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CINE-GT 2920
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November 25, 2014

Uncompressed? Unimpressed:

The Brief Yet Wondrous Life of the SMPTE Type D-1 Digital Video Tape Format

At first glance, D-1 digital video—the first professional digital video format—appears to be an ideal candidate for video format longevity. The standard, created in a transcontinental, collaborative effort, was compatible with both NTSC and PAL video systems; it was subjected to rigorous examination by working groups consisting of engineers, users, and industry representatives; and it was the first time a format was created to meet the needs of a technology which did not yet exist, giving each manufacturer the freedom to engineer its own version of the first digital television tape recorder (DTTR) or digital video tape recorder (VTR). That is, the D-1 standard dictated the composition of the tape, its container, and its electrical and mechanical function, but not the design of the machinery through which it would become a functional recording medium.[1] In addition to the flexibility it offered to manufacturers, the format's 8-bit uncompressed component digital video signal was of superior quality and enabled manipulation and duplication of content without generational loss. Why, then, did only two companies manufacture D-1 cassettes and DTTRs?[2] Why was D-1 almost completely supplanted by D-2

1. It seems reasonable to expect that this should have resulted in the production of a variety of VTRs designed to use D-1 cassettes.

2. The scope of this paper is confined to the D-1 cassettes and VTRs that were manufactured following the creation and approval, in 1986, of the Rec. 601-based SMPTE type D-1 digital video format. D-1 cassette tape stock was manufactured by Sony and Quantegy; D-1 VTRs were produced by Sony and BTS (Bosch and Philips). It is not concerned with the format released by Ampex in 1992—a data tape format that was based on the earlier D-1 cassette and also used 19 mm tape, but was designed for use with the Ampex DCT-1700D VTR and employed discrete cosine transformation (DCT) data compression.

within a couple of years? Why is the D-1 cassette not even listed in several preservation-oriented format rosters?[3]

By the mid-1980s analog video technology had not only almost completely replaced the use of directly transmitted film in the television broadcast field, it had also become somewhat familiar to domestic consumers (as opposed to artists and educational and industrial users who had already more fully exploited analog video recording and editing technology) in the form of the home video cassette recorder (VCR), which used either Betamax or VHS tape cassettes.[4] Though still a novelty in many homes, the analog video cassette existed in a variety of professionally adopted formats—starting with 3/4-inch U-matic in 1971 and arriving at Betacam and Video8 ("regular 8") in 1984—though existing open-reel and other cassette-based analog formats were still and would remain in use.[5] However, alongside this proliferation of analog video recording formats, research into digital video formats was on the agenda in research and development departments at Sony, Ampex, and Bosch G.m.B.H by the early 1970s if not before. At the same time, digital technology was already utilized in television production for "graphics generators, recursive filters (noise reducers), time base correctors and synchronizers, [and] standards converters, amongst others."[6] According to Sony's online history, "Can the VTR be digitized?" was a question asked by many video engineers in 1976, as digital audio technology

3. Mona Jimenez and Liss Platt, Materia Media, for Texas Commission on the Arts, "Videotape Identification and Assessment Guide," http://www.arts.texas.gov/wp-content/uploads/2012/04/video.pdf; and Sarah Stauderman and Paul Messer, "Video Format Identification Guide." Video Preservation Website. 2007. http://videopreservation.conservation-us.org/vid_id/85-now.html.

4. Leo Enticknap, *Moving Image Technology: From Zoetrope to Digital* (London; New York: Wallflower Press, 2005), 178–9.

5. Jimenez and Platt, 20.

6. Stanley Baron, "First-Hand: The Foundation of Digital Television: the origins of the 4:2:2 component digital standard," IEEE Global History Network website, accessed October 21, 2014, http://www.ieeeghn.org/wiki/index.php/First-Hand:The_Foundation_of_Digital_Television:_the_origins_of_the_4:2:2_component_digital_standard.

was gaining ground.[7] A formal effort, organized and recorded by the Society of Motion Picture and Television Engineers (SMPTE Digital Television Tape Recorder Working Group [WG-DTTR]) working in concert with the European Broadcasting Union's (EBU) MAGNUM Specialist Group, toward the creation of a digital video standard, began in 1979. Developments in the audio realm have often driven complementary or analogous developments in the visual; predictably, this ordinality also applies to the development of digital video. Following upon the heels of the development and adoption—with the growing availability of computer processing power and storage capacity that fulfilled the necessary functional requirements—of digital audio recording and playback in the early 1980s,[8] the first digital video recording standard, component D-1, was approved in 1986.[9] Both Sony and Bosch started marketing D-1 video tape recorders and cassettes in 1987.[10]

The backbone of D-1 is Recommendation ITU-R 601 (also known as Rec. 601, ITU-R BT.601, CCIR 601, and 4:2:2 Component Digital Television Standard or 4:2:2 DTV), the "first international standard adopted for interfacing equipment directly in the digital domain avoiding the need to first restore the signal to an analogue format."[11] Although, as stated above, digital audio and video equipment was in use in television production prior to the adoption of ITU-R 601, individual devices, with various manufacturers and interfaces, had to be integrated at an

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7. Sony, "The Beginning of the Digital Age," Sony Corporate Info: History, http://www.sony.net/SonyInfo/CorporateInfo/History/SonyHistory/2-04.html.

