The Video Disc System: A Technical Report by the SMPTE Study Group on Video Disc Recording

C. Robert Paulson, Chairman

Prepared for the Committee by Michael J. Doyle, Vice-Chairman

The method used to obtain a video signal from a circular plastic medium has taken several forms in its ultimate product-type definition. Product design philosophy has been predicted on perceived market segments and achievable efficiency of scale for player and disc manufacturing. The combination of these elements, in an order of priority that most fits the manufacturing organization, has resulted in technological differences for each format. The consequence of these differences, that four basic formats continue to exist, are discussed in this report.

Videodisc Type Description

Before a description of each of the videodisc formats is attempted, it is appropriate that a description of commonly generic features be approached that will allow the term "videodisc" to be applied to a collective group.

In its purest form, the term videodisc describes the process by which video signal information is encoded on a circular platter. The circular platter (or disc), when rotated at a predetermined rate, allows the pickup device of the playback appliance to begin the decoding process for display of a video image. This represents the "what" of videodisc, and by definition all systems meet these criteria and accomplish the same thing.

The question "how" is quite a different story, and when consideration is given to the different techniques employed to accomplish the same result, a more in-depth evaluation must take place. Within this presentation, an attempt will be made to describe the basic formats, give a description of the player appliance, and give a technical description of the disc.

The four basic formats have been given acronyms, and these are defined here for future reference: (1) Laser Optical Reflective (LOR); (2) Laser Optical Transmissive (LOT); (3) Capacitance Electronic Disc (CED); and (4) Video High Density (VHD). Each is representative of a technical approach that evolved as a result of organizational goals which are related to market strategy and economies of scale required to penetrate those market segments.

Laser Optical Reflective (LOR)

The most important advantages of the LOR system are the contact-free readout of the information, as a result of which wear of the disc or readout device is nonexistent, and the possibility of an effective protection of the information on the disc against the influence of dust is provided.

The optical principles used are based on light-ray diffraction, a phenomenon that occurs if the object dimensions are of the same order of magnitude as the wavelength of light. Due to diffraction at the lens aperture, the light "spot" is in reality a spot with annuli around it of decreasing brightness. If spot diameter is defined as the half-intensity diameter, it is found that, for a numerical aperture of 0.4 and a wavelength of the light used of 0.63 μm, the minimum (half intensity) spot diameter is 0.9 μm. This indicates that there is a maximum spatial frequency that can be read with this system, which in fact is directly proportional to the numerical aperture of the objective lens and inversely proportional to the wavelength of the light used.

The most striking difference between a video and an audio record is the mirrorlike appearance which is due to a reflective coating. The basic difference, however, lies in the structure of the information. Where the audiodisc has grooves, the walls of which are modulated with an audio signal, the videodisc, in view of the requirement for a much higher information density, has tracks with a much finer modulation and with spacing that is about 60 times smaller than that of the audiodisc.

The information of the disc is read from the inside to the outside. For this purpose the "read" objective and other optical elements must interact with the disc at a linear speed of 2.5 mm per min. The Magnavox system uses a movable optical sledge, and the DVA institutional player uses a movable disc drive transported over the fixed optical elements. Problems due to eccentricity can be measured optically using two auxiliary beams of light which are slightly displaced from the center line of the track, in opposite directions, so that they are partly on and partly alongside the track. After reflection at the disc, the main beam and the two auxiliary beams fall on their own photodiode, and the average current through the diodes depends on the amount of reflected light which is in direct relation to the position of the auxiliary beam to the main track. The signal of the two diodes, after amplification, passes a low-pass filter with a cut-off frequency of 20 kHz, and is then used as an error signal in the control system to make minor adjustments of the linear position of the transport.

The fundamental concept of reflectivity prohibits the access of information on the other side of the disc without physically turning the disc over. The trade-off is that the disc is designed with a 0.1 mm coating of ridged polymers per side that allows for complete and unrestricted physical handling of the disc.

