# Solid-state drive

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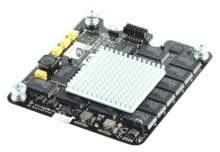
[Jump to navigation](https://en.wikipedia.org/wiki/Solid-state_drive" \l "mw-head) [Jump to search](https://en.wikipedia.org/wiki/Solid-state_drive" \l "p-search)

"SSD" redirects here. For other uses, see [SSD (disambiguation)](https://en.wikipedia.org/wiki/SSD_(disambiguation)).

"Electronic disk" redirects here. For other uses, see [Electronic disk (disambiguation)](https://en.wikipedia.org/wiki/Electronic_disk_(disambiguation)).

Solid-state drive

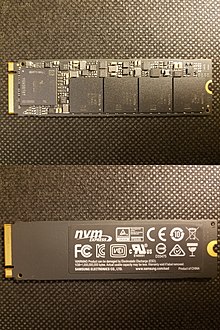
|  |  |
| --- | --- |
| A [Super Talent Technology](https://en.wikipedia.org/wiki/Super_Talent_Technology) 2.5" [Serial ATA](https://en.wikipedia.org/wiki/Serial_ATA) solid-state drive | |
| Date invented | 1978; 41 years ago |
| Invented by | [Storage Technology Corporation](https://en.wikipedia.org/wiki/Storage_Technology_Corporation) |



A PCI-attached [IO Accelerator](https://en.wikipedia.org/wiki/IO_Accelerator) SSD



An [mSATA](https://en.wikipedia.org/wiki/MSATA) SSD with an external enclosure



512GB [Samsung](https://en.wikipedia.org/wiki/Samsung) 960 PRO NVMe M.2 SSD

A **solid-state drive** (**SSD**) is a [solid-state storage](https://en.wikipedia.org/wiki/Solid-state_storage) device that uses [integrated circuit](https://en.wikipedia.org/wiki/Integrated_circuit) assemblies as [memory](https://en.wikipedia.org/wiki/Computer_storage) to store data [persistently](https://en.wikipedia.org/wiki/Persistence_(computer_science)). It is also sometimes called **solid-state disk**,[[1]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-1) although SSDs do not have physical disks. SSDs may use traditional [hard disk drive (HDD)](https://en.wikipedia.org/wiki/Hard_disk_drive) form-factors, protocols and file systems such as [SATA](https://en.wikipedia.org/wiki/SATA) and [SAS](https://en.wikipedia.org/wiki/Serial_Attached_SCSI), and [NTFS](https://en.wikipedia.org/wiki/NTFS) or [FAT32](https://en.wikipedia.org/wiki/FAT32) greatly simplifying usage of SSDs in computers, or Form factors, file systems and interfaces designed for SSDs, like [mSATA](https://en.wikipedia.org/wiki/MSATA), [m.2](https://en.wikipedia.org/wiki/M.2), [u.2](https://en.wikipedia.org/wiki/U.2), [NVMe](https://en.wikipedia.org/wiki/NVMe), Ruler SSD[[2]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-2), [PCIe](https://en.wikipedia.org/wiki/PCIe) and [APFS](https://en.wikipedia.org/wiki/APFS) or [F2FS](https://en.wikipedia.org/wiki/F2FS), often greatly improving performance and removing unnecessary features like defragmentation which can improve performance on HDDs but reduce the lifespan of SSDs. [[3]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-SNIA-101-3) Following the initial acceptance of SSDs with HDD interfaces, new form factors such as the [M.2](https://en.wikipedia.org/wiki/M.2) form factor, and new I/O protocols such as [NVM Express](https://en.wikipedia.org/wiki/NVMe) have been developed to address specific requirements of the [flash memory](https://en.wikipedia.org/wiki/Flash_memory) technology used in SSDs.

SSDs have no moving mechanical components. This distinguishes them from conventional [electromechanical](https://en.wikipedia.org/wiki/Electromechanical) drives such as [hard disk drives](https://en.wikipedia.org/wiki/Hard_disk_drive) (HDDs) or [floppy disks](https://en.wikipedia.org/wiki/Floppy_disk), which contain spinning [disks](https://en.wikipedia.org/wiki/Disk_storage) and movable [read/write heads](https://en.wikipedia.org/wiki/Disk_read-and-write_head).[[4]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-STEC-4) Compared with electromechanical drives, SSDs are typically more resistant to physical shock, run silently, have quicker [access time](https://en.wikipedia.org/wiki/Access_time) and lower [latency](https://en.wikipedia.org/wiki/Latency_(engineering)).[[5]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-dell-study-5) While the price of SSDs has continued to decline over time, SSDs are (as of 2018) still more expensive per unit of storage than HDDs and are expected to continue to be so into the next decade.

As of 2017, most SSDs use 3D TLC [NAND-based flash memory](https://en.wikipedia.org/wiki/NAND_flash), which is a type of [non-volatile memory](https://en.wikipedia.org/wiki/Non-volatile_memory) that retains data when power is lost. For applications requiring fast access but not necessarily data persistence after power loss, SSDs may be constructed from [random-access memory](https://en.wikipedia.org/wiki/Random-access_memory) (RAM). Such devices may employ batteries as integrated power sources to retain data for a certain amount of time after external power is lost.[[3]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-SNIA-101-3) Since 2018, some SSDs have 3D QLC(4 bit) [NAND-based flash memory](https://en.wikipedia.org/wiki/NAND_flash), which increases capacity and lowers costs, but at the expense of a lower endurance rating. For example, a 1 TB QLC SSD will have the same endurance rating as a 500 GB TLC(3 bit) SSD. High performance SSDs are made from SLC(1 bit) and 2 bit MLC NAND Flash, but these are prohibitively expensive and have a low capacity, making them better suited for caches or where very high speeds are required, as [SLC](https://en.wikipedia.org/wiki/Single-level_cell) NAND is, for example, faster than QLC NAND.

However, all SSDs still store data in electrical charges, which slowly leak over time if left without power. This causes worn out drives (that have exceeded their endurance rating) to start losing data typically after one (if stored at 30 °C) to two (at 25 °C) years in storage; for new drives it takes longer.[[6]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Archived_copy-6) Therefore, SSDs are not suited for archival purposes. The only exception to this rule are SSDs based on [3D XPoint](https://en.wikipedia.org/wiki/3D_XPoint) memory, which stores data not by storing electrical charges in cells, but by changing the electrical resistance of the cells. 3D XPoint however is a relatively new technology whose behaviour over long periods of time is still unknown and thus it shouldn't be used for archival storage.

[Hybrid drives](https://en.wikipedia.org/wiki/Hybrid_drive) or [solid-state hybrid drives](https://en.wikipedia.org/wiki/Solid-state_hybrid_drive) (SSHDs), such as [Apple's](https://en.wikipedia.org/wiki/Apple_Inc.) [Fusion Drive](https://en.wikipedia.org/wiki/Fusion_Drive), combine the features of SSDs and HDDs in the same unit, containing a large hard disk drive and an SSD cache to improve performance of frequently accessed data.[[7]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-WD_Black_SSHD_-_CNET_Reviews-7)[[8]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-8)[[9]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-9)

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## Development and history

### Early SSDs using RAM and similar technology

An early if not first semiconductor storage device compatible with a hard drive interface (e.g. an SSD as defined) was the 1978 [StorageTek](https://en.wikipedia.org/wiki/Storage_Technology_Corporation) STC 4305. The STC 4305, a plug-compatible replacement for the IBM 2305 fixed head disk drive, initially used [charged coupled devices](https://en.wikipedia.org/wiki/Charged_coupled_device) for storage and consequently was reported to be seven times faster than the IBM product at about half the price.[[10]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-10) It later switched to [DRAM](https://en.wikipedia.org/wiki/DRAM). Prior to the StorageTek SSD there were many DRAM and core (e.g. DATARAM BULK Core, 1976[[11]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-11)) products sold as alternatives to HDDs but these products typically had memory interfaces and were not SSDs as defined.

In the late 1980s Zitel, Inc., offered a family DRAM based SSD products, under the trade name "RAMDisk," for use on systems by UNIVAC and Perkin-Elmer, among others.

### Flash-based SSDs

Improvement of SSD characteristics over time

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Started with (1991) | Developed to (2018) | Improvement |
| Capacity | 20 megabytes | 100 terabytes(Nimbus Data DC100) | 5-million-to-one[[12]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-12) |
| Price | US$50 per megabyte | US$0.372 per gigabyte(Samsung PM1643) | 134,408-to-one[[13]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-13) |

In 1991, [SanDisk Corporation](https://en.wikipedia.org/wiki/Sandisk_Corporation) (then SunDisk) shipped the first SSD, a 20 MB solid state drive (SSD) which sold [OEM](https://en.wikipedia.org/wiki/Original_equipment_manufacturer) for around $1,000. It was used by IBM in a ThinkPad laptop[[14]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-14) In 1995, [STEC, Inc.](https://en.wikipedia.org/wiki/STEC,_Inc.) entered the flash memory business for consumer electronic devices.[[15]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-15)

In 1995, [M-Systems](https://en.wikipedia.org/wiki/M-Systems) introduced flash-based solid-state drives[[16]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Odagiri-16) as [HDD](https://en.wikipedia.org/wiki/Hard_disk_drive) replacements for the military and aerospace industries, as well as for other mission-critical applications. These applications require the SSD's ability to withstand extreme shock, vibration and temperature ranges.[[17]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-17)

In 1999, BiTMICRO made a number of introductions and announcements about flash-based SSDs, including an 18 GB 3.5-inch SSD.[[18]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-18) In 2007, Fusion-io announced a PCIe-based Solid state drive with 100,000 [input/output operations per second](https://en.wikipedia.org/wiki/IOPS) (IOPS) of performance in a single card, with capacities up to 320 gigabytes.[[19]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-19)

At Cebit 2009, [OCZ Technology](https://en.wikipedia.org/wiki/OCZ_Technology) demonstrated a 1 [terabyte](https://en.wikipedia.org/wiki/Terabyte) (TB) flash SSD using a PCI Express ×8 interface. It achieved a maximum write speed of 654 megabytes per second (MB/s) and maximum read speed of 712 MB/s.[[20]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-20) In December 2009, [Micron Technology](https://en.wikipedia.org/wiki/Micron_Technology) announced an SSD using a 6 [gigabits](https://en.wikipedia.org/wiki/Gigabit) per second (Gbit/s) [SATA](https://en.wikipedia.org/wiki/SATA) interface.[[21]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-DailyTech_SSD-21)

In 2016, Seagate demonstrates 10GB/S transfer speeds from a 16 lane PCIe SSD and also demonstrates a 60TB SSD in a 3.5 inch form factor. Samsung also launches to market a 15.36TB SSD with a price tag of US$10,000 using a SAS interface, using a 2.5 inch form factor but with the thickness of 3.5 inch drives. This was the first time a commercially available SSD had more capacity than the largest currently available HDD. [[22]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-22) [[23]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-23)[[24]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-24)[[25]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-25)[[26]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-26)

In 2017, the first products with 3D Xpoint memory are released. 3D Xpoint is entirely different from NAND Flash and stores data using different principles.

