AN OPTICAL VIDEO DISC PLAYER FOR NTSC RECEIVERS

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SUMMARY

This paper reports on a team effort to develop an optical player based on a thin flexible disc and the aerodynamic disc stabilizer of Thomson-CSF. The signal is encoded by a method which minimizes the effect of microscopic non-linearities within the disc surface: luminance and chroma together modulate an FM carrier of relatively high frequency. Radial tracking is achieved by a method which keeps the focused laser beam centered on the recorded track, requires no auxiliary beams and permits unusually high track density. Timing errors, caused by eccentricity and distortion of the disc, are suppressed by an electromechanical servo which is combined with the tracking servo. Improved timing error correction opens up an interesting possibility of simplifying the decoder.

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The general principles of an optical disc are now well understood. This paper is therefore limited to the discussion of a few specific problems and specific solutions. We have done our experimental work with a player that uses transparent flexible discs of polyvinylchloride (PVC), 150 to 250 microns (6 to 10 mils) thick. It uses the aerodynamic stabilizing system developed by Thomson-CSF to keep the disc surface positioned in a reference plane. This plane coincides with the focal plane of the final lens of a simple optical system, which also contains a one milliwatt He-Ne laser, an intermediate lens, a tiltable mirror and a photodiode arranged on the other side of the disc. There are, of course, mechanical elements such as the spin motor, cross feed etc., which will not be touched upon in this paper.

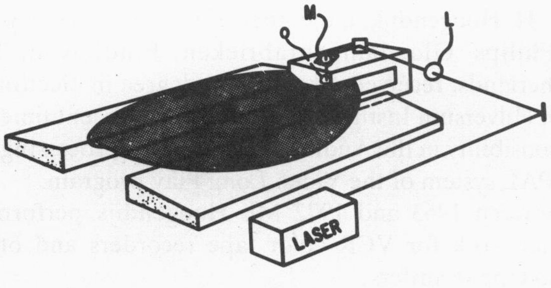

Fig. 1: Flexible disc and aerodynamic stabilizer

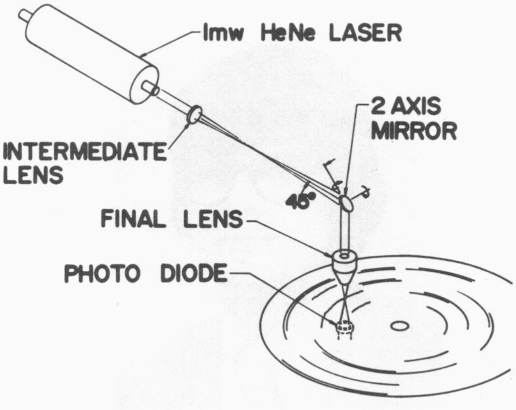

Fig. 2: Layout of the optical component

ENCODING

It is quite conventional to use frequency modulation to record TV signals on video tape. The main advantage of FM is its inherent capability of reducing low frequency noise. Such noise is very objectionable in TV pictures. Amplitude modulation was used in early experimental work on video discs which was done at SRI in the sixties and published[1] a few years ago. The published pictures look blotchy; it appears surprisingly difficult to keep amplitude fluctuations low enough.

What frequency should be chosen for the FM carrier? If we were able to record sine waves and if the entire process, from recording to playback, were linear, we could select an FM carrier just a little higher than the highest modulation frequency we wish to accommodate. At the beginning of our experiments we were able to make masters only by mechanical recording, with the signal slowed down by a factor of 54. With this method, linear recording of sine waves was possible, and an optical player could reproduce these sine waves.

But Philips and others had already shown real time recording, using a laser beam on a photoresist master. Real time recording seemed important. Unfortunately, this process appeared to permit only the recording of discrete pits with sharp edges. The information in such recordings resides in the location

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of the pit edges which correspond to the zero crossings of a rectangular wave. To reproduce the recorded information, the precise length of each pit must be accurately reproduced. If the duty factor of the rectangular wave represented by the pits departs from the correct proportion, perhaps because the record has changed its shape after pressing as a consequence of memory effects or cold flow in the material, distortion is produced. Generally, this results in transferring FM sidebands into the base band. If these two bands interpenetrate each other, the picture is impaired.

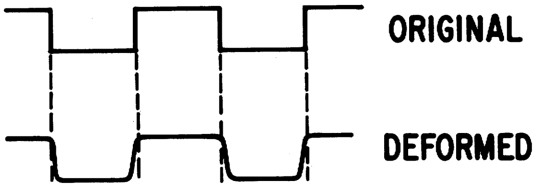


Fig. 3: Example of possible difference between intended waveform (above) and actual track contour on pressed record (below). Note change of duty factor.

