MEETING THE FUTURE NEEDS FOR HIGH DATA RATE DIGITAL RECORDING

DAN O'CLARAY AND HENRY TOBIN

DATATAPE INCORPORATED
360 SIERRA MADRE VILLA
PASADENA, CALIFORNIA 91109

ABSTRACT

In order to satisfy future instrumentation data recording requirements, the availability of high data rate recorders with long record times is most desirable. Also, assurance of commonality amongst the many users of these data requires that any system designed be compatible across the user data base. Hence, the American National Standards Institute (ANSI) has developed a tape format standard that will assure commonality and exchange of data in an acceptable manner. This standard also establishes data rate recording requirements using a commercially available media in cassette form that will satisfy the operational need. DATATAPE is developing a recorder system that will meet the ANSI requirements of the data format on tape, as well as the data rate and record times implied by the standard. This paper discusses the development of the tape format standard and the design of the system that will fully comply with the standard. Test data will be presented to verify system capabilities. Additionally, DATATAPE's progress in developing a system that will comply with the similar Department of Defense (DOD) tape format Standard, MIL-STD-2179, will be presented, along with a summary of DOD programs that require MIL-STD-2179 compliant recorder systems.

Key Words: Magnetic Recording, Digital, Cassette, Data Recording

INTRODUCTION

Sophisticated new DOD weapons and intelligence systems have led to an increased need to use digital instrumentation recorders. Tests of these new systems have resulted in the need for increased telemetry data rates as well as the desire for reproduction of the recorded tapes without discernible degradation of the signals on tape. Higher bandwidth requirements, for both analog and digital signals, have made it necessary to utilize improvements in magnetic recording technology beyond that normally used by the telemetry community.

While past developments of the improved capability systems have often been carried out with government funding, budget restrictions have required the use of modified commercial video products to meet the government's needs. Examples include the use of commercially available 8mm technology in computer peripheral applications and the use of VHS products for image recording.

Historically, advancements in telemetry data recording occurred in small, incremental steps. The most significant recent development has been DATATAPE's introduction of double density recording, which has led to a doubling of the available record time for a particular bandwidth of interest. Conventional longitudinal recording has reached its limits, however. As higher frequencies are to be recorded, the system head-to-tape speed must be increased. In longitudinal systems, this can only be achieved by increasing the linear tape speed. As this is done, the tape tends to be lifted from the head due to the presence of a layer of air between the head and the tape. Since signal strength on reproduction decreases 55 dB for every wavelength of separation, this problem becomes acute when high frequency (short wavelength) recording is required.

To allow higher frequency bandwidth recording to be achieved, rotary recording techniques must be used. Similar in technique to methods used in home video recording, rotary recording uses a slow linear tape velocity with a counter-rotating head to achieve a high head-to-tape speed. The tape passes over a drum, which houses the recording and reproduce heads which are mounted on the headwheel located in the center of the drum. The heads protrude from the drum, which assures good head-to-tape contact. The low linear tape velocity provides increased record times for an equivalent amount of data.

Rotary recording can be done using either analog or digital recording techniques. There are several reasons for the increased use of digital techniques in both commercial video and instrumentation recording. First, detection of a digital signal can be done with lower signal-to-noise ratios (SNR) as compared to analog systems. Second, extremely powerful error correction schemes have been developed for digital systems, allowing low bit error rates to be achieved. Third, digital recording allows channel encoding schemes to be used which minimize the dc content of the recorded signal. Since the magnetic recording channel has poor response at low frequencies, the channel code is able to optimize the spectral energy of the signal to match the response of the channel. Finally, the use of digital recording allows direct interface with computer systems, which are often used to analyze the recorded data. The low cost, size and power requirements of digital electronics has pushed recording technology in this direction.

The desire to use digital recording methods, while capitalizing on commercial video products, has led the government to increase efforts in utilizing the latest developments in digital television recording. This paper describes developments in the broadcast industry which have led to high data rate instrumentation recording systems. Tape format and other standards are presented which have been developed to assure interchange capability. Government programs which require the use of this technology are listed. Finally, a family of recorders which has been developed to meet these needs is described, together with preliminary test results.

HIGH RATE DIGITAL RECORDING STANDARDS

The broadcast television industry has been using rotary recording techniques since the introduction of the two inch, quadrature scan machine by the Ampex Corp. A number of scan formats have subsequently been developed, including several used by consumers at home. An important aspect of the commercial industry is the ability to duplicate recordings, either for further distribution or to facilitate material editing. Standard analog recordings tend to exhibit degradation in picture quality after only four or five duplications. This causes an economic problem for the users. Therefore, the industry decided to develop criteria for a digital video recording scheme which would provide improved duplication capability through at least twenty copies, without visible degradation.

