiple processors, several hard disks and multiple graphics cards. The power rating of a PC power supply is not officially certified and is self-claimed by each manufacturer. A common way to reach the power figure for PC PSUs is by adding the power available on each rail, which will not give a true power figure. Therefore it is possible to overload a PSU on one rail without having to use the maximum rated power.

Sometimes manufacturers inflate their power ratings, in order to gain an advantage in the market. This can be done due to a lack of clear standards regarding power supply labeling and testing.

- Advertising the peak power, rather than the continuous power;
- Determining the continuous output power capability at unrealistically low temperatures (at room temperature as opposed to 40°C, a more likely temperature inside a PC case);
- Advertising total power as a measure of capacity, when modern systems are almost totally reliant on the current available from the 12 volt line(s).

This may mean that if:

- PSU A has a **peak** rating of **550 watts at 25°C**, with **25 amps** (300 W) **on** the **12 volt** line, and
- PSU B has a **continuous** rating of **450 watts at 40°C**, **with 33 amps** (400 W) **on** the **12 volt** line,

and those ratings are accurate, then PSU B would have to be considered a vastly superior unit, despite its lower overall power rating. PSU A may only be capable of delivering a fraction of its rated power under real world conditions.

This tendency has led in turn to greatly overspecified power supply recommendations, and a shortage of high-quality power supplies with reasonable capacities. Very few computers require more than 300–350 watts maximum.[1] Higher end computers such as servers and gaming machines with multiple high power GPUs are among the few exceptions. Although, in recent years the power demand of "video cards" in the ability to watch high definition (HD) media has led to even the average ATX computer to consume between 400 and 500 watts. It may be expected to increase again as the media transitions to 3D.

Appearance

Most computer power supplies are a square metal box, and have a large bundle of wires emerging from one end. Opposite the wire bundle is the back face of the power supply, with an air vent and C14 IEC connector to supply AC power. There may optionally be a power switch and/or a voltage selector switch. A label on one side of the box lists technical information about the power supply, including safety certifications maximum output power. Common certification marks for safety are the UL mark, GS mark, TÜV, NEMKO, SEMKO, DEMKO, FIMKO, CCC, CSA, VDE, GOST R and BSMI. Common certificate marks for EMI/RFI are the CE mark, FCC and C-tick. The CE mark is required for power supplies sold in Europe and India.

A RoHS or 80 PLUS can also sometimes be seen.

Dimensions of an ATX power supply are 150 mm width, 86 mm height, and typically 140 mm depth, although the depth can vary from brand to brand.

Connectors

Typically, power supplies have the following connectors:

Various connectors from a computer PSU.

- **PC Main** power connector (usually called **P1**): Is the connector that goes to the motherboard to provide it with power. The connector has 20 or 24 pins. One of the pins belongs to the PS-ON wire (it is usually green). This connector is the largest of all the connectors. In older AT power supplies, this connector was split in two: **P8** and **P9**. A power supply with a 24-pin connector can be used on a motherboard with a 20-pin connector. In cases where the motherboard has a 24-pin connector, some power supplies come with two connectors (one with 20-pin and other with 4-pin) which can be used together to form the 24-pin connector.
- **ATX12V** 4-pin power connector (also called the **P4 power connector**). A second connector that goes to the motherboard (in addition to the main 24-pin connector) to supply dedicated power for the processor. For high-end motherboards and processors, more power is required, therefore EPS12V has an 8 pin connector.
- **4-pin Peripheral** power connectors (usually called **Molex** for its manufacturer): These are the other, smaller connectors that go to the various disk drives of the computer. Most of them have four wires: two black, one red, and one yellow. Unlike the standard mains electrical wire color-coding, each *black wire* is a ground, the *red wire* is +5 V, and the *yellow wire* is +12 V. In some cases these are also used to provide additional power to PCI cards such as FireWire 800 cards.
- **4-pin Berg** power connectors (usually called **Mini-connector** or "mini-Molex"): This is one of the smallest connectors that supplies the floppy drive with power. In some cases, it can be used as an auxiliary connector for

AGP video cards. Its cable configuration is similar to the Peripheral connector.

- **Auxiliary** power connectors: There are several types of auxiliary connectors designed to provide additional power if it is needed.
- **Serial ATA** power connectors: a 15-pin connector for components which use SATA power plugs. This connector supplies power at three different voltages: +3.3, +5, and +12 volts.
- **6-pin** Most modern computer power supplies include 6-pin connectors which are generally used for PCI Express graphics cards, but a newly introduced 8-pin connector should be seen on the latest model power supplies. Each PCI Express 6-pin connector can output a maximum of 75 W.
- **6+2 pin** For the purpose of backwards compatibility, some connectors designed for use with PCI Express graphics cards feature this kind of pin configuration. It allows either a 6-pin card or an 8-pin card to be connected by using two separate connection modules wired into the same sheath: one with 6 pins and another with 2 pins.
- A **C14 IEC connector** with an appropriate C13 cord is used to attach the power supply to the local power grid.

AT vs. ATX

There are two basic differences between AT and ATX power supplies: The connectors that provide power to the motherboard, and the soft switch. On older AT power supplies, the Power-on switch wire from the front of the computer is connected directly to the power supply.

A typical installation of an ATX form factor computer power supply.

On newer ATX power supplies, the power switch on the front of the computer goes to the motherboard over a connector labeled something like; PS ON, Power SW, SW Power, etc. This allows other hardware and/or software to turn the system on and off.

The motherboard controls the power supply through pin #14 of the 20 pin connector or #16 of the 24 pin connector on the motherboard. This pin carries 5V when the power supply is in standby. It can be grounded to turn the power supply on without having to turn on the rest of the components. This is useful for testing or to use the computer ATX power supply for other purposes.

AT stands for **A**dvanced **T**echnology when ATX means **A**dvanced **T**echnology e**X**tended.

Laptops

Most portable computers have power supplies that provide 25 to 100 watts. In portable computers (such as laptops) there is usually an external power supply (sometimes referred to as a "power brick" due to its similarity, in size, shape and weight, to a real brick) which converts AC power to one DC voltage (most commonly 19 V), and further DC-DC conversion occurs within the laptop to supply the various DC voltages required by the other components of the portable computer.

Servers

Some web servers use a single-voltage 12 volt power supply. All other voltages are generated by voltage regulator modules on the motherboard.[2]

Energy efficiency

Computer power supplies are generally about 70–75% efficient.[3] That means in order for a 75% efficient power supply to produce 75 W of DC output it would require 100 W of AC input and dissipate the remaining 25 W in heat. Higher-quality power supplies can be over 80% efficient; higher energy efficient PSU's waste less energy in heat, and requires less airflow to cool, and as a result will be quieter. Google's server power supplies are more than 90% efficient.[2] HP's server power supplies have reached 94% efficiency.[4] Standard PSUs sold for server workstations have around 90% efficiency, as of 2010.

It's important to match the capacity of a power supply to the power needs of the computer. The energy efficiency of power supplies drops significantly at low loads. Efficiency generally peaks at about 50-75% load. The curve varies from model to model (examples of how this curve looks can be seen on test reports of energy efficient models found on the 80 PLUS website [5]). As a rule of thumb for standard power supplies it is usually appropriate to buy a supply such that the calculated typical consumption of one's computer is about 60% of the rated capacity of the supply provided that the calculated maximum consumption of the computer does not exceed the rated capacity of the supply. Note that advice on overall power supply ratings often given by the manufacturer of single component, typically graphics cards, should be treated with great skepticism. These manufacturers wish to minimise support issues due to under rating the power supply and are willing to advise customers to overrate it to avoid this.

Various initiatives are underway to improve the efficiency of computer power supplies. Climate savers computing initiative promotes energy saving and reduction of greenhouse gas emissions by encouraging development and use of more efficient power supplies. 80 PLUS certifies power supplies that meet certain efficiency criteria, and encourages their use via financial incentives. On top of that the businesses end up using less electricity to cool the PSU and the computer's themselves and thus save an initially large sum(i.e. incentive + saved electricity = higher profit).

Small facts to consider


Redundant power supply.

- Life span is usually measured in mean time between failures (MTBF). Higher MTBF ratings are preferable for longer device life and reliability. Quality construction consisting of industrial grade electrical components and/or a larger or higher speed fan can help to contribute to a higher MTBF rating by keeping critical components cool, thus preventing the unit from overheating. Overheating is a major cause of PSU failure. MTBF value of 100,000 hours is not uncommon.
- Power supplies may have passive or active power factor correction (PFC). Passive PFC is a simple way of increasing the power factor by putting a coil in series with the primary filter capacitors. Active PFC is more complex and can achieve higher PF, up to 99%.
- In computer power supplies that have more than one +12V power rail, it is preferable for stability reasons to spread the power load over the 12V rails evenly to help avoid overloading one of the rails on the power supply.
    - Multiple 12V power supply rails are separately current limited as a safety feature; they are not generated separately. Despite widespread belief to the contrary, this separation has no effect on mutual interference between supply rails.
    - The ATX12V 2.x and EPS12V power supply standards defer to the IEC 60950 standard, which requires that no more than 240 volt-amps be present between any two accessible points. Thus, each wire must be current-limited to no more than 20 A; typical supplies guarantee 18 A without triggering the current limit. Power supplies capable of delivering more than 18 A at 12 V connect wires in groups to two or more current sensors which will shut down the supply if excess current flows. Unlike a fuse or circuit breaker, these limits reset as soon as the overload is removed.
    - Because of the above standards, almost all high-power supplies claim to implement separate rails, however this claim is often false; many omit the necessary current-limit circuitry,[6] both for cost reasons and because it is an irritation to customers.[1] (The lack is sometimes advertised as a feature under names like "rail fusion" or "current sharing".)
- When the computer is powered down but the power supply is still on, it can be started remotely via Wake-on-LAN and Wake-on-Ring or locally via Keyboard Power ON (KBPO) if the motherboard supports it.
- Early PSUs used a conventional (heavy) step-down transformer, but most modern computer power supplies are a type of switched-mode power supply (SMPS) with a ferrite-cored High Frequency transformer.
- Computer power supplies may have short circuit protection, overpower (overload) protection, overvoltage protection, undervoltage protection, overcurrent protection, and over temperature protection.
- Some power supplies come with sleeved cables, which is aesthetically nicer, makes wiring easier and cleaner and have less detrimental effect on airflow.
- There is a popular misconception that a greater power capacity (watt output capacity) is always better. Since supplies are self-certified, a manufacturer's claims may be double or more what is actually provided.[7] [8] Although a too-large power supply will have an extra margin of safety as far as not over-loading, a larger unit is often less efficient at lower loads (under 20% of its total capability) and therefore will waste more electricity than a more appropriately sized unit. Additionally, computer power supplies generally do not function properly if they are too lightly loaded. Under no-load conditions they may shut down or malfunction.

- Another popular misconception is that the greater the total watt capacity is, the more suitable the power supply becomes for higher-end graphics cards. The most important factor for judging a PSUs suitability for certain graphics cards is the PSUs total 12V output, as it is that voltage on which modern graphics cards operate. If the total 12V output stated on the PSU is higher than the suggested minimum of the card, then that PSU can fully supply the card. It is however recommended that a PSU should not just cover the graphics cards' demands, as there are other components in the PC that depend on the 12V output, including the CPU and disk drives.
- Power supplies can feature magnetic amplifiers or double-forward converter circuit design.

Wiring diagrams

AT power connector (Used on older AT style mainboards)

Color	Pin	Signal
	P8.1	Power Good
	P8.2	+5 V
	P8.3	+12 V
	P8.4	−12 V
	P8.5	Ground
	P8.6	Ground
	P9.1	Ground
	P9.2	Ground
	P9.3	−5 V
	P9.4	+5 V
	P9.5	+5 V
	P9.6	+5 V

24-pin ATX12V 2.x power supply connector (20-pin omits the last four: 11, 12, 23 and 24)

Color	Signal	Pin	Pin	Signal	Color
Orange	+3.3 V	1	13	+3.3 V	Orange
				+3.3 V sense	Brown
Orange	+3.3 V	2	14	−12 V	Blue
Black	Ground	3	15	Ground	Black
Red	+5 V	4	16	Power on	Green
Black	Ground	5	17	Ground	Black
Red	+5 V	6	18	Ground	Black
Black	Ground	7	19	Ground	Black
Grey	Power good	8	20	No connection	
Purple	+5 V standby	9	21	+5 V	Red
Yellow	+12 V	10	22	+5 V	Red
Yellow	+12 V	11	23	+5 V	Red

Orange	+3.3 V	12	24	Ground	Black
The three shaded pins (8, 13, and 16) are control signals, not power. "Power On" is pulled up to +5V by the PSU, and must be driven low to turn on the PSU. "Power good" is low when other outputs have not yet reached, or are about to leave, correct voltages. The "+3.3 V sense" line is for remote sensing.[9]					
Pin 20 used to provide −5VDC (white wire) in ATX and ATX12V versions up to 1.2. It is optional in version 1.2, and missing in ver. 1.3 and up.					
The right-hand pins are numbered 11 through 20 in the 20-pin version.					

Modular power supplies

A **modular power supply** is a relatively new approach to cabling, allowing users to omit unused cables. Whereas a conventional design has numerous cables permanently connected to the power supply, a modular power supply provides connectors at the power supply end, allowing unused cables to be detached from the power supply, producing less clutter, a neater appearance and less interference with airflow. It also makes it possible to supply a wider variety of cables, providing different lengths of Serial ATA power connectors instead of Molex connectors.

While modular cabling can help reduce case clutter, they have often been criticized for creating electrical resistance. Some third party websites that do power supply testing have confirmed that the quality of the connector, the age of the connector, the number of times it was inserted/removed, and various other variables such as dust can all raise resistance. However, this is somewhat inconsequential as the amount of this resistance in a good connector is small compared to the resistance generated by the length of the wire itself.[10]

See also

- Green computing
- Power management
- Power supply
- List of manufacturers
- Quiet PC
- Active Power Factor Correction (Active PFC)

External links

- How PC Power Supplies Work [11]
- Website with Information & Research on Active Mode Power Supply Efficiency [12]
- How to Buy an Energy-Efficient Power Supply [13]
- Computer Power Supply - Schematics, Reviews, Repair Guides [14]
- PC Repair and Maintenance: In-depth Look at Power Supply [15]
- ATX12V Power Supply Design Guide v2.2 [16]
- Power Supply Design Guide for Desktop Platform Form Factors Revision 1.1 [17]
- How to Discover Your Power Supply Real Manufacturer [18]
- Dell non-standard Power Supplies [19]
- How Much Power Can a Generic 500 W Power Supply Really Deliver? [20]
- Everything You Need To Know About Power Supplies [21]
- Troubleshooting an HP Power Supply [22]
- PC Power Supply Connections and Pinouts [23]
- What is power supply for computers? [24]

Computer Power Supply Calculators

- eXtreme Power Supply Calculator [25] (frequently updated)
- Snoop Power Supply Calculator [26]
- Computer Power Supply Calculator [27] (outdated)
- JOURNEYSYSTEMS' online power supply calculator [28] (outdated)

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[3] Strong Showing: High-Performance Power Supply Units | Tom's Hardware (http://www.tomshardware.com/2005/02/28/strong_showing/page38.html)

[4] http://www.80plus.org/documents/80PLUS_PLC-DSC.pdf

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[13] http://www.efficientpowersupplies.org/pages/PC_Energy_Star_Recommendation.pdf

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[15] http://www.informit.com/articles/article.aspx?p=31105

[16] http://www.formfactors.org/developer/specs/ATX12V_PSDG_2_2_public_br2.pdf

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[18] http://www.hardwaresecrets.com/article/370

[19] http://www.informit.com/articles/article.aspx?p=339053

[20] http://www.hardwaresecrets.com/article/534

[21] http://www.hardwaresecrets.com/article/181

[22] http://www.pctechbytes.com/hp-power-supply.htm

[23] http://www.smpspowersupply.com/connectors-pinouts.html

[24] https://www.nipron.co.jp/english/product_info/encyclopedia/2_1.htm

[25] http://extreme.outervision.com/psucalculator.jsp

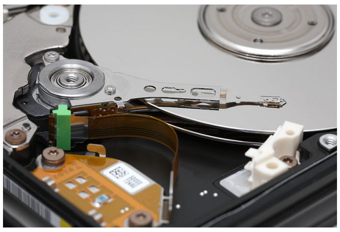
[26] http://web.aanet.com.au/SnooP/psucalc.php

[27] http://www.vbutils.com/power.asp

[28] http://www.journeysystems.com/?powercalc

Hard disk drive

Enterprise disk drive redirects here.



Interior of a hard disk drive

Date invented	December 14, 1954[1]
Invented by	An IBM team led by Rey Johnson
Connects to	Host adapter of system, in PCs typically integrated into motherboard. via one of: • PATA (IDE) interface • SATA interface • SAS interface • SCSI interface (popular on servers) • FC interface (almost exclusively found on servers) • USB interface
Market Segments	Desktop computers Mobile computing Enterprise computing Consumer electronic

A **hard disk drive**[2] (*hard disk*,[3] *hard drive*,[4] HDD) is a non-volatile storage device for digital data. It features one or more rotating rigid platters on a motor-driven spindle within a metal case. Data is encoded magnetically by read/write heads that float on a cushion of air above the platters, with modern storage capacity measured in gigabytes and terabytes.

Hard disk manufacturers quote disk capacity in SI-standard powers of 1000, wherein a terabyte is 1000 gigabytes and a gigabyte is 1000 megabytes. With file systems that measure capacity in powers of 1024, available space appears somewhat less than advertised capacity.

The first HDD was invented by IBM in 1956. They have fallen in size and cost over the years, displacing floppy disks in the late 1980s as the preferred long-term storage mechanism for personal computers. Most desktop systems today have standardized on the 3.5" form factor, and though mobile systems most often use 2.5" drives, both sizes operate on similar high-speed serial interfaces.

History

HDDs (introduced in 1956 as data storage for an IBM accounting computer)[5] were originally developed for use with general purpose computers. During the 1990s, the need for large-scale, reliable storage, independent of a particular device, led to the introduction of embedded systems such as RAIDs, network attached storage (NAS) systems, and storage area network (SAN) systems that provide efficient and reliable access to large volumes of data. In the 21st century, HDD usage expanded into consumer applications such as camcorders, cellphones (*e.g.* the Nokia N91), digital audio players, digital video players, digital video recorders, personal digital assistants and video game consoles.

Technology

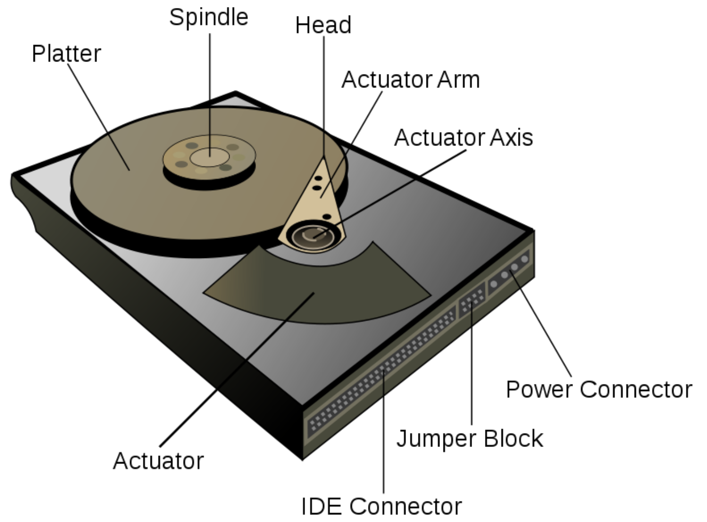
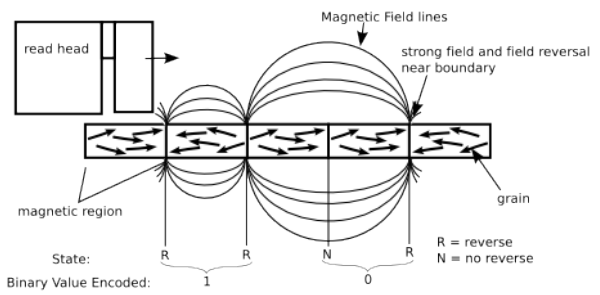


Diagram of a computer hard disk drive

HDDs record data by magnetizing ferromagnetic material directionally, to represent either a 0 or a 1 binary digit. They read the data back by detecting the magnetization of the material. A typical HDD design consists of a spindle that holds one or more flat circular disks called platters, onto which the data are recorded. The platters are made from a non-magnetic material, usually aluminum alloy or glass, and are coated with a thin layer of magnetic material, typically 10–20 nm in thickness — for reference, standard copy paper is 0.07–0.18 millimetre (70000–180000 nm) thick[6] — with an outer layer of carbon for protection. Older disks used iron(III) oxide as the magnetic material, but current disks use a cobalt-based alloy.[7]



A cross section of the magnetic surface in action. In this case the binary data are encoded using frequency modulation.

