SSD drive - Flash drive

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A solid-state drive (SSD), also sometimes incorrectly called a solid-state drive because it lacks a disk, is a type of data storage device that uses non-volatile memory, such as flash memory, to store data, rather than the magnetic platters or disks of hard disk drives (HDD) conventional.

The connector is similar in appearance to a PCI Express Mini Card interface,[56] but is not electrically compatible; the data signals (TX±/RX± SATA, PETn0 PETp0 PERn0 PERp0 PCI Express) need a connection to the SATA host controller instead of the PCI Express host controller.

A standard 2.5-inch (64 mm) form factor SATA SSD, with 525 gigabytes of capacity.Samsung 960 PRO SSD 512 gigabytes in 2018, front and back.

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Compared to traditional hard drives, solid-state drives are less sensitive to shocks because they have no moving parts, are inaudible, lighter, and have a significantly lower access time and latency, which translates into a substantial improvement in performance, in terms of loading operating systems. Software and Data Transfer. On the other hand, their useful life may be shorter, as they have a limited number of write cycles, and the absolute loss of data can occur unexpectedly and irretrievably. However, by calculating the mean time between failures and managing bad sectors, this problem can be reasonably mitigated.

SSDs can use the same SATA interface as hard drives, so they are easily interchangeable without having to resort to adapters or expansion cards to make them compatible with the computer, but also the PCIe interface for higher read/write speeds, which can exceed 10 GB/s, although this depends on the generation of PCIe you use and other factors in your design.2Although in the beginning the most common physical format of these drives was that of a standard 2.5 or 3.5-inch hard drive, there are currently other consumer formats in use such as mSATA or M.2, and other enterprise ones such as NF1.3?4?

As of 2010, most SSDs use NAND port-based flash memory, which retains data without power. For applications that require fast access, but not necessarily data persistence after power loss, SSDs can be built from random access memory (RAM). These devices can employ independent power sources, such as batteries, to maintain data after power is disconnected.

Devices that combine both technologies, hard drives with flash memory, have been developed and are available on the market in a single drive, which is called a hybrid hard disk drive (HHDD or Hybrid Hard Disk Drive), with the intention of improving speed while maintaining the capacity of the hard drive, and at prices lower than those of solid state. This results in a compromise solution with a transfer rate higher than that of a conventional hard drive but lower than that of an SSD.

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Definition
SSD SATA III

An SSD is a non-volatile storage device made exclusively of electronic components.5It is intended for use in computers to replace a conventional hard disk drive, as auxiliary memory, or to create hybrid HHDD drives consisting of SSDs and hard disks.

By having no moving parts, it drastically reduces access time, latency and others, thus differentiating itself from electromagnetic hard drives.

Being immune to external vibrations, it is especially suitable for vehicles, laptops,6and so on.

History
RAM-based SSDs
In the 1950s, two technologies called magnetic core memory and CCROS (Charged Capacitor Read-Only Storage) were used. These auxiliary memories emerged during the time when the vacuum tube was being used, but with the introduction of more affordable drum memories on the market, they were not further developed. During the 1970s and 1980s, they were applied in memories made of semiconductors. However, their price was so prohibitive that they had very little acceptance, even in the supercomputer market.

In 1978, Texas Memory introduced a 16 KiB RAM-based solid-state drive for oil companies' equipment. The following year, StorageTek developed the first type of modern solid-state drive. In 1983, the Sharp PC-5000 was introduced, boasting 128 cartridges of solid-state storage based on bubble memory. In September 1986, Santa Clara Systems introduced the BATRAM,7that it consisted of 4 MiB expandable to 20 MiB using memory modules; The unit contained a rechargeable battery to preserve data when not in operation.

Flash-based SSDs
Kingston HyperX Predator 480GB with pci express adapter.

They were invented by Dr. Fujio Masuoka in 1980 when he was working for Toshiba. He resumed the project in 1987 but they were commercialized by that company in 1989.8In 1991, SanDisk (called SunDisk at the time) also successfully commercialized a device that corrected read and write errors in flash memory.9In 1995, M-Systems introduced flash-based solid-state drives. Since then, SSDs have been successfully used as an alternative to hard drives in the military and aerospace industries, as well as in other similar endeavors.10These applications rely on a high Mean Time Between Failure (MTBF) rate, high ability to withstand heavy shocks, sudden changes in temperature, pressure, and turbulence.

