The Hard-Disk Explosion

High-Powered Mass Storage for Your Personal Computer

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High-performance, high-quality, and large-capacity hard-disk drives are now a low-cost reality for your personal-computer system. Most hard disks use *Winchester* media, head technology, and other modern techniques to achieve high density and high performance in a small space. One side effect is low power consumption. Some of the drives suitable for personal computers use the older 14-inch standard diameter platters. Many new drives use one of two new small sizes—200 mm (7.87 inch) or 210 mm (8.27 inch) diameter—and one new drive uses 130 mm (5.12 inch) platters. Even so, their data capacities are significantly larger than floppy-disk drives of the same approximate size.

The latest disk drives can be divided into two general categories:

- low-cost, relatively low-performance drives that will eventually replace floppy-disk drives, especially where multiple drives would normally be necessary to obtain enough storage. For example, instead of adding more floppy drives to increase the storage capacity of a system, one set of dual floppy-disk drives might be replaced with an 8-inch hard-disk drive that fits in the same space. This improves the storage capacity and system performance dramatically. These low-end disk products will compete on a cost-per-drive basis.
- high-capacity, top-performance drives that must compete on a cost-per-byte basis. The 8-inch or smaller versions will likely (at least at first) be more costly per byte than the 14-inch models. However, their advantages of small size, light weight, low noise, and low power requirements make them very attractive for desktop and personal computers as well as small business systems.

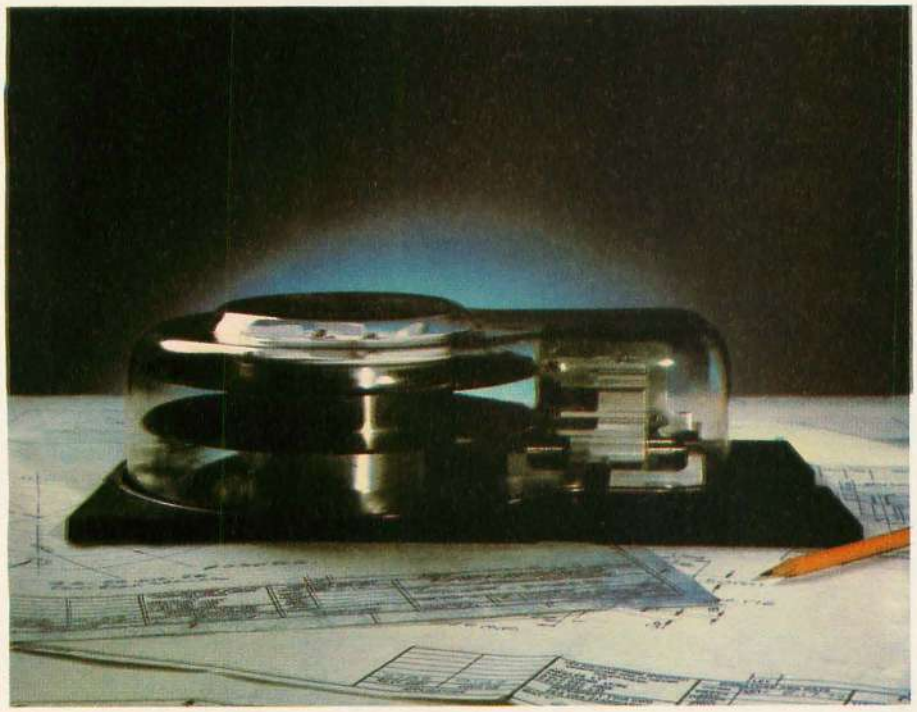

Photo 1: *The Memorex Model 101 hard-disk drive. (Photo courtesy of Memorex.)*

The Winchester disk-drive technology developed by IBM provided expensive, large-capacity, high-performance, and low cost-per-byte disk subsystems (ie: the IBM 3350 and 3370 disk-drive systems) for large, expensive computer systems. This technology and development in other areas of disk-drive performance are now being applied to the development of products suitable for smaller systems. The tremendous growth of microcomputers has created a de-

mand for small, compact disk drives. The industry has responded and is beginning to produce them. A Winchester disk drive for your personal computer is now, or soon will be, a possibility. However, it may still cost you five to ten times the price of your processor to get a complete small hard-disk subsystem with drive, controller, interface, power supply, and packaging.

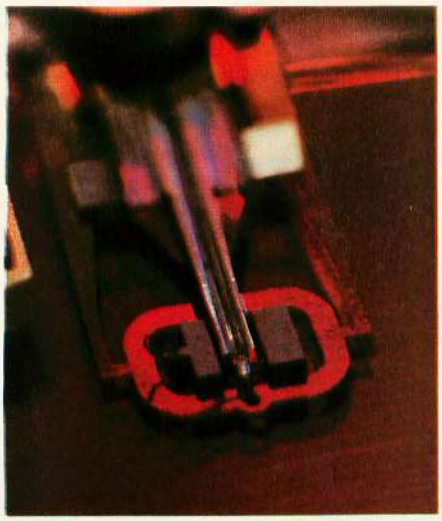

Photo 2: *Close-up of a Winchester-type read/write head. (Photo courtesy of Kennedy Company.)*

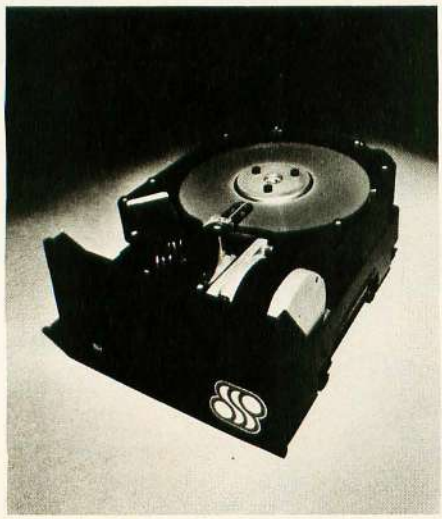

Photo 3: *The remarkable Shugart Technology Model ST506 hard-disk drive, offering 6 megabytes of mass storage in a 3.5-pound package that fits in the same space as a 5-inch floppy-disk drive. (Shugart Technology is a new company located in Scotts Valley, California, and is not affiliated with either Shugart Associates or Xerox. Photo courtesy of Shugart Technology.)*

What Is Winchester Technology?

