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DISC RECORDERS FOR VIDEO STORAGE — AN ANALOG TO DIGITAL EVOLUTION

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Abstract — **Magnetic disc recorders are in widespread use as storage devices for information in both digital and analog formats. Disc recorders used for storage of video information have been predominately analog machines; however, a new system to store and retrieve video graphics used in television broadcasting utilizes digital signal processing techniques and digital recording on computer disc drives. This paper provides a description of this digital system and a brief review of current analog video disc machines.**

I. INTRODUCTION

Disc recorders used to record and reproduce video signals have been available since the late 1960's. These devices have wide bandwidth capability to accommodate the real-time recording of frequency modulated, analog video signals. Also, their disc drive systems have usually been servo controlled in both phase and frequency to achieve stable synchronization to external sources.

These two areas: (1) high bandwidth in the analog domain (to 15 MHz) and (2) disc drive system under servo control from non-power line sources, distinguish the analog video disc system from its digital counterpart in computer disc drives. Other design differences occur in their head arrangements and control systems.

The typical format for video disc recorders is to record one video field (or frame) per disc revolution. Thus, one full field is available from each circular, recorded track on the disc. This format not only allows storage and "random" access to individual fields, but also provides the ability to reproduce successive fields at variable rates using sequentially stepped heads. These devices are known as slow motion recorders and provide the "instant replay" feature of televised sportscasts. This slow motion application, and the broadcast industry in general, is a major marketplace for existing and future technology in video disc recorders.

The capability of disc recorders to provide permanent, high quality storage of individually accessible video fields and to provide continuous, self-refreshing output with external buffers has led to many applications in:

Medicine
Aerospace
Science
Business Systems
Broadcast Systems

The basic wideband technology of video disc systems has also been applied to high density instrumentation recorders.

Progress in video disc technology has continued with stimulus for new applications by the broadcast industry. A real-time video frame storage system has been developed using digital video techniques and computer disc drives. The resulting product provides:

(1) High quality continuous reproduction of video signals using very reliable disc drives.

(2) In its particular application, fast on-line random access for a maximum of 2400 video frames.

The following sections of this paper will describe the technology and basic configuration of a digital video storage system using the Ampex ESS product as the basis for discussion. The development and technology of today's analog products that utilize "hard" disc systems will be reviewed as well as the emergence of flexible discs as video storage devices.

II. ANALOG SYSTEMS

The development of practical video disc recorders was based in large measure upon the fundamental FM technology applied to rotating head videotape recorders. The use of frequency modulation for video recording provided the necessary frequency span reduction to allow full range video signals to be within the useful magnetic recording range.[1] FM is also desirable due to amplitude variations inherent in magnetic recording. FM deviation standards have been selected to minimize noise and objectionable beat patterning (called moiré) in reproduced color pictures. These standards are used in the video disc slow motion recorder to provide high quality color recording.

Concurrent with the development of optimum FM deviation standards was the requirement for wide-range, phase-linear, reproduce equalization circuits. These circuits provide high frequency response correction and shaping to compensate for variations in head/disc response. Head/disc writing speed changes by more than 2:1 from inner to outer tracks on the disc, creating significant high frequency response (and noise) variations of the reproduced signal depending upon the radial location of the track being used.

The video disc recorder used in broadcast color applications also requires time base stabilization of the reproduced signal to preserve the color phase (hue) and synchronization. The time base correction devices employed are identical to those used in broadcast videotape recorders. (Non-broadcast color units can use a type of color stabilization using heterodyne techniques that do not require time base correction.)

While the video signal systems used in analog disc recorders were "borrowed" from previously developed videotape techniques, the head/disc technology is unique and sophisticated. In order to achieve the required frequency response, the head and disc must be in very close proximity. Head to disc spacing is typically 7-10 microinches in video disc units compared with 30-40 microinch spacing in computer disc drives.

A 16-inch disc rotating at 3600 rpm (typical numbers) in such close proximity to a delicate magnetic head has produced stringent design and manufacturing requirements on both the disc and head mounting assemblies. The discs are made of aluminum substrate, lapped to optical flatness; then electroplated with a magnetic cobalt alloy, and finally plated with a thin layer of rhodium for protection (Figure 1).