BiTMICRO, in 1999, boasted a series of presentations and announcements of 18 GiB flash-based solid-state drives in a 3.5-inch format. Fusion-io, in 2007, announced solid-state drives with PCI-Express interface capable of performing 100,000 I/O operations in expansion card format with capacities up to 320 GB. At CeBIT 2009, OCZ introduced a 1 TiB flash-based SSD with PCI Express x8 interface capable of achieving a maximum write speed of 654 MB/s and a maximum read speed of 712 MB/s. In December 2009, Micron Technology announced the world's first SSD, using the SATA III interface.11?

In 2016, Seagate shows transfer speeds of 10GB/s from a 16-way PCIe SSD and also shows a 60TB SSD with a 3.5-inch form factor, the world's largest capacity drive.12Samsung also launches a 15.36TB SSD priced at 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 that a commercially available SSD had more capacity than the largest hard drive available today.13?14?15?

In 2017, the first products with Xpoint 3D memory are launched. 3D Xpoint is completely different from NAND Flash and stores data using different principles.16?

In 2018, both Samsung and Toshiba introduce 30.72TB SSDs that use the same 2.5-inch form factor but with a 3.5-inch drive thickness that uses SAS interfaces. Nimbus Data advertises and reportedly ships 100TB drives using a SATA interface, not expected to reach a hard disk drive until 2025. Samsung introduced an m.2 SSD with speeds of 3500MB/S.17?18?19?20?

Enterprise Flash Drive
Enterprise flash drives (EFDs) are designed for applications that require a high operations per second rate, reliability, and power efficiency. In most cases, an EFD is an SSD with a set of higher specifications. The term was coined by EMC

in January 2008 to help them identify SSD manufacturers that would target higher-end markets. There are no standards bodies that coin the definition of EFD, so any manufacturer can refer to SSDs as EFDs without minimum requirements. In the same way, there may be SSD manufacturers that make drives that meet EFD requirements and are never called that.

Racetrack
IBM is researching and designing a device, still in the experimental phase, called RaceTrack. Like SSDs, they are non-volatile memories based on nanowires composed of nickel, iron and vortices that separate the stored data from each other, allowing speeds up to 100,000 times faster than traditional hard drives, according to IBM.21?

Main Parts of an SSD
A solid-state drive has four fundamental aspects that determine its main characteristics, both in terms of reading and writing as well as capacity: physical format and connector, communication interface and communication protocol.

Physical format
Solid-state drives initially hit the market in a form factor equal to hard drives, and today it is still common to find SSDs that have a 2.5-inch disk form factor and, especially in business environments, 3.5-inches. As the size of memory chips, controllers, and other chips used to operate them has been reduced, and due to the need to save space in laptops, tablets, and convertibles, there are formats that are like small cards.

The first mini-SATA (abbreviated mSATA) format is a small card 30 mm wide and 50.95 mm long. Much more common today is the M.2 format, which has a width of 22 mm and is standardized in five different lengths: 30 mm, 42 mm, 60 mm, 80 mm and 110 mm. The specific format of the card is usually named by adding the length to the width. The most common at the domestic level is the M.2 2280.

There are other less common formats and others that are in development, such as Samsung's NF1.

Physical Interface
An SSD's bus interface determines the type of bus it uses for physical communication with the device on which the SSD is located. There are two main ones: SATA3, which allows speeds of up to 6 Gb/s (750 MB/s); and PCI Express (PCIe) whose maximum speed will depend on the generation you implement, being up to 16 Gb/s per PCIe 4.0 channel. Most commonly, you have PCIe ×2 and ×4 connections (two and four PCIe channels added, respectively). There are also other buses such as SATA Express.

Physical Connector
There are different physical connectors used in SSDs, and each is tied to a bus interface. For example, 2.5-inch home SSDs use a SATA connector to use SATA3 as if they were a hard drive, while the M.2 specification determines a number of formats for connector contacts based on whether the bus is SATA3 or PCIe. There is also the SATA Express connector (SATA 3.2) which uses a PCIe ×2 bus interface, and the U.2 connector which also uses PCIe; They are usually used in drives in 2.5-inch or 3.5-inch disk form factor.

Communication protocol
The communication interface is the way in which the ones and zeros are transmitted at the physical level between the solid-state drive and the host computer. Mainly used: AHCI which is bound to Serial ATA, and NVMe which is bound to PCIe. Since it is a communication protocol at the physical level, the information is divided into groups of bits (payload) and each group is assigned a header to perform transmission control and error correction tasks.

