DIGITAL AUDIO RECORDING ON FLOPPY DISK

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ABSTRACT:

Microcomputers with magnetic disk drive storage systems have evolved to the point where significant quantities of digital audio material can be recorded onto floppy disks. Methods for recording PCM 16 bit linear, as well as various reduced data formats, have been developed and tested. Some of these formats are suitable for real time recording and playback. Others are non-real time methods appropriate for archival storage and retrieval. Both the hardware and software aspects of these systems are described. Presently working, and proposed standard formats of floppy disk audio are discussed.

0.00 INTRODUCTION:

Flexible magnetic diskettes, popularly known as "floppies", are familiar to most users of personal computers for the storage of digital data. Until now, their use in audio recording has been limited to the storage of brief samples of digitized audio source material for music synthesizers and computer voice message applications. This restricted scope of use has been due to the small storage capacity of the medium relative to the volume of digital data generated by the analog signal quantization process.

Recently, advances in floppy disk technology, coupled with sophisticated signal processing software has enabled floppy disk based audio computers to function as digital audio recorders. Floppy disks as a digital audio recording media provide the advantages of low cost, ease of duplication, random access editing and playback, with the ability to interface to external microcomputer systems for control and telecommunications. Commercially available floppy disk recording equipment is equivalent in recording time capacity with the audio tape broadcast cartridge in common use worldwide. Recording capacity increases anticipated in the near future will enable the floppy disk to compete favorably with digital and analog tape cassettes.

1.00 THE FLOPPY DISK ITSELF

1.10 General Characteristics

Flexible magnetic data storage diskettes, now commonly referred to as floppy disks, were first proposed in the mid-sixties by their inventor, Herbert Thompson, then at International Business Machines, Inc. At that time the advantages of rigid magnetic disks versus the magnetic drum memory for data storage were very clear. The rapid data access provided by the disk, combined with lower cost per megabyte made rigid disk drives ("winchesters") the media of choice in data processing applications. Thompson realized that the disk did not have to be rigid to be functional, and that the lower data storage density of the floppy would be offset by correspondingly lower costs.

The basic constuction of the floppy disk as conceived by Thompson has not changed much over the years. The disk itself is typically a high polymer plastic, such as Polyethylene terephthalate coated with iron oxide particles in a binder/lubricant. In some floppies, the center spindle hole is surrounded by a ring of small holes used as radial markers by some disk drives. Standard commercial floppies have a use rating of between 3 and 5 million passes of the recording head before the signal is unrecoverable.

The disk is permanently encased in a paper-like plastic jacket that is laminated to a synthetic non-woven liner material. This liner actually cleans the disk as it rotates in the jacket. The read/write (record) head, or heads in the case of double-sided use, access the disk through lozenge shaped cut-outs in the jacket. The jacket is notched at least once at its perimeter. If this notch is taped over by the user, the disk can not be recorded on. A removeable paper dust cover is generally used to shield the exposed portion of the coating from dust and static electricity when not in the disk drive.

By the mid-seventies the 8" diameter floppy was in common use worldwide. With 250 Kilobytes of capacity initially, rising to over 10 Megabytes presently, it has proved ideal as a medium of exchange for digital data. The floppy also serves as external data back-up to rigid disk storage devices much in the same way as digital tape.

The 8" floppy fathered the 5.25" mini-floppy, which in turn spawned the approximately 3" Micro-floppies. Now there are rumors of a 2" Nano-floppy. Among these succesors, only the 5.25" floppy has been adopted as an industry-wide form factor standard. In general, the 5.25" floppy is a directly scaled-down version of the 8". However, one novel arrangment places the 5.25" floppy inside a hard plastic case. This protects the medium from incidental handling damage. Several of the 3.5" floppies have also adopted this strategy. The cost trade-off is substantial: hard-cased floppies are at least 5 times more expensive than the standard issue soft jacket versions.

1.20 The Magnetic Medium

The floppy disk medium resembles conventional audio or video magnetic media with the major point of difference being the substrate. Most audio/video tapes are based on a polyester film instead of polyethylene. The somewhat more costly polyethylene base is required to limit hygroscopic growth of the medium in high humidity environments. This factor is not critical in an open ended application like tape. On a disk, radial expansion and contraction must be minimized since it translates into mis-tracking by the head.

The magnetic particles themselves are also similar to those used on conventional tapes. Low data density/low cost disks use plain iron oxide, medium density/medium cost disks use cobalt doped iron oxide and some high density/high cost disks use chromium oxide. Currently, magnetic particle development for ultra high density floppy disk use is moving in several different directions.

The trend is exemplified by Eastman Kodak's Spin Physics division's development of a modified iron oxide/cobalt doped particle.(3) This medium has the unique property of equal coercivity on all axis. Another direction, taken by Maxell Corporation of America, is the metallized floppy, consisting of vacuum chamber deposited chromium/cobalt particles.(14) Yet another approach is under testing at Verbatim Corporation, using barrium ferrite platelets. Each of these technologies has the potential to greatly increase data storage density on floppy disks.

1.30 The Disposition of Digital Data on the Disk.

1.31 The Concepts of Cylinders, Tracks, and Sectors.

Unlike a laser disk, or conventional vinyl disk, a floppy is usually recorded in discrete concentric bands, not a continuous spiral track or groove. The bands are called cylinders. Each cylinder contains two tracks: one on the top surface of the disk, and one on the bottom. Depending on the layout of the disk, a track may be as narrow as 1, or as wide as 20 thousanths of an inch. The tracks themselves are divided up into sectors.

Track sectors are radially subdivided portions of the track. In the early days of floppy disk technology, the sectors corresponded to the holes punched around the spindle (hub) hole. An LED/photodetector pair used the holes as a light shutter mechanism to signal the disk drive electronics when a sector went by. This system is referred to as "hard sectored". Today's floppy disk systems are "soft sectored"; the sector information is recorded magnetically on the disk to identify the sectors. The process of recording the layout of cylinders, tracks and sectors is called formatting. Some disk drive system electronics are capable of formatting their own blank diskettes, others are factory formatted.

These radial "pie slices" are somewhat arbitrary in size. The floppy disk "pie" has been cut up in as many as 32 sectors, and as few as 4, with capacity in bytes per sector ranging from 64 to 1024. The most common formats divide the disk into about 16 sectors. Each sector contains a description of its location address in digital code. Sectoring serves the purpose of ordering the information on the disk at a sufficiently small scale so that when data must be retrieved from the disk in random order, the control system can position the head within a short distance from the actual location of the desired data in the sector. The process of locating the desired sector is referred to as a "seek".

The seek command from the Central Processing Unit (CPU) to the disk controller usually includes the cylinder number, the track number, and the sector number. Once the controller succeeds in locating the head correctly, the data from the sector is read and passed to the CPU that made the request. In terms of access time, the worst case seek, from the outermost cylinder top track to the innermost cylinder bottom track, takes between 80 and 800 milliseconds, depending on the type of floppy disk drive. The length of the sector is also a factor in data retrieval. Disks divided into 4 sectors require little time to find the sector, but much more time to read the data in the sector since there's more of it. Disks divided into 32 sectors take more time to locate the sector, but the data will be handily available.

The penalties paid for the highly structured data disposition system described above include both computational and spatial overhead. The CPU and disk controller must keep track of data location parameters, and they must be stored on the disk itself. If a trade-off between high speed random access and overhead factors is allowable, then spiral recording becomes attractive.

1.32 Spiral Recording.

In spiral recording, the data is disposed in a continuous track, analogous to the groove in an LP record. Data sets of arbitrary size are delineated by index markers. These markers are magnetically recorded in the same way as the data itself. Periodic radial position markers may also be recorded to assist in contolling the position of the head. A variation on this method is employed in one floppy disk system, and in many laser disk systems. The principal drawback is the longer seek times that result from having less absolute location addressing. Spiral recording systems can easily take advantage of constant data density in the track by making the spindle speed of the disk proportional to radial distance from the hub. In this way a constant number of bits per linear inch can be achieved, resulting in efficient use of the larger diameter of the outermost portions of the spiral nearest the circumference of the disk.