The platters are spun at very high speeds. Information is written to a platter as it rotates past devices called read-and-write heads that operate very close (tens of nanometers in new drives) over the magnetic surface. The read-and-write head is used to detect and modify the magnetization of the material immediately under it. There is one head for each magnetic platter surface on the spindle, mounted on a common arm. An actuator arm (or access arm) moves the heads on an arc (roughly radially) across the platters as they spin, allowing each head to access almost the entire surface of the platter as it spins. The arm is moved using a voice coil actuator or in some older designs a stepper motor.

The magnetic surface of each platter is conceptually divided into many small sub-micrometre-sized magnetic regions, each of which is used to encode a single binary unit of information. Initially the regions were oriented horizontally, but beginning about 2005, the orientation was changed to perpendicular. Due to the polycrystalline nature of the magnetic material each of these magnetic regions is composed of a few hundred magnetic grains. Magnetic grains are typically 10 nm in size and each form a single magnetic domain. Each magnetic region in total forms a magnetic dipole which generates a highly localized magnetic field nearby. A write head magnetizes a region by generating a strong local magnetic field. Early HDDs used an electromagnet both to magnetize the region and to then read its magnetic field by using electromagnetic induction. Later versions of inductive heads included metal in Gap (MIG) heads and thin film heads. As data density increased, read heads using magnetoresistance (MR) came into use; the electrical resistance of the head changed according to the strength of the magnetism from the platter. Later development made use of spintronics; in these heads, the magnetoresistive effect was much greater than in earlier types, and was dubbed "giant" magnetoresistance (GMR). In today's heads, the read and write elements are separate, but in close proximity, on the head portion of an actuator arm. The read element is typically magneto-resistive while the write element is typically thin-film inductive.[8]

HD heads are kept from contacting the platter surface by the air that is extremely close to the platter; that air moves at, or close to, the platter speed. The record and playback head are mounted on a block called a slider, and the surface next to the platter is shaped to keep it just barely out of contact. It's a type of air bearing.

In modern drives, the small size of the magnetic regions creates the danger that their magnetic state might be lost because of thermal effects. To counter this, the platters are coated with two parallel magnetic layers, separated by a 3-atom-thick layer of the non-magnetic element ruthenium, and the two layers are magnetized in opposite orientation, thus reinforcing each other.[9] Another technology used to overcome thermal effects to allow greater recording densities is perpendicular recording, first shipped in 2005,[10] and as of 2007 the technology was used in many HDDs.[11] [12] [13]

Grain boundaries are very important to HDD design. The grains are very small and close to each other, so the coupling between adjacent grains is very strong. When one grain is magnetized, the adjacent grains tend to be aligned parallel to it or demagnetized. Then both the stability of the data and signal-to-noise ratio will be sabotaged. A clear grain boundary can weaken the coupling of the grains and subsequently increase the signal-to-noise ratio. In longitudinal recording, the single-domain grains have uniaxial anisotropy with easy axes lying in the film plane. The consequence of this arrangement is that adjacent magnets repel each other. Therefore the magnetostatic energy is so large that it is difficult to increase areal density. Perpendicular recording media, on the other hand, has the easy axis of the grains oriented perpendicular to the disk plane. Adjacent magnets attract to each other and magnetostatic energy is much lower. So, much higher areal density can be achieved in perpendicular recording. Another unique feature in perpendicular recording is that a soft magnetic underlayer is incorporated into the recording disk. This underlayer is used to conduct writing magnetic flux so that the writing is more efficient. This will be discussed in writing process. Therefore, a higher anisotropy medium film, such as L10-FePt and rare-earth magnets, can be used.

Error handling

Modern drives also make extensive use of Error Correcting Codes (ECCs), particularly Reed–Solomon error correction. These techniques store extra bits for each block of data that are determined by mathematical formulae. The extra bits allow many errors to be fixed. While these extra bits take up space on the hard drive, they allow higher recording densities to be employed, resulting in much larger storage capacity for user data.[14] In 2009, in the newest drives, low-density parity-check codes (LDPC) are supplanting Reed-Solomon. LDPC codes enable performance close to the Shannon Limit and thus allow for the highest storage density available.[15]

Typical hard drives attempt to "remap" the data in a physical sector that is going bad to a spare physical sector—hopefully while the number of errors in that bad sector is still small enough that the ECC can completely recover the data without loss. The S.M.A.R.T. system counts the total number of errors in the entire hard drive fixed by ECC, and the total number of remappings, in an attempt to predict hard drive failure.

Architecture

A hard disk drive with the platters and motor hub removed showing the copper colored stator coils surrounding a bearing at the center of the spindle motor. The orange stripe along the side of the arm is a thin printed-circuit cable. The spindle bearing is in the center.

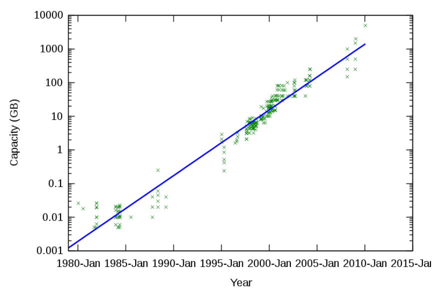
A typical hard drive has two electric motors, one to spin the disks and one to position the read/write head assembly. The disk motor has an external rotor attached to the platters; the stator windings are fixed in place. The actuator has a read-write head under the tip of its very end (near center); a thin printed-circuit cable connects the read-write head to the hub of the actuator. A flexible, somewhat 'U'-shaped, ribbon cable, seen edge-on below and to the left of the actuator arm in the first image and more clearly in the second, continues the connection from the head to the controller board on the opposite side.

The head support arm is very light, but also rigid; in modern drives, acceleration at the head reaches 550 *G*s.

The silver-colored structure at the upper left of the first image is the top plate of the permanent-magnet and moving coil motor that swings the heads to the desired position (it is shown removed in the second image). The plate supports a thin neodymium-iron-boron (NIB) high-flux magnet. Beneath this plate is the moving coil, often referred to as the *voice coil* by analogy to the coil in loudspeakers, which is attached to the actuator hub, and beneath that is a second NIB magnet, mounted on the bottom plate of the motor (some drives only have one magnet).

The voice coil itself is shaped rather like an arrowhead, and made of doubly coated copper magnet wire. The inner layer is insulation, and the outer is thermoplastic, which bonds the coil together after it's wound on a form, making it self-supporting. The portions of the coil along the two sides of the arrowhead (which point to the actuator bearing center) interact with the magnetic field, developing a tangential force that rotates the actuator. Current flowing radially outward along one side of the arrowhead and radially inward on the other produces the tangential force. If the magnetic field were uniform, each side would generate opposing forces that would cancel each other out. Therefore the surface of the magnet is half N pole, half S pole, with the radial dividing line in the middle, causing the two sides of the coil to see opposite magnetic fields and produce forces that add instead of canceling. Currents along the top and bottom of the coil produce radial forces that do not rotate the head.

Market Segmentation, Capacity and access speed



PC hard disk drive capacity (in GB) over time. The vertical axis is logarithmic, so the fit line corresponds to exponential growth.

Using rigid disks and sealing the unit allows much tighter tolerances than in a floppy disk drive. Consequently, hard disk drives can store much more data than floppy disk drives and can access and transmit them faster.

- As of May 2010, the highest capacity consumer HDDs are 2 TB.[16]
- **"Desktop HDDs"** typically store between 120 GB and 3TB (although rarely above 2.5 TB of data based on US market data[17]) and rotate at 5,400 to 10,000 rpm, and have a media transfer rate of 0.5 Gbit/s or higher. (1 GB = 10^9 Byte; 1 Gbit/s = 10^9 bit/s)
- **Enterprise HDDs** are typically used with multiple-user computers running enterprise software. Examples are:
  - transaction processing databases
  - internet infrastructure (email, webserver, e-commerce)
  - scientific computing software
  - nearline storage management software

The fastest enterprise HDDs spin at 10,000 or 15,000 rpm, and can achieve sequential media transfer speeds above 1.6 Gbit/s.[18] and a sustained transfer rate up to 1 Gbit/s.[18] Drives running at 10,000 or 15,000 rpm use smaller platters to mitigate increased power requirements (as they have less air drag) and therefore generally have lower capacity than the highest capacity desktop drives.

Enterprise drives commonly operate continuously ("24/7") in demanding environments while delivering the highest possible performance without sacrificing reliability. Maximum capacity is not the primary goal, and as a result the drives are often offered in capacities that are relatively low in relation to their cost[19] .

- **Mobile HDDs**, *i.e.*, laptop HDDs, which are physically smaller than their desktop and enterprise counterparts, tend to be slower and have lower capacity. A typical mobile HDD spins at either 4200 rpm, 5400 rpm, or 7200 rpm, with 5400 rpm being the most prominent. 7200 rpm drives tend to be more expensive and have smaller capacities, while 4200 rpm models usually have very high storage capacities. Because of physically smaller platter(s), mobile HDDs generally have lower capacity than their larger desktop counterparts.

The exponential increases in disk space and data access speeds of HDDs have enabled the commercial viability of consumer products that require large storage capacities, such as digital video recorders and digital audio players.[20] In addition, the availability of vast amounts of cheap storage has made viable a variety of web-based services with extraordinary capacity requirements, such as free-of-charge web search, web archiving and video sharing (Google, Internet Archive, YouTube, etc.).

The main way to decrease access time is to increase rotational speed, thus reducing rotational delay, while the main way to increase throughput and storage capacity is to increase areal density. Based on historic trends, analysts predict a future growth in HDD bit density (and therefore capacity) of about 40% per year.[21] Access times have not kept up with throughput increases, which themselves have not kept up with growth in storage capacity.

The expected random IOPS capability of any HDD can be calculated by dividing 1000 msecs by the sum of the average seek time and the average rotational latency.

The first 3.5″ HDD marketed as able to store 1 TB was the Hitachi Deskstar 7K1000. It contains five platters at approximately 200 GB each, providing 1 TB (935.5 GB) of usable space;[22] note the difference between its capacity in decimal units (1 TB = 10^{12} bytes) and binary units where 1 TB = 1024 GB = 2^{40} bytes. Hitachi has since been joined by Samsung (Samsung SpinPoint F1, which has 3 × 334 GB platters), Seagate and Western Digital in the 1 TB drive market.[23] [24]

In September 2009, Showa Denko announced capacity improvements in platters that they manufacture for HDD makers. A single 2.5" platter is able to hold 334 GB worth of data, and preliminary results for 3.5" indicate a 750 GB per platter capacity.[25]

Capacity measurements

Raw unformatted capacity of a hard disk drive is usually quoted with SI prefixes (metric system prefixes), incrementing by powers of 1000; today that usually means gigabytes (GB) and terabytes (TB). This is conventional for data speeds and memory sizes which are not inherently manufactured in power of two sizes, as RAM and Flash memory are. Hard disks by contrast have no inherent binary size as capacity is determined by number of heads, tracks and sectors.

This can cause some confusion because some operating systems may report the formatted capacity of a hard drive using binary prefix units which increment by powers of 1024.

A disassembled and labeled 1997 hard drive. All major components were placed on a mirror, which created the symmetrical reflections.

A one terabyte (1 TB) disk drive would be expected to hold around 1 trillion bytes (1,000,000,000,000) or 1000 GB; and indeed most 1 TB hard drives will contain slightly more than this number. However some operating system utilities would report this as around 931 GB or 953,674 MB. (The actual number for a formatted capacity will be somewhat smaller still, depending on the file system). Following are the several ways of reporting one Terabyte.

SI prefixes (hard drive)	equivalent	Binary prefixes (OS)	equivalent
1 TB (Terabyte)	$1 * 1000^4$ B	0.9095 TB (Terabyte)	$0.9095 * 1024^4$ B
1000 GB (Gigabyte)	$1000 * 1000^3$ B	931.3 GB (Gigabyte)	$931.3 * 1024^3$ B
1,000,000 MB (Megabyte)	$1,000,000 * 1000^2$ B	953,674.3 MB (Megabyte)	$953,674.3 * 1024^2$ B
1,000,000,000 KB (Kilobyte)	1,000,000,000 * 1000 B	976,562,500 KB (Kilobyte)	976,562,500 * 1024 B
1,000,000,000,000 B (byte)	-	1,000,000,000,000 B (byte)	-

Microsoft Windows reports disk capacity both in a decimal integer to 12 or more digits and in binary prefix units to three significant digits.

The capacity of an HDD can be calculated by multiplying the number of cylinders by the number of heads by the number of sectors by the number of bytes/sector (most commonly 512). Drives with the ATA interface and a capacity of eight gigabytes or more behave as if they were structured into 16383 cylinders, 16 heads, and 63 sectors, for compatibility with older operating systems. Unlike in the 1980s, the cylinder, head, sector (C/H/S) counts reported to the CPU by a modern ATA drive are no longer actual physical parameters since the reported numbers are constrained by historic operating-system interfaces and with zone bit recording the actual number of sectors varies by zone. Disks with SCSI interface address each sector with a unique integer number; the operating system remains ignorant of their head or cylinder count.

The old C/H/S scheme has been replaced by logical block addressing. In some cases, to try to "force-fit" the C/H/S scheme to large-capacity drives, the number of heads was given as 64, although no modern drive has anywhere near 32 platters.

For a formatted drive, the operating system's file system internal usage is another, although minor, reason why a computer hard drive or storage device's capacity may show its capacity as different from its theoretical capacity. This would include storage for, as examples, a file allocation table (FAT) or inodes, as well as other operating system data structures. This file system overhead is usually less than 1% on drives larger than 100 MB. For RAID drives, data integrity and fault-tolerance requirements also reduce the realized capacity. For example, a RAID1 drive will be about half the total capacity as a result of data mirroring. For RAID5 drives with x drives you would lose 1/x of your space to parity. RAID drives are multiple drives that appear to be one drive to the user, but provides some fault-tolerance.

A general rule of thumb to quickly convert the manufacturer's hard disk capacity to the standard Microsoft Windows formatted capacity is 0.93*capacity of HDD from manufacturer for HDDs less than a terabyte and 0.91*capacity of HDD from manufacturer for HDDs equal to or greater than 1 terabyte.

Form factors

Before the era of PCs and small computers, hard disks were of widely varying dimensions, typically in free standing cabinets the size of washing machines (e.g. DEC RP06 Disk Drive [26]) or designed so that dimensions enabled placement in a 19" rack (e.g. Diablo Model 31 [27]).

5¼″ full height 110 MB HDD,
2½″ (8.5 mm) 6495 MB HDD,
US/UK pennies for comparison.

With increasing sales of small computers having built in floppy-disk drives (FDDs), HDDs that would fit to the FDD mountings became desirable, and this led to the evolution of the market towards drives with certain **Form factors**, initially derived from the sizes of 8", 5.25" and 3.5" floppy disk drives. Smaller sizes than 3.5" have emerged as popular in the marketplace and/or been decided by various industry groups.

Six hard drives with 8″, 5.25″, 3.5″, 2.5″, 1.8″, and 1″ disks, partially disassembled to show platters and read-write heads, with a ruler showing inches.

- **8 in:** 9.5 in × 4.624 in × 14.25 in (241.3 mm × 117.5 mm × 362 mm)
  In 1979, Shugart Associates' SA1000 was the first form factor compatible HDD, having the same dimensions and a compatible interface to the 8″ FDD.
- **5.25 inch:** 5.75 in × 1.63 in × 8 in (146.1 mm × 41.4 mm × 203 mm)
  This smaller form factor, first used in an HDD by Seagate in 1980, was the same size as full height 5¼-inch diameter FDD, i.e., 3.25 inches high. This is twice as high as "half height" commonly used today; i.e., 1.63 in (41.4 mm). Most desktop models of drives for optical 120 mm disks (DVD, CD) use the half height 5¼″ dimension, but it fell out of fashion for HDDs. The Quantum Bigfoot HDD was the last to use it in the late 1990s, with “low-profile” (≈25 mm) and “ultra-low-profile” (≈20 mm) high versions.
- **3.5 inch:** 4 in × 1 in × 5.75 in (101.6 mm × 25.4 mm × 146 mm) = 376.77344 cm^3
  This smaller form factor, first used in an HDD by Rodime in 1984, was the same size as the "half height" 3½″ FDD, i.e., 1.63 inches high. Today it has been largely superseded by 1-inch high “slimline” or “low-profile” versions of this form factor which is used by most desktop HDDs.
- **2.5 inch:** 2.75 in × 0.374–0.59 in × 3.945 in (69.85 mm × 7–15 mm × 100 mm) = 48.895–104.775 cm^3
  This smaller form factor was introduced by PrairieTek in 1988; there is no corresponding FDD. It is widely used today for hard-disk drives in mobile devices (laptops, music players, etc.) and as of 2008 replacing 3.5 inch enterprise-class drives. It is also used in the Xbox 360 and Playstation 3 video game consoles. Today, the dominant height of this form factor is 9.5 mm for laptop drives, but high capacity drives (750 GB and 1 TB) have a height of 12.5 mm. Enterprise-class drives can have a height up to 15 mm.[28] Seagate has released a wafer-thin 7mm drive aimed at entry level laptops and high end netbooks in December 2009.[29]
- **1.8 inch:** 54 mm × 8 mm × 71 mm = 30.672 cm^3
  This form factor, originally introduced by Integral Peripherals in 1993, has evolved into the ATA-7 LIF with dimensions as stated. It is increasingly used in digital audio players and subnotebooks. An original variant exists for 2–5 GB sized HDDs that fit directly into a PC card expansion slot. These became popular for their use in iPods and other HDD based MP3 players.

- **1 inch:** 42.8 mm × 5 mm × 36.4 mm
  This form factor was introduced in 1999 as IBM's Microdrive to fit inside a CF Type II slot. Samsung calls the same form factor **"1.3 inch" drive** in its product literature.[30]
- **0.85 inch:** 24 mm × 5 mm × 32 mm
  Toshiba announced this form factor in January 2004[31] for use in mobile phones and similar applications, including SD/MMC slot compatible HDDs optimized for video storage on 4G handsets. Toshiba currently sells a 4 GB (MK4001MTD) and 8 GB (MK8003MTD) version [32] and holds the Guinness World Record for the smallest hard disk drive.[33]

3.5" and 2.5" hard disks currently dominate the market.

By 2009 all manufacturers had discontinued the development of new products for the 1.3-inch, 1-inch and 0.85-inch form factors due to falling prices of flash memory.[34] [35]

The inch-based nickname of all these form factors usually do not indicate any actual product dimension (which are specified in millimeters for more recent form factors), but just roughly indicate a size relative to disk diameters, in the interest of historic continuity.

