A REVIEW OF A VIDEO-DISC SYSTEM

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The system can be considered in terms of three techniques:

1. Mastering
2. Replication
3. Playback

1. MASTERING

1.1 Disc Properties and Information Format

The recording medium is a thin metal film evaporated onto an optically polished plate glass disc 0.24″ thick. Glass was chosen because it is very uniform and because its surface can be made smooth and free of scratches, pits and other blemishes by the well-known techniques of optical polishing. Starting with discs cut from twin-ground plate glass the surface may have hundreds of small pits per square millimeter. These discs are then reground with a fine abrasive to get rid of the deepest pits. Finally, the surface is optically polished until the pit density is reduced to less than 10 per square millimeter. The disc is then cleaned chemically and transferred to a vacuum evaporator where it receives a metallic coating a few hundred angstroms thick. For recording the disc is transferred to the mastering machine where a laser beam records picture and sound information by selectively melting the metallic coating.

The layout of a twenty-minute disc is shown in Fig. 1. The information track is a spiral of 2 micrometers pitch which is read from the outside in.

One TV frame is recorded per revolution of the disc. The information is recorded as a series of holes cut in the thin metal film deposited on the glass disc. The holes range in size from circles 1 micrometer in diameter at the 3″ radius to ovals 1 micrometer x 2 micrometers long along the path at the outer radius. The recording has a mean wavelength of 3 micrometers.

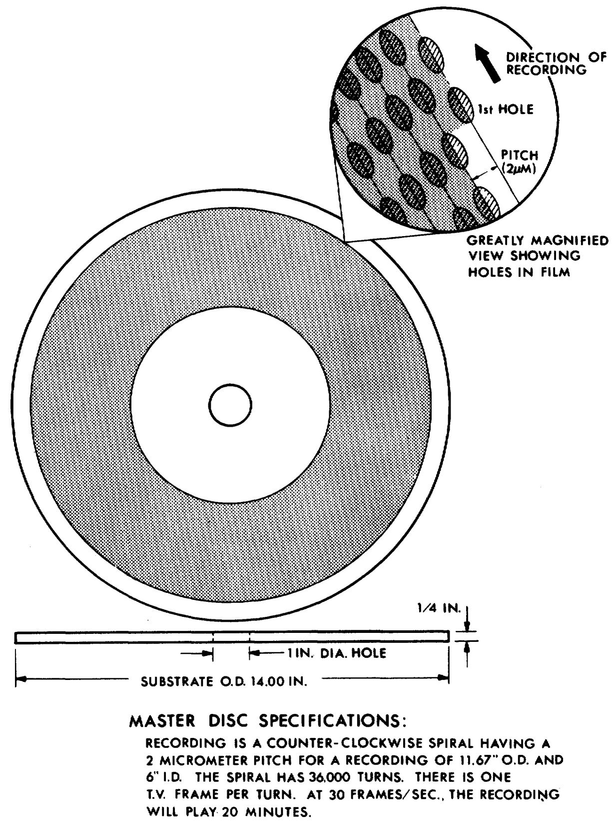

Fig. 1 Master disc layout.

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Various techniques are available to lengthen the twenty-minute playing time of the described configuration. A forty-minute Disco-Vision record has been publicly demonstrated and the technique by which forty minutes of playing time on one side of a 12″ record were achieved will be described at a later time.

To minimize the cost of the processing electronics in the home player, the information on the disc is kept in the NTSC format required by the home TV set. The relative positions and frequencies of the video, chroma and sound subcarrier are preserved when going from the program signals to the signal represented by the holes in the disc coating; therefore, no re-formatting or re-arrangement of signal components are required in the player and minimization of the player cost is accomplished.

The choice was made to record with frequency modulation (FM) because of its immunity to noise at low frequencies where much of the system noise is. The usual source of audio and video signals is a 2″ video tape recorder. The audio signal is used to frequency modulate a 4.5 MHz carrier. This carrier and the processed video are summed and fed to a voltage controlled oscillator (VCO). This device has a center frequency of approximately 7 MHz and a deviation of ±1 MHz for a 1 volt peak-to-peak video signal. The recording polarity is such that sync tips produce the highest frequency, 8 MHz, and saturated whites produce the lowest frequency, 6 MHz.

