A VLSI Magnetoic/Magneto-Optical Detection Channel

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Abstract

Emphasis has shifted from the use of magnetic storage subsystems in support of computer assisted clerical operations toward data logging/data acquisition, storage and manipulation of non-coded information and personal computer applications. More stringent demands are being made on all aspects of storage subsystem performance including capacity, accessibility, reliability, and economy. A VLSI detection channel is designed which is key to meeting these demands. Recent work indicates the feasibility of designing adaptive networks which “learn” and respond to changes in the signaling environment. Signal processing functions and computational or storage capabilities which are practical at VLSI circuit densities are the means by which multiple measures of value to the customer are increased.

Introduction

The performance demanded of data storage subsystems, whether measured in terms of storage capacity per unit cost, the rate at which data is made available, i.e., accessibility, or in terms of system and data reliability, has grown exponentially through this decade. [1] Magnetic tape, as a data storage medium, has been in use since 1952; the storage density in half-inch media products has been increased by more than three orders of magnitude. There have been many challenges to the tape role as an inexpensive, yet reliable storage medium. The emerging challenger is the rewritable optical disk, however, new and improved components, and new or revised applications, assure the viability of magnetic storage subsystems in multiple form factors into and beyond the next decade.

Upon the introduction of the Winchester disk technology in 1973, high performance, random access magnetic storage was soon to come within reach of every level of computer user, from the largest mainframe to personal computers. In the same year, Group Coded Recording was introduced in tapes, increasing the capacity and data reliability for that medium.

By 1975, tape storage had rapidly emerged as a solution to several problems faced by users of hard disk drives. [2] The ability to store tens, or hundreds of megabytes on a single DASD expanded the tape application as a low cost backup for multi-megabyte hard disks. Increased sensitivity to access time, and consequent requirements for free disk space expanded tape applications for storage of infrequently used data, and for archiving data sets. Of course, the disks were non-removable, so tape was used in the transportation of data and as an interchange medium. [3]

Whereas tapes and removable disks had once served as the primary storage medium in batch processing, the decreasing use of removable media and the associated storage subsystem in support of computer assisted clerical operations (sorting, merging and filing of various business and scientific data) now accounts for about 20% or less of computer applications. The rapid growth of the tape market over the last few years can be largely attributed to an increased number of users who are getting serious about disk backup. Figure 1 illustrates magnetic tape market projections over the next four years. While the use of open-reel tape is steadily declining, the demand for cartridge packaged 18-track media is increasing along with the growth of other formats and form-factors.

The demand for storage systems and storage media brought higher levels of competition to the marketplace. It became important to differentiate between suppliers, and to determine if “bargain basement” technology was worth the risk of more frequent errors and the potential of losing data. In the mid-1970’s measurement and

Figure 1 Estimated Shipments

reporting services were offered to data processing customers allowing them, for the first time, to quantify the reliability of their installations in a reasonably structured manner. [4] By the end of the decade, the cost associated with errors was becoming quantified and visible to the storage user. Data reliability became a marketable quantity.

In some instances, the data storage applications are being replaced by newer, better technologies. The need for tape based interchange is seen to be diminishing as more efficient methods are developing for sharing computer data. It is thought that, in the near future, fiber-optic channels may serve as the next medium of interchange, and certainly FAX services are moving in that direction. Electronic Data Interchange networks are now an efficient substitution for the postal services network. The Universal EDI network as a communications revolution could be operational in the early twenty-first century. [5]

In other cases, the market demand for data storage subsystems reflects the expansion of current applications, and the development of new ones. On the small scale, users of personal computers continue to expand their home databases, extracting information from central sources and filling 40 MB hard files or 200 MB optical files. On the large scale, multi-channel magnetic recording is generally used at several points and/or interfaces of the telecommunications process, such as in geophysical survey networks, or in spacecraft to buffer data for subsequent transmission to a remote station, at the network control center, at the data processing center, by the experimenters and by the archiving center. Volumes of data representing one-time occurrences may be gathered and held for extended periods of time prior to analysis. Magnetic recording is one of the most cost effective general data storage and retrieval system available to this environment today. [6]

The expected growth in image processing networks will require storage peripherals in unprecedented quantities. In the US domestic market alone the anticipated 1984 revenue is estimated to be $7-63 billion. [7] Typical on-line storage will soon exceed one Terabyte (10^12 bytes.) Staging, moving, and processing data in such quantities across a variety of media, while maintaining a vanishingly small error probability, and remaining transparent to the customer, requires levels of system software and VLSI hardware not to be fully realized until the early 1990’s.

