SYSTEM CODING PARAMETERS, MECHANICS AND ELECTRO-MECHANICS OF THE REFLECTIVE VIDEO DISC PLAYER

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Summary

This paper presents considerations involved in the choice of a coding system for an optical video disc system. It thereby embraces the recording process, the optical stylus, the associated servo systems, and the disc properties.
It is shown that a 30 minute high quality television program with two separate sound channels can be compressed to a 30cm diameter disc format while allowing adequate tolerances for all aspects of the signal processing.

This paper is one of a series of papers presented collectively by M.C.A., Zenith and N.V. Philips, and it describes the recommendations resulting from an exchange of views aimed at finding the best possible solution for this important new medium.

Coding Parameters

In the optical video record there is a single information track in which all the information is stored for the reproduction of a color-television program with two channels of sound and one video channel.
The non-linearity of the master recording process (which may be in part or wholly photographic), limits the choice of possible encoding techniques, and a two level signal recording was found to be the most attractive solution.
On this track the information is encoded in the length and the spacing of the pits. In other words, for a rotating record the repetition frequency is determined by the average length of the pits, and the pulse width modulation of the frequency is determined by the modulation of the length of the pits.
The composite video employed in the optical video disc system is frequency modulated on a carrier at 8MHz which is pulse width modulated by two Hi-Fi audio channels at 2.3MHz and 2.8MHz.

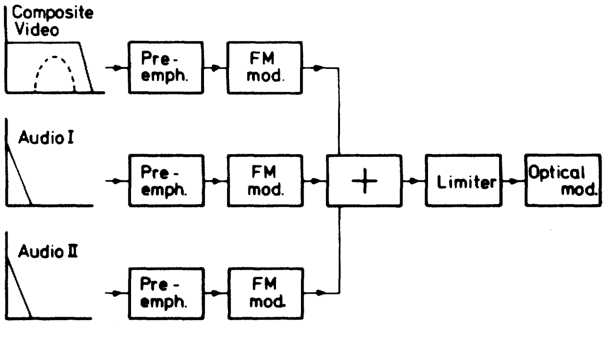

Fig. 1 Signal Processing Encoding

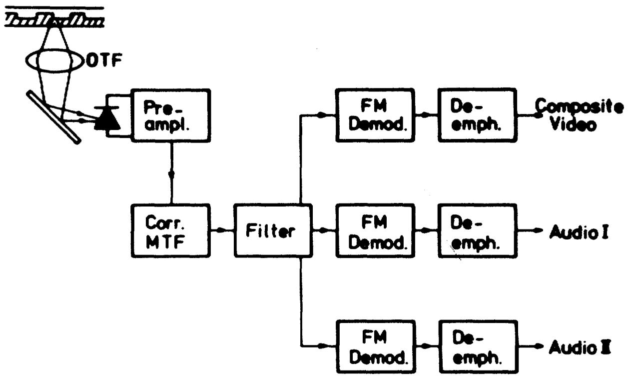

Fig. 2 Signal Processing Decoding

Figures 1 and 2 show the block-diagram of the signal processing for encoding and decoding of the video and audio signals. There are pre-emphasis time constants employed before FM modulation of the video of 50 nsec and 125 nsec.
The audio signals are FM modulated on carriers of 2.3MHz and 2.8MHz with a frequency deviation of ± 100kHz and a pre-emphasis of 75 μsec.
The two audio carriers are summed with the FM carrier and after limiting, the output signal is used to modulate the intensity of a laser beam passing through an electro-optical modulator in the master recording machine.
After appropriate processing of the photo sensitive layer on the Philips master record, the pits become immediately visible. Further processing, similar to that used for the production of audio records, provides a rapid means of producing a high volume of records.
After pressing, the record is metallized and a protective layer is applied on top of this highly reflective coating; thus the information is completely protected, especially on the read side, by the transparent material of the record itself.

Decoding

The reflected light returning from the disc falls on a photo diode and its output is amplified and corrected according to the modulation transfer function (M.T.F.) of the player which, for the purpose of this paper, is defined in the frequency domain.
The M.T.F. can change due to the differences in spatial frequency at the inner and outer radius and also due to static defocusing of the read spot.
The compensation for changes in M.T.F. is automatic, and controlled by maintaining the ratio of the carrier to the

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first order sidebands of the color burst amplitude. After M.T.F. correction the signal is applied to a low pass filter to separate the two audio channels, which are further separated by two bandpass filters.

A high pass filter separates the video information. The filters have a cross over frequency at 3.5MHz. The separated FM signals are then demodulated and a de-emphasis is applied to compensate for the pre-emphasis employed before recording, in order to achieve a better S/N ratio and a more uniform frequency response.

The allocation choice of the main carrier and the sub-carriers will now be explained.

Accommodating two discrete audio channels, with all their accrued benefits, in such a single track system demands careful selection of the audio and video carrier frequencies and due to the non-linear and asymmetrical recording process it is necessary to select, as will be shown later, the FM carrier frequency to be far higher than the highest modulation frequency (NTSC 4.2MHz).

Asymmetry is caused mainly by the previously mentioned characteristics of the photo resist, its exposure and development. The maximum allowable value of asymmetry influences the choice of carrier separation.