Three disk technologies have evolved, all pioneered by IBM. Other manufacturers have refined the designs. These technologies are usually referred to by the model numbers of the original IBM product employing the technology: "2314" technology (in the 1960s), "3330" technology (late 1960s, early 1970s), and "Winchester" technology (1973).

Disk storage, being a special type of add-on memory, can directly affect a computer system's performance, throughput, and reliability. Because of this crucial role, the principal design objectives for disks are large capacity, fast access time, absolute reliability, and low cost.

Each of the three advances has brought a significant increase in storage density. One way to increase density is to reduce the flying height of the heads over the disk surface. Each reduction in height allows an increase in tpi (tracks per inch) and bpi (bits per inch) (see figure 1). Advances in head design and positioning mechanisms have also contributed to increases in tpi and bpi.

Head flying heights have evolved as shown in table 1.

Just prior to 1973, disk-drive technology approached some limits. The flying height had been reduced to 31 microinches. Without further reduction, significant improvement in data density was difficult. At lower flying heights, a single smoke particle, whose diameter may be up to ten times the distance between the head and disk surface, can damage the disk and data. Therefore, cleaner conditions were required. Also, the disk platters and magnetic surfaces were inadequate for large increases in track and bit densities.

The 3340 Winchester disk drive, introduced by IBM in 1973, was the first breakthrough. Storage Technology Corporation announced a similar disk drive around the same time: the STC 8800 superdisk.

Winchester Characteristics

Winchester disk drives have the following characteristics:

- sealed disk, head, and positioning assemblies
- new trimaran head design—two outriggers supporting a narrower inner hull containing the read/write head (see photo 2)
- thinner magnetic coating: 44 microinches versus 185 microinches in the 2314 disk drive
- lubricated disk surfaces
- heads resting on disk surface when drive is stopped—they take off and fly low when motion starts (normal take-off and landing are done on an area reserved for that purpose)
- light loading force (10 g) and lighter heads.

These characteristics permit many performance improvements: very low flying heights (19 to 20 microinches), improved reliability, and a dramatic reduction in head crashes are possible because of the clean environment, new head and loading designs, and lubrication. Data densities are increased because of lower flying height and thinner platter coating. The higher densities improve throughput performance directly. More bits per inch allow more data to pass under the heads per unit time. More tracks per inch mean that track-to-track access times are shorter. The lighter heads and head mounts have less inertia and can be positioned faster. Throughput performance can be improved by increasing the rotational speed, up to a point—the aerodynamic characteristics of the flying head put some constraints on the rotational speed. The reliability of the Winchester drives surpassed that of any moving-head disk drive that was previously available.

Improvements and refinements have continued from many manufacturers. The costs of many of the most expensive elements in a disk (the motor, head actuator, and control electronics) are relatively independent of the capacity of the disk platters. It is, therefore, cost-effective to increase the density of the platters and the number of platters. The incentive has been to add capacity by any conceivable means, and trends have been toward more platters per spindle and greater bpi and tpi densities (data density has gone from about 1000 bpi on early 2314s to over 8600 bpi on some of the recent disks, and tpi density has gone from 200 tpi on 2314s to over 600 tpi on new products). Cost effectiveness has also been enhanced by reducing the access time and increasing the data flow; the economic payoff is increased throughput and efficiency of the total

system. In applications where disk storage is a key element, the processor is often disk-I/O-bound. Program execution speed depends on disk speed. Every increase in throughput will improve the total performance.

Other improvements in throughput performance in disk subsystems have come from RPS (rotational postioning sensing), which frees the disk controller and I/O (input/output) channel for other work during seek time (head actuator movement) and during part of the rotational delay time. Improvements have also included new automatic error detection, correction, and recovery capabilities built into disk controllers.

Photo 4: *BASF Systems' 6170 Series 8-inch, fixed hard-disk drive, available in 8- and 24-megabyte versions. (Photo courtesy of BASF.)*

Voice-coil actuators, described in the next section, are common on high-performance disk drives. There are both linear and rotary voice-coil positioners. Rotary voice coils typically take up less space, require less power, and generate less heat than linear voice coils. Stepper motors with band actuators are usually used in lower-performance, lower-cost disk drives. Many of the new small drives use brushless DC (direct current) motors with direct drive on the platters. Designed as part of the spindles, these motors are compact (about 1 inch high), maintain speed more accurately, use less power, and require simpler power supplies than AC (alternating current) motors with belt drives. In many drives, each recording surface is split into inner and outer bands with a head for each band, reducing the average access time by one-half, because twice the amount of data can be read or written without moving the heads.

Comparing the New Hard Disks to Floppy-Disk Drives

The current trends toward multiterminal systems, real-time transaction oriented systems, small business systems, and more powerful personal computers for a great variety of applications have created a demand for more on-line data storage. Floppy-disk drives and tape cassettes often do not have the required performance (access times, throughput, etc), reliability, or capacities. Thus, the need for secondary storage is being filled by new, inexpensive, high-performance, highly reliable small-disk drives with capacities, speeds, and reliability close to the very expensive drives. These new drives are physically much smaller and more reliable than 14-inch cartridge or disk-pack drives. They are aimed initially at a gap between floppy drives and 14-inch drives (eg: Winchester, 5440 cartridges and 3330 type packs). They are designed for use on small business systems, distributed-processing systems, word-processing systems, and advanced personal computer systems.