In 2018, both Samsung and Toshiba introduce to market 30.72TB SSDs using the same 2.5 inch form factor but with 3.5 inch drive thickness using SAS interfaces. Nimbus Data announces and reportedly ships 100TB drives using a SATA interface, a capacity HDDs are not expected to reach until 2025. Samsung introduces an m.2 SSD with speeds of 3500MB/S.[[27]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-27)[[28]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-28)[[29]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-29)[[30]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-30)[[31]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-31)[[32]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-32)[[33]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-33)

### Enterprise flash drives





Top and bottom views of a 2.5-inch 100 GB SATA 3.0 (6 Gbit/s) model of the Intel DC S3700 series

Enterprise flash drives (EFDs) are designed for applications requiring high I/O performance ([IOPS](https://en.wikipedia.org/wiki/IOPS)), reliability, energy efficiency and, more recently, consistent performance. In most cases, an EFD is an SSD with a higher set of specifications, compared with SSDs that would typically be used in notebook computers. The term was first used by EMC in January 2008, to help them identify SSD manufacturers who would provide products meeting these higher standards.[[34]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-34) There are no standards bodies who control the definition of EFDs, so any SSD manufacturer may claim to produce EFDs when in fact the product may not actually meet any particular requirements.[[35]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-35)

An example is the Intel DC S3700 series of drives, introduced in the fourth quarter of 2012, which focuses on achieving consistent performance, an area that had previously not received much attention but which Intel claimed was important for the enterprise market. In particular, Intel claims that, at a steady state, the S3700 drives would not vary their IOPS by more than 10–15%, and that 99.9% of all 4 KB random I/Os are serviced in less than 500 µs.[[36]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-36)

Another example is the Toshiba PX02SS enterprise SSD series, announced in 2016, which is optimized for use in server and storage platforms requiring high endurance from write-intensive applications such as write caching, I/O acceleration and [online transaction processing](https://en.wikipedia.org/wiki/Online_transaction_processing) (OLTP). The PX02SS series uses 12 Gbit/s SAS interface, featuring MLC NAND flash memory and achieving random write speeds of up to 42,000 IOPS, random read speeds of up to 130,000 IOPS, and endurance rating of 30 drive writes per day (DWPD).[[37]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-37)

## Architecture and function

The key components of an SSD are the controller and the memory to store the data. The primary memory component in an SSD was traditionally [DRAM](https://en.wikipedia.org/wiki/DRAM) [volatile memory](https://en.wikipedia.org/wiki/Volatile_memory), but since 2009 it is more commonly [NAND flash](https://en.wikipedia.org/wiki/NAND_flash) [non-volatile memory](https://en.wikipedia.org/wiki/Non-volatile_memory).[[38]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-whatisssd-38)[[3]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-SNIA-101-3)

### Controller

Every SSD includes a [controller](https://en.wikipedia.org/wiki/Flash_memory_controller) that incorporates the electronics that bridge the NAND memory components to the host [computer](https://en.wikipedia.org/wiki/Computer). The controller is an embedded processor that executes firmware-level code and is one of the most important factors of SSD performance.[[39]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-39) Some of the functions performed by the controller include:[[40]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Bechtolsheim-40)[[41]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Werner_SSD_Features-41)

* [Bad block](https://en.wikipedia.org/wiki/Bad_sector) mapping
* [Read and write caching](https://en.wikipedia.org/wiki/Cache_(computing))
* [Encryption](https://en.wikipedia.org/wiki/Encryption)
* [Error detection and correction](https://en.wikipedia.org/wiki/Error_detection_and_correction) via [error-correcting code](https://en.wikipedia.org/wiki/Error-correcting_code) (ECC)
* [Garbage collection](https://en.wikipedia.org/wiki/Garbage_collection_(SSD)" \l "Garbage_collection)
* [Read scrubbing](https://en.wikipedia.org/wiki/Memory_scrubbing) and [read disturb](https://en.wikipedia.org/wiki/Read_disturb) management
* [Wear leveling](https://en.wikipedia.org/wiki/Wear_leveling)

The performance of an SSD can scale with the number of parallel NAND flash chips used in the device. A single NAND chip is relatively slow, due to the narrow (8/16 bit) [asynchronous I/O](https://en.wikipedia.org/wiki/Asynchronous_I/O) interface, and additional high latency of basic I/O operations (typical for SLC NAND, ~25 [μs](https://en.wikipedia.org/wiki/Microsecond) to fetch a 4 [KB](https://en.wikipedia.org/wiki/KiB) page from the array to the I/O buffer on a read, ~250 μs to commit a 4 KB page from the IO buffer to the array on a write, ~2 ms to erase a 256 KB block). When multiple NAND devices operate in parallel inside an SSD, the bandwidth scales, and the high latencies can be hidden, as long as enough outstanding operations are pending and the load is evenly distributed between devices.[[42]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-SSD_Anthology-42)

Micron and Intel initially made faster SSDs by implementing [data striping](https://en.wikipedia.org/wiki/Data_striping) (similar to [RAID 0](https://en.wikipedia.org/wiki/RAID_0)) and interleaving in their architecture. This enabled the creation of ultra-fast SSDs with 250 [MB](https://en.wikipedia.org/wiki/MiB)/s effective read/write speeds with the SATA 3 Gbit/s interface in 2009.[[43]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-43) Two years later, SandForce continued to leverage this parallel flash connectivity, releasing consumer-grade SATA 6 Gbit/s SSD controllers which supported 500 MB/s read/write speeds.[[44]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-44) SandForce controllers compress the data prior to sending it to the flash memory. This process may result in less writing and higher logical throughput, depending on the compressibility of the data.[[45]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-45)

#### Wear leveling

Main articles: [Wear leveling](https://en.wikipedia.org/wiki/Wear_leveling) and [Write amplification](https://en.wikipedia.org/wiki/Write_amplification)

If a particular block was programmed and erased repeatedly without writing to any other blocks, that block would wear out before all the other blocks — thereby prematurely ending the life of the SSD. For this reason, SSD controllers use a technique called [wear leveling](https://en.wikipedia.org/wiki/Wear_leveling) to distribute writes as evenly as possible across all the flash blocks in the SSD.

In a perfect scenario, this would enable every block to be written to its maximum life so they all fail at the same time. Unfortunately, the process to evenly distribute writes requires data previously written and not changing (cold data) to be moved, so that data which are changing more frequently (hot data) can be written into those blocks. Each time data are relocated without being changed by the host system, this increases the [write amplification](https://en.wikipedia.org/wiki/Write_amplification) and thus reduces the life of the flash memory. The key is to find an optimum algorithm which maximizes them both.[[46]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-46)[[47]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-47)

### Memory

#### Flash-memory-based

Comparison of architectures[[48]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-48)

|  |  |  |
| --- | --- | --- |
| Comparison characteristics | [MLC](https://en.wikipedia.org/wiki/Multi-level_cell) : [SLC](https://en.wikipedia.org/wiki/Single-level_cell) | [NAND](https://en.wikipedia.org/wiki/NAND_Flash) : [NOR](https://en.wikipedia.org/wiki/NOR_flash) |
| Persistence ratio | 1 : 10 | 1 : 10 |
| Sequential write ratio | 1 : 3 | 1 : 4 |
| Sequential read ratio | 1 : 1 | 1 : 5 |
| Price ratio | 1 : 1.3 | 1 : 0.7 |

Most SSD manufacturers use [non-volatile](https://en.wikipedia.org/wiki/Non-volatile_memory) NAND [flash memory](https://en.wikipedia.org/wiki/Flash_memory) in the construction of their SSDs because of the lower cost compared with [DRAM](https://en.wikipedia.org/wiki/DRAM) and the ability to retain the data without a constant power supply, ensuring data persistence through sudden power outages.[[49]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-49)[[50]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-flashpaper2015-50) Flash memory SSDs are slower than DRAM solutions, and some early designs were even slower than HDDs after continued use. This problem was resolved by controllers that came out in 2009 and later.[[51]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-51)

Flash memory-based solutions are typically packaged in standard disk drive form factors (1.8-, 2.5-, and 3.5-inch), but also in smaller more compact form factors, such as the [M.2](https://en.wikipedia.org/wiki/M.2) form factor, made possible by the small size of flash memory.

Lower-priced drives usually use [triple-level cell](https://en.wikipedia.org/wiki/Triple-level_cell) (TLC) or [multi-level cell](https://en.wikipedia.org/wiki/Multi-level_cell) (MLC) flash memory, which is slower and less reliable than [single-level cell](https://en.wikipedia.org/wiki/Single-level_cell) (SLC) flash memory.[[52]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-CWorldLackluster-52)[[53]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-mlc-slc-53) This can be mitigated or even reversed by the internal design structure of the SSD, such as interleaving, changes to writing algorithms,[[53]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-mlc-slc-53) and higher [over-provisioning](https://en.wikipedia.org/wiki/Flash_over-provisioning) (more excess capacity) with which the wear-leveling algorithms can work.[[54]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Lucchesi-54)[[55]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Jim_Bagley-55)[[56]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Drossel-56)

#### DRAM-based

See also: [I-RAM](https://en.wikipedia.org/wiki/I-RAM) and [Hyperdrive (storage)](https://en.wikipedia.org/wiki/Hyperdrive_(storage))

SSDs based on volatile memory such as DRAM are characterized by very fast data access, generally less than 10 [microseconds](https://en.wikipedia.org/wiki/Microsecond), and are used primarily to accelerate applications that would otherwise be held back by the [latency](https://en.wikipedia.org/wiki/Memory_latency) of flash SSDs or traditional HDDs.

DRAM-based SSDs usually incorporate either an internal battery or an external AC/DC adapter and [backup](https://en.wikipedia.org/wiki/Backup) storage systems to ensure data persistence while no power is being supplied to the drive from external sources. If power is lost, the battery provides power while all information is copied from [random access memory](https://en.wikipedia.org/wiki/Random_access_memory) (RAM) to back-up storage. When the power is restored, the information is copied back to the RAM from the back-up storage, and the SSD resumes normal operation (similar to the [hibernate](https://en.wikipedia.org/wiki/Hibernation_(computing)) function used in modern operating systems).[[57]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-BiTMICRO-57)[[58]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-58)

SSDs of this type are usually fitted with DRAM modules of the same type used in regular PCs and servers, which can be swapped out and replaced by larger modules.[[59]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-59) Such as [i-RAM](https://en.wikipedia.org/wiki/I-RAM), [HyperOs HyperDrive](https://en.wikipedia.org/wiki/HyperOs_HyperDrive), DDRdrive X1, etc. Some manufacturers of DRAM SSDs solder the DRAM chips directly to the drive, and do not intend the chips to be swapped out—such as ZeusRAM, Aeon Drive, etc.[[60]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-60)

A *remote, indirect memory-access disk (RIndMA Disk)* uses a secondary computer with a fast network or (direct) [Infiniband](https://en.wikipedia.org/wiki/Infiniband) connection to act like a RAM-based SSD, but the new, faster, flash-memory based, SSDs already available in 2009 are making this option not as cost effective.[[61]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-61)

While the price of DRAM continues to fall, the price of Flash memory falls even faster. The "Flash becomes cheaper than DRAM" crossover point occurred approximately 2004.[[62]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-62)[[63]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-63)

#### Other

|  |  |
| --- | --- |
|  | This section's [**factual accuracy**](https://en.wikipedia.org/wiki/Wikipedia:Accuracy_dispute) **may be compromised due to out-of-date information**. Please update this article to reflect recent events or newly available information. *(December 2018)* |

Some SSDs, called [NVDIMM](https://en.wikipedia.org/wiki/NVDIMM) or *Hyper DIMM* devices, use both DRAM and flash memory. When the power goes down, the SSD copies all the data from its DRAM to flash; when the power comes back up, the SSD copies all the data from its flash to its DRAM.[[64]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-64) In a somewhat similar way, some SSDs use form factors and buses actually designed for DIMM modules, while using only flash memory and making it appear as if it were DRAM. Such SSDs are usually known as [ULLtraDIMM](https://en.wikipedia.org/wiki/ULLtraDIMM) devices.[[65]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-65)

Drives known as [hybrid drives](https://en.wikipedia.org/wiki/Hybrid_drive) or [solid-state hybrid drives](https://en.wikipedia.org/wiki/Solid-state_hybrid_drive) (SSHDs) use a hybrid of spinning disks and flash memory.[[66]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-66)[[67]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-67) Some SSDs use [magnetoresistive random-access memory](https://en.wikipedia.org/wiki/Magnetoresistive_random-access_memory) (MRAM) for storing data.[[68]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-68)[[69]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-69)