In cylinder/track/sector systems, the data density usually varies due to the fixed number of bits in the sectors themselves. To achieve more efficient use of disk space, some floppy disk systems have adopted "banded" data disposition. Contiguous groups of cylinders are assigned either different frequencies for recording, or spindle speeds. For example, on a floppy with 100 cylinders, four groups of 25 are created. The 25 cylinders closest to the hub use a lower recording frequency, or higher spindle speed, to compensate for the fact that the average circumference for that group is small relative to the group of 25 cylinders at the outside of the disk. Conversely, the outermost group of 25 has the highest recording frequency or lowest spindle speed. The more bands, the more efficient the storage density of the disk becomes. At the limit, where each band corresponds to a cylinder, the efficiency is the same as a spiral recording. Practical considerations usually limit these schemes for either multiple speeds, or multiple frequencies to no more than eight bands.

1.33 Factors Limiting Bit Density.

Bit density, or data density, is limited in the absolute sense only by the physics of magnetic recording. Figure 1. illustrates these limits for a variety of recording systems. Note that magnetic recording has a higher theoretical limit than visible light laser systems due to the wavelength of red light. Presently, magnetic recording with experimental systems is limited to about 180,000 bits per linear inch on isotropic or vertical medium with a pole type recording head. A conventional ferrite core head horizontal recording on a mass produced floppy is limited to about 40,000 bits per linear inch.

Linear density is one factor. The second principal issue is the track density. Track density is a function of the width of the recording head, the magnetic properties of the medium, and the accuracy of the head locating system. To date, the principal limitation on density has been the accuracy of the head locating system. Track densities over 100 tracks per inch (TPI) are only practical with some type of closed-loop servo system that can quickly and accurately maintain the head position over the track being written or read. Once a suitable servo system is adopted, the next barrier becomes the magnetic properties of the disk.

To achieve high areal densities, the coercivity and retentivity of the medium must be correspondingly high. The recording head itself becomes a limiting factor at densities in the range of 15 million bits per square inch. The record gap size and the width of the track combine to make a very difficult to fabricate mechanical device. In a floppy disk with 1000 TPI, the actual width of the track is only 1 mil. If the linear bit density is 40,000 BPI, the record gap will be only about 12 micro-inches across. Some relief in this area is promised by thin film head technology, and micro-machining techniques. However, at the present time there are no floppy drives taking advantage of such advances. It is reasonable to project that an advanced floppy disk drive will emerge in the near future that combines state of the art features to yield 5.25" floppies with over 50 Megabytes of capacity.

2.00 THE DISK DRIVE

Mechanically, all disk drives are very similar. A rigid plastic or metal chassis contains the three major subsystems: the drive motor, the spindle or disk hub clamp, and the head/arm assembly. Figure 2. ilustrates a typical drive. The motor may be directly connected to the hub clamp or it can be a belt drive arrangement. Various head positioning systems are discussed below. Most disk drives have a mechanical usefull life rating of 10,000 hours before maintenance is required. The mean-time-to-repair is generally listed as less than 0.50 hours by the manufacturers. Most internal components are disposable, and intended to be replaced during any repair operation.

2.10 The Physical Relationship Between the Disk Drive and the Disk.

Within each size category of disk drive system one might expect some degree of interchangeability of media based on standard configurations of the drive mechanics. It would be convenient if such items as location of the read/write head, write-protect notch detector, type of disk clamping and rotational speed were standard. Unfortunately, the only recognized standard in disk drive/diskette physical parameters is for the 8" diameter configuration. Theoretically at least, any 8" diskette will physically fit in an 8" drive, the read/write head, or heads will contact the disk in the proper area(s), and, providing the software interface is the same between the two computers using the drives, data can be exchanged. In fact, this is true with one exception: some drives have two heads, and some have one. A double-sided diskette must be flipped over, like an LP record, so the second side can be read in a single headed drive.

No such statement can be made for any other size of drive/diskette. The 5.25" systems come closest to some agreement in the area of diskette size. From that point on, the chances of interchangeability are low. (Figure 3.) For example, the floppy disk that fits into an IBM PC may fit into another computer's disk drive, but the door lock may not latch down because the write-protect notch is located differently on the diskette jacket. One version of the 5.25" diskette is contained in a rigid plastic case that only fits in one manufacturer's drive. Nor is rotational speed standard in 5.25s. Most spin at 300 rpm. Some spin at 1200, others at 600.

The situation isn't any better in the 3" variations. Physical size of the diskette may be 3.125", 3.25" or 3.5". The jacket may be soft like most 5.25s , or a rigid plastic box. Rotational speeds vary even among otherwise identical systems. The Apple MacIntosh microdisk drive is the same Sony unit that Hewlett Packard employs. Only the rotational speeds differ; making data interchange impossible between drives.

2.12 Head to Disk Interface

At the actual point of contact between the recording head and the disk three major categories of head to disk relationships have developed. The first, and most common, is the head-on-media type. This is a direct off-shoot of conventional magnetic tape recording technology wherein the recording head rides on the disk, with either another head on the opposite side of the disk providing contact pressure, or a felt pressure pad, as in a tape cassette.

A recent innovation in the direct contact category is 3M's "stretchy-floppy" system where the head is pushed into a diskette supported much like a doughnut shaped trampoline .(1) The resilience of the medium itself supplies the contact pressure. In all direct contact types, head lubrication is supplied in the media itself as either a surface impregnation or matrix in the magnetic coating.

The second type of head to disk interface is the air lubricated type. High rotational speed, over 500 rpm, with its corresponding air drag on the disk surface, is utilized to carry air molecules into the head contact area, reducing friction. One problem associated with this type is its sensitivity to relative humidity, which changes the properties of the air lubricant.

The least common head-disk interface is one where the head actually "flies" with respect to the medium. Although this technique is common to all hard disk drives, it is used by only one floppy disk drive system manufacturer, Iomega.(12) In this drive the floppy is positioned in parallel to a plate which has a banana shaped slot near the location of the head. The 1200 rpm rotation of the disk pumps air through the slot in a well-controlled laminar stream. The low pressure area created perpendicular to the airflow results in a deflection of the spinning disk towards the head. The portion of the airflow that actually enters the head-disk region acts as an air bearing. A usefull side effect of this arrangement is that any foreign material that enters the recording head region tends to disrupt the stability of the system so that the diskette "unwarps" away from the head, usually preventing damage to the medium. On the negative side is the cost inherent in the rigidly cased floppy required to maintain the tolerances for airflow control.

2.13 Recording Head Motion Systems.

Movement of the record head can be accomplished in a variety of ways. The most common is the stepper motor. This small DC motor moves the arm that contains the head in small increments that correspond to the track to track distance. The speed at which the track to track movement is accomplished is called the stepping (or step) rate. The arm may be connected to the motor shaft by a lead screw arrangement, as in a bench vise, or by a metal band.

A less popular method of positioning the head is the electomagnetic voice coil system which is similar in operation to a voice coil and magnet loudspeaker driver. The coil is fixed to the frame of the disk drive and the magnet to the arm holding the record head. Typically, a radial action of the head arm is used, as opposed to the linear configuration of a speaker driver. The most novel means of positioning the head is a proprietary design by KRS, Inc. which employs a needle-in-groove pantographic action. In this 3.5" disk system, the floppy hub ring is enlarged to accomodate an area of rigid thermoplastic molded like an LP record with a continuous spiral groove. The oversized hub reduces the recording area of the floppy by about 20%.

A steel needle attached to the record arm tracks in the groove. An inch or so beyond the needle, the record head moves in parallel. Moving the head in or out along the radial axis requires a change of direction in rotation. Since digital data is buffered as it leaves the disk in either direction, a software routine takes care of re-arranging the data into the correct order.

CompuSonics has built test beds with all but the needle following type of drive mechanism. No one commercially available drive is ideal. The stepper motor drives with metal band positioners tend to be noisy; as high as 40dB for a bare drive . The voice coil positioners, on both floppy and rigid disks are fast, quiet, and expensive at present. The one stepper motor and lead screw drive tested was quiet and effective. A special purpose version of a dual stepper motor drive system, designed for digital audio, is presently being fabricated for additional testing.

