# THE ADVENT OF D-1 TECHNOLOGY

**Tracy G. Wood**
**Manager, Advanced Technology Department**
**Data Systems Division**
**Ampex Corporation**
**Redwood City, California**

## ABSTRACT

The advent of the D-1 cassette standard will have a profound impact upon the instrumentation tape recording industry starting in about 1990. Under the auspices of the Society of Motion Picture and Television Engineers (SMPTE) and the European Broadcast Union (EBU), broadcasters, media manufacturers and television recorder manufacturers have developed a series of standards governing digital recording of television signals using a set of standard, high-quality cassettes. To support television applications, two specific formats are necessary to cover the marketplace; a "component" format, which is independent of the television standard and compatible with a digital studio, and a "composite" format which is dependent upon the national format and is compatible with analog studios found today. Standards are in place covering 4:2:2 digital component recording. Proposals covering composite digital recording formats are now being discussed in the industry. As the only U.S. recorder manufacturer with a declared intent to manufacture hardware for the television industry to these standards, Ampex has participated in the generation of these standards. This paper will discuss the cassette and data standards which have been created for the television industry. Where deficiencies and limitations in those standards exist for data recording, these will be pointed out.

## BACKGROUND

Interest in developing video recording systems based upon digital recording technology for broadcast quality television applications began in the early 1970's. It was not until 1979 that the Society of Motion Picture and Television Engineers (SMPTE) established a technology study group on this subject, and at about the same time, the European Broadcast Union (EBU) also established a specialties group. By mid-1983, the efforts of these study groups had progressed to the point where it became practical to proceed with an effort to establish a component television standard. Key players for the component standardization effort were drawn from the broadcasters, recording manufacturers, and the media manufacturers. The result of these efforts has been the establishment of a series of 4:2:2 component digital standards to which Ampex Corporation, Sony Corporation and Bosch Fernseh are now developing hardware to be sold and delivered to the professional broadcast industry.

The specific standards developed are:

| | |
|---|---|
| SMPTE 224 -- | Tape Record |
| SMPTE 225 -- | Principal Properties of Magnetic Tape |
| SMPTE 226 -- | Dimensions of Tape Cassettes |
| SMPTE 227 -- | Signal Content of the Helical Data Records and of Associated Control Records |
| SMPTE 228 -- | Signal Content of Q and Time Code Longitudinal Records |

In addition, there are two Engineering Guides;

| | |
|---|---|
| EG-10 -- | Tape Transport Geometry Parameters |
| EG-11 -- | D-1 Format Nomenclature |

At the 1986 NAB show in Dallas, Sony Corporation introduced their D-1 product to the public for the first time.

The approach taken by the standardization committees and the various ad hoc working groups was to establish a media interchange standard. Three physical cassette sizes were defined and are summarized in Table I A summary of the key parameters describing the actual tape format selected is shown in Table II. Of particular note is the track pitch of 45 $\mu$m and in-track density of 56 kbit/in.

The actual machine implementation to achieve this interchange standard is left up to the individual manufacturers. This approach permits any scanner and head configuration which is capable of providing the required tape format to be implemented. For example, Ampex has chosen to implement a scanner of approximately 96 mm in diameter containing three head-pairs located at 120° from one another, while Sony Corporation has chosen to implement a 75 mm diameter scanner with two head-pairs located 180° from one another in conjunction with an appropriately larger mechanical tape wrap around the scanner. The third manufacturer, Bosch Fernseh, is implementing a scanner also of approximately 75 mm in diameter which has four single head positions located 90° apart around the scanner. Each of these technical approaches suits the technical objectives of the corporation involved and provides a consistent tape format. Many other examples in the selected approaches exist in terms of implementation approach.