In 2015, [Intel](https://en.wikipedia.org/wiki/Intel) and [Micron](https://en.wikipedia.org/wiki/Micron_Technology) announced [3D XPoint](https://en.wikipedia.org/wiki/3D_XPoint) as a new [non-volatile memory](https://en.wikipedia.org/wiki/Non-volatile_memory) technology.[[70]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-extremetech-70) Intel plans to produce 3D XPoint SSDs with PCI Express interface in 2016,[[71]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-anandtechJuly2015-71)[*[needs update](https://en.wikipedia.org/wiki/Wikipedia:Manual_of_Style/Dates_and_numbers" \l "Chronological_items)*] which will operate faster and with higher endurance than NAND-based SSDs, while the [areal density](https://en.wikipedia.org/wiki/Areal_density_(computer_storage)) will be comparable at 128 gigabits per chip.[[71]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-anandtechJuly2015-71)[[72]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-cnet2015-72)[[73]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-73)[[74]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-74) For the price per bit, 3D XPoint will be more expensive than NAND, but cheaper than DRAM.[[75]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Projected_price-75)

### Cache or buffer

A flash-based SSD typically uses a small amount of DRAM as a [volatile](https://en.wikipedia.org/wiki/Volatile_memory) cache, similar to the [buffers](https://en.wikipedia.org/wiki/Disk_buffer) in hard disk drives. A directory of block placement and wear leveling data is also kept in the [cache](https://en.wikipedia.org/wiki/Cache_(computing)) while the drive is operating.[[42]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-SSD_Anthology-42) One SSD controller manufacturer, [SandForce](https://en.wikipedia.org/wiki/SandForce), does not use an external DRAM cache on their designs but still achieves high performance. Such an elimination of the external DRAM reduces the power consumption and enables further size reduction of SSDs.[[76]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Demerjian_TPC-C_Records-76)

### Battery or supercapacitor

Another component in higher-performing SSDs is a capacitor or some form of battery, which are necessary to maintain data integrity so the data in the cache can be flushed to the drive when power is lost; some may even hold power long enough to maintain data in the cache until power is resumed.[[76]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Demerjian_TPC-C_Records-76)[[77]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-77) In the case of MLC flash memory, a problem called *lower page corruption* can occur when MLC flash memory loses power while programming an upper page. The result is that data written previously and presumed safe can be corrupted if the memory is not supported by a supercapacitor in the event of a sudden power loss. This problem does not exist with SLC flash memory.[[41]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Werner_SSD_Features-41)

Most consumer-class SSDs do not have built-in batteries or capacitors;[[78]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-78) among the exceptions are the Crucial M500 and MX100 series,[[79]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-79) the Intel 320 series,[[80]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-80) and the more expensive Intel 710 and 730 series.[[81]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-81) Enterprise-class SSDs, such as the Intel DC S3700 series,[[82]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-82) usually have built-in batteries or capacitors.

### Host interface



An SSD with 1.2 TB of MLC NAND, using PCI Express as the host interface[[83]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-83)

The host interface is physically a connector with the signalling managed by the [SSD's controller](https://en.wikipedia.org/wiki/Solid-state_drive" \l "Controller). It is most often one of the interfaces found in HDDs. They include:

* [Serial attached SCSI](https://en.wikipedia.org/wiki/Serial_attached_SCSI) (SAS-3, 12.0 Gbit/s) – generally found on [servers](https://en.wikipedia.org/wiki/Server_(computing))[[84]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-roadmap-84)
* [Serial ATA](https://en.wikipedia.org/wiki/Serial_ATA) and mSATA variant (SATA 3.0, 6.0 Gbit/s)[[85]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-85)
* [PCI Express](https://en.wikipedia.org/wiki/PCI_Express) (PCIe 3.0 ×4, 31.5 Gbit/s)[[86]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-faq3-86)
* [M.2](https://en.wikipedia.org/wiki/M.2) (6.0 Gbit/s for SATA 3.0 logical device interface, 31.5 Gbit/s for PCIe 3.0 ×4)
* [U.2](https://en.wikipedia.org/wiki/U.2) (PCIe 3.0 ×4)
* [Fibre Channel](https://en.wikipedia.org/wiki/Fibre_Channel) (128 Gbit/s) – almost exclusively found on servers
* [USB](https://en.wikipedia.org/wiki/Universal_Serial_Bus) (10 Gbit/s)[[87]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-87)
* [Parallel ATA](https://en.wikipedia.org/wiki/AT_Attachment) (UDMA, 1064 Mbit/s) – mostly replaced by SATA[[88]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-88)[[89]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-89)
* (Parallel) [SCSI](https://en.wikipedia.org/wiki/SCSI) ( 40 Mbit/s- 2560 Mbit/s) – generally found on servers, mostly replaced by [SAS](https://en.wikipedia.org/wiki/Serial_attached_SCSI); last SCSI-based SSD was introduced in 2004[[90]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-90)

SSDs support various logical device interfaces, such as the original [ATAPI](https://en.wikipedia.org/wiki/ATA_Packet_Interface), [Advanced Host Controller Interface](https://en.wikipedia.org/wiki/Advanced_Host_Controller_Interface) (AHCI), [NVM Express](https://en.wikipedia.org/wiki/NVM_Express) (NVMe), and other proprietary interfaces. Logical device interfaces define the command sets used by [operating systems](https://en.wikipedia.org/wiki/Operating_system) to communicate with SSDs and [host bus adapters](https://en.wikipedia.org/wiki/Host_bus_adapter) (HBAs).

## Configurations

The size and shape of any device is largely driven by the size and shape of the components used to make that device. Traditional HDDs and [optical drives](https://en.wikipedia.org/wiki/Optical_disc_drive) are designed around the rotating [platter](https://en.wikipedia.org/wiki/Hard_disk_drive_platter)(s) or [optical disc](https://en.wikipedia.org/wiki/Optical_disc) along with the [spindle motor](https://en.wikipedia.org/wiki/Hard_disk_drive_spindle) inside. If an SSD is made up of various interconnected [integrated circuits](https://en.wikipedia.org/wiki/Integrated_circuit) (ICs) and an interface connector, then its shape is no longer limited to the shape of rotating media drives. Some solid state storage solutions come in a larger chassis that may even be a rack-mount form factor with numerous SSDs inside. They would all connect to a common bus inside the chassis and connect outside the box with a single connector.[[3]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-SNIA-101-3)

For general computer use, the 2.5-inch form factor (typically found in laptops) is the most popular. For desktop computers with 3.5-inch hard disk drive slots, a simple adapter plate can be used to make such a drive fit. Other types of form factors are more common in enterprise applications. An SSD can also be completely integrated in the other circuitry of the device, as in the [Apple](https://en.wikipedia.org/wiki/Apple_Inc.) [MacBook Air](https://en.wikipedia.org/wiki/MacBook_Air) (starting with the fall 2010 model).[[91]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-91) As of 2014, [mSATA](https://en.wikipedia.org/wiki/MSATA) and [M.2](https://en.wikipedia.org/wiki/M.2) form factors are also gaining popularity, primarily in laptops.

### Standard HDD form factors

The benefit of using a current [HDD form factor](https://en.wikipedia.org/wiki/HDD_form_factor) would be to take advantage of the extensive infrastructure already in place to mount and connect the drives to the host system.[[3]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-SNIA-101-3)[[92]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-92) These traditional form factors are known by the size of the rotating media, e.g., 5.25-inch, 3.5-inch, 2.5-inch, 1.8-inch, not by the dimensions of the drive casing.[[93]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-93)

### Standard card form factors

Main articles: [mSATA](https://en.wikipedia.org/wiki/MSATA) and [M.2](https://en.wikipedia.org/wiki/M.2)

For applications where space is at premium, like for ultrabooks or [tablet computers](https://en.wikipedia.org/wiki/Tablet_computer), a few compact form factors were standardized for flash-based SSDs.

There is the mSATA form factor, which uses the [PCI Express Mini Card](https://en.wikipedia.org/wiki/PCI_Express_Mini_Card) physical layout. It remains electrically compatible with the PCI Express Mini Card interface specification, while requiring an additional connection to the SATA host controller through the same connector.

[M.2](https://en.wikipedia.org/wiki/M.2) form factor, formerly known as the Next Generation Form Factor (NGFF), is a natural transition from the mSATA and physical layout it used, to a more usable and more advanced form factor. While mSATA took advantage of an existing form factor and connector, M.2 has been designed to maximize usage of the card space, while minimizing the footprint. The M.2 standard allows both SATA and [PCI Express](https://en.wikipedia.org/wiki/PCI_Express) SSDs to be fitted onto M.2 modules.[[94]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-94)

### Disk-on-a-module form factors



A 2 GB disk-on-a-module with PATA interface

A *disk-on-a-module* (*DOM*) is a flash drive with either 40/44-pin [Parallel ATA](https://en.wikipedia.org/wiki/Parallel_ATA) (PATA) or [SATA](https://en.wikipedia.org/wiki/SATA) interface, intended to be plugged directly into the motherboard and used as a computer [hard disk drive](https://en.wikipedia.org/wiki/Hard_disk_drive) (HDD). DOM devices emulate a traditional hard disk drive, resulting in no need for special drivers or other specific operating system support. DOMs are usually used in [embedded systems](https://en.wikipedia.org/wiki/Embedded_system), which are often deployed in harsh environments where mechanical HDDs would simply fail, or in [thin clients](https://en.wikipedia.org/wiki/Thin_client) because of small size, low power consumption and silent operation.

As of 2016, storage capacities range from 64 GB to 128 GB with different variations in physical layouts, including vertical or horizontal orientation.

### Box form factors

Many of the DRAM-based solutions use a box that is often designed to fit in a rack-mount system. The number of DRAM components required to get sufficient capacity to store the data along with the backup power supplies requires a larger space than traditional HDD form factors.[[95]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-95)

### Bare-board form factors

* 

Viking Technology SATA Cube and AMP SATA Bridge multi-layer SSDs

* 

Viking Technology SATADIMM based SSD

* 

MO-297 SATA disk-on-a-module (DOM) SSD form factor

* 

A custom-connector SATA SSD

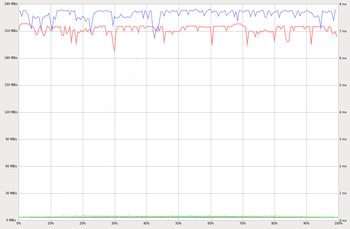
Form factors which were more common to memory modules are now being used by SSDs to take advantage of their flexibility in laying out the components. Some of these include [PCIe](https://en.wikipedia.org/wiki/PCI_Express), [mini PCIe](https://en.wikipedia.org/wiki/Mini-PCIe" \l "PCI_Express_Mini_Card), [mini-DIMM](https://en.wikipedia.org/wiki/DIMM" \l "Form_factors), [MO-297](https://en.wikipedia.org/w/index.php?title=MO-297&action=edit&redlink=1), and many more.[[96]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-96) The SATADIMM from Viking Technology uses an empty DDR3 DIMM slot on the motherboard to provide power to the SSD with a separate SATA connector to provide the data connection back to the computer. The result is an easy-to-install SSD with a capacity equal to drives that typically take a full 2.5-inch [drive bay](https://en.wikipedia.org/wiki/Drive_bay).[[97]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-97) At least one manufacturer, [Innodisk](https://en.wikipedia.org/w/index.php?title=Innodisk_Corporation&action=edit&redlink=1), has produced a drive that sits directly on the SATA connector (SATADOM) on the motherboard without any need for a power cable.[[98]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-98) Some SSDs are based on the PCIe form factor and connect both the data interface and power through the PCIe connector to the host. These drives can use either direct PCIe flash controllers[[99]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-99) or a PCIe-to-SATA bridge device which then connects to SATA flash controllers.[[100]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-100)

### Ball grid array form factors

In the early 2000s, a few companies introduced SSDs in [Ball Grid Array](https://en.wikipedia.org/wiki/Ball_Grid_Array) (BGA) form factors, such as M-Systems' (now [SanDisk](https://en.wikipedia.org/wiki/SanDisk)) DiskOnChip[[101]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-101) and [Silicon Storage Technology](https://en.wikipedia.org/wiki/Silicon_Storage_Technology)'s NANDrive[[102]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-102)[[103]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-103) (now produced by [Greenliant Systems](https://en.wikipedia.org/wiki/Greenliant_Systems)), and [Memoright](https://en.wikipedia.org/wiki/Memoright)'s M1000[[104]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-104) for use in embedded systems. The main benefits of BGA SSDs are their low power consumption, small chip package size to fit into compact subsystems, and that they can be [soldered](https://en.wikipedia.org/wiki/Soldered) directly onto a system motherboard to reduce adverse effects from vibration and shock.[[105]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-105)

## Comparison with other technologies

### Hard disk drives



SSD benchmark, showing about 230 MB/s reading speed (blue), 210 MB/s writing speed (red) and about 0.1 ms seek time (green), all independent from the accessed disk location.