8. Enticknap, 206.

9. Frederick M. Remley, Jr., "Introduction to the Papers on the Type D-1 Digital Video Recorder," Digital Television Tape Recording and Other New Developments: Selected Papers Presented During the 20th Annual SMPTE Television Conference in Chicago, Illinois, February 7–8, 1986, Jeffrey B. Friedman, ed. (White Plains, NY: Society of Motion Picture and Television Engineers, 1986).

10. While some sources give the date as 1986 and some as 1987, Sony lists 1987 as the year that its DVR-1000 was released. Similarly, I found different dates for the introduction the BTS digital VTR. It is possible that both DTTRs were displayed at conventions and test-marketed in 1986, but released for general sale in 1987.

11. Stanley Baron and David Wood, "Rec. 601—the Origins of the 4:2:2 DTV Standard." *EBU Technical Review,* October 2005, https://tech.ebu.ch/docs/techreview/trev_304-rec601_wood.pdf.

analog level once their specific digital processing function had been completed. This do-si-do between analog and digital interrupted workflow and introduced opportunity for error. In *Modern Television Standards: To HDTV and Beyond*, Jim Slater notes that "[e]stablishing a standard sampling frequency did of course have real financial consequences, it could not be randomly plucked out the air: the higher the sampling frequency, the greater overall bit rate; the greater overall bit rate, the more need for storage space in digital equipment."[12] ITU-R 601, adopted in February1982, specified a sampling frequency of 13.5 MHz for the luminance signal (Y), and 6.75 MHz for both chrominance components (C_R = analog R-Y x 0.713) and (C_B = analog B-Y x 0.564), a ratio of 4:2:2. These frequency values work in both 525-line/60 Hz and 625-line/50 Hz standard definition digital television production environments, satisfying one very important goal for the developing D-1 standard—that it be compatible with both NTSC and PAL television resolutions and color encoding systems. The corresponding picture resolutions are 720 x 486 (720 samples per line, with 486 [525-39] active picture lines) for NTSC—since 39 lines per frame contain synchronization information for television that is contained elsewhere in digital video, these 39 lines are subtracted from the active digital video picture area—and, similarly, 720 x 576 (720 samples per line, with 576 [625-49] active picture lines) for PAL. It should be noted, however, that ITU-R 601 does not provide for colorimetry differences between NTSC and PAL.[13] Other ITU-R 601 digital video specifications include: head- and foot-room for white and black overshoots; longer line lengths than are found in analog systems, to avoid picture cropping; a minimum of 8 bits per digital sample, 8-bit code values for black and white; and codes for defining picture area and for synchronizing line, field, and frame.

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12. Jim Slater, Modern Television Systems: To HDTV and Beyond (London: Pitman, 1991), 116.

13. Michael Robin, "Colorimetry Standards," TV Technology website, August 1, 2003, http://www.tvtechnology.com/rf-technology/0146/colorimetry-standards/259641.

One of the primary conditions for the D-1 digital video format was that is was to be a tape standard rather than a recorder standard since potential manufacturers had stronger preferences with regard to recorder construction than tape cassette format. D-1 allows for different head and tape wrap configurations; regardless, tapes will remain interchangeable. The following is a list of some of the technical considerations and fundamental requirements examined and then defined during the SMPTE D-1 standardization process.[14] An exhaustive report on the specifications of the D-1 standard is outside of the scope of this report, as it would require an understanding of electrical engineering that is not within my present purview.

- Tape area required per bit or areal packing density (APD): This factor determines tape consumption and the overall size of the mechanism. There is a trade-off between track width and accuracy: a narrower track reduces the tape area required, but as the track width continues to narrow it will eventually reach a tolerance limit after which tracking inaccuracies are likely to occur. D-1 track width is 1.57 mm.
- Channel coding: "In general, a data signal is not suitable for direct recording onto a magnetic medium. The reason is the DC content of the signal, which cannot be recorded, due to the fact that the rotating heads are coupled to the outside world by means of rotary transformers.... It is the task of the channel coding to reduce the disturbing DC content of the

14. See appendices for diagram and illustrations. This section of the paper combines submissions from various SMPTE and EBU working groups and much of the information provided is found in the following four papers—all from the following source: Jeffrey B. Friedman, ed., *Digital Television Tape Recording and Other New Developments: Selected Papers Presented During the 20th Annual SMPTE Television Conference in Chicago, Illinois, February 7–8, 1986* (White Plains, NY: Society of Motion Picture and Television Engineers, 1986). Papers: John L.E. Baldwin, "Digital Television Recording—History and Background," 13-26; Takeo Eguchi, "The SMPTE D-1 Format and Possible Scanner Configurations," 65–76; William C. Nicholls, "The User Requirements for the 4:2:2 Component Digital VTR," 27–37; and A. Todorovic, "Bases of the EBU Standard on Magnetic Recording of Digital Component Video Signals," 305–312.

digital video and audio signals prior to recording."[15] Since it is not possible to reproduce a zero-value frequency component (due to head sensitivity to the rate of change of flux), channel code choice is made with an eye toward striking a balance between data rate, error rate, and data loss-reduction techniques. D-1 uses Randomized NRZ (RNRZ).