Fig. 2 shows the basic signal processing used in mastering and playback. In mastering the resulting FM signal, occupying a spectrum from approximately 2.5 to 11.5 MHz, is applied by the cell driver to a Pockels cell electro-optical modulator. The Pockels cell has incident upon it the beam from the record laser. Under the influence of the signal from the cell driver, the Pockels cell alternately passes and blocks the beam, thus allowing the beam to produce holes and lands in the disc coating. An adjustable dc bias is applied to the Pockels cell to minimize 2nd-harmonic distortion that can be generated in the cutting process.

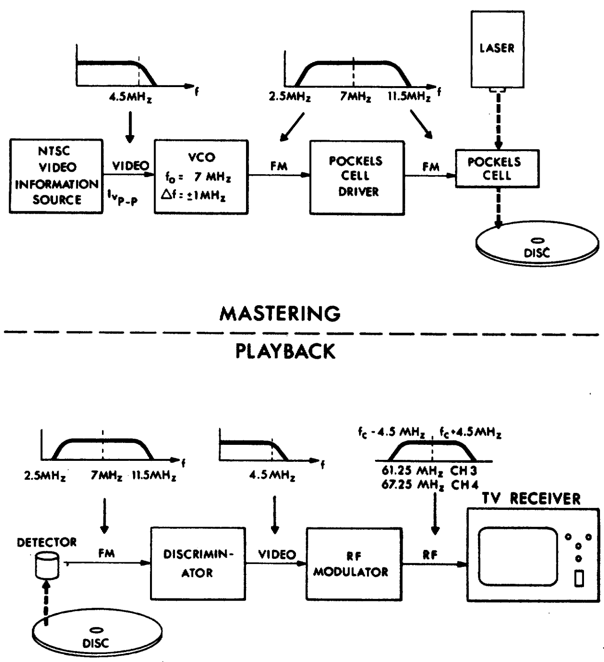

Fig. 2 Basic signal processing.

1.2 Optical and Mechanical Techniques

Details of the physical arrangement required for cutting a master are shown in Fig. 3. An argon-ion laser produces the basic "write" beam, which is modulated by the Pockels cell. Optics direct the beam onto the disc to produce the holes previously described. The rotatable Glan prism is used to adjust the average intensity of the beam reaching the disc. As shown in Fig. 3, the last few optical elements in the write beam are mounted on a carriage that is moved along the disc's radius by a motor-driven lead-screw. The objective lens is supported on an air bearing, which is loaded against the surface of the disc. A relatively small air flow at moderately high pressure maintains the head and objective lens at a constant distance of approximately 0.0005 inch (0.5 mil) from the surface of the disc. Fine focus adjustment is made by moving the diverging lens on the V block until optimum cutting is obtained.