Current hard disk form factors

Form factor	Width	Height	Largest capacity	Platters (Max)
3.5″	102 mm	25.4 mm	2 TB[36] (2009)	5
2.5″	69.9 mm	7–15 mm	1 TB[37] (2009)	3
1.8″	54 mm	8 mm	320 GB[38] (2009)	3

Obsolete hard disk form factors

Form factor	Width	Largest capacity	Platters (Max)
5.25″ FH	146 mm	47 GB[39] (1998)	14
5.25″ HH	146 mm	19.3 GB[40] (1998)	4[41]
1.3″	43 mm	40 GB[42] (2007)	1
1″ (CFII/ZIF/IDE-Flex)	42 mm	20 GB (2006)	1
0.85″	24 mm	8 GB[43] (2004)	1

Performance characteristics

Data transfer rate

As of 2008, a typical 7200 rpm desktop hard drive has a sustained "disk-to-buffer" data transfer rate of about 70 megabytes per second.[44] This rate depends on the track location, so it will be higher for data on the outer tracks (where there are more data sectors) and lower toward the inner tracks (where there are fewer data sectors); and is generally somewhat higher for 10,000 rpm drives. A current widely used standard for the "buffer-to-computer" interface is 3.0 Gbit/s SATA, which can send about 300 megabyte/s from the buffer to the computer, and thus is still comfortably ahead of today's disk-to-buffer transfer rates. Data transfer rate (read/write) can be measured by writing a large file to disk using special file generator tools, then reading back the file. Transfer rate can be influenced by file system fragmentation and the layout of the files.

The mechanical nature of hard disks introduces certain performance compromises. The manipulation of sequential data depends upon the rotational speed of the platters and the data recording density. Because heat and vibration limit rotational speed, advancing density becomes the sole method to improve sequential transfer rates. While these advances exponentially increase storage capacity, the performance gains they enable are linear. Throughput relative to capacity in new generations of hard disks has therefore fallen with time.

Seek time

Seek time for non-sequential data ranges from 3 ms[45] for high-end server drives, to 15 ms for mobile drives, with the most common mobile drives at about 12 ms[46] and the most common desktop type typically being around 9 ms There has not been any significant improvement in this speed for some years. Some early PC drives used a stepper motor to move the heads, and as a result had access times as slow as 80–120 ms, but this was quickly improved by voice coil type actuation in the late 1980s, reducing access times to around 20 ms.

Power consumption

Power consumption has become increasingly important, not just in mobile devices such as laptops but also in server and desktop markets. Increasing data center machine density has led to problems delivering sufficient power to devices (especially for spin up), and getting rid of the waste heat subsequently produced, as well as environmental and electrical cost concerns (see green computing). Similar issues exist for large companies with thousands of desktop PCs. Smaller form factor drives often use less power than larger drives. One interesting development in this area is actively controlling the seek speed so that the head arrives at its destination only just in time to read the sector, rather than arriving as quickly as possible and then having to wait for the sector to come around (i.e. the rotational latency). Many of the hard drive companies are now producing Green Drives that require much less power and cooling. Many of these 'Green Drives' spin slower (<5,400 rpm compared to 7,200, 10,000 or 15,000 rpm) and also generate less waste heat.

Also in Server and Workstation systems where there might be multiple hard disk drives, there are various ways of controlling when the hard drives spin up (highest power draw).

On SCSI hard disk drives, the SCSI controller can directly control spin up and spin down of the drives.

On Parallel ATA (aka PATA) and SATA hard disk drives, some support Power-up in standby or PUIS. The hard disk drive will not spin up until the controller or system BIOS issues a specific command to do so. This limits the power draw or consumption upon power on.

On newer SATA hard disk drives, there is Staggered Spin Up feature. The hard disk drive will not spin up until the SATA Phy comes ready (communications with the host controller starts).

To further control or reduce power draw and consumption, the hard disk drive can be spun down to reduce its power consumption.

Audible noise

Measured in dBA, audible noise is significant for certain applications, such as PVRs, digital audio recording and quiet computers. Low noise disks typically use fluid bearings, slower rotational speeds (usually 5,400 rpm) and reduce the seek speed under load (AAM) to reduce audible clicks and crunching sounds. Drives in smaller form factors (e.g. 2.5 inch) are often quieter than larger drives.

Shock resistance

Shock resistance is especially important for mobile devices. Some laptops now include active hard drive protection that parks the disk heads if the machine is dropped, hopefully before impact, to offer the greatest possible chance of survival in such an event. Maximum shock tolerance to date is 350 Gs for operating and 1000 Gs for non-operating.[47]

Access and interfaces

Hard disk drives are accessed over one of a number of bus types, including parallel ATA (P-ATA, also called IDE or EIDE), Serial ATA (SATA), SCSI, Serial Attached SCSI (SAS), and Fibre Channel. Bridge circuitry is sometimes used to connect hard disk drives to buses that they cannot communicate with natively, such as IEEE 1394, USB and SCSI.

For the ST-506 interface, the data encoding scheme as written to the disk surface was also important. The first ST-506 disks used Modified Frequency Modulation (MFM) encoding, and transferred data at a rate of 5 megabits per second. Later controllers using 2,7 RLL (or just "RLL") encoding caused 50% more data to appear under the heads compared to one rotation of an MFM drive, increasing data storage and data transfer rate by 50%, to 7.5 megabits per second.

Many ST-506 interface disk drives were only specified by the manufacturer to run at the 1/3rd lower MFM data transfer rate compared to RLL, while other drive models (usually more expensive versions of the same drive) were specified to run at the higher RLL data transfer rate. In some cases, a drive had sufficient margin to allow the MFM specified model to run at the denser/faster RLL data transfer rate (not recommended nor guaranteed by manufacturers). Also, any RLL-certified drive could run on any MFM controller, but with 1/3 less data capacity and as much as 1/3rd less data transfer rate compared to its RLL specifications.

Enhanced Small Disk Interface (ESDI) also supported multiple data rates (ESDI disks always used 2,7 RLL, but at 10, 15 or 20 megabits per second), but this was usually negotiated automatically by the disk drive and controller; most of the time, however, 15 or 20 megabit ESDI disk drives weren't downward compatible (i.e. a 15 or 20 megabit disk drive wouldn't run on a 10 megabit controller). ESDI disk drives typically also had jumpers to set the number of sectors per track and (in some cases) sector size.

Modern hard drives present a consistent interface to the rest of the computer, no matter what data encoding scheme is used internally. Typically a DSP in the electronics inside the hard drive takes the raw analog voltages from the read head and uses PRML and Reed–Solomon error correction[48] to decode the sector boundaries and sector data, then sends that data out the standard interface. That DSP also watches the error rate detected by error detection and correction, and performs bad sector remapping, data collection for Self-Monitoring, Analysis, and Reporting Technology, and other internal tasks.

SCSI originally had just one signaling frequency of 5 MHz for a maximum data rate of 5 megabytes/second over 8 parallel conductors, but later this was increased dramatically. The SCSI bus speed had no bearing on the disk's internal speed because of buffering between the SCSI bus and the disk drive's internal data bus; however, many early disk drives had very small buffers, and thus had to be reformatted to a different interleave (just like ST-506 disks) when used on slow computers, such as early Commodore Amiga, IBM PC compatibles and Apple Macintoshes.

ATA disks have typically had no problems with interleave or data rate, due to their controller design, but many early models were incompatible with each other and couldn't run with two devices on the same physical cable in a master/slave setup. This was mostly remedied by the mid-1990s, when ATA's specification was standardized and the details began to be cleaned up, but still causes problems occasionally (especially with CD-ROM and DVD-ROM disks, and when mixing Ultra DMA and non-UDMA devices).

Serial ATA does away with master/slave setups entirely, placing each disk on its own channel (with its own set of I/O ports) instead.

FireWire/IEEE 1394 and USB(1.0/2.0) HDDs are external units containing generally ATA or SCSI disks with ports on the back allowing very simple and effective expansion and mobility. Most FireWire/IEEE 1394 models are able to daisy-chain in order to continue adding peripherals without requiring additional ports on the computer itself. USB however, is a point to point network and doesn't allow for daisy-chaining. USB hubs are used to increase the number of available ports and are used for devices that don't require charging since the current supplied by hubs is typically lower than what's available from the built-in USB ports.

Disk interface families used in personal computers

Notable families of disk interfaces include:

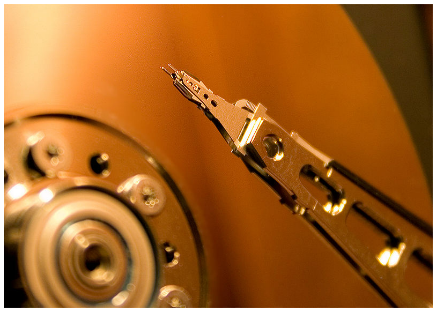
- Historical **bit serial interfaces —** connect a hard disk drive (HDD) to a hard disk controller (HDC) with two cables, one for control and one for data. (Each drive also has an additional cable for power, usually connecting it directly to the power supply unit). The HDC provided significant functions such as serial/parallel conversion, data separation, and track formatting, and required matching to the drive (after formatting) in order to assure reliability. Each control cable could serve two or more drives, while a dedicated (and smaller) data cable served each drive.
  - ST506 used MFM (Modified Frequency Modulation) for the data encoding method.
  - ST412 was available in either MFM or RLL (Run Length Limited) encoding variants.
  - Enhanced Small Disk Interface (ESDI) was an interface developed by Maxtor to allow faster communication between the processor and the disk than MFM or RLL.
- Modern **bit serial interfaces —** connect a hard disk drive to a host bus interface adapter (today typically integrated into the "south bridge") with one data/control cable. (As for historical *bit serial interfaces* above, each drive also has an additional power cable, usually direct to the power supply unit.)
  - Fibre Channel (FC), is a successor to parallel SCSI interface on enterprise market. It is a serial protocol. In disk drives usually the Fibre Channel Arbitrated Loop (FC-AL) connection topology is used. FC has much broader usage than mere disk interfaces, and it is the cornerstone of storage area networks (SANs). Recently other protocols for this field, like iSCSI and ATA over Ethernet have been developed as well. Confusingly, drives usually use *copper* twisted-pair cables for Fibre Channel, not fibre optics. The latter are traditionally reserved for larger devices, such as servers or disk array controllers.
  - Serial ATA (SATA). The SATA data cable has one data pair for differential transmission of data to the device, and one pair for differential receiving from the device, just like EIA-422. That requires that data be transmitted serially. Similar differential signaling system is used in RS485, LocalTalk, USB, Firewire, and differential SCSI.
  - Serial Attached SCSI (SAS). The SAS is a new generation serial communication protocol for devices designed to allow for much higher speed data transfers and is compatible with SATA. SAS uses a mechanically identical data and power connector to standard 3.5" SATA1/SATA2 HDDs, and many server-oriented SAS RAID controllers are also capable of addressing SATA hard drives. SAS uses serial communication instead of the parallel method found in traditional SCSI devices but still uses SCSI commands.
- **Word serial interfaces —** connect a hard disk drive to a host bus adapter (today typically integrated into the "south bridge") with one cable for combined data/control. (As for all *bit serial interfaces* above, each drive also

has an additional power cable, usually direct to the power supply unit.) The earliest versions of these interfaces typically had a 8 bit parallel data transfer to/from the drive, but 16 bit versions became much more common, and there are 32 bit versions. Modern variants have serial data transfer. The word nature of data transfer makes the design of a host bus adapter significantly simpler than that of the precursor HDD controller.

- Integrated Drive Electronics (IDE), later renamed to ATA, with the alias P-ATA ("parallel ATA") retroactively added upon introduction of the new variant Serial ATA. The original name reflected the innovative integration of HDD controller with HDD itself, which was not found in earlier disks. Moving the HDD controller from the interface card to the disk drive helped to standardize interfaces, and to reduce the cost and complexity. The 40 pin IDE/ATA connection transfers 16 bits of data at a time on the data cable. The data cable was originally 40 conductor, but later higher speed requirements for data transfer to and from the hard drive led to an "ultra DMA" mode, known as UDMA. Progressively faster versions of this standard ultimately added the requirement for an 80 conductor variant of the same cable; where half of the conductors provides grounding necessary for enhanced high-speed signal quality by reducing cross talk. The interface for 80 conductor only has 39 pins, the missing pin acting as a key to prevent incorrect insertion of the connector to an incompatible socket, a common cause of disk and controller damage.
- EIDE was an unofficial update (by Western Digital) to the original IDE standard, with the key improvement being the use of direct memory access (DMA) to transfer data between the disk and the computer without the involvement of the CPU, an improvement later adopted by the official ATA standards. By directly transferring data between memory and disk, DMA eliminates the need for the CPU to copy byte per byte, therefore allowing it to process other tasks while the data transfer occurs.
- Small Computer System Interface (SCSI), originally named SASI for Shugart Associates System Interface, was an early competitor of ESDI. SCSI disks were standard on servers, workstations, Commodore Amiga and Apple Macintosh computers through the mid-90s, by which time most models had been transitioned to IDE (and later, SATA) family disks. Only in 2005 did the capacity of SCSI disks fall behind IDE disk technology, though the highest-performance disks are still available in SCSI and Fibre Channel only. The length limitations of the data cable allows for external SCSI devices. Originally SCSI data cables used single ended (common mode) data transmission, but server class SCSI could use differential transmission, either low voltage differential (LVD) or high voltage differential (HVD). ("Low" and "High" voltages for differential SCSI are relative to SCSI standards and do not meet the meaning of low voltage and high voltage as used in general electrical engineering contexts, as apply e.g. to statutory electrical codes; both LVD and HVD use low voltage signals (3.3 V and 5 V respectively) in general terminology.)

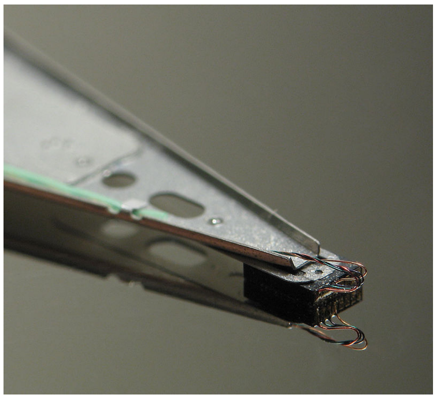
Acronym or abbreviation	Meaning	Description
SASI	Shugart Associates System Interface	Historical predecessor to SCSI.
SCSI	Small Computer System Interface	Bus oriented that handles concurrent operations.
SAS	Serial Attached SCSI	Improvement of SCSI, uses serial communication instead of parallel.
ST-506	Seagate Technology	Historical Seagate interface.
ST-412	Seagate Technology	Historical Seagate interface (minor improvement over ST-506).
ESDI	Enhanced Small Disk Interface	Historical; backwards compatible with ST-412/506, but faster and more integrated.
ATA (PATA)	Advanced Technology Attachment	Successor to ST-412/506/ESDI by integrating the disk controller completely onto the device. Incapable of concurrent operations.
SATA	Serial ATA	Modification of ATA, uses serial communication instead of parallel.

Integrity



An IBM HDD head resting on a disk platter. Since the drive is not in operation, the head is simply pressed against the disk by the suspension.

Due to the extremely close spacing between the heads and the disk surface, any contamination of the read-write heads or platters can lead to a head crash — a failure of the disk in which the head scrapes across the platter surface, often grinding away the thin magnetic film and causing data loss. Head crashes can be caused by electronic failure, a sudden power failure, physical shock, wear and tear, corrosion, or poorly manufactured platters and heads.



Close-up of a hard disk head resting on a disk platter. A reflection of the head and its suspension is visible on the mirror-like disk.

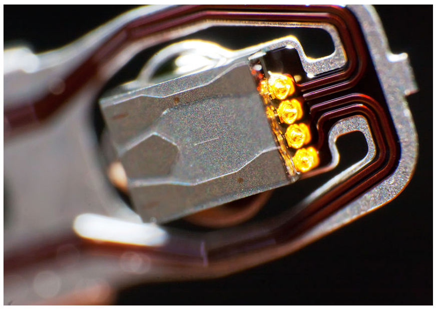
The HDD's spindle system relies on air pressure inside the disk enclosure to support the heads at their proper *flying height* while the disk rotates. Hard disk drives require a certain range of air pressures in order to operate properly. The connection to the external environment and pressure occurs through a small hole in the enclosure (about 0.5 mm in diameter), usually with a filter on the inside (the *breather filter*).[49] If the air pressure is too low, then there is not enough lift for the flying head, so the head gets too close to the disk, and there is a risk of head crashes and data loss. Specially manufactured sealed and pressurized disks are needed for reliable high-altitude operation, above about 3,000 m (10,000 feet).[50] Modern disks include temperature sensors and adjust their operation to the operating environment. Breather holes can be seen on all disk drives — they usually have a sticker next to them, warning the user not to cover the holes. The air inside the operating drive is constantly moving too, being swept in motion by friction with the spinning platters. This air passes through an internal recirculation (or "recirc") filter to remove any leftover contaminants from manufacture, any particles or chemicals that may have somehow entered the enclosure, and any particles or outgassing generated internally in normal operation. Very high humidity for extended periods can corrode the heads and platters.

For giant magnetoresistive (GMR) heads in particular, a minor head crash from contamination (that does not remove the magnetic surface of the disk) still results in the head temporarily overheating, due to friction with the disk surface, and can render the data unreadable for a short period until the head temperature stabilizes (so called "thermal asperity", a problem which can partially be dealt with by proper electronic filtering of the read signal).

Actuation of moving arm

The hard drive's electronics control the movement of the actuator and the rotation of the disk, and perform reads and writes on demand from the disk controller. Feedback of the drive electronics is accomplished by means of special segments of the disk dedicated to servo feedback. These are either complete concentric circles (in the case of dedicated servo technology), or segments interspersed with real data (in the case of embedded servo technology). The servo feedback optimizes the signal to noise ratio of the GMR sensors by adjusting the voice-coil of the actuated arm. The spinning of the disk also uses a servo motor. Modern disk firmware is capable of scheduling reads and writes efficiently on the platter surfaces and remapping sectors of the media which have failed.

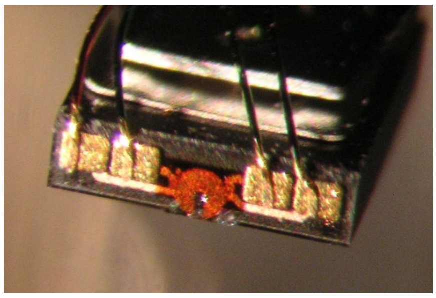
Landing zones and load/unload technology



A read/write head from a circa-1998 Fujitsu 3.5" hard disk. The area pictured is approximately 2.0 mm x 3.0mm.

Modern HDDs prevent power interruptions or other malfunctions from landing its heads in the data zone by **parking** the heads either in a **landing zone** or by unloading (i.e., **load/unload**) the heads. Some early PC HDDs did not park the heads automatically and they would land on data. In some other early units the user manually parked the heads by running a program to park the HDD's heads.

A **landing zone** is an area of the platter usually near its inner diameter (ID), where no data are stored. This area is called the Contact Start/Stop (CSS) zone. Disks are designed such that either a spring or, more recently, rotational inertia in the platters is used to park the heads in the case of unexpected power loss. In this case, the spindle motor temporarily acts as a generator, providing power to the actuator.



