High Density Digital Data Recording System

Jack Allison
Thomas Bertenshaw

Oklahoma State University
Electronics Laboratory - CEAT
Stillwater, Oklahoma 74078-0116

January 28, 1987

Scientific Report No. 3

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED
This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify AFGL/DAA, Hanscom AFB, MA 01731. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document requires that it be returned.
The state-of-the-art in High Density Digital Data Recording is such that it is now possible to evaluate the capabilities of write-once-read-many (WORM) laser disc systems vis-a-vis magnetic tape spooling. Most of such a systems' components can be purchased off-the-shelf. The potential to store unalterable data, in vast amounts, in a small space, or a medium impervious to time degradation can be realized with current technology.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Summary</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>1</td>
</tr>
<tr>
<td>Goals and Objectives</td>
<td>5</td>
</tr>
<tr>
<td>System Configurations</td>
<td>7</td>
</tr>
<tr>
<td>Discussion of Concept</td>
<td>9</td>
</tr>
<tr>
<td>Synopsis of Characteristics</td>
<td>11</td>
</tr>
<tr>
<td>Estimated Hardware Costs/Level of Effort</td>
<td>12</td>
</tr>
</tbody>
</table>

**Appendices:**

- Appendix A: Laser Disc Technology Brief .......... 13
- Appendix B: Manufacturer's Data Sheets .......... 36
SUMMARY:
The state of the art in recording technology is shifting from magnetic media systems to those which both write and read to a media by coherent light systems, i.e. a laser. The anticipated advantages of a laser system over magnetic systems include gigabyte storage through a system weighing fractions of the corresponding tape system; potential throughput speeds several times those of magnetic systems; capture of unalterable data; a virtually unlimited storage lifetime; essentially unlimited read cycling without data loss; a manyfold reduction in physical data storage media, coupled with a simultaneous manyfold increase in data volume stored.

The time threshold for assembling and evaluating a laser system capable of replacing tape mass transport systems for archiving data, and real time data capture in the field is here. Commercial systems possessing the potential to be converted to those uses are presently available. With that in mind, a prototype system conceived to accomplish those ends is proposed herein.
BACKGROUND:

The present system in use for both recording and archiving test data is by magnetic tape recording. The current system generally employs a high speed, high bandwidth, multiple track tape streamer to record both digital and analog data in real time. The real time copy also serves as the archive copy, and obviously, duplicates can be made as required.

There exist some inherent hazards with the present system. The recording media is subject to inadvertent degaussing which destroys all recorded data. The media is also subject to abrasive wear during playback, which degrades fidelity and introduces noise, both of which threaten low level analog data. The abrasive wear factor is also hazardous to high bit rate digital data. Further, the inherent shelf life of the recording media is not unlimited. As a practical matter, shelf life is proportional to handling care, mechanical condition of the tape transport/record head combination, ambient magnetic environment, ambient environmental conditions such as temperature, humidity, atmospheric corrosive constituents, etc. In short, the storage life may range from a few years (two or three) to greater than thirty, depending upon the vagaries of hazard the recording media is subjected to.

Magnetic spooling recording, such as tape recording, also possesses some restrictive physical limitations with regard to recording duration. In general, a requirement to record higher frequencies dictates a corresponding higher transport speed to faithfully capture the data. As a consequence, the amount of
tape required to record a given amount of data for a specified recording duration increases proportional to transport speed requirements. Currently, to record the data from a fifteen minute flight at 120 inches-per-second transport speed, requires approximately six pounds of tape mounted on a fourteen inch reel. This current combination has a theoretical capacity of storing 230 megabytes per track, assuming a 2 megabit data rate. The recording machine necessary to accommodate this combination is fairly large and massive. The models locally in use weigh approximately one hundred pounds and occupy somewhat more than three cubic feet of volume. A change in recording requirements which impose longer durations or higher data capture rates would also impose larger tape transport and tape mass requirements. These relationships are not imposed by the electronic components, but rather by the mechanical constituents required to mount and transport a heavy mass at a high speed.

The above limitations, notwithstanding, have served admirably well in the past to meet the requirements of recording and preserving large amounts of data, both in the field and for archive purposes. Given a reasonable amount of care, quality reproductions of real time data have been captured, stored, and preserved for many years. There is however, an emerging technology, currently available from manufacturing sources which has promise of being able to match or exceed tape transport systems as a method of recording and archiving data. This newer technology employs a process of recording digitized information on a media by means of writing and reading using a coherent
light source. These devices are commonly or collectively known as laser discs. Manufacturers claims for the available systems vary widely, as do the protocols of accomplishing the task. While the diversity of approach is as great as the number of candidates in the field, the prospect that the concept of real time recording and archiving using optical methods is believed to be achievable now.

