Without question, the most important peripheral for most computer owners is the floppy disk storage system. When you consider the alternative, the tape recorder, it becomes clear why the vast majority of Apple owners have at least one Disk II.

Because of the high demand for these units, many outside manufacturers are now offering Apple-compatible disk drives. In fact, many of these drives are superior to the Disk II in storage capacity, speed, and reliability. Even the Apple disk controller card has been improved by several companies.

Disk Basics. When it was introduced, the Disk II floppy disk system, like the Apple itself, represented a radical departure from the design of the time. Gone were the usual LSI controller IC, the sector hole detector, and the constant disk rotation when the drive was not in use. Even the head-load solenoid was eventually removed, lowering drive cost as well as the noise generated during operation.

If all of this is Greek to you, maybe reviewing a few basic principles of how the floppy disk works will help. This month's column focuses mainly on a hardware description. For a further understanding and a complete overview of the disk operating system software, refer to a treatise such as *Beneath Apple DOS* from Quality Software.

The Disk Medium. As you may already know, a floppy disk is something of a cross between recording tape and a phonograph record. As with the recorder, information is stored magnetically on a thin piece of Mylar film. Rather than using a long, narrow strip of "tape," the standard floppy is an eight-inch diameter disk that can be rotated like a record. The Disk II and other drives we will be discussing are technically classified as minifloppies because they use the smaller 5¼-inch format.

Information is stored on this film base by spinning it past a writing head so that data is laid out on a circular track. The head moves in and out to write on many different tracks. Tracks are somewhat like the grooves on a record, only each track is concentric; that is, the tracks do not continually spiral inward. A better analogy may be to an eight-track tape player, in which the head moves up and down to play back the different tracks.

How does the head actually read and write data on the disk? The secret lies in a thin coating of magnetic particles that are spread onto the surface of the Mylar. These particles are suspended in a substance that allows them limited movement, yet keeps them from falling off the disk. The coating is referred to as the *oxide.*

Each particle is like a tiny magnet; therefore, it will act like a compass under the influence of a magnetic field. That is, if the field is strong enough, these particles will turn themselves so that they are aligned with the field.

On a blank or erased disk, each particle will be pointing in a completely random direction (figure 1a). After passing over the head while it is writing, however, the particles in that track will be aligned in one of two directions, depending upon the flow of the electric current through the head (figure 1b). The direction of current flow determines the direction in which the particles line up. By changing the current's direction, we can write our desired information as a series of magnetic fields. After the particles have passed by the head and are no longer influenced by its field, they remain locked into their last orientation until acted upon by another magnetic field. Therefore, we have achieved our goal: the permanent storage of data. This is the basis for all magnetic recordings, whether of music, digital data, or television pictures.

Reading data back from the magnetic media is also quite simple. As the aligned particles move past the head (which is now being used as a pickup device), they set up their own magnetic fields, which extend into the gap of the head. Whenever there is a change in the particles' orientation, or *flux reversal,* a small voltage is induced into the head (figure 2). This voltage can be amplified and conditioned to resemble exactly the data signal originally recorded. Figure 3 shows how this is accomplished.

Packing It In. With binary digital data, an important consideration is how much data can be stored on a given disk. In this discussion, we're going to make numerical claims about the performance of disk drives in several areas.

These numbers by no means represent the actual expected limita-

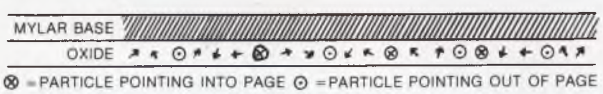


Figure 1a. Erased disk.

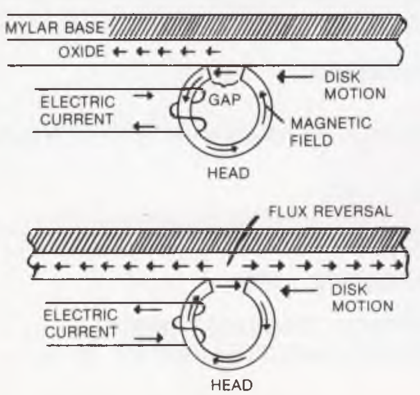


Figure 1b. Recording a bit.