2.14 Servo-Tracking Methods.

A Mechanical means of positioning the record head is half the battle. The difficult task is keeping the head on track in a medium where the disk may be more egg shaped than round. For applications where bit density is not large, and data transfer rates are low, as in small personal computer disks, the problem barely exists. If the head wanders a few mils radially, it probably is still somewhere on the track being written or read. If the disk operating system detects that it is not, the positioner makes a full track move, in or out, and tries again. This is referred to as an open-loop servo system since the disk drive itself is not responsible for locating the head properly. The penalty for this mode of operation is low response speed to out of position detection, since the host computer and its disk controller must do the job remotely. The resolution of head position in open-loop servos is unsuited to digital audio applications.

A more sophisticated approach, better suited to the high density recording of audio material, utilizes direct feedback of position information in the disk drive electronics. This is the closed-loop servo system. In closed-loop servo systems, information about the position of the head is detected locally and fed back to the head motion electro-mechanical system for immediate action. The computer's CPU and disk controller are not involved. Because the feedback loop is local, rapid compensation for irregularities in the disk or changes due to environmental factors, such as heat, can be achieved.

Three methods have been developed by different drive manufacturers to implement closed-loop servo systems on floppy disks. The most time-tested system employs factory pre-formatted disks in which the cylinder, track, and sector information is pre-recorded on the disk at the factory. In the drive, the head position control system gathers the position information from the disk as the data is being written or read. This information is used to cycle the servo mechanism in or out to get back on track whenever a position discrepancy is detected. A similar method utilizes pre-recorded "servo-bursts" that lie half on and half off each track at each sector. These "bursts" are digital data that is decoded non-digitally so that the relative voltage generated by the head as it passes over the bursts can be compared in an analog circuit. If the balance of the bursts is off, left or right, the head motion servo can respond in the correct direction. This system has performed well, and is the basis for the proposed standard detailed in Appendix 1.

The only non-magnetic closed-loop servo system employs an optical reference technique.(13) There are two parts to this scheme: a calibration reference strip attached to the frame of the drive, and special floppy disks that have an outer cylinder coated with a reflective material. The reference strip is a plastic film with the same mechanical properties as the disk. It responds to variations in environmental conditions in the same manner as the disk itself. An LED/photo-detector pair is used to monitor the length of the reference strip while the disk spins. Another LED/photo-detector pair monitors the radial position of the outside edge of the disk by reflecting off the coating there. The correct head position can then be periodically re-calculated by the servo computer, taking into account the particular diameter of the disk in the drive and environmental effects on it. It must be noted that this system depends on the assumptions that the reference scale does not age at a different rate than the floppy, and that all floppies are almost identical in mechanical properties. These assumptions may not hold in all relevant cases.

2.15 Door Locks and Other Niceties.

Floppy disk drives include door locks to prevent the the user from removing the disk from the drive while the head is on the medium. Types of locks vary widely. At one extreme are all electronic locks that are opened and closed by the drive itself, leaving the user only to insert or remove the disk . Presently, there are no floppy disk drives that feature fully automated loading, or laser disk type motor operated trays. Most floppy drives require the user to insert the disk and rotate a door latch to lock the disk hub clamp.

To remove the disk, the door lock must be rotated or lifted, releasing the disk from the hub clamp. Because unlocking the disk while it is spinning with the head on the disk can result in static discharge to the medium, and consequent data destruction, some manufacturers provide a separate release switch that is interlocked to the drive electronics. In these systems the door can not be opened until the disk is stopped and the heads unloaded.

Another feature frequently built into the front panel of the disk drive is the activity light. Whenever the disk is being recorded or played back the LED is on.

2.20 The Electronics.

The disk drive electronics perform two principal tasks: converting the digital data presented by the disk controller into analog signals that can be passed through the recording head, and head servo positioning. Secondary tasks include loading and unloading the head up/down solenoid, locking and unlocking the drive door, and controlling motor speed.

2.21 Getting the Bits on the Disk.

Physically recording digital information is accomplished in many ways. In the most straightforward least spatially efficient method, pulses of electrical current are passed through the recording head to lay down a train of magnetized regions on the medium. The only signal waveform is a square wave. This pulse of energy is utilized to represent two distinct categories of recorded information: the binary number 1 and the "clock bit". From the point of view of an oscilloscope screen they are identical. Between each pair of clock bits (pulses) there either is, or is not, a data bit. The space between the clock bits is called a data cell. Absence of a data bit in the cell means a binary zero. Presence of a data bit in the cell is a binary 1. The only problem is telling the difference between clock bits and data bits.

To enable the disk controller to locate the beginning of the first valid data cell on a track, a small portion of the track is dedicated to synchronization fields. These are sequences of binary code that are, by definition in the disk controller's software, "illegal" data. Once the sync fields are read, the edge of the first data cell can be distinguished. The sync fields are written on the disk at the time it is formatted.

In the basic FM (frequency modulated) recording process described above, approximately half the disk recording area is spent on creating data cells out of clock bits. This inefficiency has been reduced by a variety of encoding schemes (4,9) that rely on fewer clock bits, more uninterrupted strings of actual data bits, and representational strategies. The most popular density increasing method is MFM (modified frequency modulation) which reduces clock bits to achieve higher data density. GCR (group code recording) and RLL (run length limited) are representational systems that pre-process the bit stream through a software program that tokenizes specific patterns of binary data. The binary patterns of the tokens are then recorded. On playback, these tokens are expanded to the exact original bit stream.

In the magnetized medium itself, the bits can be visualized as pole magnets laying flat on the surface for horizontal recording systems, or standing on end in vertical recording systems. All commercially available floppy disk drive systems employ horizontal recording. This is primarily a function of cost. Vertical recording media and the heads to magnetize them are produced in limited quantities for laboratory use.

2.22 The Interface of the Disk Recorder Circuit to the Host.

A general schematic of a complete floppy disk system is shown in Figure 4. Three levels of data interface lie between the recording head electronics and the digital audio data leaving the signal processing module:

* Multibus
* Memory to disk controller bus
* Disk controller to disk drive electronics bus

The Multibus (7) is a 16 bit wide data path that may be controlled by any one microprocessor on the bus at any one time. Typically, the highest level of control is excersised by the system host processor. To achieve high data throughput rates, an auxilliary device may be employed to expedite direct transfers of data on the bus from system main memory RAM (Random Access Memory) to storage without continously using the host's CPU. This "helper" circuit is called a DMA (Direct Memory Access) device. Audio data flows from the signal processing module through RAM to the disk controller.

In the system illustrated, the DMA module also performs the function of converting the data from the Multibus format to the industry standard SCSI format. The disk drive controller receives parallel data from RAM via the DMA module, converts the data to a serial bit stream, and reads or writes to the disk drive electronics as required.

The first protocol to be established for communications between a floppy disk drive subsystem and a host computer was the SASI (Shugart Associates Standard Interface) bus; pronounced as "sassy". This 8 bit parallel system is still the most common protocol. When it was adopted as an ANSI standard, the name was changed to SCSI (Small Computer Systems Interface) bus; called "scuzzy". Currently, a new enhanced version called "ezdee", ESDI (enhanced small disk interface) bus is circulating as a proposed standard. This 8 bit parallel interface is primarily intended for use with small rigid disk drives and supports advanced features such as multi-disk data request with automatic re-connect after a successfull seek command.

2.23 Data Rate Issues.

In designing a digital audio recording system based on the floppy disk, the anticipated rate of the audio data must be considered carefully. Floppy disks generally are slow compared to digital tape and rigid disk systems. Digital audio data rates range from a low of 9600 BPS (Bits Per Second) for monophonic voice recording, to a high of 1,600,000 BPS for high quality stereo music recording. This range must be matched to that of the disk drive electronics.

Continous data transfer rates on and off of floppy disk range from a low 20,000 BPS to a high of 2,500,000 BPS. Note that these are not the numbers published by disk drive manufacturers. They are prone to use the "burst rate" when quoting transfer speeds. The burst rate is the instantaneous rate of data transfer in the best possible case. At minimum, continuous data transfer rate calculations must take into account the track to track head positioning time and head settling time. For true scatter storage systems, where the data may be allocated at random in split second segments anywhere on the disk, continuous data transfer rates must additionally take into account worst case cylinder to cylinder access time, and sector latency as well.

