

THE AUTHORING OF OPTICAL VIDEODISCS
WITH DIGITAL DATA

by

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ABSTRACT

The optical videodisc is a publishing medium that permanently stores large amounts of visual and aural data. The technology needed to support videodiscs is understood and available. Digital augmentation of the optical videodisc can exploit this technology for data publishing. Not only can this data be used in raw form, it can also reference the video that it augments. Publishing requires an author to create the publishable material, and this thesis addresses the problem of authoring digitally augmented videodiscs.

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1.1 INTRODUCTION

The optical videodisc is an invention of immeasurable significance in many ways, but perhaps most importantly in one currently termed media technology. Communication disciplines are separated because individuals specialize in a particular field. As an example, consider publishing, video and film cinema, and computer systems. In general, they are characterized by having their own jargon, their own conferences, and their own adherents. Often they are directed at different audiences or purposes. Interrelationships and commonalities among them are rare and often notable.

Current technology, however, is changing this. Overlaps are becoming the rule rather than the exception. Examples include electronic typesetting (between publishing and computers), image processing styles of television effects (between computers and video broadcasting), and pre-recorded video-cassette movies (publishing and cinema).

From another point of view, current social trends are a motivating factor. Americans have turned from an "anti-technology" attitude resulting from high technology's perceived link to war and social control, to a "pro-technology" one. The prevalence of automated bank tellers, home computers, video games, automated appliances, digital watches and calculators have acclimated people to machines as worthy assistants, rather than formidable and totalitarian adversaries. In effect, the reduction in size and cost of computing equip-

ment and the associated personalization afforded thereby have demystified the computing machine. It is rapidly becoming a welcome partner to a complicated interaction as opposed to an omnipotent overseer.

The optical videodisc is a perfect example of media technology and the overlaps it forces between the industries described above. As invented, it was intended to evidence the overlap between film and publishing. That is to say it was meant to be a new way to publish standard linear cinema. By virtue of two quirks in its design, however, it is actually far more than that. The existence of addressability of each frame in a 54,000 long (one half hour) sequence, combined with a computer interface capability, forces users of the device to regard it as an example of the simultaneous intersection of broadcasting, publishing, and computers.

When regarded in this light, it defines a new type of publishing, one capable of presenting "books" with the dynamics of cinema, or "movies" with the perusal characteristics of books. At all times, the interface, or controlling element, is an interactive computer maintaining a user interface and display. This thesis addresses issues related to the technology of the optical videodisc with respect to its function as an electronic publishing device. Its ability to provide dense image storage addressable by computer is only the tip of the iceberg. The revolution lies in its ability to jointly

store images and their associated data bases or retrieval programs, The disc is a repository for co-resident bits or pictures, and when used for both, becomes a carrier of self-describing images and self-programming interactions.

1.2 CHARACTERISTICS OF THE VIDEODISC

The optical videodisc has certain advantages over other tape and disc systems that make it inherently interactive (1). Among these are random access and still framing. To be truly interactive, any image or sequence must be accessible with little lag. The search times on videotape (like their computer counterparts) are prohibitive for interaction. While there are videotape instruction systems, they basically allow the selection of a short movie, with long waits between sequences. This is no more interactive than broadcast television with a TV Guide. Interaction allows a user to alter an event in progress.

The notion of random access has an implicit requirement of specific addressability. Industrial videotape editing uses a SMPTE (or similar) time code imbedded in the video signal to allow precise edits. A similar code is used by the optical videodisc player to randomly access particular frames. While other disc systems have frame numbers for internal player use, so far they cannot be accessed by the user. Other disc systems also have rotational speeds that do not allow any from to be stopped.

The frame numbers are, in and of themselves, a type of digital data. Optical discs, in fact, currently have two different frame number encodings on each frame. Both are located in the vertical retrace (blanked) portion of the

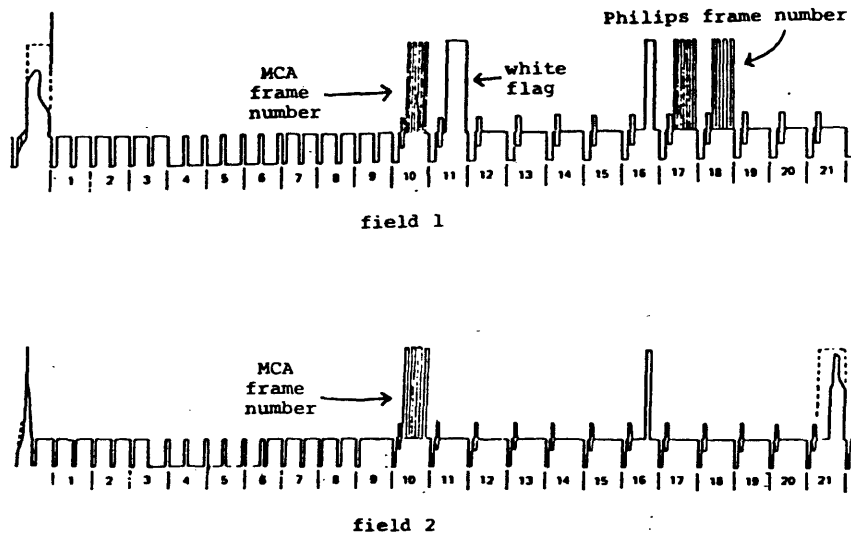


Figure 1.
Digital Information in the Vertical Interval

video signal. Figure 1 shows the vertical interval and the location of the two codes. The code on line 10 of both fields is the industrial or "MCA" code. It is read by the more expensive industrial players and is a self clocking bi-phase code with a bit time of one microsecond. The consumer or "Philips" code is located on lines 17 and 18 of field 2. It is self-clocking delay modulation (Miller modulation)

with a bit time of two microseconds. Figure 2 shows a bit pattern of bi-phase and delay modulation compared with standard Non Return to Zero (NRZ) modulation (8).

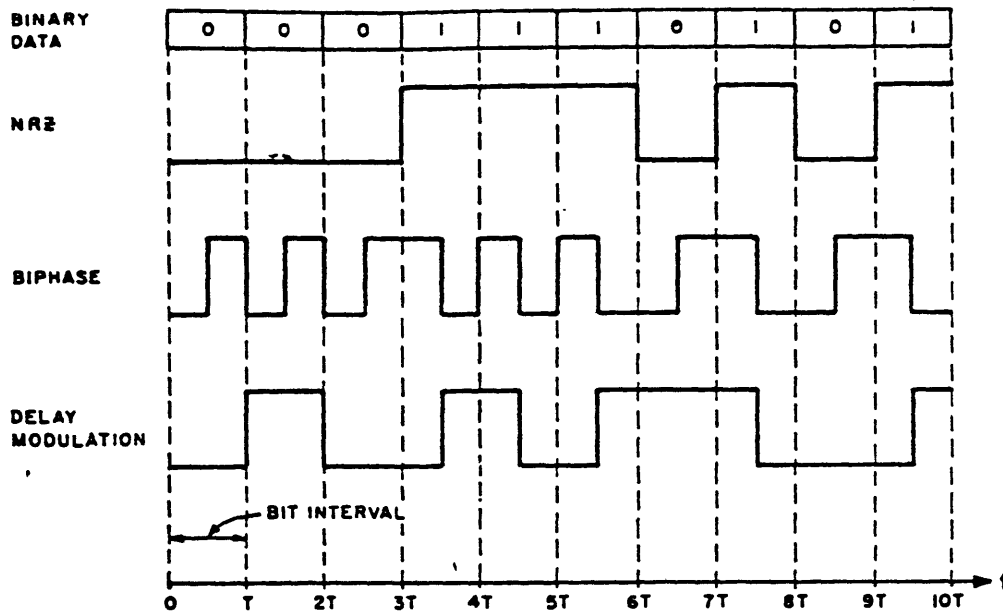


Figure 2.
Modulation Schemes

Other digital information is also stored in the vertical interval. For example, on line 11 is the "white flag", used when the player is repeatedly showing a single frame.

*Constant Linear Velocity (CLV) discs contain one hour of video per side. Still framing and searching are not possible, however, because vertical intervals don't line up.

The optical videodisc spins at 1800 rpm when playing Constant Angular Velocity (CAV) discs.* This rate yields one frame per revolution, which allows the player to skip one track during the vertical interval. This rate yields one frame per revolution, which allows the player to skip one track during the vertical interval. Since there are two vertical intervals per frame (two fields), the player must be instructed to jump during the correct interval to display a coherent frame. This is especially important for discs transferred from film, which has 24 frames per second, rather than 30. White flags instruct the player to display the correct pair of fields.

In order to manage the large amount of video "real estate" that exists on one side of a disc, the manufacturers of industrial players provide the capability of computer interface. This is either in the form of a universal serial protocol (RS-232), a universal parallel protocol (IEEE-488), or a custom parallel protocol. This interface allows all search and play functions to be performed by the computer, and also allows read-back of player status and current frame number. It should be mentioned that certain players are capable of internal programming. This basically allows any of the normal key functions of the player to be used as program steps, along with control commands (goto, accept input, etc.). Only through the connection of videodisc players and computers will the videodisc achieve its full usefulness.

1.3 USING THE VIDEODISC

The simplest form of videodisc system is nothing more than a player and a monitor (Figure 3). In this system the user must do all accessing of the disc manually via frame numbers. Imagine a disc which contains 54,000 single frame images. This was, in fact, first demonstrated by the MIT Slidathon disk. To find an individual frame, the user must direct the disc to search for a specific frame number. The frame numbers, digitally encoded on the disc, are the only means of access common to the user and the player.