Microphotograph of an older generation hard disk head and slider (1990s). The size of the front face (which is the "trailing face" of the slider) is about 0.3 mm × 1.0 mm. It is the location of the actual 'head' (magnetic sensors). The non-visible bottom face of the slider is about 1.0 mm × 1.25 mm (so-called "nano" size) and faces the platter. It contains the lithographically micro-machined air bearing surface (ABS) that allows the slider to fly in a highly controlled fashion. One functional part of the head is the round, orange structure visible in the middle - the lithographically defined copper coil of the write transducer. Also note the electric connections by wires bonded to gold-plated pads.

Spring tension from the head mounting constantly pushes the heads towards the platter. While the disk is spinning, the heads are supported by an air bearing and experience no physical contact or wear. In CSS drives the sliders carrying the head sensors (often also just called *heads*) are designed to survive a number of landings and takeoffs from the media surface, though wear and tear on these microscopic components eventually takes its toll. Most manufacturers design the sliders to survive 50,000 contact cycles before the chance of damage on startup rises above 50%. However, the decay rate is not linear: when a disk is younger and has had fewer start-stop cycles, it has a better chance of surviving the next startup than an older, higher-mileage disk (as the head literally drags along the disk's surface until the air bearing is established). For example, the Seagate Barracuda 7200.10 series of desktop hard disks are rated to 50,000 start-stop cycles, in other words no failures attributed to the head-platter interface were seen before at least 50,000 start-stop cycles during testing.[51]

Around 1995 IBM pioneered a technology where a landing zone on the disk is made by a precision laser process (*Laser Zone Texture* = LZT) producing an array of smooth nanometer-scale "bumps" in a landing zone,[52] thus vastly improving stiction and wear performance. This technology is still largely in use today (2008), predominantly in desktop and enterprise (3.5 inch) drives. In general, CSS technology can be prone to increased stiction (the tendency for the heads to stick to the platter surface), e.g. as a consequence of increased humidity. Excessive stiction can cause physical damage to the platter and slider or spindle motor.

Load/Unload technology relies on the heads being lifted off the platters into a safe location, thus eliminating the risks of wear and stiction altogether. The first HDD RAMAC and most early disk drives used complex mechanisms to load and unload the heads. Modern HDDs use ramp loading, first introduced by Memorex in 1967,[53] to load/unload onto plastic "ramps" near the outer disk edge.

All HDDs today still use one of these two technologies listed above. Each has a list of advantages and drawbacks in terms of loss of storage area on the disk, relative difficulty of mechanical tolerance control, non-operating shock robustness, cost of implementation, etc.

Addressing shock robustness, IBM also created a technology for their ThinkPad line of laptop computers called the Active Protection System. When a sudden, sharp movement is detected by the built-in accelerometer in the Thinkpad, internal hard disk heads automatically unload themselves to reduce the risk of any potential data loss or scratch defects. Apple later also utilized this technology in their PowerBook, iBook, MacBook Pro, and MacBook line, known as the Sudden Motion Sensor. Sony,[54] HP with their HP 3D DriveGuard[55] and Toshiba[56] have released similar technology in their notebook computers.

This accelerometer based shock sensor has also been used for building cheap earthquake sensor networks.[57]

Disk failures and their metrics

Most major hard disk and motherboard vendors now support S.M.A.R.T. (Self-Monitoring, Analysis, and Reporting Technology), which measures drive characteristics such as operating temperature, spin-up time, data error rates, etc. Certain trends and sudden changes in these parameters are thought to be associated with increased likelihood of drive failure and data loss.

However, not all failures are predictable. Normal use eventually can lead to a breakdown in the inherently fragile device, which makes it essential for the user to periodically back up the data onto a separate storage device. Failure to do so can lead to the loss of data. While it may sometimes be possible to recover lost information, it is normally an extremely costly procedure, and it is not possible to guarantee success. A 2007 study published by Google suggested very little correlation between failure rates and either high temperature or activity level; however, the correlation between manufacturer/model and failure rate was relatively strong. Statistics in this matter is kept highly secret by most entities. Google did not publish the manufacturer's names along with their respective failure rates,[58] though they have since revealed that they use Hitachi Deskstar drives in some of their servers.[59] While several S.M.A.R.T. parameters have an impact on failure probability, a large fraction of failed drives do not produce predictive S.M.A.R.T. parameters.[58] S.M.A.R.T. parameters alone may not be useful for predicting individual drive failures.[58]

A common misconception is that a colder hard drive will last longer than a hotter hard drive. The Google study seems to imply the reverse—"lower temperatures are associated with higher failure rates". Hard drives with S.M.A.R.T.-reported average temperatures below 27 °C (80.6 °F) had higher failure rates than hard drives with the highest reported average temperature of 50 °C (122 °F), failure rates at least twice as high as the optimum S.M.A.R.T.-reported temperature range of 36 °C (96.8 °F) to 47 °C (116.6 °F).[58]

SCSI, SAS and FC drives are typically more expensive and are traditionally used in servers and disk arrays, whereas inexpensive ATA and SATA drives evolved in the home computer market and were perceived to be less reliable. This distinction is now becoming blurred.

The mean time between failures (MTBF) of SATA drives is usually about 600,000 hours (some drives such as Western Digital Raptor have rated 1.4 million hours MTBF)[60] , while SCSI drives are rated for upwards of 1.5 million hours. However, independent research indicates that MTBF is not a reliable estimate of a drive's longevity.[61] MTBF is conducted in laboratory environments in test chambers and is an important metric to determine the quality of a disk drive before it enters high volume production. Once the drive product is in production, the more valid metric is annualized failure rate (AFR). AFR is the percentage of real-world drive failures after shipping.

SAS drives are comparable to SCSI drives, with high MTBF and high reliability.

Enterprise S-ATA drives designed and produced for enterprise markets, unlike standard S-ATA drives, have reliability comparable to other enterprise class drives.[62] [63]

Typically enterprise drives (all enterprise drives, including SCSI, SAS, enterprise SATA and FC) experience between 0.70%-0.78% annual failure rates from the total installed drives.

Eventually all mechanical hard disk drives fail, so to mitigate loss of data, some form of redundancy is needed, such as RAID[64] or a regular backup[64] system.

Manufacturers

See also List of defunct hard disk manufacturers

A Western Digital 3.5 inch 250 GB SATA HDD. This specific model features both SATA and Molex power inputs.

The technological resources and know-how required for modern drive development and production mean that as of 2010, virtually all of the world's HDDs are manufactured by just five large companies: Seagate, Western Digital, Hitachi, Samsung, and Toshiba.

Dozens of former HDD manufacturers have gone out of business, merged, or closed their HDD divisions; as capacities and demand for products increased, profits became hard to find, and the market underwent significant consolidation in the late 1980s and late 1990s. The first notable casualty of the business in the PC era was Computer Memories Inc. or CMI; after an incident with faulty 20 MB AT disks in 1985,[65] CMI's reputation never recovered, and they exited the HDD business in 1987. Another notable failure was MiniScribe, who went bankrupt in 1990 after it was found that they had engaged in accounting fraud and inflated sales numbers for several years. Many other smaller companies (like Kalok, Microscience, LaPine, Areal, Priam and PrairieTek) also did not survive the shakeout, and had disappeared by 1993; Micropolis was able to hold on until 1997, and JTS, a relative latecomer to the scene, lasted only a few years and was gone by 1999, after attempting to manufacture HDDs in India. Their claim to fame was creating a new 3″ form factor drive for use in laptops. Quantum and Integral also invested in the 3″ form factor; but eventually ceased support as this form factor failed to catch on. Rodime was also an important manufacturer during the 1980s, but stopped making disks in the early 1990s amid the shakeout and now concentrates on technology licensing; they hold a number of patents related to 3.5-inch form factor HDDs.

Seagate's hard disk drives being manufactured in a factory in Wuxi, China

The following is the genealogy of the current HDD companies:

- 1967: Hitachi enters the HDD business. [66]
- 1967: Toshiba enters the HDD business. [67]
- 1979: Seagate Technology[68] founded.
- 1988: Western Digital, then a well-known controller designer, enters the HDD business by acquiring Tandon Corporation's disk manufacturing division.[69]
- 1989: Seagate Technology purchases Control Data's HDD business.
- 1990: Maxtor purchases MiniScribe out of bankruptcy, making it the core of its low-end HDDs.
- 1994: Quantum purchases DEC's storage division, giving it a high-end disk range to go with its more consumer-oriented *ProDrive* range.
- 1996: Seagate acquires Conner Peripherals in a merger.
- 2000: Maxtor acquires Quantum's HDD business; Quantum remains in the tape business.
- 2003: Hitachi acquires the majority of IBM's disk division, renaming it Hitachi Global Storage Technologies (HGST).
- 2006: Seagate acquires Maxtor.
- 2009: Toshiba acquires Fujitsu's HDD division.[70]

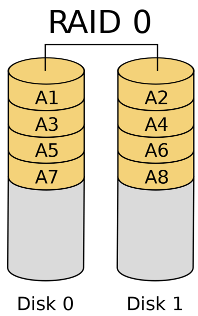
Sales

In the year 2007 516.2 million hard disks were sold.[71]

Icons

Hard drives are traditionally symbolized as either a stylized stack of platters (in orthographic projection) or, more abstractly, as a cylinder. This is particularly found in schematic diagrams or on indicator lights, as on laptops, to indicate hard drive access. In most modern operating systems, hard drives are instead represented by an illustration or photograph of a hard drive enclosure. These are illustrated below.

Today, hard drives are symbolized by a picture of the enclosure.



Schematically, hard drives may be represented by cylinders or stacks of platters, as in this RAID diagram.

The cylinder schematic derives from hard drives internally being a stack of platters, as in these 1970s vintage hard drive internals.

See also

- Automatic Acoustic Management
- Binary prefix
- Clean Room
- Click of death
- Data erasure
- Disk formatting
- Drive mapping
- du (Unix disk usage program)
- External hard disk drive
- File System
- HDD recorder
- History of hard disk drives
- Hybrid drive
- IBM 305 RAMAC
- kilobyte, megabyte, gigabyte definitions
- Multimedia
- Solid-state drive
- Spintronics
- Write precompensation
- Giant magnetoresistance (GMR)

External links

- Computer History Museum's HDD Working Group Website [72]
- HDD Tracks and Zones [73]
- HDD from inside [74]
- Hard Disk Drives Encyclopedia [75]

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[5] IBM.com (http://www-03.ibm.com/ibm/history/exhibits/storage/storage_350.html) IBM 350 disk storage unit

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Data Ports

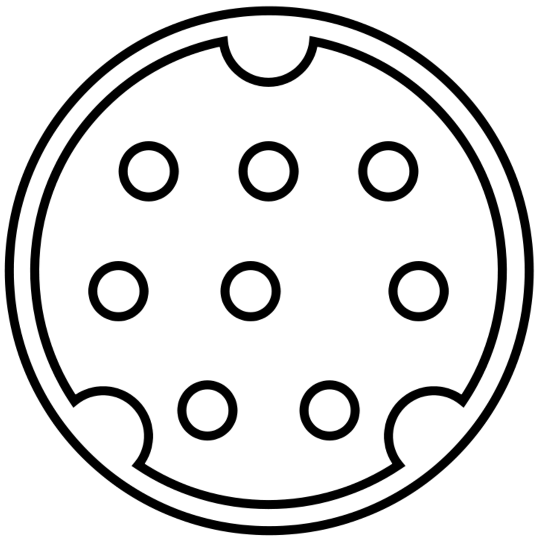
Serial port

In computing, a **serial port** is a serial communication physical interface through which information transfers in or out one bit at a time (contrast parallel port).[1] Throughout most of the history of personal computers, data transfer through serial ports connected the computer to devices such as terminals and various peripherals.

A male DE-9 connector used for a serial port on a IBM PC compatible computer. (Pinout)

While such interfaces as Ethernet, FireWire, and USB all send data as a serial stream, the term "serial port" usually identifies hardware more or less compliant to the RS-232 standard, intended to interface with a modem or with a similar communication device.

In modern personal computers the serial port has largely been replaced by USB and Firewire for connections to peripheral devices. Many modern personal computers do not have a serial port since this legacy port has been superseded for most uses. Serial ports are commonly still used in applications such as industrial automation systems, scientific analysis, shop till systems and some industrial and consumer products. Server computers may use a serial port as a control console for diagnostics. Network equipment (such as routers and switches) often use serial console for configuration. Serial ports are still used in these areas as they are simple, cheap and their console functions are highly standardized and widespread. A serial port requires very little supporting software from the host system.



A male Mini DIN-8 connector used for a serial port on a Macintosh or SGI style computer.

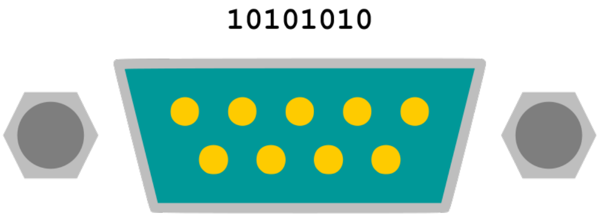
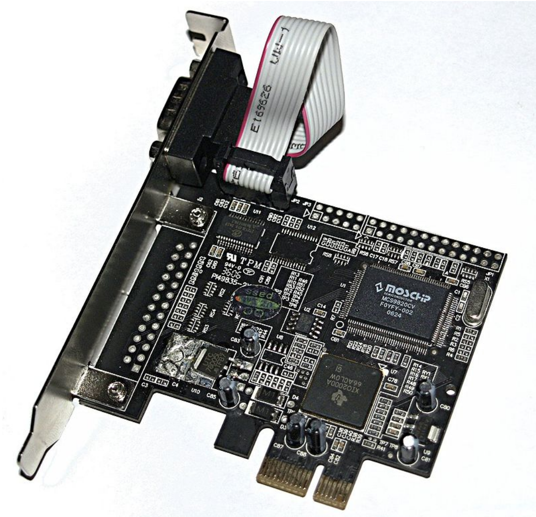


Diagram of a typical DE-9 male connector used on many IBM compatible PCs prior to being succeeded by USB.

Hardware

Some computers, such as the IBM PC, used an integrated circuit called a UART, that converted characters to (and from) asynchronous serial form, and automatically looked after the timing and framing of data. Very low-cost systems, such as some early home computers, would instead use the CPU to send the data through an output pin, using the so-called bit-banging technique. Before large-scale integration (LSI) UART integrated circuits were common, a minicomputer or microcomputer would have a serial port made of multiple small-scale integrated circuits to implement shift registers, logic gates, counters, and all the other logic for a serial port.



PCI Express card with one serial port

Early home computers often had proprietary serial ports with pinouts and voltage levels incompatible with RS-232. Inter-operation with RS-232 devices may be impossible as the serial port cannot withstand the voltage levels produced and may have other differences that "lock in" the user to products of a particular manufacturer.

Low-cost processors now allow higher-speed, but more complex, serial communication standards such as USB and FireWire to replace RS-232. These make it possible to connect devices that would not have operated feasibly over slower serial connections, such as mass storage, sound, and video devices.

Many personal computer motherboards still have at least one serial port. Small-form-factor systems and laptops may omit RS-232 connector ports to conserve space, but the electronics are still there. RS-232 has been standard for so long that the circuits needed to control a serial port became very cheap and often exist on a single chip, sometimes also with circuitry for a parallel port.

Connectors

While the RS-232 standard originally specified a 25-pin D-type connector, many designers of personal computers chose to implement only a subset of the full standard: they traded off compatibility with the standard against the use of less costly and more compact connectors (in particular the DE-9 version used by the original IBM PC-AT). Starting around the time of the introduction of the IBM PC-AT, serial ports were commonly built with a 9-pin connector to save cost and space. However, presence of a 9-pin D-subminiature connector is neither necessary nor sufficient to indicate use of a serial port, since this connector was also used for video, joysticks, and other purposes.

Some miniaturized electronics, particularly graphing calculators and hand-held amateur and two-way radio equipment, have serial ports using a jack plug connector, usually the smaller 2.5 or 3.5 mm connectors and use the most basic 3-wire interface.

Many models of Macintosh favored the related (but faster) RS-422 standard, mostly using German Mini-DIN connectors, except in the earliest models. The Macintosh included a standard set of two ports for connection to a printer and a modem, but some PowerBook laptops had only one combined port to save space.

Hardware abstraction

Operating systems usually use a symbolic name to refer to the serial ports of a computer. Unix-like operating systems usually label the serial port devices `/dev/tty*` (*tty* an abbreviation for *teletype*) where `*` represents a string identifying the terminal device; the syntax of that string depends on the operating system and the device. The Microsoft MS-DOS and Windows environments refer to serial ports as COM ports: COM1, COM2, etc. On Linux, 8250/16550 UART hardware serial ports are named `/dev/ttyS*`, USB adapters appear as `/dev/ttyUSB*` and various types of virtual serial ports do not necessarily have names starting with `tty`.

Common applications for serial ports

The RS-232 standard is used by many specialized and custom-built devices. This list includes some of the more common devices that are connected to the serial port on a PC. Some of these such as modems and serial mice are falling into disuse while others are readily available.

- Computer terminal
- Dial-up modems
- Printers
- Networking (Macintosh AppleTalk at 230.4 kbit/s)
- Serial mouse
- Older Joysticks
- GPS receivers (typically NMEA 0183 at 4800 bit/s)
- Older GSM mobile phones
- Satellite phones, low-speed satellite modems and other satellite based transceiver devices
- Microcontroller, EPROM and other programmers
- Bar code scanners and other point of sale devices
- LED and LCD text displays
- Homemade electronic devices
- Older digital cameras
- Test and measuring equipment such as digital multimeters and weighing systems
- Updating Firmware on various consumer devices.
- Some CNC controllers
- Uninterruptible Power Supply
- Software debuggers that run on a 2nd computer.

Settings

Many settings are required for serial connections used for asynchronous start-stop communication, to select speed, number of data bits per character, parity, and number of stop bits per character. In modern serial ports using a UART integrated circuit, all settings are usually software-controlled; hardware from the 1980s and earlier may require setting switches or jumpers on a circuit board. One of the simplifications made in such serial bus standards as Ethernet, FireWire, and USB is that many of those parameters have fixed values so that users can not and need not change the configuration; the speed is either fixed or automatically negotiated. Often if the settings are entered incorrectly the connection will not be dropped; however, any data sent will be received on the other end as nonsense.

Speed

Serial ports use two-level (binary) signaling, so the data rate in bits per second is equal to the symbol rate in bauds. A standard series of rates is based on multiples of the rates for electromechanical teleprinters; some serial ports allow many arbitrary rates to be selected. The port speed and device speed must match. The capability to set a bit rate does not imply that a working connection will result. Not all bit rates are possible with all serial ports. Some special-purpose protocols such as MIDI for musical instrument control, use serial data rates other than the teleprinter series. Some serial port systems can automatically detect the bit rate.

The speed includes bits for framing (stop bits, parity, etc.) and so the effective data rate is lower than the bit transmission rate. For example with 8-N-1 character framing only 80% of the bits are available for data (for every eight bits of data, two more framing bits are sent).

Data bits

The number of data bits in each character can be 5 (for Baudot code), 6 (rarely used), 7 (for true ASCII), 8 (for any kind of data, as this matches the size of a byte), or 9 (rarely used). 8 data bits are almost universally used in newer applications. 5 or 7 bits generally only make sense with older equipment such as teleprinters.

Most serial communications designs send the data bits within each byte LSB (Least Significant Bit) first. This standard is also referred to as "little endian". Also possible, but rarely used, is "big endian" or MSB (Most Significant Bit) first serial communications. (See Endianness for more about bit ordering.) The order of bits is not usually configurable, but data can be byte-swapped only before sending.

Parity

Parity is a method of detecting errors in transmission. When parity is used with a serial port, an extra data bit is sent with each data character, arranged so that the number of 1 bits in each character, including the parity bit, is always odd or always even. If a byte is received with the wrong number of 1s, then it must have been corrupted. However, an even number of errors can pass the parity check.