Linear bit density is also a data rate issue. The higher the linear bit density for a given rotational speed, the higher the recording frequency. Consequently, the disk drive electronics are designed to support the burst rate of data transfer, and usually can not be arbitrarily slowed down to match an audio rate. Nor can the disk rotational speed be modified for this purpose. The result is frequently a mismatch between the proposed audio data rate and that at which the disk drive electronics will function.

Two solutions are readily available: a hardware match between audio data rate and disk drive continuous transfer rate, or software controlled data sector interleaving. For a digital audio section/disk drive hardware match to work, the difference of burst rate to continuous rate must be arbitrated by a data storage buffer. This buffer is usually a FIFO (First In First Out) solid state memory sized to meet the worst case condition. A more flexible solution depends on a software routine programmed into the disk controller microprocessor.

Under software control, the disk write command can be modified to skip sectors on the disk while writing. For example, if there are 16 sectors in a track, and a mismatch between the audio data rate and burst rate of 2 to 1, every other sector is skipped during the first revolution of the disk. On the second revolution, the head remains on the same track and records in the 8 sectors not previously recorded in the first revolution. On playback the process is reversed. This has the net effect of making the rotational speed of the disk look like half its true speed. This data sector interleaving process can be carried out in any number of revolutions. The number of revolutions required to record a single track is called the interleaving factor. In the worst case, one sector per track will be unrecorded because the interleaving factor is not an integer divisor of the number of sectors in a track.

The continuous digital audio data rate that can be recorded on the floppy is also a function of the error rate of the floppy disk subsystem. Bit errors are divided into two categories: soft errors and hard errors. The soft errors are those found on the first attempt to read the data and can be easily re-read because the questionable bit still exists. Hard errors result when a bit has been destroyed. Usually the medium itself has not been damaged, but nonetheless the particular bit in question has become unreadable. In either soft or hard error situations, the disk controller is programmed to attempt a retry. Since an extra revolution of the disk is required, time is wasted, and the average data transfer rate suffers.

For non-audio digital recording, time is not nearly as critical as audio; a brief pause in transfer of data may go unnoticed for most financial file transfers. With audio, even a momentary gap in musical material is unacceptable. A time budget must be established for read error retries and factored into the continuous data transfer rate calculations.

2.24 Error Detection and Correction.

Virtually all commercially available floppy disk controllers contain a system for detecting errors. The most basic record a parity bit for each byte and test parity during the read operation. More advanced designs use CRC (Cyclic Redundancy Code) to write checksums at the end of each data sector. Some controllers both detect errors and correct them. The most common ECC (Error Correction Code) systems write a polynomial code based on the sector data at the end of each sector. The larger the polynomial, the more bytes it takes up, and the more bit errors it can correct. Some ECCs can correct contiguous bit errors up to 88 bits long in a data sector of 2048 bits.

In selecting a detection and correction system for digital audio material, the ability of the system to perform in real time is the prime factor. A slow correction system can be given a larger time window in which to operate at the expense of more buffer memory space. However, in all systems there is some finite probability that an error will be found that can not be corrected. The disk controller then has three options: pass the data sector through with the error, use a redundant data sector, or pass the data through with a flag notifying the host system that the data is flawed.

Recording the data more than once is inefficient for raw sound samples. It is a viable option for parametric data, or directory maps, that if lost could render the entire disk useless. If the controller has the ability to flag bad data, the host can implement a concealment scheme on the fly to mask the error. This has proven effective in digital tape systems for errors as large as 80,000 bits. For raw 16 bit samples this represents about a tenth of a second in mono. Audio samples from both sides of the error can be used to synthesize the missing split second in the data stream.

3.00 THE AUDIO COMPUTER HOST OF THE DISK DRIVE.

Commercially available disk drives are designed to be interfaced to computers. It is conceivable that disk drive electronics could be re-designed to facilitate direct connection of analog to digital and digital to analog converters. Certainly, many component level redundancies would be eliminated in such a system. However, one of the principal reasons for selecting a disk drive for digital audio recording is to gain the advantages of random access editing. This type of high level functional control can only be implemented readily with a microcomputer. Once this premise is accepted, and a microcomputer integrated into the digital audio recording chain, further uses of the microcomputer may be gained by software means with no additional hardware costs.

3.10 The Audio Head/Tail Ends of the System.

3.11 Brief Review of the AD/DA Interface.

At the points where the audio signal enters and leaves the system the signal is in the analog domain. The conversion process of analog to digital and digital to analog signals has been well documented elsewhere.(16) On the input side, once the conversion process is completed, a digital bit stream results. This data may be in the form of parallel or serial bits. A serial bit stream is appropriate for use by digital audio tape recorder electronics "as is". If the data is to be further processed, or buffered in RAM, the parallel data format is preferable since RAM is usually organized to store specific size digital words whole.

Some buffering is necessary in any digital audio system, if only to provide time for error correction or concealment on playback. When digital signal processing is required in the recording system, for digital level control, crossfades, or delay lines, a substantial buffer memory will be needed. This buffer typically ranges from 128,000 bytes to 3,000,000 bytes, depending on the system.

3.12 Consequences of User Intervention.

Buffers could be smaller than they usually are if the equipment was never managed by a person. Automated digital recording systems in laboratory applications do not require a sophisticated user interface, and can record or playback unattended. On the contrary, audio systems are heavily manipulated by their users. In conventional analog tape recording, the electromechanical start or stop of recording is a simple matter of relay/servo control. A digital audio system must monitor its FIFO memory buffer contents and properly dispose of them when the start or stop command is issued by the user. Failure to do so will result in recording gaps.

3.20 Role of the CPU.

3.21 Memory Manager.

The Multibus computer architecture is designed to support multi-processor system designs for a wide variety of general computer applications. The fundamental reason for building computers with multiple processors is to increase the usefull work the system can do in any given period of time. Audio computers built on the Multibus are a special subset of multi-processor systems, subject to specific constraints that do not occur in more general applications. The requirement for real-time throughput discussed in 2.23 above is one of these constraints. Another severe constraint is the requirement of virtually instantaneous user control of data flow in the computer.

In the audio computer many processors are asynchronously working on a variety of tasks. The disk controller may be reading or writing the disk, the signal processors may be controlling the level of the audio, and the DMA controller may be setting up the next transfer of audio data to the disk controller. One micro-processor must maintain control of priorities and respond to the user's actions in a timely way. Since all processors on the Multibus utilize RAM as main system memory, the potential for internal contention and data collisions is large, as they each attempt to go about their business. The CPU acts as system master; arbitrating access to memory and intermediating for the user. The Operating System is the name of the program the CPU executes to perform the management task.

3.22 DMA Controller Controller.

The CPU's most important task is to set up the path for audio data to get to or from the disk. The actual moving of the bits is handled by the DMA device itself. However, the DMA device must rely on the CPU's assistance in locating the data to be moved from RAM to the disk controller. In effect, the CPU is a controller for another controller. This layering of task allocation and control is the key to efficient non-stop operation during recording and playback.

3.30 Signal Processing in Real-Time.

3.31 Various Purposes of Processing.

Digital signal processing (DSP) is useful for many audio tasks. Most of these have been discussed at length elsewhere.(15) DSP has been used to build digital mixers capable of performing all the functions of an analog mixer in the digital domain.(5) In the context of digital audio recording on floppy disk, the three principal uses of DSP are special effects, EQ, and data reduction.

Special audio effects such as echo, reverberation, harmonizing and chorusing can be implemented in software on an audio computer. Special purpose micro-processors such as the Texas Instruments TMS320 family are well suited to these routines. The key to software support in any special purpose DSP chip is an on-board high speed multiplier that can yield a 32 bit product in less than 200 nanoseconds. General purpose bit-slice processors have also been used successfully by others to perform these functions.(15)

Digital equalization of the audio signal can also be implemented in software routines on a signal processing chip. A floppy disk recording deck can then also serve as an equalizer without the phase shifting side effect found in many analog graphic equalizers. To get the full benefit of built-in DSP hardware and software, a video display and typewriter style keyboard is necessary. The present generation of CompuSonics audio computers use either a standard computer terminal (dumb terminal), or the IBM PC running smart graphics terminal software to access the advanced signal processing capabilities of the audio computer.