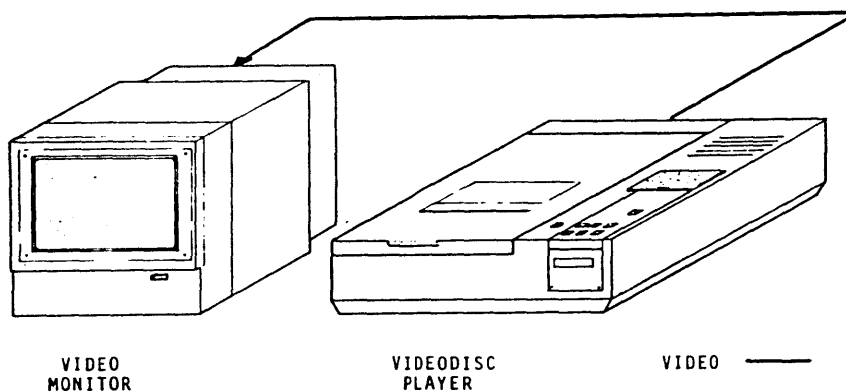


Figure 3.
Videodisc Station

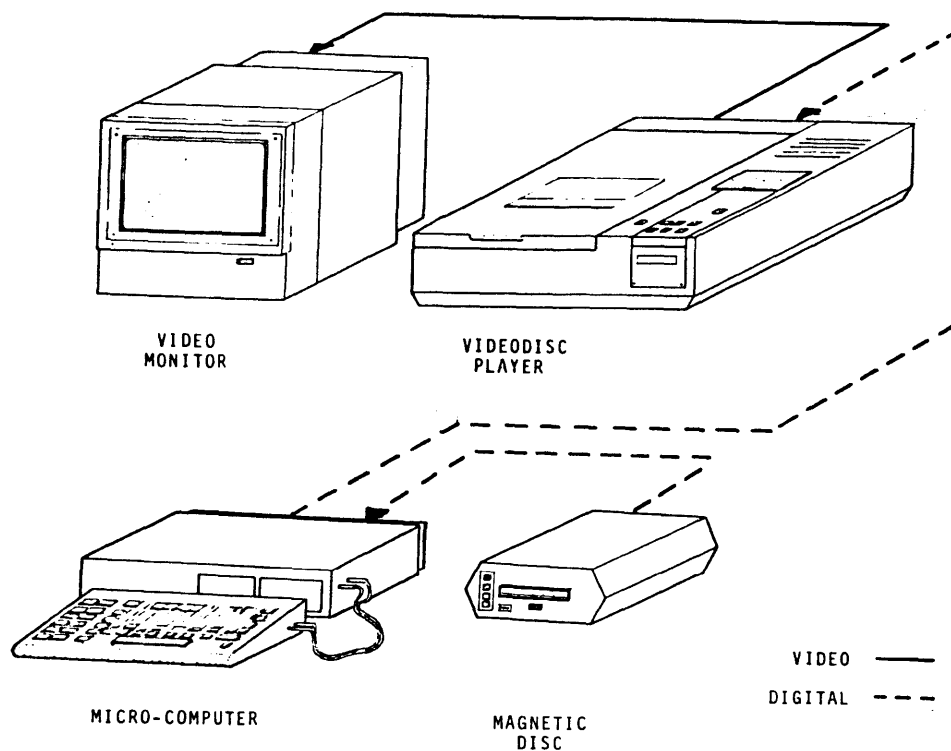


Figure 4.
Micro-Computerized Videodisc Station

Now consider the addition of a simple computer to control the videodisc (Figure 4). That computer can have an index to the disc that the user accesses in English, and that cross references the frame numbers understood by the player. The computer is merely translating between two referencing systems.

The computer can provide much more than simple indexing, however. Interactivity, the simultaneous display and control of the videodisc, is now possible. Figure 5 shows

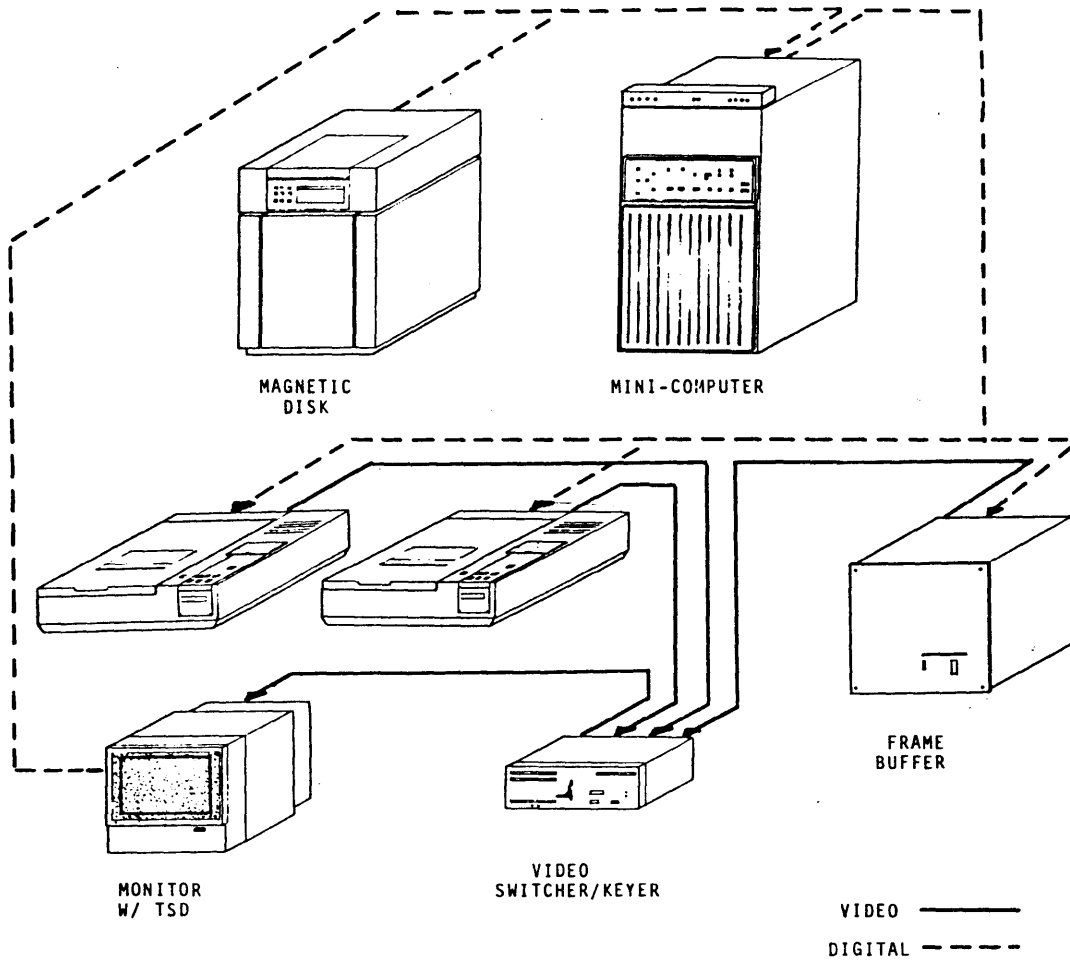


Figure 5.
Mini-Computerized Videodisc Station

a more robust interactive videodisc system. A fairly sophisticated mini-computer is necessary to manage the user inputs, data retrieval, and videodisc control. This particular system uses a touch sensitive screen and overlaid graphics to facilitate user input. Also, two disc players

are included to provide continuous viewing. While one player is being viewed, the other can be searching. This system is used at the Architecture Machine Group for the Movie-Map and Movie-Manual systems (9).

The Movie-Map (17) is, in some sense, closely related to much more sophisticated graphic 3D simulators. By pre-storing display imagery on the videodisc, the burden of creating images in real-time is removed from the computer. Obviously, one can only travel where there is data on the disc, and only with the detail of the disc's sampling.

The first movie-map was made of Aspen, Colorado. A stabilized movie camera was mounted on a truck and one frame was photographed every ten feet up and down every street. Likewise, turns between each street were filmed. Other types of visual data, such as maps, facades, and interior views were also included.

A data-base was then created for the disc and stored on the mini-computer's magnetic disk. This data-base linked all the streets with their respective turns.

The Movie-Manual (10) is a personalized instruction manual aimed at making people more creative and productive in their respective tasks. It allows visualization of actual repairs being made, and the requisite detail is user selectable.

The Movie-Map distributed data over a simple, spatially relevant topology. The Movie-Manual distributes topics over a cognitively relevant array.

Imagine that the data-base for the manual or map was distributed on the videodisc. Several advantages are accrued. First, responses to user inputs can be pre-computed, allowing the computer to spend its resources on input monitoring and control. Large data-bases can be distributed throughout the disc, rather than concentrated on magnetic media. Further, a distributed data-base parallels the image organization. Secondly, image analysis is possible by trading storage for computation. Objects in a picture can be described rather than analyzed. Lastly, programs themselves can take the form of data. The actual code needed to respond to a user input can be loaded and run.

Just as pre-storing imagery allowed simulation to be handled by a mini-computer rather than unique hardware, pre-computed responses allow micro-computer based videodisc systems.

1.4 THE DIGITALLY AUGMENTED VIDEODISC

Digital data on the videodisc augments the visual and sound sequences currently available. This augmentation allows efficient storage and automatic access to descriptive information, which frees the computer from data-base retrieval in order to enrich the user interface.

In order to understand the issues involved with digital data, we must hypothesize a modulation scheme. The second half of this thesis will examine the technical issues in detail. For now, let it suffice that the disc can hold data modulation at 7.16 Mbs (7). After allowance for video blanking and error correction, this yields approximately 80,000 bits per frame, or 4.3 billion bits per disc side.

To get a handle on how much information this really is, imagine that well over 20 Boston-sized telephone books could be coded on one side of the videodisc. Likewise, 1440 digitally encoded 640 x 480 x 8 bit pictures could be stored.

These are examples of storing mass amounts of raw data on the disc, and this is one mode of digital data use. If a user needs only very large amounts of data, then a computer peripheral specifically designed for data storage might be more applicable. On the other

hand, the digitally augmented videodisc is one of the few alternatives for mass replication of data.

The videodisc is permanent storage for imagery, and digitally augmented videodiscs would permanently store information describing that imagery. For example, in the Slidathon, the digital data that referred to a particular frame was the frame number. That number could be used as an index to other information about that frame, but implicitly, the frame number is meaningless. Other digital information stored in the frame could be the actual description of that frame, or its history, or whatever. The descriptive information is physically bonded to what it describes.

Figure 6 shows a videodisc system that could be used for a Slidathon type application with digital data. This corresponds to figure 4, except now the magnetic storage is replaced by videodisc digital data storage. In reality, any small system would probably have a magnetic mass storage, but now that mass storage need not be used for the descriptive data-base.

In the Movie-Map or Manual, processing consists of determination of reactions to possible user input. In the current computer data-base, a sequence of frames are lumped together, and the possible actions are the same for the entire group. If every frame had a separate data-

base, a sequence of frames are lumped together, and the possible actions are the same for the entire group. If every frame had a separate data-base entry, the data-base would be huge. Videodisc capacity is huge and digitally encoded information in each frame could have possible actions pre-computed for all user input, resulting in the computational videodisc. The pre-computed actions that are possible at any one time are available only at that time.

Figure 7 shows the computational videodisc station. This system is like figure 5, but now the mini-computer is replaced by a micro or home computer. Processing power has been supplanted by pre-computation.