Laser Optical Transmissive (LOT)

The LOT system consists of a flexible two-sided transparent 150 μmm (6 mil) thick disc that is protected by a caddy. The system is characterized by an optical laser spot serial readout. The primary feature is that the photodiode pickup is positioned on the opposite side of the main "read" beam. This beam is modulated by the successive spaces between the edges of the micropits. These spaces have been laid down on the disc in a spiral track with a constant depth and width (0.15 μm $\times$ 0.6 μm) with about 1.56 μm between tracks. For each revolution (at 1800 rpm) of the disc, one corresponding completely interlaced video frame is present, and information is read from outside to inside. A low-power generated laser light of a constant diameter is focused on the disc by means of a vertically-servoed objective lens. A radial servo-control system keeps the beam along the track. The radial tracking beam is modulated by passing over the edges of the micropits, which induce a variable diffraction pattern. The modulated beam passes through the disc, and there it is detected by a differential photodiode sensor. To pick up the information on the other side of the disc, an automatic system changes the focus point of the vertically-servoed objective lens onto micropit serial spacing encoded there.

The concept of transmissiveness allows for the immediate access of information on the other side of the disc without physically turning it over. The trade-off is that the disc is flexible and unprotected, requiring restricted handling through the use of a caddy.

Capacitance Electronic Disc (CED)

In the CED system, up to an hour of information appears on each side of a 12-in disc as a frequency-modulated vertical undulation of a V-shaped spiral groove. The modulation of the groove is in response to signals derived from a tape program via a tape machine. The recorded wavelength varies from 0.5 μm to 1.5 μm. Radial tracking occurs from outside to inside at a rate of 2.5 μm per rotation, providing 10,000 grooves per in. For the NTSC version of the system, the disc rotates at 450 revolutions per min.

During playback, a metal electrode attached to a diamond stylus "reads" signals from the disc. The end of the diamond fits the groove cross section and is long enough to cover two or more of the recorded waves, much like a sled runner rides over small hillocks. As it does so, the surface of the disc rises and falls under the end of the stylus electrode, causing variations in electrical capacitance between the electrode and the disc surface. The disc is made conductive to enhance these variations.

The forces exerted on the stylus by the disc are adequate to cause instantaneous alignment of the stylus tip in the signal groove, permitting grooves to be skipped for visual search, tracking correction, etc., without picture breakup. These forces are also adequate to cause the stylus to track irregularities in the disc in both the vertical and lateral directions. However, they are inadequate to move the larger mass of the arm assembly, which must be driven to maintain an approximately correct position as the stylus follows the spiral groove of the disc.

In the introductory RCA player, an arm assembly servo is used to do this; a servo in which the stylus itself picks up the centering signal. Equal and opposite phase 260 kHz rate capacitance modulations of varactor diodes are coupled from sensors on either side of the stylus to provide balanced operation. The 260 kHz signal is separated from the arm output signal with a band pass amplifier and is synchronously detected. When the stylus is in the center of the servo sensors, the 260 kHz signal recovered by the stylus will be zero. However, as the stylus moves closer to one of the pickup sensors due to the lateral force of the groove on the stylus, a 260 kHz error signal of a particular phase will be detected. This error voltage is used to drive the arm servo motor in the direction necessary to move the arm assembly to reduce the error signal to zero. Time constants in this detection circuit insure that the correct average position, with respect to the stylus position, is maintained to insure optimum stylus tracking.

Video High Density/Audio High Density (VHD/AHD)

The VHD/AHD system plays a 10.2-in grooveless plastic disc. Each disc contains one hour of color video programming per side with stereo sound, providing a total of up to two hours of information per disc. The system also plays digitally-recorded, super high-fidelity pulse-code modulated audio high-density (AHD) discs, a JVC development.

The system's disc uses no grooves to guide its diamond pick-up stylus. The restrictions of the groove-guided disc system are avoided by using spiral tracks consisting of micropits. With no grooves, the pickup arm can move freely over the entire surface of the disc. This design allows the VHD system to have special-effect modes, like random access, stop, and slow and quick motion.

The disc rotates at a constant speed of 900 revolutions per min. The grooveless capacitance design, combined with the large contact area of the stylus and disc, increases the total life of the system.

An important design feature of the VHD/AHD system is the stylus tracking section. Because there are no grooves, the stylus can be moved across the smooth surface of the disc with precision and yet with complete freedom. This allows for certain special effects, such as random access. It also minimizes wear on the disc and stylus.

The stylus is mounted on the end of a cantilever pickup arm opposite to that on which a magnet is attached. Fixed coils are mounted near the magnet; a single coil is wound around but not in contact with the magnet, and a pair of vertical coils are mounted, one on either side of the single coil and in phase opposition to each other. Thus, the stylus can move transversely and longitudinally in response to the particular current flowing in these coils. The current in the appropriate coil is varied by the tracking error signal, by the time-base error signal, or by a command to move the stylus to a desired track, thus permitting various functions during playback.