Concurrent efforts were begun by the Society of Motion Picture and Television Engineers (SMPTE) and the European Broadcast Union (EBU) to develop a digital recorder standard which would provide improved performance capabilities, utilize a cassette and would be based on the use of a component recording scheme, rather than the previously used composite scheme. It was further recognized that any standards developed should allow the use of the broadcast machines in both the US and Europe.

The developed standards describe the tape to be used, the cassette which holds the tape, the auxiliary track format, and the helical scan format. Figure 1 shows the agreed upon format. As can be seen, a 19mm tape format is used, with two auxiliary tracks for time code and cue signals, one control track, and four audio channels, located in the center of each scan. While revisions to the standard are ongoing, it is interesting to note that the standards were basically agreed upon before hardware existed. The error correction scheme is also defined in the standard, as well as techniques to be used for error concealment. The scheme selected was based upon use of a tape model which used best estimates of the expected burst lengths which would be encountered.

The overall data rate on tape, which includes video and audio signals together with the necessary overheads, is about 227 million bits per second (Mbps). This data rate is significantly higher than that normally seen in the best standard longitudinal recorders, which is typically about 100 Mbps for a 28 track system. It was soon recognized by the government that this type of system could be adapted for instrumentation applications. By building on the baseline of the commercial recorders, development costs as well as acquisition costs could be minimized. In addition, it was assumed that the media would be widely available at relatively low cost.

This development approach, however, has certain disadvantages. The first is that the data rate, while high, will not meet all the projected government needs. Commercial video machines run at a fixed data rate while instrumentation recording requires a variable data rate capability, both during record and reproduce. In addition, military equipment must often operate in hostile environments for which the commercial machines would be inadequate. Finally, the video industry can utilize error concealment schemes since the viewer tends to integrate errors in the image and the system itself can examine pixels surrounding that which is in question and fairly accurately predict what the erroneous pixels should be. Instrumentation applications require error detection and correction, which is technically a more difficult problem.

To take advantage of this commercial technology and to assure interchange between various manufacturers' recorders, two separate standards groups became involved in the development of instrumentation standards. The two Standards which have been prepared, ANSI X3B.6 ID-1 and MIL-STD-2179, are similar in most respects but differ in one significant aspect, namely, azimuth recording. We will first describe the ANSI Standard and then differences in the military Standard. The footprint on tape described in the ID-1 Standard is shown in Figure 2. It can be seen that the footprint is very similar to that of the broadcast machine, except that the audio channels in the center of each scan have been removed and a continuous data scan is substituted. Also, azimuth recording is used, whereas the broadcast standard calls for a zero azimuth angle with guard bands between each scan.

Since no machines were available to acquire test data at the time the standards were prepared, the ANSI Working Group decided to use azimuth recording based upon both theoretical analyses and from data obtained from other helical scan instrumentation recorders. Both the data and the analyses indicated a two-to-one margin in mistracking error by the azimuth method over the non-azimuth. When the changes in dimensions of the scanner and tape over the typical range of operating conditions were examined, it was clear that this advantage in tracking error would considerably enhance the operation of the system. The use of azimuth recording is the one major difference between the ANSI and the military standard. All manufacturers represented on the ANSI Working Group agreed to the use of the azimuth recording method.

Similar to the approach taken by SMPTE, the ANSI Standard references the tape standard and the cassette standard. The media used is a 850 Oersted, gamma ferric oxide. Although higher coercivity media was available when the SMPTE Standard was being prepared, it was decided not to use the metal particle tape, primarily because its archival capabilities are not known.

Three cassette sizes are described in the standards. Dimensions of each size are given in Table I, together with the length of tape in each cassette, total data storage capacity, and the record/reproduce time available at a data rate of 200 Mbps. Since the record/reproduce time is inversely proportional to the data rate, the available time would be halved if the data rate were doubled. It should be noted that the standard describes both a 16 and a 13 micron thick tape. At the present time, the thinner tape is not commercially available, so all data in the table is based upon the 16 micron thickness media. For comparison, conventional HDDR longitudinal recorders use a 25 micron thick tape. The ANSI Standard does not call out specific data rates for the recorder, while MIL-STD-2179 indicates that this class of machine should be capable of operation at data rates of between 10 and 480 Mbps, although not necessarily in one machine. As a comparison to conventional longitudinal HDDR operation, it should be noted that a single large cassette will be able to store the equivalent of about ten reels of data recorded on a twenty-eight track longitudinal recorder.