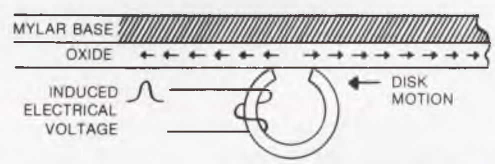


Figure 2. Reading a bit. Induced voltage pulse caused by flux reversal passing over gap.

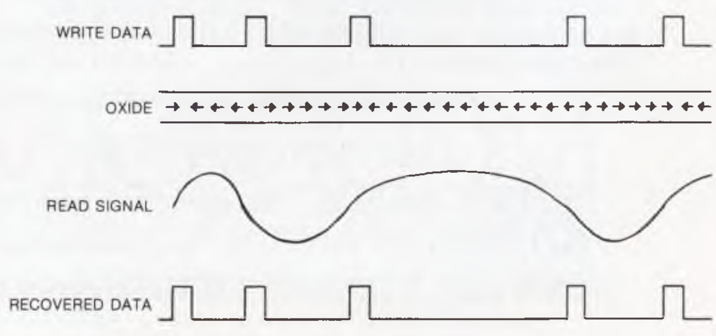
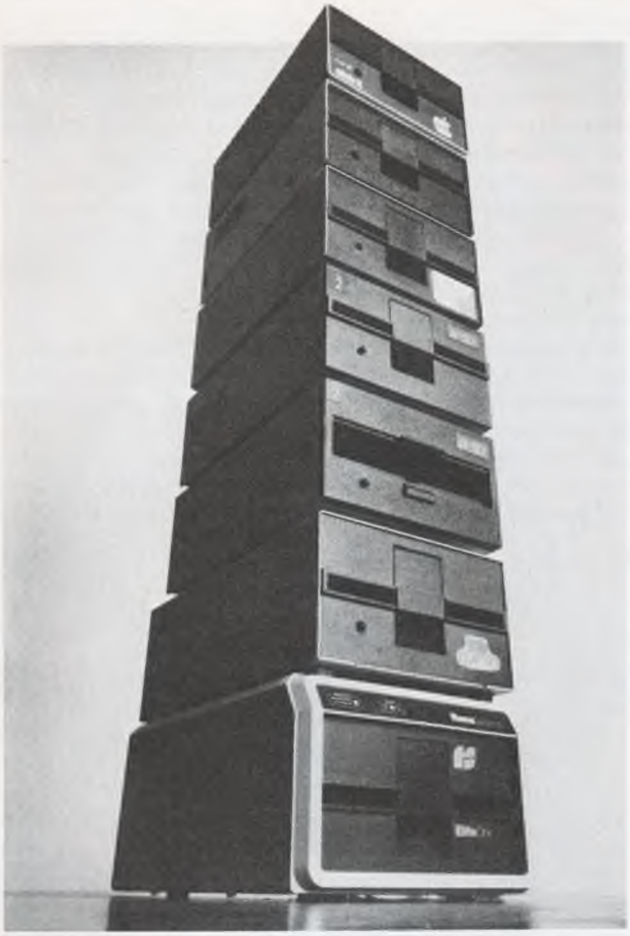


Figure 3. Data is recovered by producing a pulse for every polarity change of the read signal.



Above, our first collection of Apple-compatible drives. Starting from the penthouse on down: the Disk II made by Apple Computer; the Model 3101 by Lobo Drives; the Super Drive by Fourth Dimension; the A2 and the A40 drives, both by Micro-Sci; the Apple-Mate by Quentin Research; and the Elite One by Rana Systems.

tions at any given time. Instead, they are relatively standard figures that give a considerable margin of safety to ensure reliable operation. Thus, for example, when we say that a disk can hold 25,000 bits per track, it may be true that we could store as many as 50,000 bits in some instances. But after allowing for disk and drive variations, environmental factors such as temperature, humidity and dust, and wear and tear, it may be that the lower number is the limit we can approach and still have a reasonable chance of recovering our data without error.

The total amount of data that can be stored on one disk depends upon two factors: the number of tracks and the number of bytes per track. The number of tracks used is determined by the accuracy of the positioner and the track recording width. The Disk II and its equivalents all use thirty-five tracks. While most drives for the Apple are physically capable of reaching one or more extra tracks (moving closer to the disk's center), many manufacturers are now using the popular forty-track drives. Of course, changes must be made to the DOS in order to use the extra tracks.