See also: [Hard disk drive performance characteristics](https://en.wikipedia.org/wiki/Hard_disk_drive_performance_characteristics)

Making a comparison between SSDs and ordinary (spinning) HDDs is difficult. Traditional SSD [benchmarks](https://en.wikipedia.org/wiki/Benchmark_(computing)) tend to focus on the performance characteristics that are poor with HDDs, such as [rotational latency](https://en.wikipedia.org/wiki/Rotational_latency) and [seek time](https://en.wikipedia.org/wiki/Seek_time). As SSDs do not need to spin or seek to locate data, they may prove vastly superior to HDDs in such tests. However, SSDs have challenges with mixed reads and writes, and their performance may degrade over time. SSD testing must start from the (in use) full drive, as the new and empty (fresh, out-of-the-box) drive may have much better write performance than it would show after only weeks of use.[[106]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-106)

Most of the advantages of solid-state drives over traditional hard drives are due to their ability to access data completely electronically instead of electromechanically, resulting in superior transfer speeds and mechanical ruggedness.[[107]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-107) On the other hand, hard disk drives offer significantly higher capacity for their price.[[5]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-dell-study-5)[[108]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-108)

Field failure rates indicate that SSDs are significantly more reliable than HDDs.[[109]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-behardware_2011-109)[[110]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-110)[[111]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-behardware_2012-111) However, SSDs are uniquely sensitive to sudden power interruption, resulting in aborted writes or even cases of the complete loss of the drive.[[112]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-112) The reliability of both HDDs and SSDs varies greatly among models.[[113]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-PC_World_2014-113)

As with HDDs, there is a tradeoff between cost and performance of different SSDs. Single-level cell (SLC) SSDs, while significantly more expensive than multi-level (MLC) SSDs, offer a significant speed advantage.[[50]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-flashpaper2015-50) At the same time, DRAM-based solid-state storage is currently considered the fastest and most costly, with average response times of 10 microseconds instead of the average 100 microseconds of other SSDs. Enterprise flash devices (EFDs) are designed to handle the demands of tier-1 application with performance and response times similar to less-expensive SSDs.[[114]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-114)

In traditional HDDs, a re-written file will generally occupy the same location on the disk surface as the original file, whereas in SSDs the new copy will often be written to different NAND cells for the purpose of [wear leveling](https://en.wikipedia.org/wiki/Wear_leveling). The wear-leveling algorithms are complex and difficult to test exhaustively; as a result, one major cause of data loss in SSDs is firmware bugs.[[115]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-115)[[116]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-116)

The following table shows a detailed overview of the advantages and disadvantages of both technologies. Comparisons reflect typical characteristics, and may not hold for a specific device.

Comparison of NAND-based SSD and HDD

|  |  |  |
| --- | --- | --- |
| Attribute or characteristic | Solid-state drive | Hard disk drive |
| Reliability on storage retention | If left without power, worn out SSDs typically start to lose data after about one to two years in storage, depending on temperature. New drives are supposed to retain data for about ten years.[[6]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Archived_copy-6) MLC and TLC based devices tend to lose data earlier than SLC-based devices. SSDs are not suited for archival use. | If kept in a dry environment at low temperature, HDDs can retain their data for a very long period of time even without power. However, the mechanical parts tend to become clotted over time and the drive fails to spin up after a few years in storage. |
| Start-up time | Almost instantaneous; no mechanical components to prepare. May need a few milliseconds to come out of an automatic power-saving mode. | Drive [spin-up](https://en.wikipedia.org/wiki/Spin-up) may take several seconds. A system with many drives may need to stagger spin-up to limit peak power drawn, which is briefly high when an HDD is first started.[[117]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-diffen-117) |
| Sequential access performance | In consumer products the maximum transfer rate typically ranges from about 200 MB/s to 3500 MB/s, depending on the drive. Enterprise market offers devices with multi-gigabyte per second throughput. | Once the head is positioned, when reading or writing a continuous track, a modern HDD can transfer data at about 200 MB/s. Data transfer rate depends also upon rotational speed, which can range from 3,600 to 15,000 [rpm](https://en.wikipedia.org/wiki/Revolutions_per_minute)[[118]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-118) and also upon the track (reading from the outer tracks is faster). |
| Random access performance[[119]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-anandtech_deterministic_perf-119) | [Random access](https://en.wikipedia.org/wiki/Random_access) time typically under 0.1 ms.[[120]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-120)[[121]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-121) As data can be retrieved directly from various locations of the flash memory, access time is usually not a big performance bottleneck. Read performance does not change based on where data is stored. In applications where hard disk drive seeks are the limiting factor, this results in faster boot and application launch times (see [Amdahl's law](https://en.wikipedia.org/wiki/Amdahl's_law)).[[122]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-xbitSSDvsHD-122)[[117]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-diffen-117)  SSD technology can deliver rather consistent read/write speed, but when lots of individual smaller blocks are accessed, performance is reduced. SSDs suffer from a write performance degradation phenomenon called [write amplification](https://en.wikipedia.org/wiki/Write_amplification), where the [NAND](https://en.wikipedia.org/wiki/NAND_Flash) cells show a measurable drop in performance, and will continue degrading throughout the life of the SSD.[[123]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-123) A technique called [wear leveling](https://en.wikipedia.org/wiki/Wear_leveling) is implemented to mitigate this effect, but due to the nature of the NAND chips, the drive will inevitably degrade at a noticeable rate.[[*verification needed*](https://en.wikipedia.org/wiki/Wikipedia:Verifiability)] | Read [latency](https://en.wikipedia.org/wiki/Latency_(engineering)" \l "Mechanical_latency) time is much higher than SSDs.[[124]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-124) [Random access](https://en.wikipedia.org/wiki/Random_access) time ranges from 2.9 (high end server drive) to 12 ms (laptop HDD) due to the need to move the heads and [wait for the data to rotate](https://en.wikipedia.org/wiki/Rotational_latency) under the magnetic head.[[125]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-HDD_Glossary-125) Read time is different for every different seek, since the location of the data and the location of the head are likely different. If data from different areas of the platter must be accessed, as with fragmented files, response times will be increased by the need to seek each fragment.[[126]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-reliability-126) |
| Impacts of [file system fragmentation](https://en.wikipedia.org/wiki/File_system_fragmentation) | There is limited benefit to reading data sequentially (beyond typical FS block sizes, say 4 KB), making fragmentation negligible for SSDs. Defragmentation would cause wear by making additional writes of the NAND flash cells, which have a limited cycle life.[[127]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-127)[[128]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-128) However, even on SSDs there is a practical limit on how much fragmentation certain file systems can sustain; once that limit is reached, subsequent file allocations fail.[[129]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-:0-129) Consequently, defragmentation may still be necessary, although to a lesser degree.[[129]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-:0-129) | Some file systems, like [NTFS](https://en.wikipedia.org/wiki/NTFS), become fragmented over time if frequently written; periodic defragmentation is required to maintain optimum performance.[[130]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-130) This usually is not an issue in modern file systems. |
| [Noise (acoustic)](https://en.wikipedia.org/wiki/Noise_(acoustic))[[131]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-131) | SSDs have no moving parts and therefore are basically silent, although on some SSDs, high pitch noise from the high voltage generator (for erasing blocks) may occur. | HDDs have moving parts ([heads](https://en.wikipedia.org/wiki/Disk_read-and-write_head), [actuator](https://en.wikipedia.org/wiki/Hard_disk_drive_actuator), and [spindle](https://en.wikipedia.org/wiki/Hard_disk_drive_spindle) motor) and make characteristic sounds of whirring and clicking; noise levels vary between models, but can be significant (while often much lower than the sound from the cooling fans). Laptop hard drives are relatively quiet. |
| Temperature control[[132]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-132) | A study conducted by Facebook found a consistent failure rate at temperatures between 30 and 40 °C. Failure rate rises when operating at temperatures higher than 40 °C, further increase of temperature may trigger [thermal throttling](https://en.wikipedia.org/wiki/Thermal_throttling) around 70 °C, resulting reduced runtime performance. Reliability of early SSDs without thermal throttling are more affected by temperature, than newer ones with thermal throttling.[[133]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-133) In practice, SSDs usually do not require any special cooling and can tolerate higher temperatures than HDDs. High-end enterprise models installed as add-on cards or 2.5-inch bay devices may ship with [heat sinks](https://en.wikipedia.org/wiki/Heat_sink) to dissipate generated heat, requiring certain volumes of airflow to operate.[[134]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-134) | Ambient temperatures above 35 °C (95 °F) can shorten the life of a hard disk, and reliability will be compromised at drive temperatures above 55 °C (131 °F). Fan cooling may be required if temperatures would otherwise exceed these values.[[135]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-135) In practice, modern HDDs may be used with no special arrangements for cooling. |
| Lowest operating temperature[[136]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-136) | SSDs can operate at −55 °C (−67 °F). | Most modern HDDs can operate at 0 °C (32 °F). |
| Highest altitude when operating[[137]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-137) | SSDs have no issues on this.[[138]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-138) | HDDs can operate safely at an altitude of at most 3,000 meters (10,000 ft). HDDs will fail to operate at altitudes above 12,000 meters (40,000 ft).[[139]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-IHDDF-139) With the introduction of helium-filled[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)] (sealed) HDDs, this is expected to be less of an issue. |
| Moving from a cold environment to a warmer environment | SSDs have no issues on this.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)] | A certain amount of acclimation time is needed when moving HDDs from a cold environment to a warmer environment prior to operating it; otherwise, internal condensation will occur and operating it immediately will result in damage to its internal components.[[140]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-140) |
| Breather hole | SSDs do not require a breather hole. | Most modern HDDs require a breather hole in order for it to function properly.[[139]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-IHDDF-139) Helium-filled devices are sealed and do not have a hole. |
| Susceptibility to [environmental factors](https://en.wikipedia.org/wiki/Hard_disk_drive" \l "Integrity)[[122]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-xbitSSDvsHD-122)[[141]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Samsung_SSD_vs_HDD-141)[[142]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-142) | No moving parts, very resistant to [shock](https://en.wikipedia.org/wiki/Hard_disk_drive" \l "Shock_resistance), vibration, movement, and contamination. | Heads flying above rapidly rotating platters are susceptible to shock, vibration, movement, and contamination which could damage the medium. |
| Installation and mounting | Not sensitive to orientation, vibration, or shock. Usually no exposed circuitry. Circuitry may be exposed in a card form device and it must not be short-circuited by conductive materials. | Circuitry may be exposed, and it must not be short-circuited by conductive materials (such as the metal chassis of a computer). Should be mounted to protect against vibration and shock. Some HDDs should not be installed in a tilted position.[[143]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-143) |
| Susceptibility to [magnetic fields](https://en.wikipedia.org/wiki/Magnetic_field) | Low impact on flash memory, but an [electromagnetic pulse](https://en.wikipedia.org/wiki/Electromagnetic_pulse) will damage any electrical system, especially [integrated circuits](https://en.wikipedia.org/wiki/Integrated_circuit). | In general, magnets or magnetic surges may result in data corruption or mechanical damage to the drive internals. Drive's metal case provides a low level of shielding to the magnetic platters.[[144]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-144)[[145]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-145)[[146]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-146) |
| Weight and size[[141]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Samsung_SSD_vs_HDD-141) | SSDs, essentially semiconductor memory devices mounted on a circuit board, are small and lightweight. They often follow the same form factors as HDDs (2.5-inch or 1.8-inch), but the enclosures are made mostly of plastic. | HDDs are generally heavier than SSDs, as the enclosures are made mostly of metal, and they contain heavy objects such as motors and large magnets. 3.5-inch drives typically weigh around 700 grams (about 1.5 pounds). |
| [Reliability](https://en.wikipedia.org/wiki/Reliability_engineering) and lifetime | SSDs have no moving parts to fail mechanically. Each block of a flash-based SSD can only be erased (and therefore written) a limited number of times before it fails. The controllers manage this limitation so that drives can last for many years under normal use.[[147]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-CWorldLackluster2-147)[[148]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-148)[[149]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-149)[[150]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-150)[[151]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-151) SSDs based on DRAM do not have a limited number of writes. However the failure of a controller can make a SSD unusable. Reliability varies significantly across different SSD manufacturers and models with return rates reaching 40% for specific drives.[[111]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-behardware_2012-111) As of 2011 leading SSDs have lower return rates than mechanical drives.[[109]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-behardware_2011-109) Many SSDs critically fail on power outages; a December 2013 survey of many SSDs found that only some of them are able to survive multiple power outages.[[152]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-152)[*[needs update?](https://en.wikipedia.org/wiki/Wikipedia:Manual_of_Style/Dates_and_numbers" \l "Chronological_items)*] | HDDs have moving parts, and are subject to potential mechanical failures from the resulting [wear and tear](https://en.wikipedia.org/wiki/Wear_and_tear). The storage medium itself (magnetic platter) does not essentially degrade from read and write operations.  According to a study performed by [Carnegie Mellon University](https://en.wikipedia.org/wiki/Carnegie_Mellon_University) for both consumer and enterprise-grade HDDs, their average failure rate is 6 years, and life expectancy is 9–11 years.[[153]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-153) Leading SSDs have overtaken HDDs for reliability,[[109]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-behardware_2011-109) however the risk of a sudden, catastrophic data loss can be lower for HDDs.[[154]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Tom's_Hardware_2011-154)  When stored offline (unpowered in shelf) in long term, the magnetic medium of HDD retains data significantly longer than flash memory used in SSDs. |
| Secure writing limitations | NAND flash memory cannot be overwritten, but has to be rewritten to previously erased blocks. If a software [encryption](https://en.wikipedia.org/wiki/Encryption) program encrypts data already on the SSD, the overwritten data is still unsecured, unencrypted, and accessible (drive-based hardware encryption does not have this problem). Also data cannot be securely erased by overwriting the original file without special "Secure Erase" procedures built into the drive.[[155]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-IDG_Communications-155) | HDDs can overwrite data directly on the drive in any particular sector. However, the drive's firmware may exchange damaged blocks with spare areas, so bits and pieces may still be present. Some manufacturers' HDDs fill the entire drive with zeroes, including relocated sectors, on ATA Secure Erase Enhanced Erase command.[[156]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-156) |
| Price per capacity | SSDs generally are more expensive than HDDs and expected to remain so into the next decade.[[157]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-157)  SSD price as of first quarter 2018 around 30 cents (US) per gigabyte based on 4 TB models.[[158]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Backblaze2018-158)  Prices have generally declined annually and as of 2018 are expected to continue to do so. | HDD price as of first quarter 2018 around 2 to 3 cents (US) per gigabyte based on 1 TB models.[[158]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Backblaze2018-158)  Prices have generally declined annually and as of 2018 are expected to continue to do so. |
| Storage capacity | In 2016, SSDs were available in sizes up to 60 TB,[[159]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-159) but less costly, 120 to 512 GB models were more common. | In 2016, HDDs of up to 14 TB[[160]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-160) were available. |
| Read/write performance symmetry | Less expensive SSDs typically have write speeds significantly lower than their read speeds. Higher performing SSDs have similar read and write speeds. | HDDs generally have slightly longer (worse) seek times for writing than for reading.[[161]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-161) |
| Free block availability and TRIM | SSD write performance is significantly impacted by the availability of free, programmable blocks. Previously written data blocks no longer in use can be reclaimed by [TRIM](https://en.wikipedia.org/wiki/TRIM); however, even with TRIM, fewer free blocks cause slower performance.[[42]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-SSD_Anthology-42)[[162]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-162)[[163]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-163) | HDDs are not affected by free blocks and do not benefit from TRIM. |
| Power consumption | High performance flash-based SSDs generally require half to a third of the power of HDDs. High-performance DRAM SSDs generally require as much power as HDDs, and must be connected to power even when the rest of the system is shut down.[[164]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-164)[[165]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-165) Emerging technologies like [DevSlp](https://en.wikipedia.org/wiki/DevSlp) can minimize power requirements of idle drives. | The lowest-power HDDs (1.8-inch size) can use as little as 0.35 watts when idle.[[166]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-166) 2.5-inch drives typically use 2 to 5 watts. The highest-performance 3.5-inch drives can use up to about 20 watts. |
| Maximum areal storage density (Terabits per square inch) | 2.8[[167]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Landscape2018-167) | 1.2[[167]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-Landscape2018-167) |