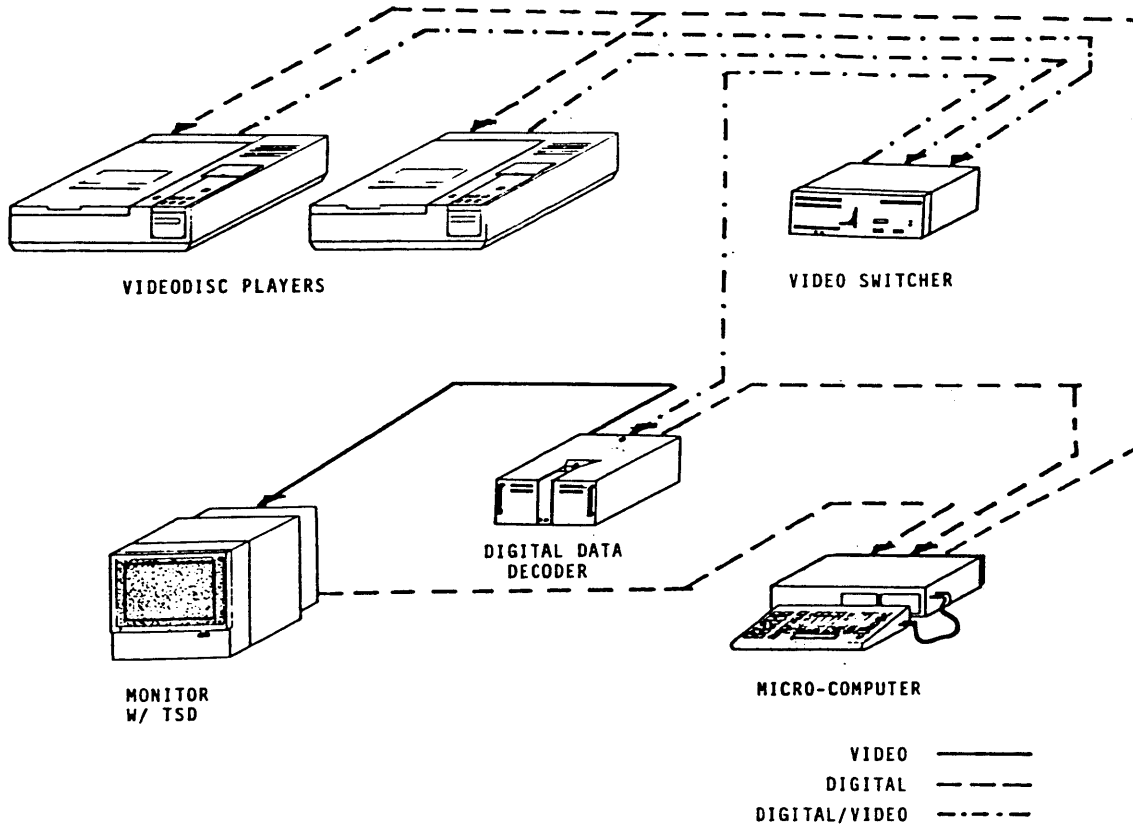
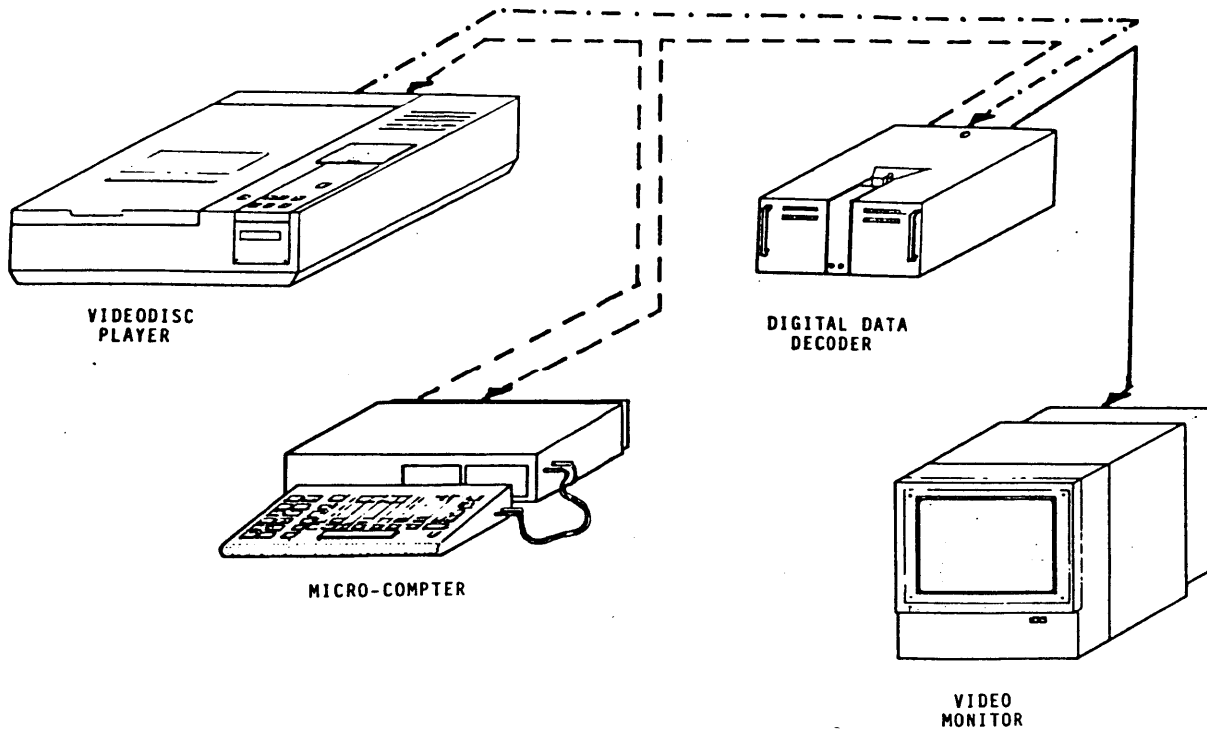
The digitally augmented videodisc can be used in basically three ways:

1. Mass Storage of Data - data unrelated to the video (Figure 8)
 - a. digital imagery
 - b. digital sound
 - c. text
 - d. programs
 - e. etc.
2. Descriptive Data - references internal to a frame (Figure 9)
 - a. picture labels, history or content
 - b. Fourier image analysis
 - c. image maps
 - d. etc.

3. Relational Data - references to other frames
(Figure 10)

- a. spacially coherent frames
- b. branching points
- c. zooms or pans from this frame
- d. etc.

The digitally augmented videodisc must be viewed as a book with words, pictures, motion and sound. It also must be viewed as a huge graphic read only memory, with storage for data and executable code.



Figures 6 & 7.
Digitally Augmented Videodisc Stations

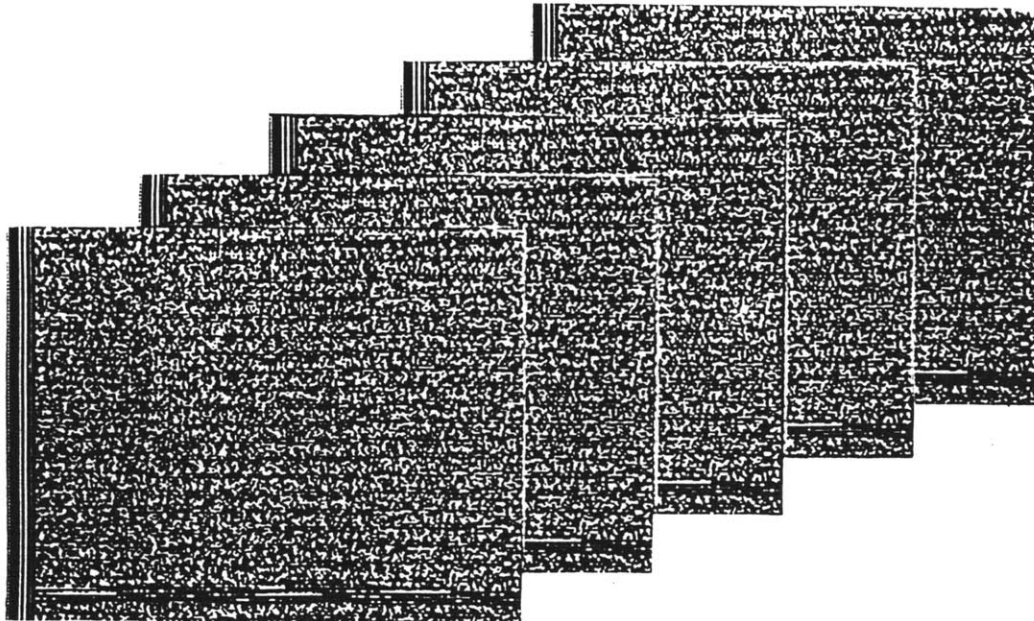
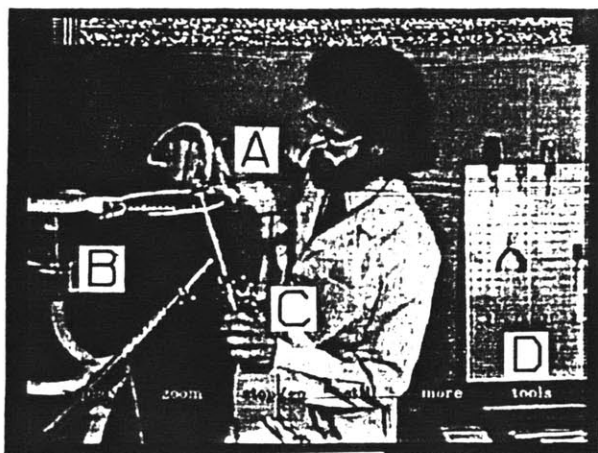


