Winchester disks reach for a gigabyte

Poised for a 200-fold increase in capacity over initial models of six years ago, 5¼-inch hard disks are emerging as major elements for small-system designs

When the 5¼-inch Winchester rigid disk drive was first shipped in 1980, its capacity was 5 megabytes. Today drives the same size store as much as 760 megabytes of data in a space hardly larger than a thick paperback book. Nor has the limit been reached. Within a year or two these drives are expected to hold more than a gigabyte of data.

Yet that first 5¼-inch hard disk—the ST506 from Seagate Technology of Scotts Valley, Calif.—was itself considered a revolutionary leap in storage for small computer systems. The typical 5¼-inch floppy disk drive of the time could hold only 160 kilobytes of data.

Disk drive capacity is one of three critical technologies in small computer design. The others are the performance of microprocessors and the storage density of random-access memory chips. But while the first microprocessor—Intel's 4004—appeared in 1971, and RAM chips made their debut during the mid-1960s, hard disk technology dates to 1953.

The first hard disk drive was IBM's Ramac 350, composed of 50 disks, each 24 inches in diameter. The drive stored a grand total of 5 megabytes. Since that time, disk drive dimensions have steadily fallen—and their storage capacity has risen astronomically.

The 5¼-inch disk drive is now the standard for most hard drives in personal computers and desktop workstations, although 3¼-inch drives are now entering the field at low capacities. The least expensive 5¼-inch drives have capacities of 10 to 40 megabytes, while the storage of the highest-capacity drives is rapidly approaching 1 gigabyte [see table]. This year more than 5 million 5¼-inch hard disk drives are expected to be sold, according to Jim Porter, publisher of Disk/Trend Report, an annual industry market study.

'Flying' millionths of an inch high

How does a 5¼-inch hard disk drive work? Broadly, much like a floppy disk drive. Data bits are stored in sectors that make up concentric tracks on both sides of a platter. The formatting of the sectors and tracks is determined by both manufacturer and user. When specifying capacity, drive makers usually quote the maximum number of bits that can be written onto a platter. Some bits are used for format information and error identification, reducing the volume of user-supplied data that can be stored on the recording surface.

The stationary read-write heads "fly" over the surfaces of the rotating platters on a layer of air a few millionths of an inch thick. The arms containing the read-write heads move from track to track, but the heads never touch the moving disk surface.

To position the arms properly in high-capacity drives, the read-write heads follow the signal generated from a prerecorded servo track on one platter. To read data from the platters, or to write it back, the computer's operating system issues commands to a disk controller. Track and sector addresses are transmitted from a table maintained in memory by the operating system. The controller positions the read-write heads over the appropriate track on a particular platter, based on the starting address for the desired data.

The disk controller reads the addresses of the sectors that pass under the head, and it either reads the contents of the appropriate number of sectors into memory or writes data from memory into empty or unneeded sectors. The data transfer rate depends on which of several industry-standard interface specifications has been used.

Behind the black panel

Most 5¼-inch hard disk drives look the same. The majority have black plastic front panels, with a small red light in the lower left-hand corner that flicks on when the drive is reading or writing data. But the technology behind those similar-looking front panels differs substantially, depending on capacity.

Low-end drives—those storing 10 to 40 megabytes of data—use designs and materials that lend themselves to high-volume, low-cost production. On the other hand, the higher-capacity drives [Fig. 1]—ranging from 100 megabytes to almost a gigabyte—require much more costly and complex approaches. The goal of these designs is to stuff as many bits of data as possible into a box 3¼ by 5¼ by 8 inches (82.6 by 146 by 203 millimeters).

There are several ways to raise the capacity of a disk drive without increasing its physical size. One of the more obvious is to put more platters into the case. The first Seagate drive of 1980 had two platters; current drives from such companies as Maxtor Corp., San Jose, Calif.; Micropolis Corp., Chatsworth, Calif.; and Priam Corp., San Jose, Calif., have as many as eight.

Defining terms

Average access time: the average time required to locate data written at a random position on the disk.
Flux reversal: the reversal of magnetic polarity in the medium on the platter of a hard disk drive.
Formatted capacity: the capacity for data storage on a hard disk. Unformatted capacity—the maximum number of bits that can be put on the disk—is always higher because it includes bits that will be used for formatting information and error correction codes rather than for data.
Medium: the material on the surface of a platter in which information is magnetically recorded.
Platter: the metal disk covered by some magnetic medium for storing information.
Read-write head: an electromagnet capable of producing a switchable magnetic field to read and record bit streams.
Vertical recording: a recording method in which the magnetic domains are oriented perpendicular to the recording surface rather than along the surface.

John Voelcker  Associate Editor
To pack more platters into the case, Winchester drive designers moved the drive motor inside the disks' hubs from its previous location underneath the stack of platters [Fig. 2]. Not only did this leave more of the case's vertical dimension to be used for disks, but it also improved the distribution of the motor's heat, reducing the thermal difference between the top and bottom disks in the stack.