There are several reasons for considering an undertaking to evaluate the merits of laser disc technology as a supplement for, or an eventual replacement for, tape transport mechanisms. Two of these advantages is size and data capacity. Current off-the-shelf technology is available in 5.25 and 12 inch diameter discs, which weigh but a few ounces. The data storage on the devices range from 400 to over 2500 megabytes of data. The smaller of these two units is physically able to be mounted in, and operate from a computer similar to an IBM portable PC, (Personal Computer - a trade name for a type of micro computer) or any other comparable portable PC. The larger 12 inch device is equally capable of interfacing with micro computers of this kind, but it is peripheral to the CPU chassis. The data transfer rate of these devices exceed the current tape system from 10 to over 150%.

An added benefit inherent in the current technology is that the recording media allows itself to be written to only once. While information can be written one time, it nevertheless can be read an indefinite number of times. The built-in advantage to this system is that it provides an unalterable audit trail, in which
an analyst is guaranteed a faithful reproduction of the original data. Errors caused by inadvertent write-over of data are precluded with this type of (known as WORM, Write Once Read Many) laser disc technology.

The significant disadvantage in the off-the-shelf technology available today is that the laser disc recording devices provide for only a single track of data per disc at a time. The immediate impact of this constraint is that simultaneous, or parallel, data cannot be captured in time coincidence. There are possibly some "work arounds" to this limitation which might largely negate the disadvantage of serial string recording of time coincident data. However any such scheme would require developmental testing.
A project is proposed in which the merits of optical recording versus magnetic tape recording are investigated using WORM devices and their host microprocessor. Two goals of the project are proposed:

a. the development of an ensemble capable of archiving unalterable data.

b. the development of an ensemble capable of capturing unalterable data in the field.

Supporting these goals are several objectives, which include:

1. the development and testing of a workable scheme which negates the loss of simultaneity in recording time coincident data.

2. the assembly of, and field testing of at least one equipment ensemble capable of satisfying goal a.

3. the assembly of, and field testing of at least one equipment ensemble capable of satisfying goal b.

4. determining the feasibility and/or advisability of using only one type of equipment ensemble to satisfy both goal a. and goal b.

5. maximizing data capture rates to the limit of the capacity of currently available equipment.

6. increasing the data storage capacity per unit of storage medium to the limit of currently available equipment (unit of storage medium is currently 9600 feet of one-half inch magnetic tape; a unit of storage with optical technology is the appropriate optically read disc).

7. developing techniques to restore simultaneity in
displaying time coincident data.

8. develop an ensemble package using commercially available off-the-shelf equipment, with a minimum of custom design.
Two configurations, each with a unique recording constituent roster, are proposed for evaluation. Both configurations, however, would be hosted by a micro computer similar to an IBM AT PC or equivalent. Therefore the differences in configuration devolves into the type of optical disc system with the interfacing appropriate to the particular system. The systems chosen for evaluation are representative of the range of capacity currently available from the optical disc industry. One system is very small and lightweight, and can be virtually contained within a portable micro-processor chassis, with a minimum of one five pound peripheral. The other system, while hosted by the same computer type cannot be self contained; this larger system requires some seventy pounds of peripherals. The major capability difference between the two systems is data storage capacity. In the case of the smaller system, the storage capacity exceeding 200 megabytes per disc surface, while the larger has a capacity exceeding 1300 megabytes per surface. Both systems have the capability of double sided writing, which effectively doubles those numbers for data storage per storage unit.

A representative block diagram for the smaller system (System 1) is:

```
Datum -> Data Spooler -> Micro CPU -> Optical Drives 2 Ea.
```
A representative block diagram for the larger system (System 2) is:

Datum → Data Spooler → Micro CPU → Formatter Controller → Optical Drive
A signal flow diagram of each system follows (recognize that the micro-processor CPU and spooler are physically the same units for both systems):

**System 1**

- Datum
- Spooler
- CPU
- Interface
- Disc Drive

**System 2**

- Datum
- Spooler
- CPU
- Interface
- Formatter/Controller
- Disc Drive

Initially System 1 will be evaluated for its ability to perform in the field, and System 2 for its ability to archive. However, either system may ultimately prove capable of performing both functions. This proposed evaluation will investigate and determine the relative strengths and weakness of each system as each is configured to support both goal a. and goal b. This type of "fly-off" will then be gauged against the merits of the currently used magnetic tape system as the benchmark.

The precise configuration of the Data Spooler has not as yet been fixed. This system component will perform the task of interleaving time coincident parallel datum into serial data for transcription onto the optical media. Presently a scheme is under consideration which DMA's (Direct Memory Access) a specific track of data into an assigned block of memory, each block under the control of its own DMA controller. Each block acting as a high speed FIFO (First In First Out) buffer for serial retrieval and subsequent transcription under CPU control.
The necessary protocol, along with minimum track/memory requirements are an expected deliverable result of this proposed evaluation. Every attempt will be made to use commercially available off-the-shelf modules as a spooler; failing that a custom designed spooler will be built using the highest speed MOS technology obtainable. The block diagram of such a sub-system would be similar to:

```
Data   DMA Controller   Partitioned Memory
Track 1    →    #1    →    Block 1
Track 2    →    #2    →    Block 2
.          .          .
Track n    →    #n    →    Block n
```