**Table I**
**D-1 Cassette Summary**

| Specification | Small<br>ANS D-1.S | Medium<br>ANS D-1.M | Large<br>ANS D-1.L |
|---|---|---|---|
| Size, in. | 1.3x4.29x6.77 | 1.3x5.91x10.0 | 1.3x8.11x14.40 |
| Volume, $in^3$ | 37.76 | 76.83 | 152 |
| Weight, lb | 0.69 | 1.40 (est) | 2.78 (est) |
| Tape Thickness, $\mu$m | 16 13 (fut) | 16 13 (fut) | 16 13 (fut) |
| Tape Length, ft. | 620 733 | 1918 2313 | 4288 5300 |
| Search Time (at 300 IPS)<br>seconds<br>(minutes) | 24.8 29.6<br>(0.41) (0.49) | 76.7 92.5<br>(1.29) (1.54) | 171.6 212<br>(1.86) (3.53) |
| Tape Pack Diameter Ratio, I.D. to O.D. | 1.7 to 1 | 2.6 to 1 | 3.0 to 1 |
| Record Time, minutes (4:2:2 / 16 $\mu$m) | 11 | 34 | 76 |

## STANDARDS

The existence of these standards and the commitment on the part of these three recorder manufacturers has now opened up the possibility of creating a data recorder which shares much of the hardware being developed for the broadcast industry. Two efforts within the government community are currently underway to establish standards to which data recorders should be designed. The Navy is attempting to establish a military standard based on efforts spearheaded by Borys Umyn of NADC. ANSI, under the auspices of the X3B.6 Committee, has formed an effort, led by Al Montgomery and Jim Keeler of DoD. The purpose of the NADC effort is to provide a clear interchange standard which will be applicable to a large number of major, upcoming military programs across all the Armed Services. The format so selected must be sufficiently robust as to operate in a harsh environment. The ANSI effort is aimed much more at general laboratory applications and is not addressing environmental considerations. The ANSI effort is highly interactive with the industry in that strawman standards were requested and

**Table II**
**Format Parameters for D-1 Component (4:2:2)**

| | |
|---|---|
| Cassette | D-1.S, M & L |
| Tape | Metal Oxide (13 $\mu$m & 16 $\mu$m) (Will probably include but benefit little from metal particle) |
| Track Angle | 5.4° |
| Helix Angle | Manufacturer's Option |
| Wavelength | 0.9 $\mu$m (50 kbit/in) |
| Track Pitch | 45 $\mu$m |
| Effective Width | 35 $\mu$m |
| Density | 49 Gbit/$m^2$ |
| Azimuth | 0° |
| Editing | No Compromise |
| Play Time | 11, 34, 76 minutes |
| Channel Code | R-NRZ |
| Error Correction | 60 x 30 Product Code<br>Single x Double Correction |
| Interleave/Shuffle | 50 TV Lines |
| Audio: | |
| Data Rate | 4 x 48 k samples/s x 20 bits |
| Location | Center of Track |
| Error Correction | Product Code + Duplication<br>(Extremely Powerful) |
| Market | Upper |
| Acceptance | Slow |

presented by interested recorder companies, and ad hoc working groups are being formed to work on various aspects of the standard with a goal to have an agreed-to standard during mid to fate 1987. The NADC effort is under tremendous time pressure, and the industry's involvement has been one of in-private, one-on-one forums, providing comments and feedback to the government. The Navy's intent is to have a final draft standard available by the time this paper is published. In the case of both the ANSI and NADC efforts, the track pitch, in-track density and track length of 4:2:2 component have been held inviolate so as to maximize the use of existing mechanical hardware.

There are several motivating factors for driving the government user to consider 19 mm technology First, there is a wide variety of hardware currently becoming available in the high density, high data rate rotary digital recording area. None of the resulting tape is interchangeable between Manufacturers' hardware. Second, the bandwidth required for television recording at the head-to-tape interface is approximately 225 Mbit/s for component recording. This is well above most data recording needs. Third, the existence of standard, easy-to-use cassettes which will be produced in high volume and at low cost by many manufacturers provides a great attraction.