It is this head/disc interface that produces major limitations for analog video disc systems, namely:

(1) High operating costs due to expensive, precision discs.

(2) Operational reliability due to the close head/disc spacing (Figure 2).

Performance specifications for analog video disc recorders are comparable to high quality videotape recorders. Typical figures for key specifications are:

Signal-to-noise ratio:	−43 to −46 dB.
Frequency response:	Flat, ±0.5 dB to 4.2 MHz.

A recent introduction to the video disc market has been an analog recorder using flexible disc magnetic recording medium. These devices are intended for video frame storage and have a single-surface capacity of about 200 frames. At present, they have a single moving head assembly and thus, are not used for continuous slow motion.

Their signal performance is close to other analog disc units although writing speed is less than the larger, rigid discs. Flexible disc recorders offer promise in providing lower initial and operating costs over rigid disc units. They are typically smaller size and more convenient to operate than the rigid disc type. However positive, penetrating contact is required between disc and head to obtain the necessary frequency response. This limits the useful life of both head and disc. It is uncertain at this time, about the flexible disc's usefulness as a permanent, non-destructive medium for archival storage applications.

III. DIGITAL SYSTEM

Development of a digital video storage product was spurred by a broadcast industry need for an improved system to record, store, and retrieve still frames of video information, such as slides or graphics. The resulting Ampex product is the Electronic Still Store* graphic retrieval system. The system stores video images (frames), in digitized form, on mass storage devices, namely, computer disc drives. The product includes a sophisticated, computer-based control system that provides fast random access to any frame plus the ability to assemble and reproduce a prearranged sequence of frames.

The general technical requirements for this application included:

(1) High reliability.

(2) Large permanent storage capacity.

(3) Fast random access.

(4) High picture quality.

(5) Continuous output without external buffers.

The fifth requirement narrowed the choice of storage devices to some type of magnetic disc technology. "Hard" video discs, as used in existing analog recorders, did not meet the high reliability criteria due to their critical head/disc interface. Flexible discs were considered, but have not yet been used in large archival applications where unattended, repeated usage is a requirement.

The type of disc thus chosen was the disc drive currently in widespread use in the computer/peripherals industry. These devices have proven reliability and a sufficient capacity to satisfy the application.

The magnetic storage medium of these devices consist of industry standard disc packs containing ten discs and 19 available data recording surfaces. The storage capacity of one disc pack for the chosen format is 800 video frames. Disc packs are easily loaded on and off the drive to provide readily available off-line storage of recorded material.

Head-to-disc interface reliability is enhanced by the disc material and the head design. The discs are made from a thin aluminum disc coated with gamma ferrous oxide. This magnetic oxide coating is more tolerant of occasional head/disc contact than the hard rhodium surface of analog discs. The head "flies" or is separated from the disc approximately 40 microinches and is mounted in a ceramic slider mechanism. The head sliders are not loaded onto the disc until the full rotational speed has been achieved for several seconds after startup. This allows for dimensional stabilization of the disc pack with temperature as well as purging the pack of any loose dust particles. Similarly, the heads are withdrawn before the spindle stops upon shutdown.

These basic features of the computer drive were not altered in any way for the video storage system, thus preserving the reliable head/disc interface.

The disc drive has a unique electromechanical head positioner system. There is one head for each of the 20 disc surfaces and they are all mounted in parallel on a common carriage controlled by a linear dc motor. One of the heads, designated as the servo head, travels on a pack surface containing servo-track pairs prerecorded by the pack manufacturer. These servo tracks fill two functions: (1) to provide information that determines the instantaneous location of the heads, and (2) to provide an error signal that is used to control the linear motor position that keeps the head centered on the appropriate servo track. This feedback system makes it possible to achieve a radial packing density of 400 tracks per inch, or 800 tracks per disc.

The design of the access system provides stack acceleration sufficient to traverse the entire range of 800 tracks in approximately 60 milliseconds, including settling and to move between adjacent tracks in ten milliseconds. Thus, the requirement for fast, random access to any track is met by the computer disc drive.