There are intricate timing relationships to be accounted for between data cycle time and spooler clock cycles to prevent loss of data caused by a read/write conflict for the bus. Ultimately, the relationship between time needed to write data and the time needed to transfer data to the CPU will dictate the maximum number of tracks which can be accommodated. At least two different schemes are in consideration, however neither is at a sufficient degree of maturity at this point to determine which is the most meritorious. Again, the protocol selected, developed, and tested during the evaluation will become part of the deliverable system.
The commercially available equipment proposed for this evaluation includes the following:

**System 1**  
IBM PC AT or equivalent  
Optotech PC controller  
Optotech #5984 Disc Drive

**System 2**  
System 1 micro-computer  
Optotech SCSI Controller  
Hitachi OF301 Formatter  
Hitachi OD301A Disc Drive

Selection of the Data Spooler has been deferred pending the results of an industry search to determine whether or not such a device is available off-the-shelf, or must be custom made.

The cogent performance characteristics of the WORM disc systems for the two configurations are:

<table>
<thead>
<tr>
<th></th>
<th><strong>System 1</strong></th>
<th><strong>System 2</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Disc transfer rate (bps):</td>
<td>2.2 Meg</td>
<td>3.52 Meg</td>
</tr>
<tr>
<td>Formatter transfer rate (Bps):</td>
<td>NA</td>
<td>1.5 Meg</td>
</tr>
<tr>
<td>Capacity per disc side (Bytes):</td>
<td>202 Meg</td>
<td>1310 Meg</td>
</tr>
<tr>
<td>Capacity per disc (Bytes):</td>
<td>404 Meg</td>
<td>2620 Meg</td>
</tr>
</tbody>
</table>
The estimated hardware costs are as follows:

IBM PC AT or equivalent $5000
Data Spooler 3000

**System 1**

PC Controller 650
Disc Drives (2 each) 9400
Discs (10 each) 2500

**System 2**

SCSI Interface 650
Formatter/Controller 4200
Disc Drive 11300
Discs (5 each) 2250

Miscellaneous

Cables/Connectors 200
Electronic Components 500
Bits and pieces 500

Grand Total (Hardware): $40150

It is anticipated that twelve man-months of effort will be required to design, fabricate, and evaluate a system of this kind. The design effort includes the generation of required software. The time line can be reduced to seven man-months if a suitable commercially available spooler is found. In either event, operationally ready hardware will be delivered at the end of the applicable time line.
APPENDIX A

The following pages are a brief tutorial on laser disc technology, which is the result of an engineering study done by a staff member of Oklahoma State University's Electronics Lab. The study is perishable in the sense that this whole field of technology is in its embryonic phase, and standards have not been frozen in place. Further, active industrial research is ongoing to the extent that more than one approach has promise; hence it is difficult to foresee with certainty what the preferred methods/systems will be within five years. All that notwithstanding, WORM technology, for all its present limitations seems to be the right choice for both archiving and non-alterable data capture. Therefore the following document is included within this proposal for background purposes.
## TABLE OF CONTENTS

PRESENT STATUS-AND FUTURE POSSIBILITIES
FOR READ - WRITE OPTICAL STORAGE SYSTEMS

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 INTRODUCTION</td>
<td>19</td>
</tr>
<tr>
<td>1.1 Laser Optics for Data Storage</td>
<td>19</td>
</tr>
<tr>
<td>1.2 Advantages of Optical Storage</td>
<td>19</td>
</tr>
<tr>
<td>2.0 WRITE ONCE OPTICAL STORAGE SYSTEMS</td>
<td>20</td>
</tr>
<tr>
<td>2.1 General Principles</td>
<td>20</td>
</tr>
<tr>
<td>2.2 Components of an Optical Head</td>
<td>21</td>
</tr>
<tr>
<td>2.3 Read/write System</td>
<td>21</td>
</tr>
<tr>
<td>2.4 Specifications</td>
<td>23</td>
</tr>
<tr>
<td>3.0 ERROR MANAGEMENT AND CORRECTION</td>
<td>23</td>
</tr>
<tr>
<td>3.1 Disk Protection and Handling</td>
<td>23</td>
</tr>
<tr>
<td>3.2 Bit-error Rate Correction</td>
<td>23</td>
</tr>
</tbody>
</table>
4.0 ERASABLE OPTICAL STORAGE SYSTEMS .................. 25

4.1 Impact of Erasable Storage Systems .................. 25
4.2 Approaches to Optical Erasure ....................... 25
4.3 Magneto-optical Erasing ............................ 26
4.4 Kerr Effect and Faraday Effect ....................... 26
4.5 Erasure ........................................ 30
4.6 Signal/noise Limitations ............................ 32

5.0 SMALL COMPUTER SYSTEMS INTERFACE ............... 32

5.1 An American National Standards effort ................ 32
5.2 Uses Standard Cable and Connections ................ 32