The new drives offer a lower cost per unit than 14-inch drives, and lower cost per byte than floppy-disk drives. They provide the advantages in capacity and performance of hard disks in a package the same size as an

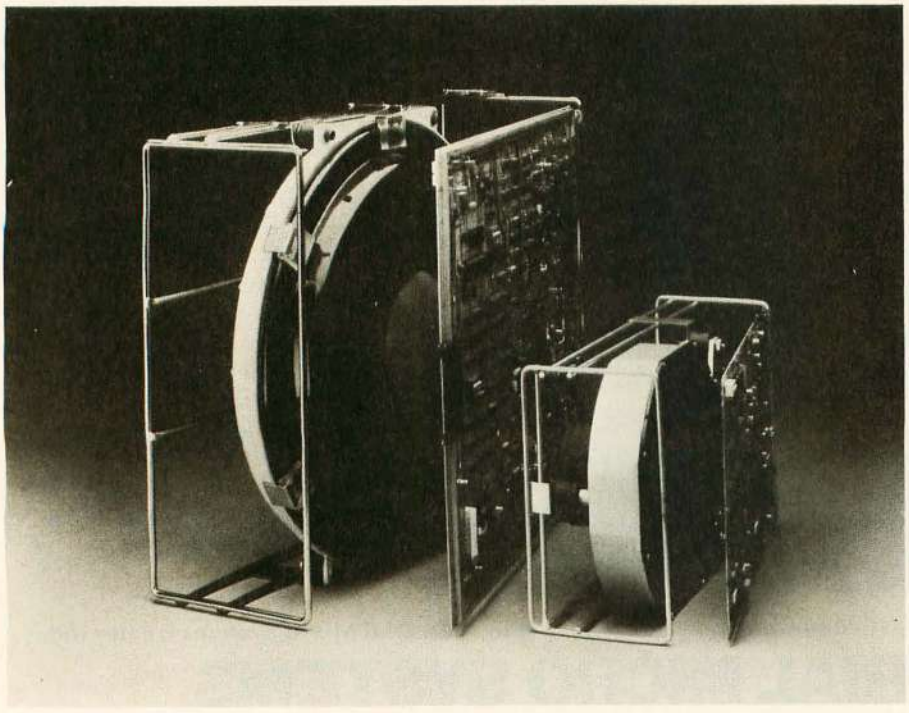

Photo 5: *Priam 14-inch (at left) and 8-inch Winchester hard-disk drives. (Photo courtesy of Priam.)*

Photo 6: *Kennedy Series 7000 8-inch hard-disk drive. (Photo courtesy of Kennedy Company.)*

8-inch or even a 5-inch floppy-disk drive—many will actually fit the panel openings for floppy-disk drives. Reliability will be better than with floppy and cartridge drives, and power consumption will be significantly lower than that of the 14-inch drives.

Systems based on 16-bit processors or microcomputers often require much more and much faster secondary storage than floppy disks can provide. The more sophisticated multiprogramming and file-management software currently being added to small computer systems requires so much continuous use of mass storage that the high performance and durability of hard disks may soon be a necessity.

The new 8-inch and 5-inch disk drives offer several advantages over both floppy and 14-inch hard drives:

- They have five to sixty times the storage capacity of a floppy-disk drive in the same space.
- They access data four times faster than the floppy-disk drive.
- They weigh less, take up less space, and use less power than 14-inch drives.
- They are only three to five times more expensive than floppy-disk drives, with cost reductions likely.

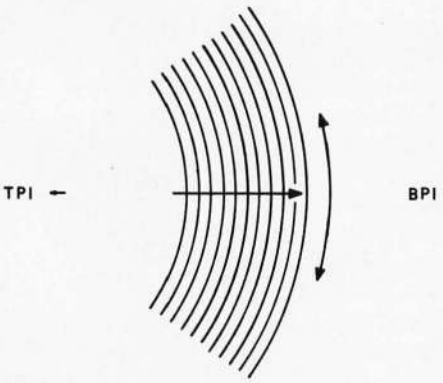

Figure 1: *Detail of hard-disk surface, illustrating the ideas of tpi and bpi.*

The availability of low-cost-per-function hard disks has long been awaited by the small system marketplace. The wait is all but over. This summer a score of products are scheduled to be available, at least in sample or evaluation quantities.

Though many of the new small disk products are advertised as fitting the same 4.6 by 8.5-inch opening as the standard floppy-disk drive (Shugart Technology's 5-inch Micro Winchester fits a 5-inch floppy-drive opening, see photo 3), a floppy-disk drive cannot literally be pulled out and replaced by the hard drive. To begin with, the packages contain different electronics. Most of the drives

	2314	3330	Winchester
Head flying height (in microinches)	100 to 120	31 to 45	19 to 20

Table 1: *Evolution of head flying heights in hard-disk drives.*

	Floppy-Disk Drives	Hard-Disk Drives, Cartridges and Disk Packs
Standard platter diameters	8-inch 5-inch	14-inch, 8-inch, and 5-inch
Capacity	100 K bytes to 1 megabyte	2 megabytes to 300 + megabytes
Average Access Time	0.1 to 1 second	25 to 70 ms
Rotational Speed	300 rpm	2400 to 4700 rpm
Reliability and Useful Life Relative to Floppy-Disk Drives	1	2 +

Table 2: *Technical comparisons between floppy-disk drives and hard-disk drives, cartridges, and disk packs.*

	Memorex Corporation Santa Clara CA	New World Computer Co Inc Costa Mesa CA	Shugart Associates Sunnyvale CA	Shugart Technology Scotts Valley CA
Model	101	211	SA1002/SA1004	ST506
Unformatted Capacity (millions of bytes)	11.7	2.1	5.33/10.67	6.38
Platter Size millimeters and (inches)	200 (7.87)	8 inch	200 (7.87)	130 (5.12)
Number of Platters	2	1	1 or 2	2
Average Access Time	70 ms	18.825 ms	70 ms	170 ms
Maximum Data Transfer Rate (K bytes per second)	—	756	543	625
Average Latency	10.1 ms	8.825 ms	9.6 ms	8.3 ms
Rotational Speed	2964 rpm	3600 rpm	3125 rpm	3600 rpm
Motor Type	DC	—	AC	brushless DC
Spindle Drive	direct drive	—	belt drive	direct drive
Actuator Type	high speed band	simplified band	band	band
Positioning Mechanism	open loop stepper motor	stepper motor	stepper motor	open loop stepper motor
Density bpi	6100	8000	6270	7690
Density tpi	195	100	172	254
Physical Size (inches)	4.38 by 8.55 by 14	2 by 9.5 by 9.5	4.62 by 8.55 by14.25	3.25 by 5.75 by 8
Weight (pounds)	10	8	17	3.5
Single Quantity Price	—	$4,500	$1,600/$1,980	$1,500
OEM Discount Price	$1,200[1]	$1,250	$1,140/$1,400	$925
Cost Per Thousand Bytes (OEM Discount)	$.103	$.595	$.214/$.131	$.145
Comments	[1] Includes a data separator	20 heads, 8 tracks per head. Low-end only in capacity, not in performance.		First micro Winchester Drive. Fits 5-inch floppy space

Table 3: *Specifications and characteristics of low-end, 5-inch and 8-inch hard-disk drives.*

have the basic drive electronics, signal amplifiers, read/write electronics, and motor and servo control circuitry integrated into the package. Some have room to add optional, separately priced controllers to do error-checking and correction, data formatting, and interfacing to the computers.