For each surface of a platter, a read-write head is needed. Heads do not move independently; the arms are mounted together so that every head is positioned over the same track on the surface beneath it. Data that exceeds the length of a single track is written not to the next track on the platter, but to the same track on another platter. This avoids the comparatively slow mechanical movement of the arm, reducing the time required to store or retrieve any given amount of data.

Some manufacturers use "minislider" read-write heads [Fig. 3], also known as Whitney heads. They are similar in size to the heads used in IBM's 3370 mainframe disk drive—smaller, thinner, and lighter than the more traditional Winchester heads. Consequently, they can be mounted on simpler flexures, or arms. Minislider heads also allow platters to be positioned closer together, increasing the number of platters in a drive.

More bits and tracks per inch

Capacity also rises when more data can be put onto each platter. Manufacturers do this in two ways: by increasing the density of bit storage on the platter and by using a larger area of each platter's surface.

Increased storage density requires increasing the bit density of each track (measured in bits per inch, or bpi) and increasing the track density on each platter (measured in tracks per inch, or tpi).

The number of bits that can be put into a given area depends on the magnetic material that coats the disk's surface, on the head size and configuration, and on the data encoding technique. The read-write head is an electromagnet; when the head is to write a 1-bit to the disk surface, current is turned on between the poles and a flux is generated. The actual reversal in the magnetization of a bit is produced by the fringing field between the pole faces, which passes through the disk's surface.

The highest-density magnetic disk media today are thin films of alloys of various metals—cobalt or chromium, for instance—plated onto the disk. The smaller magnetic domains and greater magnetic strength of the thin films allow more than 21,000 flux reversals per inch—compared with a maximum of roughly 16,000 for the relatively thick iron oxide media.

To write the higher bit densities onto the platter, thin-film recording heads with much smaller gaps between the poles are required. These heads fly even closer to the surface of the platter than the heads used with iron oxide media.

Some of the greatest improvements in bit density are a payoff of encoding techniques. The standard modified frequency modulation...
The traditional Winchester head [left] is wider and thicker, and is contained in a larger flexure, than the newer "minislider," or Whitney head [right], which allows disk platters to be spaced closer together. The Whitney head is similar to heads in large mainframe direct-access storage devices, or DASDs.

High-capacity drives use a closed-loop, track-following servo system to indicate to the positioning mechanism the exact position of each head above the platter. The servo-reference tracks are usually recorded on one surface of a disk in the stack, although some drives now use "embedded servo" information, with the positioning data interspersed with data on each track. The disk drive electronics vary the current to the positioning mechanism, based on the different signals read from these servo tracks, to indicate whether the head is on track or moving off the track.

The positioner is driven back and forth over the platter by a voice-coil actuator, like those that drive high-fidelity loudspeaker cones. The coil, which is attached to the head arm, moves between fixed magnets in response to power and frequency changes in the current supplied by the drive electronics.

The better head positioning techniques have significantly reduced data access times. There are two actions that make up the access time: seek time, in which the head moves to the correct track, and latency time, during which the disk rotates to the correct sector.

Mass-produced Winchester drives with capacities of 10 to 30 megabytes have access times ranging from 40 to 100 milliseconds. The highest-capacity drives, by contrast, have access times as low as 10 milliseconds.

**SCSIs, ESDIs and more**

Along with greater bit density comes a higher data transfer rate. When platters rotate at 3600 revolutions per minute, data stored at a density of 8000 bits per inch can be read at 5.0 megabits per second. This rate has been an accepted standard since the first 51/4-inch Winchester drive was designed.

Data transfer rates are set by interface specifications. The first interface specification for linking 51/4-inch Winchester drives to small computer systems is now called the ST506/412, a combination of the names of Seagate's first 5-megabyte product and the later 10-megabyte version.

The ST506/412, derived from interfaces for floppy disks and 8-inch drives, was low-cost and somewhat primitive. For instance, it lacked a data separator to synchronize clock bits and other information and identify the data bits. Nor could it handle hard-sectoring—the positioning of fixed-length sectors at specific physical locations on the disk surface. Another drawback was its exact specification of 10 416 bytes per track.

In late 1982, members of the hard disk industry introduced the enhanced small device interface, or ESDI. It allowed the data transfer rate to double—to 10 megabits per second—and added new ways to upgrade the recording density and the software flexibility of higher-capacity drives.

One new possibility, for instance, was specifying a track number directly instead of sending a sequence of step pulses to move through the tracks in order. Recent implementations of ESDI have achieved a data rate of up to 15 megabits per second.

Even higher data transfer rates will be possible with the small computer system interface, or SCSI (pronounced "scuzzy"). Current versions transfer data at up to 12 megabits per second, and rates approaching 32 megabits are possible.

SCSI is known as an intelligent interface, because it contains a microprocessor to perform traditional disk controller functions. An increasing number of systems designers are adopting intelligent interfaces because they allow the drive electronics to perform some of the control and data separation work formerly performed by the computer's central processor.