- Linear recording density: 57, 000 frpi (flux reversals per inch)
- Number of channels: With regard to channel count, of concern are the problems that could result from a defective head. Therefore, four channels are preferable to two in that information is more widely dispersed. The creation of 20 "half-tracks," or sectors, per field (each with 26 lines) for NTSC—using a number divisible by four allowed for the creation of four sectors for each picture segment, or one for each head—allows for the even distribution of information between four channels. Similarly, in PAL systems, the recording of one field occupies 12 tracks, so that 24 sectors are easily divided between the four heads. However, because information is evenly distributed between channels, a 4-channel configuration still leaves the signal vulnerable to loss. That is, a single problematic head would affect the whole picture area. Spreading the information among four channels reduces the potential density of signal impairment. With D-1, increased digital buffer storage effectively mitigates this problem, reducing vulnerability to drop-out due to head clogs or damage.
- Data rate: The total sampling frequency is 27 MHz (13.5 + 6.75 + 6.75) or 27 million samples per second. With D-1's 8-bit sampling frequency, the maximum data rate for the video signal is 216 Mbps (8 x 27 MHz); the actual average data rate for active line samples is

15. Jürgen K.R. Heitmann, "The D-1 DTTR: The Design for the Electrical Part of the Standard," Digital Television Tape Recording and Other New Developments: Selected Papers Presented During the 20th Annual SMPTE Television Conference in Chicago, Illinois, February 7–8, 1986, ed. Jeffrey B. Friedman (White Plains, NY: Society of Motion Picture and Television Engineers, 1986), 77.

173 Mbps. Combined with the digital audio channels and error detection and correction, the gross data rate is 240 Mbps.[16]

- Signal to Noise Ratio=56 dB
- Error correction and concealment: By carefully constructing the manner and order in which data words are distributed among sectors, error detection and correction systems should be able to recover dropped data. Where only part of a sector can be recovered, spatial and temporal error concealment up to a rate of 1000 concealments per second is available. Error concealment is intended only as a backup measure; during normal operation, existing error correction should be robust enough to detect and handle sector problems.
- Audio: 4 channels of digital audio with a 48 MHz, 16-bit via AES/EBU interface signal (as per ITU-R 601)

  In order to provide greater quality than the existing 1-inch Type C, more than 2 or 3 channels would be needed for original recordings and air copy playback. However, too many tracks (i.e., more than four) would move the D-1 format into the realm of audio post-production. The provision of four audio channels also satisfied the Electronic Industries Alliance (EIA) call for left and right stereo channels along with an additional channel for foreign language or other use. Digital audio bursts were moved from the ends of the tracks, where they were most vulnerable to tape damage and placed, as four bursts of audio, in the middle of each video sector at the center of the helical scan. Thereby, each track is made up of 2 video sectors separated by 4 audio sectors.

16. John C. Mallinson, *The Foundations of Magnetic Recording*, 2nd ed. (Boston: Academic Press, 1993), 168.

- Track pitch: The 45 μm (micrometer) distance between tracks is relatively wide, which should provide better resistance to mistracking due to frequent tape changes during use in professional environments.
- Track length: 170 mm was chosen in order to accommodate the desired wavelength of 0.9 μm.
- Longitudinal track records: Control track, time code track, and audio cue track—via microphone, line level, or internal mixer feed input—would retain the same form as that of analog video tape. The users' group specified that the quality of the audio cue track was to be far better than telephone quality but not necessarily broadcast quality.
- Time code: The format provides for both a separate video-related longitudinal track and vertical integrated time code (VITC). In addition to closed captioning, VITC is one of the possible ancillary signals that D-1 is configured to record. The longitudinal time code track can record two independent time codes, if the user so desires.
- Scanning system: Multi-head helical scan
- Tape speed: 11.28 ips (inches per second); 286.588 mm/s
- Tape base and coating composition: The tape is polyester with metal oxide particles (850 Oested Cobalt-Gamma ferric oxide: 850-Oe coercivity class)—This is a relatively high coercivity value, which means that information held by the oxide particles on D-1 tape are less liable to self-erasure (self-demagnetization) or bleed-through than tapes with lower coercivity values.

- Tape width: A wider tape width provides a better ratio of rewind to play time. For a one-hour tape, the difference between rewind speeds for 3/4-inch and 1-inch tape widths was determined to be negligible.[17]
- D-1 stock sizes: Citing the protective quality of U-matic as a standard, users requested that the D-1 format be cassette-based. They also desired different tapes sizes (and corresponding VTRs) for use in various environments: multi-cassette machines (small), in the field (medium), and in the studio (large). Sony and Quantegy are the only two companies who manufactured D-1 cassette tape stock. I have found evidence online that D-1 cassettes with all of the following recording/playback times were eventually available for purchase: 6, 8, 12, 22, 34, 76, and 94 minutes. In their "SMPTE Type D-1 Cassette Design Considerations," P.K. Dare and K. Ike chart play times for two tape thicknesses: 13 and 16 µm.[18] Initial tape play times projected by the authors—11, 34, and 76 minutes—were based on the available 16 µm tape thickness, and a 94-minute tape was projected as possible once 13 µm tape became available. Since I have also seen other tape thicknesses ascribed to D-1, namely 12.3 and 14 µm, it makes sense that small, medium, and large D-1 tape sizes would have each been available with more than one play length option, as different tape thicknesses were utilized. In the "User Requirements" report, it is noted that "users required that the tape be able to withstand 100 threading cycles at the same place without noticeable impairment and 500 at the head of the tape, without significant damage or poor playback results."[19] The tape also needed to be able to withstand 60 minutes with a still frame, whether that time period passed