Player Description

LOR

The LOR type player system is being manufactured by several organizations around the world. It should be noted that, within this group of companies, two separate types of player configurations have evolved. The separately distinct yet compatible systems primarily derive their differences from product design philosophies, as illustrated in the introduction.

The technical difference centers around the method of linear transport which causes the necessary interaction between the coded disc strata and laser beam detector. For our purposes in this discussion, it is sufficient to say that the *institutional* player utilizes a disc drive servo transport, while the *consumer* player utilizes an optical sledge (or bench) transport. The difference again relates to perceived market segments, degree of use, and manufacturing cost.

To avoid the exclusion of any one manufacturer or marketer of the LOR player format, it is again appropriate that the description center around the consumer player first commercially promoted and delivered to the U.S. market. Recognition should be given to MCA, who delivered the first commercial LOR player (Model 700) to the Central Intelligence Agency (CIA).

The Magnavox videodisc player is housed in a plastic case of modern design. All operating controls but one are arranged on a sloping panel at the front (see Table 1), together with a number of light-emitting diodes (LEDs), indicating which function has been switched on. In a recession on the top of the appliance, a latch can be operated for releasing the lock of the lid. Measures have been taken to prevent opening the lid when the disc is spinning and/or the laser is on. Below and fixed to the lid is a magnetic device for clamping the videodisc on its turntable. The spinning motor is a standard dc ironless rotor type, directly driving the turntable. The electronic circuit is divided in functional units that can be easily plugged in and out, thus simplifying fault-finding in repair. All optical components—the laser, the sledge drive transport, and pre-amplifier—are situated on the sledge. Incorporated in this electronic video processing is a one-line dropout compensator. Two available audio channels can be used independently, i.e., for dual-language requirements, or together for stereo through a stereo amplifier.

The institutional player incorporates an on-board microprocessor that allows more complex control, as well as providing external control through a Universally External Interface (UEI).

The list of manufacturers and selling agents for LOR systems include: DiscoVision Associates, Magnavox, N. V. Phillips, Pioneer Electronics, and Sony Corporation.

LOT

The laser optical transmissive videodisc player is a front-loading caddy compatible laser system which displays video information with sound.

The transmissive videodisc player is promoted and sold solely by the major French electronics manufacturer, Thomson-CSF. In accordance with their own product philosophy, Thomson-CSF has chosen to configure its product strictly for the institutional/industrial market. The result of this preparation has evolved a player with a high-degree of durability, along with a multiple of control modes. The system exists in the three major television standards: SECAM, PAL, and NTSC*.

The player configuration is rectangular with dimensions of 20.5 cm (H), 62 cm (W) and 43.5 cm (D) (8.1 in × 24.4 in × 17.1 in) and a weight of 19 kg (41.9 lb). On the front panel, located from left to right are:

A. *Load/Unload button:* When a disc has been inserted into the player, this function commands the player to pick the disc from its caddy tray and identify frame number one.

B. *Level indicator:* This meter visually indicates that an acceptable level of signal is being "read" by the laser.

C. *Red, orange, green load monitoring LED lamps:* Used to indicate status of loading procedure.

D. *On/Off power button.*

E. *Three mode selection pushbuttons:*

1. *Standard mode:* user control via the remoteable keypad allows for:
   Play-Forward/Reverse
   Freeze Frame
   Fast Search-Forward/Reverse
   Fast Play 2 × Normal
   Frame Adv.-Forward/Reverse
   Frame Number Display-On/Off
   Sound Channel-1 or 2 or Off
   Slow Motion-15 frames per sec to 5 sec per frame
2. *Specific mode:* In this configuration the player operates through the use of keypad control to call up chapter sequence, menu loop, or chapter stop with frame-by-frame advance. The requirement here is to manually address the frame number location into memory of the onboard microprocessor.
3. *Remote control mode:* Allows for a player to be used peripherally in a more complex system controlled by a variety of computer controllers through an interface with an IEEE 488 compatible bus. In this mode, the keypad is inoperable and all commands are generated externally.