### Memory cards

Main article: [Memory card](https://en.wikipedia.org/wiki/Memory_card)



CompactFlash card used as an SSD

While both [memory cards](https://en.wikipedia.org/wiki/Memory_card) and most SSDs use flash memory, they serve very different markets and purposes. Each has a number of different attributes which are optimized and adjusted to best meet the needs of particular users. Some of these characteristics include power consumption, performance, size, and reliability.[[168]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-SanDisk_SSD_CF-168)

SSDs were originally designed for use in a computer system. The first units were intended to replace or augment hard disk drives, so the operating system recognized them as a hard drive. Originally, solid state drives were even shaped and mounted in the computer like hard drives. Later SSDs became smaller and more compact, eventually developing their own unique form factors such as the [M.2](https://en.wikipedia.org/wiki/M.2) form factor. The SSD was designed to be installed permanently inside a computer.[[168]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-SanDisk_SSD_CF-168)

In contrast, memory cards (such as [Secure Digital](https://en.wikipedia.org/wiki/Secure_Digital) (SD), [CompactFlash](https://en.wikipedia.org/wiki/CompactFlash) (CF), and many others) were originally designed for digital cameras and later found their way into cell phones, gaming devices, GPS units, etc. Most memory cards are physically smaller than SSDs, and designed to be inserted and removed repeatedly.[[168]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-SanDisk_SSD_CF-168) There are adapters which enable some memory cards to interface to a computer, allowing use as an SSD, but they are not intended to be the primary storage device in the computer. The typical [CompactFlash](https://en.wikipedia.org/wiki/CompactFlash) card interface is three to four times slower than an SSD.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)] As memory cards are not designed to tolerate the amount of reading and writing which occurs during typical computer use, their data may get damaged unless special procedures are taken to reduce the wear on the card to a minimum.

## SSD failure

SSDs have very different [failure modes](https://en.wikipedia.org/wiki/Failure_mode) than traditional magnetic hard drives. Because of their design, some kinds of failure are inapplicable (motors or magnetic heads cannot fail, because they are not needed in an SSD). Instead, other kinds of failure are possible (for example, incomplete or failed writes due to sudden power failure can be more of a problem than with HDDs, and if a chip fails then all the data on it is lost, a scenario not applicable to magnetic drives). However, on the whole statistics show that SSDs are generally highly reliable, and often continue working far beyond the expected lifetime as stated by their manufacturer.[[169]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-2016study-169)

### SSD reliability and failure modes

An early test by [*Techreport.com*](https://en.wikipedia.org/wiki/Techreport.com) which ran for 18 months during 2013 - 2015 had previously tested a number of SSDs to destruction to identify how and at what point they failed; the test found that "All of the drives surpassed their official endurance specifications by writing hundreds of terabytes without issue", described as being far beyond any usual size for a "typical consumer".[[170]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-TR2015-170) The first SSD to fail was a TLC based drive - a type of design expected to be less durable than either SLC or MLC - and the SSD concerned managed to write over 800,000 GB (800 TB or 0.8 [petabytes](https://en.wikipedia.org/wiki/Petabyte)) before failing; three SSDs in the test managed to write almost three times that amount (almost 2.5 PB) before they also failed.[[170]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-TR2015-170) So the capability of even consumer SSDs to be remarkably reliable was already established.

A 2016 study of "millions of drive days" in production use by SSDs over a six-year period, found that SSDs fail at a "significantly lower" rate than HDDs, but have potential for localized data loss due to unreadable blocks to be more of a problem than with HDDs. It came to a number of "unexpected conclusions":[[169]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-2016study-169)

* In the real world, [MLC](https://en.wikipedia.org/wiki/Multi-level_cell) based designs - believed less reliable than [SLC](https://en.wikipedia.org/wiki/Single-level_cell) designs - are often as reliable as SLC. (The findings state that "SLC [is] not generally more reliable than MLC")
* Device age, measured by days in use, is the main factor in SSD reliability, and not amount of data read or written. Because this finding persists after controlling for early failure and other factors, it is likely that factors such as "silicon aging" is a cause of this trend. The correlation is significant (around 0.2 - 0.4).
* Raw bit error rates (RBER) grows much slower than usually believed and is not exponential as often assumed, nor is it a good predictor of other errors or SSD failure.
* The uncorrectable bit error rate (UBER) is widely used but is not a good predictor of failure either. However SSD UBER rates are higher than those for HDDs, so although they do not predict failure, they can lead to data loss due to unreadable blocks being more common on SSDs than HDDs. The conclusion states that although more reliable overall, the rate of uncorrectable errors able to impact a user is larger.
* "Bad blocks in new SSDs are common, and drives with a large number of bad blocks are much more likely to lose hundreds of other blocks, most likely due to die or chip failure. 30-80 percent of SSDs develop at least one bad block and 2-7 percent develop at least one bad chip in the first four years of deployment."
* There is no sharp increase in errors after the expected lifetime is reached.
* Most SSDs develop no more than a few bad blocks, perhaps 2 - 4. SSDs that develop many bad blocks often go on to develop far more (perhaps hundreds), and may be prone to failure. However most drives (99%+) are shipped with bad blocks from manufacture. The finding overall was that bad blocks are common and 30-80% of drives will develop at least one in use, but even a few bad blocks (2 - 4) is a predictor of up to hundreds of bad blocks at a later time. The bad block count at manufacture correlates with later development of further bad blocks. The report conclusion added that SSDs tended to either have "less than a handful" of bad blocks or "a large number", and suggested that this might be a basis for predicting eventual failure.
* Around 2-7% of SSDs will develop bad chips in their first 4 years of use. Over 2/3 of these chips will have breached their manufacturers' tolerances and specifications, which typically guarantee that no more than 2% of blocks on a chip will fail within its expected write lifetime.
* 96% of those SSDs that need repair (warranty servicing), need repair only once in their life. Days between repair vary from "a couple of thousand days" to "nearly 15,000 days" depending on the model.

### Data recovery and secure deletion

Solid state drives have set new challenges for [data recovery](https://en.wikipedia.org/wiki/Data_recovery) companies, as the way of storing data is non-linear and much more complex than that of hard disk drives. The strategy the drive operates by internally can largely vary between manufacturers, and the TRIM command zeroes the whole range of a deleted file. Wear leveling also means that the physical address of the data and the address exposed to the operating system are different.