17. Though Baldwin uses the measurement 3/4 inch the actual tape width of D-1 is 19 mm. (3/4 inch equals 19.05 millimeters). He points out that this difference is a "matter of tolerances."

18. P. A. Dare and K. Ike, "SMPTE Type D-1 Cassette Design Considerations," Digital Television Tape Recording and Other New Developments: Selected Papers Presented During the 20th Annual SMPTE Television Conference in Chicago, Illinois, February 7–8, 1986, Jeffrey B. Friedman, ed. (White Plains, NY: Society of Motion Picture and Television Engineers, 1986), 61.

19. Nicholls, 29–30.

during a single stoppage or over the additive course of several shorter time periods. These capabilities were understood by users to be provided by 1-inch Type C and the BCT-G Broadcast Standard Betacam cassettes[20] manufactured for use with Betacart, a programmable system that combined four Betacam decks and allowed the user to automate both programming and insertion of commercials for television broadcast.

- Cassette construction: Tape cassette construction as laid out in the Dare and Ike report is of particularly interest in that the reasoning behind every feature of the cassette's design is detailed, including dimensions; lid function; reel support (for a fully packed 800 gram reel in the large-sized cassette); manufacturer and user identification holes; asymmetry to prevent misinsertion; reel hub size; reel lock release mechanisms; tape leader thickness, transmissivity, and length; label areas; and reel removal provisions for damaged tapes. Compared to analog 8 mm video tape, which was already in use when D-1 went on the market, the D-1 cassette footprint appeared excessively large.[21] However, the size of the cassette was dictated by "a minimum spacing between hubs to accommodate two spooling motors with sufficient torque for the various 'stunt' modes. The larger cassette is as small as possible while providing 94 minutes of recording time using the thinnest tape foreseen in the next five years. Making the reel hub diameter any smaller would result in excessive tension on the already thin tape."[22] Since the projected spooling speed for D-1 tapes was 50 times normal play speed—as opposed to 35 times normal play speed for existing cassette tape formats—upper and lower tension support and hubs with 12 drive teeth were required in

20. Sony, "Rugged Reliability for Betacam & Betacart: BCT-G Broadcast Standard Videocassettes," http://www.sony-asia.com/microsite/b2b/_media/downloads_pdf/pro_media/bct-g.pdf.

21. There is much evidence that the use of 8 mm tape was a poor trade-off between size and quality. See, for example, Jimenez and Platt, 21.

22. Nicholls, 30.

order to attain the desired acceleration rate. For protection against contaminants, the tape is completely enclosed in a cassette body with two double-flanged reels that lock automatically when the tape is not inside a VTR; the cassette can also be removed from the machine at any point on the tape. The cassette has four tabs that can be broken off by the manufacturer in order to indicate particular tape characteristics that may change over time, as new material specifications become possible or are adopted, e.g. coercivity, tape thickness, length, etc., manufacturers could program their DTTRs to respond to these tabs on the tape by making appropriate functional adjustments. There are also four holes, two of which are assigned as record-safe and video-only record controls; the other two relay contact-controlled holes can be assigned to suit the user's needs. One of the less technical factors considered by the users' group was cassette labeling for content identification. While final specifications allow for the placement of labels on any of the sides and on the top of the tape (since the cassettes can be used with top-, front-, and side-loading machines), the user group expressed that, rather than haphazardly applying labels to whichever facet of the cassette seemed best at the time, they preferred to regulate the placement of labels on the D-1 and agreed that it would be most efficient in terms of storage to place tapes on a shelf with the spine perpendicular to the shelf surface and with one of the short ends labeled (and bar-coded) facing outwards.

- DTTR performance: According to a Library of Congress report on television and video preservation from October 1997, "Among the advantages of digital recording are higher resolutions, error measurement and correction, the ability to record—or clone, as it were—copies without generational loss, and, for postproduction, nonlinear editing."[23] The users'

23. William T. Murphy, "Television and Video Preservation 1997: A Report on the Current State of American Television and Video Preservation," Report of the Librarian of Congress: Television and Video Preservation 1997 Vol. 1 (October 1997), Washington, D.C.: Library of Congress, http://www.loc.gov/programs/static/national-film-preservation-board/documents/tvstudy.pdf.

group quantified this benefit of digital video, specifying that the DTTR should be "capable of 10 generations with no perceptible degradation to either the video or the audio and 20 generations with a loss of only half a point on the CCIR quality scale (from a 5.0 to a 4.5). This is halfway between a perfect and a just noticeable impairment rating, with critical audio and video material."[24]