DSP's main purpose in CompuSonics' floppy disk recording to date has been to reduce the quantity of raw data coming off the analog to digital converters prior to disk storage. DSP software as simple as log companding, and as complex as digital filterbank frequency following has been implemented in real time. Data reduction rates have ranged from 2 to 1 to 16 to 1. As DSP chips become more powerful and less costly higher data reduction rates are anticipated. Reducing the data rate has several advantages. Floppy disk capacity is effectively increased in terms of recording time per megabyte, and the bandwidth that must be processed by the disk controller and the disk drive electronics is reduced. Both items increase the cost effectiveness of the system.

A secondary benefit of DSP for data reduction is in the area of music editing. Some of the reduction methods developed at CompuSonics yield well ordered data sets, as opposed to a continuously varying bit stream like companded delta PCM. These ordered sets are mapped on the disk so that they can be manipulated easily in post-processing. Functions such as splicing, fading, and re-ordering are possible without re-expanding the data to its original volume. Other functions such as mixing and level control do require expansion of the data into RAM prior to operating on the data.

4.00 CONCLUSIONS/RECOMMENDATIONS.

Digital audio recording on floppy disks using audio computers for control and signal processing has been successfully accomplished in a variety of prototype configurations. CompuSonics is presently manufacturing a professional audio computer that records on both rigid and floppy disks. CompuSonics' first consumer level floppy disk based audio computer, the DSP-1000 is scheduled for introduction in 1985. The development system for that machine is presented below. Preliminary specifications for the proposed non-proprietary disk format are also disclosed.

4.10 Hardware-Software Configurations That Work.

4.11 Intel Multibus Based Systems.

Four Multibus based prototypes of audio computers configured as floppy disk digital audio recorders have been built and tested. In general layout they are all similar to Figure 4. The first machine, built in 1983, utilizes an Iomega Beta 5 drive (7.5 megabytes) and an OMTI 20C disk controller. This version of the floppy disk recorder still has the highest data transfer rate of any CompuSonics prototype: 5,000,000 BPS burst rate, 2,500,000 BPS continuous. It is the only unit capable of recording 16 bit 50 kHz sample rate stereo without any data reduction. Without data reduction this yields a recording time of about 1 minute in mono. On the negative side, some problems were encountered with disk reliability, despite the hard cartridge design of the floppy disk. In all fairness to Iomega, it should be pointed out that other factors in the hardware and software systems may have been responsible for the problems.

The next two prototypes, built in 1984, contained Drivetec 320 disk drives (3.3 megabytes) and Data Technology Corporation 535 BK disk controllers. These units operated at between 120,000 BPS and 160,000 BPS continuous data transfer rates, making them dependant on data reduction for real-time recording and playback. The AD/DA sections were built in a variety of formats, from 12 bit/12 kHz to 12 bit/32 kHz. These were the first CompuSonics machines to incorporate front panel controls, VU meters, and a scrolling LED text display. Recording time was a maximum of 4 minutes in mono. One of these prototypes was converted to a Kodak 3.3 drive, and the other was rebuilt into the dashboard of a 4-wheel drive vehicle for environmental testing. Rigidly mounted to the sheetmetal dashboard, the unit plays reliably under most driving conditions. Road surface irregularities which cause a wheel to leave the surface cause disk read errors, but do not damage the disk.

The final Multibus based prototype was initially built in 1984 with a Drivetec 320 drive and a Data Technology disk controller. The AD/DA section was 16 bit/32 kHz. In 1985 the machine was rebuilt with a Drivetec 640 (6.6 megabyte) drive and 16 bit/50 kHz AD/DA section. The continuous transfer rate is over 200,000 BPS. With an 8 to 1 data reduction rate, this yields about 3.5 minutes of stereo recording.

4.12 CompuSonics DSP-1000 Single Board System.

The final Multibus prototype served as the basis for a pilot production audio computer design in which all board or module level components of the Multibus version have been placed on one large (15" x 16") circuit board. This unit, called the DSP-1000, will begin field testing in May, 1985. Figure 5. shows the basic block diagram of the circuit, and a photo of one of the early prototypes. The components not shown in the diagram, required for operation, are the disk drive, power supplies, meters, liquid crystal display, front panel controls, and audio connectors.

Complete audio specifications have not been determined as of this date. Some of the preliminary specifications are:

Dynamic range..............90 dB
Channel separation..........90 dB
Signal to noise.............90 dB
Frequency response..........DC to 20,000 Hz
Wow & flutter...............Not measurable
Access time.................0.25 seconds
THD @ 1 kHz, 3rd harmonic...0.05%

4.20 Proposed Disk Data Format and Integral Labelling System.

The data storage scheme used in the DSP-1000 floppy disk based audio computer is based on a random access, scatter storage type allocation scheme (10) that contains three types of data: directories, coded waveforms and decoding parameters. This allows the user to make recordings and perform edits in the most efficient manner, without having to worry about the physical location of data on the disk. Since a scatter storage allocation scheme can potentially result in long head seeks due to widely distributed data, there is the possibiltiy that "worst cases" may arise where the seek/read sequence cannot be performed fast enough to meet data transfer requirements. These situations occur when either the data playback rate is too high and/or the data is dispersed too widely on the disk. This problem can be solved by lowering the data rate or recording the data into contiguous sectors and adjacent tracks.

For prerecorded diskettes, data rate and data distribution will never be a problem. The disks are simply formatted in the optimal way when recorded. For the most part, this means a linear distribution of data. This does not necessarily mean that the head can proceed track by track for the entirety of a music selection. Since the parameters and coded waveforms are in two different data streams, the head may have to seek ahead or seek back in order to pick up the next parameter track while reading through the coded waveform (see soundfiles format, below). Fortunately, these requirements can be predicted, and application of sufficient track buffering in memory solves the problem. The number of tracks buffered should be equivalent to the number of revolutions lost by seeking to the next sector in the soundfile.

For preformatted, "linearly" stored data, the worst case seek will be about two revolutions in addition to the 1/2 revolution normal latency per seek. Additional strategies can be employed to minimize head movement and still retain random access continuous data streams. For example, assume that the parameter stream data rate is about 1/10 that of the coded waveform stream. In starting playback, a parameter track is read first; then about 10 coded waveform tracks. Now, if another parameter track is needed in order to complete reconstruction of the 10 coded waveform tracks, it may be read after the 10 waveform tracks are cued up in buffer memory. This process increases data buffer size, but results in a higher overall transfer rate.

Adequate buffering capability is particularly important when recording music, because there may be no way to predict a priori the relative percentage of parameter data vs. coded waveform data. When recording music onto floppy disk, it is always a good idea to linearize the disk space allocation directory to avoid a playback audio gap. It is possible to have the audio computer report to the user the data rate which the current data sector distribution can support, allowing the user to decide in advance whether he should spend the time to linearize or not. The ultimate solution is to have enough data reduction and fast enough disk drives so that data distribution issues never arise at all.

4.21 Header Format.

The disk is formatted with a header data structure, data directories, and embedded servo control information. Servo strategy was discussed in 2.14, above, and the proposed servo system is presented in detail in Appendix 1. The header and directory structures are arranged as follows:

Track 0: Disk header structure.

This data structure starts at the beginning of the track, and is repeated several times for the entire track. Note that if track 0 is bad, then the disk header is recorded onto track 1, if track 1 is bad, then the header goes on track 2, etc. At start up, the audio computer reads the disk header structure, finds and reads any special files required for operation, gets the user's control panel commands and executes them. From power up to start of audio playback takes about 1 second.

The header structure gives essential information about the format of the disk, and the version of software and hardware that the disk is compatible with. This data structure contains the addresses of the various important files on the disk such as the space allocation directory, soundfile directory, playfile directory, comment file (for liner notes, graphics, and the like) and other data which may be desired. The process of executing the header instructions may redefine the operating system. Similarly, the disk header may point to a sector that contains signal processing code which is specific to the selections on the disk.