Next we examine the requirement for a high quality signal system and relate the computer disc drive, with its unmodified heads and discs, to the needs of video recording. The Ampex DM-331 model drive was chosen primarily because of its large storage capacity of 200 megabytes per disc pack (1 byte = 8 bits) and its convenient rotational speed of 3600 rpm. This drive, with its high bit packing density and rotational speed, can transfer digital data at about 6.5 Mbits/sec with linear writing speeds of about 2000 in./sec. Due to the wide separation between head and disc, however, its actual record/reproduce frequency response is insufficient to accommodate a high carrier (10 MHz) FM signal required for high quality color recording. Thus, analog recording was not practical using computer disc drives (Figure 3).

Fortunately, extensive work has been done in designing practical digital video processing systems. Such systems began appearing in the broadcast market about 1973. They were designed to provide time base correction of video signals from videotape recorders. Much of the technology developed for digital time base correctors is utilized within the video system of ESS for the development of a highly accurate, high-speed analog-to-digital converter and an equally accurate, transient-free, digital-to-analog converter. There is general acceptance within the industry of an eight-bit resolution system (256 discrete levels) operating at a signal-coherent sampling rate of 10.7 MHz (three times the video color subcarrier in NTSC) as a digital coding system that will provide high quality/low noise video signals.[2]

By redesign of the read/write circuits in the basic drive, a throughput response was achieved to accommodate a digital data stream of 10.7 megabits/second on any signal channel of the drive. This represents an approximate 60% increase in linear packing density of the drive or 6000 bits/inch at 3600 rpm.

Pack rotation of 3600 rpm is maintained for this application; however, the power-line synchronous drive is replaced by a servo system that locks pack rotation to a TV field rate reference. The servo design is of the ac "power inverter" type in order to retain use of the original ac motor in the drive (and thus avoid commutation).

The availability of multiple parallel heads and discs on the computer drive led to a fundamental, key element in the ESS design — the technique of simultaneous, parallel use of eight read/write channels to record/reproduce one field of digitized video information (Figure 4). This allows eight individual data streams operating at a 10.7 megabit/seconds rate to be simultaneously recorded on the disc pack. This provides an effective, instantaneous data transfer rate of 86 megabits/second when considering all eight channels. This is the data rate needed to achieve high quality, color images at a normal video bandwidth without resorting to bit rate reduction schemes.

The signal-to-noise ratio of this digital TV system is primarily determined by quantization noise rather than by disc and preamp noise as in the case of an analog disc recorder. This is true provided that the digital random error rate of the storage channels is low enough to make occasional transmission errors invisible. With quantization as the limiting factor, the system delivers a signal-to-noise ratio of better than −50 dB.

Using this technique, recording one TV field requires one revolution of the disc, and simultaneous use of eight parallel heads, and recording a full TV frame requires two revolutions and a total of 16 parallel heads. Thus, a frame occupies 16 of the 19 available tracks of any one cylinder. A disc pack cylinder comprises all of the tracks

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on the disk pack that lie on the same radius. A disc pack contains 800 such cylinders and therefore, can store 800 video frames as mentioned earlier.

The record/reproduce system of ESS at a block diagram level will now be examined.

In the simplified record-signal flow diagram (Figure 5), the composite video-input signal passes through the entry stage where video dc clamping takes place. Sync and subcarrier components are stripped and regenerated for use by the digital clock generator. The signal is then digitized in the A/D converter. At the output of the converter, digital video is available in a parallel eight-bit format sampled at 10.7M samples per second. Sampling involves use of the PALE method, an inversion of sampling phase every TV line to facilitate digital chroma processing on the reproduce side.[3]

In the next stage, the eight-bit NRZ video word is converted to a special recording code called Miller[2] and is particularly suitable for digital magnetic recording.[4] This code minimizes the dc content of data streams if long strings of similar data are encountered. In addition, each of the eight data lines receives a synchronizing word once every TV line, timed precisely with respect to a reference horizontal sync. On playback, the sync word is used as a reference for correction of time base and skew error.

As stated earlier, to record a full TV frame, the disc performs two revolutions. The first field of the frame is switched to one group of eight heads via eight record amps, and the second field to another group of eight heads so that recording of a frame involves 16 heads without mechanical motion of the head carriage.