6.0 CONCLUSIONS AND RECOMMENDATIONS ................. 32
<table>
<thead>
<tr>
<th>Figure</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic Components of an Optical Reading Head</td>
<td>22</td>
</tr>
<tr>
<td>2</td>
<td>Error Correction System for an Optical Recorder</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>Illustrations of the Basic Write Systems in a Magneto-optic System</td>
<td>27</td>
</tr>
<tr>
<td>4</td>
<td>General Character of the Kerr Effect</td>
<td>28</td>
</tr>
<tr>
<td>5</td>
<td>Optics used in Kerr Effect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Magneto-optic Systems</td>
<td>29</td>
</tr>
<tr>
<td>6</td>
<td>Schematic of a Faraday Effect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Magneto-optic System</td>
<td>31</td>
</tr>
</tbody>
</table>
1.0 INTRODUCTION

1.1. Recent advances in laser technology have led to the development of laser-based data storage systems that offer significant advantages over conventional storage systems based on magnetic tapes or disks. This Report will examine the characteristics of these laser optic storage systems, describe some of the research efforts underway to perfect and standardize their performance, and explore the potential advantages and problems associated with their use in large data storage systems.

Read-write systems have been under development in laboratories in Europe, America, and Japan for the past five years. Some systems have reached beyond the development stage to prototype units with significant performance capabilities. (One technology promises several million read-write cycles in the near future.) Several non-compatible technologies are under development, and no industry standard seems likely in the next two or three years.

1.2. The use of optical techniques and materials for data storage has several advantages over conventional magnetic storage techniques. An optical storage system provides higher density of stored material as well as a means for data recording (approximately $3 \times 10^8$ bits/inch$^2$ for magnetic storage and $13 \times 10^8$ bits/inch$^2$ for laser storage) and retrieval without physical contact with the medium. Remote read/write operations have significant advantages over conventional physical operations in terms of overall system reliability, maintenance, and wear on the recording machine. Typical magnetic read/write heads must either contact, or be within a few tenths of a micron of the tape or disk surface. Optical heads can operate effectively from a distance of a few millimeters from the medium, reducing the need for precise vertical alignment and highly controlled environments.
In an optical storage system, the recording medium is generally embedded in a
disk that rotates beneath a focused laser beam. The laser and its associated optics and
optoelectronics constitute a read/write head that can move radially to address different
tracks on the disk. Read only disks consist of a plastic substrate on which the
information is prerecorded in the form of surface moldings. Write once and erasable
disks utilize an appropriate substrate on which the recording medium is deposited in a
thin film form. Ablative media with tellurium layers and bubble-forming media with
gold-chromium layers are used in most of the write-once systems, while magneto-optic
and phase-change media are in the erasable group.\textsuperscript{2,4,5,6}

2.0 WRITE ONCE OPTICAL STORAGE SYSTEM

2.1 In write once optical systems, data is stored optically by writing on light-
sensitive material with pulses from a tightly focused laser beam. The laser pulse
produces a visible change in the impact area, typically a pit, blister, or darkened spot
that reflects more (or less) light than the surrounding area. The recorded data can be
read by scanning the surface with a continuous laser beam that is weak enough to have no
effect on the storage medium. One milliwatt of laser power is more than sufficient to
perform the read function, and ten milliwatts is sufficient to write to some of the
systems under development. Such power requirements clearly indicate that small,
compact, and portable systems are entirely feasible.

The disk drive is the system component that writes data to and reads data from
the optical disk. Within the electro-optics area of the disk drive is the laser and the
optics required for writing, reading, focusing, and playback tracking. A translation slide
is usually used to support and move the optical head, read/write, and focus optics, while
a servo-controlled spindle rotates the disk at a precise speed for the read or write
operations. The disk drive electronics includes the servo electronics that control all of
the disk drive moving mechanisms and channel electronics that transfer data to and from the media.

2.2 The basic components of an optical reading head are shown in Figure One. As shown in Figure One, part of the laser beam is deviated by means of a small wedge. This beam is incident on the disk at a specific angle that causes the distance between the side spot and the main spot to increase as the disk goes up. The position of the side spot is measured in the image plane of the disk (in the light source plane) by means of a split photodiode. For convenience, a second wedge is placed in the returning skew beam, increasing the distance between the laser and the photodetector. In this way a servo system with a large acquisition range is obtained.

2.3. The read/write portion of a laser disk system contains a single read/write station where the data is stored and retrieved from the disk. The media disk is mounted on a spindle mechanism where it is rotated at a constant angular velocity within its protective enclosure. Highly accurate servo control systems within the read/write unit precisely control the focusing, tracking, and slide the spindle actuation functions of the unit. Data handling is performed by channel electronics that include laser modulation, playback direction, and data reconstruction. The write function is done one track at a time, but recent advances in handling capacity facilitate multiple track playback that effectively increases output data rate and search speed.
FIGURE ONE. Basic Components of an Optical Reading Head

DISK

$N = 0.58$

CYLINDRICAL LENS

$N = 0.29$

DIODE LASER

RF SIGNAL DETECTOR

FOCUS ERROR DETECTOR
2.4 Write once optical disk systems are available commercially. Some utilize 30cm (12 inch) disks with a double-sided capacity of 2 GBytes, a corrected residual error rate of $10^{-12}$, and a data transfer rate of 3.83 Mbits/sec.