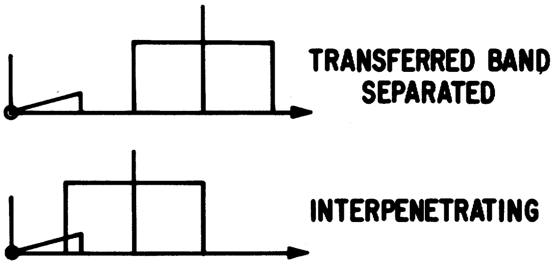


Fig. 4: Spectrum of FM signal (rectangle) is contaminated by spurious baseband signal (small triangle near zero frequency) as a result of duty factor error.

We can avoid all these potential difficulties by choosing an FM carrier at least twice as high as the highest video frequency we want to reproduce. For the video components of an NTSC signal (luminance and chroma) 4.2 MHz are required, thus the FM carrier should be no lower than 8.4 MHz. This is a little higher than we like to go for various reasons, and in our experiments we have used the arrangement described in the following.

We set the sync pulse at 6 MHz, black level at 6.5 and white at 8 MHz. Thus, luminance frequencies up to 3.25 MHz are fully protected. But it is no longer possible to transmit chroma on the usual subcarrier frequency of 3.58 MHz. Therefore we have reduced the chroma subcarrier frequency in such a way that the entire chroma band fits within the luminance band, making sure, however, that the sidebands of luminance and chroma remain interleaved as usual.

The normal NTSC subcarrier frequency equals 455 times the half horizontal scanning rate (455=5x7x13). Instead, we picked a factor of 195 which equals 5x3x13. This comes out 1.53 MHz. Many other choices are possible; we have, for instance, considered a factor of 325 which equals 5x5x13 (2.56 MHz). Regardless of the specific choice of frequency, the object is to contain the chroma band within the luminance band of about 3.25 MHz, thus conserving bandwidth, and then modulate the FM carrier with the combined luminance-chroma signal. In the decoder we use a comb filter to separate luminance and chroma cleanly from each other.

Such a transmission system, in which the duty factor of the recorded pits is of no importance, produces pictures of excellent quality. The fine differences that distinguish it from a straight NTSC system are difficult to spot.

We have also experimented with straight NTSC encoding. Here, the chroma subcarrier remains at its usual value of 3.58 MHz and the FM carrier frequency is raised to avoid interpenetration of base band and lower FM sideband. More about this later.

RADIAL TRACKING

Any optical player - in fact, any disc player in which the pickup does not make mechanical contact with the record - needs a radial tracking servo to make the pickup follow a given track on the disc. Eccentricity alone causes radial track displacements of the order of 100 microns (4 mils) at the frequency of rotation (30 Hz); mechanical distortion of the disc may cause smaller components at higher frequencies. With a track spacing in the order of 2 microns, the radial positioning error should be no larger than perhaps 0.2 microns. This requires a servo gain at 30 Hz of at least 500. It is not particularly difficult to move a light beam over a distance of 100 microns at audio rates: a small mirror attached to a piezoelectric or electromagnetic transducer will do nicely. But a servo also needs a source of error signal - the control signal that tells it when the beam is off-center, in which direction and how much.

We started our experiments with mechanically cut records, with grooves having a cross section like a shallow V. The FM signal is impressed upon these

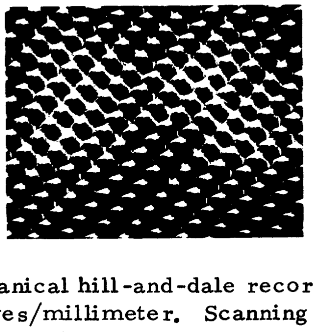


Fig. 5: Mechanical hill-and-dale recording, 400 grooves/millimeter. Scanning electron micrograph of **pressed disc.**

grooves as a sinusoidal hill-and-dale modulation which can be read out by utilizing the deflection of the light beam back and forth along the direction of the groove as the beam glides over the alternating slopes of the sine wave. At the same time, the sloping sides of the groove deflect the light beam radially inward or outward if it is not centered on the bottom of the groove, and this radial deflection can be used to produce a radial error signal in a pair of push-pull photocells.