## DATA RECORDING REQUIREMENTS

The performance requirements of a data recorder differ substantially from those of a television recorder. The first and most obvious difference is in the need to record a wide variety of user data rates. Present multi-channel longitudinal machines work over many octaves in order to satisfy the wide variety of applications in this community. Television signals have no such requirement. In order to successfully modify a video tape recorder to provide variable data rate recording capability, significant modification's to the system are required. The specific approach chosen is dependent upon the total data rate range which one wishes to cover, as well as the precision or granularity to which one plans to accept variable input data rates. For example, accepting specific, binarily-related input rates as opposed to continuously variable input rates significantly reduces the complexity of the implementation but may limit the applicability of a machine to selected programs.

There are several potential solutions to the variable data rate recording problem, one of which must be chosen by each manufacturer to adapt standard hardware. One technique for performing variable data rate record is speed scaling, where the head-to-tape speed, capstan speed, and clock frequency for the record data electronics are scaled proportionately. Datatape Corporation claims to have successfully implemented this kind of a scheme on their Mallard recorder, a one-inch, reel-to-reel system using a modified Bosch Fenseh B-Format scanner. Extending this approach beyond 8:1 is complex, due to significant differences in the characteristics of the head-to-tape interface. A second approach, used by Ampex Corporation on its SHBR recorder, is AST™ head position tracking servo as implemented on the ADR-300 product. Using this technique, one can maintain constant head-to-tape velocity and adjust for required helix angle changes as the tape speed slows down through use of the servo-controlled scan tracking device. This approach is more complicated in terms of hardware but is not limited in the same way speed scaling is. A third technique is incremental motion, whereby a very large digital buffer is used in the electronics to mask start-stop and rewind times of the tape transport. This technique is presently being implemented on Ampex's DCRS 310 product, and provides for continuously variable data rates. Its main limitation is the cost of memory, which is declining rapidly in the marketplace as larger chips become available. This implementation is more difficult, but not impossible, on a helical scan device, due the large mechanical wraps involved. The final technique which could be applied is one of using variable tape path geometry. In this type of solution, which in many respects is the inverse of the AST™ technique, required changes in helix angle are made by adjusting transport guiding elements as opposed to adjusting head position. Although never implemented and delivered in a practical helical system, these techniques have been studied in several companies over the last few years and are still under investigation.

The next major problem which must be solved for data recorders is that of bit error rate performance. In television recorders, heavy reliance on error concealment techniques is possible. The 4:2:2 system does use a powerful Reed-Solomon product code consisting of an inner code of R-S (64,60) and an outer code of R-S (32,30) For many applications, this code will probably be adequate. However, at the time of this paper, insufficient knowledge existed to clearly define what consistent bit error rate performance can be achieved at the SMPTE densities under all tape interchange conditions. It is estimated that the answer is somewhere between a BER of $10^{-8}$ and $10^{-9}$. For applications requiring a BER performance of $10^{-9}$ or better, more powerful ECC systems will be required. Both the NADC and ANSI efforts are attacking this issue head-on.

The choice of channel code is also a very interesting subject. The 4:2:2 component digital VTR standard has selected randomized NRZ. There are many people in the data recording business who would like to see the code selection changed. Codes such as various block codes and Miller-Squared are under investigation. Those who want the code selection changed are particularly concerned about the DC aspects of randomized NRZ, which can be easily handled in the playback system by use of decision feedback equalization or by use of Class IV partial response signal processing. Both of these signal processing techniques are more complex and costly than traditional flat equalized playback channels, but do not carry the additional overhead of block codes. Although Miller-Squared carries an inherent 3 dB penalty in SNR, it is DC-free and lends itself to very straightforward playback processing. In most cases, the preference of one manufacturer for a particular code as opposed to another manufacturer is based upon his internal expertise and invested base in current designs, or the manufacturer's approach to solving some other recorder problem such as speed scaling. Ad hoc working group activities as planned by ANSI should be quite useful in sorting out and selling these problems.

