A VIDEO DISC OPTICAL DESIGN SUITABLE FOR THE CONSUMER MARKET

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1. - ORDERS OF MAGNITUDE.

1.1. The difference between the video disc and the familard audiodisc lies not so much in the type of the recorded signal but in the way this signal has to be recorded an read. This becomes clear if we compare the audio bandwidth of 15 KHz and the video bandwidth of 4 MHz. There is 267 times more bandwidth necessary in the case of video and for the same playing time and disc we need an elementary surface which is roughly 267 times smaller.

An extrapolation to Video of the main parameters involved in the audiodisc can be made very easily starting from the simple formula

$$f(t) = f(s) \times v$$

where f(t) is the signal function of time, which should be delivered by the readout pick up :

f(s) the spatial signal, recorded on the disc,
and v the linear speed of the disc under the pick up.

If f(t) has to be multiplied by K, a logic approach of the problem consists in sharing with an equal weight the effect of this factor both on f(s) and v :

$$K\, f(t) = \sqrt{K}\, f(s) \times \sqrt{K}.v$$

giving both on the sample size of information and on the pitch of the signal a reduction by $\sqrt{K}$.

For a 20-30 minutes audio record the spiral pitch is of the order of 100 µm.

For the video disc of the same playing time, the pitch is then reduced to $100\sqrt{267}$, i.e. about 6 µm ; and the rotation speed would be :

$$33\,\frac{1}{3} \times \sqrt{267} = 545 \text{ rpm or } 9 \text{ rp sec approximately.}$$

There would be thus for each elementary vibration a length of 0.9 µm available on the spiral (Figure 1).

As it seems difficult to record the amplitude of the signal on this microscopic surface, the information is stored as a frequency modulated signal (Figure 2) and the zero crossing are measured. So, the highest instantaneous frequency is of the order of 8 to 10 MHz according to the type of coding used. It is therefore necessary to correct the previous numerical values by a factor of about 2 which brings us to :

- spiral pitch of 4 µm, $(6/\sqrt{2})$
- speed of rotation 780 rpm, $(545 \times/\sqrt{2})$
- elementary sample size about 0.6 µm, $(0.9/\sqrt{2})$.

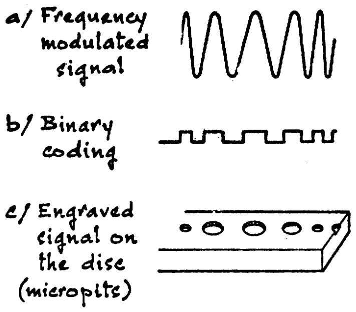


Figure 2.

1.2. As for the audiodisc, the engraving follows a spiral (Figure 3).

The same line sequence which forms the framework of the television signal is then reproduced on the spiral and with the same chronology : odd lines first, even lines after, but end to end and not interlaced as on the television screen.

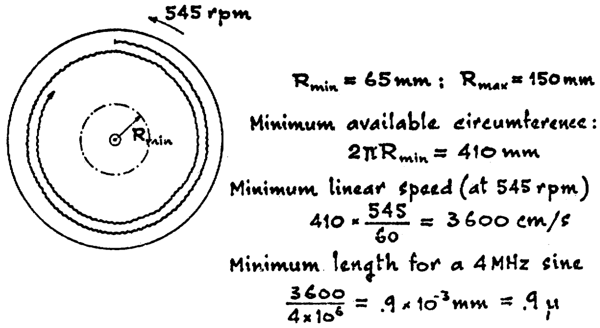


Figure 1.

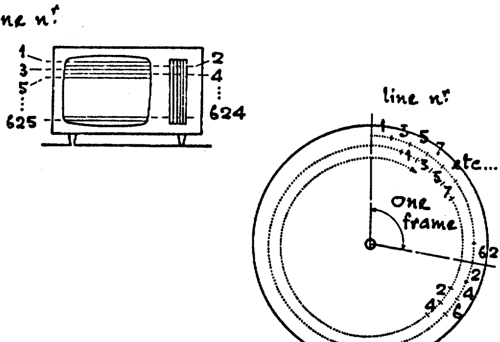


Figure 3.

Received September 17, 1974

1.3. Finally it is advantageous to record one image on one complete revolution of its rotating support (Figure 4) as even in the case of an accidental jump of the reading head along the radius there will be only a negligible effect on the television screen in the same manner as in a film projector when, by accident, a whole number of images is withdrawn.