The maximum value of the ratio of the length of the pits and the spacing between the pits is at present 60-40 or 20% related to a fixed frequency and is a compromise with the mastering technology. A typical value is 55-45 or 10%, and is relatively easily obtained.

Due to the faithful reproduction of the pressing technique the pit geometry and also the asymmetry is unaffected.

Furthermore, the sub-carrier amplitudes of the chroma and audio carriers have to be determined. A suitable compromise between S/N ratio and intermodulation caused by the color sub-carrier (fsc) is obtained when using a modulation index of m=0.32, resulting in an amplitude of the first order color sideband J_1 chroma of -16dB in relation to the unmodulated main carrier for a 75% saturated red.

The second and third order chroma sidebands J_2 and J_3 will appear at a level of -38 dB and -63 dB respectively in relation to the main carrier (fo).

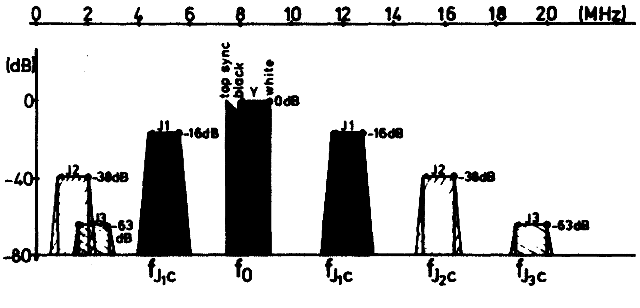


Fig. 3 Frequency Spectrum of FM modulated Video Signal for 75% saturated red color. Pre-emphasis is 6 dB for 3.6MHz.

Since the color sub-carrier frequency fsc is 3.58MHz, the position in the frequency spectrum of the main carrier and the chroma sidebands are shown in figure 3.

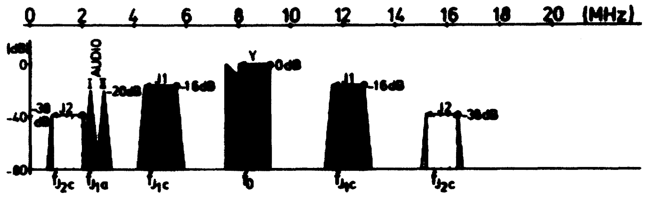
fo ± fsc the first order chroma sideband J_1 at −16 dB

fo ± 2 fsc the second order chroma sideband J_2 at −38 dB

fo ± 3 fsc the third order chroma sideband J_3 at −63 dB

Audio

In order to realize a good compromise between audio S/N, the modulation by products ± J_2, plus the intermodulation of the audio in the luminance and/or the color, the audio carrier's amplitudes before limiting are chosen 20 dB below that of the unmodulated main carrier.



FM modulated Video and two superimposed FM modulated Audio carriers

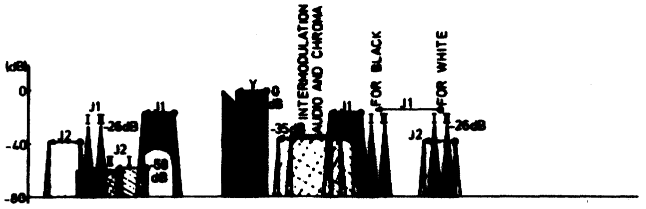


Fig. 4 Spectrum of signal after passing hard limiter

In figure 4 the effects of the limiter on the spectrum are shown and it can be seen that after limiting additional components appear in the spectrum and the audio J_1 is reduced by 6 dB.

In general we will find odd frequency components of the audio carriers around all even harmonics of the main carrier, including zero, and even frequency components around all odd harmonics of the main carrier.

$$(2n+1)\ fo \pm 2m\ fa_1 \qquad n, m = 0, 1, 2, \ldots\ldots.$$

$$(2n+1)\ fo \pm 2m\ fa_2$$

and

$$2n\ fo \pm (2m+1)\ fa_1$$

$$2n\ fo \pm (2m+1)\ fa_2$$

Figure 4 indicates only the most important components of the above spectrum.

$fo \pm (fo - fa_1) = fo \pm (fo - fa_2)$

fo		the main carrier
fa_1	fa_2	the audio carriers or J_{1a} which is the first order lower sideband at −26 dB.
2fo − fa_1		the upper sideband of the audio carrier J_{1a}
2fo − fa_2		is also at a level of −26 dB, but has twice the frequency deviation of the main carrier.

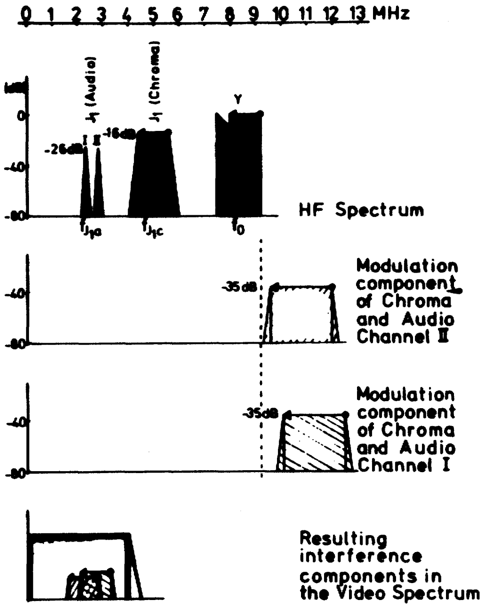


Fig. 5

Furthermore, there appear in the spectrum in addition to the above mentioned modulation components, color - sound beat frequencies, with twice the frequency deviation of the main carrier whenever color information is present, and having an amplitude of -35 dB. (see fig. 5)