3.0. ERROR MANAGEMENT AND CORRECTION

3.1 A variety of error control measures are taken to insure the integrity of the data stored in most optical disk systems. The first of these control measures deals with the defects that occur when the disks are manufactured to provide a low raw bit error rate. Second, a protective covering consisting of an overcoat and a dust free enclosure is used to keep unwanted particles from affecting data during record and playback operations. The overcoat and enclosure also protect the disk from damage due to handling.

3.2 Commercially available write once systems have a bit-error specification of $10^{-12}$ for data retrieval. Figure Two indicates the type of error correction scheme generally used to obtain such a specification. Data is encoded before writing, and redundant bits are added that can be used to correct short bit-error bursts. Interleaving the encoded data on the disk further improves error correction by spreading the effect of a relatively long burst over an entire sector.

Buffering the data and matching the data spectrum to the special characteristics of the read/write process decreases the bit-error rate of the read information. Dropouts are detected by reading the information immediately after it has been recorded and comparing the detected and demodulated data with the original information in the buffer. If the comparison does not match, the sector is invalidated and the information is rewritten on another sector. Essentially all of the errors can be corrected during the recording process.
FIGURE TWO. Error Correction System for an Optical Recorder
4.0 ERASABLE OPTICAL STORAGE SYSTEMS

4.1. It seems clear that the impact of optical storage systems as replacements for magnetic tape or disk storage systems will not be until a reliable method of erasure can be developed and proven. The inability of present systems to provide for erasure and subsequent re-recording of data limits their ability to compete with magnetic systems, where erasure is a requirement. When multiple read/write/erase systems become available, optical storage systems can be expected to replace magnetic storage systems in those applications. Promising research on erasable optical systems is now underway, and some units will be completely available within the next two or three years. This Section will describe the general character of erasable storage systems and indicate some of the problems that must be overcome before they reach a commercial stage of development.

4.2 Three different approaches toward erasing an optical storage system are currently under development—phase-change, magento-optic and erasable light-sensitive dyes. In phase-change technology the recording medium must be heated and quenched quickly to force the recording medium from an amorphous to a crystalline state. Reversing the process requires reheating the medium and slow cooling, this process degrades the recording medium over time, limiting the number of erasure cycles the disk can withstand before they must be replaced.

Phase-change technology was very popular a few years ago, but disk life problems will probably prevent its acceptance, given the existence of a competing technology that does not appear to suffer from that disadvantage. Erasable light-sensitive dye techniques have only recently appeared in the literature, and preliminary indications are that it can be a relatively low cost technology, though dye fading problems appear to limit its usefulness to a few hundred write-erase-write cycles. Magneto-optic systems
promise an essentially unlimited disk lifetime,
and the remainder of this section will describe its operating principles, promise, and capabilities.

4.3 Magneto-optic storage systems use a laser beam to write and read data from a specially prepared metal surface - usually a thin amorphous film of some rare-earth transition metal deposited on a glass or plastic substrate. Erasable systems utilize the laser's heat to change the magnetic properties of the metallic disk, not to burn a pit or form a blister on the recording medium as is done with write once systems. This technique has been found to work effectively with materials that exhibit a coercivity greater than 3000 Oersteds. The disks are magnetized uniformly in one direction during manufacture.

When writing, the laser beam heats a very small portion of the disk surface to its Curie point, the temperature of transition at which the phenomena of ferromagnetism disappear and the substance becomes merely paramagnetic - a temperature that is usually lower than the melting point of the substance. The Curie point ranges between 130° and 150° C. When the magnetic material cools below its Curie point, its flux lines will assume the direction of the flux lines of an applied external field that opposes the direction of the field in the premagnetized disk. A magnetized domain thus reversed represents a binary digit "one" in digital recording applications, while an unreversed domain represents a binary "zero". The basic configuration associated with this effort is shown in Figure Three.

4.4 Laser power required to affect the change in magnetism described above is approximately ten milliwatts. To read the bit domains, the same laser, operating at approximately 1 milliwatt, bounces its beam off the surface of the disk through an objective lens and a photodetector. In some systems the disk is transparent, and the
FIGURE THREE. Illustration of the Basic Write System in a Magneto-optic System
Figure Four. General Character of the Kerr Effect
FIGURE FIVE. Optics used in Kerr Effect Magneto-optic Systems
It has been found that the reversal of the flux lines caused by the write pulse causes the plane of polarization of the reflected (or transmitted) light to rotate slightly, and that the reversed bit domains appear as a series of black spots on a light background with the objective lens has an appropriate polarizing filter. This phenomena is known as the Kerr effect when reflected light is used, and the Faraday effect when the light beam passes through a transparent medium. The Kerr effect is illustrated in Figure Four, and a diagram information based on the Kerr effect is shown in Figure Five.