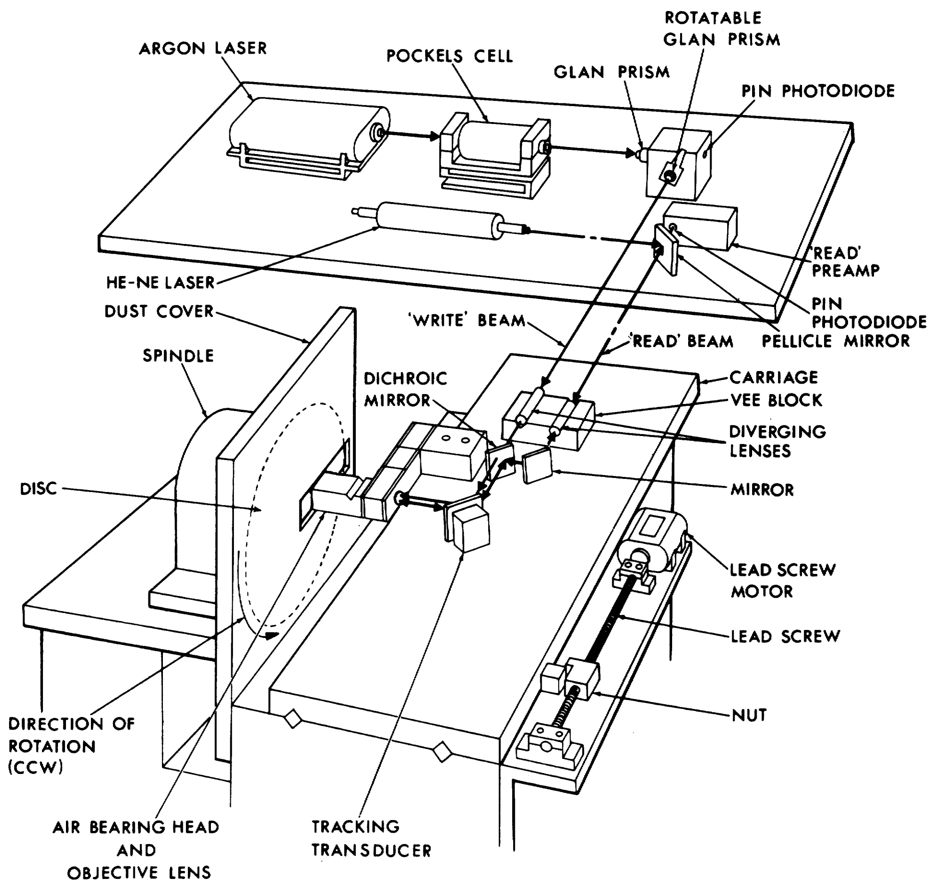

Fig. 3 Mastering optical and mechanical configuration.

1.3 Read-While-Write

Since there is no need to develop or process the master in order to read it, an optical system is included in the mastering configuration so that masters can be read while they are being cut. This feature allows the recording parameters to be adjusted while cutting and also provides continuous monitoring of the video quality of the master. Measurements of SNR and other video parameters can be completed and logged while mastering is in progress. Continuous monitoring also reveals defects in the master which could only be detected by playing it.

The optical arrangement consists of a 1 milliwatt He-Ne laser, a beam splitter, a second diverging lens, an adjustable mirror and an adjustable dichroic mirror for combining the read and write beams before they enter the microscope objective. The two adjustable mirrors are used to position the read spot about 10 micrometers down stream from the write spot and directly on the track it has just cut. The 10 micron spacing insures that the recorded surface is in its final state at the time it is read. The return beam comes out the same way it enters (the system is retro-reflective) until a portion of it is reflected into a PIN photodiode by the beam splitter. The diode, pre-amp and discriminator are all components of the playback system described later in this paper.

2. REPLICATION

After the master disc has been cut, it must be transformed into a configuration from which replicas can be made. This is done by transforming the essentially "two-dimensional" master record, which consists of holes in a thin metal film, into a "three-dimensional" configuration which can be used to stamp or form inexpensive, plastic replica discs.

2.1 Master Transformation

The master is coated with a photoresist material and is exposed through the rear (under-surface) of the disc. The ultraviolet light source exposes (polymerizes) the photoresist through the information holes. The uncut metal film shields the photoresist where there are no holes. This results in an array of hardened areas which coincide with the initial array of information holes. The unpolymerized photoresist material is then washed away with an appropriate solvent leaving bumps over the holes. Depending upon the photoresist used, the hardening program and other parameters, the height and profile of these bumps may be tailored to optimize the optical contrast between these bumps and the surrounding flat area when they are illuminated by the high numerical-aperture, diffraction limited optical scanning system of the player.

2.2 Replica Forming

The prime method of producing good quality, inexpensive replica discs uses a polyethylene terephthalate ("Mylar") material and is a proprietary process at this time. It will be treated elsewhere when the patent circumstances and the proprietary elements permit. It has among its advantages a better quality, tougher record, a shorter production cycle-time, and web or automated belt handling of the entire disc replication process.

An alternate process which has also been employed involves treating the transformed master described above by electroless and electrodeposition to form a metal tool ("stamper") from which replicas are thermoformed, typically from polyvinylchloride (PVC), by a method close to that used to make audio records.

2.3 Post Forming Operations

The plastic discs are finally metallized with a reflective coating and coated with a transparent plastic for protection against degradation by handling. An alternate process to the final protective coating is to produce the discs using a transparent plastic permitting optical reading of the record through the transparent back side. Due to the limited depth of focus of the read-out optical system, typically ± 1 micron, scratches or dirt on the surface of the protective coating are out of focus and have no degrading effect on the record playback. Optically read records of this type actually require less care in handling than ordinary audio LPs.

The replicated discs are typically 5 to 10 mils in thickness and may be configured either with information bumps as indicated in the master transformation section or information holes made by forming these bumps into a mating surface—depending upon how many generations or reversals are involved between the transformed master and the final plastic replica. These two configurations are both satisfactory from an optical read-out standpoint.