Table I - 19mm Cassette Characteristics

CASSETTE SIZE	DIMENSIONS (INCHES)	TAPE LENGTH (FEET)	CAPACITY (BITS X 10E11)	RECORD TIME (MINUTES)
Small	6.8 x 4.3	620	1.1	9.5
Medium	10.0 x 5.9	1,922	3.4	30
Large	14.4 x 8.1	4,298	7.6	66

Note 1 - All cassettes are 1.3 inches thick.
Note 2 - Record time is given for a 200 Mbps data rate and is inversely proportional to the data rate.

A Bit Error Rate (BER) of less than one error in 10E10 bits is specified in the Standard. In order to meet this objective, a Reed-Solomon error correction scheme is used. The design of the error correction algorithm was based upon the model developed by SMPTE to describe, as a function of burst length, the probability of the occurrence of a given size burst. The data to prepare the curve was estimated by media suppliers and then assumed to be ten times worse. An 8/9 channel code is also described in the Standard which has been designed to minimize the dc content of the recorded pattern.

Except for the use of azimuth recording, the use of randomization, and the allowable location of the control track head, MIL-STD-2179 is identical to that of the ANSI specification. Manufacturers, in order to satisfy both standards, will manufacture scanners with different head wheels. A switch will be included in the design to include, when needed, the randomization feature.

DOD PROGRAMS

The two Standards described, namely the ANSI ID-1 and MIL-STD-2179, have been used in the procurement of recording systems for a number of Department of Defense programs. Included are HIPERLON, the P3C-Upgrade IV, ATARS, JSIPS, and the EO-LOROP system. These are programs for which contracts have already been awarded. In addition, there are a number of ASW programs for which a recorder meeting MIL-STD-2179 will be specified. These include both surface and sub-surface vessels, as well as US and other NATO country aircraft.

In addition to these specific programs, the Telemetry Group of the Range Commander’s Council recently decided to recommend incorporation of the ANSI ID-1 Standard into Document 106-86, TELEMETRY STANDARDS. When this recommendation is adopted, all 19mm rotary data recorders used on instrumented ranges will be required to comply.

DCTR-LP FAMILY OF PRODUCTS

To meet the needs of the instrumentation recording community, DATATAPE is developing a series of laboratory and portable recorders which will meet the requirements of either the ANSI ID-1 Standard or MIL-STD-2179. Each member of this family of recorders will cover at least an 8-1 data range on record or reproduce. The machines will basically be identical except that the number of heads used on the scanner will vary, depending on the highest data rate required. Table II gives a comparison of the characteristics of this family for two data rates, namely, 400 and 200 Mbps. For comparison, the same characteristics of the SMPTE broadcast machines are shown. Figure 3 shows a prototype of this family of recorders.

Table II Comparison of SMPTE and ANSI Standards

	SMPTE D-1 DTTR	400 Mbit/s RECORDER	200 Mbit/s RECORDER
DRUM DIAMETER (Inches)	2.95	2.95	2.95
WRAP ANGLE	257^0	256^o	258^o
AZIMUTH	0^o	$\pm15^o$ or 0^o	$\pm15^o$ or 0^o
TRACK PITCH	1.8 (45um)	1.8 (45 um)	1.8 (45 um)
SCANNER RATE (Radians/sec)	149.9	173.1	173.1
NUMBER OF HEADS	4	8	4
TAPE VELOCITY (In/sec)	11.3	26.1	13
HEAD-TO-TAPE SPEED (In/sec)	1401	1632	1619
RECORD TIME (Minutes)			
D-1L	76	33	66
D-1M	34	15	30
D-1S	11	5	10
USER DATA RATE (Mbit/s)	179	400	200
TAPE DATA RATE (Mbit/s)	225	533	265
INSTANTANEOUS HEAD DATA RATE (Mbit/s)	79	94	93
LINEAR DENSITY (Kbit/in)	56	57	57
USER CAPACITY PER CASSETTE (Bits)			
D-lL	N/A	7.9×10^{11}	7.9×10^{11}
D-1M	N/A	3.5×10^{1}	3.5×10^{11}
D-lS	N/A	1.1×10^{11}	1.1×10^{11}
SPEED/RATE RANGE	Single Speed	8:1	8:1
CHANNEL CODE	Randomized NRZ	8/9 DC FREE CODE FOR VARIABLE SPEED. ANSI-ID-1 ALSO INCLUDES RANDOMIZING	
BER WITH ERROR CORRECTION	1×10^{-6} W/ECC	1×10^{-10} W/ECC (RS)	

The transport used in these machines is a modified broadcast version. All signal electronics, however, are being developed specifically at DATATAPE for satisfying instrumentation data recording and retrieval requirements.