Electromechanical teleprinters were arranged to print a special character when received data contained a parity error, to allow detection of messages damaged by line noise. A single parity bit does not allow implementation of error correction on each character, and communication protocols working over serial data links will have higher-level mechanisms to ensure data validity and request retransmission of data that has been incorrectly received.

The parity bit in each character can be set to none (N), odd (O), even (E), mark (M), or space (S). None means that no parity bit is sent at all. Mark parity means that the parity bit is always set to the mark signal condition (logical 1) and likewise space parity always sends the parity bit in the space signal condition. Aside from uncommon applications that use the 9th (parity) bit for some form of addressing or special signalling, mark or space parity is uncommon, as it adds no error detection information. Odd parity is more common than even, since it ensures that at least one state transition occurs in each character, which makes it more reliable. The most common parity setting, however, is "none", with error detection handled by a communication protocol.

Stop bits

Stop bits sent at the end of every character allow the receiving signal hardware to detect the end of a character and to resynchronise with the character stream. Electronic devices usually use one stop bit. If slow electromechanical teleprinters are used, one-and-one half or two stop bits are required.

Conventional notation

The D/P/S (Data/Parity/Stop) conventional notation specifies the framing of a serial connection. The most common usage on microcomputers is 8/N/1 (8N1). This specifies 8 data bits, no parity, 1 stop bit. In this notation, the parity bit is not included in the data bits. 7/E/1 (7E1) means that an even parity bit is added to the seven data bits for a total of eight bits between the start and stop bits. If a receiver of a 7/E/1 stream is expecting an 8/N/1 stream, half the possible bytes will be interpreted as having the high bit set.

Flow control

A serial port may use signals in the interface to pause and resume the transmission of data. For example, a slow printer might need to handshake with the serial port to indicate that data should be paused while the mechanism advances a line. Common hardware handshake signals use the RS-232 RTS/CTS, DTR/DSR signal circuits. Generally, the RTS and CTS are turned off and on from alternate ends to control data flow, for instance when a buffer is almost full. DTR and DSR are usually on all the time and are used to signal from each end that the other equipment is actually present and powered-up.

Another method of flow control may use special characters such as XON/XOFF to control the flow of data. The XON/XOFF characters are sent by the receiver to the sender to control when the sender will send data, that is, these characters go in the opposite direction to the data being sent. The XON character tells the sender that the receiver is ready for more data. The XOFF character tells the sender to stop sending characters until the receiver is ready again. These are non-printing characters and are interpreted as handshake signals by printers and terminals.

If all possible values of a character must be sent as user data, XON/XOFF handshaking presents difficulties since these codes may appear in user data. Control characters sent as part of the data stream, must be sent as part of an escape sequence to prevent data from being interpreted as flow control. Since no extra signal circuits are required, XON/XOFF flow control can be done on a 3 wire interface.

"Virtual" serial ports

A **virtual serial port** is an emulation of the standard serial port. This port is created by software which enable extra serial ports in an operating system without additional hardware installation (such as expansion cards, etc.). Unlike a physical serial port the virtual one can be assigned *any* name (COM255, VSP33, etc.). It is possible to create unlimited number of virtual serial ports in a PC. The only limitation is the computer performance, as it may require a substantial amount of resources to emulate large numbers of serial ports.

Virtual serial ports emulate all hardware serial port functionality, including Baud rate, Data bits, Parity bits, Stop bits, etc. Additionally they allow controlling the data flow, emulating all signal lines (DTR/DSR/CTS/RTS/DCD/RI) and customizing pinout. Virtual serial ports are common with Bluetooth and are the standard way of receiving data from Bluetooth-equipped GPS modules.

Virtual serial port emulation can be useful in case there is a lack of available physical serial ports or they do not meet the current requirements. For instance, virtual serial ports can share data between several applications from one GPS device connected to a serial port. Another option is to communicate with any other serial devices via internet or LAN as if they are locally connected to computer (Serial-over-Ethernet technology). Two computers or applications can communicate through an emulated serial port link. Virtual serial port emulators are available for Microsoft Windows and some of them run under Windows CE, Windows Mobile and Pocket PC.

See also

- RS-232
- Teleprinter

External links

- How to make a RS232 Monitor (In French language only) [2]
- Serial interfaces ports of modern and obsolete computers [3]
- Tronisoft's Printable ASCII Serial Port Crib Sheets [4]
- Serial port programming example for Linux and Windows [5]
- Serial port : .NET programming and interface with hardware [6]

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Parallel port

A **parallel port** is a type of interface found on computers (personal and otherwise) for connecting various peripherals. In computing, a parallel port is a parallel communication physical interface. It is also known as a **printer port** or **Centronics port**. The IEEE 1284 standard defines the bi-directional version of the port, which transmits data bits at the same time (in "parallel"). This is the opposite of serial transmission where one bit is transmitted at a time.

A DB-25 parallel printer port, as on IBM-PC style, and a few other types of computers.

History

The Centronics Model 101 printer was introduced in 1970 and included the first parallel interface for printers.[1] The interface was developed by Robert Howard and Prentice Robinson at Centronics. The Centronics parallel interface quickly became a de facto industry standard; manufacturers of the time tended to use various connectors on the system side, so a variety of cables were required. For example, early VAX systems used a DC-37 connector, NCR used the 36-pin micro ribbon connector, Texas Instruments used a 25-pin card edge connector and Data General used a 50-pin micro ribbon connector.

Micro ribbon 36 pin female, such as on printers and on some (particularly industrial and early- and pre-1980s personal) computers.

Dataproducts introduced a very different implementation of the parallel interface for their printers. It used a DC-37 connector on the host side and a 50 pin connector on the printer side—either a DD-50 (sometimes incorrectly referred to as a "DB50") or the block shaped M-50 connector; the

M-50 was also referred to as Winchester.[2] [3] Dataproducts parallel was available in a short-line for connections up to 50 feet (15 m) and a long-line version for connections from 50 feet (15 m) to 500 feet (150 m). The Dataproducts interface was found on many mainframe systems up through the 1990s, and many printer manufacturers offered the Dataproducts interface as an option.

IBM released the IBM Personal Computer in 1981 and included a variant of the Centronics interface— only IBM logo printers (rebranded from Epson) could be used with the IBM PC.[4] IBM standardized the parallel cable with a DB25F connector on the PC side and the Centronics connector on the printer side. Vendors soon released printers compatible with both standard Centronics and the IBM implementation.

IBM implemented an early form of bidirectional interface in 1987. HP introduced their version of bidirectional, known as *Bitronics*, on the LaserJet 4 in 1992. The Bitronics and Centronics interfaces were superseded by the IEEE 1284 standard in 1994.

Uses

Before the advent of USB, the parallel interface was adapted to access a number of peripheral devices other than printers. Probably one of the earliest devices to use parallel were dongles used as a hardware key form of software copy protection. Zip drives and scanners were early implementations followed by external modems, sound cards, webcams, gamepads, joysticks and external hard disk drives and CD-ROM drives. Adapters were available to run SCSI devices via parallel. Other devices such as EPROM programmers and hardware controllers could be connected parallel.

Current use

For consumers, the USB interface—and in some cases Ethernet—has effectively replaced the parallel printer port. Many manufacturers of personal computers and laptops consider parallel to be a legacy port and no longer include the parallel interface. USB-to-parallel adapters are available that can make parallel-only printers work with USB-only systems.

Custom Peripherals

Because of the simplicity of its implementation, the parallel port is often used to interface with custom-made peripherals such as microcontroller programming boards. In this case the peripheral relies on special driver software, installed on the PC, to transmit data. It is not always possible to use USB-to-parallel adapters with these custom peripherals if the driver software depends on exact timing of the data through the port interface.

Implementation on IBM personal computers

Port addresses

Traditionally IBM PC systems have allocated their first three parallel ports according to the configuration in the table below.

PORT NAME	Interrupt #	Starting I/O	Ending I/O
LPT1	IRQ 7	0x3bc	0x3bf
LPT2	IRQ 7	0x378	0x37f
LPT3	IRQ 5	0x278	0x27f

If there is an unused LPTx slot, the port addresses of the others are moved up. (For example, if a port at 0x3bc does not exist, the port at 0x378 will then become LPT1.)[5] The IRQ lines, however, remain fixed (therefore, 0x378 at LPT1 would use IRQ 7). Unfortunately the default IRQ used by the first two addresses is the same, and it's difficult to get correct interrupt behaviour if both of these addresses are in use. The port addresses assigned to each LPTx slot can be determined by reading the BIOS Data Area (BDA) at 0000:0408.

Bit to Pin Mapping for the Standard Parallel Port (SPP):

Address		MSB							LSB
	Bit:	7	6	5	4	3	2	1	0
Base (Data port)	Pin:	9	8	7	6	5	4	3	2
Base+1 (Status port)	Pin:	~11	10	12	13	15			
Base+2 (Control port)	Pin:					~17	16	~14	~1

~ indicates a hardware inversion of the bit.

Program interface

In versions of Windows that did not use the Windows NT kernel (as well as DOS and some other operating systems), programs could access the parallel port with simple outportb() and inportb() subroutine commands. In operating systems such as Windows NT and Unix (NetBSD, FreeBSD, Solaris, 386BSD, etc.), the microprocessor is operated in a different security ring, and access to the parallel port is inhibited, unless using the required driver. This improves security and arbitration of device contention. On Linux, inb() and outb() can be used when a process is run as root and an ioperm() command is used to allow access to its base address.

Pinouts

Pinouts for parallel port connectors are:

Pin No (DB25)	Pin No (36 pin)	Signal name	Direction	Register - bit	Inverted
1	1	*Strobe	In/Out	Control-0	Yes
2	2	Data0	Out	Data-0	No
3	3	Data1	Out	Data-1	No
4	4	Data2	Out	Data-2	No
5	5	Data3	Out	Data-3	No
6	6	Data4	Out	Data-4	No
7	7	Data5	Out	Data-5	No
8	8	Data6	Out	Data-6	No
9	9	Data7	Out	Data-7	No
10	10	Ack	In	Status-6	No

11	11	*Busy	In	Status-7	Yes
12	12	Paper-Out	In	Status-5	No
13	13	Select	In	Status-4	No
14	14	*Linefeed	In/Out	Control-1	Yes
15	32	Error	In	Status-3	No
16	31	Reset	In/Out	Control-2	No
17	36	*Select-Printer	In/Out	Control-3	Yes
18-25	19-30,33,17,16	Ground	-	-	-

* means low true, e.g., *Strobe.

Unidirectional parallel ports

In early parallel ports the data lines were unidirectional (data out only) so it was not easily possible to feed data in to the computer. However, a workaround was possible by using 4 of the 5 status lines. A circuit could be constructed to split each 8-bit byte into two 4-bit nibbles which were fed in sequentially through the status lines. Each pair of nibbles was then re-combined into an 8-bit byte. This same method (with the splitting and recombining done in software) was also used to transfer data between PCs using a laplink cable.

See also

- Parallel communication
- IEEE 1284

References

[1] Webster, Edward C. (2000). *Print Unchained: Fifty Years of Digital Printing: A Saga of Invention and Enterprise*. West Dover, VT: DRA of Vermont. ISBN 0-9702617-0-5.
[2] "Dataproducts D-Sub 50 Parallel" (http://www.hardwarebook.info/Dataproducts_D-Sub_50_Parallel). *Hardware Book*. . Retrieved 2008-01-25.
[3] "Dataproducts M/50 Parallel" (http://www.hardwarebook.info/Dataproducts_M/50_Parallel). *Hardware Book*. . Retrieved 2008-01-25.
[4] Durda IV, Frank (2004). "Centronics and IBM Compatible Parallel Printer Interface Pin Assignment Reference" (http://nemesis.lonestar.org/reference/computers/interfaces/centronics.html). . Retrieved 2007-10-05.
[5] Frank Van Gilluwe, The Undocumented PC, 1994, page 703, ISBN 0-201-62277-7

- Axelson, Jan (2000). *Parallel Port Complete*. Lakeview Research (http://www.lvr.com). ISBN 0-9650819-1-5.
- The (Linux) Parallel Port Subsystem by Tim Waugh (http://kernelbook.sourceforge.net/parportbook.pdf)

External links

- Interfacing to the Standard Parallel Port (http://www.beyondlogic.org/spp/parallel.htm)
- Video on basics of standard parallel port (http://www.lcdinterfacing.info/Parallel-Port-Basics.php)
- Parallel Port programming and interfacing (http://www.globu.net/pp/english/pp/)
- Parallel Port .NET Programming and Interface with Hardware (http://www.thaiio.com/cgi-bin/html/vhtml.pl?name=.NET&topic=2)
- Linux I/O port programming mini-HOWTO (http://www.faqs.org/docs/Linux-mini/IO-Port-Programming.html)
- The Linux 2.4 Parallel Port Subsystem (http://people.redhat.com/twaugh/parport/html/parportguide.html)
- Parallel Port interfacing with Windows NT/2000/XP (http://logix4u.net/Legacy_Ports/Parallel_Port/A_tutorial_on_Parallel_port_Interfacing.html)

- Parallel Port Programming Interface (http://entechtaiwan.net/dev/lpt/index.shtm)

Universal Serial Bus

Universal Serial Bus	
Original logo	
Year created	January 1996
Created by	Intel, Compaq, Microsoft, NEC, Digital Equipment Corporation, IBM, Nortel
Width in bits	1
Number of devices	127 per host controller
Capacity	1.5, 12, 480, or 4000 Mbit/s (0.2, 1.5, 60, 500 MByte/s)
Style	Serial
Hotplugging interface	Yes
External interface	Yes

The OSI/IP Model
7. Application Layer
NNTP · SIP · SSI · DNS · FTP · Gopher · HTTP · NFS · NTP · SMPP · SMTP · DHCP · SNMP · Telnet · (more)
6. Presentation Layer
MIME · XDR · TLS · SSL
5. Session Layer
Named Pipes · NetBIOS · SAP
4. Transport Layer
TCP · UDP · SCTP · DCCP
3. Network Layer
IP · ICMP · IPsec · IGMP · IPX · AppleTalk
2. Data Link Layer
ARP · CSLIP · SLIP · Ethernet · Frame relay · ITU-T G.hn DLL · L2TP · PPP · PPTP
1. Physical Layer
RS-232 · RS-449 · V.35 · V.34 · I.430 · I.431 · T1 · E1 · POTS · SONET/SDH · OTN · DSL · 802.11a/b/g/n PHY · ITU-T G.hn PHY · Ethernet · USB · Bluetooth

USB (**Universal Serial Bus**) (pronounced /ˈjuː.ɛsbiː/ "*YOO-ess-bee*") is a specification[1] to establish communication between devices and a host controller (usually personal computers), developed and invented by Ajay Bhatt while working for Intel.[2] [3] USB is intended to replace many varieties of serial and parallel ports. USB can connect computer peripherals such as mice, keyboards, digital cameras, printers, personal media players, flash drives, and external hard drives. For many of those devices, USB has become the standard connection method. USB was designed for personal computers, but it has become commonplace on other devices such as smartphones, PDAs and video game consoles, and as a power cord between a device and an AC adapter plugged into a wall plug for charging. As of 2008, there are about 2 billion USB devices sold per year, and approximately 6 billion total sold to date.[4]

The basic USB *trident* logo; each released variant has a specific logo variant

A USB Series "A" plug, the most common USB plug.

History

The Universal Serial Bus (USB) is a standard for peripheral devices. It began development in 1994 by a group of seven companies: Compaq, DEC, IBM, Intel, Microsoft, NEC and Nortel. USB was intended to make it fundamentally easier to connect external devices to PCs by replacing the multitude of connectors at the back of PCs, addressing the usability issues of existing interfaces, and simplifying software configuration of all devices connected to USB, as well as permitting greater bandwidths for external devices. The first silicon for USB was made available by Intel in 1995.[5]

The USB 1.0 specification was introduced in January 1996. The original USB 1.0 specification had a data transfer rate of 12 Mbit/s.[5] The first widely used version of USB was 1.1, which was released in September 1998. It allowed for a 12 Mbps data rate for higher-speed devices such as disk drives, and a lower 1.5 Mbps rate for low bandwidth devices such as joysticks.[6]

The USB 2.0 specification was released in April 2000 and was standardized by the USB-IF at the end of 2001. Hewlett-Packard, Intel, Lucent Technologies (now Alcatel-Lucent following its merger with Alcatel in 2006), NEC and Philips jointly led the initiative to develop a higher data transfer rate, with the resulting specification achieving 480 Mbit/s, a fortyfold increase over 12 Mbit/s for the original USB 1.0. data.

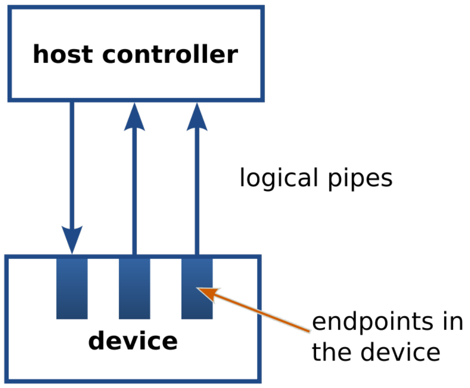
Overview

A USB (Universal Serial Bus) system has an asymmetric design, consisting of a host, a multitude of downstream USB ports, and multiple peripheral devices connected in a tiered-star topology. Additional USB hubs may be included in the tiers, allowing branching into a tree structure with up to five tier levels. A USB host may have multiple host controllers and each host controller may provide one or more USB ports. Up to 127 devices, including hub devices if present, may be connected to a single host controller.

USB devices are linked in series through *hubs*. There always exists one hub known as the root hub, which is built into the host controller. So-called *sharing hubs*, which allow multiple computers to access the same peripheral device(s), also exist and work by switching access between PCs, either automatically or manually. Sharing hubs are popular in small-office environments. In network terms, they converge rather than diverge branches.

A physical USB device may consist of several logical sub-devices that are referred to as *device functions*. A single device may provide several functions, for example, a webcam (video device function) with a built-in microphone (audio device function). Such a device is called a *compound device* in which each logical device is assigned a distinctive address by the host and all logical devices are connected to a built-in hub to which the physical USB wire is connected. A host assigns one and only one device address to a function.

USB device communication is based on *pipes* (logical channels). A pipe is a connection from the host controller to a logical entity, found on a device, and named an endpoint. The term *endpoint* is occasionally incorrectly used for referring to the pipe. However, while an endpoint exists on the device permanently, a pipe is only formed when the host makes a connection to the endpoint. Therefore, when referring to the connection between a host and an endpoint, the term *pipe* should be used. A USB device can have up to 32 active pipes: 16 into the host controller and 16 out of the host controller.



USB endpoints actually reside on the connected device: the channels to the host are referred to as pipes.

There are two types of pipes: stream and message pipes depending on the type of data transfer.

- *isochronous transfers*: at some guaranteed data rate (often, but not necessarily, as fast as possible) but with possible data loss (e.g. realtime audio or video).
- *interrupt transfers*: devices that need guaranteed quick responses (bounded latency) (e.g. pointing devices and keyboards).
- *bulk transfers*: large sporadic transfers using all remaining available bandwidth, but with no guarantees on bandwidth or latency (e.g. file transfers).
- *control transfers*: typically used for short, simple commands to the device, and a status response, used, for example, by the bus control pipe number 0.