These components are given by

$$f_o + f_{J_1c} - f_{a_1}$$

with $f_{J_1c} = f_o - f_{sc}$

$$f_o + f_{J_1c} - f_{a_2}$$

and they will appear in the video spectrum after demodulation at a level of -45 dB whenever maximum color is present. In practice there are many more components present but their amplitudes are so low that they will not appreciably influence the wanted modulation components.

Asymmetry

When two sinsoidal waves of frequency fo and fl with different amplitudes are added and then processed in a non-linear manner, frequency components are created with amplitudes which are strongly dependent on the symmetry of this process.

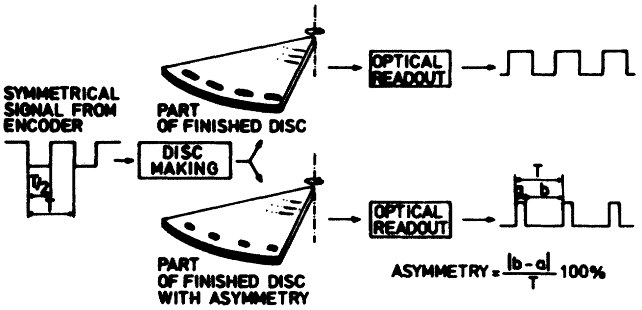


Fig. 6

When asymmetry is present during processing the above mentioned FM signals, even frequency components will appear in the spectral area around all even harmonics of the main carrier, and odd frequency components around all odd harmonics of the main carrier at levels depending on the asymmetry introduced.
Additional unwanted audio components will in general appear in the spectral range:

$$2n\,f_o \pm 2m\,f_{a_1}$$

$$n, m = 0, 1, 2, \ldots\ldots$$

$$2n\,f_o \pm 2m\,f_{a_2}$$

$$\text{and } (2n+1)\,f_o \pm (2m+1)\,f_{a_1}$$

$$(2n+1)\,f_o \pm (2m+1)\,f_{a_2}$$

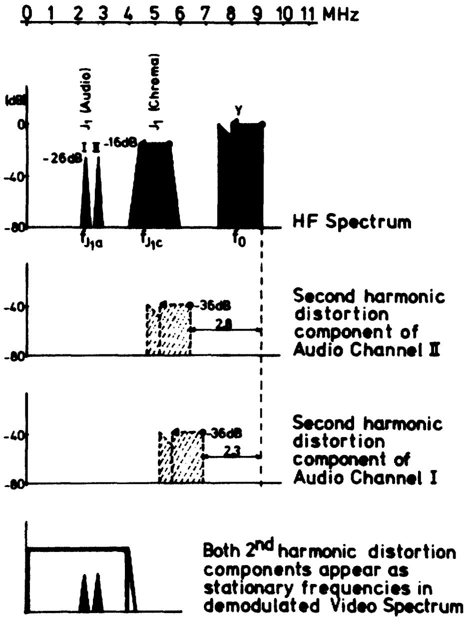


Fig. 7

The most important components are positioned close to the upper first order chroma sideband J_{1_c} shown in figure 7.

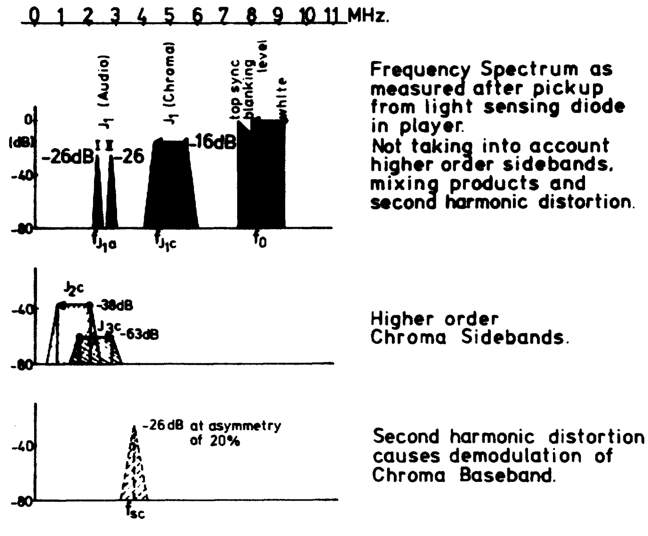
$f_o \pm f_{a_1}$ having a maximum level of -36 dB for an asymmetry of 20%.
$f_o \pm f_{a_2}$

$2f_o \pm 2f_{a_1}$ having a maximum level of -60 dB for an asymmetry of 20%. These components are
$2f_o \pm 2f_{a_2}$ not indicated.