As for secure deletion of data, ATA Secure Erase command could be used. A program such as [hdparm](https://en.wikipedia.org/wiki/Hdparm) can be used for this purpose.

### Endurance

The [*JEDEC Solid State Technology Association*](https://en.wikipedia.org/wiki/JEDEC_Solid_State_Technology_Association) (JEDEC) has published standards for reliability metrics:[[171]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-NullLobur2014-171)

* Unrecoverable Bit Error Ratio (UBER)
* Terabytes Written (TBW) - The number of terabytes that can be written to a drive within its warranty.
* Drive Writes Per Day (DWPD) - The number of times the total capacity of the drive may be written to per day within its warranty.

## Applications

Until 2009[[*why?*](https://en.wikipedia.org/wiki/Wikipedia:Please_clarify)], SSDs were mainly used in those aspects of [mission critical](https://en.wikipedia.org/wiki/Mission_critical) applications where the speed of the [storage system](https://en.wikipedia.org/wiki/Computer_data_storage) needed to be as high as possible. Since flash memory has become a common component of SSDs, the falling prices and increased densities have made it more cost-effective for many other applications. Organizations that can benefit from faster access of system data include [equity trading](https://en.wikipedia.org/wiki/Equity_securities" \l "Trading) companies, [telecommunication](https://en.wikipedia.org/wiki/Telecommunication) corporations, and [streaming media](https://en.wikipedia.org/wiki/Streaming_media) and [video editing](https://en.wikipedia.org/wiki/Video_editing) firms. The list of applications which could benefit from faster storage is vast.[[3]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-SNIA-101-3)

Flash-based solid-state drives can be used to create network appliances from general-purpose [personal computer](https://en.wikipedia.org/wiki/Personal_computer) hardware. A [write protected](https://en.wikipedia.org/wiki/Write_protection) flash drive containing the operating system and application software can substitute for larger, less reliable disk drives or CD-ROMs. Appliances built this way can provide an inexpensive alternative to expensive router and firewall hardware.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)]

SSDs based on an [SD card](https://en.wikipedia.org/wiki/SD_card) with a [live SD](https://en.wikipedia.org/w/index.php?title=Live_SD&action=edit&redlink=1) operating system are easily [write-locked](https://en.wikipedia.org/wiki/SD_card" \l "Optional_write-protect_tab). Combined with a [cloud computing](https://en.wikipedia.org/wiki/Cloud_computing) environment or other writable medium, to maintain [persistence](https://en.wikipedia.org/wiki/Persistence_(computer_science)), an [OS](https://en.wikipedia.org/wiki/Operating_system) [booted](https://en.wikipedia.org/wiki/Booting) from a write-locked SD card is robust, rugged, reliable, and impervious to permanent corruption. If the running OS degrades, simply turning the machine off and then on returns it back to its initial uncorrupted state and thus is particularly solid. The SD card installed OS does not require removal of corrupted components since it was write-locked though any written media may need to be restored.

### Hard drives caching

In 2011, Intel introduced a caching mechanism for their [Z68](https://en.wikipedia.org/wiki/Z68) chipset (and mobile derivatives) called [Smart Response Technology](https://en.wikipedia.org/wiki/Smart_Response_Technology), which allows a [SATA](https://en.wikipedia.org/wiki/SATA) SSD to be used as a [cache](https://en.wikipedia.org/wiki/Cache_(computing)) (configurable as write-through or [write-back](https://en.wikipedia.org/wiki/Write-back)) for a conventional, magnetic hard disk drive.[[172]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-172) A similar technology is available on [HighPoint](https://en.wikipedia.org/w/index.php?title=HighPoint&action=edit&redlink=1)'s RocketHybrid [PCIe](https://en.wikipedia.org/wiki/PCIe) card.[[173]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-173)

[Solid-state hybrid drives](https://en.wikipedia.org/wiki/Solid-state_hybrid_drive) (SSHDs) are based on the same principle, but integrate some amount of flash memory on board of a conventional drive instead of using a separate SSD. The flash layer in these drives can be accessed independently from the [magnetic storage](https://en.wikipedia.org/wiki/Magnetic_storage) by the host using [ATA-8](https://en.wikipedia.org/w/index.php?title=ATA-8&action=edit&redlink=1) commands, allowing the operating system to manage it. For example, Microsoft's [ReadyDrive](https://en.wikipedia.org/wiki/Windows_Vista_I/O_technologies" \l "ReadyDrive) technology explicitly stores portions of the [hibernation file](https://en.wikipedia.org/wiki/Hibernation_(computing)" \l "Microsoft_Windows) in the cache of these drives when the system hibernates, making the subsequent resume faster.[[174]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-RussinovichSolomon2009b-174)

[Dual-drive hybrid systems](https://en.wikipedia.org/wiki/Dual-drive_hybrid_system) are combining the usage of separate SSD and HDD devices installed in the same computer, with overall performance optimization managed by the computer user, or by the computer's [operating system](https://en.wikipedia.org/wiki/Operating_system) software. Examples of this type of system are [bcache](https://en.wikipedia.org/wiki/Bcache) and [dm-cache](https://en.wikipedia.org/wiki/Dm-cache) on [Linux](https://en.wikipedia.org/wiki/Linux),[[175]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-175) and Apple’s [Fusion Drive](https://en.wikipedia.org/wiki/Fusion_Drive).

## File system support for SSDs

Main article: [File systems optimized for flash memory, solid state media](https://en.wikipedia.org/wiki/List_of_file_systems" \l "File_systems_optimized_for_flash_memory,_solid_state_media)

Typically the same [file systems](https://en.wikipedia.org/wiki/File_system) used on hard disk drives can also be used on solid state drives. It is usually expected for the file system to support the [TRIM command](https://en.wikipedia.org/wiki/Trim_(computing)) which helps the SSD to recycle discarded data (support for TRIM arrived some years after SSDs themselves but is now nearly universal). This means that file system does not need to manage [wear leveling](https://en.wikipedia.org/wiki/Wear_leveling) or other flash memory characteristics, as they are handled internally by the SSD. Some flash file systems using [log-based](https://en.wikipedia.org/wiki/Log-structured_file_system) designs ([F2FS](https://en.wikipedia.org/wiki/F2FS), [JFFS2](https://en.wikipedia.org/wiki/JFFS2)) help to reduce write amplification on SSDs, especially in situations where only very small amounts of data are changed, such as when updating [file system metadata](https://en.wikipedia.org/wiki/File_system" \l "Metadata).

While not a file system feature, operating systems should also aim to [align partitions](https://en.wikipedia.org/wiki/Partition_alignment) correctly, which avoids excessive [read-modify-write](https://en.wikipedia.org/wiki/Read-modify-write) cycles. A typical practice for personal computers is to have each partition aligned to start at a 1 [MB](https://en.wikipedia.org/wiki/Binary_prefix) (= 1,048,576 bytes) mark, which covers all common SSD page and block size scenarios, as it is divisible by all commonly used sizes - 1 MB, 512 KB, 128 KB, 4 KB, and 512 bytes. Modern operating system installation software and disk tools handle this automatically.

### Linux

The [ext4](https://en.wikipedia.org/wiki/Ext4), [Btrfs](https://en.wikipedia.org/wiki/Btrfs), [XFS](https://en.wikipedia.org/wiki/XFS), [JFS](https://en.wikipedia.org/wiki/JFS_(file_system)), and [F2FS](https://en.wikipedia.org/wiki/F2FS) file systems include support for the discard ([TRIM or UNMAP](https://en.wikipedia.org/wiki/Trim_(computing))) function. As of November 2013, ext4 can be recommended as a safe choice.[*[by whom?](https://en.wikipedia.org/wiki/Wikipedia:Manual_of_Style/Words_to_watch" \l "Unsupported_attributions)*] F2FS is a modern file system optimized for flash-based storage, and from a technical perspective is a very good choice,[*[according to whom?](https://en.wikipedia.org/wiki/Wikipedia:Manual_of_Style/Words_to_watch" \l "Unsupported_attributions)*] but is still in experimental stage.[*[when?](https://en.wikipedia.org/wiki/Wikipedia:Manual_of_Style/Dates_and_numbers" \l "Chronological_items)*][[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)]

Kernel support for the TRIM operation was introduced in version 2.6.33 of the Linux kernel mainline, released on 24 February 2010.[[176]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-176) To make use of it, a filesystem must be mounted using the discard parameter. Linux [swap](https://en.wikipedia.org/wiki/Paging) partitions are by default performing discard operations when the underlying drive supports TRIM, with the possibility to turn them off, or to select between one-time or continuous discard operations.[[177]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-man-8-swapon-177)[[178]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-debian-ssd-178)[[179]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-3.12.5-swapfile.c-179) Support for queued TRIM, which is a [SATA 3.1](https://en.wikipedia.org/wiki/SATA_3.1) feature that results in TRIM commands not disrupting the command queues, was introduced in Linux kernel 3.12, released on November 2, 2013.[[180]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-180)

An alternative to the kernel-level TRIM operation is to use a user-space utility called fstrim that goes through all of the unused blocks in a filesystem and dispatches TRIM commands for those areas. fstrim utility is usually run by [cron](https://en.wikipedia.org/wiki/Cron) as a scheduled task. As of November 2013, it is used by the [Ubuntu](https://en.wikipedia.org/wiki/Ubuntu_(operating_system)) [Linux distribution](https://en.wikipedia.org/wiki/Linux_distribution), in which it is enabled only for Intel and Samsung solid-state drives for reliability reasons; vendor check can be disabled by editing file /etc/cron.weekly/fstrim using instructions contained within the file itself.[[181]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-181)

Since 2010, standard Linux drive utilities have taken care of appropriate partition alignment by default.[[182]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-182)

#### Linux performance considerations



An SSD that uses [NVM Express](https://en.wikipedia.org/wiki/NVM_Express) as the logical device interface, in form of a [PCI Express 3.0](https://en.wikipedia.org/wiki/PCI_Express_3.0) ×4 [expansion card](https://en.wikipedia.org/wiki/Expansion_card)

During installation, [Linux distributions](https://en.wikipedia.org/wiki/Linux_distribution) usually do not configure the installed system to use TRIM and thus the [/etc/fstab](https://en.wikipedia.org/wiki/Fstab) file requires manual modifications.[[183]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-183) This is because of the notion that the current Linux TRIM command implementation might not be optimal.[[184]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-184) It has been proven to cause a performance degradation instead of a performance increase under certain circumstances.[[185]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-185)[[186]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-186) As of January 2014, Linux sends an individual TRIM command to each sector, instead of a vectorized list defining a TRIM range as recommended by the TRIM specification.[[187]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-187) This deficiency has existed for years and there are no known plans to eliminate it.