A stream pipe is a uni-directional pipe connected to a uni-directional endpoint that transfers data using an *isochronous*, *interrupt*, or *bulk* transfer. A message pipe is a bi-directional pipe connected to a bi-directional endpoint that is exclusively used for *control* data flow. An endpoint is built into the USB device by the manufacturer and therefore exists permanently. An endpoint of a pipe is addressable with tuple *(device_address, endpoint_number)* as specified in a TOKEN packet that the host sends when it wants to start a data transfer session. If the direction of the data transfer is from the host to the endpoint, an OUT packet (a specialization of a TOKEN packet) having the desired device address and endpoint number is sent by the host. If the direction of the data transfer is from the device to the host, the host sends an IN packet instead. If the destination endpoint is a uni-directional endpoint whose manufacturer's designated direction does not match the TOKEN packet (e.g., the manufacturer's designated direction is IN while the TOKEN packet is an OUT packet), the TOKEN packet will be ignored. Otherwise, it will be accepted and the data transaction can start. A bi-directional endpoint, on the other hand, accepts both IN and OUT packets.

Endpoints are grouped into *interfaces* and each interface is associated with a single device function. An exception to this is endpoint zero, which is used for device configuration and which is not associated with any interface. A single device function composed of independently controlled interfaces is called a *composite device*. A composite device only has a single device address because the host only assigns a device address to a function.

Two USB connections on the front of a computer.

When a USB device is first connected to a USB host, the USB device enumeration process is started. The enumeration starts by sending a reset signal to the USB device. The data rate of the USB device is determined during the reset signaling. After reset, the USB device's information is read by the host and the device is assigned a unique 7-bit address. If the device is supported by the host, the device drivers needed for communicating with the device are loaded and the device is set to a configured state. If the USB host is restarted, the enumeration process is repeated for all connected devices.

The host controller directs traffic flow to devices, so no USB device can transfer any data on the bus without an explicit request from the host controller. In USB 2.0, the host controller polls the bus for traffic, usually in a round-robin fashion. The slowest device connected to a controller sets the bandwidth of the interface. For SuperSpeed USB (USB 3.0), connected devices can request service from host. Because there are two separate controllers in each USB 3.0 host, USB 3.0 devices will transmit and receive at USB 3.0 data rates regardless of USB 2.0 or earlier devices connected to that host. Operating data rates for them will be set in the legacy manner.

Device classes

USB defines class codes used to identify a device's functionality and to load a device driver based on that functionality. This enables every device driver writer to support devices from different manufacturers that comply with a given class code.

Device classes include:[7]

Class	Usage	Description	Examples
00h	Device	Unspecified[8]	(Device class is unspecified. Interface descriptors are used for determining the required drivers.)
01h	Interface	Audio	Speaker, microphone, sound card
02h	Both	Communications and CDC Control	Ethernet adapter, modem
03h	Interface	Human Interface Device (HID)	Keyboard, mouse, joystick
05h	Interface	Physical Interface Device (PID)	Force feedback joystick
06h	Interface	Image	Webcam, scanner
07h	Interface	Printer	Laser printer, inkjet printer, CNC machine
08h	Interface	Mass storage	USB flash drive, memory card reader, digital audio player, digital camera, external drive
09h	Device	USB hub	Full bandwidth hub
0Ah	Interface	CDC-Data	(This class is used together with class 02h—Communications and CDC Control.)
0Bh	Interface	Smart Card	USB smart card reader
0Dh	Interface	Content Security	Finger Print Reader
0Eh	Interface	Video	Webcam

0Fh	Interface	Personal Healthcare	Pulse monitor (watch)
DCh	Both	Diagnostic Device	USB compliance testing device
E0h	Interface	Wireless Controller	Wi-Fi adapter, Bluetooth adapter
EFh	Both	Miscellaneous	ActiveSync device
FEh	Interface	Application Specific	IrDA Bridge, Test & Measurement Class (USBTMC),[9] USB DFU (Direct Firmware update)[10]
FFh	Both	Vendor Specific	(This class code indicates that the device needs vendor specific drivers.)

USB mass-storage

A flash drive, a typical USB mass-storage device.

USB implements connections to storage devices using a set of standards called the *USB mass storage device class* (referred to as MSC or UMS). This was initially intended for traditional magnetic and optical drives, but has been extended to support a wide variety of devices, particularly flash drives. This generality is because many systems can be controlled with the familiar metaphor of file manipulation within directories (the process of making a novel device look like a familiar device is also known as extension).

Though most newer computers are capable of booting off USB mass storage devices, USB is not intended to be a primary bus for a computer's internal storage: buses such as ATA (IDE), Serial ATA (SATA), or SCSI fulfill that role in PC class computers. However, USB has one important advantage in that it is possible to install and remove devices without rebooting the computer (hotswapping), making it useful for mobile peripherals, including drives of various kinds. Originally conceived and still used today for optical storage devices (CD-RW drives, DVD drives, etc.), several manufacturers offer external portable USB hard drives, or empty enclosures for disk drives, which offer performance comparable to internal drives, limited by the current number and type of attached USB devices and by the upper limit of the USB interface (in practice about 40 MiB/s for USB 2.0 and perhaps potentially 400 MiB/s or more[11] for USB 3.0). These external drives have typically included a "translating device" that bridges between a drive's interface (IDE, ATA, SATA, PATA, ATAPI, or even SCSI) to a USB interface port. Functionally, the drive appears to the user much like an internal drive. Other competing standards for external drive connectivity include eSATA, ExpressCard (now at version 2.0), and FireWire (IEEE 1394).

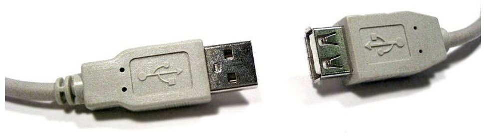
Another use for USB mass storage devices is the portable execution of software applications (such as web browsers and VoIP clients) without requiring installation on the host computer.[12] [13]

Human-interface devices (HIDs)

Mice and keyboards are frequently fitted with USB connectors, but because most PC motherboards still retain PS/2 connectors for the keyboard and mouse as of 2007, they are often supplied with a small USB-to-PS/2 adaptor, allowing use with either USB or PS/2 interface. There is no logic inside these adaptors: they make use of the fact that such HIDs are equipped with controllers that are capable of serving both the USB and the PS/2 protocol, and automatically detect which type of port they are plugged into. Joysticks, keypads, tablets and other human-interface devices are also progressively migrating from MIDI, PC game port, and PS/2 connectors to USB.

Connector properties

The connectors specified by the USB committee were designed to support a number of USB's underlying goals, and to reflect lessons learned from the menagerie of connectors which have been used in the computer industry.



Series "A" plug and receptacle.

Usability and "upside down" connectors

- It is deliberately difficult to attach a USB connector incorrectly. Most connectors cannot be plugged in upside down, and it is clear from the appearance and kinesthetic sensation of making a connection when the plug and socket are correctly mated.
  - However, it is not obvious at a glance to the inexperienced user (or to a user without sight of the installation) whether the connector should be face up or face down, and thus it is often necessary to try both ways. The side of the connector on a USB cable with the "USB Icon" (trident logo) *should* be "visible" to the user during the mating process. Many manufacturers do not, however, make the trident logo on USB cables easily visible or detectable by touch. Further, most USB compatible devices such as PCs do not indicate on the device which way the USB cable should be plugged in. In many Japanese computers and other devices, the trident logo on the cable must be facing down, while in many American computers and devices the logo must be facing up. However, this is not always the case, including in most Dell (an American company) computers. This lack of consistency of the orientation of the USB connectors in computers and other devices means that users have only a 50% chance of plugging in a USB cable correctly the first time, thus resulting in a significant amount of wasted time considering the very large number of USB devices. However, the USB 2.0 specification states that the required USB Icon (trident logo) is to be "embossed" ("engraved" on the accompanying diagram) on the "topside" of the USB plug, which "provides easy user recognition and facilitates alignment during the mating process."[14] The specification also shows that the "recommended" (optional) "Manufacturer's logo" ("engraved" in the diagram but not specified in the text) is on the *opposite* side of the USB Icon. The specification further states "The USB Icon is also located adjacent to each receptacle. Receptacles should be oriented to allow the Icon on the plug to be visible during the mating process." However, the specification does not consider the height of the device compared to the eye level height of the user, so the side of the cable that is "visible" when mated to a computer on a desk can depend on whether the user is standing or kneeling. A clearer specification would be "the USB Icon should face up or to the left during the mating process."
- Only moderate insertion/removal force is needed (by specification). USB cables and small USB devices are held in place by the gripping force from the receptacle (without need of the screws, clips, or thumbturns other connectors have required). The force needed to make or break a connection is modest, allowing connections to be made in awkward circumstances (i.e., behind a floor-mounted chassis, or from below) or by those with motor disabilities. This has the disadvantage of easily and unintentionally breaking connections that one has intended to be permanent in case of cable accident (e.g., tripping, or inadvertent tugging).
- The standard connectors were deliberately intended to enforce the directed topology of a USB network: type A connectors on host devices that supply power and type B connectors on target devices that receive power. This prevents users from accidentally connecting two USB power supplies to each other, which could lead to dangerously high currents, circuit failures, or even fire. USB does not support cyclical networks and the standard connectors from incompatible USB devices are themselves incompatible. Unlike other communications systems (e.g. RJ-45 cabling) gender changers make little sense with USB and are almost never used.

Durability

USB extension cord

- The standard connectors were designed to be robust. Many previous connector designs were fragile, specifying embedded component pins or other delicate parts which proved liable to bending or breaks, even with the application of only very modest force. The electrical contacts in a USB connector are protected by an adjacent plastic tongue, and the entire connecting assembly is usually further protected by an enclosing metal sheath. As a result USB connectors can safely be handled, inserted, and removed, even by a young child.
- The connector construction always ensures that the external sheath on the plug makes contact with its counterpart in the receptacle before any of the four connectors within make electrical contact. The external metallic sheath is typically connected to system ground, thus dissipating any potentially damaging static charges (rather than via delicate electronic components). This enclosure design also means that there is a (moderate) degree of protection from electromagnetic interference afforded to the USB signal while it travels through the mated connector pair (this is the only location when the otherwise twisted data pair must travel a distance in parallel). In addition, because of the required sizes of the power and common connections, they are made after the system ground but before the data connections. This type of staged make-break timing allows for electrically safe hot-swapping and has long been common practice in the design of connectors in the aerospace industry.
- The newer Micro-USB receptacles are designed to allow up to 10,000 cycles of insertion and removal between the receptacle and plug, compared to 1500 for the standard USB and 5000 for the Mini-USB receptacle. This is accomplished by adding a locking device and by moving the leaf-spring connector from the jack to the plug, so that the most-stressed part is on the cable side of the connection. This change was made so that the connector on the (inexpensive) cable would bear the most wear instead of the micro-USB device.

Compatibility

- The USB standard specifies relatively loose tolerances for compliant USB connectors, intending to minimize incompatibilities in connectors produced by different vendors (a goal that has been very successfully achieved). Unlike most other connector standards, the USB specification also defines limits to the size of a connecting device in the area around its plug. This was done to prevent a device from blocking adjacent ports due to the size of the cable strain relief mechanism (usually molding integral with the cable outer insulation) at the connector. Compliant devices must either fit within the size restrictions or support a compliant extension cable which does.
- Two-way communication is also possible. In USB 3.0, full-duplex communications are done when using SuperSpeed (USB 3.0) transfer. In previous USB versions (i.e., 1.x or 2.0), all communication is half-duplex and directionally controlled by the host.

In general, cables have only plugs (very few have a receptacle on one end), and hosts and devices have only receptacles. Hosts almost universally have type-A receptacles, and devices one or another type-B variety. Type-A plugs mate only with type-A receptacles, and type-B with type-B; they are deliberately physically incompatible. However, an extension to USB standard specification called USB On-The-Go allows a single port to act as either a host or a device—chosen by which end of the cable plugs into the receptacle on the unit. Even after the cable is hooked up and the units are talking, the two units may "swap" ends under program control. This capability is meant for units such as PDAs in which the USB link might connect to a PC's host port as a device in one instance, yet connect as a host itself to a keyboard and mouse device in another instance.

- USB 3.0 receptacles are electrically compatible with USB 2.0 device plugs if they can physically match. Most combinations will work, but there are a few physical incompatibilities. However, only USB 3.0 Standard-A receptacles can accept USB 3.0 Standard-A device plugs.

Host Interface receptacles (USB 1.x/2.0)

	Plug				
Receptacle	**USB-A**	**USB-B**	**Mini-B**	**Micro-A**	**Micro-B**
USB-A	Yes	No	No	No	No
USB-B	No	Yes	No	No	No
Mini-B	No	No	Yes	No	No
Micro-AB	No	No	No	Yes	Yes
Micro-B	No	No	No	No	Yes

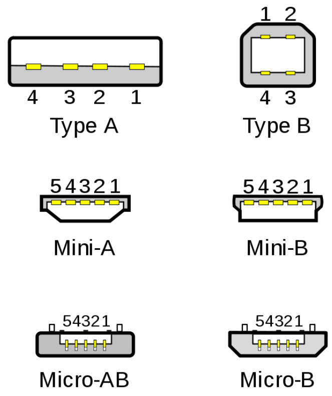
Cable plugs (USB 1.x/2.0)

	Plug				
Plug	**Micro-B**	**Micro-A**	**Mini-B**	**USB-B**	**USB-A**
USB-A	Yes	NS	Yes	Yes	NS
USB-B	No	NS	No	No	
Mini-B	No	NS	No		
Micro-A	Yes	No			
Micro-B	No				

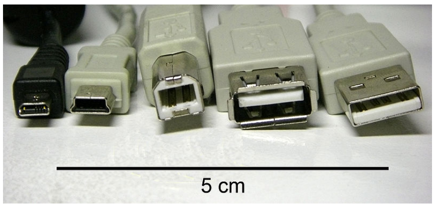
NS: non-standard, existing for specific proprietary purposes, and not interoperable with USB-IF compliant equipment.

In addition to these cable assemblies a cable with Micro-A and Standard-A receptacle is compliant with USB specifications. Other combinations of connectors are not compliant. However, some older devices and cables with Mini-A connector have been certified by USB-IF; the Mini-A connectors have been deprecated though some are still in use, and no new certification for assemblies using Mini-A connector will be allowed.[15]

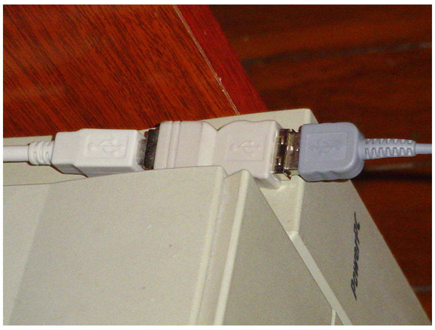
Connector types



Pinouts of Standard, Mini, and Micro USB connectors.(Male)



Different types of USB connectors from left to right:
- male Mini USB (8-pin) B-type
- male Mini USB (5-pin) B-type
- male B-type
- female A-type
- male A-type



B receptor to A receptor plug adapter connecting a beige USB "printer cable" to a grey USB digital camera cable

There are several types of USB connectors, including some that have been added while the specification progressed. The original USB specification detailed Standard-A and Standard-B plugs and receptacles. The first engineering change notice to the USB 2.0 specification added Mini-B plugs and receptacles.

The data connectors in the Standard-A plug are actually recessed in the plug as compared to the outside power connectors. This permits the power to connect first which prevents data errors by allowing the device to power up first and then transfer the data. Some devices will operate in different modes depending on whether the data connection is made. This difference in connection can be exploited by inserting the connector only partially. For example, some battery-powered MP3 players switch into file transfer mode (and cannot play MP3 files) while a USB plug is fully inserted, but can be operated in MP3 playback mode using USB power by inserting the plug only part way so that the power slots make contact while the data slots do not. This enables those devices to be operated in MP3 playback mode while getting power from the cable.

USB-A

The Standard-A type of USB plug is a flattened rectangle which inserts into a "downstream-port" receptacle on the USB host, or a hub, and carries both power and data. This plug is frequently seen on cables that are permanently attached to a device, such as one connecting a keyboard or mouse to the computer via usb connection.

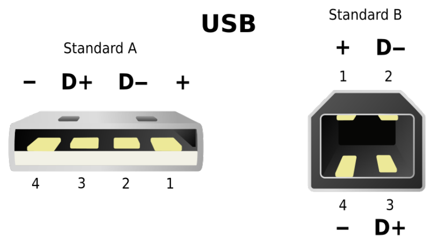
USB connections eventually wear out as the connection loosens through repeated plugging and unplugging. The lifetime of a USB-A male connector is approximately 1,500 connect/disconnect cycles.[16]

There are female-female connectors.

USB-B

A Standard-B plug—which has a square shape with bevelled exterior corners—typically plugs into an "upstream receptacle" on a device that uses a removable cable, e.g. a printer. A Type B plug delivers power in addition to carrying data. On some devices, the Type B receptacle has no data connections, being used solely for accepting power from the upstream device. This two-connector-type scheme (A/B) prevents a user from accidentally creating an electrical loop.[17]

Mini and Micro



Pin configuration of the USB connectors Standard A/B, viewed from face of plug

Various connectors have been used for smaller devices such as PDAs, mobile phones or digital cameras. These include the now-deprecated[15] (but standardized) Mini-A and the currently standard Mini-B,[18] Micro-A, and Micro-B connectors. The Mini-A and Mini-B plugs are approximately 3 by 7 mm, while the Micro plugs have a similar width but approximately half the thickness, enabling their integration into thinner portable devices.

Mini-USB is often used by digital camcorders.

The Micro-USB connector was announced by the USB-IF on January 4, 2007[19] and the Mini-A and Mini-AB USB connectors were deprecated at the same time. As of February 2009, many currently available devices and cables still use Mini plugs, but the newer Micro connectors are being widely adopted. The thinner micro connectors are intended to replace the Mini plugs in new devices including smartphones and personal digital assistants. The Micro plug design is rated for 10,000 connect-disconnect cycles which is significantly more than the Mini plug design.[20] The *Universal Serial Bus Micro-USB Cables and Connectors Specification*[20] details the mechanical characteristics of Micro-A plugs, Micro-AB receptacles, and Micro-B plugs and receptacles, along with a Standard-A receptacle to Micro-A plug adapter.

The cellular phone carrier group, Open Mobile Terminal Platform (OMTP), have recently endorsed Micro-USB as the standard connector for data and power on mobile devices.[21] These include various types of battery chargers, allowing Micro-USB to be the single external cable link needed by some devices. As of Micro-USB has been accepted by almost all cell phone manufacturers as the standard charging port (including Apple, HTC, Motorola, Nokia, LG, Samsung, Sony Ericsson, Research In Motion) in the EU and most of the world. Worldwide conversion to the new cellphone charging standard is expected to be completed between 2010 to 2012.

In addition, on 22 October 2009 the International Telecommunication Union (ITU) announced that it had embraced micro-USB as the *Universal Charger Solution* its "energy-efficient one-charger-fits-all new mobile phone solution", and added: "Based on the Micro-USB interface, UCS chargers will also include a 4-star or higher efficiency rating—up to three times more energy-efficient than an unrated charger."[22]

Micro-AB Socket OTG

An OTG device is required to have one, and only one USB connector: a Micro-AB receptacle as defined in [Micro-USB1.01]. This receptacle is capable of accepting either a Micro-A plug or a Micro-B plug attached to any of the legal cables and adapters defined in [Micro-USB1.01].

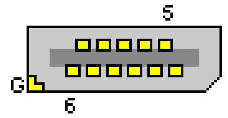
The OTG device with the A-plug inserted is called the A-device and is responsible for powering the USB interface when required and by default assumes the role of host. The OTG device with the B-plug inserted is called the B-device and by default assumes the role of peripheral. An OTG device with no plug inserted defaults to acting as a B-device. If an application on the B-device requires the role of host, then the HNP protocol is used to temporarily transfer the host role to the B-device.