Disk Header Contents:

* multiple sync fields for various disk/disk drive configurations
* disk label
* copy and write protection fields
* date that disk was formatted
* date of last modification to disk
* hardware and software version
* floppy disk parameters
* address of the sector distribution directory itself
* beginning address of the soundfile directory
* beginning address of the playfile directory
* beginning address of liner notes, graphics, etc.
* beginning address of new operating system code (optional)
* beginning address of special data
* structure definition for floppy disk parameters
* size of sectors in bytes
* number of sectors per track
* number of tracks on disk
* floppy parameters required by the operating system

4.22 Data Formats.

Track 1 to N: All of the disk space data sectors.

The balance of the diskette contains sector directories, various special files which are pointed to by the disk header, as well as all the sound files and playfiles.

4.23 Soundfiles.

The soundfile structure points to the data on the disk required for audio playback. The contents of a soundfile are:

* soundfile number
* date this soundfile was defined
* title of soundfile
* names of performers and comments
* length of selection in seconds
* beginning address of playback decoding parameters
* beginning address of coded waveform data

Within the soundfile data structures the data is broken into two streams: one for parameters and important information, and another for the coded waveform data which drives the resynthesis of the audio. This is an important distinction for three reasons.

1. Parameters occur at a relatively low data rate, but are very important. If there is an error during playback, multiple re-reads may have to be executed until the data is valid. Since the parameter data stream is low bandwidth, (frequently less than 1/10 the coded waveform data), there is adequate time for many attempts to correctly read the data or reconstruct the bad data through error correction algorithms.

2. Since the efficiency of the data coding varies in time, some blocks may be larger than other blocks. To scan forward or backward in a piece of music, the headers must be followed until counted to the right place. If the parameters and the data were interleaved, every track of the music selection would have to be read until the correct offset was located . That would be slow due to the reading of a lot of unnecessary coded waveform data. When the parameters and waveforms are separated into two streams, the headers can be quickly scanned by reading only the essential data in the parameter stream. The offset is counted up while this is done, and the appropriate place may then be seeked to in the coded waveform stream.

3. Having two streams allows the choice between "high data integrity" and "low data integrity." As coding techniques become more and more effective (in the limit becoming pure synthesis at extremely low data rates), more and more data integrity is necessary. That is resolved naturally because more coding results in less data representing more music in real time after resynthesis. Nonetheless some "high bandwidth" audio data will inevitably remain. For example, in some applications a very large quantity of parametric data will serve to drive various arrangements of a small quantity of actual audio recording that may be on the disk at various reduction rates.

4.24 Playfiles.

Playfiles are structures which may be used to customize the playback of a soundfile. Each playfile is followed by an arbitrary number of performance parameters for scheduling and modifying playback.

The playfile structure contains:

* playfile number
* date that playfile was defined
* title of playfile
* names of performers and comments
* notes or memos about this playfile
* number of playback decoding parameters to follow

The playfile structures are modeled after those on the CompuSonics DSP-2000 professional audio computer.(5) At their simplest level, they call up a soundfile with "in" and "out" points. In addition, a playfile structure has an arbitrary number of parameters following it. Normally, the first parameter will indicate the type of event this is, and then the event parameters will follow. Events range from "play a soundfile" to "set up a synthesizer orchestra and perform the following score."

4.25 The Disk Space Data Sector Allocation Directory.

The sector allocation directory is a linked chain of locations specifying sectors of disk storage. These groups of sectors are typically chosen to correspond with a single data track on the disk. A single track (multiple sector) allocation is optimal in the sense that the data may be read from the disk in a single revolution, thereby maximizing data transfer rate. Use of the allocation directory leads to a truly random access disk storage system which can transparently accomodate a wide variety of file additions, deletions, and edits.

The user always retains the option to "linearize" the sector allocation directory; automatically shuffling the data around to produce contiguous files. It should be noted that a newly defined (or redefined) allocation directory is always linear. Another feature of this directory structure is that it allows easy removal of regions on the disk with defects. These regions are simply deleted from the directory.

4.26 Upward Compatability.

The above proposed data formats for digital audio recording on floppy disk are intended to support future growth and change. With the exception of the synchronization and servo fields themselves, the entire structure is "soft"; defined in software and re-configurable by the audio computer itself. Even the set of sync fields within the disk header, and the servo bursts in the sectors, can be expanded to encompass a range of disk drive hardware that is as yet unknown.

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A GLOSSARY OF FLOPPY DISK TERMINOLOGY

Access Time
Usually refers to the time required to retrieve the desired data from the disk.

Average Access Time
Manufacturers use the formula:

[(Max. number of tracks) x (step rate) + (seek settle time)] / 3

Note that this formula usually does not include the latency factor in the seek settle time.

Bit Shift
Also called peak shift. A shift in expected peak position of the signal on the disk due to infuences of neighboring flux changes.

BPI
Bits Per Inch. Usually the inside track is used to maximize the following formula:

(number of bits in 1 revolution) / [(2) x (Pi) x (Radius)]

Note that the encoding method packing factor (below) may multiply BPI.

CAPACITY
Amount of data (usually in bytes) that can be stored on the media. Given as capacity/track, capacity/surface and capacity/disk. Unformatted - total number of bytes available. Formatted - total available for user data. Rest is lost to overhead.

CRC
Cyclic Redundancy Check. Expanded, nearly foolproof parity check used for error detection in the address and data fields.

CYLINDER
Also called tracks. Concentric rings on the diskette on which the data lies.

ECC
Error Correction Code. Similar to CRC but actually allows for correcting a burst of errors.

ENCODE
Method of putting data on the disk. Most popular are:

FM - Frequency Modulation or double frequency
MFM - Modified FM - double density
M^2FM - Modified - modified FM - double density
GCR - Group Code Recording - 5/4 - 1.8 x density

ERROR RATE
Number of errors per bit transferred. Usually on the order of 10^{-8} or 10^{-9}.

FCI
Flux Changes per Inch. Similar to BPI. This is what the drive electronics sees BPI=FCI for double density codes. BPI= 1/2 FCI for FM. BPI= 4/5 FCI for GCR and BPI= 1.5 FCI for RLL (2-7 Code).

FORMAT
The manner is which data is placed on the diskette, i.e. number of bytes per record, the number of records per track, the number of bytes in the gaps, sync fields and ID fields.

HARD ERROR
An error which cannot be recovered by re-reading. Usually attributable to a media problem or incorrect writing.

HARD SECTOR
Sectors on the diskette are defined by pre-punched holes.

HEAD SETTLING TIME
Time required after a head load command until data is valid or writing can begin.

INDEX
Beginning of a track. Usuallly defined by a hole in the diskette.

INTIALIZE
Usually the act of formatting the diskette with specific data. Sometimes means retracting the head to track zero.

LATENCY
Time to access desired sector on a track. Usually 1/2 revolution time.

MARGIN
A figure of merit which describes the amount of data window remaining after peak shift and other variables effectively reduce the data window.

MEDIA/MEDIUM
The diskettes/disk.

POST COMPENSATION
A method of offsetting the effects of peak shift by changing the group delay of the read signal.

PRE COMPENSATION
A method of offsetting the effects of peak shift by changing the "locations" of the write data bits.

RECORD
Also called a sector. An isolated group of data bytes.

REV TIME
Time Required to travel one revolution of the diskette. 166.67 Ms for 8" and 200 Ms for most 5-1/4" disks.

SECTOR
A radial subdivision of a track, also called a record.

SEEK SETTLE TIME
Time required after last step before data is valid or writing can begin.