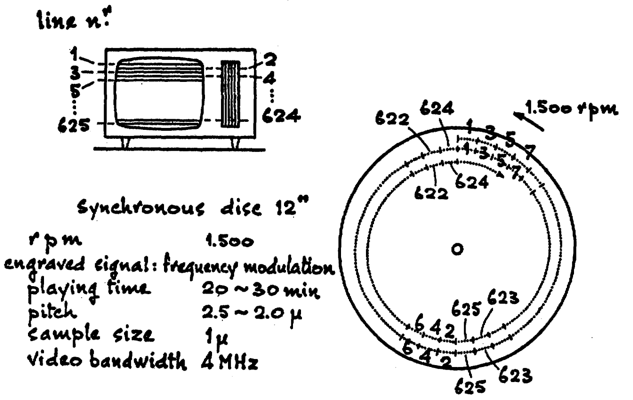


Figure 4.

Another advantage of the synchronous disc is the possibility to stop on one picture, to accelerate or slow the movement and also a rapid random access to each recorded picture or sequence of pictures.

With 25 revolutions per second, that is 1500 revolutions per minute (for the European TV Standard), the video disc, according to this scheme, will contain 30.000 grooves for a 20 min recording or 45.000 grooves for 30 minutes which brings us to a pitch of 2.5 µm or 2 µm, respectively.

On the other hand, the maximum dimension of the elementary sample grows from 0.6 to 1 µm which makes slightly easier to keep the mechanical tolerances both in the reading and recording process.

2. - DEFINITION OF THE PROBLEM.

2.1. Physics teaches us that the smaller the elementary bits, the more precautions have to be taken to measure them. For example, in optics, this means that the vertical position of the lens objective has to be maintained very accurately, in our case better than within a 2 µm range.

Similar constraints exist also in mechanics where it is necessary to keep the level of unwanted vibrations sufficiently low in order to be able to read the engraved significant signal.

The spiral itself has to be tracked with precision better than the dimensions of the elementary signals inscribed on it, i.e. of the order of 0.3 µm. It is the approach to this double problem : vertical and radial control (figure 5) in which the differences betwenn the 5 or 6 announced video disc systems lies.

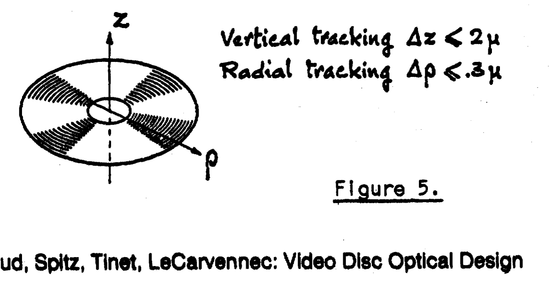


Figure 5.

2.2. It is obvious that the realisation of such a disc and a corresponding player is a difficult task for an engineer, but all problems can be solved by present techniques. The most difficult problem is to build a real consumer market low price product, which boils down to selecting the right types of technical solutions.

There are few problems concerning the disc itself which, by principle, is well suited for duplication by embossing and whose hardware part of the retail price should be of the order of half a dollar per copy. But many complicated problems are encountered in the player which has to read, one by one, the very small bits of information on the disc exactly in the same order as they have been recorded. Our target : less than a color TV set, in terms of retail price.

3. - THE SOLUTION WHICH WAS CHOSEN BY THOMSON is dictated by two main aims ; One is the quality of the image and the possibility of its widespread exploitation. The second is the huge consumer market which must be attained. That is the reason why Thomson chose optics associated with an aerodynamic stabilization of the disc (thus getting rid of any delicate vertical servo-focussing of the objective).

4. - THE STABILIZER IS CONSTITUTED by a horizontal U-shaped guide in which the rotating disc is introduced (Figure 6). When a suitable cross-section profile is chosen, the air current produced by the rotation of the disc is compressed and then decompressed which creates a combination of aerodynamic forces. These can be roughly simplified into 3 localised force components at points A, B and C. according to the figure 7. There is compression at A and B and decompression at C ; Thus the disc bends by an angle of about 20°.