SCSI has been widely accepted because designers can "daisy-chain" up to six peripheral units—like hard disk drives, tape backups, optical disks, and printers—through a single system port, with arbitration among different devices. And it allows system designers to issue standard commands—the SCSI common command set—to the disk controller. ESDI, on the other hand, is a device interface, requiring a controller built specifically for the host machine.

**Head positioning crucial**

The track density of a disk drive depends on how accurately the head can be positioned. In high-capacity drives, the track width is typically 0.0007 inch (0.018 millimeters). The resulting density—980 tpi—requires that the head-arm assembly move smoothly and very accurately across the platter.

The stepper-motor designs of low-capacity Winchester drives (and floppy drives) do not suffice. In these drives the precise position of the head is not known. The drive electronics or disk controller simply moves the arm in fixed increments across the platter and counts the number of steps.

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**Why call it 'Winchester'?**

The origin of the term "Winchester" to identify hard disk drives has been subject to debate. Two of the competing explanations cite the IBM Corp.'s use of the term as an interim code name for its Model 3340 direct-access storage device, or DASD, introduced in 1973.

One of these theories says the Winchester name was based on the IBM unit's original "30-30" design—two 30-megabyte hard disk modules. According to this explanation, the hard disk drive is the namesake of the famous Winchester 30-30 rifle. The second theory points to IBM's development laboratory in Winchester, England, where research was done on hard disk storage devices.

The third explanation—although termed "baloney" by one source—is that the make-or-Silicon Valley, which stretches from San Jose to Palo Alto, Calif. Many of the early third-party manufacturers of hard disk drives—those other than such large computer makers as IBM and Control Data—were located along Winchester Road, a major artery in San Jose. Proponents of this etymology argue that the location of these companies lent its name to their products.

Which of these theories fits the facts? Ken Haughton, dean of engineering at Santa Clara University, Santa Clara, Calif., who named the prototype that became the Model 3340, explained that the inspiration was the Winchester 30-30 rifle he had at home. By now, he noted, the name has come to refer to any fixed hard disk, no matter what size or format.

—J.V.
Disk drive arrays on the way

What effect will the rising storage capacity of these drives have on the personal computer or workstation user? Today's PC user may dream of hundreds of megabytes of storage, but only a few companies, there is life left in the magnetic hard disk drive. By the early 1990s, the same 5 1/4-inch drive that today stores three-quarters of a gigabyte may store four or eight times that amount.

To probe further

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"Information on a Silver Platter" is a booklet published by Maxtor Corp. covering the history, development, design, and operation of high-density 5 1/4-inch Winchester disk drives. It is available from the company at 150 River Oaks Parkway, San Jose, Calif. 95134; telephone 408-942-1700. 

as 16 milliseconds—the same as the highest-performance drives used with mainframe computers.

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1ESDI—enhanced small device interface; SCSI—small computer system interface; ST412—ST508/412 interface

2MFM—modified frequency modulation encoding; RLL — run-length limited encoding

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Polymorphic Storage Corp. of Los Gatos, Calif., is one of several companies working on such arrays. Ron Lesti, president of Polymorphic, said that the company is currently developing a storage array that uses up to 80 high-capacity 5 1/4-inch drives with data transfer rates up to 200 megabits a second. At a cost of $5 a megabyte, he expects that such arrays will compete on very favorable terms with traditional mainframe disk storage, like that of IBM's 3380.

And coming next . . .

The drive for higher capacity continues, of course. Many industry observers say vertical recording will be the next major technical step to increase storage. The principles of orienting magnetic regions vertically in the recording medium—in contrast with the usual method, in which the particles lie along the surface of the disk—are already well known. As yet no small hard disks with vertical recording are commercially available, although Toshiba has issued a preliminary specification for a 3 1/4-inch floppy disk drive that uses it.

Vertical bit recording is not a panacea, however. Stuart Mabon, president of Micropolis Corp., said that it helps reduce the coercivity—the strength of a magnetic field necessary to reduce the remaining magnetism in a material. But, he said, reducing the flying height, to raise the allowable density of flux changes, will be more important than vertical recording in increasing capacity.

Continuing improvements should bring the flying height down from 20 to 10 micrometers (0.5 to 0.25 micrometer), Mabon said. The gap between poles of the read-write head will decrease from 60 to 30 micrometers (1.5 to 0.75 micrometer), he said, and in five years manufacturers will be able to provide 2000 tracks per inch and 40 000 flux reversals per inch.

Another possible improvement is the use of more than one read-write head for each disk surface. Larger disk drives—those with 14-platter platters from such companies as IBM and Control Data Corp.—have applied this technique for a decade. But no manufacturer has yet incorporated the technology into 5 1/4-inch drives.

Erasable optical disks may ultimately prove strong competition for conventional magnetic disk storage. But while research on erasable optical storage technology is under way at dozens of companies, there is life left in the magnetic hard disk drive. By the early 1990s, the same 5 1/4-inch drive that today stores three-quarters of a gigabyte may store four or eight times that amount.

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