For performance reasons, it is recommended to switch the I/O scheduler from the default [CFQ](https://en.wikipedia.org/wiki/CFQ) (Completely Fair Queuing) to [NOOP](https://en.wikipedia.org/wiki/Noop_scheduler) or [Deadline](https://en.wikipedia.org/wiki/Deadline_scheduler). CFQ was designed for traditional magnetic media and seek optimizations, thus many of those I/O scheduling efforts are wasted when used with SSDs. As part of their designs, SSDs offer much bigger levels of parallelism for I/O operations, so it is preferable to leave scheduling decisions to their internal logic – especially for high-end SSDs.[[188]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-188)[[189]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-189)

A scalable block layer for high-performance SSD storage, known as *blk-multiqueue* or *blk-mq* and developed primarily by [Fusion-io](https://en.wikipedia.org/wiki/Fusion-io) engineers, was merged into the [Linux kernel mainline](https://en.wikipedia.org/wiki/Linux_kernel_mainline) in kernel version 3.13, released on 19 January 2014. This leverages the performance offered by SSDs and [NVM Express](https://en.wikipedia.org/wiki/NVM_Express), by allowing much higher I/O submission rates. With this new design of the Linux kernel block layer, internal queues are split into two levels (per-CPU and hardware-submission queues), thus removing bottlenecks and allowing much higher levels of I/O parallelization. As of version 4.0 of the Linux kernel, released on 12 April 2015, [VirtIO](https://en.wikipedia.org/wiki/VirtIO) block driver, the [SCSI](https://en.wikipedia.org/wiki/SCSI) layer (which is used by Serial ATA drivers), [device mapper](https://en.wikipedia.org/wiki/Device_mapper) framework, [loop device](https://en.wikipedia.org/wiki/Loop_device) driver, [unsorted block images](https://en.wikipedia.org/wiki/Unsorted_block_images) (UBI) driver (which implements erase block management layer for flash memory devices) and [RBD](https://en.wikipedia.org/wiki/RBD_(software)) driver (which exports [Ceph](https://en.wikipedia.org/wiki/Ceph_(software)) RADOS objects as block devices) have been modified to actually use this new interface; other drivers will be ported in the following releases.[[190]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-190)[[191]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-191)[[192]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-192)[[193]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-193)[[194]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-194)

### OS X

OS X versions since 10.6.8 (Snow Leopard) support TRIM but only when used with an Apple-purchased SSD.[[195]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-195) TRIM is not automatically enabled for third-party drives, although it can be enabled by using third-party utilities such as *Trim Enabler*. The status of TRIM can be checked in the System Information application or in the system\_profiler command-line tool.

OS X version 10.11 (El Capitan) and 10.10.4 (Yosemite) include sudo trimforce enable as a Terminal command that enables TRIM on non-Apple SSDs.[[196]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-196) There is also a technique to enable TRIM in versions of OS X earlier than 10.6.8, although it remains uncertain whether TRIM is actually utilized properly in those cases.[[197]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-197)

### Microsoft Windows

Versions of Microsoft Windows prior to 7 do not take any special measures to support solid state drives. Starting from Windows 7, the standard NTFS file system provides TRIM support (other file systems on Windows do not support TRIM[[198]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-198)).

By default, Windows 7 and newer versions execute TRIM commands automatically if the device is detected to be a solid-state drive. To change this behavior, in the [Registry](https://en.wikipedia.org/wiki/Windows_Registry) key HKEY\_LOCAL\_MACHINE\SYSTEM\CurrentControlSet\Control\FileSystem the value DisableDeleteNotification can be set to 1 to prevent the mass storage driver from issuing the TRIM command. This can be useful in situations where data recovery is preferred over wear leveling (in most cases, TRIM irreversibly resets all freed space).[[199]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-199)

Windows implements TRIM command for more than just file delete operations. The TRIM operation is fully integrated with partition- and volume-level commands like *format* and *delete*, with file system commands relating to truncate and compression, and with the System Restore (also known as Volume Snapshot) feature.[[200]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-:1-200)

#### Windows 7 and later

Windows 7 and later versions have native support for SSDs.[[200]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-:1-200)[[201]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-201) The operating system detects the presence of an SSD and optimizes operation accordingly. For SSD devices Windows disables [SuperFetch](https://en.wikipedia.org/wiki/SuperFetch) and [ReadyBoost](https://en.wikipedia.org/wiki/ReadyBoost), boot-time and application prefetching operations.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)] Despite the initial statement by Steven Sinofsky prior to the release of Windows 7,[[200]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-:1-200) however, defragmentation is not disabled, even though its behavior on SSDs differs.[[129]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-:0-129) One reason is the low performance of [Volume Shadow Copy Service](https://en.wikipedia.org/wiki/Volume_Shadow_Copy_Service) on fragmented SSDs.[[129]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-:0-129) The second reason is to avoid reaching the practical maximum number of file fragments that a volume can handle. If this maximum is reached, subsequent attempts to write to the drive will fail with an error message.[[129]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-:0-129)

Windows 7 also includes support for the TRIM command to reduce garbage collection for data which the operating system has already determined is no longer valid. Without support for TRIM, the SSD would be unaware of this data being invalid and would unnecessarily continue to rewrite it during garbage collection causing further wear on the SSD. It is beneficial to make some changes that prevent SSDs from being treated more like HDDs, for example cancelling defragmentation, not filling them to more than about 75% of capacity, not storing frequently written-to files such as log and temporary files on them if a hard drive is available, and enabling the TRIM process.[[202]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-202)[[203]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-203)

#### Windows Vista

[Windows Vista](https://en.wikipedia.org/wiki/Windows_Vista) generally expects hard disk drives rather than SSDs.[[204]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-204)[[205]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-CWorldSpeedupSSD-205) [Windows Vista](https://en.wikipedia.org/wiki/Windows_Vista) includes [ReadyBoost](https://en.wikipedia.org/wiki/ReadyBoost) to exploit characteristics of USB-connected flash devices, but for SSDs it only improves the default partition alignment to prevent read-modify-write operations that reduce the speed of SSDs. Most SSDs are typically split into 4 kB sectors, while most systems are based on 512 byte sectors with their default partition setups unaligned to the 4 KB boundaries.[[206]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-206) The proper alignment does not help the SSD's endurance over the life of the drive; however, some Vista operations, if not disabled, can shorten the life of the SSD.

Drive [defragmentation](https://en.wikipedia.org/wiki/Defragmentation) should be disabled because the location of the file components on an SSD doesn't significantly impact its performance, but moving the files to make them [contiguous](https://en.wikipedia.org/wiki/Contiguous_data_storage) using the Windows Defrag routine will cause unnecessary write wear on the limited number of P/E cycles on the SSD. The [Superfetch](https://en.wikipedia.org/wiki/SuperFetch) feature will not materially improve the performance of the system and causes additional overhead in the system and SSD, although it does not cause wear.[[207]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-207) Windows Vista does not send the TRIM command to solid state drives, but some third part utilities such as SSD Doctor will periodically scan the drive and TRIM the appropriate entries.[[208]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-208)

### ZFS

[Solaris](https://en.wikipedia.org/wiki/Solaris_(operating_system)) as of version 10 Update 6 (released in October 2008), and recent[*[when?](https://en.wikipedia.org/wiki/Wikipedia:Manual_of_Style/Dates_and_numbers" \l "Chronological_items)*] versions of [OpenSolaris](https://en.wikipedia.org/wiki/OpenSolaris), [Solaris Express Community Edition](https://en.wikipedia.org/wiki/Solaris_(operating_system)" \l "SXCE), [Illumos](https://en.wikipedia.org/wiki/Illumos), [Linux](https://en.wikipedia.org/wiki/Linux) with [ZFS on Linux](https://en.wikipedia.org/wiki/ZFS" \l "Native_ZFS_on_Linux), and [FreeBSD](https://en.wikipedia.org/wiki/FreeBSD) all can use SSDs as a performance booster for [ZFS](https://en.wikipedia.org/wiki/ZFS). A low-latency SSD can be used for the ZFS Intent Log (ZIL), where it is named the SLOG. This is used every time a synchronous write to the drive occurs. An SSD (not necessarily with a low-latency) may also be used for the level 2 [Adaptive Replacement Cache](https://en.wikipedia.org/wiki/Adaptive_Replacement_Cache) (L2ARC), which is used to cache data for reading. When used either alone or in combination, large increases in performance are generally seen.[[209]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-brendan_entry_test-209)

### FreeBSD

ZFS for FreeBSD introduced support for TRIM on September 23, 2012.[[210]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-210) The code builds a map of regions of data that were freed; on every write the code consults the map and eventually removes ranges that were freed before, but are now overwritten. There is a low-priority thread that TRIMs ranges when the time comes.

Also the [Unix File System](https://en.wikipedia.org/wiki/Unix_File_System) (UFS) supports the [TRIM](https://en.wikipedia.org/wiki/TRIM) command.[[211]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-211)

### Swap partitions

* According to Microsoft's former Windows division president [Steven Sinofsky](https://en.wikipedia.org/wiki/Steven_Sinofsky), "there are few files better than the pagefile to place on an SSD".[[212]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-sinofsky1-212) According to collected [telemetry](https://en.wikipedia.org/wiki/Telemetry) data, Microsoft had found the [pagefile.sys](https://en.wikipedia.org/wiki/Pagefile.sys) to be an ideal match for SSD storage.[[212]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-sinofsky1-212)
* [Linux swap](https://en.wikipedia.org/wiki/Linux_swap) partitions are by default performing [TRIM](https://en.wikipedia.org/wiki/TRIM) operations when the underlying [block device](https://en.wikipedia.org/wiki/Block_device) supports TRIM, with the possibility to turn them off, or to select between one-time or continuous TRIM operations.[[177]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-man-8-swapon-177)[[178]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-debian-ssd-178)[[179]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-3.12.5-swapfile.c-179)
* If an operating system does not support using TRIM on discrete [swap](https://en.wikipedia.org/wiki/Paging) partitions, it might be possible to use swap files inside an ordinary file system instead. For example, OS X does not support swap partitions; it only swaps to files within a file system, so it can use TRIM when, for example, swap files are deleted.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)]
* [DragonFly BSD](https://en.wikipedia.org/wiki/DragonFly_BSD) allows SSD-configured swap to also be used as file system cache.[[213]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-213) This can be used to boost performance on both desktop and server workloads. The [bcache](https://en.wikipedia.org/wiki/Bcache), [dm-cache](https://en.wikipedia.org/wiki/Dm-cache), and [Flashcache](https://en.wikipedia.org/wiki/Flashcache) projects provide a similar concept for the Linux kernel.[[214]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-214)

## Standardization organizations

The following are noted standardization organizations and bodies that work to create standards for solid-state drives (and other computer storage devices). The table below also includes organizations which promote the use of solid-state drives. This is not necessarily an exhaustive list.

| Organization or committee | Subcommittee of: | Purpose |
| --- | --- | --- |
| [INCITS](https://en.wikipedia.org/wiki/International_Committee_for_Information_Technology_Standards) | N/A | Coordinates technical standards activity between ANSI in the US and joint ISO/IEC committees worldwide |
| T10 | INCITS | [SCSI](https://en.wikipedia.org/wiki/SCSI) |
| T11 | INCITS | [FC](https://en.wikipedia.org/wiki/Fibre_Channel) |
| T13 | INCITS | [ATA](https://en.wikipedia.org/wiki/AT_Attachment) |
| [JEDEC](https://en.wikipedia.org/wiki/JEDEC) | N/A | Develops open standards and publications for the microelectronics industry |
| [JC-64.8](https://en.wikipedia.org/wiki/JEDEC) | JEDEC | Focuses on solid-state drive standards and publications |
| [NVMHCI](https://en.wikipedia.org/wiki/Nvmhci" \l "Standardization) | N/A | Provides standard software and hardware programming interfaces for nonvolatile memory subsystems |
| [SATA-IO](https://en.wikipedia.org/wiki/Serial_ATA_International_Organization) | N/A | Provides the industry with guidance and support for implementing the SATA specification |
| [SFF Committee](https://en.wikipedia.org/wiki/Small_Form_Factor_committee) | N/A | Works on storage industry standards needing attention when not addressed by other standards committees |
| [SNIA](https://en.wikipedia.org/wiki/Storage_Networking_Industry_Association) | N/A | Develops and promotes standards, technologies, and educational services in the management of information |
| [SSSI](https://en.wikipedia.org/wiki/Solid_state_storage_initiative) | SNIA | Fosters the growth and success of solid state storage |

## Commercialization

### Availability

Solid-state drive technology has been marketed to the military and niche industrial markets since the mid-1990s.[[215]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-215)

Along with the emerging enterprise market, SSDs have been appearing in ultra-mobile PCs and a few lightweight laptop systems, adding significantly to the price of the laptop, depending on the capacity, form factor and transfer speeds. For low-end applications, a USB flash drive may be obtainable for anywhere from $10 to $100 or so, depending on capacity and speed; alternatively, a [CompactFlash](https://en.wikipedia.org/wiki/CompactFlash) card may be paired with a CF-to-IDE or CF-to-SATA converter at a similar cost. Either of these requires that write-cycle endurance issues be managed, either by refraining from storing frequently written files on the drive or by using a [flash file system](https://en.wikipedia.org/wiki/Flash_file_system). Standard CompactFlash cards usually have write speeds of 7 to 15 MB/s while the more expensive upmarket cards claim speeds of up to 60 MB/s.