Figure 8
Mass Storage of Data



- A HEADSET
- B HANDLEBARS
- C BRAKES
- D TOOLS

Figure 9
Descriptive Data

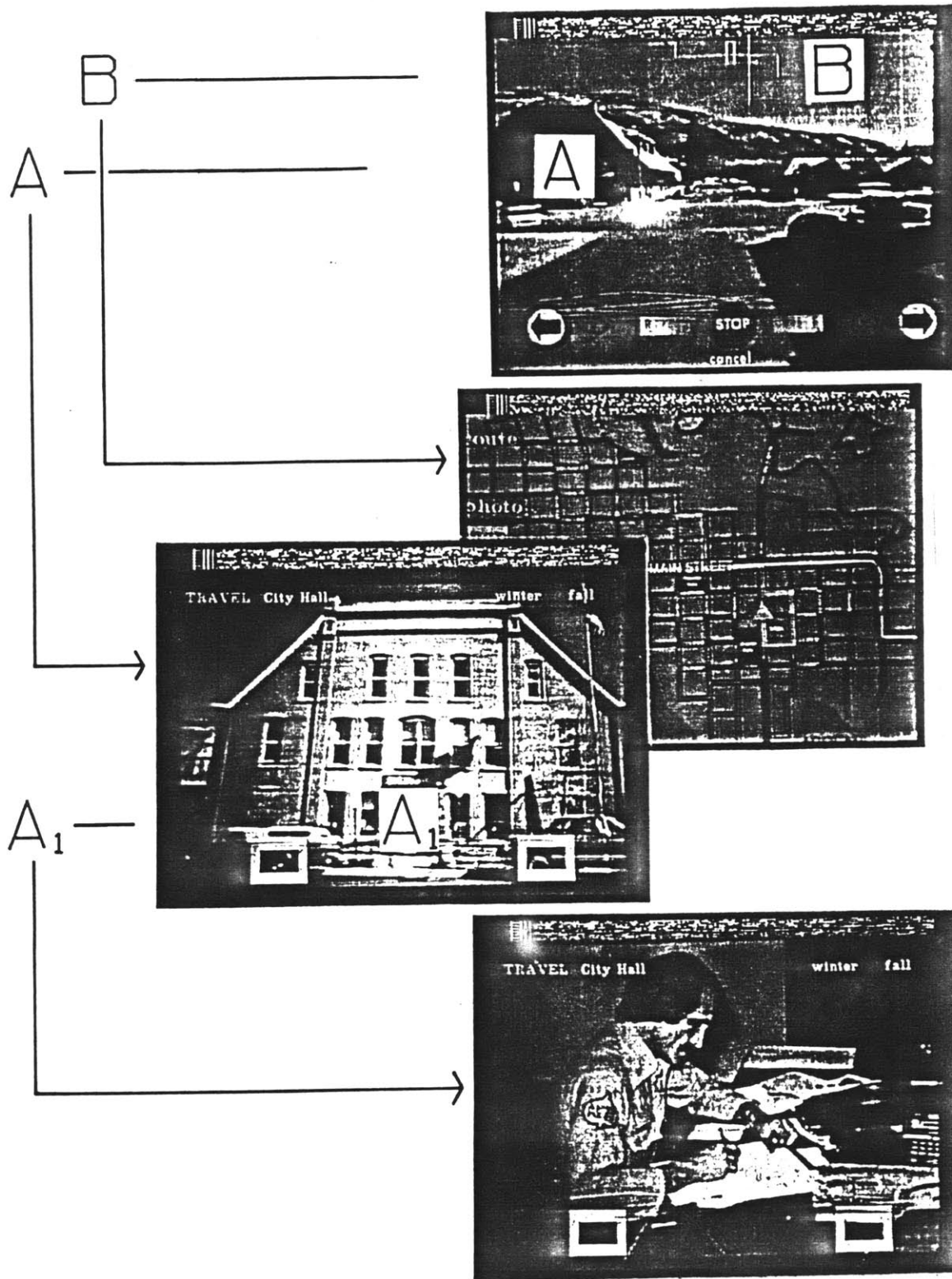


Figure 10
Relational Data

1.5 CONSTRAINTS ON VIDEODISC DIGITAL DATA

In the last section we hypothesized a data rate in order to gain an understanding of data storage issues. In hypothesizing that rate, we assumed that encoding would occur within the NTSC signal. The disc and player manufacturers could, however, directly encode data onto the pits of the disc, which would result in an order of magnitude greater data density. For instance, about 100 minutes of digital mono sound could be encoded with 7.16 Mbs. modulation on a 12 inch videodisc. By comparison, 60 minutes of stereo sound is recorded on the Philips 5 inch compact audio disc, which uses the same laser technology as the videodisc.

Unfortunately, direct modulation of the disc would require special players and a new method of mastering. These options are not available to the average videodisc user. The fact that digital videodisc players and mastering facilities already exist makes digital augmentation not only possible, but very economical compared to developing a completely new scheme. In order to exploit this "piggy-backing" of technologies, certain constraints must be met.

The first constraint is is no intrusion on videodisc mastering. Videodisc mastering technology is very complex and not completely understood, as evidenced by the fact that manufacturers trying to enter the field are having so much trouble. Creating a new scheme, or even signifi-

cantly modifying the current one would destroy any advantage to be accrued by using existing technology. Mastering must be looked at as a black box; videotape in, videodisc out.

The second constraint is that the data must be replicable by current methods. Once again, new methods can never be economical until their startup costs have been amortized. Even high density computer tape systems don't approach the information density of broadcast videotape systems. Over 20 years of research have been put into videotape; it would be very costly to repeat even a small part of that research. Since it is videotape that must be submitted to the mastering process, the data must be relatively immune to videotape replication and editing. Some level of tape deck sophistication can be required, however. It is not necessary to be able to pre-master on a home video cassette deck; to do so would mean that the pre-master tape would actually have much lower quality than the mastered videodisc.

The third and final constraint is no significant modification to the disc player itself. This is important insofar as any user should be able to recover data from whatever player he is using. If a substantial improvement in density or reliability is possible without extensive re-engineering and players, modification could be quite desirable.

The NTSC standard has existed for 30 years, and certainly will not be replaced in the very near future.

Creation of a digital standard of encoding within the video signal exploits widespread use of the NTSC signal.

1.6 THE ECONOMICS OF PUBLISHING

Consider the digitally augmented videodisc in the light of publishing. The parallels are many. Creating the plates for a book is expensive, but when those costs are amortized among all the copies made, the costs aren't so significant. Likewise, it can cost a great deal to master a videodisc, but this cost is spread among all the copies made.

The same sort of publishing economics apply to the hardware needed to author the pre-master videotape and hardware needed to read the replicated disc. The digital data encoder needs a fast (read: expensive) computer or single frame recording device (disc or tape) in order to write the pre-master tape. The decoders, however, must exist at each videodisc station. Therefore, digital data decoders must be cheap and easy to manufacture.

Processing also can be looked at from the standpoint of publishing. Possible actions can be pre-processed and published on the disc. Processing costs are concentrated in the pre-mastering stage, so that the actual processing cost per disc is rather small.

If we are then involved in a new publishing medium, someone must create the material to publish. This person can be looked at as the "author" of the disc material.

All activities leading to the creating of the pre-master tape are a part of authoring the videodisc. Just as the typewriter is the tool of a book author, the digital data encoder is the tool of the digitally augmented videodisc author.

1.7 AUTHORIZING THE PRE-MASTER VIDEOTAPE

Fairly large pre-mastering costs can be amortized, but just how large are these initial expenditures going to be? Clearly the interface needed to produce a masterable videotape depends on the tape facility available. While it might be possible to master visual material with 3/4" (U-Matic), or even 1/2" (Beta or VHS) tape cartridges, the available bandwidth would be far below that of the disc itself. Just as a book can only be as good as the plates it was printed from, the pre-master tape must have bandwidth and signal to noise characteristics better than the video-disc produced from it.

One or two inch videotape machine certainly meet the fidelity characteristics, and magnetic videodiscs would also be usable for pre-mastering. Hopefully optical write-once discs with good fidelity will be available in the near future. Whatever medium used for pre-mastering, the digital data encoder required depends mostly on whether or not single frame recording is possible.

If single frame recording is possible, the digital data encoder is a simple frame buffer. It would even be possible to use existing frame buffers, if their pixel size were equal to the desired bit time. The computer used to drive the encoder could actually be quite small and slow, as long as it was able to access the quantity of

information to be encoded on the disc.

If, on the other hand, single frame recording is not possible, the digital data encoder becomes more complex. The computer must have input/output bandwidth to write the tape in real-time. For the hypothesized 7.16 Mbs data scheme, taking blanking into consideration, an aggregate output rate of 4.5 million bits per second is necessary. The encoder must be buffered to dump data to video at the same time it is accepting data from the computer at this rate.

In the next section, I will look closely at the technical issue of digitally augmented videodisc. I will describe the hypothesized encoding scheme, and detail the construction of the digital data encoder.

2.1 DATA MODULATION

Modulation is the transformation of the logical bit stream into the analog transmission signal. The video signal on an optical videodisc is frequency modulated by the presence or absence of small reflective pits. Figure 11 shows the frequency spectrum of the disc. As was mentioned before, bypassing the FM and directly encoding the digital information on the pits could result in much higher density. We have, however, constrained the digital data to the NTSC signal.