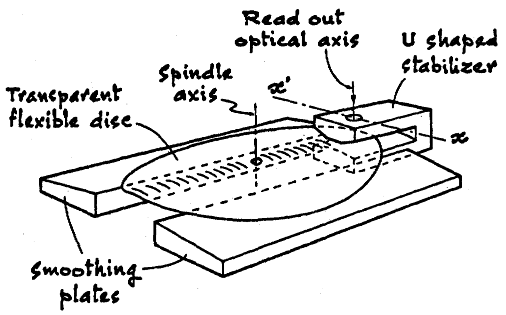


Figure 6.

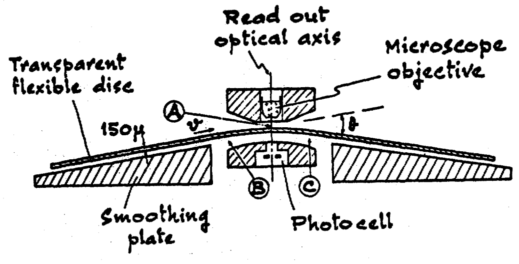


Figure 7.

The "smoothing" roof has been added to the U stabilizer in order to induce accomodation to this curvature. This mode of stabilization needs a flexible disc which at the present time is a 6 mils thick embossed PVC sheet. Then the stabilizer is perfectely suitable for maintaining the upper surface of the disc with a precision of better than 2 μm.

On the contrary, if the stabilizing effects were symmetrical the constant distance would be maintained to the middle of the disc (in thickness) and it would be necessary to use carefully calibrated discs with 1 μm thickness precision which would tremendously increase its price.

5. - THE FUNCTION OF THE RADIAL SERVO CONTROL is performed by a tilting mirror which deflects the light beam entering the objective (Figure 8).

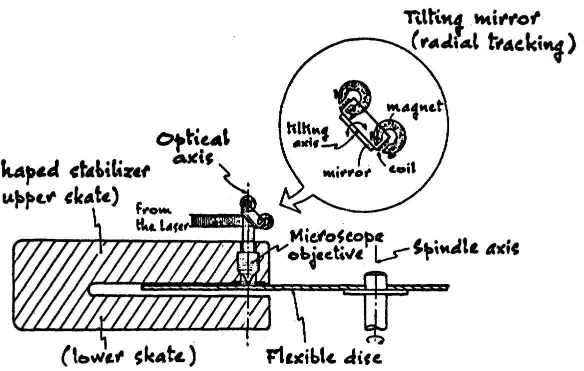


Figure 8.

5.1. - The Thomson solution does not need any special sensor device for the error signal. The latter is obtained directly, as is the RF signal, from the ligth diffracted by the micropits which represents the recorded signal on the disc (Figure 9).

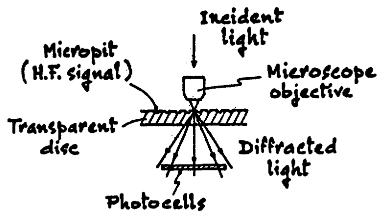


Figure 9.

The diffraction pattern is analysed in the transmitted beam. This avoids metallization of the embossed disc as well as other additional optical elements to isolate the reflected beam. The general mothod is however also valid in reflection.

On figure 10, P_1 is the output pupil of the objective ; P_2 the engraved surface of the disc and the photo detector plane. **A**, **B**, **C**, **D** are 4 sectors of a photocell electrically isolated from each other. Which are placed symmetrically according the axis $O\rho$ and $O\eta$. They are connected two by two the differential amplifiers Δ_s and Δ_ρ.

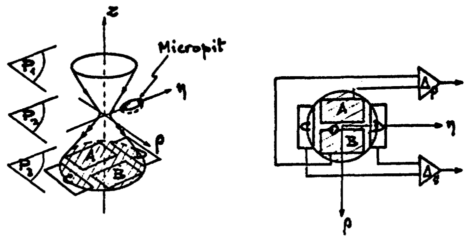


Figure 10.

5.2. In the absence of engraved pits in the illuminated zone, the transmitted cone of light rays is placed exactly in the axis of the incident rays. The detected energy of cells **A** and **B** are equal and the same happens for cells **C** and **D**. The signals delivered by the both amplifiers Δ_s and Δ_ρ are equal to zero.