OTG devices attached either to a peripheral-only B-device or a standard/embedded host will have their role fixed by the cable since in these scenarios it is only possible to attach the cable one way around.

Proprietary connectors and formats

- Microsoft's original Xbox game console uses standard USB 1.1 signalling in its controllers and memory cards, but uses proprietary connectors and ports.
- IBM UltraPort uses standard USB signalling, but via a proprietary connection format.
- American Power Conversion uses USB signalling and HID device class on its uninterruptible power supplies using 10P10C connectors.

HTC manufactures Windows Mobile and Android-based Communicators which have a proprietary connector called HTC ExtUSB (Extended USB). ExtUSB combines mini-USB (with which it is backwards-compatible) with audio input as well as audio and video output in an 11-pin connector.



HTC ExtUSB

Nokia includes a USB connection as part of the Pop-Port connector on some older mobile phone models.

Nokia's Pop-Port connector

- The second and third generation iPod Shuffles use a TRRS connector to carry USB, audio, or power signals.
- iriver added a fifth power pin within USB-A plugs for higher power and faster charging, used for the iriver U10 series. A mini-USB version contains a matching extra power pin for the cradle.
- Apple has shipped non-standard USB extension cables with some of their computers, for use with the included Apple USB keyboards. The extension cable's socket is keyed with a small protrusion to prevent the insertion of a standard USB plug, while the Apple USB keyboard's plug has a matching indentation. The indentation on the keyboard's plug does not interfere with insertion into a standard USB socket. Despite the keying, it is still possible to insert standard USB plugs into the extension cord. The protrusion can also be shaved off with an appropriate blade.
- HP Tablet computers use non-standard connectors to transmit the USB signals between the keyboard/mouse unit and the Computer Tablet Unit.
- PDMI (Portable Digital Media Interface) is a 30-pin docking connector for portable devices standardized by ANSI/CEA which includes USB 3.0 "SuperSpeed" and USB 2.0 "High/Standard Speed" with USB-on-the-go, as well as DisplayPort, HDMI CEC, 5 V power, and analog audio.

Cables

USB 1.x/2.0 cable wiring

Pin	Name	Cable color	Description
1	VCC	Red	+5 V
2	D−	White	Data −
3	D+	Green	Data +
4	GND	Black	Ground

The maximum length of a standard USB cable (for USB 2.0 or earlier) is 5.0 metres (16.4 ft). The primary reason for this limit is the maximum allowed round-trip delay of about 1,500 ns. If USB host commands are unanswered by the USB device within the allowed time, the host considers the command lost. When adding USB device response time, delays from the maximum number of hubs added to the delays from connecting cables, the maximum acceptable delay per cable amounts to be 26 ns.[23] The USB 2.0 specification requires cable delay to be less than 5.2 ns per meter (192,000 km/s, which is close to the maximum achievable transmission speed for standard copper cable).[24] This allows for a 5 meter cable. The USB 3.0 standard does not directly specify a maximum cable length, requiring only that all cables meet an electrical specification. For copper wire cabling, some calculations have suggested a maximum length of perhaps 3m. No fiber optic cable designs are known to be under development, but they would be likely to have a much longer maximum allowable length, and more complex construction.

USB 1.x/2.0 Miniplug/Microplug

Pin	Name	Color	Description
1	VCC	Red	+5 V
2	D−	White	Data −
3	D+	Green	Data +
4	ID	none	permits distinction of Micro-A- and Micro-B-Plug Type A: connected to Ground Type B: not connected
5	GND	Black	Signal Ground

The data cables for USB 1.x and USB 2.x use a twisted pair to reduce noise and crosstalk. They are arranged much as in the diagram below. USB 3.0 cables are more complex and employ shielding for some of the added data lines (2 pairs); a shield is added around the pair sketched.

Maximum useful distance

USB 1.1 maximum cable length is 3 metres (9.8 ft) and *USB 2.0* maximum cable length is 5 metres (16 ft).[25] Maximum permitted hubs connected in series is 5. Although a single cable is limited to 5 metres, the *USB 2.0* specification permits up to five USB hubs in a long chain of cables and hubs. This allows for a maximum distance of 30 metres (98 ft) between host and device, using six cables 5 metres (16 ft) long and five hubs. In actual use, since some USB devices have built-in cables for connecting to the hub, the maximum achievable distance is 25 metres (82 ft) + the length of the device's cable. For longer lengths, USB extenders that use CAT5 cable can increase the distance between USB devices up to 50 metres (160 ft).

A method of extending USB beyond 5 metres (16 ft) is by using low resistance cable. The higher cost of USB 2.0 Cat 5 extenders has urged some manufacturers to use other methods to extend USB, such as using built-in USB hubs, and custom low-resistance USB cable. It is important to note that devices which use more bus power, such as USB hard drives and USB scanners will require the use of a powered USB hub at the end of the extension, so that a constant connection will be achieved. If power and data does not have sufficient power then problems can result, such as no connection at all, or intermittent connections during use.

USB 3.0 cable assembly may be of any length as long as all requirements defined in the specification are met. However, maximum bandwidth can be achieved across a maximum cable length of approximately 3 metres.[26]

Power

The USB 1.x and 2.0 specifications provide a 5 V supply on a single wire from which connected USB devices may draw power. The specification provides for no more than 5.25 V and no less than 4.75 V (5 V±5%) between the positive and negative bus power lines. For USB 2.0 the voltage supplied by low-powered hub ports is 4.4 V to 5.25 V.[27]

A unit load is defined as 100 mA in USB 2.0, and was raised to 150 mA in USB 3.0. A maximum of 5 unit loads (500 mA) can be drawn from a port in USB 2.0, which was raised to 6 (900 mA) in USB 3.0. There are two types of devices: low-power and high-power. Low-power devices draw at most 1 unit load, with minimum operating voltage of 4.4 V in USB 2.0, and 4 V in USB 3.0. High-power devices draw the maximum number of unit loads supported by the standard. All devices default as low-power but the device's software may request high-power as long as the power is available on the providing bus.[28]

A bus-powered hub is initialized at 1 unit load and transitions to maximum unit loads after hub configuration is obtained. Any device connected to the hub will draw 1 unit load regardless of the current draw of devices connected to other ports of the hub (i.e. one device connected on a four-port hub will only draw 1 unit load despite the fact that all unit loads are being supplied to the hub).[28]

A self-powered hub will supply maximum supported unit loads to any device connected to it. A battery-powered hub may supply maximum unit loads to ports. In addition, the V_{BUS} will supply 1 unit load upstream for communication if parts of the Hub are powered down.[28]

In *Battery Charging Specification*[29] , new powering modes are added to the USB specification. A host or hub Charging Downstream Port can supply a maximum of 1.5 A when communicating at low-bandwidth or full-bandwidth, a maximum of 900 mA when communicating at high-bandwidth, and as much current as the connector will safely handle when no communication is taking place; USB 2.0 standard-A connectors are rated at 1500 mA by default. A Dedicated Charging Port can supply a maximum of 1.8 A of current at 5.25 V. A portable device can draw up to 1.8 A from a Dedicated Charging Port. The Dedicated Charging Port shorts the D+ and D- pins with a resistance of at most 200Ω. The short disables data transfer, but allows devices to detect the Dedicated Charging Port and allows very simple, high current chargers to be manufactured. The increased current (faster, 9 W charging) will occur once both the host/hub and devices support the new charging specification.

Mobile device charger standards


The Micro-USB interface is a new standard charger for mobile phones.

As of , all new mobile phones applying for a license in China are required to use the USB port as a power port.[30] [31] This was the first standard to use the convention of shorting D+ and D-.[32]

In September 2007, the Open Mobile Terminal Platform group—a forum of mobile network operators and manufacturers such as Nokia, Samsung, Motorola, Sony Ericsson and LG—announced that its members had agreed on micro-USB as the future common connector for mobile devices.[33] [34]

On , the GSM Association announced[35] that they had agreed on a standard charger for mobile phones. The standard connector to be adopted by 17 manufacturers including Nokia, Motorola and Samsung is to be the micro-USB connector (several media reports erroneously reported this as the mini-USB). The new chargers will be much more efficient than existing chargers.[35] Having a standard charger for all phones means that manufacturers will no longer have to supply a charger with every new phone. The basis of the GSMA's Universal Charger Solution (UCS) is the technical recommendation from OMTP and the USB-IF battery charging standard.[36] [37] [38]

On , this was further endorsed by the CTIA – The Wireless Association.[39]

On the European Commission announced an agreement with ten producers that starting in 2010, data-enabled mobile phones sold in the European Union would include a micro-USB connector for recharge.[40] [41]

On the International Telecommunication Union (ITU) announced that it had embraced the Universal Charger Solution as its "energy-efficient one-charger-fits-all new mobile phone solution", and added: "Based on the Micro-USB interface, UCS chargers will also include a 4-star or higher efficiency rating—up to three times more energy-efficient than an unrated charger."[42]

Non-standard devices

USB vacuum cleaner novelty device

Some USB devices require more power than is permitted by the specifications for a single port. This is common for external hard and optical disc drives, and generally for devices with motors or lamps. Such devices can use an external power supply, which is allowed by the standard, or use a dual-input USB cable, one input of which is used for power and data transfer, the other solely for power, which makes the device a non-standard USB device. Some external hubs may, in practice, supply more power to USB devices than required by the specification but a standard-compliant device may not depend on this.

Some non-standard USB devices use the 5 V power supply without participating in a proper USB network which negotiates power draws with the host interface. These are usually referred to as USB decorations. The typical example is a USB-powered keyboard light; fans, mug coolers and heaters, battery chargers, miniature vacuum cleaners, and even miniature lava lamps are available. In most cases, these items contain no digital circuitry, and thus are not Standard compliant USB devices at all. This can theoretically cause problems with some computers; prior to the Battery Charging Specification, the USB specification required that devices connect in a low-power mode (100 mA maximum) and state how much current they need, before switching, with the host's permission, into high-power mode.

In addition to limiting the total average power used by the device, the USB specification limits the inrush current (i.e., that used to charge decoupling and filter capacitors) when the device is first connected. Otherwise, connecting a device could cause problems with the host's internal power. Also, USB devices are required to automatically enter ultra low-power suspend mode when the USB host is suspended. Nevertheless, many USB host interfaces do not cut off the power supply to USB devices when they are suspended since resuming from the suspended state would become a lot more complicated if they did.

There are also devices at the host end that do not support negotiation, such as battery packs that can power USB-powered devices; some provide power, while others pass through the data lines to a host PC. USB power adapters convert utility power and/or another power source (e.g., a car's electrical system) to run attached devices. Some of these devices can supply up to 1 A of current. Without negotiation, the powered USB device is unable to inquire if it is allowed to draw 100 mA, 500 mA, or 1 A.

Powered USB

Powered USB uses standard USB signaling with the addition of extra power lines. It uses four additional pins to supply up to 6 A at either 5 V, 12 V, or 24 V (depending on keying) to peripheral devices. The wires and contacts on the USB portion have been upgraded to support higher current on the 5 V line, as well. This is commonly used in retail systems and provides enough power to operate stationary barcode scanners, printers, pin pads, signature capture devices, etc. This modification of the USB interface is proprietary and was developed by IBM, NCR, and

FCI/Berg. It is essentially two connectors stacked such that the bottom connector accepts a standard USB plug and the top connector takes a power connector.

Sleep-and-charge

Sleep-and-charge USB ports can be used to charge electronic devices even when the computer is switched off.[43]

Signaling

USB supports the following signaling rates:

- A *low-speed* rate of 1.5 Mbit/s (~183 KB/s) is defined by USB 1.0. It is very similar to "full-bandwidth" operation except each bit takes 8 times as long to transmit. It is intended primarily to save cost in low-bandwidth human interface devices (HID) such as keyboards, mice, and joysticks.
- The *full-speed* rate of 12 Mbit/s (~1.43 MB/s) is the basic USB data rate defined by USB 1.1. All USB hubs support full-bandwidth.
- A *high-speed* (USB 2.0) rate of 480 Mbit/s (~57 MB/s) was introduced in 2001. All hi-speed devices are capable of falling back to full-bandwidth operation if necessary; they are backward compatible. Connectors are identical.
- A *SuperSpeed* (USB 3.0) rate of 4800 Mbit/s (~572 MB/s). The written USB 3.0 specification was released by Intel and partners in August 2008. The first USB 3 controller chips were sampled by NEC May 2009 [44] and products using the 3.0 specification arrived beginning in January 2010.[45] USB 3.0 connectors are generally backwards compatible, but include new wiring and full duplex operation. There is some incompatibility with older connectors.

USB signals are transmitted on a twisted-pair data cable with 90Ω ±15% Characteristic impedance,[46] labeled D+ and D−. Prior to USB 3.0, these collectively use half-duplex differential signaling to reduce the effects of electromagnetic noise on longer lines. Transmitted signal levels are 0.0–0.3 volts for low and 2.8–3.6 volts for high in full-bandwidth and low-bandwidth modes, and −10–10 mV for low and 360–440 mV for high in hi-bandwidth mode. In FS mode the cable wires are not terminated, but the HS mode has termination of 45 Ω to ground, or 90 Ω differential to match the data cable impedance, reducing interference due to signal reflections. USB 3.0 introduces two additional pairs of shielded twisted wire and new, mostly interoperable contacts in USB 3.0 cables, for them. They permit the higher data rate, and full duplex operation.

A USB connection is always between a host or hub at the "A" connector end, and a device or hub's "upstream" port at the other end. Originally, this was a "B' connector, preventing erroneous loop connections, but additional upstream connectors were specified, and some cable vendors designed and sold cables which permitted erroneous connections (and potential damage to the circuitry). USB interconnections are not as fool-proof or as simple as originally intended.

The host includes 15 kΩ pull-down resistors on each data line. When no device is connected, this pulls both data lines low into the so-called "single-ended zero" state (SE0 in the USB documentation), and indicates a reset or disconnected connection.

A USB device pulls one of the data lines high with a 1.5 kΩ resistor. This overpowers one of the pull-down resistors in the host and leaves the data lines in an idle state called "J". For USB 1.x, the choice of data line indicates a device's bandwidth support; full-bandwidth devices pull D+ high, while low-bandwidth devices pull D− high.

USB data is transmitted by toggling the data lines between the J state and the opposite K state. USB encodes data using the NRZI convention; a 0 bit is transmitted by toggling the data lines from J to K or vice-versa, while a 1 bit is transmitted by leaving the data lines as-is. To ensure a minimum density of signal transitions, USB uses bit stuffing; an extra 0 bit is inserted into the data stream after any appearance of six consecutive 1 bits. Seven consecutive 1 bits is always an error. USB 3.00 has introduced additional data transmission encodings.

A USB packet begins with an 8-bit synchronization sequence '00000001'. That is, after the initial idle state J, the data lines toggle KJKJKJKK. The final 1 bit (repeated K state) marks the end of the sync pattern and the beginning of the USB frame. For high bandwidth USB, the packet begins with a 32-bit synchronization sequence.

A USB packet's end, called EOP (end-of-packet), is indicated by the transmitter driving 2 bit times of SE0 (D+ and D− both below max) and 1 bit time of J state. After this, the transmitter ceases to drive the D+/D− lines and the aforementioned pull up resistors hold it in the J (idle) state. Sometimes skew due to hubs can add as much as one bit time before the SE0 of the end of packet. This extra bit can also result in a "bit stuff violation" if the six bits before it in the CRC are '1's. This bit should be ignored by receiver.

A USB bus is reset using a prolonged (10 to 20 milliseconds) SE0 signal.

USB 2.0 devices use a special protocol during reset, called "chirping", to negotiate the high bandwidth mode with the host/hub. A device that is HS capable first connects as an FS device (D+ pulled high), but upon receiving a USB RESET (both D+ and D− driven LOW by host for 10 to 20 ms) it pulls the D− line high, known as chirp K. This indicates to the host that the device is high bandwidth. If the host/hub is also HS capable, it chirps (returns alternating J and K states on D− and D+ lines) letting the device know that the hub will operate at high bandwidth. The device has to receive at least 3 sets of KJ chirps before it changes to high bandwidth terminations and begins high bandwidth signaling. Because USB 3.0 uses wiring separate and additional to that used by USB 2.0 and USB 1.x, such bandwidth negotiation is not required.

Clock tolerance is 480.00 Mbit/s ±500 ppm, 12.000 Mbit/s ±2500 ppm, 1.50 Mbit/s ±15000 ppm.

Though high bandwidth devices are commonly referred to as "USB 2.0" and advertised as "up to 480 Mbit/s", not all USB 2.0 devices are high bandwidth. The USB-IF certifies devices and provides licenses to use special marketing logos for either "basic bandwidth" (low and full) or high bandwidth after passing a compliance test and paying a licensing fee. All devices are tested according to the latest specification, so recently compliant low bandwidth devices are also 2.0 devices.

Transfer speeds in practice

The actual throughput currently (2006) of USB 2.0 high bandwidth attained with real-world devices is about two thirds of the maximum theoretical bulk data transfer rate of 53.248 MiB/s, a typical observation being around 28-29 MiB/s. For USB 1.1, an average transfer speed of 880 KiB/s has been observed. Typical high bandwidth USB devices operate at lower data rates, often about 3 MiB/s overall, sometimes up to 10–20 MiB/s.[47]

Data packets

USB communication takes the form of packets. Initially, all packets are sent from the host, via the root hub and possibly more hubs, to devices. Some of those packets direct a device to send some packets in reply.

After the sync field described above, all packets are made of 8-bit bytes, transmitted least-significant bit first. The first byte is a packet identifier (PID) byte. The PID is actually 4 bits; the byte consists of the 4-bit PID followed by its bitwise complement. This redundancy helps detect errors. (Note also that a PID byte contains at most four consecutive 1 bits, and thus will never need bit-stuffing, even when combined with the final 1 bit in the sync byte. However, trailing 1 bits in the PID may require bit-stuffing within the first few bits of the payload.)

USB PID bytes

Type	PID value (msb-first)	Transmitted byte (lsb-first)	Name	Description
Reserved	0000	0000 1111		
Token	1000	0001 1110	**SPLIT**	High-bandwidth (USB 2.0) split transaction
	0100	0010 1101	**PING**	Check if endpoint can accept data (USB 2.0)
Special	1100	0011 1100	**PRE**	Low-bandwidth USB preamble
Handshake			**ERR**	Split transaction error (USB 2.0)
	0010	0100 1011	**ACK**	Data packet accepted
	1010	0101 1010	**NAK**	Data packet not accepted; please retransmit
	0110	0110 1001	**NYET**	Data not ready yet (USB 2.0)
	1110	0111 1000	**STALL**	Transfer impossible; do error recovery
Token	0001	1000 0111	**OUT**	Address for host-to-device transfer
	1001	1001 0110	**IN**	Address for device-to-host transfer
	0101	1010 0101	**SOF**	Start of frame marker (sent each ms)
	1101	1011 0100	**SETUP**	Address for host-to-device control transfer
Data	0011	1100 0011	**DATA0**	Even-numbered data packet
	1011	1101 0010	**DATA1**	Odd-numbered data packet
	0111	1110 0001	**DATA2**	Data packet for high-bandwidth isochronous transfer (USB 2.0)
	1111	1111 0000	**MDATA**	Data packet for high-bandwidth isochronous transfer (USB 2.0)

Packets come in three basic types, each with a different format and CRC (cyclic redundancy check):

Handshake packets

Handshake packets consist of nothing but a PID byte, and are generally sent in response to data packets. The three basic types are *ACK*, indicating that data was successfully received, *NAK*, indicating that the data cannot be received at this time and should be retried, and *STALL*, indicating that the device has an error and will never be able to successfully transfer data until some corrective action (such as device initialization) is performed.