Additional unwanted chroma components appear in the spectrum as shown in figure 8 due to asymmetry introduced by the recording process, and are given by

$f_o \pm f_{J_1c}$ with $f_{J_1c} = f_o - f_{sc}$

when considering only the most important frequency components. The original color sub-carrier $f_o - f_{J_1c} = f_{sc}$ appears by demodulation, due to asymmetry of the recording process, as a fixed frequency in the high frequency spectrum, its amplitude is -26 dB when the asymmetry is 20%.



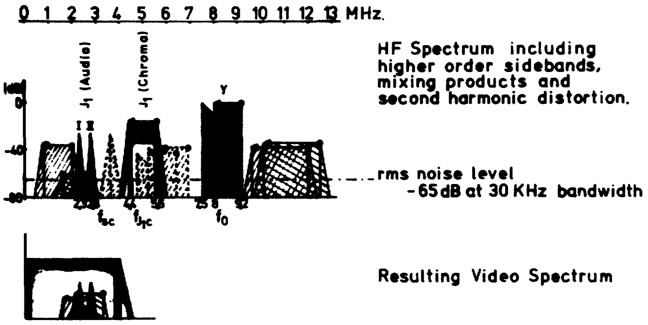
Frequency Spectrum as measured after pickup from light sensing diode in player.
Not taking into account higher order sidebands, mixing products and second harmonic distortion.

Higher order Chroma Sidebands.

Second harmonic distortion causes demodulation of Chroma Baseband.

Fig. 8

After correctly weighting the interaction of the unwanted with the desired frequency components, it is possible to design a coding system that tolerates a practical amount of asymmetry and still guarantees a good quality TV picture. In order to achieve the best compromise, the main carrier fo must be positioned at such a frequency (8MHz) that the first order chroma sideband comes at the right of the most important asymmetry component $fsc = fo - f_{J_1c}$.
The spectrum is shown in figure 9, when considering only those interference components which will eventually have an influence on the wanted video and audio signals.



HF Spectrum including higher order sidebands, mixing products and second harmonic distortion.

rms noise level
-65dB at 30 KHz bandwidth

Resulting Video Spectrum

Fig. 9 (For measured noise and interference levels see table 1.)

Since the components are symmetrically positioned around the main carrier only the lower part of the spectrum is shown. When the video gives a black level the stationary asymmetry component of the chroma is then closest to the f_{J_1c} first order chroma sideband.

Although a minimum separation of 0.8MHz is then present, in practice the color is sufficiently separated from the unwanted asymmetry component. The information contained in the frequency components fo, f_{J_1c} which are the upper and lower chroma sidebands contains all the original video information.
The audio carriers are situated at frequencies in between the second order chroma sidebands and the asymmetry chroma component. The resulting asymmetry components of the audio carrier are also shown, and they fall just to the side of the first order chroma sideband and swing with it while maintaining a constant frequency separation.
Asymmetry components appear, after demodulation the FMsignal, in the video spectrum at levels of −45 dB.
The resulting spectrum of the most important wanted and unwanted frequency components after demodulation is shown beneath the HF spectrum.

Having allocated the main carrier at 8MHz, it can be seen that a minimum bandwidth requirement is 12.8MHz in order to maintain the information in the upper side band. The noise and interference levels for the coding system presented, are indicated in table 1, figure 10.

Table 1: Measured Performance
of the choosen Coding System

$$S/N = 20 \log \left[\frac{\text{black-white voltage}}{\text{rms noise (interference) voltage}}\right]$$

Video:

a) Disc noise:

S/N IRE weighted 50 dB — Starting from -65 dB (30 KHz) in HF Spectrum

At the innerradius 44 dB

b) Interference:

asymmetry component S/N weighted 44 dB

modulation component of Chroma + Audio S/N weighted 45 dB

Audio:

a) Disc noise:

S/N weighted 70 dB — Starting from -65 dB noise level in HF spectrum.

b) Interference:

using colour bar and 20% asymmetry S/N weighted 57 dB

Fig. 10

The measured values of S/N ratio are 50 dB and 70 dB, for video and audio respectively, during practically the whole of the playing time.
At present the record's noise reduces the S/N ratio in the video by 6 dB, during the first 3 minutes. The lowest values of signal to interference obtained with a 20% assymetry are 44 dB and 57 dB, for video and audio respectively. If the frequency difference between wanted and unwanted signal is constant for all luminance levels, as is often the case for the asymmetry components of the audio carriers which appear in the video spectrum at 2.3MHz and 2.8MHz, then their visual effect can be minimized by using a well known half line offset technique, such that:

$$fa_1 = 2.3 = \frac{297}{2} \times F.H. \quad MHz$$

$$fa_2 = 2.8 = \frac{357}{2} \times F.H. \quad MHz$$

(F.H. – Horizontal line frequency)

Optical Stylus

An important aspect of an optical stylus with a defined numerical aperture (N.A.), is the influence of its modulation

transfer function M.T.F. on the bandwidth during play back of a disc recorded with one picture per revolution.
The track density of the recorded information is dependent on the required bandwidth, the record's rotation speed and the radius of the innermost track. It has been shown that a minimum bandwidth of 12.8MHz is required for FM.
A property of an optical stylus is that its resolving power at a defined number of lines per mm becomes zero.
For an optical video disc system this gives rise to a defined cut off frequency, which was fixed at 13.2MHz.
Attractive play back features become feasible when one TV frame per revolution is recorded, therby fixing the record's rotational frequency at 30Hz.
Within the constraints of the chosen system parameters, as shown in figure 11 we can derive the necessary track pitch, inner track radius and the smallest possible Numerical Aperture (N.A.) of the objective lens. These are respectively 1.66 μm, 55 mm and 0.4.