5.3. But this situation changes where a micropit enters into the focal region (Figure 11). The light diffracted by the pit wall will tilt the axis of the transmitted cone of light rays and also distort its cross section.

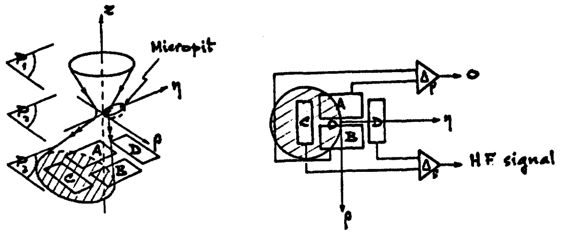


Figure 11.

If the objective is in the right position as shown on this figure, its axis follows the motion of the micropits and the diffraction pattern is shifted to C but stays symmetrical to $O\eta$. A signal appears on the output of Δ_s but not on Δ_ρ. The same phenomenous(but opposite) occurs when the micropit leaves the focal region (Figure 12). Thus the succession of the alternatively positive and negative signals from Δ_s are the zero crossings of the frequency modulated recorded information.

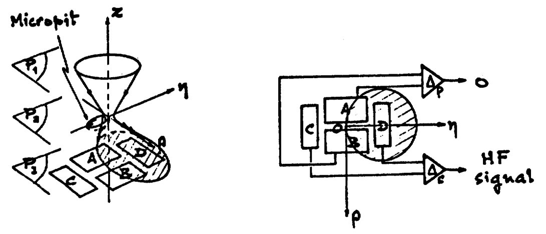


Figure 12.

5.4. If the optical axis is not in the right position, i.e if there is an error $\delta\rho$ between the focal point and the micropits path (Figure 13), the diffraction figure is no longer symmetrical with respect to $O\eta$. There will be a difference in illumination on the cells A and B and a signal appears on Δ_ρ. This is the error signal used to control the radial servo of the reading beam on the rotating disc.

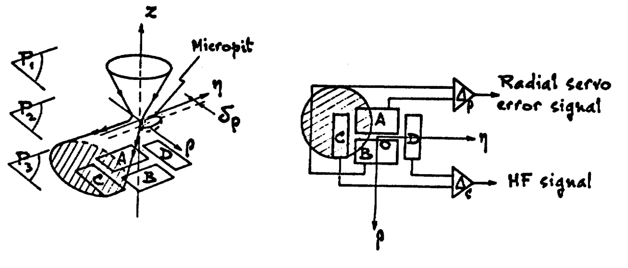


Figure 13.

5.5. The diffraction phenomena which determine the distribution of light on the cells are difficult to analyse both theoretically and experimentally. A useful explanation of the observed effect can nevertheless be given using geometrical optics only but comparing the diffraction of the focal point to a simple refraction of the cone axis of the light rays (Figure 14).

A simulation of this phenomena has been carried out experimentally at 35 GHz, i.e. with a wavelenght of 8.5 mm, and interesting results were obtained.

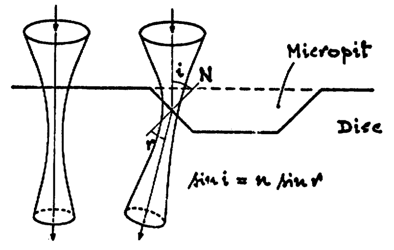


Figure 14.

6. - CODING

6.1. Several coding systems are possible. In order to fully exploit the available bandwidth, i.e. 8 or 9 MHz, separate frequency modulated carriers are used for each fundamental signal :

- luminance
- chroma
- sound (2 channels)

As it is known that the SECAM coding is relatively insensitive to phase errors, it seemed advantageous to use this color coding to smooth out the effects of possible motor hunting and off-axis spinning.

6.2.The figure 15 shows how the baseband signals are processed in order to get the total composite waveform which is to be recorded. As usual, the Red, Green and Blue signals are combined in a linear matrix which delivers the conventional components.

Y + Synchro
B - Y
R - Y

The bandwidth of each component is then reduced to fit into the allocated channels on the disc.