Reliability requirements are increasing. The error correction capability tabulated in Figure 2 shows that random data errors may be all but eliminated by Error Correction Codes (ECC) usually reduced to practice and practicality by the circuit density of VLSI coder-decoders. System failure rates and downtime are addressed, in part, by reducing discrete component counts through the development of VLSI chip sets. Data errors encountered because of transducer wear may be addressed, in principle, by adaptive electronics in the detection channel. It is, therefore, the VLSI
Byte error probability at 20 dB SNR using Reed-Solomon Code
(Raw length < 240; Uncorrected error probability Redundancy Failure Probability
22.2% < 3.0 x 10^-11
27.8% < 1.5 x 10^-11
33.3% < 2.5 x 10^-11
38.9% < 2.5 x 10^-11
44.4% < 2.0 x 10^-11

Figure 2. Reliability projections

Because the design requirements of the detection channel are determined by the environment established by the write channel and the recording medium, some write-side characterizations are vital prerequisites.

Fundamental capacity limits are imposed by areal density limitations of the recording channel. As indicated in Figure 3, the recording channel includes the write transducer (write head), the recording medium, and the read transducer (read head). A series of thin film heads was constructed to assess the density response, signal output vs. write current, and the signal-to-noise ratio (SNR) which might be obtained from several tapes. Data was obtained at each of three operating points determined by the head parameters with experimental Barium Ferrite media as well as metal particle video recording tape.

<table>
<thead>
<tr>
<th>Track width (µm)</th>
<th>Gap (µm)</th>
<th>Density (fr/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.35</td>
<td>1200</td>
</tr>
<tr>
<td>50</td>
<td>0.20</td>
<td>2500</td>
</tr>
<tr>
<td>10</td>
<td>0.35</td>
<td>2500</td>
</tr>
</tbody>
</table>

(These operating points bracket parameters reported for experimental digital HDTV: Tw = 27 µm, G = 0.35 µm, 2553 fr/mm [8])

Figure 4. Experimental Operating Points

The SNR data summarized in Figure 5 is consistent with obtaining bit error probabilities of 10^-6 at areal densities exceeding 70 million events/mm^2. (The data assumes white noise, and is acquired under conditions of in-contact recording on AC-erased media assuming perfect equalization, and is therefore highly optimistic.) Optical recording and magnetic recording channels have similar noise limited reliability when compared under certain conditions [9].

The effects of noise and distortion introduced by the recording medium and the writing/reading transducer increase with both linear and lateral recording densities in magnetic tape; however, once the transfer function of the transmission channel is characterized and analytically described, and assuming (restricted) linearity of the recording channel [10], an appropriate equalizer can be synthesized, incorporated in the write channel or the detection channel, or distributed between write and read sides.

Non-linear distortions (commonly associated with less than ideal write channel, and with pulse crowding at high density) have been effectively handled by ad hoc compensation. In specific cases, modification of the write compliance voltage, or write current (as a function of the data pattern) [11] or modification of the write timing [12] can provide benefit in the form of reduced error rates. In a VLSI channel implementation, it is impractical to adjust the compliance voltage in response to data content; it is practical to shift the transition time opposite to the characteristic shift produced by earlier data.

Figure 6. Write Equalization, an Example

Linear distortions can, in principle, be reduced by suitable linear equalization. The use of write side equalization as shown in Figure 6, although known to be of great benefit [13], entails a hidden hazard. Data archived using the equalized write channel must be accepted as a recorded standard for information interchange by subsequent product generations in order to retain compatibility. Anticipated shifts in transducer or media response, whether a function of wear (in tape), age (electro-optics), manufacturing procedures, cost reductions, supplier changes, etc. dictate retaining the capability of altering the read side equalizer to compensate for changes or accommodate new specifications and maintain overall system performance.