The first flash-memory SSD based PC to become available was the Sony Vaio UX90, announced for pre-order on 27 June 2006 and began shipping in Japan on 3 July 2006 with a 16Gb flash memory hard drive. [[216]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-216) In late September 2006 Sony upgraded the SSD in the Vaio UX90 to 32Gb. [[217]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-217)

One of the first mainstream releases of SSD was the [XO Laptop](https://en.wikipedia.org/wiki/OLPC_XO-1), built as part of the [One Laptop Per Child](https://en.wikipedia.org/wiki/One_Laptop_Per_Child) project. Mass production of these computers, built for children in developing countries, began in December 2007. These machines use 1,024 MiB SLC NAND flash as primary storage which is considered more suitable for the harsher than normal conditions in which they are expected to be used. [Dell](https://en.wikipedia.org/wiki/Dell) began shipping ultra-portable laptops with SanDisk SSDs on April 26, 2007.[[218]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-dellflash-218) [Asus](https://en.wikipedia.org/wiki/Asus) released the [Eee PC](https://en.wikipedia.org/wiki/ASUS_Eee_PC) [subnotebook](https://en.wikipedia.org/wiki/Subnotebook) on October 16, 2007, with 2, 4 or 8 gigabytes of flash memory.[[219]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-219) On January 31, 2008, [Apple](https://en.wikipedia.org/wiki/Apple_Inc.) released the [MacBook Air](https://en.wikipedia.org/wiki/MacBook_Air), a thin laptop with an optional 64 GB SSD. The Apple Store cost was $999 more for this option, as compared with that of an 80 GB 4200 RPM hard disk drive.[[220]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-macbookairspec-220) Another option, the [Lenovo](https://en.wikipedia.org/wiki/Lenovo) [ThinkPad](https://en.wikipedia.org/wiki/ThinkPad) X300 with a 64 gigabyte SSD, was announced by Lenovo in February 2008.[[221]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-221) On August 26, 2008, Lenovo released ThinkPad X301 with 128 GB SSD option which adds approximately $200 US.[[222]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-222)



Some Mtron solid-state drives

In 2008, low-end [netbooks](https://en.wikipedia.org/wiki/Netbooks) appeared with SSDs. In 2009, SSDs began to appear in laptops.[[218]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-dellflash-218)[[220]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-macbookairspec-220)

On January 14, 2008, [EMC Corporation](https://en.wikipedia.org/wiki/EMC_Corporation) (EMC) became the first enterprise storage vendor to ship flash-based SSDs into its product portfolio when it announced it had selected [STEC, Inc.](https://en.wikipedia.org/wiki/STEC,_Inc.)'s Zeus-IOPS SSDs for its Symmetrix DMX systems.[[223]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-EMC_STEC-223) In 2008, [Sun](https://en.wikipedia.org/wiki/Sun_Microsystems) released the *Sun Storage 7000 Unified Storage Systems* (codenamed Amber Road), which use both solid state drives and conventional hard drives to take advantage of the speed offered by SSDs and the economy and capacity offered by conventional HDDs.[[224]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-224)

[Dell](https://en.wikipedia.org/wiki/Dell) began to offer optional 256 GB solid state drives on select notebook models in January 2009.[[225]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-225)[[226]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-226) In May 2009, Toshiba launched a laptop with a 512 GB SSD.[[227]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-227)[[228]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-228)

Since October 2010, Apple's [MacBook Air](https://en.wikipedia.org/wiki/MacBook_Air) line has used a solid state drive as standard.[[229]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-229) In December 2010, [OCZ](https://en.wikipedia.org/wiki/OCZ_Technology) RevoDrive X2 PCIe SSD was available in 100 GB to 960 GB capacities delivering speeds over 740 MB/s sequential speeds and random small file writes up to 120,000 IOPS.[[230]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-230) In November 2010, Fusion-io released its highest performing SSD drive named ioDrive Octal utilising PCI-Express x16 Gen 2.0 interface with storage space of 5.12 TB, read speed of 6.0 GB/s, write speed of 4.4 GB/s and a low latency of 30 microseconds. It has 1.19 M Read 512 byte IOPS and 1.18 M Write 512 byte IOPS.[[231]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-231)

In 2011, computers based on Intel's [Ultrabook](https://en.wikipedia.org/wiki/Ultrabook) specifications became available. These specifications dictate that Ultrabooks use an SSD. These are consumer-level devices (unlike many previous flash offerings aimed at enterprise users), and represent the first widely available consumer computers using SSDs aside from the MacBook Air.[[232]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-232) At CES 2012, OCZ Technology demonstrated the R4 CloudServ PCIe SSDs capable of reaching transfer speeds of 6.5 GB/s and 1.4 million IOPS.[[233]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-233) Also announced was the Z-Drive R5 which is available in capacities up to 12 TB, capable of reaching transfer speeds of 7.2 GB/s and 2.52 million IOPS using the PCI Express x16 Gen 3.0.[[234]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-234)

In December 2013, Samsung introduced and launched the industry's first 1 TB [mSATA](https://en.wikipedia.org/wiki/MSATA) SSD.[[235]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-235) In August 2015, Samsung announced a 16 TB SSD, at the time the world's highest-capacity single storage device of any type.[[236]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-236)

### Quality and performance

Main article: [Disk drive performance characteristics](https://en.wikipedia.org/wiki/Disk_drive_performance_characteristics)

In general, performance of any particular device can vary significantly in different operating conditions. For example, the number of parallel threads accessing the storage device, the I/O block size, and the amount of free space remaining can all dramatically change the performance (i.e. transfer rates) of the device.[[237]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-master2010-237)

SSD technology has been developing rapidly. Most of the performance measurements used on disk drives with rotating media are also used on SSDs. Performance of flash-based SSDs is difficult to benchmark because of the wide range of possible conditions. In a test performed in 2010 by Xssist, using [IOmeter](https://en.wikipedia.org/wiki/IOmeter), 4 kB random 70% read/30% write, queue depth 4, the IOPS delivered by the Intel X25-E 64 GB G1 started around 10,000 IOPs, and dropped sharply after 8 minutes to 4,000 IOPS, and continued to decrease gradually for the next 42 minutes. IOPS vary between 3,000 and 4,000 from around 50 minutes onwards for the rest of the 8+ hour test run.[[238]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-238)

[Write amplification](https://en.wikipedia.org/wiki/Write_amplification) is the major reason for the change in performance of an SSD over time. Designers of enterprise-grade drives try to avoid this performance variation by increasing [over-provisioning](https://en.wikipedia.org/wiki/Flash_over-provisioning), and by employing wear-leveling algorithms that move data only when the drives are not heavily utilized.[[239]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-nw-239)

### Sales

|  |  |
| --- | --- |
|  | This section needs to be **updated**. Please update this article to reflect recent events or newly available information. *(April 2018)* |

SSD shipments were 11 million units in 2009,[[240]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-240) 17.3 million units in 2011[[241]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-i2013-04-05-241) for a total of US$5 billion,[[242]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-242) 39 million units in 2012, and were expected to rise to 83 million units in 2013[[243]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-243) to 201.4 million units in 2016[[241]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-i2013-04-05-241) and to 227 million units in 2017.[[244]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-tg2013-05-09-244)

Revenues for the SSD market (including low-cost PC solutions) worldwide totalled $585 million in 2008, rising over 100% from $259 million in 2007.[[245]](https://en.wikipedia.org/wiki/Solid-state_drive" \l "cite_note-245)

## See also

* [Board solid-state drive](https://en.wikipedia.org/wiki/Board_solid-state_drive)
* [List of solid-state drive manufacturers](https://en.wikipedia.org/wiki/List_of_solid-state_drive_manufacturers)
* [RAID](https://en.wikipedia.org/wiki/RAID)

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## Further reading

* ["Solid-state revolution: in-depth on how SSDs really work"](https://arstechnica.com/information-technology/2012/06/inside-the-ssd-revolution-how-solid-state-disks-really-work/). Lee Hutchinson. Ars Technica. June 4, 2012.
* Mai Zheng, Joseph Tucek, Feng Qin, Mark Lillibridge, "[Understanding the Robustness of SSDs under Power Fault](http://www.cse.ohio-state.edu/~qin/pub-papers/SSDFault-FAST13.pdf)", FAST'13
* Cheng Li, Philip Shilane, Fred Douglis, Hyong Shim, Stephen Smaldone, Grant Wallace, "[Nitro: A Capacity-Optimized SSD Cache for Primary Storage](https://www.usenix.org/system/files/conference/atc14/atc14-paper-li_cheng_nitro.pdf)", USENIX ATC'14

## External links

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|  | Wikimedia Commons has media related to [***Solid-state drives***](https://commons.wikimedia.org/wiki/Category:Solid-state_drives). |

Background and general

* [StorageReview.com SSD Guide](http://www.storagereview.com/ssd_reference_guide)
* [A guide to understanding Solid State Drives](http://www.happysysadm.com/2011/07/solid-state-drives-some-theory-and.html)
* [SSDs versus laptop HDDs and upgrade experiences](http://www.notebookcheck.net/SSD-versus-HDD-in-comparison.18750.0.html)
* [Understanding SSDs and New Drives from OCZ](http://www.anandtech.com/printarticle.aspx?i=3531)
* [Charting the 30 Year Rise of the Solid State Disk Market](http://www.storagesearch.com/chartingtheriseofssds.html)
* [Investigation: Is Your SSD More Reliable Than A Hard Drive?](http://www.tomshardware.com/reviews/ssd-reliability-failure-rate,2923.html) - long term SSD reliability review
* [SSD return rates review by manufacturer (2012), hardware.fr](http://www.hardware.fr/articles/862-7/ssd.html) - French ([English](http://translate.googleusercontent.com/translate_c?depth=1&hl=it&ie=UTF8&prev=_t&rurl=translate.google.com&sl=fr&tl=en&u=http://www.hardware.fr/articles/862-7/ssd.html)) a 2012 update of a 2010 report based on data from a leading French tech retailer
* [Enterprise SSD Form Factor Version 1.0a](http://www.ssdformfactor.org/docs/SSD_Form_Factor_Version1_a.pdf), SSD Form Factor Work Group, December 12, 2012

Other

* [Ted Tso - Aligning filesystems to an SSD's erase block size](http://tytso.livejournal.com/2009/02/20/)
* [JEDEC Continues SSD Standardization Efforts](http://www.jedec.org/news/pressreleases/jedec-continues-ssd-standardization-efforts)
* [Linux & NVM: File and Storage System Challenges](http://snia.org/sites/default/files/NVM13-Wheeler_Linux_and_NVM.pdf) (PDF)
* [Linux and SSD Optimization](https://wiki.debian.org/SSDOptimization)
* [Understanding the Robustness of SSDs under Power Fault](https://www.usenix.org/system/files/conference/fast13/fast13-final80.pdf) (USENIX 2013, by Mai Zheng, Joseph Tucek, Feng Qin and Mark Lillibridge)
* [SSD vs. m.2](https://www.frugalgaming.org/best-pcie-ssd/), FrugalGaming, by James Heinfield
* [**Electronics portal**](https://en.wikipedia.org/wiki/Portal:Electronics)
* [**Information Technology portal**](https://en.wikipedia.org/wiki/Portal:Information_Technology)
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