① $\boxed{\frac{V_i}{\nu_{max.}} = \frac{\lambda}{2NA}}$ ② $\boxed{p=\alpha\frac{\lambda}{NA}}$ ③ $\boxed{T=\frac{R_o-R_i}{pf}}$

Derived Parameters	NA = 0.4	Numerical Aperture of the objective
	p = 1.66 μm	Pitch of the tracks
	Ri = 55 mm	Innerradius of the recorded information
	λ = 0.63 μm	Wavelength of the laserlight
	$\nu_{max.}$ = 13.2 MHz	Cut-off frequency
Choosen Parameters	$V_i = fR_i 2\pi$	Velocity at the innerradius
	f = 30	Rev./sec. rotational speed (NTSC)
	$1.05 < \alpha < 1.2$	Related to Crosstalk
	T = 30 min.	Playing time
	Ro = 145 mm.	Outerradius of the recorded information

Fig. 11 Optical System Parameters

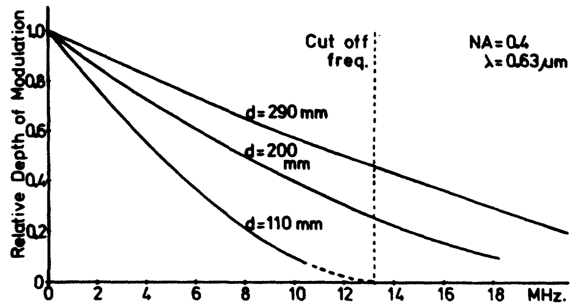


Fig. 12 Frequency Characteristics for various Disc diameters on linear scale.

In figure 12 it can be seen from the measured M.T.F. of the chosen optical stylus that the change in the depth of modulation, due to the optical modulation transfer function of the read lens, is practically linear except at the inner radius.
It is, however, very important that the phase relationship between the carrier and both sidebands be kept constant and therefore the amplitude characteristic within the f.m. frequency bandwidth must be kept a linear function when reading the disc. This necessitates a small correction at the inner radius as shown in figure 13 in which the upper sideband at 12.2MHz is compensated by + 5 dB and at the lower sideband at 5.0MHz by −5 dB, 0 dB being at 8.5MHz.

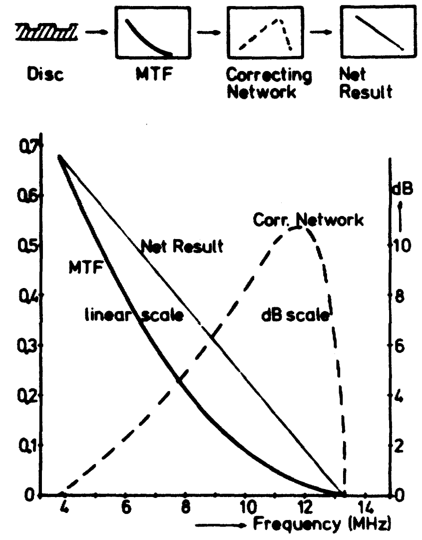


Fig. 13 Correction for MTF at inner diameter 110mm.

The parameters of the optical stylus have, however, been fixed without further consideration of their effects on the complete system's performance.
The influence of noise when applying the above mentioned parameters to the system is shown in figure 14.

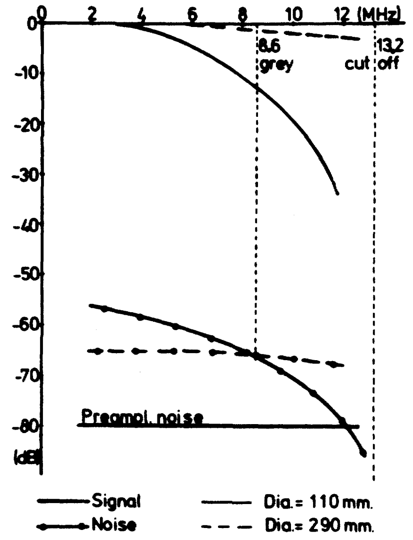


Fig. 14 Noise measured with 30kHz bandwidth

In figure 14 it can be seen that the roll off the noise amplitude is almost similar in character to that of the FM-signal.
In order that the S/N ratio will not be limited at high frequencies, i.e. 12MHz, at the inner radius, it is necessary to ensure that the pre-amplifier noise level is sufficiently high that the cross over frequency, where the disc's own

low or that the light level on the photo diode is sufficiently high that the cross over frequency, where the disc's own noise is identical with that of the white noise of the pre-amplifier, be as close as possible to the cut off frequency (13.2MHz).

For 90% of the disc playing time the picture quality is not impaired by the pre-amplifier or disc's noise.
From figure 14 we can derive the practical S/N ratio of the complete system which is shown in figure 15, at both outer and inner radius. It is seen to be virtually flat and of a high value up to a frequency of 9MHz, even at the inner radius.