The interrogating laser beam is first collimated and polarized, and, after passing through the beam splitter, is focused on the magnetic layer of the disk. The effect of the beam splitter on the incident beam is relatively unimportant here, but the incident beam must pass through the splitter if the reflected beam is to be separated out for analysis. The beam splitter thus separates the reflected beam and directs it toward the detection arm of the system. Here the polarizing beam splitter divides the energy of the beam between the two photodetectors according to the logic state at that point. Therefore, as the disk rotates under the beam the output of the differential amplifier reproduces the pattern of magnetization.

Advocates of Kerr effect systems point to the fact that such systems can make use of both sides of a disk, and Faraday system developers believe such systems will ultimately prove to be less expensive than competing Kerr effect systems, primarily because of the in-line orientation of the laser and polarized objective lens. Figure Six describes a system based on the Faraday effect.

4.5 Erasure can be accomplished by repeating the above process with field reversed. Overwriting involves an erasure, then delaying one revolution (to allow the spot to cool) before writing again. Fast erasure is possible because the time required for cooling is less than 1 microsecond.
FIGURE SIX. Schematic of a Faraday Effect Magneto-optic System
4.6. The polarization angle caused by the Kerr (or Faraday) effect is very small—less than one degree. The signal generated by these effects is accomplished by noise from a variety of sources, including shot noise due to a quantum nature of photodetection, thermal noise in the electronic circuitry, and noise due to surface roughness and discontinuities in the magnetic media. At present, the signal/noise performance of erasable optical system does not approach that of write once systems, though promising research is expected to narrow this gap within a relatively short time.

5.0. SMALL COMPUTER SYSTEMS INTERFACE

5.1. Most optical disk system manufacturers have adopted the Small Computer Systems Interface (SCSI) as a standard interface for coupling to a computer. The SCSI standard was developed by an American National Standards committee that attempted to set constraints for an interface that was capable of interconnecting multiple computers and their peripherals. Device independence allows new peripherals, such as optical disk systems, to be integrated easily into an existing computer system through an SCSI port—without major hardware or software development problems.

5.2. SCSI is an eight-bit, bi-directional, parallel interface. It provides host computers with device independence within a class of devices by using a standard 30-pin connector and a general set of high-level commands. Hardware and software installations of additional devices are greatly simplified and SCSI interfaces are available for most popular mini and microcomputers that are backplane based or have expansion slots.

6.0. CONCLUSIONS AND RECOMMENDATIONS

Storage systems utilizing laser read/write technology are commercially available.
and they are rapidly replacing magnetic tape and other storage media in a wide variety of applications. An optical disk "jukebox" mass storage system that can provide access to any data in a store of 1250 gigabytes within six seconds has been developed by RCA Corporation, engineering models of that system are planned for NASA Marshall Space Flight Center and the Air Force Rome Air Development Center. 19

Write once optical technology, though new, is commercially available from a variety of sources. For many applications, such as telemetry recording, the fact that erasure is not possible with such systems is not a significant disadvantage. Many who are intrigued by write once technology hesitate to invest in it because of the promise offered by the systems that can provide multiple write/erase/write cycles. Such hesitation can be costly however, and those who wish to be at the leading edge of this new technology would do well to acquire write once systems and evaluate their characteristics. Experience gained by taking such an action is certain to translate directly to the write/erase/write systems as they become available - given their essential compatibility through an SCSI interface.
Bibliography


The following pages are reproductions of vendor data sheets for the components proposed in the evaluation.
Optotech SCSI Controller

Features

- Selectable Interleave through 1:1
- Multi-track buffer
- Static Error Handling on formatting
- Dynamic Error Handling at runtime
- Supports one to four disk drives
- Alternate sectors divided into 9 bands for fast access
- ECC correction of up to 24 bytes of bad data per sector (The most powerful ECC in industry)
- User formatting capability
- LSI implementation for low power draw
- Disks written using SCSI or PC Controllers are totally interchangeable.

Optotech SCSI Controller Block Diagram

Optotech SCSI Controller Command Set

<table>
<thead>
<tr>
<th>OP Code</th>
<th>Command Name</th>
<th>OP Code</th>
<th>Command Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Test Unit Ready</td>
<td>04</td>
<td>Format Unit</td>
</tr>
<tr>
<td>01</td>
<td>Rezero Unit</td>
<td>05</td>
<td>Read Sense</td>
</tr>
<tr>
<td>02</td>
<td>Request Sense</td>
<td>06</td>
<td>Reserve Unit</td>
</tr>
<tr>
<td>03</td>
<td>Format Unit</td>
<td>07</td>
<td>Reserve Unit</td>
</tr>
<tr>
<td>08</td>
<td>Reassign Blocks</td>
<td>10</td>
<td>Inquiry</td>
</tr>
<tr>
<td>12</td>
<td>Inquiry</td>
<td>15</td>
<td>Mode Select</td>
</tr>
<tr>
<td>16</td>
<td>Reserve Unit</td>
<td>17</td>
<td>Release Unit</td>
</tr>
<tr>
<td>18</td>
<td>Copy</td>
<td>19</td>
<td>Copy</td>
</tr>
<tr>
<td>20</td>
<td>Read Capacity</td>
<td>21</td>
<td>Read Capacity</td>
</tr>
<tr>
<td>28</td>
<td>Read Extended</td>
<td>30</td>
<td>Search Data High</td>
</tr>
<tr>
<td>31</td>
<td>Search Data Equal</td>
<td>32</td>
<td>Search Data Low</td>
</tr>
<tr>
<td>33</td>
<td>Set Limits</td>
<td>37</td>
<td>Read Defect Data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>39</td>
<td>Compare</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0A</td>
<td>Write</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0B</td>
<td>Seek</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1A</td>
<td>Mode Sense</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1B</td>
<td>Start/Stop Unit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1C</td>
<td>Receive Diagnostic Results</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1D</td>
<td>Send Diagnostic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1E</td>
<td>Prevent Allow Medium Removal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2A</td>
<td>Write Extended</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2B</td>
<td>Seek Extended</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2C</td>
<td>Write Verify</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2D</td>
<td>Verify</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3A</td>
<td>Copy and Verify (Vendor Unique)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3B</td>
<td>Write Data Buffer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3C</td>
<td>Read Data Buffer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CA</td>
<td>Write Post Field</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C8</td>
<td>Read Post Field</td>
</tr>
</tbody>
</table>