In the case of AHCI, the send is done with a large loss of useful bus when doing an 8b/10b encoding (eight payload bits are ten bits sent), while NVMe has a 128b/130b encoding, so less bus width is wasted on the transmission of information. Because of this, the actual maximum speed of SATA3 is 600 MB/s, although the theoretical speed is 750 MB/s. In the case of PCIe, the actual maximum speed of a PCIe 3.0 ×1 connection would be 984 MB/s.

Architecture & Operation
Open chassis of a traditional hard drive (left). Appearance of an SSD especially suitable for laptops (right).

There are two distinct periods: at first, they were built with volatile DRAM memory, and later they began to be manufactured with non-volatile NAND flash memory.

Controller
Every SSD includes a control chip, more commonly called a controller, that allows the drive to manage how it reads and

writes information. It features a system-on-chip design in that it includes a single- or more-core processor, similar to an application-specific integrated circuit with internal SRAM. Sometimes a DRAM chip is also included in the controller-managed SSD to act as a cache of user data and internal metadata on the SSD.22?

While the first drivers were fairly basic, they now provide a wide variety of features related to saved information protection and security. Since it is also responsible for managing the loss of power to the drive, the design of the SSD usually includes capacitors to allow the controller to finish performing the transactions it was carrying out in an orderly manner.

The controller takes care of tasks such as:

Marking Erroneous Blocks
Read & Write Cache
Encryption
Error Detection Using Error Correction Code
Secure Cryptographic Erase
Trash collection
Read debugging
Reading crosstalk management
Cell Wear Management

Memory
Flash Memory
Almost all manufacturers market their SSDs with non-volatile NAND memory in order to develop a device that is not only fast and with a large capacity, but also robust and at the same time as small as possible for both the consumer and professional markets. As they are non-volatile memory, they do not require any type of constant power or batteries so as not to lose stored data, even in sudden blackouts, although it should be noted that NAND SSDs are slower than those based on DRAM. They are marketed with the dimensions inherited from hard drives, i.e. in 3.5 inches, 2.5 inches and 1.8 inches, although certain SSDs also come in expansion card format.

In some cases, SSDs can be slower than hard drives, especially with older, low-end controllers, but since the access times of an SSD are negligible, they are faster in the end. This short access time is due to the absence of moving mechanical parts, inherent in hard drives.

An SSD is mainly made up of:

Controller: it is an electronic processor that is responsible for administering, managing and joining the NAND memory modules with the input and output connectors. It runs firmware-level software and is arguably the most important determinant of device speeds.
Cache: An SSD uses a small DRAM memory device similar to the cache on hard drives. The directory of block placement and data leveling wear is also kept in the cache while the drive is operational.
Capacitor: This is necessary to maintain the integrity of the data in the cache, if the power has been stopped unexpectedly, long enough so that the retained data can be sent to the non-volatile memory.

The performance of SSDs is increased by adding NAND chips in parallel. A single NAND chip is relatively slow, given that the I/O interface is 8-bit or 16-bit asynchronous and also because of the additional latency of basic I/O operations (typical of NAND SLCs, approximately 25 ?s to fetch a 4 KiB page of the array in the I/O buffer in one read, approximately 250 ?s for a 4 KiB page of I/O buffer to write matrix and over 2 ms to erase a 256 KiB block). When multiple NAND drives operate in parallel within an SSD, bandwidth scales are increased and high latencies are minimized, as long as enough operations are pending and the load is evenly distributed across the devices.

SSDs from Micron and Intel manufactured flash drives by applying banding data (similar to RAID 0) and interleaving. This enabled the creation of ultra-fast SSDs with 250 MB/s read and write.

Sandforce's SF 1000 series controllers achieve transfer rates close to the saturation of the SATA II interface (close to 300 MB/s symmetrical in both read and write). The successor generation, Sandforce's SF 2000 series, allow beyond 500 MB/s symmetrical sequential read and write, requiring a SATA III interface to achieve these registers.

Comparison between MLC and SLC chips.

Each NAND memory cell can contain one or more bits, and as a result, they are manufactured differently and given different names.