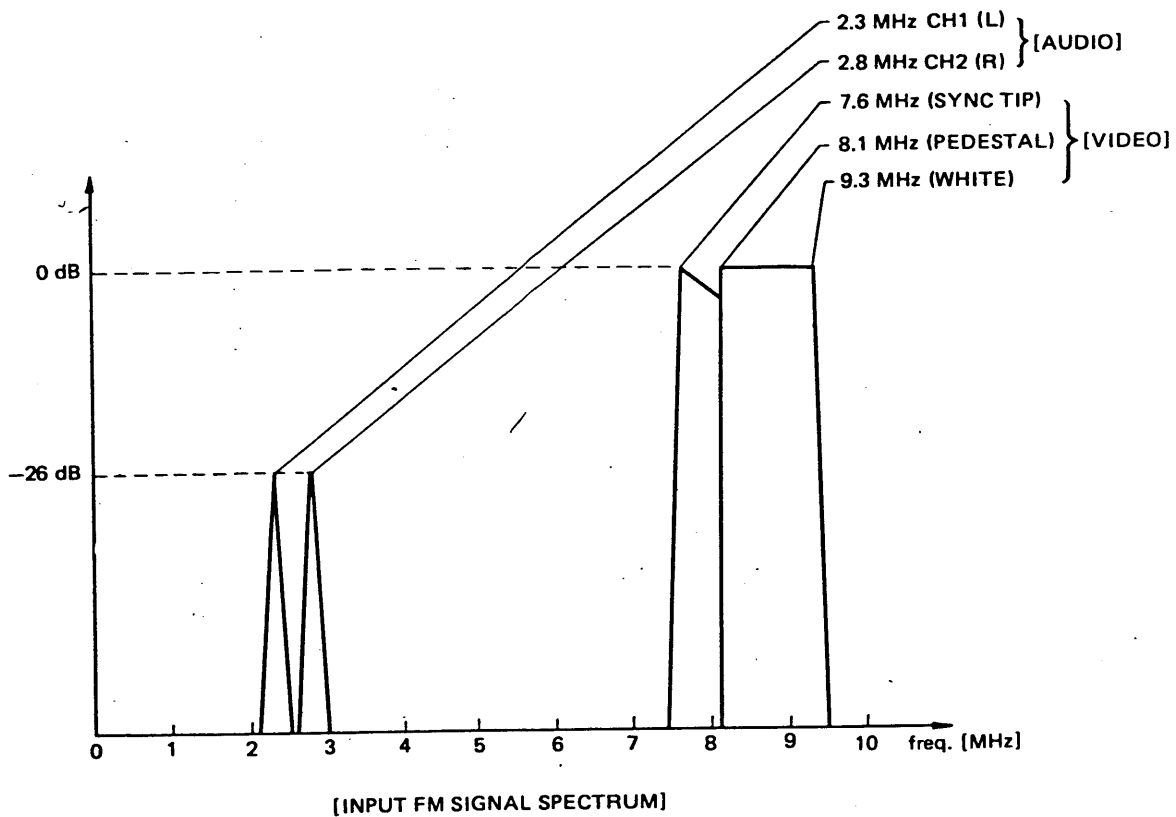


Figure 11.
FM Spectrum of the Optical Videodisc

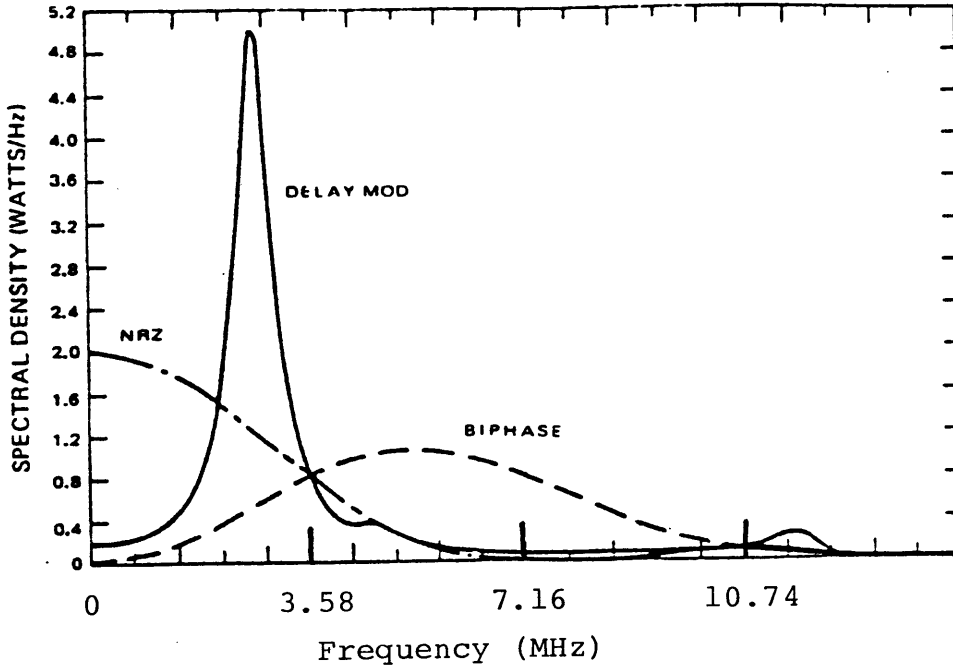


Figure 12.
Spectral densities of 7.16 Mbs Modulation techniques

The available bandwidth in the video signal is nominally 4.2 MHz. Figure 12 shows a spectrum of the three binary modulation techniques from figure 2. The frequency scale assumes a data rate of 7.16 Mbs. An increase in data rate can be achieved by encoding more than one bit per sample. This assumes that bandwidth is limited while signal to noise is not. Multi-level encoding also increases decoder complexity.

Bi-phase encoding has too much spectral energy over 4.2 MHz; if it were to be used, the data rate would have to be cut at least in half. As we will see, its self-clocking capability is not worth the decreased data density.

When deciding between Miller and NRZ modulation, two factors are important; clockability and decoder complexity. The two codes are equally as dense for a given bandwidth, as shown in figure 12. Miller encoding is self clocking, and needs a fairly complex decoder. Because of its self clocking nature, it takes a number of samples to recover from phase distortions over one half bit time. Basically, a self clocking code demands twice the accuracy of edge transition times as NRZ.

If a method for recovering the clocking information is found, then NRZ encoding can provide the simplest decoder. The 7.16 Mbs data rate was hypothesized because it is twice the color subcarrier frequency (3.58 MHz). The video signal must be very accurate relative to the color subcarrier, since hue is derived from phase with respect to the color burst. The videodisc player has a Time Base Corrector (TBC) to keep the video relatively phase stable. The color subcarrier can therefore be used as a data clock, with two bits per cycle.

It seems that a Miller modulation scheme offers some advantages over NRZ, but these advantages are basically redundant. The NTSC signal already has a color clock, and the player corrects for time base errors relative to that clock. Once again, exploitation of existing technology simplifies design.

While this is not a comprehensive examination of all possible encoding schemes, the more popular ones have been looked at. For the basic reason of simplicity, NRZ encoding clocked synchronously with the color subcarrier seems like a reasonable method of digitally augmenting the optical videodisc.

2.2 Error Correction

The optical videodisc, like any transmission system, is prone to certain types of signal degradation. Noise in the signal can decrease the ability to accurately threshold binary levels. The SMPTE Study Group on the Videodisc measured signal to noise ratios between 25 dB and 40 dB (29). This signal to noise ratio is high enough so that the probability of an error due to noise is quite small in a two level modulation scheme. Videotape noise degradation is shown in figures 13 through 16, which are three generations of digital data duplication on a two inch videotape machine.

Dropouts are a major signal degradation on the videodisc (3), and the player manufacturers have developed a dropout compensator. This consists of one video line of memory, a piece of which is inserted whenever a dropout occurs. Since this is a visual compensator, it is important that a clean replacement is made. In order to assure this, all dropouts are extended by about 2.5 micro-seconds. When reading digital data, these extensions would be replacing 10 bits of possibly good data. This is an uncomfortable data loss, and can be overcome by reading uncompensated video, which is available inside the player. The player could be modified to output uncompensated video, or the manufacturers convinced to install uncompensated video outputs. If neither of these seem desirable, it is neces-

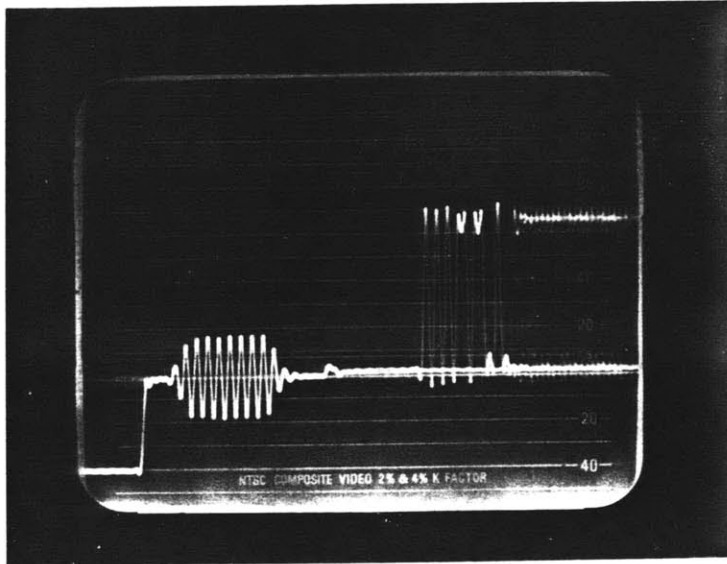


Figure 13
 NTSC Signal Directly Out of Encoder
 Notice Framing Code; 1010101101100100

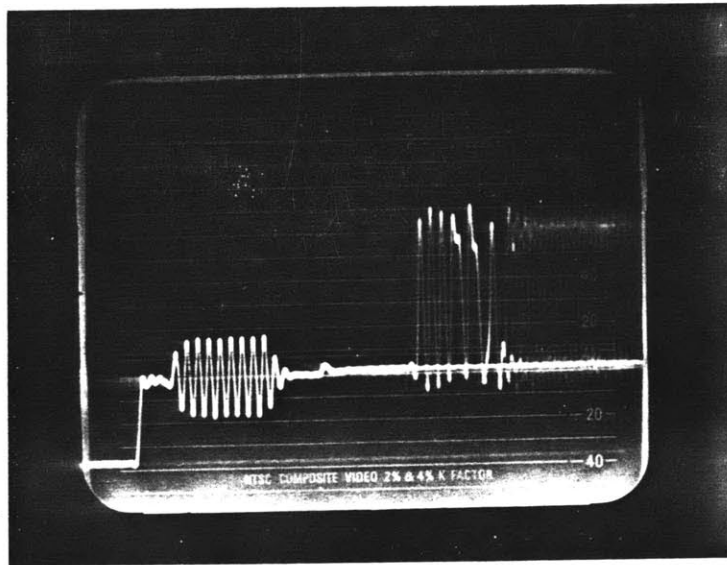


Figure 14
 Playback of First Generation 2" Quad Tape

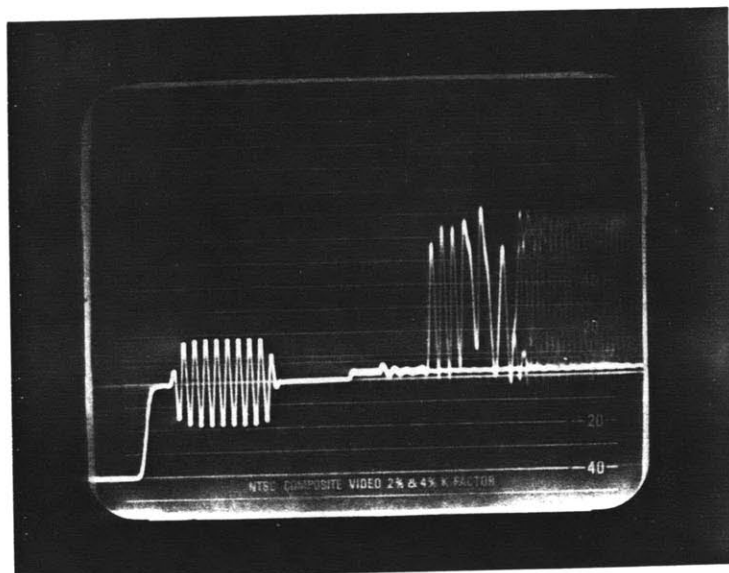


Figure 15
Playback of Second Generation 2" Quad Tape

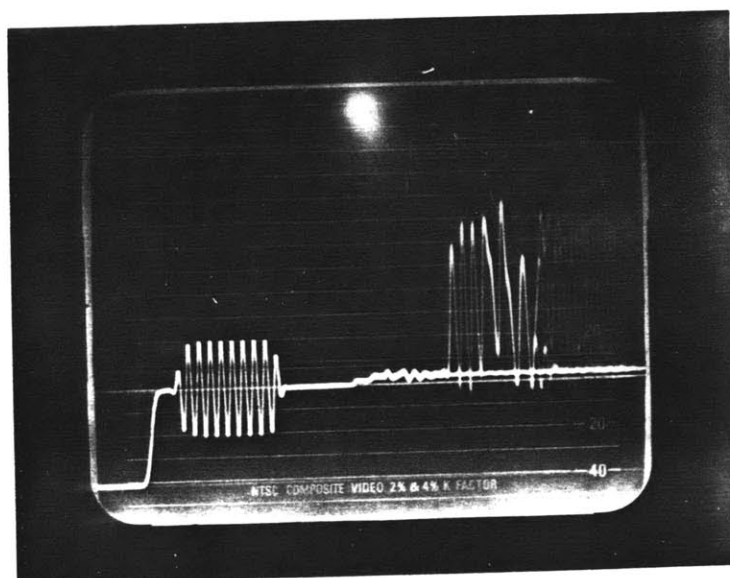


Figure 16
Playback of Third Generation 2" Quad Tape

sary to develop an error correction scheme to deal with the increased data loss.

