Hard disk drive

A **hard disk drive** (**HDD**), **hard disk**, **hard drive**, or **fixed disk**, is an electro-mechanical data storage device that stores and retrieves digital data using magnetic storage with one or more rigidrapidly rotating platters coated with magnetic material. The platters
are paired with magnetic heads, usually arranged on a moving actuator arm, which read and write data to the platter surfaces. Data is accessed in a random-access manner, meaning that individual blocks of data can be stored and retrieved in any order.
HDDs are a type of non-volatile storage, retaining stored data when powered off. Modern HDDs are typically in the form of a small rectangular box.

Hard disk drives were introduced by IBM in 1956, and were the dominant secondary storage device for general-purpose computers beginning in the early 1960s. HDDs maintained this position into the modern era of servers and personal computers, though personal computing devices produced in large volume, like mobile phones and tablets, rely on flash memory storage devices.

The revenues for SSDs, most of which use NAND flash memory, slightly exceeded those for HDDs.
Though SSDs have four to nine times higher cost per bit, they are replacing HDDs in applications where speed, power consumption, small size, high capacity and durability are important. As of 2019, the cost per bit of SSDs is falling, and the price premium over HDDs has narrowed.

The primary characteristics of an HDD are its capacity and performance. Capacity is specified in unit prefixes corresponding to powers of 1000: a 1-terabyte (TB) drive has a capacity of 1,000 gigabytes, where 1 gigabyte = 1 000 megabytes = 1 000 000 kilobytes (1 million) = 1 000 000 000 bytes (1 billion). Typically, some of an HDD's capacity is unavailable to the user because it is used by the file system and the computer operating system, and possibly inbuilt redundancy for error correction and recovery. There can be confusion regarding storage capacity, since capacities are stated in decimal gigabytes (powers of 1000) by HDD manufacturers, whereas the most commonly used operating systems report capacities in powers of 1024, which results in a smaller number than advertised. Performance is specified as the time required to move the heads to a track or cylinder (average access time), the time it takes for the desired sector to move under the head (average latency, which is a function of the physical rotational speed in revolutions per minute), and finally, the speed at which the data is transmitted (data rate).

The two most common form factors for modern HDDs are 3.5-inch, for desktop computers, and 2.5-inch, primarily for laptops. HDDs are connected to systems by standard interface cables such as SATA (Serial ATA), USB, SAS (Serial Attached SCSI), or PATA (Parallel ATA) cables

Technology

Magnetic recording

A modern HDD records data by magnetizing a thin film of ferromagnetic material on both sides of a disk. Sequential changes in the direction of magnetization represent binary data bits. The data is read from the disk by detecting the transitions in magnetization. User data is encoded using an encoding scheme, a typical HDD design consists of a *spindle* that holds flat circular disks, called platters, which hold the recorded data. The platters are made from a non-magnetic material, usually aluminum alloy, glass, or ceramic. They are coated with a shallow layer of magnetic material

The platters in contemporary HDDs are spun at speeds varying from 4,200 RPM in energy-efficient portable devices, to 15,000 rpm for high-performance servers. Information is written to and read from a platter as it rotates past devices called read-and-write heads that are positioned to operate very close to the magnetic surface. In modern drives, 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.

Components

A typical HDD has two electric motors: a spindle motor that spins the disks and an actuator (motor) thatpositions the read/write head assembly across the spinning disks. The disk motor has an external rotor attached to the disks; the stator windings are fixed inplace. Opposite the actuatorat the end of the head support arm is the read-write head; thin printed-circuit cables connect the read-write heads to amplifier electronics mounted at thepivot of the actuator. The head support arm is very light, but also stiff; in modern drives, acceleration at the head reaches 550 *g*.

The *actuator* is a permanent magnet and moving coil motor that swings the heads to the desired position

The HDD's electronics controls the movement of the actuator and the rotation of the disk and transfers data to/from a disk controller.

Capacity

The highest-capacity HDDs shipping commercially in 2024 are 32 TB The capacity of a hard disk drive, as reported by an operating system to the end user, is smaller than the amount stated by the manufacturer for several reasons, e.g. the operating system using some space, use of some space for data redundancy, space use for file system structures. Confusion of decimal prefixes and binary prefixes can also lead to errors.

Formatting

Data is stored on a hard drive in a series of logical blocks. Each block is delimited by markers identifying its start and end, error detecting and correcting information, and space between blocks to allow for minor timing variations. These blocks often contained 512 bytes of usable data, but other sizes have been used.