Stepper-motor actuators are a technique borrowed from floppy drives for use in hard-disk drives. This idea allowed lower prices for Winchester-technology units such as the 14-inch Shugart SA4000 and Century Data Systems Marksman, but at a cost of greater access time and reduced storage capacities when compared with voice-coil actuator-based units.

A voice-coil actuator is a cylindrical, permanent magnet with a hole machined from pole to pole. A coil rides on bearings within the magnet and moves back and forth. The read/write positioning mechanism with electromagnetic heads is attached to the coil. A voice-coil actuator is positioned by servo-control with servo tracks written on one platter's surface at the factory.

Voice-coil actuators allow increases in data-storage capacity because their accuracy in small movements allows high tpi densities. Since the distance between tracks is smaller, access time is reduced. Also, voice-coil actuators do not impose the additional penalty of settling time.

One disadvantage of a voice-coil actuator is the magnetic field produced by the coil: the coil's magnetic field must not get too close to the disk platters or it could erase them. Efficient design can keep the magnetic field intensity at a safe level near the recording surfaces. Table 2 gives a partial technical comparison between floppy-disk drives and hard disks.

Future Technological Progress

Some of the more recent developments in heads (such as thin film heads) and disks (thin-film-plated disks) mean that data densities will probably advance from the presently attainable 8 to 10 megabytes per 8-inch surface to 50 or more megabytes per surface as track densities of 1000 tpi and bit densities of 10,000 bpi are achieved. A small, relatively inexpensive disk drive could then store 100 megabytes or more of data with an additional 100 megabytes added for nominal cost. Thin-film

technology may be the next breakthrough in mass-storage techniques.

Secondary storage and storage backup are currently being supplied by a wide variety of devices, including

- cassette tapes
- 8-inch floppy-disk drives
- 5-inch floppy-disk drives
- reel-to-reel magnetic tapes
- cartridge magnetic tapes
- cartridge-disk drives
- disk-pack drives
- fixed storage Winchester drives
- combinations: fixed Winchester-disk/cartridge-disk drive or fixed Winchester/magnetic-tape cartridge
- streaming-tape drives
- bubble memories
- nonvolatile semiconductor programmable memory
- videocassette recorders
- video disks

The last three or four types are more for the future than now. Bubble memories and nonvolatile integrated circuits will have the great advantage of no moving parts and the potential convenience of plug-in modules; but they are still quite expensive. At least one interface and controller for American and European standard VCRs (videocassette recorders) is available to provide removable back-up for high-capacity disks on small systems (the Corvus Mirror, manufactured by Corvus Systems Inc, San Jose, California). It stores up to 100 megabytes on one videocassette and has a transfer rate of 15 K bytes/second. Video disks have the potential to offer extremely high data-storage capacity and fast access rates (up to 1250 megabytes per 12-inch disk, equal to approximately four times the contents of the Encyclopaedia Britannica).

Small vs Large Hard-Disk Drives

Hard-disk drives for small systems fall roughly into two size categories: up to 12 megabytes and over 12 megabytes; and two performance categories: slow, with stepping-motor positioning, and fast, with voice-coil positioning. Those with stepping-motor positioning have average access times of 70 ms and capacities of under 12 megabytes. The drives with fast voice-coil positioning have average access times ranging from 25 ms to 50 ms, with models that fall into both size categories. The less expensive units are aimed at replacing floppy-disk drives directly. Examples of this type of product are the Memorex 101, the Shugart Associates SA-1000 series, and the Shugart Technology ST 506. The high end is led by IBM with the Piccolo drive, which is integrated into the System 34, and is an add-on peripheral for the Series 1. It features a rotary voice coil, 17 ms average access time, and up to 64.5 megabytes of storage capacity. Other contenders in this category offer high performance in a wide range of sizes (eg: the BASF Systems 6170 Series, IMI (International Memories, Inc) 7700 Series, Kennedy Company 7000 Series, Microcomputer Systems MSC-8000, Micropolis Corporation Micro Disk 1200 Series, Pertec Computer Corporation D-8000, and Priam Diskos 2050/3450).

The disk capacity and the performance you need depend on your particular application, which in turn has a significant impact on the cost of a system. Small-system applications, as

mentioned before, can be placed in two major classes: *single-user, single task* and *multi-user, multi-task*.

- Single-user, single-task systems are usually stand-alone workstations, intelligent terminals, or personal computers. Their chief use of magnetic storage, in general, is for program storage and data storage. The amount of storage required is often less than 10 megabytes. Because the speed need only match one human operator's response time, there is no benefit to be derived from disks with extremely fast access times. An average access time of 70 ms is usually sufficient in such applications. This class of application is cost-per-unit-oriented, since the storage device is dedicated to one user. It is price-oriented, and performance is not a vital factor. The low-end, small hard-disk drives fill this need splendidly.
- Multi-user, multi-task systems require that more than one, sometimes many, users have access to a common data base. They typically require from 30 to 100 megabytes of magnetic storage, usually on one spindle. Some require less storage and some will require multiple spindles. The cost per byte of storage is a more important consideration than the cost per drive unit, because the basic device cost is spread over many users.