3. PLAYBACK

The playback unit is self-contained and is designed to be connected to the antenna terminals of any domestic American color television receiver to provide playback of replicated videodiscs. It employs an optical technique to read the videodisc that does not require any physical contact between the read head and the videodisc. This non-contact system provides for long life of both the videodisc and the read head and it also permits freeze-framing without any wear penalties. The essential elements of the playback unit include the following: (1) an optical system that directs and focuses a low-power helium-neon laser beam to a small read spot on the surface of the videodisc and then collects the reflected optical energy and directs it to a single photodetector; (2) a means of rotating the videodisc at the correct speed; (3) a means of positioning the read spot on the videodisc surface which acquires and locks on to the spiral data track; (4) a means of maintaining the optical system in focus on the surface of the videodisc; (5) the necessary electronics to process the signals for the television receiver; (6) the controls, control electronics and power supplied to operate and power the unit; and (7) a functional and decorative enclosure to house the unit.

3.1 Optical System

The playback optical system is shown in Fig. 4. The light source used is a low-power helium-neon laser tube. The laser tube has a nominal output power of 1 milliwatt which is single mode (TEMoo) and linearly polarized. The laser beam is initially directed by two mirrors that are adjustable for alignment purposes. The laser beam is then expanded to fill the back of the objective lens by a plano-convex lens. This beam expanding lens is adjustable along its axis to provide for fine focus of the optical system. The beam is then transmitted through a specially coated beam splitter. The direction of the laser beam polarization is such that most of the beam will pass through the beam splitter. A quarter-wave plate changes the beam polarization from plane to circular. The beam is then directed into the back of the objective by two mirror transducers which consist of mirrors that can be rotated by piezoelectric bender motors. These rotations produce a corresponding motion of the read spot on the disc surface. One transducer is used to move the read spot in a radial direction to provide the high speed tracking corrections required to follow the data track. The other mirror transducer causes the read spot to move in a tangential direction on the videodisc to provide the time base corrections. These high speed tracking and time base corrections are required because of videodisc eccentricity, mechanical vibrations, etc.

The objective lens which focuses the laser beam to a small spot on the surface of the videodisc has a numerical aperture of .35 and an effective focal length of approximately 12 millimeters. The laser light that is reflected from the surface of the videodisc is collected by the objective lens and returned along substantially the same path that the

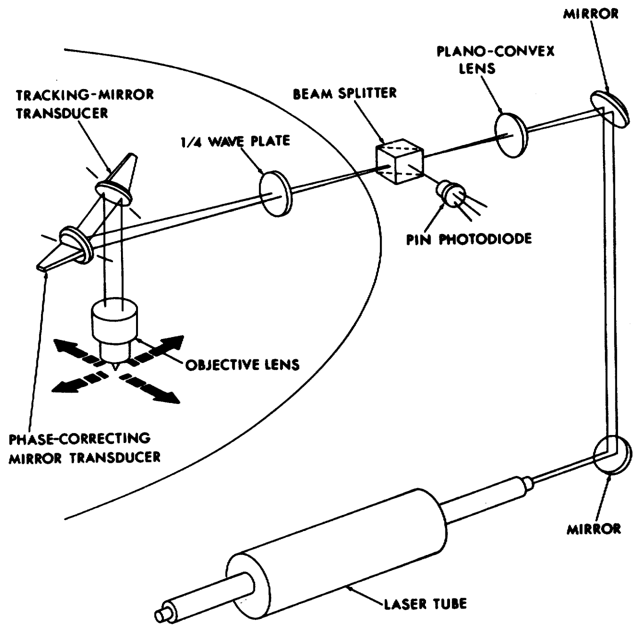

Fig. 4 Player optics.

incoming beam traveled. When the reflected beam passes through the quarter-wave plate, it is changed again to plane polarized light, but it is polarized at a right angle to the direction of the incoming laser beam. The reflected beam is then reflected by the beam splitter to the PIN photodiode detector where the optical signal is converted to an electrical signal for processing by the electronics. The use of the plane polarized laser tube, the specially coated beam splitter, and the quarter-wave plate results in a high efficiency optical system that minimizes the reflected signal that is fed back into the laser cavity.