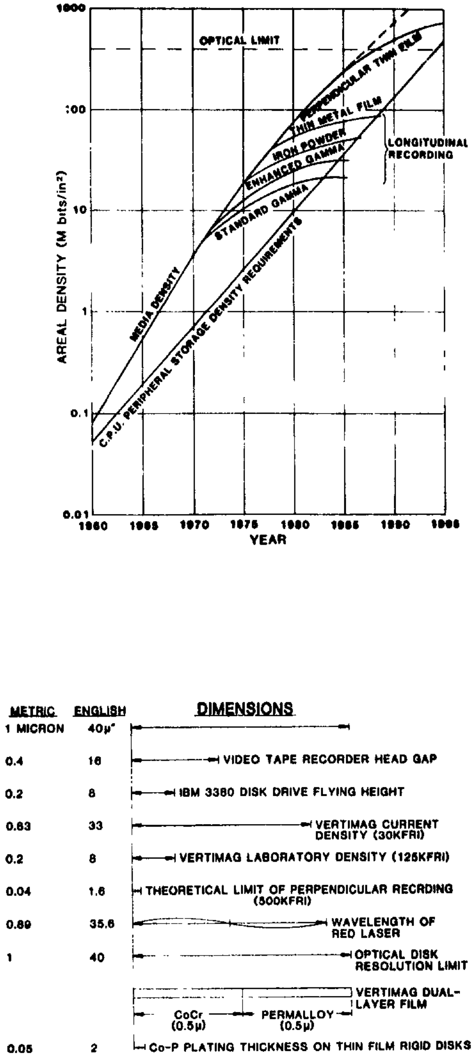
SERVO
Method of increasing number of tracks by looking at a feedback signal. Embedded servo places information in each track. Dedicated servo has one surface for servo information.

SOFT ERROR
An error which can be overcome by re-read. Usually caused by noise.

SOFT SECTOR
A sector whose length can be changed at will. That is, not confined to alignment with prepunched holes around the diskette hub area.

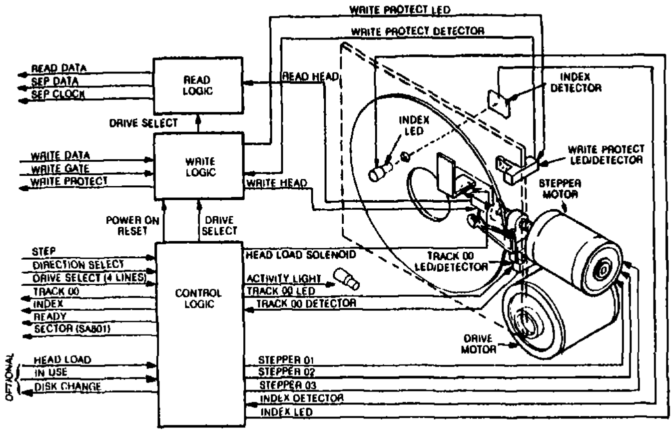
TPI
Tracks Per Inch. Generally 48 TPI although 96 TPI minifloppies are popular. Newer drives have higher TPI's ranging from 125 to 500.

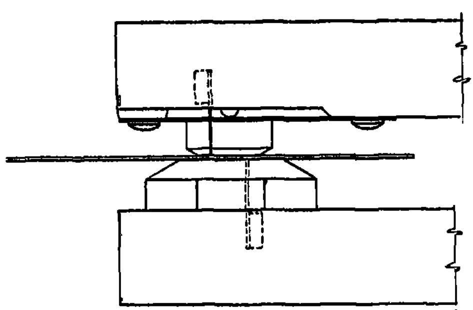
WINDOW
The time between clock bits. The data cell width. Usually refers to data window. Time in which a data bit is expected to occur. Time varies according to diskette size and encode used.



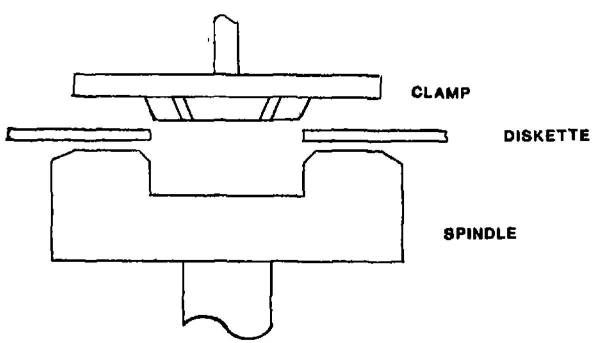
Digital Bit Storage Density Limits

Figure 1.



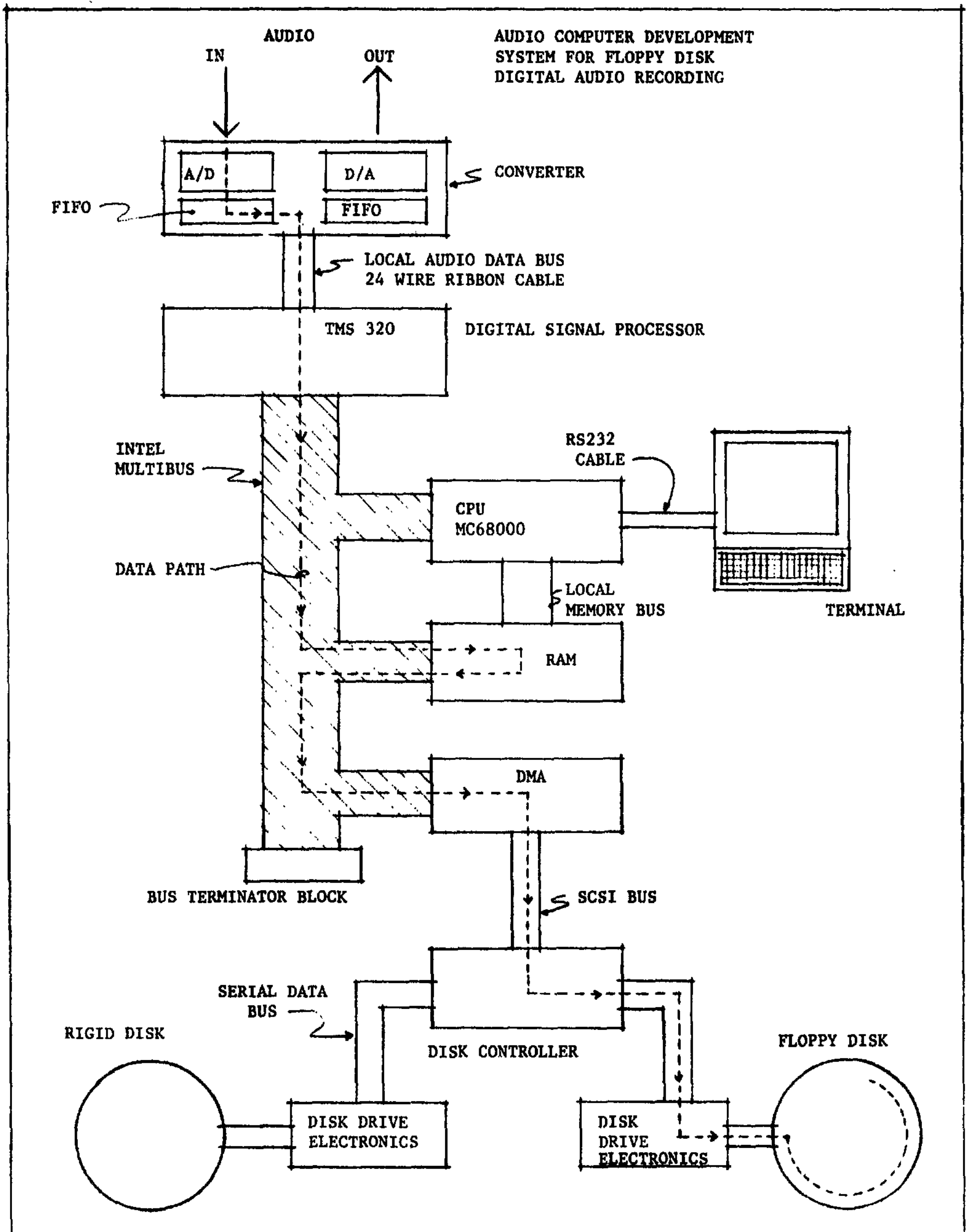


Typical double sided head configuration



Major Components of Floppy Disk Drive

Figure 2.



AUDIO
IN
OUT
AUDIO COMPUTER DEVELOPMENT
SYSTEM FOR FLOPPY DISK
DIGITAL AUDIO RECORDING
A/D
D/A
CONVERTER
FIFO
FIFO
LOCAL AUDIO DATA BUS
24 WIRE RIBBON CABLE
TMS 320
DIGITAL SIGNAL PROCESSOR
INTEL
MULTIBUS
RS232
CABLE
CPU
MC68000
DATA PATH
LOCAL
MEMORY BUS
TERMINAL
RAM
DMA
BUS TERMINATOR BLOCK
SCSI BUS
SERIAL DATA
BUS
RIGID DISK
DISK CONTROLLER
FLOPPY DISK
DISK DRIVE
ELECTRONICS
DISK
DRIVE
ELECTRONICS

FIGURE 4.