TEST DATA

As of Spring, 1989, no machines meeting either ANSI ID-1 or MIL-STD-2179 had yet been delivered to customers, although three US firms, including DATATAPE, were under contract to deliver prototypes of such machines. One of the major concerns was the correction scheme. In order to verify the model, and to also demonstrate crossplay capability, tests were made utilizing two of the systems which were under development.

For these tests, scanners configured for 400 Mbps operation were used, that is, each scanner had eight write and read heads. The transports were capable of operation over an eight to one speed range to handle data rates of between 50 and 400 Mbps. However, only a single channel was recorded. The single channel data rate at the head, including overhead, is 94 Mbps, which is equivalent to a total user data rate of 400 Mbps if all eight channels are used.

Recordings were made on one machine at single channel rates of 94 and 11.75 Mbps. They were then played back at a data rate of 75 Mbps. On record, a pseudo-random sequence of 1008 bits was stored in memory. The sequence was sequentially read out and written on tape. The reproduced data was captured by a logic analyzer and stored in memory. A byte-to-byte comparison is made to the recorded data to determine that proper synchronization has been established. Byte-to-byte and bit-to-bit comparisons were then made on one scan every four seconds to determine the bit error rate.

The results of this test are shown in Figure 4. The data indicate that the model meets the expected media performance quite well. The data also demonstrate the ability to achieve crossplay between two different transports and scanners, as well as the capability to reproduce at data rates other than the record rate.

It should be noted, however, that the test described represents a limited sample of the available media. As development continues, the database will be expanded to media from more than one manufacturer and with more than a single channel in operation.

SUMMARY

A new class of digital cassette recorders is under development by a number of manufacturers. These recorders are based upon a digital broadcast recorder, and are based upon two standards developed by the American National Standards Institute and the DOD. This development is unique in that it represents the first time that standards have been developed before any hardware existed.

When these machines are in full production in 1990, they will offer new and expanded capabilities in terms of data rates, bit error rates, and record time to the user of instrumentation recorders. The use of a cassette will also provide the user with improved media handling capability as well as greatly increased volumetric data storage capabilities.