Multi-user, multi-task systems require an average access time of 50 ms or less because multiple users must contend for the common storage device. The main purpose of these applications is usually not to share the processing power, but rather to share the data. These systems are often "disk-bound" rather than "computer-bound." Disk performance becomes a critical factor in system performance. Even when the disk capacity required might be relatively small (8 to 10 megabytes), the fast performance of the high end mini-disks will be required.

With their faster access times, higher capacities, greater reliability and OEM (original equipment manufacturer) quantity prices ranging from $1000 to $5000 (some may soon drop below $1000), both classes of the new hard-disk drives should be attractive to personal-computer systems builders who want additional capacity and performance, but not the traditional 14-inch disk size and price per unit. Some complete packages of drives, controllers, interfaces, and power supplies are available for about $5000. Even though they cost five to ten times as much as the processor, these units are still cheaper per drive than 14-inch drives. They are also applicable where more capacity and performance than a floppy disk can supply are needed, but the space or the cost of a 14-inch disk drive is prohibitive. Tables 3, 4, and 5 list some of the current disk-drive products for small systems. The reliability and maintainability of these products are essentially high and are consistent across the board. (See table 6.)

Controllers and Interfaces

One of the problems with the new 8-inch hard-disk drives is the variety of interface systems to choose from. Such variety is inevitable at this stage because of the many personal computers already on the market, and the diversity of interface requirements. In the absence of a comprehensive interface standard, many of the drive suppliers have designed their own. A similar situation has developed in the audio industry. Consider the many types of noncompatible audio recording standards including: the LP (long-playing) record, 45 rpm records, open reel tapes, cassettes, and eight-track cartridges. This kind of variety at the outset of new products is not necessarily bad—there is much freedom for innovation.

In August of 1979 an ANSI (American National Standards Institute) Subcommittee (number X3T9.3) began to standardize an interface for 8-inch hard disks. If a standard interface is widely accepted by the industry, users may soon be able to interface drives from several vendors.

Types of Interfaces

There are two main categories of disk-drive interfaces, *device level* and *host level*. The main characteristics for the device level are:

- serial data transfer
- formatting/de-formatting external to drive

Text continued on page 138

	BASF Systems Bedford MA	Corvus Systems, Inc. San Jose CA	IBM Corporation General Systems Div	International Memories Inc (IMI) Cupertino CA
Model	6171/6172	11T	4963 29A/64A	7710/7720
Unformatted Capacity (millions of bytes)	8/24	11	29/64	11/20
Platter Size	210mm (8.27 inch)	200mm (7.87 inch)	210mm (8.27 inch)	200mm (7.87 inch)
Number of Platters	1 or 2	2	3 or 6	2
Average Access Time	42 ms	50 ms	27 ms	50 ms
Maximum Data Transfer Rate (K bytes per second)	800	648	1030	648
Average Latency	8.3 ms	8.3 ms	9.7 ms	8.3 ms
Rotational Speed	3600 rpm	3600 rpm	approx. 3100 rpm	3600 rpm
Motor Type	brushless DC	brushless DC	—	brushless DC
Spindle Drive	direct drive	direct drive	—	direct drive
Actuator Type	linear voice coil	linear voice coil	rotary voice coil	linear voice coil
Positioning Mechanism	servo	servo	servo	servo
Density bpi	6542	5868	8530	5868/6000
Density tpi	500	300	450	300
Physical Size (inches)	4.59 by 8.99 by 18	5.5 by 8.57 by 19.25	—	5.5 by 8.57 by 19.25
Weight (pounds)	20	22	—	22
Single Quantity Price	—/$3,100[1]	$5,350[2]	approx. $9,300/$10,700	$2,990/$3,590
OEM Discount Price	Competitive OEM discounts available	—	—	$1,900/$2,290 (100)
Cost Per Thousand Bytes (OEM Discount)	—/—	—	—	$.173/$.112
Comments	Available with integrated SMD interface @$3,500 and integrated controller with host bus interface for $3,900; all prices quoted are for 24 megabyte Model 6172. 1. Includes disk bus interface	Up to 4 drives per subsystem. Add-on drives @$2,990. Uses IMI 7710 drive. 2. Complete subsystem	Integrated into System/34. Add-on peripheral for Series 1.	Optional integrated controller available @$500 (quantity 1); $325 (quantity 100). Power supply @$250

Text continued from page 70:

- hardware-oriented control and status

The main characteristics for the host level are:

- *parallel* data transfer
- formatting/de-formatting included in drive electronics
- function-oriented control and status by functional command like read/write sector and format

Device-level interfaces can be divided into four groups:

- ANSI
- ANSI-like
- SMD
- Floppy-disk-like

The *ANSI interface*, as far as it is currently defined, will use a single 50-conductor flat cable. Up to four drives can be connected in a daisy-chain configuration. Differential drivers and receivers will be used only for block and data signals for read and write functions. All other lines will use standard TTL (transistor-transistor logic) signals. Control commands and status information will be transferred over an 8-bit-wide bidirectional bus. The bus control lines use an asynchronous handshake mechanism, allowing simple adaptation of the bus speed to any microprocessor. Data is transferred in serial NRZ (nonreturn-to-zero) format separated from the clock signal.

In the *ANSI-like* interface, most of the current device-level interfaces are more or less similar to the ANSI interface. Common to all are an 8-bit parallel control bus and serial NRZ data transfer.