In the reproduce signal-flow diagram (Figure 6), the signal is routed from two groups of eight heads, each into eight preamplifiers, analogous to the two-field record cycle. The following equalizer compensates for the head response and corrects the timing of signal transitions. A zero-crossing detector produces a square wave from the equalizer output, representing the encoded original signal.

In the next stage, the signal is decoded to an NRZ format. Each of the eight individual data lines is brought to a time base corrector that will locate the inserted sync word and use it to remove any head skew and time base error contained in the signal. (Head skew is the static and dynamic displacement of parallel heads with respect to each other). The signal is now timed to an external reference. In this manner, all eight data lines are individually corrected and the original digital video word stream is reproduced. It is significant to note that there are eight channels of reproduce electronics up to and through the time base corrector. A ninth channel is also there for a data track.

Before the digital signal can be reconverted to the analog domain, another processing step takes place peculiar to NTSC video. In order to regenerate the appropriate four-field NTSC chroma cycle from two recorded fields, the color signal must be separated, inverted at frame rate, and recombined with the luminance. This is accomplished in a digital comb filter and chroma inverter. The final step is the conversion of eight parallel digital data streams to a serial, analog video signal. The output stage adds the necessary sync and color burst information and serves as a video line driver.

Signal system and disc performance of the system have been excellent. It has been difficult for experienced video technicians to detect differences in subjective picture quality between pictures being reproduced from the disc and those that have passed only through the system electronics. Formal performance specifications for video performance are comparable to the highest quality videotape recorders. It has been possible to perform over 100 recording transfers (dubs) of the digital data between disc drives without picture degradation.

The first commercial system has been installed at the customer site, with on -line operations expected in early 1977 (Figure 7).

REFERENCES

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(3) J. P. Rossi, "Color Decoding a PCM NTSC Television Signal," Journal SMPTE, 83:489-495, June 1974.

(4) J. C. Mallinson and J. W. Miller, "On Optimal Codes for Digital Magnetic Recording," a paper presented at the International Telemetering Conference, Los Angeles, California, Sept. 1976.