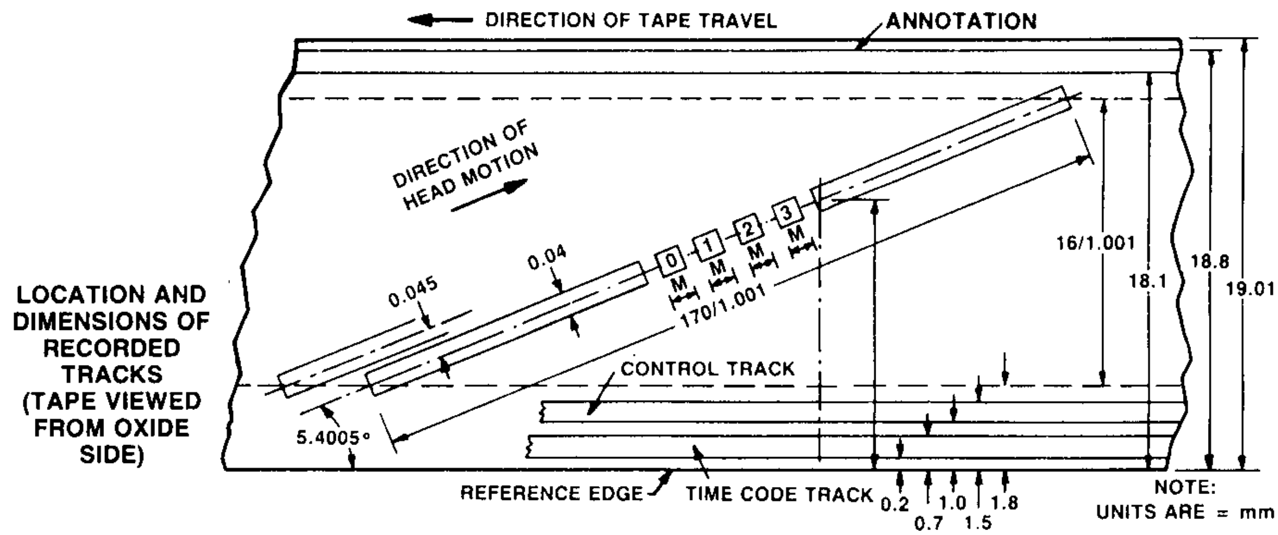

Figure 1 - SMPTE D-1 Tape Format

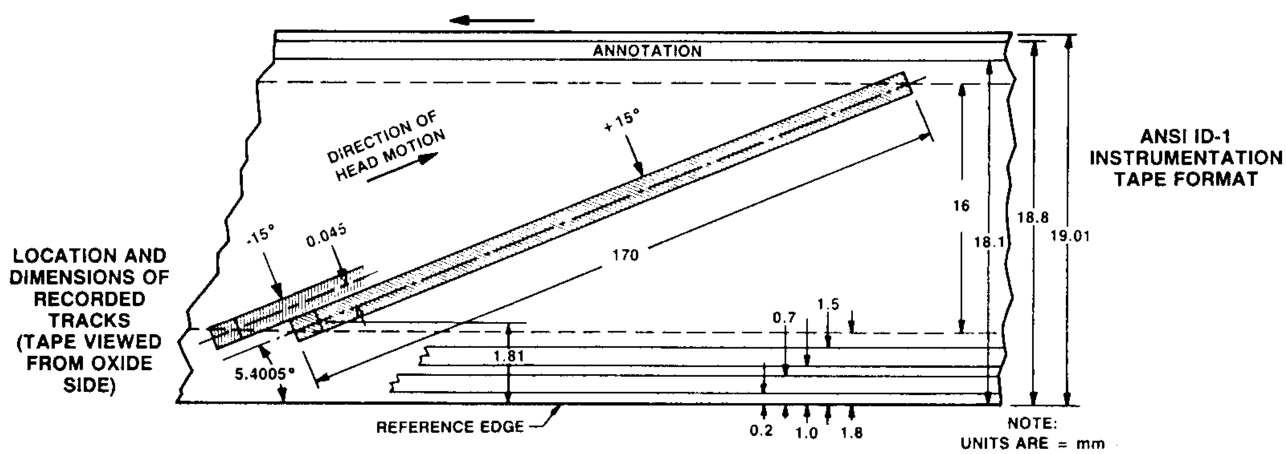

Figure 2 - ANSI ID-1 Tape Format

Figure 3 - ID-1 Prototype Recorder

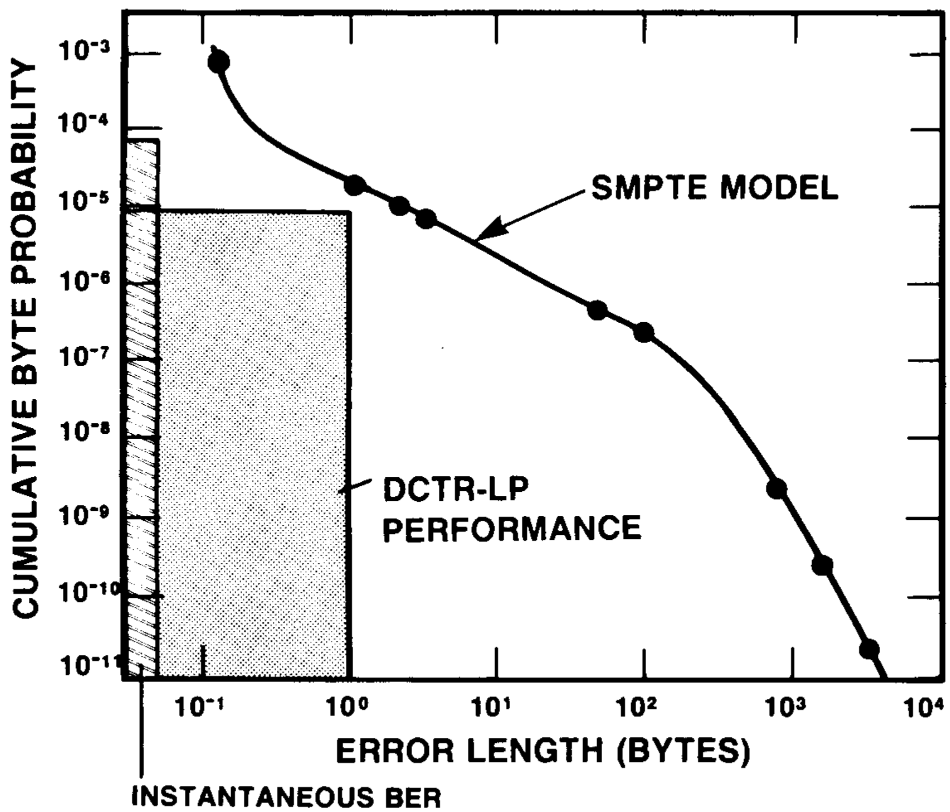

Figure 4 - Bit Error Rate Performance Compared to the SMPTE Tape Model