SMD (storage module drive) *interface* is a *de facto* industry standard for 14-inch drives and is being adapted for 14-inch drives by ANSI. It has also been implemented for 8-inch drives. The SMD interface uses differential drivers and receivers for all signals. (They give excellent performance as regards high speed, long cable lengths, and high noise immunity.) The drives are connected through

Kennedy Co Altadena CA	Microcomputer Systems Corp Sunnyvale CA	Micropolis Corp Chatsworth CA	Pertec Computer Corp Chatsworth CA	Priam San Jose CA
7000	MSC-8000	1201-I/1202-I/1203-I	D8000	2050/3450
4/12/20	40	9/27/45	20	20/34
210mm (8.27 inch)	8 inch	200mm (7.87 inch)	210mm (8.27 inch)	8 inch
1, 2, or 3	3	1, 2, or 3	2	2 or 3
50 ms	25 ms	42 ms	50 ms	50 ms
—	1200	922	870	1030
8.3 ms	—	8.3 ms	—	6.4 ms
3600 rpm	—	3600 rpm	—	4700 rpm
AC	—	brushless DC	—	brushless DC
belt drive	—	direct drive	—	direct drive
rotary	—	rotary voice coil	—	linear voice coil
servo	—	servo	servo	servo
5280	—	8626	6000	6370
300	—	478	476	480
5.25 by 8.5 by 16.5	—	4.62 by 8.55 by 14.25	4.62 by 8.55 by 14.25	4.62 by 8.55 by 14.25
20	—	22	—	20
$2,100/$2,300/$2,650	—	$1,962/$2,591/$3,007	$3,000	$3,000/$3,750
$1,680/$1,840/$2,120(100)	—	—	$1,800	$2,200/$2,750(100)
$.42/$.153/$.106	—	—	$.09	$.11/$.08
	Included in package is an 80 megabyte, ½ inch magnetic-tape drive on the same motor spindle for removable back-up storage	Available with integrated controller as Models: 1221-I $2,834; 1222-I $3,463; 1223-I $3,879, single quantities		

Table 4: *Specifications and characteristics of high-end, 8-inch hard-disk drives.*

one daisy-chain cable for control and one radial cable for read/write and additional control. Control information is transferred on a 10-bit-wide unidirectional synchronous bus. Data is transferred in serial NRZ format.

The SMD interface allows very high transfer rates and long cable lengths. Because SMD uses differential drivers and receivers for all signals, it is somewhat more costly than other interfaces using TTL circuits. Because of the 10-bit synchronous bus structure, SMD is not easy to interface to current 8-bit processors. The main advantage of SMD for 8-inch drives is that it is a standard, and controllers are readily *available* for easy integration into existing or currently supplied systems.

Having a *floppy-disk-like interface* for 8-inch hard disks allows the combination of floppy-disk drives and hard-disk drives in one system. Because of the differences in transfer rates and other parameters, floppy- and hard-disk drives are not fully interface-compatible. Hard-disk users must add a radial cable for differential read/write signals in addition to the normally used daisy-chain cable. By adding 15% to 20% more circuitry, a hard-disk controller can be designed to also control floppy-disk drives. However, a floppy-disk controller cannot handle a Winchester-type hard-disk drive.

In comparing floppy-disk-like interfaces with other device-level interfaces, there are three major differences. First, with floppy-disk-like interfaces there is no control bus because commands and status signals are transferred on discrete lines. Second, positioning control is achieved with step and direction signals as opposed to the transfer of a parallel-cylinder address with other interfaces. Third, data is transferred in the raw format as recorded on the disk. This implies that synchronization, separation (or generation) of clock and data, and generation and detection of sector and address marks must all be performed externally to the drive. The floppy-disk-like concept minimizes drive electronics, but puts the burden of developing and producing the balance of the required electronics on the user.

	Century Data Systems Anaheim CA	Century Data Systems Anaheim CA	Fujitsu America Inc Santa Clara CA
Model	Marksman M-10/M-20/M-30	Hunter H-32/H-64/H-96	M2282/M2283/M2284
Unformatted Capacity (millions of bytes)	10/20/30	34/67/100	66/133/166
Platter Size (inches)	14	14	14
Number of Platters	1, 2, or 4	2, 3, or 4	—
Average Access Time	60 ms[1]	30 ms	27 ms
Maximum Data Transfer Rate (K bytes per second)	960	1209	1012
Average Latency	12.5 ms	8.3 ms	10.12 ms
Rotational Speed	2400 rpm	3600 rpm	3000 rpm
Motor Type	—	—	—
Spindle Drive	—	—	—
Acutator Type	band	—	rotary
Positioning Mechanism	stepper motor	servo	servo
Density bpi	—	—	6475
Density tpi	—	—	668
Physical Size (inches)	8 by 16.5 by 21.5	10.5 by 17.5 by 30	10.3 by 18.9 by 26.6
Weight (pounds)	45	175	100
Single Quantity Price	—	—	$4,350/$5,200/$5,500
OEM Discount Price	—	—	$3,450/$4,300/$4,600 (quantity 100)
Cost Per Thousand Bytes (OEM Discount)	—	—	$.052/$.033/$.028
Comments	Winchester Technology	16.7 megabytes of removable storage on each model (5440 Type)	Optional 655 K byte fixed head storage for $700

[1] includes settling time

Host-Level Interface

A typical implementation for host-level interface is the BASF 6170 series drive with integral formatter/controller. The BASF host bus interface uses a single daisy-chain cable that can connect one or more units to the host adapter. Transfer of data, command, and status information is done across one common 8-bit-wide bi-directional asynchronous bus. The eight bus lines, as well as additional lines for bus control and interrupt generation, all use standard TTL drivers and receivers. Using a host-level interface is the easiest and fastest way to interface an 8-inch Winchester drive to a given host system.

How Intelligent Should a Controller Be?

With the decreasing cost of microprocessors and memories, the trend is toward the use of intelligent subsystems to handle all I/O-related functions, rather than tying up the processor.

These subsystems can communicate with the main system through a high-level command language (eg: one that is file-oriented as opposed to hardware-oriented). Functions such as automatic backup, automatic error recovery, power-on bootstrap loading, etc, can be completely controlled locally in the subsystem, thus taking the burden off the main processor and improving the system's performance.

Further improvement can be gained by adding hardware and software for such things as double-buffering for data transfer, overlapped operation in a multiple drive configuration, and RPS (rotational-positioning sensing) for access optimization.

There is a limit to the transparency of the disk system to the operating system. If a disk with higher packing density is substituted, the number of sectors on each track or the number of tracks per surface will likely be different. This information must be communicated to the operating system. (With luck, this is a small parameter change in the I/O driver of a well-designed, modular operating system). But, however easy or difficult it is to change, it must be done to take full advantage of the new higher-capacity drive.