## COMPOSITE DIGITAL VIDEO

A major wrinkle in what otherwise seemed to be a clear-cut movement into data recording based on the D-1 component standard occurred with the announcement earlier this year by Ampex Corporation that it would introduce a composite digital video tape recorder system based upon the use of the same three standard 19 mm cassettes as used in the D-1 standard. Since that announcement, Sony Corporation has announced that it will support the Ampex-proposed tape format for 4Fsc composite recording applications. It is felt that the D-1 component system will satisfy the top-end, quality conscious user, but that the number of such customers is quite limited. The objective of the emerging composite product is to provide the user approximately three times as much record time per cassette as he would achieve using the component format. Secondly, a composite machine, competitively priced, would be a logical evolution path for those customers now using composite analog machines such as B-Format and C-Format equipment. Although all details of the format have not been finalized at the time of this paper, certain characteristics can be described as highly probable. In particular, a composite equipment will probably use 13 $\mu$m thick, 1500 Oe metal particle tape and azimuth gap heads. Miller-Squared code, in conjunction with an adequate error detection and correction system, will provide a very robust tape format at track densities considerably higher than those on the 4:2:2 component system. Table III summarizes a preliminary set of parameters now under investigation for use on that format. It is anticipated that some of these parameters could change.

Ampex introduced its first digital video product at the 1986 NAB show in Dallas. The product shown was an automatic tape library system called the ACR-225, which is based on the proposed component recording format and uses 256 small-size D-1 cassettes, for use as a studio spot player.

If the efforts on generating a mutually-acceptable composite format continue to fruition in the near term, the data recording community will discover that this format will be particularly attractive from the standpoint of tracking robustness and its higher volumetric packing density. Direct data recording derivatives of this hardware will operate in the 114 Mbit/s region, as opposed to the 172 Mbit/s region available using an unmodified D-1 recorder. The inherent cost advantage of this product over the 4:2:2 system should result broad acceptance of this hardware as a data recorder in an appropriate configuration.

| Table III<br>Ampex Digital Format Parameters for Composite 4Fsc | |
|---|---|
| Cassette | D-1.S, M & L |
| Tape | Metal Particle (1 3 $\mu$m)<br>(Oxide a Fall-Back Position) |
| Track Angle | 5.425° NTSC |
| Helix Angle | Matches D-1 |
| Wavelength | 0.96 $\mu$m |
| Track Pitch | 35 $\mu$m NTSC |
| Effective Width | 35 $\mu$m NTSC |
| Density | 59 Gb it/M$^2$ |
| Azimuth | 15° |
| Editing | Possible First & Last Track Degradation |
| Play Time | 32, 94, 208 minutes |
| Channel Code | Miller-Squared |
| Error Correction | 64 x 8 Product Code<br>Detect x Single Correct |
| Interleave/Shuffle | 2 TV Lines |
| Audio: | |
| Data Rate | 4 x 48 k samples/s x 16 bits |
| Location | Each End of Track |
| Error Correction | Concatenated Code + Duplication<br>(Extremely Powerful) |
| Market | Middle to Upper |
| Acceptance | Rapid |

## SUMMARY

By the early 1990's, the data recording industry will see dramatic effects based upon instrumentation recorder products derived from 19 mm cassette-based video recorder products. Recorders based both upon D-1 component technology and 4Fsc composite technology will find their application in the government community. Current D-1 standardization efforts are being conducted by NADC and ANSI.

The broadcast industry currently believes that a much larger market exists for composite recorders than exists for component recorders, but each of the major manufacturers will produce systems based on both formats. The advantages to the data recording industry of taking advantage of the significant investments made by broadcast recorder manufacturers should be obvious. Improved performance, reliability, and reduced costs should result. Finally, by standardizing on two or three data formats (preferably one), the data recording user community will find it much easier to share databases than in the past.