While the list of characteristics described above is not fully comprehensive, it does provide a rough idea of the factors that went into the creation of the D-1 standard. Shortly thereafter, in 1987, Sony's first digital VTR, the two-piece DVR-1000/DVPC-1000 system, was released. In his *History of Television, 1942 to 2000,* Albert Abramson reports that at the 64th annual NAB convention in April 1986, "Sony showed its new digital video recorder the DVR-1000, as a studio recorder. It was claimed that Sony had sold 12 of the new recorders and had orders for 300 more."[25] According to its promotional pamphlet, the VTR was "engineered with maximum interface flexibility. Video interfaces are available in analog R/G/B, Y/R-Y/B-Y, Betacam component, and digital parallel/serial. The four digital audio channels are each equipped with both analog and AES/EBU compatible I/O ports."[26] In keeping with D-1's compatibility with both NTSC and PAL, the machine's power supply could operate on both 100–120 and 220–240 line voltage standards. In addition to the D-1 standard specifications described in the preceding pages, benefits as touted by the pamphlet included:

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24. Nicholls, 31.

25. Albert Abramson, *The History of Television, 1942 to 2000* (Jefferson, N.C.: McFarland, 2003), 211. Abramson also reports that the price for the DVR-1000 along with its DVCP signal processor cost $120,000. On page 215, he writes that the first production VTR was "described" in September 1986 and "delivered in 1987." See note 10 regarding inconsistent DTTR release dates in this report. During the course of my research I saw prices for the DVR-1000/DVPC-1000 listed at $140,000, $160,000, and $200,000. Abramson, in particular, provides conflicting information.

26. Sony, "4:2:2 Component Digital VTR: DVR-1000/DVPC-1000" product brochure, available online at http://www.broadcaststore.com/pdf/model/5167/sony_dvr-1000.pdf.

- “first generation audio and video quality offered throughout several dozen generations of dubbing”
- “sophisticated keying, matting, and film-to-tape transfers,” “freedom from color framing problems,” and “ideal [for] color correction and other picture processing”
- “independently editable digital audio channels” with “internal signal routing, allowing the VTR to dub channel-to-channel” and perform “fade-in/fade-out, sound-on-sound, etc.”
- multi-cassette operation for medium- and large-size cassettes with 12-, 22-, 34-, 76-, and 94-minute recording/playback times
- wide electroluminescent (EL) panel which keeps the “operator informed of all data required for operation,” with data “logically grouped into 12 main menus”
- non-linear editing via “built-in editing facility” with “control of two machines via simple connections using the RS-422 port”
- “very detailed” chroma and luminance information, giving “most realistic depth to pictures”
- error rate monitoring which “eliminates the need for watching picture monitors during simple dubbing procedures”
- enhanced editing functions including parallel operation, sequence operation, graphic operation where “the out point of the edit is automatically registered as the in point of the next edit, and film-525 operation, which gives “greater efficiency to the edition of film material” for “once the in point and field number of the first edit are set the [VTR] will automatically set the out point and field numbers of the edits to follow so that each edit matches the 2/3 pull down sequence”

- automatic tracking
- “plug-in type boards for convenient servicing” and a “sophisticated self-diagnostics system”

Despite these substantial video production benefits, the DVR-1000/DVPC-1000 had two immediately evident drawbacks: it cost $140,000–$200,000 and, though conveniently mounted on casters, had a combined weight of 326 pounds 10 ounces, with a width, height, and depth of approximately 24 x 38 x 27 inches. The second generation of the DVR-1000 series, the DVR-2000 and DVR-2100, had the deck and the electronic processing components integrated into one unit so that both the size and weight were greatly reduced, to 16 ¾ x 14 x 25 inches and 143 pounds 5 ounces. According to the product pamphlet, the DVR-2000 also made the following improvements upon its predecessor:[27]

- detection and compensation for playback equalizing errors with “RF gain and phase [are] automatically optimized in playback so that the error rate is minimized...without continuous manual optimization”
- three time code signals: VITC was added to the existing video-related longitudinal and audio sector time codes (ASTC).
- Tension regulation was improved to allow “smooth and precise tape tension control” and improved response for the jog dial.

The DVR-2100 built on these improvements with the following:[28]

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27. Sony, “4:2:2 Component Digital VTR: DVR-2000” product brochure, available online at http://www.broadcaststore.com/pdf/
/12111/sony_dvr-2000.pdf.

28. Sony, “4:2:2 Component Digital VTR: DVR-2100” product brochure, available online at http://www.broadcaststore.com/pdf/model/12111/sony_dvr-2100.pdf.

- new dynamic tracking heads that provide normal speed playback quality at speeds varying between -1 to +2 times, including still and slow motion, ensuring “excellent interpolation of missing fields of information in terms of both luminance (Y) and chrominance (C), to give smooth variable speed playback”
- an optional BKDV-2001 Digital Jog Sound Kit, with which “complete recovery of digital audio is realized over the range of -1 to +1 times normal playback speed even during the jog operation”
- the ability to check channel condition during normal playback and confidence playback which “eliminates the need for continuously watching picture monitors while recording or playing back”
- control track longitudinal (CTL) record/playback and erasure head positioned in the lower drum to allow precise servo control and accurate tracking adjustments
- enhanced built-in test signal generator provides five video test signals and two test audio signals

The difference between the first-generation DVR-1000 and the two second-generation machines seems to lie mainly in the reduced size and weight. The drop in price, to $120,000, was not quite as substantial as the decrease in size. BTS (Broadcast Television Systems, a joint venture between Bosch and Philips) also produced a series of D-1 VTRs that went on the market in 1987. I was not able to find much information on the BTS DCR-100/300/500 machines; they don’t appear to have been as popular as the Sony models, at least not in the United States.