Both thirty-five and forty track drives use a standard track density of 48 TPI (tracks per inch). This means that the head only moves about ¾ of an inch from track 0 to track 34. Seventy and eighty track drives achieve their greater density by packing the tracks closer together, at ninety-six TPI. Obviously, this requires a very accurate positioner and a head with a narrower field.

The number of bytes that can be recorded per track also depends upon a number of factors. First, a certain constraint is imposed by the disk material itself. This has to do with the density of the magnetic particles, or how many there are on a given area of the disk. It takes many particles in alignment to represent either of the magnetic states; therefore, the density of particles really sets a limitation on the density of flux changes. At the same time, the read-write head has a limiting factor of its own. This relates to the size of the field it creates when writing and responds to when reading. The drives we will be discussing are typically rated at about 5,500 FCI (flux changes per inch).

Keeping in Sync. Given this limitation on the number of flux changes per inch, the number of bits per track depends upon the track length and the number of flux changes required per bit. The first figure is easy to calculate. Since we must assume the "worst case" conditions, we use the innermost track dimension, which turns out to be a circle of about 1.54-inch radius. Using two-pi-R, the circumference formula, this translates to 9.68 inches.

The number of flux changes per bit is determined by the type of recording format used. Since the data is stored serially, that is, one bit at a time, by a mechanical device whose motion is not extremely precise, it must be sent asynchronously. This means that some extra *clock pulses* are added to the data so that when reading, the playback circuits can later synchronize with the data stream coming from the head. Several different techniques have been developed for this function.

Recording Format. Before trying to understand the recording technique used by Apple DOS, it is helpful to examine the standard format that was used by most other manufacturers when the Disk II came out. A typical 5¼-inch floppy disk system might have consisted of a Shugart SA400 drive, a controller interface designed around an LSI controller IC, and a disk operating system such as CP/M. The system might have used *hard sectoring,* in which the beginning of each block of data was indicated by the presence of a sector hole in the disk. This hole was detected by a simple lamp-photocell arrangement located on either side of the disk. Another sectoring scheme, called *soft sectoring,* might also have been employed. This technique signifies the beginning of each sector by writing a special series of bits, sort of a road sign, to the disk to mark the address of each location.

The actual recording technique used is known as double frequency (FM) NRZI modulation and is characterized in figure 4. A *bit cell* is defined as the space between two clock bits. The absence or presence of a pulse within each cell determines whether it represents a zero or a one. With this technique a "zero" is written by one flux reversal and a "one" is written by two reversals within each bit cell.

Given the previous restraints on flux density, the standard single density recording was set at 25,000 bits per track. This works out to 2,581 bits per inch on the inner track. Since each bit takes a maximum of two flux reversals to record, this translates to 5,126 flux changes per inch, which is well within any disk's capabilities. After accounting for the sectoring information and safety gaps, this allows about 80K of storage per disk.

However, using one clock pulse per bit is quite inefficient. All that is required for read synchronization is that a pulse be received every so often. If the data *ones* recorded on the disk could provide this pulse, we could eliminate the clock pulses. Without clock pulses, however, there must be some guarantee that there will not be a long string of zero bits. Such a string would be read back as a long space without any pulses. If long enough, it could cause the read circuits, or *data separator,* to become unsynchronized.

Thus, the data to be stored must first be translated into a series of legal codes that can be written to the disk. This is the function of a routine in DOS. There is a similar function to restore the data when it is read back from the disk. With DOS 3.3, eight-bit data is first transformed into one of thirty-two different codes. This allows six bits of the original data to be represented by the eight-bit code. With this technique, known

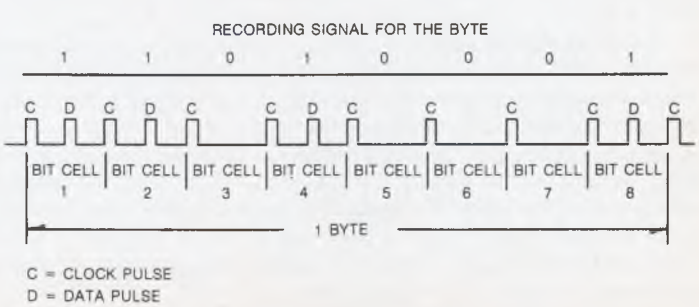


Figure 4. FM recording.

as group code recording (GCR), six bits of data can be represented by only eight flux changes instead of the twelve previously required. That's a 50 percent improvement!