We have done some analysis of the dropout characteristics of the videodisc, and figure 17 shows a histogram of the number of dropped out bits per 1000 frames, where the bit rate is 7.16 Mbs. From this analysis, it has been concluded that the probability of a bit dropping out is 0.142 percent.

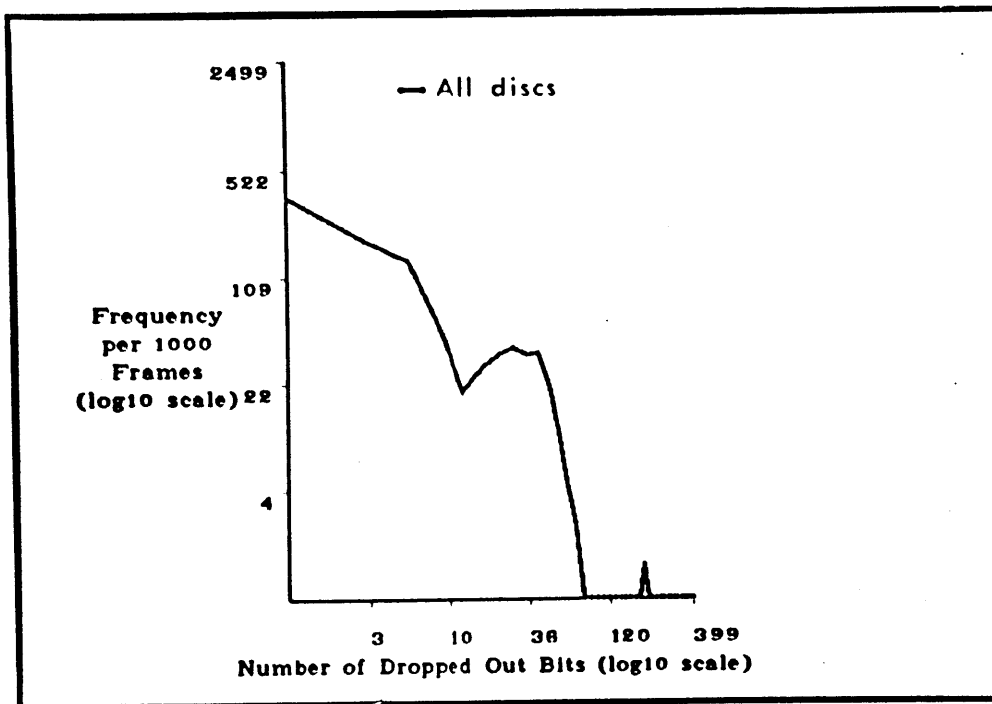


Figure 17
Dropout Histogram

Some method is needed to deal with these errors. Data redundancy is one method of providing error correction. If a particular word is read incorrectly, then that word can, hopefully, be read from someplace else on the disc. This is, however, a rather inefficient means of error correction.

Many different error correction codes have been devised. A code can be described as an (n,k) code; where 'k' is the number of bits in the original message with 'n-k' additional check bits yielding an 'n' bit codeword. A random bit error correction code will detect and properly decode any received word if it has 't' or fewer errors. A burst error correction code works poorly with many scattered errors, but can correct a run of errors within the received word.

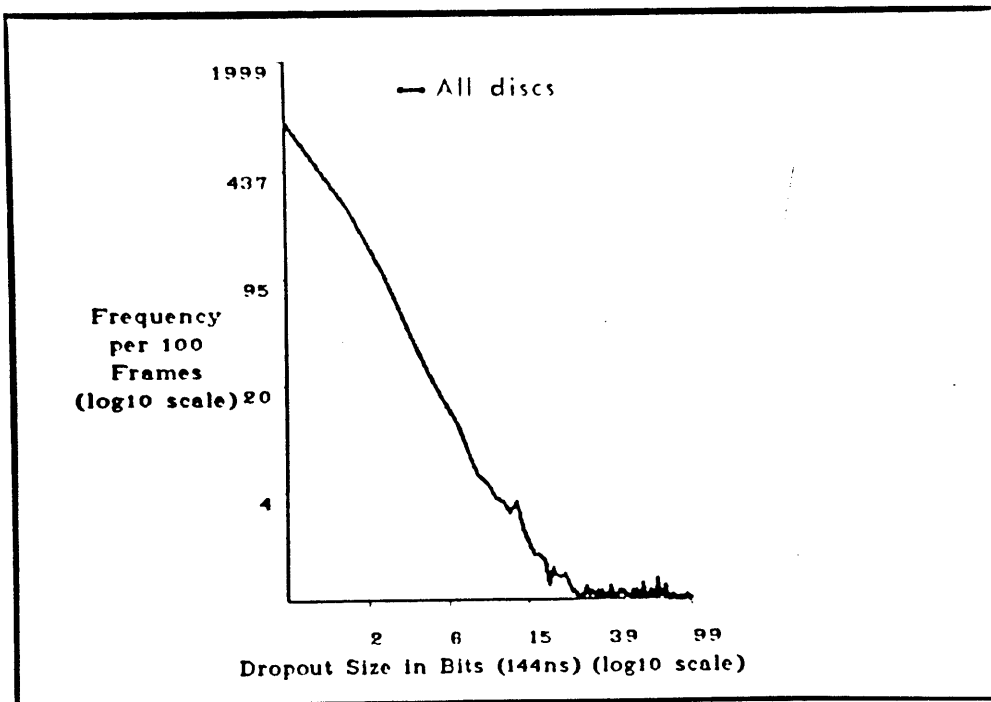


Figure 18
Dropout Histogram

Unfortunately, some dropouts are quite large, as seen in figure 18. Burst errors can also be caused by improper identification of the first bit, i.e., bad sync. A burst error correction code of a size sufficient to correct dropouts observed on a video disc would be too expensive to implement. A more simple method would be to interleave the codewords so that a dropout is distributed between codewords. Interleaving is accomplished by encoding a number of codewords into a block. Within that block, all the first bits of the codewords are transmitted first, then all the second bits, and so on. The number of codewords per block is called the degree of interleaving. The interleaving degree multiplied by the number of correctable bits per word defines the maximum single dropout correctable in a block. If we choose an order of interlacing sufficiently large relative to error burst lengths, analysis can continue on the basis of the observed overall bit error rate. Bit errors within a codeword become a random event, and a random bit error correcting code can be used on each codeword. A large degree of interleaving means a large block size, which increases decoder size. A large block size also increases the data latency, since the entire block must be read in order to decode one codeword.

Many such codes have been discovered, and the selection of an error correction scheme for digital storage on optical videodiscs can be made by using data reliability,

code efficiency, and decoder complexity as criteria. Encoder complexity is not an issue, since the data can be pre-encoded and needs to be done only once. A number of cyclic codes exist, and they combine relative efficiency with hardware implementability. Table 1 illustrates the relative power of some common codes. These probabilities assume that errors are random and not correlated to errors elsewhere in a codeword. These codes are all about 50% efficient (k/n) and are all about the same length. Several values for bit error probability 'p' were chosen given the above observation and the expectation that disc quality will continue to improve. The probability that at least one non-correctable error (i.e. more than 't' bit errors in 'n') will occur in one gigabyte is used as a measure of each code's error correcting power. One gigabyte represents about one side of raw data in 54,000 full data frames. The differences in user data density between the codes is small compared to the order of magnitude differences in reliability. Within the expected range of bit error rates, the Golay (23,12) seems the most powerful. The Golay code is also easier to decode than the BCH (31,16) or the Reed-Solomon (21,9) code. The (22,16) Hamming code is available as a chip and a (15,7) BCH code can be decoded using ROM and a table lookup scheme, but these codes are much less powerful. The Golay code was chosen as a good compromise. Its decoder is simply realizable, and its efficiency is better than any other known error correcting

P = PROBABILITY OF A BIT ERROR
 Q = PROBABILITY OF NO BIT ERROR = (1 - P)
 A = PROBABILITY OF A CODEWORD BEING UNCORRECTABLE
 B = EXPECTED NUMBER OF UNRECOVERABLE CODEWORDS IN
 ONE SIDE OF SOLID DATA (1 GIGABYTE, RAW) AS
 SHOWN IN TABLE

$$A = \sum_{I=T+1}^N \binom{N}{I} \cdot P^I \cdot Q^{(N-I)} \quad B = 8.0 \times 10^9 \times A / N$$

CODE TYPE (N,K) T	P, PROBABILITY OF A BIT ERROR				
	10 ⁻²	10 ⁻³ *	10 ⁻⁴	10 ⁻⁵	10 ⁻⁶
HAMMING (22,16) 1	9.2x10 ⁶	1.0x10 ⁴	1.1x10 ¹	1.1x10 ⁻²	1.1x10 ⁻⁵
REED-SOLOMON (21,9) 2	3.4x10 ⁵	3.8x10 ¹	3.9x10 ⁻³	3.9x10 ⁻⁷	3.9x10 ⁻¹¹
BCH (15,7) 2	7.3x10 ⁴	7.9x10 ⁰	8.0x10 ⁻⁴	8.0x10 ⁻⁸	8.0x10 ⁻¹²
BCH (31,16) 3	9.2x10 ⁴	1.1x10 ⁰	1.1x10 ⁻⁵	1.1x10 ⁻¹⁰	1.1x10 ⁻¹⁵
GOLAY (23,12) 3	1.8x10 ⁴	2.1x10 ⁻¹	2.1x10 ⁻⁶	2.1x10 ⁻¹¹	2.1x10 ⁻¹⁶

*CLOSEST TO OBSERVED ERROR RATE

Table 1
 Comparison of the Error Correcting
 Capabilities of Some Codes

code with under 31 bits per codeword.

Note that the bit error rate and our quality ratings are not linearly related. In fact, for both the Golay code and the large BCH code, a decrease in bit error rate by a factor of 'x' will decrease the probability of a non-correctable error by a factor on the order of 'x⁵'. Increases in disc quality will have a profound impact on data reliability, as will decreases.