Requirements

- Power: 5 Watts at 5 Vdc, 1 Amp (Max)
- Voltage: 5 Vdc ± 5%
- Size: Controller Board is standard 5.75 by 8.0

Optotech, Inc.

110 Woolen Road
Colorado Springs, CO 80915 USA
303 570 7000 (Fax 570 966)
Optotech PC Controller

Features

- Selectable DMA or Program I/O data transfer.
- Automatic seek and verification.
- Automatic ECC is the most powerful in the industry.
- Disks written using PC or SCSI controllers are totally interchangeable.
- Static Error Handling mapped at disk format time.
- Dynamic Error Handling at runtime.
- Alternate Sectors are divided into 9 bands for fast access.
- One to four disk drives are supported.
- Single PC slot (piggybacked boardset).
- Low power requirements (15 Watts).
- Two optional commands available to Read/Write Post Field for updating Write-Once data files.
- 4:1 Interleave.

Optotech PC Controller Block Diagram

Command Set

- 00 Test Unit Ready
- 01 Rezero Unit
- 03 Request Sense
- 08 Read
- 0A Write
- 08 Seek

- 1C Receive Diagnostic Results
- 1D Send Diagnostics
- 1E Prevent Allow Media Removal
- 3B Write Data Buffer
- 3C Read Data Buffer
- CA Write Post Field
- CB Read Post Field

Seek, Select, Deselect, Reset, ECC Control, and Read and Write Extended are implied in Send/Receive Diagnostic Command.

All commands are supplied to the PC Controller in a fixed-length command block similar to the SCSI interface specification. Status results are returned in a similar block.

Requirements

- IBM PC or Hardware Compatible Device
- Power Requirements: 15 Watts at 5 VDC
- Physical Requirements: One full-length card slot

Optotech, Inc.

120 Waverly Road
Colorado Springs, CO, 80917, USA
303 757-7600 - Fax 303-296-6666

38
### SPECIFICATIONS

#### Disk Cartridge

<table>
<thead>
<tr>
<th>Model</th>
<th>OC301-1</th>
<th>OC301-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disk Capacity (Formatted)</td>
<td>1.370 MB</td>
<td>2.620 MB</td>
</tr>
<tr>
<td>Storage Capacity (Track Capacity)</td>
<td>317 KB track</td>
<td></td>
</tr>
<tr>
<td>Sector Capacity</td>
<td>512 B sector</td>
<td></td>
</tr>
<tr>
<td>Recording Density</td>
<td>19,500 bpi</td>
<td></td>
</tr>
<tr>
<td>Track Density</td>
<td>16,000 tpi</td>
<td></td>
</tr>
<tr>
<td>Number of Data Tracks</td>
<td>41,300</td>
<td></td>
</tr>
<tr>
<td>Number of Track Sectors (alternate)</td>
<td>62 (2)</td>
<td></td>
</tr>
</tbody>
</table>

#### Formatter Controller

<table>
<thead>
<tr>
<th>Model</th>
<th>OF30IS-1/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface</td>
<td>ANSI X3T9.2 (SCSI)</td>
</tr>
<tr>
<td>Data Transfer Rate (max)</td>
<td>1.5 MB/sec</td>
</tr>
<tr>
<td>Buffer Size</td>
<td>Equivalent to two tracks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>OF301G-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface</td>
<td>IEEE488-1978 (GP-IB)</td>
</tr>
<tr>
<td>Data Transfer Rate (max)</td>
<td>1 MB/sec</td>
</tr>
<tr>
<td>Buffer Size</td>
<td>Equivalent to two tracks</td>
</tr>
</tbody>
</table>

#### Disk Drive

<table>
<thead>
<tr>
<th>Model</th>
<th>OD301A-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Transfer Rate (max)</td>
<td>440 KB/sec</td>
</tr>
<tr>
<td>Access Time</td>
<td></td>
</tr>
<tr>
<td>Average Seek Time</td>
<td>200 ms</td>
</tr>
<tr>
<td>Average Latency</td>
<td>50 ms</td>
</tr>
<tr>
<td>Rotational Speed</td>
<td>600 rpm</td>
</tr>
</tbody>
</table>