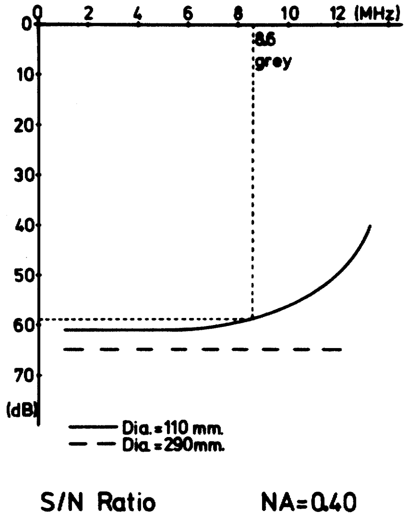


Fig. 15 Noise measured with 30kHz bandwidth

A larger N.A. read lens, i.e. 0.45, will give a larger possible system bandwidth and also some slight improvement in S/N ratio at the inner radius, when using the same light level and pre-amplifier, but this has further implications for the system as a whole, due to its reduced depth of focus.
A read lens of N.A. 0.4 is less sensitive to defocusing and thus reduces the demands on the focusing system, and/or relaxes the record specification.
In figure 16 the defocusing effects on the frequency characteristic is shown for an N.A. of 0.4.

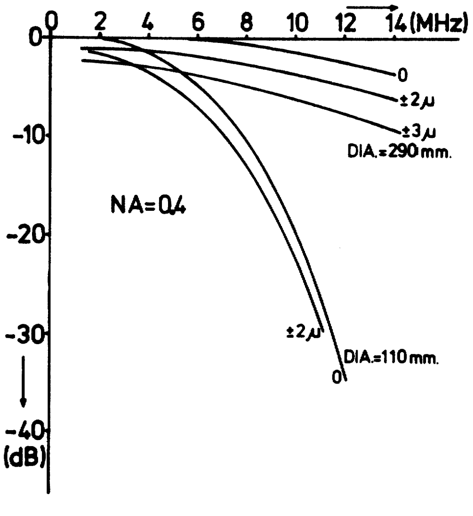


Fig. 16 Effect of Defocusing

It can be seen that at the inner radius the focusing is critical since it results in a bandwidth reduction, but due to the lower relative velocity between the read lens and the disc's surface the information is much easier to read.
A typical focusing error is ± 0.5 μm at the inner radii.
At the outer radius of the record the influence on the frequency characteristic is so small that a defocusing of more than ± 3 μm will not affect the linearity of the frequency characteristic.
A typical value for the complete system's momentary defocusing is ± 1.5 μm at the outer radius of the information.

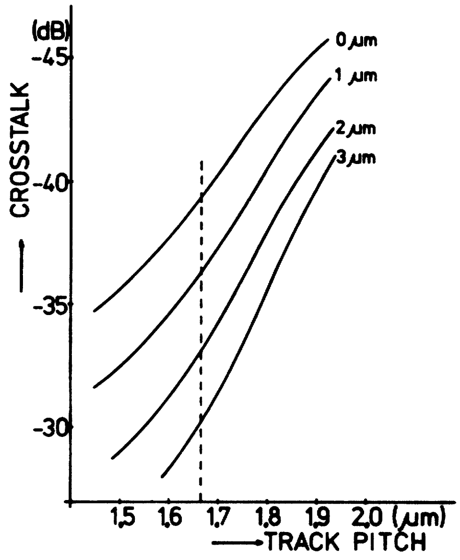


Fig. 17 Measured Crosstalk as a function of Track Pitch and Defocusing (NA = 0.40)

In figure 17 the crosstalk is plotted as a function of defocusing. From this figure it can be seen that the crosstalk increases about 3 dB for every 1 μm of defocusing. Disturbances due to local defocusing of the probing spot have in general little or no effect on the picture quality since the information in adjacent tracks is mostly similar, thus a crosstalk of −35 dB is acceptable.
If a high quality still picture is required, the distance between the tracks could be made somewhat larger i.e. $p = 1.8$ μm gives a crosstalk in focus of −43 dB, which is reduced to −38 dB by a defocusing of 1.5 μm.

The influence of optical disc surface deterioration caused by dust, scratches and fingerprints.

The depth of modulation of the returning light beam from the record's surface will also be reduced in amplitude due to the deterioration of the protective surface covering the information.
The reason for the reduction in amplitude of modulation is the scattering of light by dust particles and/or scratches and its absorption due to fingerprints, etc.

Figure 18 shows the statistical distribution of the size of dust particles as measured from a record after lying in a normal living room for two days.