Figure 1
Disc Drive with Mounted Disc
Ampex HS-100C Slow Motion Recorder

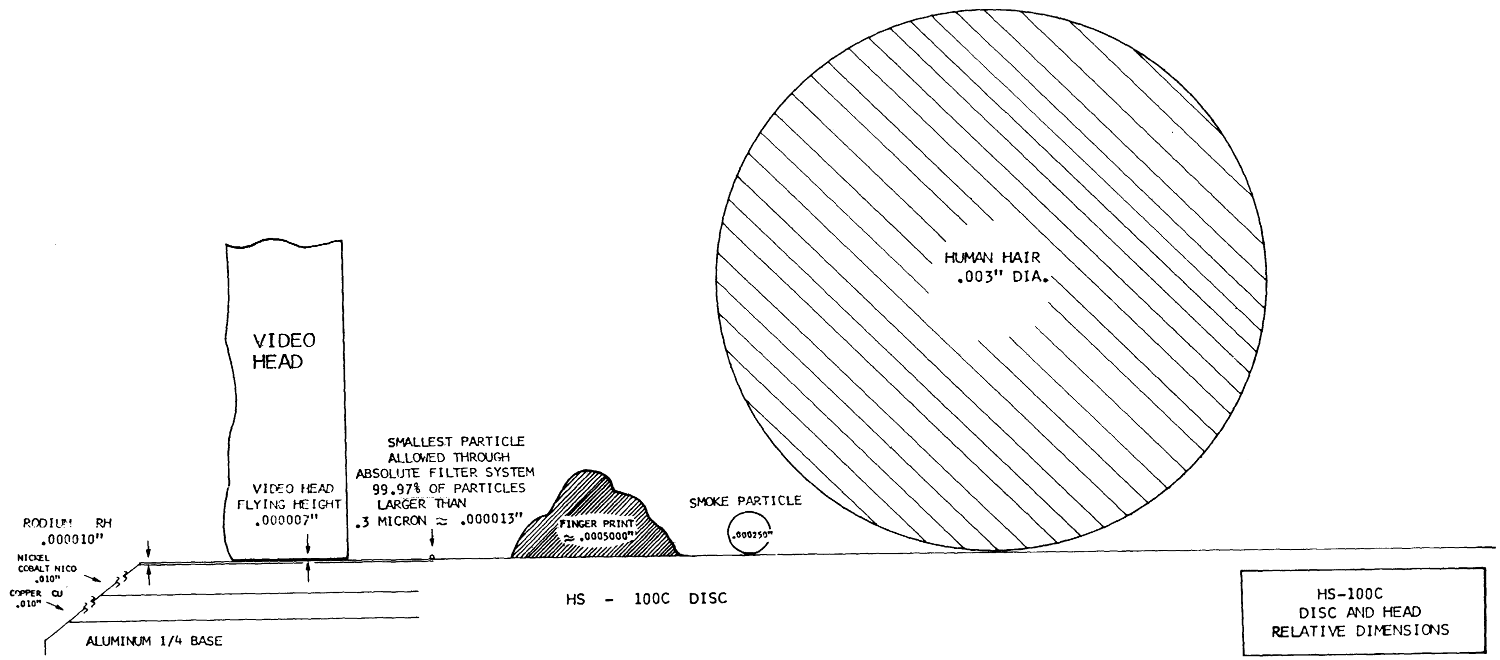

Figure 2
Comparison of Common Contaminants to Head/Disc Spacing

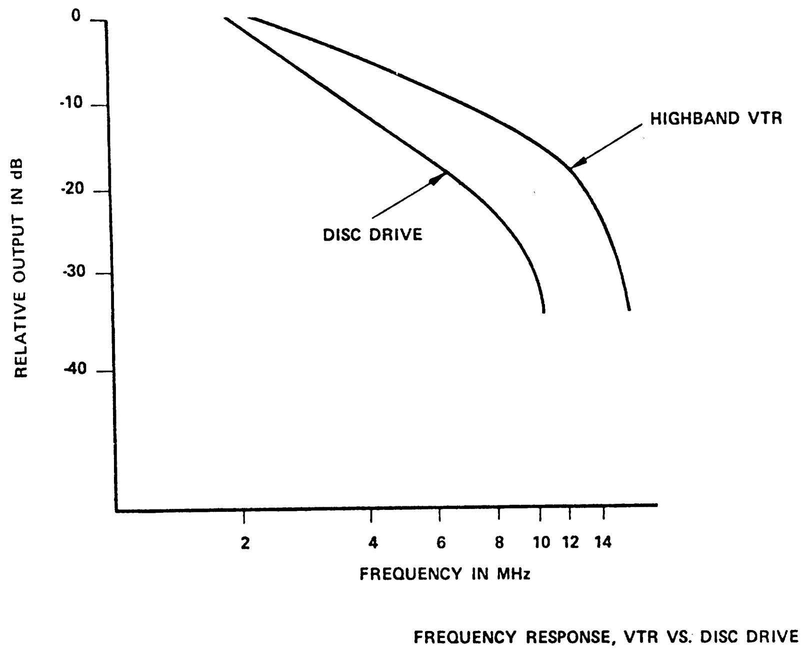

Figure 3

Frequency Response Comparison
Broadcast Videotape Recorder (VTR) and Computer Disc Drive