The Question of Backup for Fixed Disks

The usefulness of removable media on fixed-disk-based systems arises from three needs:

- system backup for crash/fault recovery
- program and data-base dissemination
- archival storage of information

The excellent reliability record of Winchester-technology disks is caus-

Fujitsu America Inc Santa Clara CA	Kennedy Co Altadena CA	Priam San Jose CA	Shugart Associates Sunnyvale CA
M2201/M2211	5300	3350/6650/15450	SA4000
50/83	14/42/70	33/66/154	14.5/29
14	14	14	14
2 or 3	1, 2, or 3	1	1
30 ms	70 ms	50 ms	87 ms
819	—	1030	—
12.5 ms	10 ms	9.7 ms	—
2400 rpm	3000 rpm	approx. 3100 rpm	—
—	AC	brushless DC	—
—	—	direct drive	—
linear motor	rotary	linear voice coil	band
servo	servo	servo	stepper motor
6135	6000	6370	5534
370	300	480/960/—	172
10.3 by 19 by 30.2	7 by 19 by 22	6.8 by 16.6 by 20	—
150	75	33	—
$5,400/$7,200	$3,200/$3,700/$4,200	—	—
$3,900/$4,990 (quantity 100)	$2,560/$2,960/$3,360 (quantity 100)	$1,800/—/—	—
$.078/$.060	$.183/$.07/$.048	$.055/—/—	—
Front-loading cartridge removable storage	Winchester Technology	Winchester Technology	Winchester Technology

Table 5: *Specifications and characteristics of 14-inch, hard-disk drives.*

ing some system builders and users to take a fresh look at backup requirements for data storage. They are concluding that, for *some* applications, it is no longer necessary to include removable media for backup protection in systems design.

Error-correcting capabilities of system software and intelligent controllers help to eliminate the need for backup in some cases. However, there will probably always be applications—perhaps the majority—in which backup cannot be eliminated. Many systems require removable media for program and data-base dissemination and/or archival storage in addition to any backup considerations. Therefore, it seems that there will be a continuing need for removable-media storage peripherals on some fixed-disk-based systems.

According to many small-system designers and users, system backup is needed regardless of the *hardware* reliability of the fixed-storage subsystem. System crashes or failures can be caused by software bugs and human error as well as by hardware faults.

Until the new wave of small Winchester disks came on the scene beginning about a year and a half ago, the small-systems hard-disk market was being served primarily by products based on IBM 5440-type removable-cartridge disk technology. Most of these products have the unique characteristic of having 50% of their spindle capacity removable—in other words, they have built-in backup. But the major drawbacks to their use in small systems are relatively low performance (70 ms average access time); relatively high cost per byte; large physical size; and high maintenance costs that get higher as field engineering labor costs grow. Even with the introduction of cost-effective, small, reliable Winchester-type products, these 5440-based products still have a place in some small systems. After all, the backup problem is solved, whereas no generally accepted backup method has yet emerged for the "mini Winnies" to make most customers feel comfortable. It is a problem yet to be solved.

Several approaches are being tried for backup. There are floppy disks, tape cassettes, tape cartridges, reel-to-reel tape drives, and, in at least one case, videocassettes.

The ideal characteristics of a backup device are:

- The cost of the modular removable medium should be low (less than $20).
- The cost of the transport device should be low.
- The data-transfer rate should be similar to the transfer rate of the disk.
- A single removable module should hold more, or at least as

Error Rates				
Recoverable	Unrecoverable	Seek Errors		
1 in 10^{10} bits	1 in 10^{12} bits to 1 in 10^{13} bits	1 in 10^{6} seeks to 1 in 10^{7} seeks		
Maintainability				
Preventive Maintenance	(MTBF) (Mean Time Between Failures) (sealed modules)	(MTBF) (Mean Time Between Failures) (product)	(MTTR) (Mean Time to Repair)	Component Life
None	25,000 hours	8000 to 10,000* POH (power-on hours)	½ to 1 hr	5 years

* Exception: Kennedy 7000 Series, 1500 hours

Table 6: *Reliability data for hard-disk drives.*

much, data as the fixed disk, preferably an integer multiple of the disk capacity (ie: a 100-megabyte videocassette to back up a 20-megabyte disk).

With the relatively unsophisticated operating-system software present in many small systems today (though this is rapidly changing), the backup strategy is usually to write the entire contents of the disk to a removable backup medium on a daily basis. This procedure results in a significant loss in system availability (while dumping or restoring) unless the backup device has a fast transfer rate and a large capacity.

Perhaps the most appropriate backup for a small Winchester is a device that can be included in the same package, sharing the same spindle drive mechanism and/or some of the same electronics. For the low end this may be a floppy disk; for the high end it can be a cartridge tape drive or a streaming reel-to-reel tape drive. But, except for the very low end where system cost is a prime consideration, a small-capacity, slow floppy disk is not an ideal backup for a large, fast, fixed disk. Streaming tape drives may be good backup devices for high-performance, high-capacity hard disks, but they are too expensive for most personal computer systems. Nevertheless, some streaming tape drives are becoming available. Kennedy Company of Monrovia, California, is delivering (60 to 90 days) its Model 6809 Data Streamer. It is a microprocessor-controlled reel-to-reel (10.5-inch reels) tape transport with formatter for reading, writing, and controlling the 9-track, 100 ips (inches per

second), 1600 character per inch, ANSI- and IBM-compatible half-inch tape drive. It has an unformatted capacity of 46 megabytes per reel. It can transfer 12 megabytes in 75 seconds and 40 megabytes in 250 seconds. It costs about $2500 in OEM quantities. Data Electronics Inc (DEI), of Pasadena, California, is marketing a 34-megabyte streaming microtape cartridge drive for $1219 (OEM quantities). Cypher Data Products Inc of San Diego, California, produces a 37-megabyte streaming reel-to-reel tape drive for under $2000 (OEM quantities). IBM's answer to the backup problem for its 8-inch disk drive is the model 8809 streaming tape drive.