Apple Innovations. By stretching things a little farther, DOS 3.3 is able to place more than one hundred forty-three thousand bytes of data per disk. This is accomplished with a flux density of approximately 5,460 FCI. The only penalty for this increased storage capacity is a similar increase in the complexity of the storage system.

Whereas the previous single density format lends itself to a simple hardware interface (usually contained within one chip), the GCR format requires extensive software overhead to perform disk operations. Apple felt that the computer would be tied up anyway during disk operations, so they placed many of the typically hardware functions in software.

Another example of this is in the control circuits for the head positioner. By using software, Apple was able to design a faster positioning mechanism. Instead of moving the head at a constant rate like its predecessors, the Disk II accelerates the head as fast as possible until it is halfway to where it needs to go. Then the head is decelerated at the same rate until it finally comes to a stop at the desired location. Since several different positioners are used by the drives under consideration, we will now look at these mechanisms.

Head Positioning Mechanisms. The function of any head positioning mechanism is to move the head to a precise location under the disk. This selects which track the head will access. Almost all disk drives use a stepper motor to perform the actual movement. Unlike a normal motor that spins freely when a voltage is applied, a stepper motor only turns in small increments, or steps, according to changes in the voltages applied to its coil.

Each possible position of the motor's shaft corresponds to one track on the disk. The Apple Disk II and all "fully compatible" drives use a ninety-six TPI, or seventy-track, stepper motor. This means that the stepper motor can position the head to within 1/96 of an inch. The standard head, however, makes a recording whose track width is greater than this. Thus Apple's disk operating system only uses every other position, or *phase,* yielding a forty-eight TPI or thirty-five-track drive. Many software protection schemes make use of these in-between positions, or *half-tracks;* therefore, to be completely "Apple compatible," a drive must have this ninety-six TPI compatibility.

The magnetic head within a drive sits in a small carriage that rides along a metal rail. This keeps the head tangential to the disk recording (just like those straight-line tracking phonograph turntables). Linking the carriage to the stepper motor is usually accomplished in one of three ways: by means of a plastic cam, a lead screw, or a metal band.

The least expensive approach is to attach a small plastic disk, or *cam,* to the stepper motor. Molded into the top of this disk is a spiral groove. A small ball bearing attached to the carriage rides in this groove. Thus, as the cam rotates, the head moves in and out. With this type of coupling, there is a significant amount of sloppiness, or *play,* and this limits the accuracy of the head positioning. By the way, it is this plastic cam that causes most of the noise (especially those squeaks) when the head is changing tracks.

Another limitation of cam drive is the time it takes to step from track to track or over multiple tracks. For reliable operation, the carriage should have at least thirty-five milliseconds to move one track. Because of this, Apple DOS has a built-in delay routine that waits forty msec. for track-to-track stepping. Even with DOS's clever accelerate/decelerate positioning software, this yields an average access time of about two hundred msec.

Other Head Positioners. Many of the newer drives have now gone to a lead screw—type positioner. This works on the same principle as the bench vise and monkey wrench. The stepper motor drives a worm gear that runs parallel to the motion of the head.

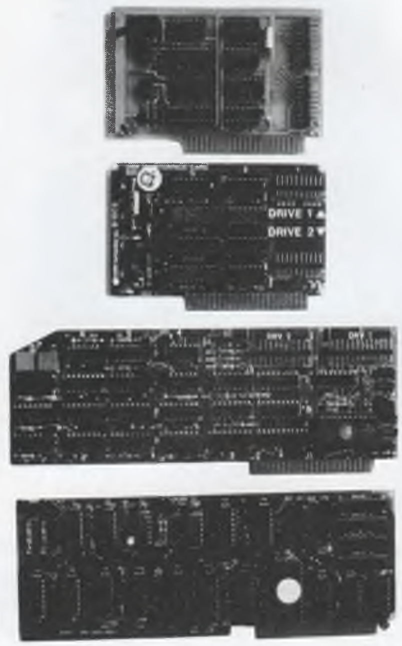
Riding on this gear, or lead screw, is an assembly connected to the head carriage. As the screw turns clockwise, for example, the carriage moves toward the inner disk tracks. The lead screw positioner provides more accurate alignment of the head and allows all forty tracks to be used reliably. It can also move faster, cutting the track-to-track access time down to fifteen to twenty-five msec.