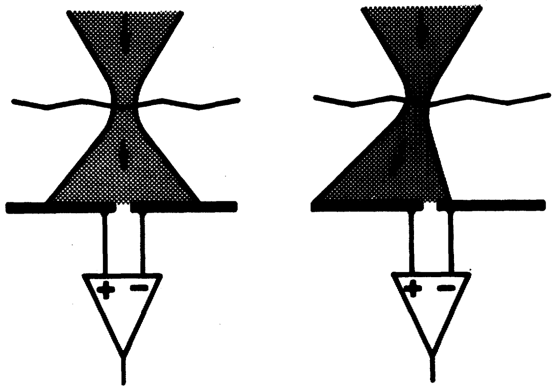


Fig. 6: Sloping sides of groove produce error signal for radial servo. Left side: beam centered on groove. Right side: Beam off center.

Four photocell areas on a single piece of silicon can be matrixed to produce the FM signal and the radial error in two orthogonal output ports. This system works very well in practice.

Surprisingly, the same tracking and readout system also works with discs that carry the information in the form of discrete pits rather than continuous grooves, provided that the pits are of the right depth. For optimum operation the depth should be such that the optical phase difference between light going through the air inside the pit and through the plastic adjacent to the pit is about 90 degrees.

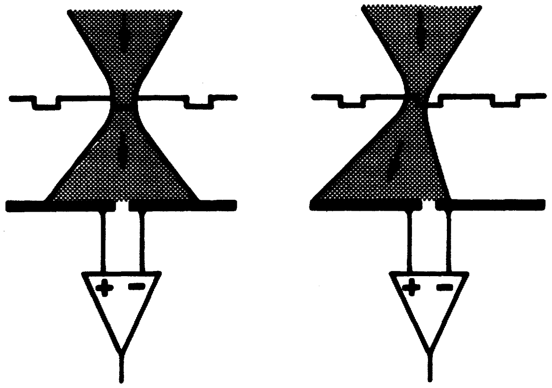


Fig. 7: Sharp-edged pits of the right depth act like portions of a groove.

Figure 8 shows an electrical analog, with the plastic material on both sides of the pit represented by delay lines while the air path within the pit is represented by a coaxial line. The illustrated condition corresponds to a light beam displaced to the left - a wave of uniform phase arrives at the coaxial line and at the left delay line, and the flow of power is steered to the left.

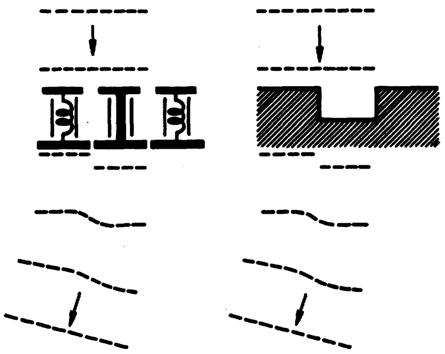


Fig. 8: Electrical analog (left) explains effect of pits on light (right). Arriving flat wave front encounters differential delay and emerges with a tilt.

Note that this system would not work if the phase difference were 180 degrees; plus and minus 180 degrees are equivalent, so there would be no way of distinguishing positive and negative positioning errors.

The refractive index of PVC is about 1.5. A distance that corresponds to one wavelength in air therefore contains 1.5 wavelengths in PVC. For half that distance - one-half wavelength in air - there are 3/4 wavelengths in PVC, and the optical path difference between air and PVC is one-quarter wavelength or 90 degrees. Thus our pits should have a depth of one-half wavelength in air, or about 0.3 microns.

The fact that mechanically cut grooved records and laser-cut records with pits of a certain depth act in such a similar manner is of great practical interest. These records are interchangeable and can be played on the same machine. It is often thought that records of the pitted type are preferable because they can be made in real time. But sinusoidally modulated grooved records have the advantage that there is no duty factor to worry about, and perhaps a way will be found to make them also in real time. It appears unwise to exclude them from consideration.

The radial tracking system described above uses a single beam - the same beam that serves to read the signal - and in its equilibrium position this beam is centered on the center of the track. Adjacent tracks have very little effect. We have been able to record and track as many as 900 tracks per millimeter (fig. 9 left), a density which would yield 45 minutes of playing time on one side of a 12 inch disc.

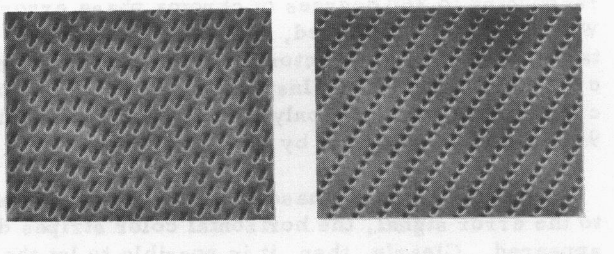


Fig. 9: Laser recording. Scanning electron micrograph of pressed disc. Left: 900 tracks/millimeter. Right: 400 tracks/millimeter.