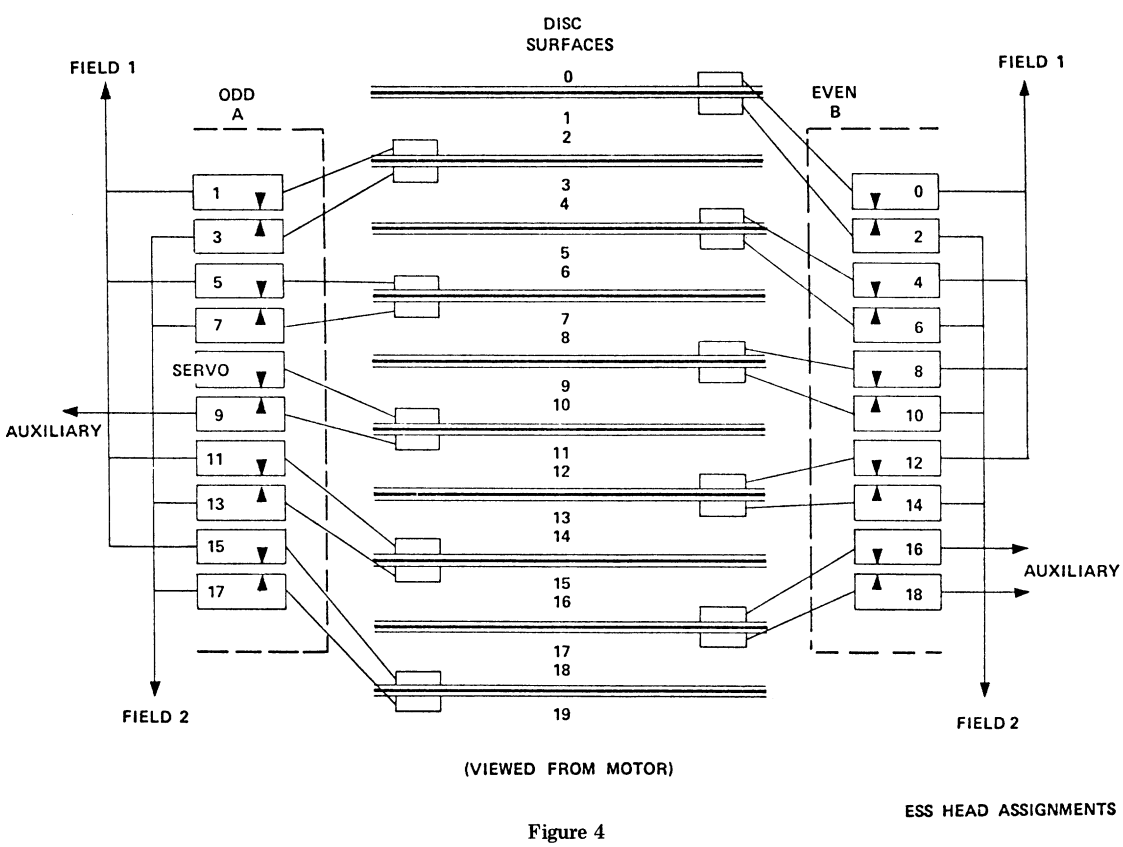

Figure 4
Ampex ESS Head/Disc Surface Assignments to the Eight Data Paths
of Odd and Even Video Fields