#### Library Unit

<table>
<thead>
<tr>
<th>Model</th>
<th>OL30IS-1/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Capacity (Formatted)</td>
<td>42,000 MB</td>
</tr>
<tr>
<td>Number of Cartridges</td>
<td>16 (32)</td>
</tr>
<tr>
<td>Mount</td>
<td></td>
</tr>
<tr>
<td>Average Access Time</td>
<td>8 sec (9 sec)</td>
</tr>
<tr>
<td>Demount</td>
<td>7 sec (7.5 sec)</td>
</tr>
</tbody>
</table>

- **Note**: OF30IS-1, Single End Interface
- OF30IS-2X, Differential Interface

#### Physical Characteristics

<table>
<thead>
<tr>
<th>Model</th>
<th>OF30IS-1/2</th>
<th>OD301A-1</th>
<th>OL30IS-1/2</th>
<th>OL30IS-1/2</th>
<th>OD301A-L1</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Power Requirements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>–</td>
<td>–</td>
<td>1.2 KVA (2.1 KVA*)</td>
<td>0.2 KVA</td>
<td>1.000 Kcal/h</td>
</tr>
<tr>
<td>Heat Dissipation</td>
<td>–</td>
<td>–</td>
<td>170 Kcal/h (1,800 Kcal/h*)</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

| Dimensions |
| Width | 380 mm (14.96 in) | 360 mm (14.15 in) |
| Depth | 250 mm (9.84 in) |
| Height | 310 mm (12.20 in) |

| Weight (Approximate) |
| Temperature |
| Operating | 50 C |
| Non-operating | 50 C |
| Relative Humidity |
| Operating | 8 % |
| Non-operating | 8 % |

- **Environmental Conditions**
- **Vibration**
- Operating | 0.25G or less |
- **Shock**
- Operating | 2G or less |

The above specifications are subject to change without prior notice.

*Only when the cartridge is being loaded or unloaded.*
Optical Disk Drive 5984

Benefits
- High capacity, low cost per stored bit in standard 5¾" form factor make the 5984 the most cost-effective storage solution for on- and off-line applications.
- Removable disk cartridge protects media and allows data to be interchanged across drives. Recorded data has a projected life of 10+ years or more, making it ideal for archival purposes. No backup is required.
- Disks are updatable, thus supporting applications where audit trails are required.
- Pre-grooved media provides faster access and up to twice the storage capacity of flat media.
- Designed-in product reliability is highest in the industry. Proprietary Direct-Read-During-Write techniques for data verification ensure system error rates less than 1 in 10¹⁹. MTBF is 20,000 hours.

Markets and Applications
- Electronic file cabinets in small business and office automation systems
- Low cost archival systems
- Local and distributed data bases
- Medical, pharmaceutical and legal records
- Financial records with audit trails
- Software distribution and updating
- Electronic publishing
- Military/space mission control and logging
- Image storage and retrieval systems
- Data logging
- On-line mass storage with integral backup

Drive Specifications

Performance
- Data Transfer Rate: 2.2 Mbits/sec
- Rotational Speed: 1200 rpm
- Seek Time: 457 msec max, 155 msec average
- Average Track-to-Track: 1.5 msec
- Average Latency: 25 msec
- Access Time: 525 msec max, 220 msec average
- Linear Velocity (innermost): 3.77 mm/msec
- Linear Velocity (outermost): 7.54 mm/msec
- Positioning (Seek): Error Rate: 10⁻¹⁰, Corrected Read BER: 10⁻¹⁰, MTTR: 15 minutes
- Preventive Maintenance: None
- End User Maintenance: None
- Design Life: 5 years

Physical and Environmental
- External Dimensions: 146 x 85.1 x 203 mm
- Weight: 5.2 lb
- Power Requirements: +5 Volts, 0.5 Amps, +12 Volts, 0.75 Amps
- Power Consumption: 12 Watts average
- Temperature: 0°C to 40°C
- Relative Humidity: 90%, non-condensing
- Altitude: 1200 ft to 12,000 ft

Media Specifications

Performance
- Capacity/Side (raw): 244.3 Mbytes
- Capacity/Side (user): 202.4 Mbytes
- Data Surfaces: 2
- Tracks/Side: 18,826
- Track Pitch: 1.81 μm
- Bit Spacing: 1.71 μm
- Sectors/Track: 21
- Sector Size (raw): 644 bytes
- Sector Size (user): 512 bytes
- Overhead Header/Wall ECC: 26%
- Projected Storage Life: 10 years

Physical and Environmental
- Disk Diameter: 5¾ inches
- Outermost Track Radius (130 mm disk): 60 mm
- Innermost Track Radius (130 mm disk): 30 mm
- Weight: 5.3 lb
- Storage Temperature: 10°C to 50°C
- Storage Humidity: 95%, non-condensing
END
7-87
DTIC