3.2 Playback Signal-to-Noise Ratio

Measurements were made of the optical efficiency of the player by comparing the energy returned to the PIN diode by (1) a large "land" area on a videodisc and (2) a series of bumps having 2.2 micrometer wavelength, corresponding to an FM frequency of 6.75 MHz at a 3 inch radius. The return from the large land was 10.0%; from a bump 3.0%; from the space between bumps 5.5%. Hence, if a player with a 1 milliwatt laser was reading a 2.2 micrometer recording, a peak to peak signal of .025 milliwatt would return to the PIN diode. This in turn would yield a photocurrent of 2×10^{-6} amp RMS. The noise floor of such a system would be determined by photon shot effects, thermal effects, laser noise and pre-amp noise. Measurements indicate that the thermal and pre-amp noise dominate and are roughly equal. They give rise to a noise current of 2×10^{-8} amp RMS so that the FM SNR would be 100:1 or 40 db assuming perfectly recorded bumps having a 2.2 micrometer wavelength. When demodulated this FM SNR yields a video SNR of better than 58 db which does not limit the playback quality. The actual playback video SNR is limited by replica disc quality and is presently better than 40 db.

3.3 Disc Rotation

The videodisc is mounted on a turntable that is rotated at 1798.2 revolutions per minute by an electric motor. The speed of the turntable is sensed by a tachometer that consists of a phototransistor and light emitting diode that are located on either side of an incremental encoder disc that is mounted on the turntable spindle. The belt driven turntable spindle is powered by a universal type motor that is driven from the ac power lines using a triac. The triac is controlled by a phase locked loop control circuit that compares the tachometer output frequency with the counted down output of the 3.58 MHz crystal controlled oscillator in the signal processing electronics. Thus, the spindle drive motor is brought to and maintained at an angular velocity that produces zero mean error between the frequency produced by the tachometer wheel and that of the divided crystal oscillator. This is the rate required to make the frequency of the color signal, and hence the horizontal sync signal, within the range of the time base correction servo.

3.4 Tracking Servo

Due to possible non-concentricity of the replicated disc and the turntable, replicated disc out-of-roundness and vibration, the read beam and the tracks relative positions do not remain constant. The tracking servo controls the radial position of the read beam in a manner that results in constant read beam position within the track. The ratio of opened to closed loop gain in the control loop would reduce a simple eccentricity of 0.1 millimeters to a reading error of less than 0.15 micrometers. The maximum trackable eccentricity is about 0.25 millimeters, but as a practical matter, the replicated discs will have eccentricities less than half that value.

Since the overall development objective was aimed at a reasonably priced consumer product, a simple tracking and information reading system requiring only a single photo-surface for all functions combined was developed (after considering a variety of techniques). This not only minimizes the cost of photo-detectors and their associated electronics, but even more importantly, reduces to one the number of optical paths that must be critically aligned and registered during the manufacturing process. The tracking servo technique is illustrated in Fig. 5. A single PIN photodiode is used to recover the tracking servo and video signals. A limited bandwith, high gain dc pre-amp outputs a signal that is a function of read beam position within a track. It is clear that this signal is also directly proportional to laser power output. Since laser output power is influenced by a variety of conditions, some means of compensation is required for long term stable tracking. A portion of the direct beam is directed onto an inexpensive silicon solar cell with the cell output used as a compensating signal in the servo pre-amp, allowing the tracking servo to respond only to the read beam position within the track.

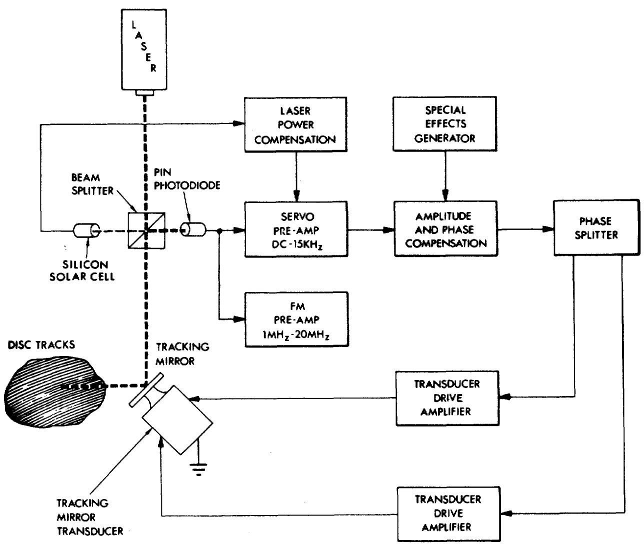

Fig. 5 Tracking servo.