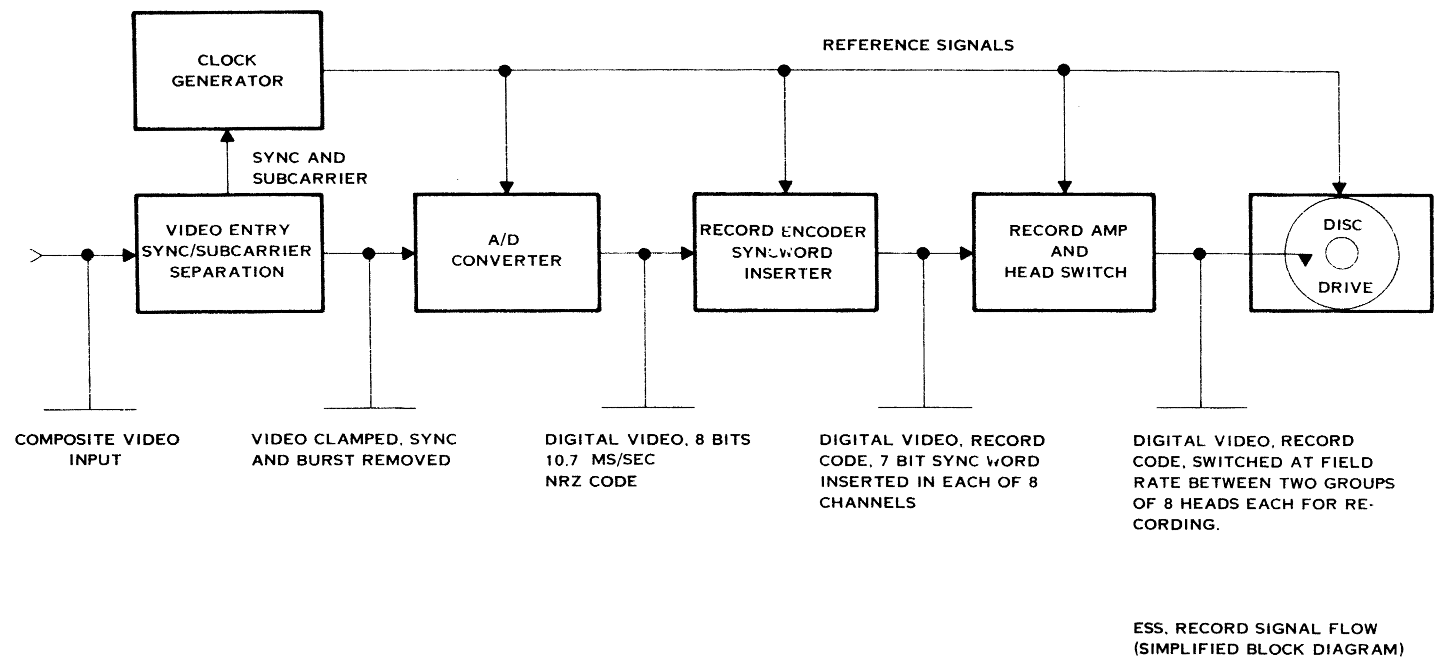

Figure 7
Ampex ESS System

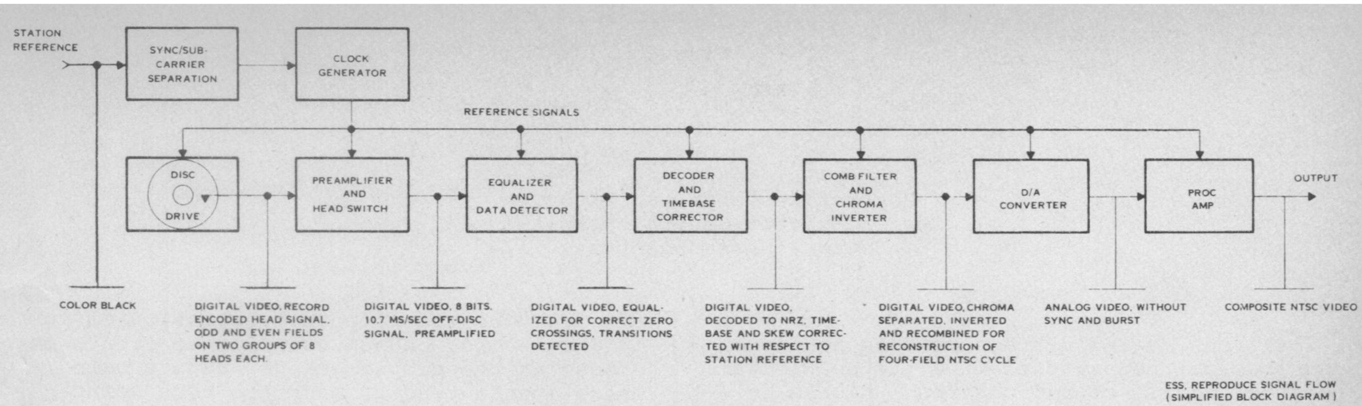

Figure 5
Ampex ESS Record System Diagram

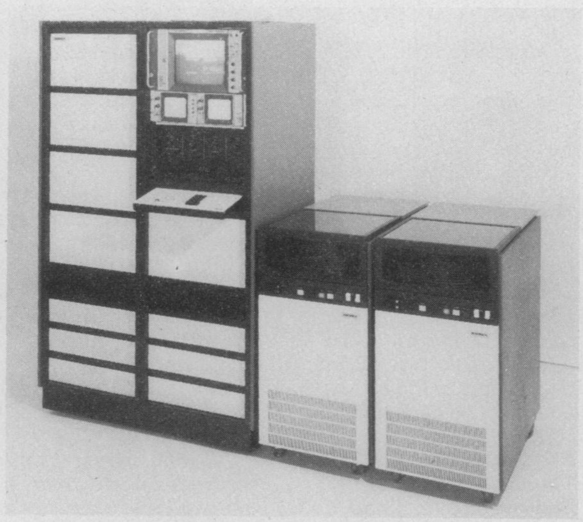

Figure 6
Ampex ESS Reproduce System Diagram