The process of initializing these logical blocks on the physical disk platters is called *low-level formatting*, which is usually performed at the factory and is not normally changed in the field. *High-level formatting* writes data structures used by the operating system to organize data files on the disk. This includes writing partition and file system structures into selected logical blocks. For example, some of the disk space will be used to hold a directory of disk file names and a list of logical blocks associated with a particular file. Examples of partition mapping scheme include Master boot record (MBR) and GUID Partition Table (GPT). Examples of data structures stored on disk to retrieve files include the File Allocation Table (FAT) in the DOS file system and inodes in many UNIX file systems, as well as other operating system data structures (also known as metadata). As a consequence, not all the space on an HDD is available for user files, but this system overhead is usually small compared with user data.

Performance characteristics

The factors that limit the time to access the data on an HDD are mostly related to the mechanical nature of the rotating disks and moving heads, including:

- Seek time is a measure of how long it takes the head assembly to travel to the track of the disk that contains data.
- Rotational latency is incurred because the desired disk sector may not be directly under the head when data transfer is requested. Average rotational latency is shown in the table, based on the statistical relation that the average latency is one-half the rotational period.
- The bit rate or data transfer rate (once the head is in the right position) creates delay which is a function of the number of blocks transferred; typically relatively small, but can be quite long with the transfer of large contiguous files.

Delay may also occur if the drive disks are stopped to save energy.

Defragmentation is a procedure used to minimize delay in retrieving data by moving related items to physically proximate areas on the disk. Some computer operating systems perform defragmentation automatically. Although automatic defragmentation is intended to reduce access delays, performance will be temporarily reduced while the procedure is in progress.

HDD data transfer rate depends upon the rotational speed of the platters and the data recording density. Because heat and vibration limit rotational speed, advancing density becomes the main method to improve sequential transfer rates. Higher speeds require a more powerful spindle motor, which creates more heat.

Current hard drives connect to a computer over one of several bus types, including parallel ATA, Serial ATA, SCSI, Serial Attached SCSI (SAS), and Fibre Channel. Some drives, especially external portable drives, use IEEE 1394, or USB. All of these interfaces are

digital; electronics on the drive process the analog signals from the read/write heads Modern interfaces connect the drive to the host interface with a single data/control cable. Each drive also has an additional power cable, usually direct to the power supply unit. Older interfaces had separate cables for data signals and for drive control signals.

Market segments

Desktop HDDs

Desktop HDDs typically rotate at 5,400 to 10,000 rpm, and have a media transfer rate of 0.5 Gbit/s or higher the typical speed of a hard drive in an average desktop computer is 7,200 RPM, whereas low-cost desktop computers may use 5,900 RPM or 5,400 RPM drives.

Mobile (laptop) HDDs

Smaller than their desktop and enterprise counterparts, they tend to be slower and have lower capacity, because typically were 2.5" or 1.8" physical size instead of more common for desktops 3.5" form-factor. Mobile HDDs spin at 4,200 rpm to 5400 rpm

Consumer electronics HDDs

These drives typically spin at 5400 RPM and include:

- **Video hard drives**, sometimes called "**surveillance hard drives**", are embedded into digital video recorders and provide a guaranteed streaming capacity, even in the face of read and write errors.
- Drives embedded into automotive vehicles; they are typically built to resist larger amounts of shock and operate over a larger temperature range.

External and portable HDDs

Current external hard disk drives typically connect via USB-C; earlier models use USB-B (sometimes with using of a pair of ports for better bandwidth) or (rarely) eSATA connection. Variants using USB 2.0 interface generally have slower data transfer rates when compared to internally mounted hard drives connected through SATA. Plug and play drive functionality offers system compatibility and features large storage options and portable design.

Competition from SSDs

HDDs are being superseded by solid-state drives (SSDs) in markets where the higher speed (up to 7 gigabytes per second for and 2.5 gigabytes per second for PCIe expansion card drives), ruggedness, and lower power of SSDs are more important than price, since the bit cost of SSDs is four to nine times higher than HDDs. However, SSDs have more un-correctable data errors than HDDs. SSDs offer larger capacities (up to 100 TB) than the largest HDD and/or higher storage densities (100 TB and 30 TB SSDs are housed in 2.5 inch HDD cases but with the same height as a 3.5-inch HDD) although their cost remains prohibitive.