REPRESENTATIVE FLOPPY DISK DRIVES (17)

PARAMETER			CANNON CMD-500	HITACHI FDD 541	IOMEGA BETA-5	SONY OA-D30V	KODAK 3.3	TANDON TM-35-4
DISK DIAMETER (inches)			3.8	5.25	5.25	3.5	5.25	3.5
JACKET			hard	soft	hard	hard	soft	hard
HUB			plastic	none	metal	metal	none	metal
CAPACITY (kbytes)			160	6,500	7,500	437.5	3,300	875(2)
TRACKS				208	565	70	160	70
TPI			26	125	600	135	192	135
BPI			5584	30,000	20,000	7610	9908	7610
STEP RATE (msec)			40	2	6	15	3	3
SETTLE (msec)			16	37	11	15	35	15
HEADLOAD (msec)			60	50	cont	60	15	cont
RPM			100	720	1200	600	360	600
TRANS. RATE (kbits/sec)			67	3,000	5,000	500	500	500
DRV.:	height	(inches)	2.5	1.63	3.50	2	1.625	2
SIZE	width	(inches)	4.25	5.75	5.75	4	5.75	4
	depth	(inches)	6	8.62	8.00	5.1	8.49	6
COMPATIBILITY			none	SCSI	SCSI	?	SCSI	?

FIGURE 3.

COMPUSONICS DSP-1000 AUDIO COMPUTER
BLOCK DIAGRAM OF CIRCUIT BOARD

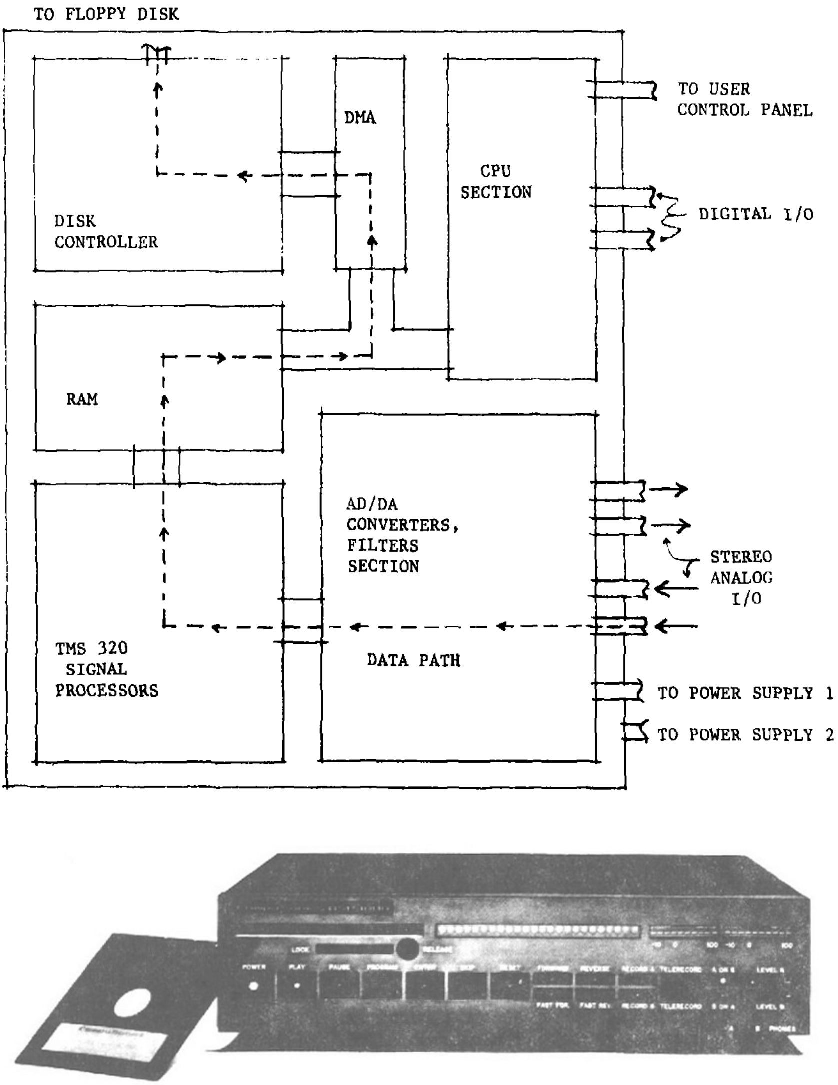
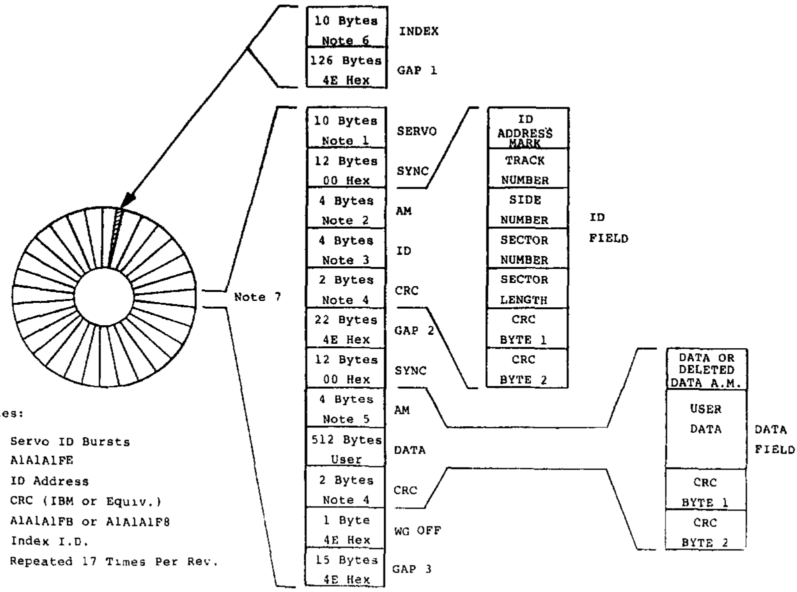


FIGURE 5.



Notes:

1. Servo ID Bursts
2. A1A1A1FE
3. ID Address
4. CRC (IBM or Equiv.)
5. A1A1A1FB or A1A1A1F8
6. Index I.D.
7. Repeated 17 Times Per Rev.

17 SECTOR TRACK FORMAT

EMBEDDED SERVO DATA

LOCATION

During the formatting process of the diskette, servo data will be recorded before each sector ID header on each track. It is recorded one half track off in either direction of the center line of recorded data.

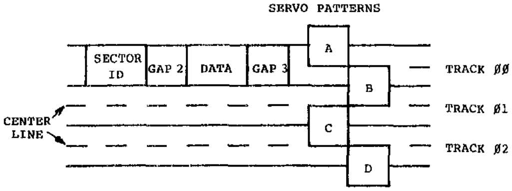
SERVO DATA DESCRIPTION

There are four unique servo data patterns recorded A, B, C, and D. The servo data patterns will utilize the same data with only the length of the data recorded identifing the unique pattern. Only two patterns will be used per track A + B for track 00, B + C for track 01, C + D for track 02, D + A for track 03, etc.

TRACK FOLLOWING OPERATION

As the read data is decoded from the diskette it will be presented to two electronic devices. The first device will do a digital indentification of the servo patterns. Once the servo patterns have been identified it will interrupt the microprocessor and transfer the ID of the two servo patterns (i.e. A,B,C, or D servo bursts). The second device will perform an analog to digital conversion of the servo data patterns. It will then transfer this digital data to the microprocessor in the form of a two bit code which indicates any differences in the amplitude that occurred between the two patterns. When differences occur the microprocessor will reposition the fine stepper motor toward the center line of recorded data. This process will be repeated each time a servo pattern is detected. The multiple servo patterns recorded on each track allow the electronics to constantly update the position of the read/write heads compensating for any thermal or hydroscopic expansion or contraction of the diskette.

SERVO PATTERNS



Proposed Audio SuperFloppy
Disk Servo and Data Format

Appendix 1.