While the benefits of an uncompressed, component digital signal, for telecine remastering, non-linear editing, chroma-keying and other special effects, and tape cloning, were evident, the development of an all-digital television production system was a costly endeavor.

D-1 VTRs were "very complex, difficult to manufacture, and therefore very expensive...they also suffer from the disadvantage that being component machines, requiring luminance and colour-difference signals at input and output, they are difficult to install in a standard studio which has been built to deal with composite PAL signals. Indeed, to make full use of the D1 format the whole studio distribution system must be replaced, at considerable expense."[29] Using a single composite cable for analog video was the norm in television studios at the time, and rewiring for the multiple cables required to integrate the newly introduced component D-1 standard into existing systems must have seemed a somewhat risky investment, especially given the historical and continuing rate of change for video formats. Therefore, D-1 was purchased and implemented for production only by major broadcasting entities. The D-1 format, as a whole, suffered from a lack of adoption and was already on its way to being pushed out of the digital video market as early as 1986 when the seeds of its demise were planted by the Ampex's ACR-225 digital composite system. When the newly approved D-1 standard was introduced at the 20th annual SMPTE conference in February 1986, presentations were "mainly concerned with the discussion of the new digital television tape recorder (DTTR) specifications agreed upon by SMPTE and EBU. The standards avoided dictating any particular recorder design, and allowed systems to function with equal ease in 525 and 625 lines. The decision of Ampex to introduce a composite digital signal for its ACR-25 [sic] was criticised. The conference was mostly concerned with the broadest possible acceptance of the D-1 standard."[30] Nonetheless, Sony decided to collaborate with Ampex and in February 1987 they submitted the composite digital video format for SMPTE/ANSI standards approval. Both Ampex VPR-300 and the Sony DVR-10 D-2 VTRs debuted at the 1988 National Association of Broadcasters convention. Sony's DVR-10 was on

29. Slater, 125. This applies to NTSC signals as well as PAL.
30. Abramson, 210.

sale at the convention for $72,250, with a $2,500 discount and a substantially lower price than its D-1 VTR series.[31] As a digital signal, D-2 could be used to duplicate material without generational loss, used less expensive composite circuitry, easily integrated with existing composite equipment, and "was considered to be more economical than D-1 for studios looking to replace their type C one-inch gear. There was no need for extensive wiring changes, new routing, distribution and signal processing systems, a new production switcher and other pieces of new equipment." However, "Sony continued to sell its D-1 machines, and claimed that about 90 D-1 recorders had been sold the previous year and that 100 more were on order."[32] There was a fairly rapid succession of digital video "D" formats before the digital video cassette format somewhat stabilized, at least for production, with the arrival of Digital Betacam in 1993.

Even after D-2 and subsequent digital video standards gained wider acceptance, large, professional studios/networks continued to use D-1 as an archival format because of its high-quality component standard. D-2 is not an archival format. In a 1997 report on television and video preservation,[33] Philip Murphy, vice president of Paramount Pictures' Operations Television Group, explained the studio's continued use of D-1 for asset protection as follows: "Shows transferred in most recent years to D1 component videotape are protected with a D1 in the mine.... For long-term archival purposes, we never want to be so cutting-edge with technology that problems with new formats may not emerge before we have manufactured hundreds of protections." With regard to D-1 tape longevity he also reported that "last month we specifically evaluated two of the earliest D1 tapes which were made and shipped to the mine. After the eight years that they have resided in that very stable environment, since 1988, they

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31. Abramson, 217.
32. Abramson, 224.
33. Quotations from this point forward in the paragraph are from Murphy, "*Television and Video Preservation 1997,* chap. 3.

show no signs of deterioration." At the same meeting, Edward Zeier, Vice President Post Production, Universal City Studios, also affirmed retention of D-1 video tape masters; Peter Schade, Director Video & Technical Services, Turner Entertainment Co. added that "[s]ince 1994, all new transfers for long form material, including features and made for television movies, have been transferred to D1 component digital videotape"; and Michael Friend, Director of the Academy Film Archive, Academy of Motion Picture Arts and Sciences, asked "Well, storage in two different places is a good idea, but what about storing in two different media? What about, for example, a D1 tape and some form of advanced optical media? So that at least we have perhaps twice the number of chances of having a surviving media when we go to play back that tape." Clearly, D-1 cassettes were still available and D-1 DTTRs were being maintained over 10 years after the standard was created. However, the studio representatives also acknowledged that format and machine obsolescence were major drawbacks to using digital video as an archival format and that the current solution to that problem was to "continually transfer the signal onto better and better formats." Roger Mayer, President and Chief Operating Officer, Turner Entertainment Co. elaborated, "We feel that our efforts to keep up with current videotape technology, both when mastering from film to tape and when dealing with "tape only" programs, as well as proper storage conditions of all our elements, is vital for proper preservation of television product." James Wheeler, president of Tape Archival and Restoration Services, reiterated the benefits of D-1, explaining that "[d]igital videotape recording was born when SMPTE established the D1 standard in 1987. Digital has a major advantage over the previous analog based recorders because there is no degradation when tapes are copied. It is difficult to differentiate a camera original from a multi-generation digital copy. I have done 40 generations, and I couldn't really tell the difference between the original and the 40th," but also addressing the question of obsolescence thusly:

> The main problem with using rapidly developing technology, like videotape recording, is that new developments quickly make equipment obsolete. Eventually, your favorite tape recorder will no longer be produced, and in a few years, it will be difficult to find someone who can maintain it. For this reason, I am recommending the creation of a repository for old videotape recorders, like a retirement home. Such a national video center could also be a repository for literature and technical manuals for the equipment, which is also very necessary. This center could maintain a database of the location of other equipment around the world and also have a list of the technicians who know how to repair the equipment. So, it is not just the equipment; it is the parts and the people to repair them.

Since D-1's native resolution is 8-bit uncompressed 4:2:2 with 4 channels of 48 MHz, 16-bit audio, it almost measures up to the standards for analog signal digitization that are advocated by archives and preservation professionals today; it would not make sense to "up-res" from 8-bit to 10-bit if working with a D-1 signal. The same tape degradation problems that apply to other polyester-base, metal oxide-particle tapes, especially hydrolysis, also apply to D-1 tapes and recommendations for care and storage of these types of tapes are adequately documented.[34] Aside from the examples of archival D-1 detailed in the 1997 Library of Congress report, I was only able to locate a few items that purported to be transferred from D-1,[35] and no one that I queried was able to provide anecdotal evidence with regard to D-1 tape transfer issues.[36] D-1 is still in the video vocabulary as a recommended resolution—720 x 486—for CCTV. Several

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34. For example, Jean-Louis Bigourdan, James M. Reilly, Karen Santoro, and Gene Salesin, "The Preservation of Magnetic Tape Collections: A Perspective" (Rochester Institute of Technology: Image Permanence Institute, Rochester, NY, December 2006).

35. A Marlboro commercial, motion graphics experiment, and a feature film are listed on the Internet Archive as being transferred from D-1, available at https://archive.org/details/tobacco_myp23e00, https://archive.org/details/2LayerVideoStencilTestD1, and https://archive.org/details/CVAN_MI-492. Many popular television programs and film presentations may still reside in network archives on D-1.

36. I consulted four video-preservation professionals whose combined experience spanned at least four different preservation workplaces.

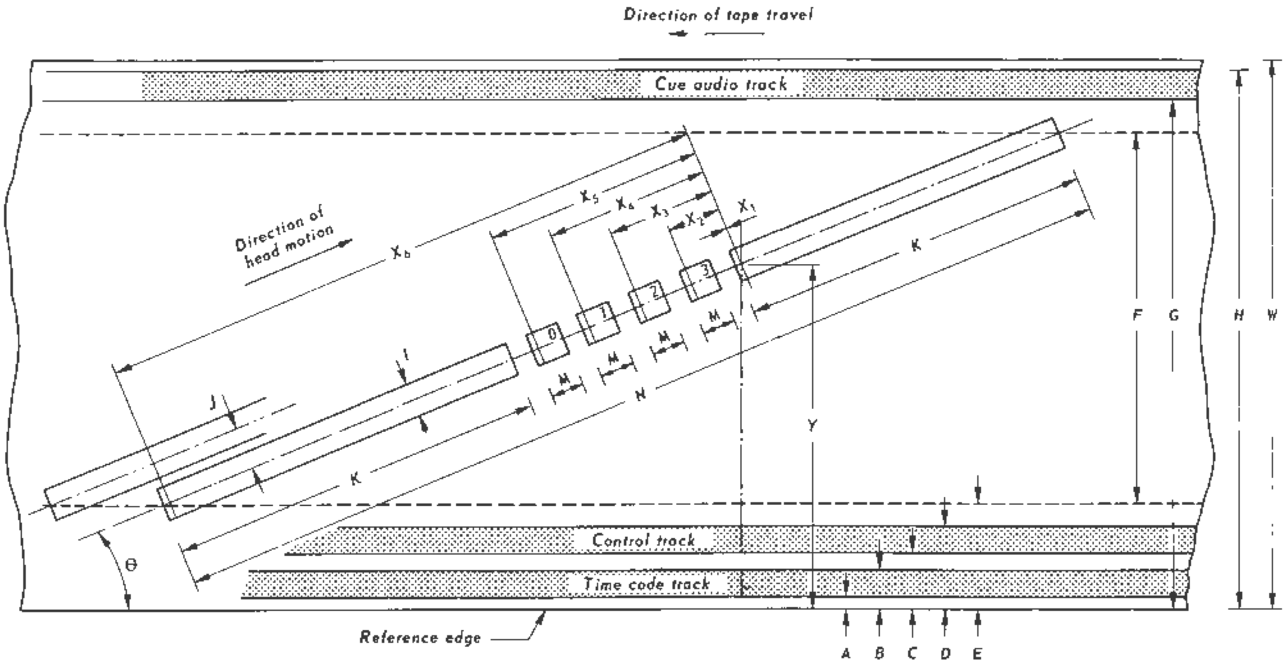
vendors offer D-1 transfer services[37] and one, DC Video, opined that “[a]rchive D-1 recordings have been known to be very finicky when attempting to re-produce years later.”[38] Vintage D-1 VTRs are also available online, starting at $150 in one online classifieds listing and going up to MSRP-levels at $126,000 for an unused DVR-2000.[39] Since D-1 was mainly adopted by major studios and networks, it is probable that archives, libraries, and museums rarely encounter D-1 cassette tapes. However, the study of the D-1 format is enlightening with regard to the underpinnings of digital video tape specifications and workflow. It paved the way to now-standard digital video television, feature film, and artwork production and post-production practices, and provides an early example of an uncompressed archival standard that is part of the standard recommendations of archiving- and preservation-oriented professionals today.