One-level cell (SLC): This process involves cutting the silicon wafers and obtaining memory chips. This monolithic process has the advantage that the chips are considerably faster than those of the opposite technology (MLC), greater longevity, lower consumption, a shorter data access time. On the other hand, the capacity density per chip is lower, and therefore, a considerably higher price in devices manufactured with this method. On a technical level, they can store only one bit of data per cell.
Multi-Level Cell (MLC): This process involves stacking multiple wafer molds to form a single chip. The main advantages of this manufacturing system are to have a higher capacity per chip than with the SLC system and therefore, a lower final price on the device. On a technical level, it is less reliable, durable, fast and advanced than SLCs. These types of cells store two bits each, i.e. four states, so the data read and write rates are reduced. Toshiba has managed to develop three-bit cells.23?
Triple-level cell (TLC): The most common technology in today's SSDs, in which three bits are maintained for each cell. Its biggest advantage is the considerable price reduction. Its biggest disadvantage is that it only allows 1000 writes.24?
Quad-Level Cell (QLC): The latest innovation in that they are increased to four bits for each cell. The price reduction compared to the previous ones is greater. Increasing the bits reduces the number of writes/erase to only about 100 times.25Even if it has a small number of writes, there is no limit to the number of reads and speed of an SSD.

DRAM
SSDs based on this type of storage provide very low data access time, around 10 ?s, and are primarily used to accelerate applications that would otherwise be undermined by the latency of other systems. These SSDs incorporate a battery or a DC adapter, as well as a storage backup system for abrupt disconnections that when reset is re-dumped to non-volatile memory, somewhat similar to the hibernation system of operating systems.

These SSDs are generally equipped with the same RAM modules as any regular computer, allowing them to be replaced or expanded.

However, improvements to flash-based drives are making DRAM-based SSDs less effective and bridging the gap between them in terms of performance. In addition, DRAM-based systems are much more expensive.

Other Applications
Solid-state drives are especially useful in a computer that has already maxed out its RAM. For example, some x86 architectures have a 4 GiB limit, but this can be extended by placing an SSD as a swap file (virtual memory mechanism). These SSDs don't provide as fast storage as the main RAM due to the bottleneck of the bus that connects them and the distance from one device to another is much greater, but it would still improve performance over putting the swap file on a traditional hard drive.

SSD-related optimizations in file systems
File systems were designed to work and manage your files according to the functionalities of a hard drive. This management method is not effective for ordering the files inside the SSD, causing a serious degradation of performance the more it is used, recoverable by total formatting of the solid state drive, but being cumbersome, especially in operating systems that depend on daily storage of databases. To solve this, different operating systems optimized their file systems to work efficiently with solid-state drives, when they were detected as such, rather than as hard drives.26?

NTFS and exFAT
Prior to Windows 7, all operating systems were prepared to precisely handle hard disk drives. Windows Vista included the ReadyBoost feature to improve and take advantage of the features of USB drives, but for SSDs it only optimized partition alignment to prevent read, modification, and write operations, since on SSDs the sectors are usually 4 KiB, and currently hard disks have 512-byte sectors misaligned (which were later also increased to 4 KiB). Among some things, it is recommended to disable the defragmenter; using it on an SSD is pointless, and would reduce its life by making continuous use of read and write cycles.

Windows 7 is optimized as standard to properly handle SSDs without losing compatibility with hard drives. The system automatically detects whether it is a solid state drive or a hard drive, and changes various settings; for example, it automatically disables the defragmenter, Superfetch, Readyboost, changes the boot system, and introduces the TRIM command, which prolongs the life of SSDs and prevents performance degradation.

ZFS

Solaris, version 10u6, and the latest versions of OpenSolaris and Solaris Express Community Edition, can use SSDs to improve the performance of the ZFS system. Two modes are available, using an SSD for ZFS Intent (ZIL) registration or for the L2ARC. When used alone or in combination, performance is radically increased.

The new SSDs include GC (Garbage Collector) technology, another very useful mechanism, especially for people who don't have their PC on all day, which consists of scheduling or forcing manual cleanings. These utilities are known as garbage collectors and allow you to manually delete these unused blocks. These types of utilities are useful if you don't use an operating system like Windows 7 and can also be used in combination with TRIM.27?

Advantages, disadvantages and solutions

Advantages

Solid-state devices that use blocks of flash memory have several unique advantages over mechanical hard drives:28?

Start faster, as you don't have chainrings that need to take a constant speed.
Great typing speed.
Faster reads, even ten times faster than the fastest traditional hard drives thanks to internal RAID on the same SSD.
Low read and write latency, hundreds of times faster than mechanical disks.
Launch and launch applications in less time: result of the faster reading speed and especially the search time. But only if the application resides in flash and is more dependent on read speed than on other aspects.
Lower energy consumption and heat production: the result of having no mechanical elements.
Noiseless: The very lack of mechanical parts makes them completely inaudible.
Improved the mean time between failures, exceeding two million hours, much higher than that of hard drives.
Security: allowing a very fast "cleansing" of the stored data.
Deterministic performance: Unlike mechanical hard drives, SSD performance is constant and deterministic across the entire storage. The "search" time is constant.
Performance does not deteriorate as the medium fills up. (See Defragmentation.)
Lighter weight and size than a traditional hard drive of similar capacity.
Resistant: withstands drops, shocks and vibrations without being damaged or decalibrated, the opposite happens with hard drives because they contain precision mechanical elements.
More secure and irretrievable deletion of data, i.e. it is not necessary to use the Gutmann Algorithm to ensure the irretrievable deletion of a file.