Compared to that, the 400 tracks per millimeter (fig. 9 right) with which we have done most of our experiments seem a long way apart.

TIME BASE CORRECTION

Disc eccentricity of the order of one-thousandth of the average track radius appears unavoidable. We have already discussed radial tracking; but there is also a tangential error - the disc is not in the right place at the right time. For a disc rotating at 30 Hz with an eccentricity of 1/1000 the timing error is plus and minus 5 microseconds, with opposite polarities appearing in alternate fields. Even though the horizontal APC circuit in the TV set follows the timing variations to some degree, its response is usually too slow, and the residual horizontal shaking of the picture is unacceptable. In addition to the 30 Hz eccentricity component, some discs are mechanically distorted and show timing errors at frequencies of 60 and 120 Hz; without correction these higher frequencies produce warping of vertical lines on the screen.

In Europe, color sets have for some time been equipped with a so-called A-V (Audio-Visual) switch. This switch reduces the APC time constant in order to permit connecting the set to video tape players which have similar problems. But in this country, the fifty or sixty million color sets in the hands of the public have no such switch. We must therefore suppress the timing variations at the source. A suppression ratio between 10 and 50 appears necessary.

One way to compensate for the timing error is to deflect the light beam tangentially, along the direction of the track, by appropriate amounts. Again the question arises how to obtain a suitable error signal. We have achieved our best results with a pilot carrier, an unmodulated c. w. signal recorded on the disc. This signal, typically at about 3 MHz, is picked out by a tuned circuit, passed through a limiter and fed to an FM detector. The output signal from this detector corresponds to the rate of change of the timing error; it is used to drive a mirror which moves the light beam tangentially.

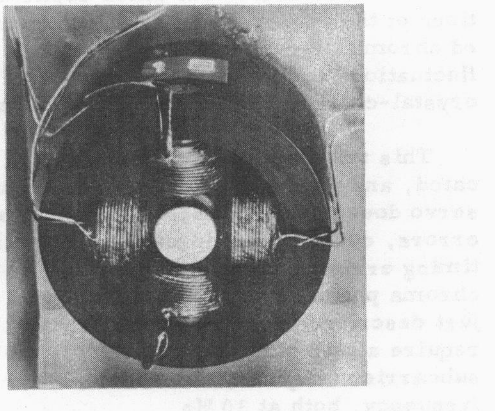


Fig. 10: Mirror deflects about two axes to take care of radial and tangential corrections simultaneously.

The radial and tangential corrections can be done with two separate transducers driving separate mirrors. We have experimented with a single transducer which tilts a single mirror about two orthogonal axes (Fig. 10). The mirror is mounted on a small, axially poled ring magnet which rides on a pivot located approximately at its center of gravity (fig. 11). The ring magnet is flanked by four coils connected in pairs to the two servo amplifiers, and held against the pivot by a larger ring magnet which also provides the restoring torque needed to obtain the desired resonant frequency for the two tilting motions (between 30 and 60 Hz). There is little interaction between the radial and tangential motions, and by using enough gain in the tangential servo the timing error can be rendered invisible on a conventional set with unmodified APC time constant.

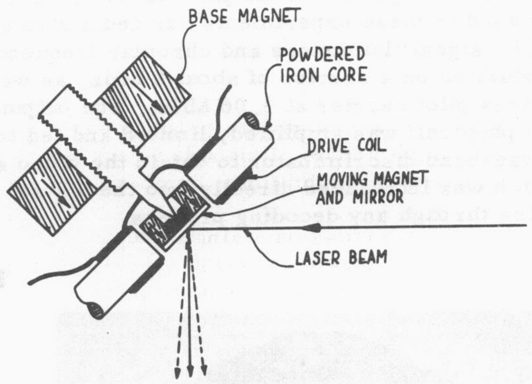


Fig. 11: Schematic view of two-axis servo motor.

The uncorrected timing error of about plus and minus 5 microseconds corresponds to about plus and minus 18 complete cycles of phase error at the usual chroma subcarrier frequency of 3. 58 MHz, about 8 cycles at our reduced subcarrier frequency. This is hundreds of times more than the permissible limit of 10 degrees. A similar problem exists in video tape machines, and our decoder circuit borrows from that technology: from the bursts of the recorded signal, a subcarrier is regenerated which shares the timing errors of the recorded chroma signal; the fluctuating subcarrier is then added to a crystal-controlled 3. 58 MHz signal, resulting in a new carrier whose nominal frequency is the sum of 3. 58 and the recorded subcarrier but which duplicates the fluctuations of the recorded signals. Subtracting the recorded chroma signal from this new carrier cancels the fluctuations and yields a chroma signal centered on a crystal-controlled carrier at 3.58 MHz.