A dc bias, whose value represents position within the track, is summed with the pre-amp output and applied to the amplitude and phase compensation circuit which is designed to make the servo loop stable at high gain. The compensation deviates somewhat from normal control theory techniques because of the need to compensate the high Q of the piezoelectric mirror transducer that changes the radial position of the read beam. The output of the compensation circuit then is applied to the phase splitter which feeds the transducer drive amplifiers. When the loop is closed, the mirror transducer constantly positions the read spot with respect to the track so that the average reflected signal corresponds to the set dc bias.

There is a leadscrew drive system which moves the read head on a near radial path at the nominal pitch rate (2 micrometers/revolution). A secondary servo loop samples the low frequency portion of the servo signal to make the average head radius equal the read spot radius during playback.

To implement stop motion and other special effects a means of causing the read beam to "jump back" one track, at a predetermined time, is required. This is done by injecting into the tracking servo loop a modified impulse function with sufficient area to move the read beam one track (2 micrometers). Due to the dynamics of this process several compensating signals are also summed in the servo loop to keep the read beam positioned properly within the track immediately after "jump back."

3.5 Time Base Correction Servo

In the normal television receiver the chrominance and horizontal sync circuits are very intolerant of time base errors in the composite video signal. To assure proper playback a corrective motion is applied to the read spot in the direction of the information track. The sources of time base error are the same as for the tracking error. The frequency of the burst signal is used as the basis of the control action. With the burst signal corrected all other portions of the video will be correct. The time base correction technique is illustrated in Fig. 6.

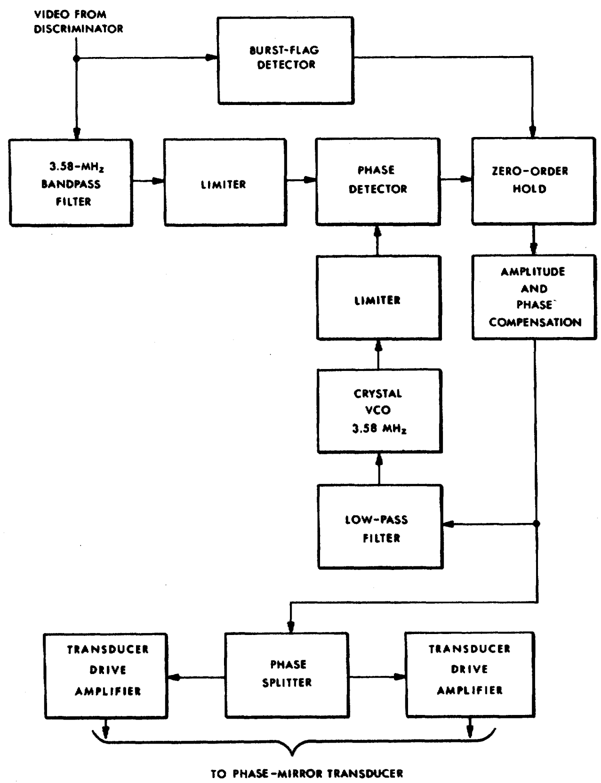

Fig. 6 Time base correction servo.

The chrominance signal is extracted from the video and applied as one input to a phase detector. The other input is derived from a narrow range crystal VCO operating at the nominal color burst frequency. A zero order hold samples the phase detector output during the burst time-slot. Thus, the output signal has an amplitude proportional to the phase difference between the video burst signal and the VCO. This signal is then applied to an amplitude and phase compensation circuit (similar to the tracking servo) to stabilize the servo operation. The output of the compensation circuit is applied to a phase-splitter and then to the transducer drive amplifiers. The mirror transducer constantly positions the read beam such that the video burst frequency is exactly identical to the VCO.

Since the mirror transducer has finite dynamic range, static errors must be corrected by another technique. Another loop has been added to correct this problem. A signal containing the very low frequency components of the main servo loop is applied to the referenced VCO in a manner to cancel the static errors.

3.6 Reading Height Regulation

The videodisc is maintained at the focus of the optical system by means of a vacuum controlled aerodynamic reading head that carries the objective lens. The thin videodisc is separated from the turntable by a film of air when the turntable is rotating at speed. This film is due to the radial outward flow of air drawn through a circle of ventilating holes bored in the turntable just outside of the clamp ring. The air film decreases the coupling between the videodisc and the turntable enough to permit a vacuum applied to the face of the reading head to make a bulge in the surface of the thin videodisc.