The Products and the Companies

The specifications in tables 3, 4, and 5 speak for themselves. There are a few special features of some of these products worth mentioning. BASF Systems of Bedford, Massachusetts (whose parent corporation, the BASF Group based in Germany, invented magnetic recording tape in 1934), established a Memory Division in early 1979 to manufacture computer-disk drives. Their first product is the 6170 Series 210 mm Fixed-Disk Drives available in 8- and 24-megabyte versions. The 24-megabyte version with the integrated, microprogrammed BASF host-bus interface and controller at $3900 (single quantity price, substantial discounts available for OEM quantitites) is a cost-effective, high-performance source of reliable data storage for small systems. BASF offers a variety of interfaces. BASF is also a supplier of disk and tape media.

Century Data Systems, a Xerox Company, of Anaheim, California, offers a wide range of disk products for small systems including the 14-inch Marksman model (Winchester technology) with capacities from 10 to 30 megabytes, and the Hunter model with a removable 16.7-megabyte 5440-type cartridge, plus fixed-disk capacity ranging from 16.7 to 83.9 megabytes. Century Data Systems is a long-time manufacturer of computer peripherals. Corvus Systems Inc, San Jose, California, is offering a complete hard-disk subsystem based on the IMI 7710 10-megabyte 8-inch disk. It includes the Z80-based Corvus intelligent disk controller with comprehensive diagnostics and interfaces for TRS-80, Apple II, S-100-bus, and LSI-11 computers. As mentioned above, Corvus also markets a 100-megabyte removable backup in the form of an interface to a standard videocassette recorder using the microprocessor and interface bus of the Corvus disk subsystem. IMI was the first manufacturer to deliver a high-performance 8-inch Winchester drive.

Memorex Corporation of Santa Clara, California, is introducing its first in a planned family of 8-inch hard-disk products, the Model 101. It offers low cost per megabyte, low weight (10 pounds), low power requirements (56 W), and high reliability. With 11.7 megabytes and 70 ms access time, it is a good example of a product in the low-end segment of the small hard-disk-drive market. Memorex has been manufacturing disk drives since 1967 and has been a major supplier of magnetic media since the company was formed in 1961. The MSC-8000 from Microcomputer Systems Corporation of Sunnyvale, California, is an 8-inch disk drive with built-in removable backup in the form of an 80-mega-

byte half-inch tape drive on the same motor spindle. Micropolis Corporation, of Chatsworth, California, is offering the largest capacity (now available) 8-inch Winchester disk, the Model 1203-I, with 45 megabytes on five surfaces. The density is high (8626 bpi, 478 tpi), the access time fast (42 ms), and the price reasonable. It is another good example of a high-capacity, high-performance 8-inch disk in the high-end segment. New World Computer Company Inc, of Costa Mesa, California, is making an unconventional, miniature hard disk, the Mikro-Disc 211. It is a cross between a high-performance, one-head-per-track disk and a cost-effective moving head mini-Winchester drive. It is small, light (8 pounds), and very fast (18.825 ms access time). It has relatively low capacity (2.1 megabytes) but makes up for it in performance, price (less than $1000 in large OEM quantities), size (9½ inch by 9½ inch), weight, and power requirements (less than 50 W). In the words of company president, Phil Haines, "It's a little screamer." The Mikro-Disc 211 is a versatile storage system suitable for a variety of uses: it can efficiently augment or replace floppy-disk drives, supplement other larger and slower mass-storage devices by acting as a high-speed cache memory, improve system response time by providing fast-access key-directory storage, and be the primary file device in small systems. It has an assembly with twenty proprietary low-cost heads that write and read data onto 0.008-inch-wide tracks. The head assembly is moved only seven 0.010-inch steps (eight positions) across the disk. Each step is accomplished in 5 ms, precisely and accurately, by a low-cost open-loop stepper motor.

The Model 3450 from Priam, San Jose, California, is another example in the high-end segment, along with BASF and Micropolis. It has 34 megabytes on five surfaces, fast transfer rate (1.02 megabytes per second), and high density (6370 bpi, 480 tpi). It is a state-of-the-art product at a reasonable price. The Shugart Associates SA1000-series drives are another example of the low-end segment along with the Memorex 101 with 5- and 11-megabyte models.

Shugart Technology of Scotts Valley, California (a new company *not* connected with Shugart Associates or Xerox) has just announced its Model ST506 5-inch 6-megabyte Winchester disk drive. It is the size of a 5-inch floppy drive and weighs only 3.5 pounds — 6 megabytes of reliable Winchester disk storage in the palm of your hand for $925 (OEM quantity 500)! In the popular parlance, this is a hot little product for the small computer system. Evaluation units are scheduled to be available this month and production quantities by next month.

The latest in disk drives for small systems are these 8-inch and 5-inch wonders. The hard disks are upon us, and they're taking personal computing forward by a giant step.■

Directory of Hard-Disk Manufacturers

BASF Systems
OEM Peripheral Sales
Crosby Dr
Bedford MA 01730
(617) 271-4000

Century Data Systems Inc
A Xerox Company
1270 North Kraemer Blvd
Anaheim CA 92806
(714) 632-7500

Corvus Systems Inc
900 S Winchester Blvd
San Jose CA 95128
(408) 246-0461

Fujitsu America Inc
2945 Oakmead Village Ct
Santa Clara CA 95051
(408) 985-2300

International Memories Inc
10381 Bandley Dr
Cupertino CA 95014
(408) 446-9779

Kennedy Company
1600 South Shamrock Ave
Monrovia CA 91016
(213) 357-8831

Memorex Corporation
Recording Components Div
San Tomas and Central Expys
Santa Clara CA 95052
(408) 987-1000

Microcomputer Systems Corporation
432 Lakeside Dr
Sunnyvale CA 94086
(408) 733-4200

Micropolis Corporation
21329 Nordhoff St
Chatsworth CA 91311
(213) 709-3300

New World Computer Company Inc
3176 Pullman St, Suite 119
Costa Mesa CA 92626
(714) 556-9320

Pertec Computer Corporation
Peripherals Div
9610 De Soto Ave
Chatsworth CA 91311
(213) 999-2020

Priam
3096 Orchard Dr
San Jose CA 95134
(408) 946-4600

Shugart Associates
475 Oakmead Pky
Sunnyvale CA 94086
(408) 733-0100

Shugart Technology
340 El Pueblo Road, Suite C
Scotts Valley CA 95066
(408) 438-6550