USB 2.0 added two additional handshake packets, *NYET* which indicates that a split transaction is not yet complete. A NYET packet is also used to tell the host that the receiver has accepted a data packet, but cannot accept any more due to buffers being full. The host will then send PING packets and will continue with data packets once the device ACK's the PING. The other packet added was the *ERR* handshake to indicate that a split transaction failed.

The only handshake packet the USB host may generate is ACK; if it is not ready to receive data, it should not instruct a device to send any.

Token packets

Token packets consist of a PID byte followed by 2 payload bytes: 11 bits of address and a 5-bit CRC. Tokens are only sent by the host, never a device.

IN and *OUT* tokens contain a 7-bit device number and 4-bit function number (for multifunction devices) and command the device to transmit DATAx packets, or receive the following DATAx packets, respectively.

An IN token expects a response from a device. The response may be a NAK or STALL response, or a DATAx frame. In the latter case, the host issues an ACK handshake if appropriate.

An OUT token is followed immediately by a DATAx frame. The device responds with ACK, NAK, NYET, or STALL, as appropriate.

SETUP operates much like an OUT token, but is used for initial device setup. It is followed by an 8-byte DATA0 frame with a standardized format.

Every millisecond (12000 full-bandwidth bit times), the USB host transmits a special *SOF* (start of frame) token, containing an 11-bit incrementing frame number in place of a device address. This is used to synchronize isochronous data flows. High-bandwidth USB 2.0 devices receive 7 additional duplicate SOF tokens per frame, each introducing a 125 µs "microframe" (60000 high-bandwidth bit times each).

USB 2.0 added a *PING* token, which asks a device if it is ready to receive an OUT/DATA packet pair. The device responds with ACK, NAK, or STALL, as appropriate. This avoids the need to send the DATA packet if the device knows that it will just respond with NAK.

USB 2.0 also added a larger 3-byte *SPLIT* token with a 7-bit hub number, 12 bits of control flags, and a 5-bit CRC. This is used to perform split transactions. Rather than tie up the high-bandwidth USB bus sending data to a slower USB device, the nearest high-bandwidth capable hub receives a SPLIT token followed by one or two USB packets at high bandwidth, performs the data transfer at full or low bandwidth, and provides the response at high bandwidth when prompted by a second SPLIT token. The details are complex; see the USB specification.

Data packets

A data packet consists of the PID followed by 0–1023 bytes of data payload (up to 1024 in high bandwidth, at most 8 at low bandwidth), and a 16-bit CRC.

There are two basic data packets, *DATA0* and *DATA1*. They must always be preceded by an address token, and are usually followed by a handshake token from the receiver back to the transmitter. The two packet types provide the 1-bit sequence number required by Stop-and-wait ARQ. If a USB host does not receive a response (such as an ACK) for data it has transmitted, it does not know if the data was received or not; the data might have been lost in transit, or it might have been received but the handshake response was lost.

To solve this problem, the device keeps track of the type of DATAx packet it last accepted. If it receives another DATAx packet of the same type, it is acknowledged but ignored as a duplicate. Only a DATAx packet of the opposite type is actually received.

When a device is reset with a SETUP packet, it expects an 8-byte DATA0 packet next.

USB 2.0 added *DATA2* and *MDATA* packet types as well. They are used only by high-bandwidth devices doing high-bandwidth isochronous transfers which need to transfer more than 1024 bytes per 125 µs "microframe" (8192 kB/s).

PRE "packet"

Low-bandwidth devices are supported with a special PID value, *PRE*. This marks the beginning of a low-bandwidth packet, and is used by hubs which normally do not send full-bandwidth packets to low-bandwidth devices. Since all PID bytes include four 0 bits, they leave the bus in the full-bandwidth K state, which is the same as the low-bandwidth J state. It is followed by a brief pause during which hubs enable their low-bandwidth outputs, already idling in the J state, then a low-bandwidth packet follows, beginning with a sync sequence and PID byte, and ending with a brief period of SE0. Full-bandwidth devices other than hubs can simply ignore the PRE packet and its low-bandwidth contents, until the final SE0 indicates that a new packet follows.

Protocol analyzers

Due to the complexities of the USB protocol, USB protocol analyzers are invaluable tools to USB device developers. USB analyzers are able to capture the data on USB and display information from low-level bus states to high-level data packets and class-level information.

Comparisons with other device connection technologies

FireWire

USB was originally seen as a complement to FireWire (IEEE 1394), which was designed as a high-bandwidth serial bus which could efficiently interconnect peripherals such as hard disks, audio interfaces, and video equipment. USB originally operated at a far lower data rate and used much simpler hardware, and was suitable for small peripherals such as keyboards and mice.

The most significant technical differences between FireWire and USB include the following:

- USB networks use a tiered-star topology, while FireWire networks use a tree topology.
- USB 1.0, 1.1 and 2.0 use a "speak-when-spoken-to" protocol; peripherals cannot communicate with the host unless the host specifically requests communication. USB 3.0 is planned to allow for device-initiated communications towards the host (see USB 3.0 below). A FireWire device can communicate with any other node at any time, subject to network conditions.
- A USB network relies on a single host at the top of the tree to control the network. In a FireWire network, any capable node can control the network.
- USB runs with a 5 V power line, while Firewire in current implementations supplies 12 V and theoretically can supply up to 30 V.
- Standard USB hub ports can provide from the typical 500 mA[2.5 Watts] of current, only 100 mA from non-hub ports. USB 3.0 & USB On-The-Go supply 1800 mA[9.0W] (for dedicated battery charging, 1500 mA[7.5W] Full bandwidth or 900 mA[4.5W] High Bandwidth), while FireWire can in theory supply up to 60 watts of power, although 10 to 20 watts is more typical.

These and other differences reflect the differing design goals of the two buses: USB was designed for simplicity and low cost, while FireWire was designed for high performance, particularly in time-sensitive applications such as audio and video. Although similar in theoretical maximum transfer rate, FireWire 400 is faster than USB 2.0 Hi-Bandwidth in real-use,[48] especially in high-bandwidth use such as external hard-drives.[49] [50] [51] [52] The newer FireWire 800 standard is twice as fast as FireWire 400 and faster than USB 2.0 Hi-Bandwidth both theoretically and practically.[53] The chipset and drivers used to implement USB and Firewire have a crucial impact on how much of the bandwidth prescribed by the specification is achieved in the real world, along with compatibility with peripherals.[54]

Ethernet

The IEEE 802.3af Power over Ethernet (PoE) standard has a more elaborate power negotiation scheme than powered USB. It operates at 48 VDC and can supply more power (up to 15.4 W) over greater distances than USB 2.0 can at 5 V. This has made PoE popular for VoIP telephones, security cameras, wireless access points and other networked devices within buildings. However, USB is cheaper than PoE.

Ethernet requires electrical isolation between the networked device (computer, phone, etc) and the network cable up to 1500 VAC or 2250 VDC for 60 seconds. [55] USB has no such requirement as it was designed for peripherals closely associated with a host computer, and in fact it connects the peripheral and host grounds. This gives Ethernet a significant safety advantage over USB with peripherals such as cable and DSL modems connected to external wiring that can assume hazardous voltages under certain fault conditions. [56]

Digital musical instruments

Digital musical instruments are another example of where USB is competitive for low-cost devices. However power over ethernet and the MIDI plug standard are preferred in high-end devices that must work with long cables. USB can cause ground loop problems in audio equipment because it connects the ground signals on both transceivers. By contrast, the MIDI plug standard and ethernet have built-in isolation to 500V or more.

eSATA

The eSATA connector is a more robust SATA connector, intended for connection to external hard drives and SSDs. It has a far higher transfer rate (3Gbps, bi-directional) than USB 2.0. A device connected by eSATA appears as an ordinary SATA device, giving both full performance and full compatibility associated with internal drives.

eSATA does not supply power to external devices. This may seem as a disadvantage compared to USB, but in fact USB's 2.5W is usually insufficient to power external hard drives. eSATAp (power over eSATA) is a new (2009) standard that supplies sufficient power to attached devices using a new, backwards-compatible, connector.

eSATA, like USB, supports hot plugging, although this might be limited by OS drivers.

Version history

Prereleases

- *USB 0.7*: Released in November 1994.
- *USB 0.8*: Released in December 1994.
- *USB 0.9*: Released in April 1995.
- *USB 0.99*: Released in August 1995.
- *USB 1.0 Release Candidate*: Released in November 1995.

USB 1.0

- *USB 1.0*: Released in January 1996.
  Specified data rates of *1.5 Mbit/s* (*Low-Bandwidth*) and *12 Mbit/s* (*Full-Bandwidth*). Does not allow for extension cables or pass-through monitors (due to timing and power limitations). Few such devices actually made it to market.
- *USB 1.1*: Released in September 1998.
  Fixed problems identified in 1.0, mostly relating to hubs. Earliest revision to be widely adopted.

USB 2.0

- *USB 2.0*: Released in April 2000.
  Added higher maximum bandwidth of *480 Mbit/s* (now called *"Hi-Speed"*). Further modifications to the USB specification have been done via Engineering Change Notices (ECN). The most important of these ECNs are included into the USB 2.0 specification package available from USB.org [57]:

The Hi-Speed USB Logo

  - *Mini-B Connector ECN*: Released in October 2000.
    Specifications for Mini-B plug and receptacle. These should not be confused with Micro-B plug and receptacle.
  - *Errata as of December 2000*: Released in December 2000.
  - *Pull-up/Pull-down Resistors ECN*: Released in May 2002.
  - *Errata as of May 2002*: Released in May 2002.
  - *Interface Associations ECN*: Released in May 2003.
    New standard descriptor was added that allows multiple interfaces to be associated with a single device function.
  - *Rounded Chamfer ECN*: Released in October 2003.
    A recommended, compatible change to Mini-B plugs that results in longer lasting connectors.
  - *Unicode ECN*: Released in February 2005.
    This ECN specifies that strings are encoded using UTF-16LE. USB 2.0 did specify that Unicode is to be used but it did not specify the encoding.
  - *Inter-Chip USB Supplement*: Released in March 2006.
  - *On-The-Go Supplement 1.3*: Released in December 2006.
    USB On-The-Go makes it possible for two USB devices to communicate with each other without requiring a separate USB host. In practice, one of the USB devices acts as a host for the other device.
  - *Battery Charging Specification 1.1*: Released in March 2007 (Updated 15 Apr 2009).
    Adds support for dedicated chargers (power supplies with USB connectors), host chargers (USB hosts that can act as chargers) and the No Dead Battery provision which allows devices to temporarily draw 100 mA current after they have been attached. If a USB device is connected to dedicated charger, maximum current drawn by the device may be as high as 1.8A. (Note that this document is not distributed with USB 2.0 specification package only USB 3.0 and USB On-The-Go.)
  - *Micro-USB Cables and Connectors Specification 1.01*: Released in April 2007.
  - *Link Power Management Addendum ECN*: Released in July 2007.
    This adds a new power state between enabled and suspended states. Device in this state is not required to reduce its power consumption. However, switching between enabled and sleep states is much faster than switching between enabled and suspended states, which allows devices to sleep while idle.

USB 3.0

The USB 3.0 Promoter Group announced on November 17, 2008, that version 3.0 of the specification had been completed and was transitioned to the USB Implementers Forum (USB-IF), the managing body of USB specifications.[58] This move effectively opened the specification to hardware developers for implementation in future products. The first certified USB 3.0 consumer products were announced January 5, 2010, at the Las Vegas Consumer Electronics Show (CES), including two motherboards by ASUS and Gigabyte Technology.[59] [60]

Features

A new major feature is the *"SuperSpeed"* bus, which provides a fourth transfer mode at 5.0 Gbit/s. The raw throughput is 4 Gbit/s, and the specification considers it reasonable to achieve 3.2 Gbit/s (0.4 GByte/s or 400 MByte/s), or more, after protocol overhead.[61]

When operating in SuperSpeed mode, full-duplex signaling occurs over two differential pairs separate from the non-SuperSpeed differential pair. This results in USB 3.0 cables containing two wires for power and ground, two wires for non-SuperSpeed data, and four wires for SuperSpeed data, and a shield that was not required in previous specifications.[62]

To accommodate the additional pins for SuperSpeed mode, the physical form factors for USB 3.0 plugs and receptacles have been modified from those used in previous versions. Standard-A cables have extended heads where the SuperSpeed connectors extend beyond and slightly above the legacy connectors. Similarly, the Standard-A receptacle is deeper to accept these new connectors. On the other end, the SuperSpeed Standard-B connectors are placed on top of the existing form factor. A legacy standard A-to-B cable will work as designed and will never contact any of the SuperSpeed connectors, ensuring backward compatibility. SuperSpeed standard A plugs will fit legacy A receptacles, but SuperSpeed standard B plugs will not fit into legacy standard B receptacles, so a new cable can be used to connect a new device to an old host, but not to connect a new host to an old device; for that, a legacy standard A-to-B cable will be required.[63]

SuperSpeed establishes a communications pipe between the host and each device, in a host-directed protocol. In contrast, USB 2.0 broadcasts packet traffic to all devices.

USB 3.0 extends the bulk transfer type in SuperSpeed with Streams. This extension allows a host and device to create and transfer multiple streams of data through a single bulk pipe.

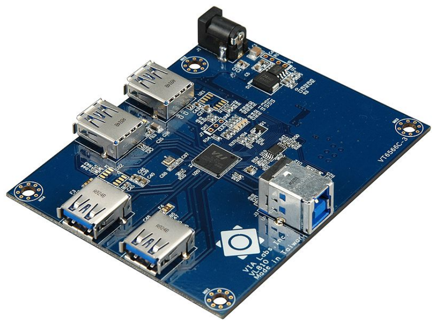
New power management features include support of idle, sleep and suspend states, as well as link-, device-, and function-level power management.

The bus power spec has been increased so that a unit load is 150 mA (+50% over minimum using USB 2.0). An unconfigured device can still draw only one unit load, but a configured device can draw up to six unit loads (900 mA, an 80% increase over USB 2.0 at a registered maximum of 500 mA). Minimum device operating voltage is dropped from 4.4 V to 4 V.

USB 3.0 does not define cable assembly lengths, except that it can be of any length as long as it meets all the requirements defined in the specification. Although electronicdesign.com estimated cables will be limited to 3 m at SuperSpeed[26] , cables which support SuperSpeed are already available up to 5 m in length. [64] [65]

The technology is similar to a single channel ("1×") of PCI Express 2.0 (5 Gbit/s). It uses 8B/10B encoding, linear feedback shift register (LFSR) scrambling for data and spread spectrum. It forces receivers to use low frequency periodic signaling (LFPS), dynamic equalization, and training sequences to ensure fast signal locking.

Availability



USB 3.0 hub demonstration board using the VIA VL810 chip

Consumer products became available in January 2010.[59] [60] 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 on the market.[66]

On January 5, 2010, USB-IF announced the first two certified USB 3.0 motherboards, one by Asus and one by Gigabyte.[60] [67] Previous announcements included Gigabyte's October 2009 list of seven P55 chipset USB 3.0 motherboards,[68] and an ASUS motherboard that was canceled before production.[69]

Commercial controllers are expected to enter into volume production in the first quarter of 2010.[70] On September 24, 2009 Freecom announced a USB 3.0 external hard drive.[71] On January 4, 2010, Seagate announced a small portable HDD with PC Card targeted for laptops (or desktop with PC Card slot addition) at the CES in Las Vegas.[72] [73]

Drivers are under development for Windows 7, but support was not included with the initial release of the operating system.[74] The Linux kernel has supported USB 3.0 since version 2.6.31, which was released in September 2009.[75] [76] [77]

Intel will not support USB 3.0 until 2011,[78] which will slow down mainstream adoption. These delays may be due to problems in the CMOS manufacturing process,[79] a focus to advance the Nehalem platform,[80] a wait to mature all the 3.0 connections standards (USB3, PCIe3, SATA3.0) before developing a new chip set,[81] [82] or a tactic by Intel to boost its upcoming Light Peak interface.[83] Current AMD roadmaps indicate that the new southbridges released in the beginning of 2010 will not support USB 3.0.[79] Market researcher In-Stat predicts a relevant market share of USB 3.0 not until 2011.[84]

USB 2.0 data rates

The theoretical maximum data rate in USB 2.0 is 480 Mbit/s (60 MB/s) per controller and is shared amongst all attached devices. Some chipset manufacturers overcome this bottleneck by providing multiple USB 2.0 controllers within the southbridge. Big performance gains can be achieved when attaching multiple high bandwidth USB devices such as disk enclosures in different controllers. The following table displays southbridge ICs that have multiple EHCI controllers.

Vendor	Southbridge	USB 2.0 ports	EHCI controllers	Maximum data rate
AMD	SB7x0/SP5100	12	2	120 MB/s
AMD	SB8x0	14	3	180 MB/s
Broadcom	HT1100	12	3	180 MB/s
Intel	ICH8	10	2	120 MB/s
Intel	ICH9	12	2	120 MB/s
Intel	ICH10	12	2	120 MB/s
Intel	PCH	8/12/14	2	120 MB/s
nVIDIA	ION/ION-LE	12	2	120 MB/s

Every other AMD, Broadcom, and Intel southbridge supporting USB 2.0 has only one EHCI controller. All SiS southbridge, ULi, and VIA southbridge, single chip northbridge/southbridge supporting USB 2.0 have only one EHCI controller. Also all PCI USB 2.0 ICs used for add-in cards have only one EHCI controller. Despite that some card manufacturers offer improved cards which have 2 PCI USB 2.0 ICs attached to one PCI to PCI bridge. In PCIe, the usual design with multiple USB ports per EHCI controller has changed with the introduction of the MosChip MCS9990 IC. MCS9990 has one EHCI controller per port so all its USB ports can operate simultaneously without any performance limitations. Dual IC cards have been introduced as well and come with 2 PCI USB 2.0 ICs attached to one PCI to PCIe bridge.

Related technologies

The PictBridge standard allows for interconnecting consumer imaging devices. It typically uses USB for its underlying communication layer.

The USB Implementers Forum is working on a wireless networking standard based on the USB protocol. Wireless USB is intended as a cable-replacement technology, and will use ultra-wideband wireless technology for data rates of up to 480 Mbit/s.

See also

- CEA-936-A
- DE-9 connector
- Enhanced mini-USB
- Ethernet over USB
- FireWire
- HCI (UHCI, EHCI {xHCI 0.9 SuperSpeed - USB 3.0}, WHCI 1.0,)
- HP-HIL
- HP-IL
- List of device bandwidths
  - ACCESS.bus
  - Apple Desktop Bus
- PortableApps.com
- PS/2 connector
- RS-232
- Secure USB drive
- Serial ATA
- Serial cable (Bidirectional Communication)
- Serial null modem cable
- Sync cable
- U3
- USB Attached SCSI
- USB On-The-Go (master / slave)
- USB streaming
- Wireless USB
- Light Peak

External links

- USB offical website (USB Implementers Forum, Inc.) [85]
  - USB specifications and other documents [86]
    - USB 2.0 specification (.zip file) [87]
    - USB 3.0 specification (.zip file) [88]
  - Wireless USB specification and other documents [89]
  - USB Device Class documentation [90]
- USB Overview and Plug / Receptacle Pinouts. [91]
- Overview comparison between USB 2.0 and FireWire 400 [92]
- Intel Universal Host Controller Interface (UHCI) [93]
- USB Protocol Analyzer [94]

USB 3.0

- [USB 3.0 specification (.zip file) [88]]
- USB Promoter Group - Mission Statement [95] at the Wayback Machine.
- Intel announces, demonstrates USB 3.0 [96] Ars Technica 2007-09-18
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- www.everythingusb.com [99] Large FAQ
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