The distance between the reading head and the surface of the videodisc is stabilized by the balance between the aerodynamic forces tending to push the disc away from the read head and the vacuum that tends to pull the disc toward the read head. The separation between the read head and the videodisc is controlled by vacuum pressure and air flow into the vacuum port on the read head. This fail-safe, vacuum controlled, aerodynamic reading head operates with a head-to-disc spacing of greater than 1 mil and provides stiff head-to-disc coupling that maintains the distance between the objective lens and the thin replicated videodisc to within 1 micrometer which is adequate to keep the optical system in focus.

3.7 Discriminator and Drop-out Compensator

Because the FM encoded signal recorded on the disc is video in the NTSC format with the sound at 4.5 MHz, the signal processing electronics can be relatively simple. As shown in Fig. 7, the video signal is first recovered with a discriminator and then used to modulate an oscillator tuned to an unused TV channel. A more detailed description follows: The FM encoded information from the PIN photodiode is amplified by a wide band, low noise pre-amp located near the photodiode. The signal is limited and applied to the FM drop-out compensator.

Due to the nature of the Disco-Vision record and reproduce process, drop-outs tend to be caused by a missed half-cycle of the FM carrier. This requires a different compensation technique than that for systems such as magnetic tape where the duration of the drop-out is generally a large portion of a horizontal line. A missed half-cycle of carrier looks like a large decrease in instantaneous frequency so that the discriminator produces a whiter than white impulse in the video signal. If not compensated, the drop-out would produce a very distracting white spot in the TV image. To reduce the viewers awareness of the drop-out, the playback electronics includes an FM drop-out compensator which detects the missing half-cycle and synthesizes a signal to replace it. Although it contains no information, the synthetic pulse greatly reduces the visibility of the drop-out. This entire section, including the multiplying type of discriminator, is implemented with digital techniques for cost savings and ease of alignment.

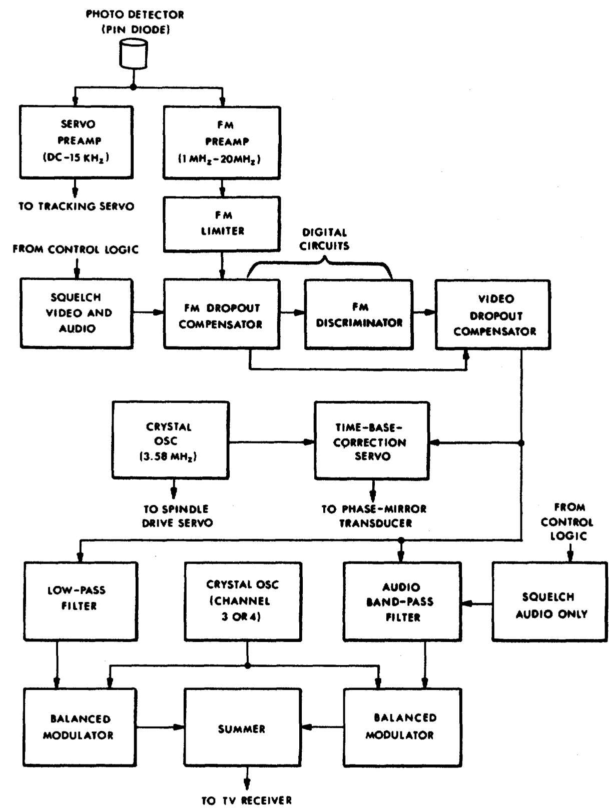

Fig. 7 Player signal electronics.

On rare occasions drop-outs with a duration of several cycles of carrier are encountered. When this happens compensation is most easily done in the video domain. This is accomplished by passing the video signal through a zero order hold which operates normally in the sample mode. When a multiple cycle drop-out is detected, the circuit is switched to the hold mode. This supplies the last sampled value of luminance signal for the duration of the drop-out.

After discrimination what results is a full bandwidth NTSC composite signal complete with audio subcarrier.

The Disco-Vision recording and reproducing system, if not limited by the TV receiver, produces an image with more than 450 lines of horizontal resolution (on the basis of two lines of horizontal resolution per cycle of video signal) and video signal-to-noise ratio of greater than 40 db in the replica disc.

3.8 R. F. Modulator

The R. F. modulator is illustrated in a portion of Fig. 2. The audio subcarrier and the video signals are separated by filters. Each is then applied as one input to a pair of balanced modulators. The other pair of inputs are derived from an oscillator tuned to the carrier frequency of the unused TV channel selected. The outputs of the modulators are then summed to form the RF signal for application to the antenna terminals of a TV receiver. A switching arrangement linked to the player power switch, connects normal TV antenna to the TV receiver when the player is not in use.