With these facts in consideration, the following encoding scheme was devised:

Data Rate:	7.16 million bits per second
Modulation:	two level NRZ
Clocking:	synchronous with color subcarrier; 90 degrees out of phase
Bits/Video Line:	16 lead-in framing bits; "1010101101100100" 320 raw data bits
Error Correction:	Golay (23,12) cyclic code; corrects 3 bit errors
Interleaving Degree:	139
Block Size:	3197 bits 10 video lines
Raw Data/Block:	400 bytes
Raw Data/Frame:	19,200 bytes
Raw Data/Disc:	1,000 megabytes
User Data/Block:	1668 bits
User Data/Frame:	10,000 bytes
User Data/Disc:	540 megabytes

In applications that involve data and an image sharing a frame, there are twenty lines available at both the top and bottom of the non-blanked area of the signal that are outside the TV safe area. On most monitors, these lines would not be visible and could contain for blocks of data (834 user bytes).

As a note, if the player were to present an additional logical output signalling 'loss of carrier' (dropout), then the disc becomes an 'erasure channel' as opposed to a 'binary symmetric channel.' Additional error correction (see (21), page 305) allows the Golay code to correct up to 'e' erasures and 't' additional bit errors, where $d = 7 = 2t + e + 1$. In the ideal case, if all bit errors are erasures, then six can be corrected per codeword, effectively doubling the correction power of the code. This technique can be applied to any binary error correction scheme, as long as the exact location of dropouts is known.

2.3 DIGITAL AUTHORIZING STATION DESIGN

In order to convert a computer memory output into video digital data, an interface that can deliver 7.16 million bits per second is required. Because of video blanking, the aggregate speed necessary from the computer is 4.8Mbs. In order to exploit this lower aggregate speed, memory buffereing synchronized with the video signal is necessary. Figure 19 is a block diagram of the proto-type digital authoring station. A Perkin-Elmer 3230 computer with 300 Mbyte disk drive supplies the data to the digital data encoder. A Panasonic switcher/sync generator provides video synchronization and sync insertion. The final video signal is then recorded on 2 inch video-tape.

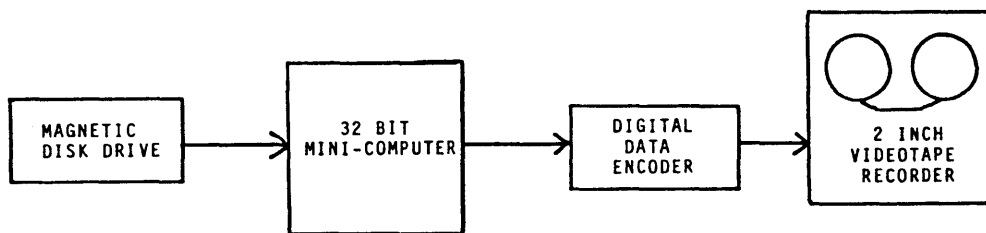


Figure 19.
Digital Authoring Station

In this scheme, the computer is effectively buffering data from the disk drive. The software driver for the digital data encoder must keep track of two buffers, one for the digital data disk drive, and another for output to the encoder. When the input buffer is full and the output buffer empty, then they must be switched. The video field number is available to synchronize this buffer switching.

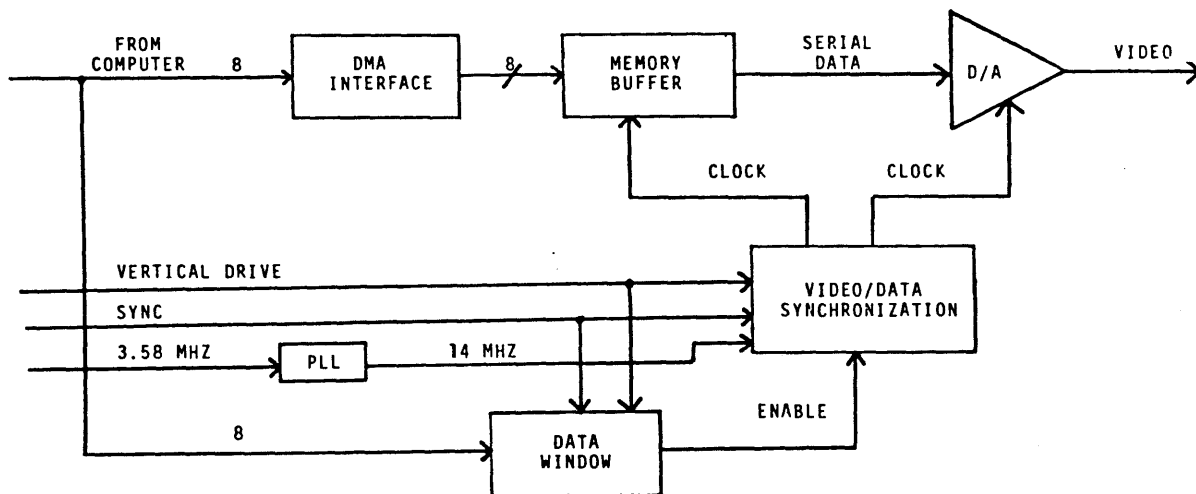


Figure 20.
Digital Data Encoder.

Figure 20 shows a block diagram of the digital data encoder. Connection to the computer bus delivers commands and data to the digital data encoder. The commands allow the data window parameters (start line, number of lines,

and number of fields) to be set. The data window enables data output only during the specified portion of the video signal. Parallel data is extracted by the DMA (Direct Memory Access) interface and delivered to the memory buffer. A phase lock loop multiplies the color subcarrier for use by the video/date synchronization circuitry. The circuitry then clocks serial data out of the memory buffer and into the video digital to analog converter/(D/A).

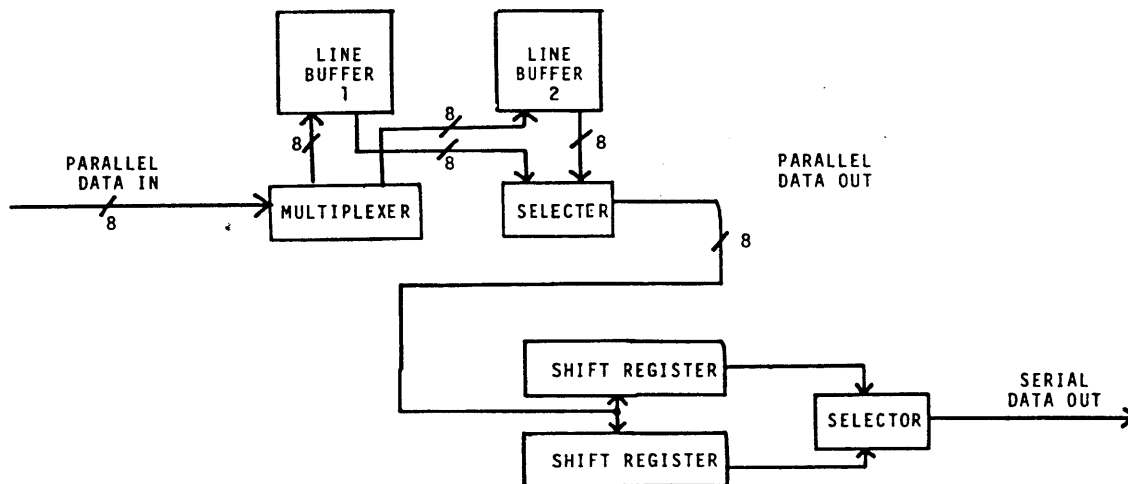


Figure 21.
Memory Buffer

Taking a closer look at the memory buffer in figure 21, parallel data is multiplexed to one of the dual buffers.

Each buffer contains 42 bytes of 500 nanosecond memory. Since a 7.16 MHz bit clock specifies an 8 bit byte time of 1.15 microseconds, there is plenty of time to write to or read from the buffers. While one memory buffer is loaded by the computer, the other is read into one of the dual shift registers. The other shift register is simultaneously shifting serial data out to the video D/A.

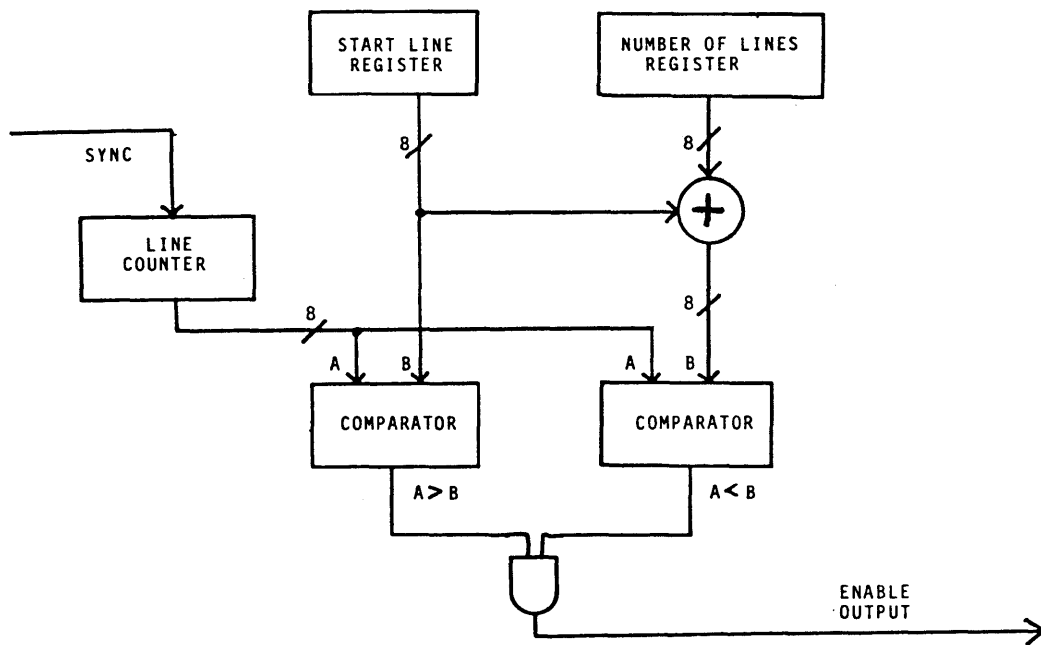


Figure 22.
Data Window

Figure 22 shows a detail of the data window. The video sync signal increments the line counter, which is used as one input to the dual comparators. The start line number and number of lines per field are loaded by the computer, and their outputs used to determine if the current line is in the data window.