Limitations

Solid-state devices that use flash memory also have several disadvantages:

Price: Flash memory prices are considerably higher in price/gigabyte ratio, due to lower demand. This as such is not a technical disadvantage, and as its mass use is achieved to the detriment of the previous standard, it is expected that its price will be regulated and made more affordable as it happens with mobile hard drives, which in theory are more expensive to produce because they have metal parts and have high-precision mechanisms.

Limited data recovery: after a physical failure data is completely lost, as the cell is destroyed, whereas on a normal hard drive that suffers mechanical damage the data is often recoverable using the help of experts who access the saucer.

Failure produced unexpectedly: unlike traditional disks that begin to accumulate erroneous sectors spaced out in time, giving the possibility of making a data dump; SSDs fail imminently without giving you time to save any data at the time of the first error message. Therefore, they are not recommended for the storage of user-important data, nor in business environments without backup.

Lifespan: Reducing the size of the transistor directly decreases the lifespan of NAND memories. This would already be solved in later models when installing systems using memristors. The lifetime of SSDs is indicated by TBWs, which are the number of TeraBytes Writen that disk memory supports.29This information is theoretical and is provided by the manufacturer, so it cannot be considered a guarantee. It is very difficult to calculate its duration, as it does not depend on the time, but mainly on the intensive use of writing and reading that is given to it.

Smaller storage sizes offered. In 2015 the maximum storage available in stores was 960 GB, and in 2019 they are already 4TB.

Traditional maintenance tasks on operating systems dramatically shorten their lifespan and disabling them is recommended. Hard drive defragmentation, virtual memory utilization, or search indexing processes contribute to continuous write cycles that shorten the life of the SSD. The worst processes applicable to solid-state memory are read/write performance tests and formatting, which automatically wears out the drive.30?

SSDs need to receive power periodically, otherwise the stored data may be lost.31This means that a power outage affects them and can cause the absolute loss of all data. There is a method to recover them that consists of recharging them with a full charge cycle that is not always effective. It is recommended to use them with a UPS electrical power protection device.

Solutions

Some of the problems that most affected its mass use were:

Performance degradation after a lot of NAND memory usage (partly solved with the TRIM system).

Vulnerability to certain types of effects: including abrupt power loss (on DRAM-based SSDs), magnetic fields, and static charges compared to normal hard drives (which store data inside a Faraday cage).

See also

Portable Hard Drive

Memory (computing)

Hard Disk Drive

Fragmentation of a file system

References

? Izquierdo, Robin (November 13, 2019). "Hard Disk Types" (html). Pandora FMS. Archived from the original on 21 November 2019. Retrieved December 29, 2019. "The structure of SSD devices has little or nothing to do with that of classic HDDs, so they are only called "hard drives" because they are dedicated to similar functions. SSDs are not, in fact, disks, and they lack mechanical parts; On the contrary, they have their own microprocessor (called a "controller") that takes care of the tasks of reading/writing data, and they store the data on microchips that have interconnected flash memories. »

? "Seagate boasts of the fastest SSD flash drive at 10 GB/s". SlashGear. March 9, 2016. Retrieved May 9, 2020.

? «NF1 SSD | Samsung Semiconductor." www.samsung.com. Retrieved May 9, 2020.

? Cunningham, Andrew (February 8, 2015). "Understanding M.2, the interface that will speed up your next SSD". Ars Technica. Retrieved May 9, 2020.