3.9 Operating Controls

The operating controls for the playback unit are located in a control panel on the top front left corner of the unit. The control panel consists of a slide switch to turn the unit on and five push button switches labeled "play," "stop," "in," "out," and "reject." The power to the playback unit is turned on by the slide switch. The slide switch also disconnects the television antenna from the television receiver and connects the television receiver to the playback unit.

The "play" push button is used to initiate the start of the playback sequence. When it is depressed and the cover on the unit is closed the turntable starts to rotate and the player arm moves to position the read head over the start of the program on the videodisc. When the turntable is up to speed and the player arm is in position, the player will automatically play through the entire program on the videodisc unless it is interrupted by pushing one of the other push buttons. Upon completion of the program the turntable will automatically stop and the player arm will move clear of the videodisc.

The function of the "stop" push button switch is to stop the motion of the player arm and "freeze" the scene of the television screen to a single TV frame. This single TV frame will then continue until interrupted by pushing another button. The audio is suppressed during this stop motion sequence.

The "in" push button switch is used to translate the player arm in toward the center of the disc at approximately 100 times the normal playing speed for fast scanning to another part of the program. This fast scanning continues as long as the push button is depressed or until the program is completed. The function of the "out" push button switch is similar to the "in" switch except it translates the player arm back toward the start of the program on the disc. The optical, non-contact nature of the system permits fast scanning to be performed at will with no wear or degradation of the disc. It may be the ideal way for the consumer to locate a desired band for playback since even with the 100 times speed up in the fast scan arm translation, picture content can be recognized on the TV screen.

The function of the "reject" push button is to terminate the program and when depressed will stop the turntable and move the player arm clear of the videodisc.

3.10 Special Effects and Applications

Because of the lack of physical contact inherent in this optical system and because information or frames within the disc may be random accessed very rapidly, many applications in addition to home entertainment are possible. These include archival storage of documents and facsimiles; audio-visual encyclopedias, dictionaries, catalogs, etc., that may be accessed immediately on a frame address basis; teaching machine and educational applications which involve inter-active programming with addressable sub-routines and branching and many other applications where data, pictures, motion or general audio-video information must be stored inexpensively and accessed flexibly and rapidly. To this end initial work in frame numbering and coding and search programming has been carried out.

3.10.1 Frame Number Encoding

This is accomplished by placing within each vertical interval a coded digital word containing the following:

Pseudo Random Sync Words
Parity Check
Five Decimal Digit Frame Number
Field I.D.

The information is coded in a self-clocking format to simplify the data recovery process.

3.10.2 Search Program

The digitally encoded frame identification data is recovered with a self-clocking decoder. The data is stored in a buffer and updated every vertical interval. A parity check and pseudo random sync codes are used to ensure only valid data is used. A five digit display presents the number of the frame being viewed.

When the search mode is initiated, logic compares the present frame number with the desired frame number. The direction in which the desired frame lies is determined, and the leadscrew servo is set into fast scan in that direction. The digital data is read during the fast scan until passing the desired number. If the initial scan was in reverse, the leadscrew stops, and the player resumes normal real-time play until the desired frame is reached. If the initial scan was forward, the leadscrew reverses direction after passing the selected number and continues until the number is again passed. This places the read beam again ahead of the desired frame. The leadscrew again stops, and normal real-time play is resumed until the desired frame is reached. When the desired frame is reached, the logic switches to the stop motion mode where the desired frame can now be viewed. With the present player, this technique permits access to any frame out of about 36,000 within a few seconds. The search logic has the capability to perform other special effects. They are forward and reverse slow-motion (variable rate), and single-frame step forward and reverse.

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BIOGRAPHY

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Prior to his affiliation with MCA, Mr. Broadbent was president of Broadbent Laboratories, Inc., and before that was director of American Systems, Inc's solid state division. Previously, he was head of the subsystems, components and devices section of Hughes Research Laboratories. He has also served as a technical consultant to Hughes Aircraft Company, North American Aviation, Lockheed Electronics and MCA Inc.

Mr. Broadbent has a BS in physics and mathematics from Brigham Young University and an MS in physics from Case Institute of Technology. He also completed extensive additional graduate work in physics and electronics.

Mr. Broadbent holds 13 patents and has published papers in technical journals on advanced information processing systems and solid state research. He has also delivered technical papers at the International Solid State Conference and at various meetings of the IEEE.