Of course, to take advantage of the extra tracks and faster seek rate, patches must be made to the DOS. These patches can stir up some difficulties of their own, however. For example, when you have a mixture of standard Apple drives and enhanced drives on the same system, the standard drives will undoubtedly experience problems (such as I/O error) under the "improved" DOS.

Another problem with the patches is that they may conflict with other modifications to the DOS. The biggest annoyance may be that most of your favorite programs, which use their own modified DOS for protection, cannot take advantage of the drive's extra capabilities. But even under standard DOS, these improved drives should perform as well as standard drives, if not better.

Another mechanism, the *band* positioner, has found its way into at least one of the Apple-compatible drives. This type of positioner offers even greater accuracy and speed by providing an almost direct coupling between the stepper motor and the carriage.

Essentially, the carriage supports a long, narrow metal band that loops around a drive pulley exiting from the stepper motor. The special shape of the band allows a small screw to fix the band securely to the pulley to prevent slippage. With virtually no mechanical constraints to slow it down, the band positioner can achieve track stepping in less than five msec.



Controller cards for Apple-compatible drives (from the top): controllers from Lobo Drives; Apple Computer; the four-drive controller from Rana Systems; and Micro-Sci's controller.

Beyond the three types of positioners already described, there are more exotic techniques such as the voice coil positioner, which provides motion in the same manner as the cone of a loudspeaker. This can overcome even the shortcomings of a stepper motor, but only at a much higher cost. The advantages of these techniques are questionable for the 5 ¼-inch floppy format.

The Contenders. For purposes of this overview, we evaluated several of the disk drives currently available for the Apple. A Dymek alignment disk and disk speed program were used to check quality control on the subject drives. Current measurements were taken and overall drive noise was evaluated. Finally, we looked at the length of the connecting cable and whether it was shielded or not. This may prove important in multidrive systems, especially where you have an interference problem. All the drives we evaluated are styled to match the Apple and include beige cabinets.

Apple Disk II. The Disk II, a thirty-five-track cam-positioned drive, is essentially a stripped-down version of a Shugart SA400 or equivalent. All Disk IIs now come with a shielded cable about twenty inches long. Current retail price of a drive, without controller, is $525; with controller the tag is $645.

Lobo Drives Model 3101. The Lobo drive is an exact replacement for the Disk II. It uses the same type of drive mechanism, a similar analog board, and works equally well with an Apple disk controller card or Lobo's own 3.2 to 3.3 switchable boot controller. An interesting feature of the Lobo products is that one pin of the disk cable connector is keyed to a cutoff pin on the controller connectors, making it impossible to plug the cable in backward.

Unfortunately, you can still connect the cable missing an entire row of contacts; powering up the computer under this circumstance is guaranteed to blow a chip on the analog board. The Lobo drive comes with a thirty-inch unshielded cable and is priced at $385. With the 13/16 sector controller the price is $455.

Interface Inc. Drive. An Apple-compatible drive available from Interface Inc. uses an upgraded forty-track version of the SA400, the SA390. For those with an appetite for variety, this drive comes with a case in one of eight different colors. The price is also quite attractive: $325 for a single drive (with a thirty-six-inch unshielded cable). It uses a standard Apple controller card.

Micro-Sci A2 and A40. The A2 drive from Micro-Sci is another Disk II replacement. It rated very well in our alignment test and sells for $479. This includes a twenty-eight-inch unshielded cable.

The A40 is a forty-track, band positioned drive that is *not* Apple compatible without a special controller card (used by the seventy-track Model A70) that comes with various utilities on disk. These utilities are mainly used to modify DOS, Pascal, and CP/M to take advantage of the extra tracks and faster seek rate (five msec). The A40 is the fastest drive we tested. Other utilities are provided to modify FID, CopyA, and other Apple utilities to perform correctly with the extra tracks. A complete user manual is included that details all operations with both standard DOS and modified DOS.