Controls on the rear panel include:

F. *Vertical and horizontal sync output:* Allows other external video equipment to synchronize with the player.

G. *Radio Frequency (RF) output.*

H. *Video output:*-BNC connector or DIN-6 plug.

Table 1 — Controls on the Magnavox LOR Videodisc System

On/Off Switch	*Fast Forward*
Freeze Frame	*Sound Channel* (1 × 2)
Slow Motion — 30 frames per second to 4 seconds per frame	*Search* (forward and reverse)
	Index Display of Frame Numbers
Normal Speed	*Chapter Stops* included in automatic actions

* Séquential Colour à Memoire, Phase Alternation Line, and National Television System Committee.

I. *Audio output:*–mini jack or DIN-6.

J. *Black-and-white and color switch.*

The LOT player, unlike the LOR institutional player, cannot currently accept in-memory frame number address information digitally coded on the lead-in of the disc. The player does, however, provide twice the amount of accessible capacity as that of the LOR player.

CED

The CED system is being introduced with consumer-type players. These feature ease-of-operation and functions such as Pause, Visual Search, and Rapid Access, among others. Organizations that have announced plans to manufacture or market CED players include: Elmo, Hitachi, K-Mart, Montgomery Ward, J. C. Penney, Radio Shack, RCA, Sanyo, Sears, Toshiba, and Zenith.

The introductory RCA videodisc player consists of a turntable driven at 450 rpm synchronously with a 60 Hz power line, a mechanism for inserting and retrieving the disc, a stylus cartridge mount and associated circuitry, signal processing circuitry, and control elements.

The player measures 17 in (W) by 15.5 in (D) by 5.75 in (H) (43.2 cm × 39.4 cm × 14.6 cm), and weighs 20 lb (9.08 kg). Controls on the front panel include Load/Unload, Play, and Off. In the Load/Unload position, a caddy entry door is opened to permit the loading or retrieving of a disc by means of caddy insertion. In the Play position, the caddy-entry door is closed, the turntable is energized, and the disc is played.

During the playing of a disc, player operation is controlled by five pushbuttons. The Pause pushbutton causes the stylus to lift from the disc and the arm advance to stop. A second push of this button causes play to resume. The Pause button allows interruption of the program for as long as desired without missing any of the program content and without harm to the disc. The two Visual Search pushbuttons cause the stylus to be moved two grooves, either forward or reverse, during each vertical blanking interval so that the program action proceeds at 16 times the normal rate without picture breakup. These Visual Search buttons are used for locating a precise section of the program. The two Rapid Access pushbuttons lift the stylus carriage at about 150 times the normal speed in either the forward or reverse direction. During this operation, both video and audio signals are muted.

Table 2 — Features of the VHD/AHD Videodisc System

Normal Play (forward and reverse) for up to 120 min (both sides)	*Forward Quick Motion* at two and five times normal speed
Fast Visual Search (forward and reverse) at up to 64 times normal speed	*Reverse Quick Method* at three times normal speed
Selection of Audio Channel for stereo sound, mono, or bilingual playback	*Forward Slow Motion* at $\frac{1}{16}$ or $\frac{1}{2}$ normal speed
Picture-by-Picture Playback (forward and reverse)	*Reverse Slow Motion* at $\frac{1}{2}$ normal speed

The Play Time indicators (LEDs) give an indication of the stylus position measured in minutes of play from the beginning of the disc. These indicators also show an "L" for the Load/Unload position of the function lever, "P" for Pause, and "E" to indicate that the program has ended.

After a disc has been inserted into the player, the Side Indicator shows which side of the disc, 1 or 2, is uppermost in the player and is being played or is ready to be played.

The removable door on the top of the player provides access to the stylus cartridge so that it can be changed when required.

The stylus is designed to operate for many years in a normal home environment. Discs can be played many hundreds of times without deterioration. All other parts of the system are also designed for extended life.

VHD/AHD

Antenna connection or audio output terminals allow simple hookup of the player to either a monaural TV receiver or a stereo audio system. Dimensions are 430 mm (W) by 390 mm (D) by 136 mm (H) (16.9 in × 15.4 in × 5.4 in), weight 12.9 kg (28.4 lb).

The VHD/AHD system player has manual search using a "see-saw" button control. Searching can be done at speeds of up to 64 times normal in either direction. Fast Search will "play" an entire disc side in less than one minute. Slow Search is approximately $\frac{1}{16}$ normal speed forward and $\frac{1}{3}$ normal for reverse.

Chapter Search and Repeat are keyed to number codes on each disc that identify a program portion, like a chapter in a book. A user can code in chapter points and can summon them or repeat them with a simple control.