? Alecrim, Emerson (May 19, 2019). «O que é SSD? Tudo sobre velocidade, tipos e tecnologias" (html). Info Wester (in Portuguese). Archived from the original on 29 September 2019. Retrieved December 30, 2019. "The "Solid State" thermo, in truth, refers to the use of solid material for the transport of electrical sins between transistors instead of a passagem based on vacuum tubes, as was the case at the time of the valves. Em aparelhos SSD, o armazenamento é feito em um ou mais chips de memória, dispensando totalmente o uso de sistemas mecânicos para o seu funcionamento. »

? Alecrim, Emerson (May 19, 2019). «O que é SSD? Tudo sobre velocidade, tipos e tecnologias" (html). Info Wester (in Portuguese). Archived from the original on 29 September 2019. Retrieved December 30, 2019. «Essa caracteristica também faz "discos SSD" (não se trata de um disco, portanto, o uso desta denominação não é correto, apesar de relativamente comum) usarem menos espaço físico, pois os dados são armazenados em chips especiais, de tamanho muito reduzido. Graças a isso, os SSDs começaram a ser usados de forma ampla, inclusive em dispositivos extremamente portáteis, como notebooks ultrafinos (ultrabooks) e tablets. »

? "BATRAM – Battry-Backed RAM Disk".

? "Biography of Dr. Fujio Masuoka~Inventors Flashdisk" (html). My Article. Archived from the original on 23 February 2016. Retrieved December 30, 2019. «Masuoka then transferred to Toshiba memory engineered products division in 1980 to begin work on the development of flash memory. »

? "1991: Solid State Drive module demonstrated" (html). Computer History Org. (in English). November 15, 2015. Archived from the original on 21 December 2015. Retrieved December 30, 2019.

? Odagiri, Hiroyuki; Goto, Akira; Sunami, Atsushi; Nelson, Richard R (2010). Intellectual Property Rights, Development, and Catch Up: An International Comparative Study . Oxford University Press. pp. 224-227. ISBN 978-0-19-957475-9.
? Jansen, Ng (December 2, 2009). "Micron Announces World's First Native 6Gbps SATA Solid State Drive." DailyTech. Archived from the original on 5 December 2009. Retrieved December 2, 2009.
? "Seagate, with the largest SSD: 60TB of flash memory."
? "Seagate Demonstrates Fastest-Ever SSD Flash Drive". www.seagate.com. March 8, 2016.
? "Seagate Introduces 10GB/s PCIe SSD And 60TB SAS SSD." www.anandtech.com.
? "Samsung's massive 15TB SSD can be yours -- for about $10K - Computerworld". www.computerworld.com.
? "Intel and Micron Increase 3D XPoint Manufacturing Capacity with IM Flash Fab Expansion". newsroom.intel.com. November 13, 2017.
? "Samsung Electronics Begins Mass Production of Industry's Largest Capacity SSD – 30.72TB – for Next-Generation Enterprise Systems". news.samsung.com. February 20, 2018.
? "Seagate 60TB SSD Named "Best of Show" at Flash Memory Summit". blog.seagate.com. August 13, 2016.
? "NNimbus Data Launches the World's Largest Solid State Drive – 100 Terabytes – to Power Data-driven Innovation". nimbusdata.com. March 19, 2018.
? "Samsung Electronics Sets New Performance Standards for NVMe SSDs with 970 PRO and EVO". news.samsung.com. April 24, 2018.
? "News3D - Racetrack, possible replacement for SSDs". www.noticias3d.com. Retrieved May 10, 2016.
? Cornwell, Michael (2012-12). "Anatomy of a solid-state drive". Communications of the ACM 55 (12): 61. ISSN 0001-0782. doi:10.1145/2380656.2380672. Retrieved May 31, 2020.
? "3D News - Toshiba Makes 8GB 24nm NAND Chip" www.noticias3d.com. Retrieved May 10, 2016.
? "3D News - OCZ will launch SSDs up to 30% cheaper thanks to TLC". www.noticias3d.com. Retrieved May 10, 2016.
? "Types of NAND FLASH memory in your SSD." discodurossd.info. Retrieved March 18, 2019.
? Sandforce SF-1200 SSD Controller (OCZ Vertex 2) Opening Applications Immediately, August 2010 video) YouTube video showing the opening speed of 40 applications using an OCZ Vertex 2 with SandForce SF 1200 Series controller (285 MB/s read - 275 MB/s write).
? Solid-state drives (SSDs) inserted into a DIMM.
? Raptor vs Intel X25-M, May 2009 YouTube video comparing the time it takes to boot 51 applications using a traditional hard drive (Western Digital Raptor WD1500ADFD) and a solid-state drive (Intel X-25M). (250 MB/s read - 70 MB/s write).
? "Data Degradation and Retention on SSDs".
? Crucible, Leandro (January 23, 2013). "How to optimize the performance of our SSD in Windows 8". www.xatakawindows.com. Retrieved May 10, 2016.
? "Is there a way to protect SSD from corruption due to power loss?".