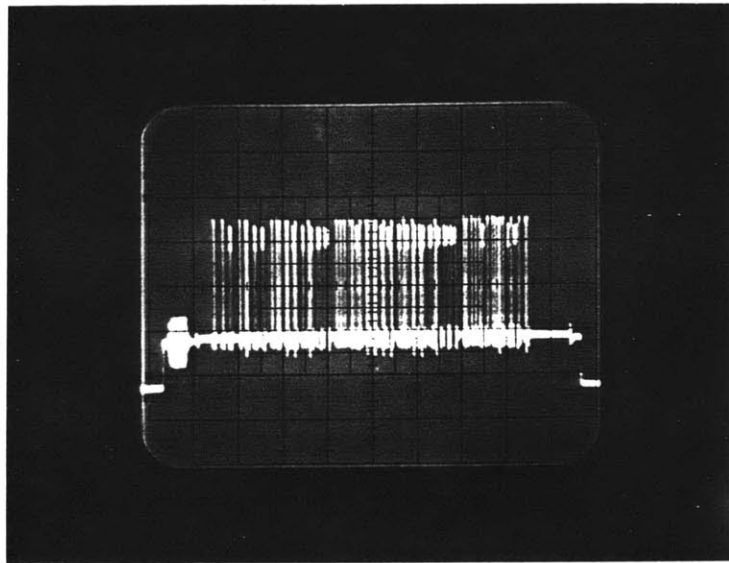


Figure 23.
1 Digital Video Line; 6.3 us/Division

Figure 23 shows one line of video output from the prototype digital data encoder, and figure 24 shows the waveform of twenty bits. Figure 25 shows the phase relationship of the data on an NTSC vectorscope.

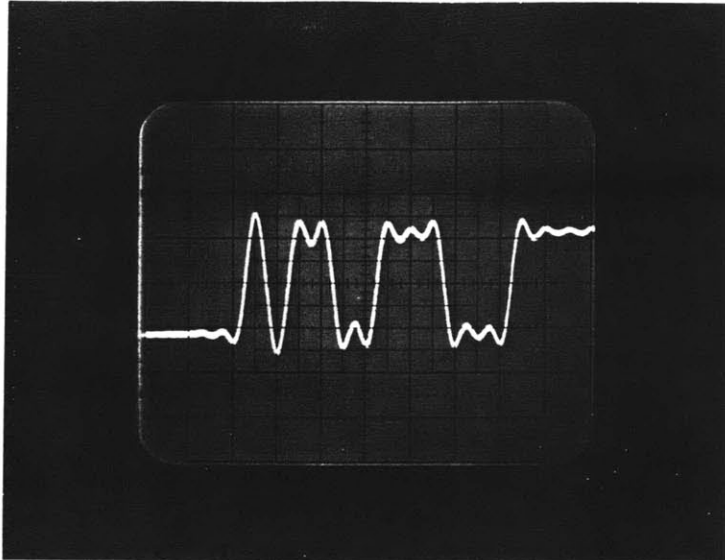


Figure 24.
 20 Bits of Digital Data Modulation;
 "00001011001110001111"
 2 Bits (288 ns) per Division

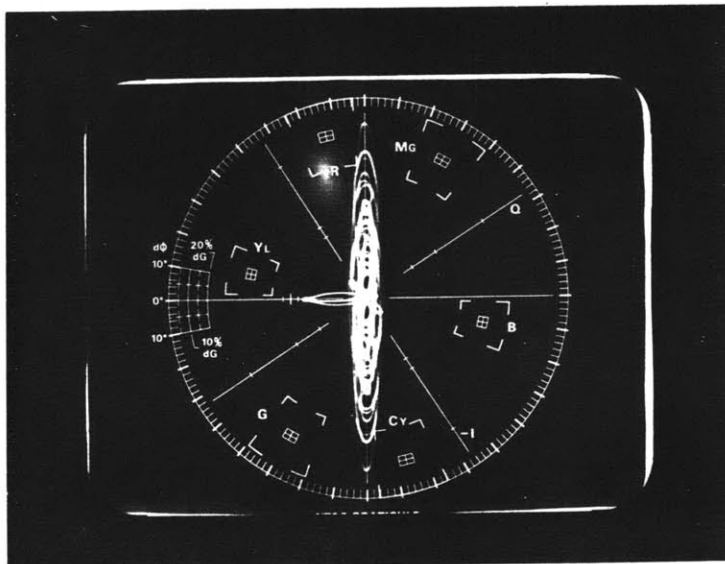


Figure 25.
 NTSC Phase Plot of Digital Data

The prototype digital data encoder was used to author an automatic transmission manual onto videodisc in early 1982. By use of a digital data decoder, the modulation and error correction of use pre-master tape were verified before being sent to DiscoVision Associates (DVA) for mastering.

2.4 ALTERNATIVES AND DEVELOPMENTS

The data scheme described was picked for its simplicity, reliability, and realizability. Other schemes could be devised to meet other criteria. For instance, the data rate could be lowered so that data could be encoded on consumer videotape recorders. This could encourage a video digital data standard for many different types of video storage. The decreased data rate would also allow a less sophisticated digital data encoder to be employed, providing much wider access to authoring equipment.

Contrawise, a denser data medium could be provided by multi-level modulation. Bypassing intermediate tape generations and direct to videodisc digital data mastering could make this possible. If direct control of the mastering process was available, video could be bypassed altogether and direct FM encoding employed. Either of these possibilities would require acceptance of the digital data concept by the manufacturers.

If the pre-mastering medium could be recorded one frame at a time, the digital data encoder would be simplified to a digital frame store. The speed requirements on the encoding computer would no longer be critical, and single frame visual material could be assembled without the need of an intermediate film stage. A write once

optical videodisc would not only provide these benefits, but would also allow interactive programming to be tested directly. Write once capability would turn the pre-mastering station into a powerful programming tool with feedback for the videodisc author.

2.5 CONCLUSION

Ultimately, the success of the digitally augmented videodisc depends on its perceived need by users and acceptance by manufacturers. The optical videodisc, while expensive as a consumer movie medium, is cheap as a computer peripheral. The only way videodiscs are going to overcome their tepid success is by digital augmentation. The ramifications of personal access to upwards of 500 Megabytes of information have barely been touched.

The program outlined in this thesis should not be seen as the only scheme available, but rather as a test bed for developments yet to come. A standard for video digital data encoding, however, will benefit all involved. A user should need access to but one type of decoder, and a videodisc author should be assured universal readability of his product.

REFERENCES

1. Backer, David S. and Lippman, Andrew B., "Future Interactive Graphics: Personal Video," Cambridge; MIT Architecture Machine Group paper, 1980.
2. Barstow, J.M., "ABC's of Color Television," Journal of the SMPTE, Vol. 65, February 1956, p. 3.
3. Brown, Eric S., "Digital Data Bases on Optical Videodiscs," Cambridge; MIT Bachelor of Science thesis, 1981.
4. Clark, A.P., "Principles of Digital Data Transmission," New York; John Wiley & Sons, 1976.
5. Hecht, M. and A. Guida, "Delay Modulation," Proceedings of the IEEE, Letters, July 1969.
6. "I/O Interface Design Specification," Perkin-Elmer Computer Systems Division, 1975.
7. Kenney, G.C., "Special Purpose Applications of the Philips-MCA Videodisc System," IEEE Consumer Electronics Transactions, November 1976.
8. Lindsay, W.C. and M.K. Simon, "Telecommunications System Engineering," Prentice-Hall, Inc., 1973.
9. Lippman, Andrew B., "Movie-Maps: An Application of the Optical Videodisc to Computer Graphics," Proceedings, Graphics and Interactive Techniques, 1980, Seattle.
10. Lippman, Andrew B., "Movie Manuals: Personalized Cinema as an Instructional Partner," Cambridge; MIT Architecture Machine Group, ONR Proposal, 1980.
11. Lippman, Andrew B., "The Computational Videodisc," IEEE Transactions on Consumer Electronics, Vol. CE-27, No. 3, August 1981.
12. Lucky, R.W., J. Salz and E.J. Weldon, Jr., "Principles of Data Communication," New York; McGraw-Hill Book Co., 1968.
13. Lucky, R.W., "Common Carrier Data Communications," Computer Communication Networks, ed. F.F. Kuo, Prentice-Hall, Inc., 1973.

14. Marti, B., A. Poignet, C. Schwartz, and V. Michon, "The Antiope Videotex System," IEEE Transactions on Consumer Electronics, Vol. CE-25, No. 3.
15. "Model PR-7820 Videodisc Player Service Manual," MCA DiscoVision Associates, 1979.
16. Mohl, Robert F., "Cognitive Space in the Interactive Movie Map: An Investigation of Spatial Learning in Virtual Environments," Cambridge, MIT PhD thesis, 1981.
17. Mohl, Robert G., "The Interactive Movie Map: Surrogate Travel with the Aid of Dynamic Aerial Overviews," Cambridge; MIT Architecture Machine Group paper, 1980.
18. Mothersole, P.L., "Teletext Signal Generation Equipment and Systems," IEEE Transactions on Consumer Electronics, Vol. EC-25, No. 3, July 1979, p. 345.
19. Negroponte, Nicholas P., "The Impact of Optical Videodiscs on Filmmaking," Cambridge, MIT Architecture Machine Group paper, June 1979.
20. NTC Report No. 7, Video Facility Testing/Technical Performance Objectives, June 1975 and January 1976.
21. Peterson, W.W. and E.J. Weldon, Jr., "Error-Correcting Codes," Cambridge; MIT Press, 1972.
22. "Phase Locked Loops," Signetics Analog Data Manual, 1977, Application Notes Section 26, p. 807.
23. Pioneer VP-1000 Laser Disc Service Manual, Japan; May 1980.
24. Schneider, E.W. and J.L. Bennion, "Videodiscs," Vol. 16, The Instructional Media Library, Educational Technology Publications, New Jersey, 1981.
25. Schwartz, M.D., "Integrating CAI and Videotape," Creative Computing, September 1980, p. 116.
26. Schwartz, Mischa, "Information, Transmission, Modulation and Noise: A Unified Approach to Communications Systems," New York; McGraw-Hill Book Company, 1980.
27. Shannon, C.E., and W. Weaver, "The Mathematical Theory of Communication," University of Illinois Press, 1949.

28. Sigel, Efrem, Mark Schubin and Paul F. Merrill, "Video Discs: The Technology, the Applications and the Future," White Plains; Knowledge Industry Publications, Inc., 1980.
29. SMPTE - Study Group on the Videodisc, Meeting Report, April 14, 1981.
30. "U.S. Demo" videodisc, MCA DiscoVision Associates, 1978.
31. Winslow, J., "Mastering and Replication of Optical Videodisc," Journal of Optical Society of America, April 1976, p. 379.

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