Random Search (time mode) is keyed to the time code recorded on every videodisc. To skip any desired section, a user simply enters the starting time on the numerical readout and presses the Start button. The VHD unit will continuously repeat a given program segment as set by the user. Several combinations of the player and auxiliary units provide different video and audio functions.

In the case of video operation (VHD), Normal (back and forth), Special Effect (stop, slow, and quick motion back and forth), and Fast Visual Search (back and forth) modes are performed by the player itself (see Table 2).

In the case of audio operation (AHD), super high-fidelity stereo sound can be enjoyed by simply connecting the pulse-code modulation (PCM) demodulator to the player.

Disc Description

LOR

The production process for a videodisc is more or less comparable to that used for conventional gramophone records. First, a master recording is made (Fig. 1). It consists of a glass plate with a photosensitive layer deposited on one side. The coded signal of the information to be stored modulates the beam of a 1 mW laser which "writes" the information into the surface of the master disc.

"Cutting" is done on a real-time basis; that is, it requires only as much time as the program lasts. In principle, every normal type of TV signal source can be connected to the master recorder.

The information on the disc is stored in a spiral track starting at a fixed diameter on the inside and moving to the outside. Average track pitch is 1.6 μm. The information in the track exists on small depressions, called "pits," with variable distance and length. Pit width is 0.4 μm and pit depth is approximately 0.1 μm. A simple calculation shows that the total track length on a 30 cm disc is about 34 km. It can also be calculated that one complete tele-

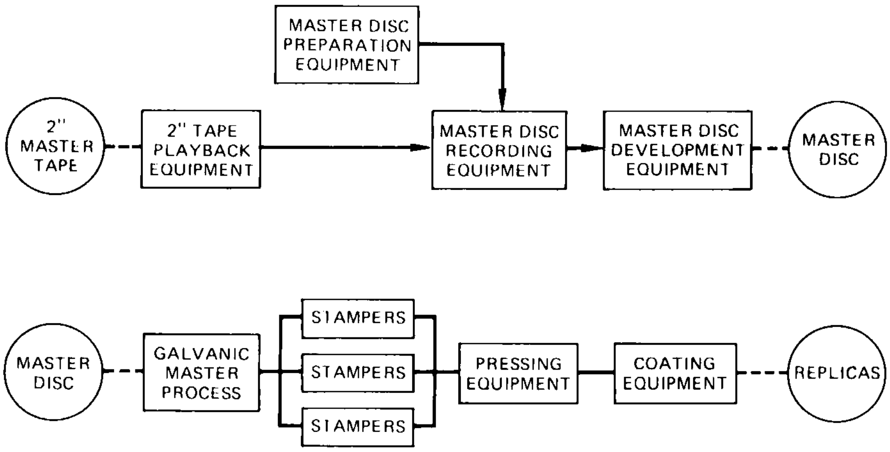

Figure 1. Videodisc mastering and replication.

vision picture requires a disc surface of 0.6 mm^2.

Exposure to the laser beam is followed by a development process which leaves a pattern of pits on the master from which, via a galvanic process, stampers are made which are used for disc production in a way similar to pressing gramophone records, or by means of a recently-developed completely new process, typically adopted to VLP disc requirements.

After pressing, an extremely thin metal coating of no more than about 0.04 μm thick is deposited on the information side, which is then sealed with a protective layer. As the final operation, two discs are glued together, resulting into one disc that can be read from both sides.

LOT

The process specific to large volume LOT videodisc replication involves several steps:

A thick glass disc undergoes a specific polishing treatment to become the original recording substrate. It is then coated with a thin film of photosensitive resin, which will be subjected to the effect of a focused laser beam.

The laser beam of the optical recorder is modulated in alternations of on/off states by video and audio electronic signals. Any part of the exposed resin undergoes instant chemical change which latently marks the spot of a micropit-to-be, the relief of which will appear after immersion in the development bath. At this stage, the original disc which is engraved in relief is called "master."

The master is then coated with a thin conductive film prior to immersing in a bath which, by an electrolytic process, will result in a nickel negative copy named "father," and is usable as a stamper to replicate modulation relief on discs for playbacks on the Thomson-CSF system.

When a large quantity of discs is required (over 1000 units), the father is first replicated via the same electrolytic process in order to form, by three generations, several positive copies. From there several negative copies are made, each of which will subsequently be used as a disc production stamper.