37. http://mistervideo.net/d1-d2-tape-transfer/; http://www.thegreatbear.net/transfer-video-tape/professional-broadcast/d1-d2-d3-d5-d9-digitals/; http://www.preservetodvd.com/digital-beta-d1-d2-transfer-conversion-service.html; http://valleyphotoservice.net/?page_id=8; http://www.videolabs.net/media-services/duplicationreplication/i-need-multiple-copies-of-a-videotape/

38. DC Video, “SMPTE D-1 Video Format,” available at http://www.dcvideo.com/ql-smpte-d-1.php.

39. Broadcast Store, http://www.broadcaststore.com/store/prod_detail.cfm?eq_id=425028.

Appendix A[40]



Track locations and dimensions.
Sizes, expressed in millimeters, except for the angle, are valid when the tape is subject to a tension of 1 N.
The significance of the symbols is as follows:

A	Time-code track lower edge	0.2	± 0.1
B	Time-code track upper edge	0.7	± 0.1
C	Control track lower edge	1.0	± 0.1
D	Control track upper edge	1.5	± 0.05
E	Lower edge of programme aree	1.8	(derived)
F	Programme area width	16.00	(derived)
G	Cue audio track lower edge	18.1	± 0.15
H	Cue audio track upper edge	18.8	± 0.2
I	Programme track width	0.040	+ 0/-0.005
J	Programme track pitch	0.045	basic
K	Video sector length	77.78	
M	Audio sector length	2.56	
N	Programme track total length	170.00	
W	Tape width	19.010	± 0.015

X_1	Location of start of upper video sector	0	± 0.1
X_2	Location of start of audio sector 3	3.4	± 0.1
X_3	Location of start of audio sector 2	6.8	± 0.1
X_4	Location of start of audio sector 1	10.2	± 0.1
X_5	Location of start of audio sector 0	13.6	± 0.1
X_6	Location of start of lower video sector	92.2	± 0.1
Y	Programme track reference location	10.490	basic
θ	Programme track angle	5° 24' 2"	(arcsin F/N)

40. Todorovic, 307.

Appendix B[41]

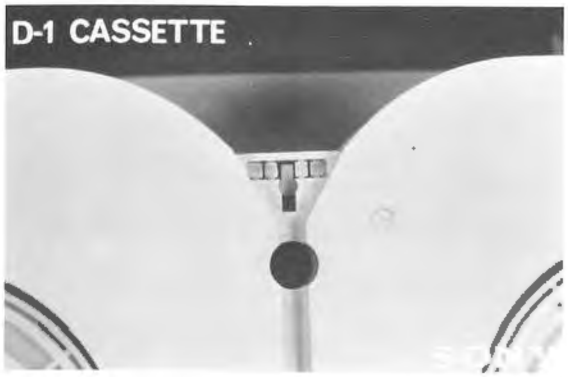


Fig. 4. SMPTE D-1 cassette — manufacturers tabs.

Fig. 7. SMPTE D-1 cassette — internal construction.

Fig. 5. SMPTE D-1 "S" cassette showing user holes.

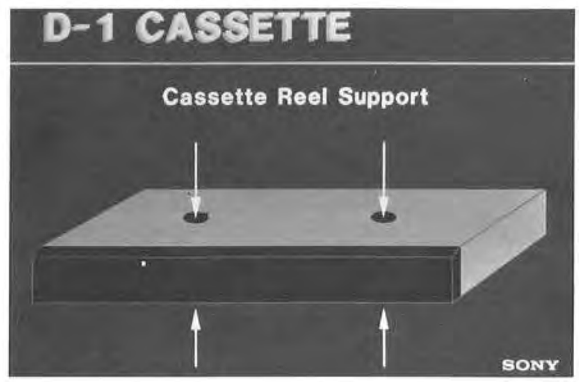


Fig. 8. SMPTE D-1 cassette — reel support during play and spooling modes.

Fig. 6. SMPTE D-1 cassette — reel.

Fig. 9. SMPTE D-1 cassette showing window and label areas.

41. Eguchi, 62–3.

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