This tried-and-proven technique is a bit complicated, and we asked ourselves: If the tangential servo does such a good job of correcting timing errors, could it be improved to the point where the timing error is reduced to less than 10 degrees of chroma phase, so that the complicated procedure just described becomes unnecessary? This would require a loop gain of about 700 for the 3.58 MHz subcarrier frequency, or about 300 for our reduced frequency, both at 30 Hz.

With the error signal derived from an FM detector as described previously, we have so far not succeeded in obtaining the required loop gain, because, with the low pilot carrier level we like to use, the signal-noise ratio is too low. But we were able to do the job by deriving an additional error signal from a phase detector which is referenced to a crystal-controlled duplicate of the pilot carrier. The record we used in these experiments carried a straight NTSC signal (luminance and chroma) frequency-modulated on a carrier of about 8 MHz, as well as a weak pilot carrier at 3.06 MHz. The output from the photocell was amplified, limited and fed to a broad-band discriminator to obtain the video signal, which was introduced directly into the TV set without going through any decoding process.

With the tangential servo loop open, the picture exhibited many horizontal color stripes, each corresponding to 360 degrees of chroma phase error. When the loop was closed, with the error signal taken from the FM detector only, the phase error decreased substantially. Instead of perhaps 30 color cycles there were now only 2 or 3. Thus more than 90% of the job was done by the FM detector.

Finally, when the phase detector output was added to the error signal, the horizontal color stripes disappeared. Clearly, then, it is possible to let the tangential servo take care of correcting the chroma phase and thereby simplify the decoder considerably.

ACKNOWLEDGMENT

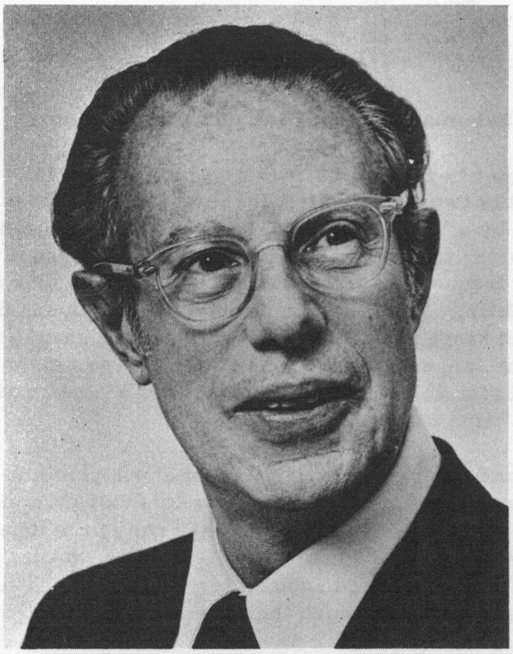
The work reported here was done by a team composed of members of the Research and Engineering departments of Zenith. The large number of contributors makes it impractical to single out individuals.

Our work was greatly aided by close cooperation with a similar team at the Central Research Laboratory of Thomson-CSF in France. Their valuable help is gratefully acknowledged.

REFERENCE

[1] Philip Rice et al., "An Experimental Television Recording and Playback System Using Photographic Discs", J. SMPTE, Vol. 79, Nov. 1970.

BIOGRAPHY



Robert Adler

Robert Adler was born in 1913 at Vienna, Austria. He received the PhD degree in physics in 1937 from the University of Vienna. The following year, he was assistant to a patent attorney in that city. From 1939 to 1940, he worked in the laboratory of Scientific Acoustics, Ltd. in London, England.

After one year with Associated Research, Inc. in Chicago, he joined the research group of Zenith Radio Corporation in Chicago in 1941; he became Zenith's Associate Director of Research in 1952 and Director of Research in 1963.

Dr. Adler has been active in two fields—electron beam tubes and ultrasonic devices. His work in the vacuum tube field includes the phasitron modulator used in early FM transmitters, receiving tubes for FM detection and color demodulation, transverse-field traveling wave tubes, and the electron beam parametric amplifier. In the ultrasonics field, his work includes an electromechanical IF filter at an early date (1943) and later, the development of ultrasonic remote control devices for television receivers. In recent years he has been active in the fields of acousto-optical interaction (light deflection and light modulation) and of acoustic surface waves (filters and amplifiers).

Dr. Adler has been a Fellow of the IEEE since 1951 and a member of the National Academy of Engineering since 1967.