Thus :

- The n° 1 sound signal is then sampled by the horizontal synchro frequency.
- The B-Y and R-Y signals are switched alternatively from line to line and, after adding n°1 sound during the

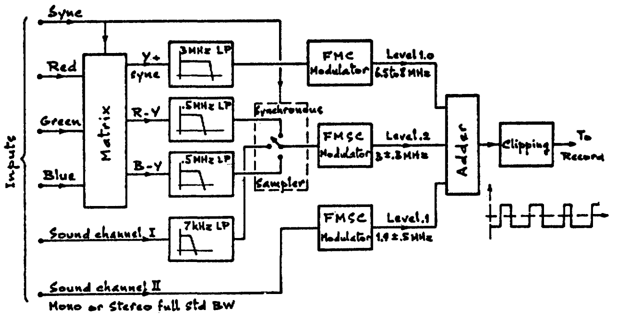


Figure 15.

line blanking intervals, the total sequence is fed into the frequency modulator which produces a 3 MHz average frequency subcarrier.

- The nr 2 sound signal is frequency modulated onto a 1.9 MHz subcarrier. This channel is wide enough for a complete standard 15 KHz stereo sound. The Y + Synchro signal is frequency modulated onto a carrier with a maximum frequency deviation in the 6.5 to 8.0 MHz range. The outputs of the 3 modulators are added with the following amplitude ratio :

1 for the carrier (Y + Synchro)
0.2 for the 3 MHz subcarrier (chroma + sound nr 1)
0.1 for the 1.9 MHz subcarrier (sound nr 2)

This is the total composite signal which is recorded on the disc and which is then read by the player as described before.

6.3. The spectrum is represented on the Figure 16. It is important ot point out that the chroma subcarrier frequency is slighty higher than the upper limit of the baseband. This avoids spurious intermodulation effects from hogh amplitude subcarrier signals which otherwise appear due to the nonlinearities in the whole channel

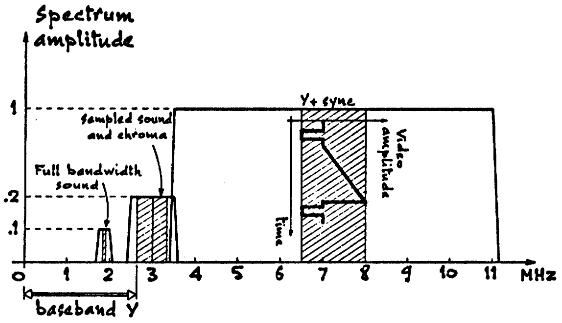


Figure 16

-7. - SPECIAL EFFECTS.

7.1. During readout several "effects" can be obtained when the jump, between adjacent tracks is combined with a full period of a frame. As the optical readout system has no material contact with the disc, these jumps can be repeated as long as needed without wear. Specifically, it is possible to perform :

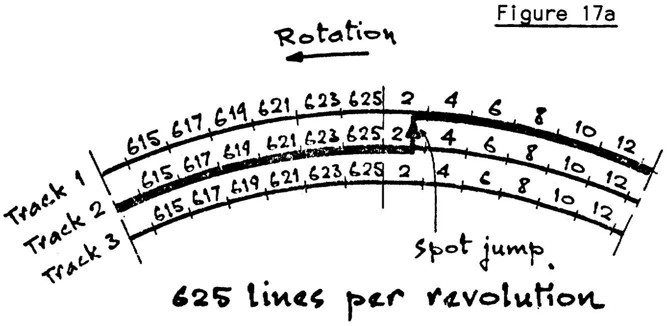
- freeze frame,
- periodic progression from one frame to another accelerating or slow down effects, forward and backward.

Thus the "page flipping" effect which is so useful for manipulating a book is possible with the disc.

7.2. To get all these effects, it is necessary to take into account the sequential color coding of which one example is shown on figure 17a. The lines alternatively red (R-Y) and blue (B-Y) which correspond to the SECAM coding used in our disc could just as well represent the phase alternance of the chroma subcarrier of a PAL standard recorded disc.

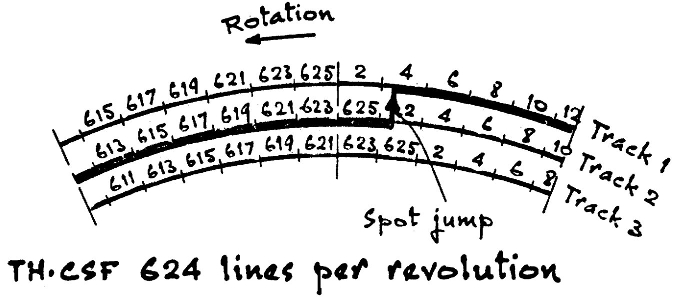
From the picture it is evident that the jump of the reading spot to the preceeding track destroys each time the color alternance and in this way the TV receiver can no longer suitably decode the signal. Of course it would be possible to correct the sequence by an electronic circuit in the player, but this would be costly.