In figure 19 the influence on the depth of modulation is shown as a function of the thickness of the protected layer

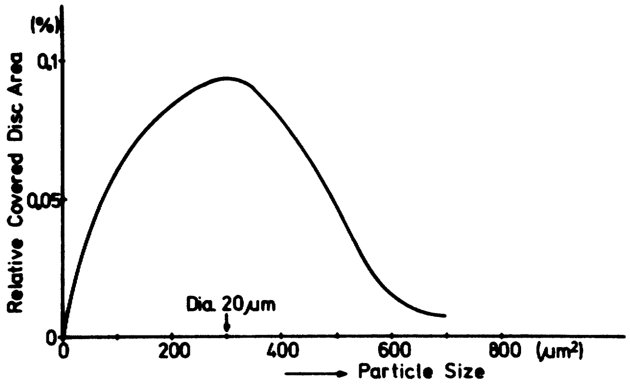


Fig. 18 After Two Days in a Living Room 0.1% of the Surface of the Disc is covered by Dust Particles with a diameter of 20 µm

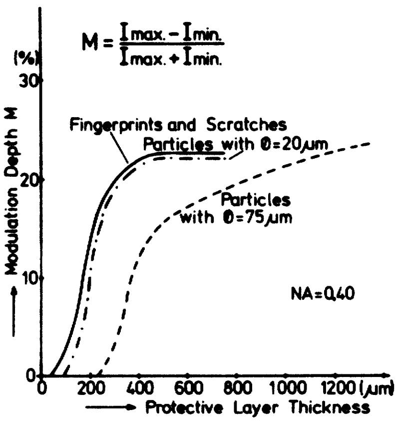


Fig. 19 The Influence on the existing Depth of Modulation as a function of the distance between Dust and Information

for various sources of protective surface degradation.

It can be clearly seen that small particles and also fingerprints drastically decrease the depth of modulation if the protective layer is less than 300 µm thick. For larger particles the depth of modulation degradates even with a protective layer thickness of 600 µm.

Since the optical record is 1.1 mm thick and of a transparant material, the disc thickness itself acts as a protective layer for the recorded information.
The protection so provided is very effective as has been proven from the experience of recent years and is very important in ensuring that the disc has a long life.
For the thin disc the specification is fixed at 200 µm.

Mechanical and electro-mechanical aspects of the optical player.

Disc Stabilization

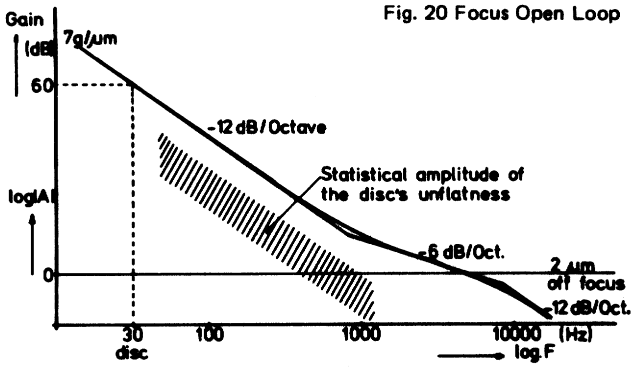
A thick video disc (1.1 mm) rotating in free air at 30 Hz is in general stable but not critically damped. In order to restrict the action of transverse waves in the frequency range of 10 - 15 Hz and also to compensate for the "umbrella" form deflection of the disc under its own weight, a stabilization system has been designed. Stabilization is achieved in the player by means of an air bearing, which is created by the centrifugal action of the rotating disc on its surrounding air.
A plate with a central hole is positioned in the vicinity of the rotating disc's surface which creates an air bearing having both the desired damping and stiffness.
There are several philiosophies concerned with the stabilization of a thin disc. One possibility is the use of a turntable in order to support the thin disc during play-back.
This support can be provided by means of an air bearing created by a rotating transparent plate, and the disc itself. This plate has central holes and a raised central section, which enables a thin disc to be played back in the same way as a thick disc.
Another solution is a turntable proposed by Zenith which consists of a flat plate on which circumferential knife edges are superimposed.
Centrifugal action expels the air and pulls the thin or the thick disc on to the knife edges. Such a system requires that the disc be read from the top side of the turntable.

Since the optical stylus is no longer compensated as was the case for the transparent 1 mm turntable discussed previously, some means of correction will be necessary when playing back a thin disc.
Having stabilized the rotating optical disc in the player it is necessary to focus the microscope reading lens, within its depth of focus, onto the information plane within the disc. A linear motor is used to drive the microscope lens, its drive signal being derived from a focus detector described in the Zenith paper. All deviations from a read reference plane such as disc unflatness, disc vibration and the disc's mean dynamic line are thereby compensated for.

Some of the specifications of the microscope lens drive are:
- weight 6 gr. - the lens being 3 gr., total displacement 2.5 mm.
From statistical measurements concerning the frequency/amplitude displacement spectrum of a rotating video disc's surface it becomes clear that a good approximation is a 12 dB/octave fall in amplitude.
Hence in order to obtain optimum servo performance with regard to the S/N ratio the servo system has an open loop gain with the same slope.

In the time domain such a system working in close loop will function as a disc surface accelerometer. The gain of the system can be expressed either as a stiffness, or as an acceleration figure for a unit defocusing.
A typical value for the present focusing system is 7 g/µm, as shown in figure 20.

Fig. 20 Focus Open Loop



With the chosen system's parameters a 2 μm defocusing is tolerable, when considering the servo's performance; hence the disc's surface may have a maximum "acceleration" of 14g. (within the bandwidth of the servo).
The specified allowable "acceleration" of the spinning video disc is 10g. A similar approach is used for the radial tracking servo as indicated in figure 21.