Functional Blocks of the Read Channel

The essential elements of the VLSI read channel are shown in Figure 7.
The preamplifier is designed for transducers having outputs from about 100 μV to above 1 mV. (Magnetoresistor) or 10 pA to 100 pA (Photo detector). The bias generator conditions the transducer to quasilinearity. Coupling between gain stages of the preamplifier eliminate DC offsets and attenuate low frequency media noise and noise due to thermal shifts.

AGC, bias adaptive feedback

A Gilbert multiplier is included in the preamplifier; the control voltage is derived from an envelope detector, and is heavily filtered. The function of the AGC is to normalize long term gain drift, transducer sensitivity drift, and media variations. The adaptive bias control signal is derived from the zero-signal noise floor, and should be digitally locked to prevent modulation of the detected signal.

Equalizer

Equalization is accomplished in the frequency domain with a series of first- and second- order active filters. Recent work indicates the feasibility of designing adaptive networks which "learn" and respond to changes in the signalling environment. Loss of resolution in the read transducer can be compensated by altering a gain element in the equalizer. Figure 8 shows the block diagram of an equalizer configured for adaptive control.

Figure 9 shows the nominal response, and examples of the adaptive response. The concept of adaptive equalization has been evaluated on an experimental tape drive. ([15] Reliability improvements of up to ten times better than a fixed equalizer have been observed. Such networks can reduce the requirements for operating margins thus improving the areal density and consequently, capacity.

Equalizer control blocks

A training sequence (typically consisting of a series of tones of different density) is used to direct the alteration of a gain term in the equalizer. ([16] Such networks can reduce the requirements for operating margins thus improving the areal density and consequently, capacity.

Threshold qualified peak detection was selected for simplicity of implementation and compatibility with the run-length-limited code (d,k)=(1,7) used in the experiments. Individual thresholds are developed for opposing polarity signal peaks. Depending on the transmission characteristics of the recording channel, up to 10 dB of additional margin might be available with more optimal detection.

PLL clock recovery

A phase locked loop is the widely practiced means of restoring the data clock.

Serial Error Correction

Presently implemented as a separate digital process, the Reed-Solomon decoder ([17,18] could be included in the VLSI channel using IBM's advanced one-micron CMOS technology. The use of a pipelined dataflow for the decoder can minimize processing delays and achieve the correction of multiple symbol errors in real time ([19].

Accessibility and Buffering

Accessibility of data considers tradoff between access time (the average time distance between targets within a storage volume), volume capacity (amount of data machine addressable without demount or disengagement of a storage volume), search or locate rates (the rate at which data is traversed without processing, as in a SEEK command to a disk), and the data transfer rate (the actual processing time in retrieving a requested record, file, image or article).

The storage capabilities which are practical at VLSI circuit densities are used to minimize the otherwise inevitable time lost in mechanical operations. On a per-transport basis, an (economical) local data buffer must be of sufficient size to sustain the full I/O channel data transfer for an interval exceeding a typical mechanical initiation (SEEK in a disk, start time for tape).

Reliability

Reliability of the storage subsystem may be addressed in three ways. First, the component reliability: infant mortality, constant failure rate or lifetime, and wearout; second, the intrinsic defect rate of the storage medium: exponentially distributed in size and separation; and finally, random failures: noise induced, stress induced, and technology limited.

With near-perfect reliability of the VLSI components themselves, with single-fault protection design, and with suitably powerful error control codes, the probability of unrecoverable error within the subsystem can be made arbitrarily small. Media library maintenance procedures, unattended system operation, and storage hierarchical management software work toward perfecting the integrity of stored data. The individual detection channel circuits, which less than a decade ago were individually packaged, have been highly integrated in this channel, virtually eliminating errors due to interconnections.
The cost of the storage subsystem can be expressed in a number of ways, the dollars per Megabyte of stored data being common. Projections of the cost of stored data in the next decade (anticipating the savings in packaging and power following from the use of VLSI circuits) approaches $0.04 per megabyte.

Other figures of merit include Dollars per Megabyte per second (a throughput measure), Dollars per Error-recovery (a reliability measure), and Dollars per Megabyte per media-volume (a capacity, or accessibility measure).

In all cases, the VLSI implementation shown for the detection channel is a means by which value to the customer is increased.

References