Figure 17a



On figure 17b is represented a recording which enables the right alternance of the R-Y and B-Y signals to be maintained independently of the track jumps.

Figure 17b

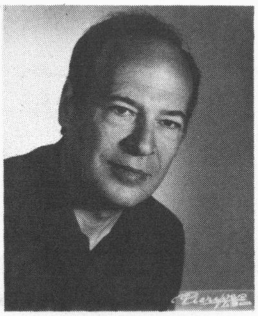


7.3. That is the reason why there is no longer one frame per revolution but one frame minus one line per revolution, i.e 624 lines instead of 625 lines in the european standard.

It can be seen that the right sequences are re-established for any jump of reading spot. The same effect could be obtained with 626 lines per revolution. During continuous playing, without jumps, the frame is still analysed with 625 lines. For special effects it is analysed only with 624 lines, but this is imperceptible for the average observer.

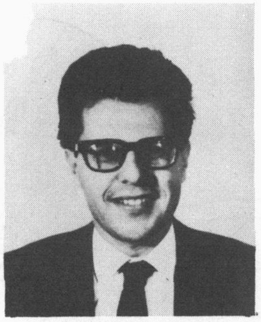
We wish to think our many co-workers from both Thomson/CSF and Zenith for their enthusectic accomplishment of this work.

BIOGRAPHIES



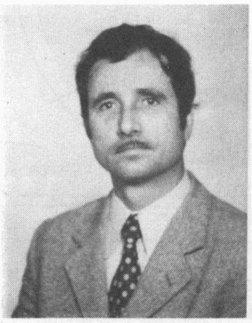
Georges J. Broussaud

Georges J. Broussaud was born on April 11, 1925 in St. Léonard, France. He graduated from the Ecole Supérieure d'Electricité in 1948 and received the doctor degree from the University of Paris in 1955. Since 1948, he has been with CSF, now Thomson-CSF, working first on microwave circuits and antennas, then on radiometric systems at both microwave and infrared frequencies. Manager of the Applied Physics department from 1964 to 1969, he developed an important activity in coherent optics and opto-electronics. Dr. Broussaud is now Director of research at the Thomson-CSF Central Laboratory. He is member of the Societe francaise des électriciens, des électroniciens et des radioélectriciens (SEE).



Erich Spitz

Erich Spitz was born on March 27th 1931, in Brno, Czechoslovakia. He graduated from the Polytechnical University of Prague in 1954 and received there his doctor degree in 1956. In 1957 he worked at the Observatory of Meudon, France, on radioastronomic problems. Since 1958 he has been with CSF now THOMSON-CSF working first in the microwave and antenna field and then in optics and optoelectronics. Dr. Spitz is the head ot the Systems and Devices Department of the Thomson-CSF Central Laboratory.



Claude M. Tinet

Claude M. Tinet was born on June 4, 1933 in Paris. He obtained a degree in Electronic Systems from the Ecole Speciale de Mécanique et d'électricité of Paris in 1954. He joined CSF in 1957 and worked in Microwave Tubes till 1967 joining the Central Research Lab. of Thomson-CSF in Corbeville as head of the Microwave Laboratory, he worked mainly on electronic systems in remote sensing devices, Mr. Tinet began to work an Videodisc systems in early 1971 directing, since that time, the Videodisc Laboratory.

Francois M. Le Carvennec

Francois M. Le Carvennec was born on August 28, 1938 in Ploemeur, France. He graduated from the Ecole Nationale Supérieure des Tĺécommunications in 1962. Since 1964 he has been with CSF, now THOMSON!CSF, working first in the Electron Tube Department Laboratory on electron optic and image tubes and in particular on image shutter tubes, an infrared pyroelectric pick-up tube, and liquid crystal displays. Since 1972 Mr. Corvennec has been the head of the holography and coherent optic laboratory at the TH-CSF Central Laboratory and has been working since this time on the Videodisc program.