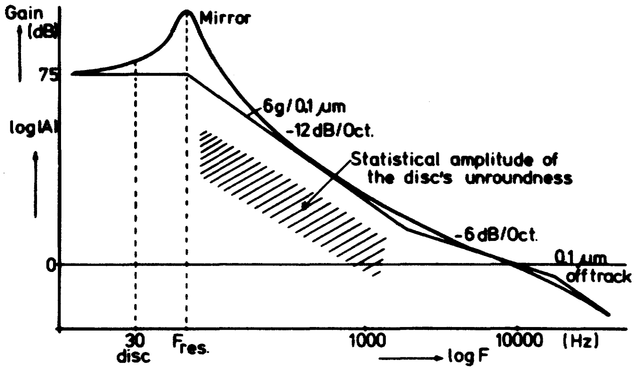


Fig. 21 Radial Open Loop

The gain of the system can also be expressed as an acceleration per unit deviation from the track which is typically 2g/0.1 μm.
Since a total eccentricity of 100 μm, for the disc player combination is allowed, a reduction of at least 60 dB is required at 30 Hz, which is the disc rotational frequency, in order to maintain the read spot within a tenth of a micron from the track.
The statistical spectrum for the amplitude of unroundness is seen to fall at 12 dB/octave and as in the case of the focusing system it is desirable to use a double integrating servo.
Another aspect of the choice of a low resonant frequency of the mirror suspension is that it approximates a ballistic galvanometer, which has desirable characteristics especially for the application of a pulse used for operating features.
Correction of time errors is achieved by a second pivoting mirror positioned at right angles to the radial mirror, having an open loop gain as shown in figure 22.

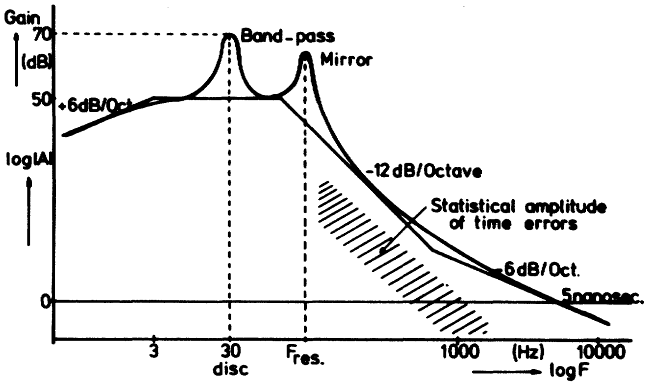


Fig. 22 Tangential Open Loop

The major component in the time error spectrum is due to the fact that a 100 μm eccentricity is allowed for the disc player combination. The effect of this eccentricity is a time error of 10 μsec. at 30 Hz.
It is necessary for most TV receivers to reduce the time error to within an amplitude of 5 nsec, hence it can be seen that a reduction of 66 dB is required. The system's performance beyond 70 dB is at present limited by the fact that the burst is used to obtain an error signal.

Since the repetition frequency of the burst is that of the line frequency or 16 kHz, the bandwidth of the system is limited in practice to approximately 1.6 kHz in order to obtain sufficient stability.
Because the stiffness of the tangential mirror is not compatible with the required gain at 30 Hz it was necessary to simulate a resonant peak by means of an active filter and thereby achieve higher reduction in gain at the disc's rotation frequency.
A block diagram of the complete player showing audio, video and servo sections is shown in figure 23.

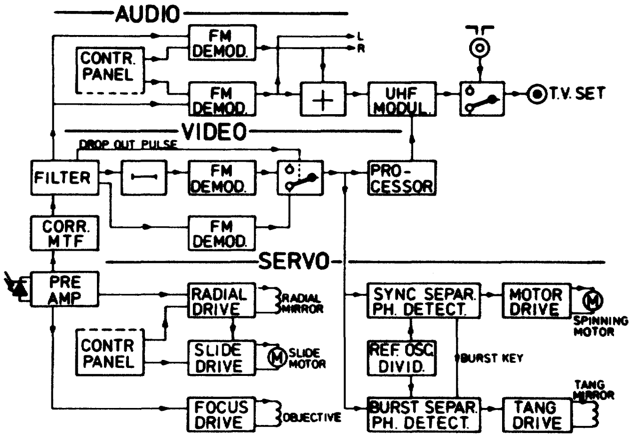


Fig. 23

It is possible to provide via signals incorporated on the disc or from an external source, additional control commands for the player's servo systems. For the radial servo this is a particularly attractive feature since automatic chapter finding, fast accurate random access, pre-programmed still pictures, relieved with normal motion, are feasible.
These signals can be inserted in the non-visible lines of the blanking period of each field, which also incorporates track numbers, chapter and control numbers, both of which enable the player to perform various attractive features, thereby increasing its possible areas of application.

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Peter Willibrord Bögels was born in 1936 in Brunssum, Holland.
He received his Ms degree in Mechanical Engineering in 1964 from the Technische Hogeschool of Eindhoven.
He worked in 1964 in the P.T.T. laboratories in Den Haag on airconditioning of the telecommunication equipment rooms.
He joined N.V. Philips Gloeilampenfabrieken Eindhoven from 1964 till 1970 in the pre-development of video and audio recorders.
From 1970 till 1973 he was manager of a development group for phono equipment, Philips S.A. in Flers, France.
In 1973 he became manager of the V.L.P. development group in N.V. Philips Eindhoven, The Netherlands.
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