The process by which disc production takes place with either "father" or stampers is thermoforming under pressure. Thin foil is relief-printed and the central hole is punched during this final operation, thus yielding a flexible and transparent disc.

The thin flexible transmissive disc is stamped on both sides and enclosed in a caddy, the dimensions of which are 1.3 cm (H), 31 cm (W), and 37 cm (D) (0.5 in × 12.2 in × 14.6 in) with a weight of 550 g (19.4 oz) max. The caddy itself consists of a sleeve and a tray, the disc resting on the latter.

The disc may be recorded on either one or both sides. A conventional readout yields a maximum capacity of about 30 min, corresponding to a maximum of 45,000 pictures per side in SECAM or PAL TV standards, and 49,999 from video source or 43,200 from film source in NTSC standard. Each picture possesses its own code number, which is inserted during mastering in the vertical blanking interval of the video signal. (*Note*: No opening of the caddy should take place outside standard operating procedure.)

CED

The CED videodisc signal pattern is initially recorded on an electro-deposited copper surface. The recorded pattern is then replicated by one or more successive nickel electroplating operations to produce a negative, or stamper. Two stampers are mounted in a multi-ton compression-molding press, on which two-sided discs of carbon-loaded PVC (polyvinyl chloride) are molded. The discs are then coated with about 300 Å of oil to lubricate the disc-stylus interface in order to extend the playing life.

Copper is used for the original recording because very smooth surfaces can be cut in it. A diamond cutting stylus with a V-shaped cutting surface is driven perpendicularly to the copper surface by a piezoelectric transducer to cut the modulated groove in response to signal input.

The finished disc is designed to be played back at 450 revolutions per min. At this speed the signals from the disc vary from 4.3 MHz at sync tips to 6.3 MHz at peak white. The diameter of discs are 12 in and 70 mils in thickness, roughly the same dimensions as those of an audio LP disc.

The videodisc caddy is an important part of the CED system and provides two significant functions. First, the caddy provides a convenient means for storage of the videodisc and protects the disc from dust and other debris which might impair playback. The second function is to allow a relatively simple mechanical interface with the player.

Contained within the caddy is a plastic spine which surrounds and captures the disc during insertion into the player. The spine has a side identification molded into the front edge, with side reference always maintained between the disc and spine. A key at the front edge of the spine provides a means for mechanically identifying which side is being played within the player. At the outside of the front edge are two locking tabs to retain the spine inside the caddy when it is not inside the player.

RCA is currently mass-producing CED discs, and CBS, Inc., is also preparing to do so.

VHD

Each VHD/AHD disc is contained in a protective plastic case. The case is inserted edgewise into the player and all loading after insertion is automatic. Each disc measures 26 cm (10.2 in) in diameter, and each one-hour side contains both video and stereo audio or bilingual information. Each disc is made of standard electroconductive plastics.

The VHD/AHD disc is constituted of multiple-pit rows in a spiral form on the flat surface. Each track has the information pits which are recorded with video and audio (or with PCM audio). Signals and tracking pits are recorded between information tracks, which guide the capacitance pickup, tracking precisely along the information tracks.

Recording is performed on a glass master disc using a special laser recording machine installed in a clean room. The flat polished glass is coated with ordinary photo-resist material. While rotating at a speed of 900 rpm, minute laser beams are irradiated onto the disc, which is being moved radially at a constant speed. As a result, fine pits are spirally recorded on the coated glass disc with a depth of 0.3 μm and width of 1.35 μm. Tracking pit depth is 0.15 μm with a tracking pitch of 1.35 μm.

The optical system splits the laser beam in two. One half is for the information signals, and the other is for the tracking signals. The information and the tracking pits are recorded simultaneously by combining these two beams.

A metal master disc is produced from the glass master disc by the conventional audio process.

The disc each consumer purchases is made of electro-conductive plastics which require no additional processing.

Summary

A more in-depth evaluation would be needed to illustrate the different type descriptions of videodisc. This paper may not have depth enough for some and too much for others, but it shows that approaches to videodisc technology are as diverse as its uses.

What is clear is that the complex diversity should be used as a guide for this SMPTE committee to strive for those areas that are commonly measurable. This is not a recommendation that all constituent formats be combined in one boiling pot, but rather is a recommendation to join, where feasible, common elements in the establishment of measurement for professionally commercial qualities.