The Micro-Sci controller card can handle two drives and includes a jumper to select either thirteen-sector or sixteen-sector boot code. The prices for the A40 (with twenty-six-inch unshielded cable) and controller card are $449 and $100 respectively.

Quentin Apple-Mate and Fourth Dimension Super Drive. These two drives are almost identical. Both use the Siemens FDD100-5 forty-track drive with a lead screw positioner. Although these drives offer greater capacity and faster operation, neither manufacturer includes the DOS patches necessary to take advantage of these features. Some other features of the Apple-Mate and Super Drive are disk-protection systems that prevent the drive doors from closing unless the disk is fully inserted and motor stall sensors that can prevent a burnout if the disk jams.

Track zero switches silence the drives during recalibration, adding to their overall smooth and quiet operation. Of course, some people may miss all that racket that the other drives make; at least you know when they're working, especially when they run across an I/O error.

The Apple-Mate is a very fine drive at a reasonable price of $379. It uses a twenty-two-inch shielded cable that will plug into any Apple standard controller card. The Super Drive retails for $329. The Apple-Mate and Super Drive both carry one-year warranties. Either would be a good choice for an add-on drive.

Rana Systems Elite One. The Elite One is the first in a series of floppy disk drives from Rana Systems. Looking a bit different from the rest because of its larger size, it is still stylishly designed to match the Apple. The only disadvantage in its greater height will be for those who use an Apple stand to hold their drives and monitor. The Rana drives will not fit into the small shelf.

The extra size gives the drive a place to put two small LEDs that indicate disk activity and write-protect status. A small touch switch next to the write-protect indicator also allows you to protect the disk manually without having to remove it and place a tab over the notch. A small jumper inside the disk can be set to have the drive come up unprotected (like a regular drive) or protected when the computer is first turned on.

Inside the Elite One there may be either a Siemens, MPI, or Tandon drive assembly. No matter which is used, the drive offers fast and accurate head positioning, forty-track operation, and automatic power-down of the analog circuits when the drive is not being accessed. Another real plus is the small loose-leaf user manual that comes with the Elite One. This manual is quite comprehensive and includes sections on the hardware and software.

Although the Elite One can be connected to any Apple controller, Rana also makes its own controller card. This, too, is a rather unique device. It can control up to four drives (with simple patches to the DOS); it automatically selects the booting code for either thirteen or sixteen sector disks; it offers improved data separation; and it incorporates power reduction features. This last claim was confirmed by our current measurements: despite its overwhelming increase in circuitry, it drew only 190 milliamperes from the +5 volt supply, as compared to 270 milliamperes for the Apple controller.

The *Elite Enhancer* disk contains several utilities to modify DOS for the Elite drives. Rana has solved the problem of mixed drive types by including a drive table within the DOS itself. This table is configured according to the type of drive(s) in each slot. When the modified DOS tries to access any disk, it first checks this table and then uses the proper seek delays for the type of drive. Of course, if you change any drives around, you must reconfigure the DOS to match. While this special DOS still has some limitations, it presents a most reasonable solution to the maximum use of mixed drives. The Elite One is priced at $449; the four-drive controller is $135. Extended warranties can also be purchased on either item.

In Conclusion. The disk drive market for the Apple II is just beginning to heat up. Apple Computer has always been in a good position to supply the first drive to most users. Now, however, the improved features and lower prices of outside vendors are attracting the first-time buyer as well as the add-on shopper. ⬛

Apple Computer Inc., 10260 Bandley Drive, Cupertino, CA 95014; (408) 996-1010. Fourth Dimension Systems, 3100 West Warner Avenue, Suite 7, Santa Ana, CA 92704; (714) 850-1228. Interface, Inc., 7630 Alabama Avenue, Unit 3, Canoga Park, CA 91304; (213) 341-7914. Lobo Drives International, 358 South Fairview Avenue, Goleta, CA 93117; (805) 683-1576. Micro-Sci, 2158 South Hathaway Street, Santa Ana, CA 92705; (714) 662-2801. Quentin Research, Inc., 19355 Business Center Drive, Northridge, CA 91324; (213) 701-1006. Rana Systems, 20620 South Leapwood Avenue, Carson, CA 90746; (213) 538-2353.