DIGITAL AUDIO MODULATION IN THE PAL AND NTSC LASERVISION VIDEO DISC CODING FORMATS

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Abstract

We present an extension of the current LaserVision video disc format that includes a digital audio signal. We show the feasibility of a combined digital audio signal according to the Compact Disc Digital Audio format and the current analog audio signals in the NTSC video format, enabling the realization of a compatible system. For the PAL and SECAM video formats we show the feasibility of digital audio, but unfortunately it cannot be combined with the analog audio carriers.

0. Introduction

In the current LaserVision (LV) video disc coding formats (NTSC, PAL and SECAM), the analog audio stereo channels are frequency-modulated and added by means of pulse-width modulation of the frequency-modulated video signal (refs. 1,2,3). The maximum audio signal-to-noise ratio of the LV 525 lines NTSC format at present attainable is approximately 70 dB, which includes 15 dB improvement by the CX noise reduction system (ref. 3). In the 625 lines PAL and SECAM formats of the LV the audio signal is approximately 10 dB superior to the NTSC LV format.

An improvement in audio quality seems possible only by going digital. For example the 16 bits linear quantization used in the Compact Disc Digital Audio System format (refs. 4,5) achieves a signal-to-noise ratio of 96 dB. Furthermore the powerful error correction system of this digital format has a beneficial influence on the effect of drop-outs. In this paper we report on experiments and simulations to show the feasibility of adding a digital audio signal according to the Compact Disc Digital Audio format in the current LV video disc formats.

The bandwidth of the digital audio signal spectrum (approximately 1.5 MHz) and its modulation index on the main carrier are of great importance. The disturbance of the digital audio signal in the video picture plays an important role in the overall design.
A low modulation index of the digital audio signal results in a poor signal-to-noise ratio, giving rise to a high bit error rate. Many experiments have been done to arrive at a compromise on these conflicting parameters.

In Section 1 we briefly describe the LV video formats and derive requirements which a digital audio modulation system should meet. We describe the simulations used to find quantitatively the constraints for the digital audio modulation within the LV coding format. In Section 2 we describe the experimental results obtained with actual discs.

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1. Requirements to be met by digital audio modulation systems in the LaserVision formats

In this section we describe the LaserVision coding formats, and give the particular requirements to be met by a digital audio modulation system in order that it can be added to the current LaserVision formats.

1.1. Description of the LaserVision coding formats

The signal format of current NTSC and PAL LaserVision is a two-level signal (HF) which is frequency-modulated, after pre-emphasis, by the composite (luminance and chroma) video signal. Addition of the stereo sound signal is achieved by means of pulse-width (duty-cycle) modulation of the HF-signal by the two frequency-modulated audio carriers. Figure 1 shows a block diagram of the signal path of the encoder. The signal $x_0(t)$ is the frequency-modulated composite video signal. Signals $x_1(t)$ and $x_2(t)$ are the frequency-modulated sound signals. The sum signal is limited, so that a pulse-width and frequency-modulated two-level signal y(t) results. Figure 2 depicts the principle of pulse-width modulation; x(t) is the input signal to the limiter, y(t) is the resulting two-level output signal.

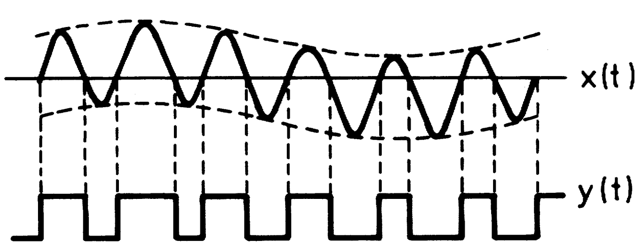

Figure 1.
Generation of the modulator signal. The sum signal is limited so that a pulse-width and frequency-modulated two-level signal results.

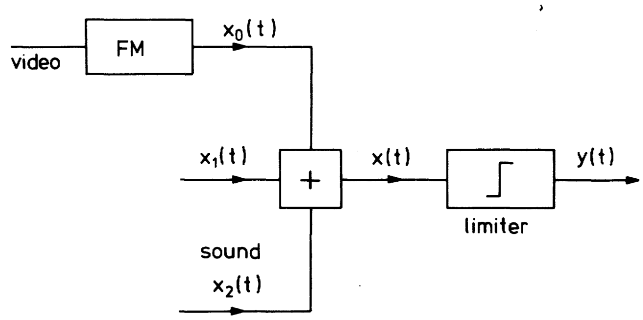

Figure 2.
Principle of pulse-width modulation; x(t) is the input signal to the limiter, y(t) is the resulting two-level output signal.

Figure 3b shows the spectrum of a PAL video signal which is frequency-modulated on a carrier of 7.1 MHz (i.e. the frequency corresponding to the black level of the video signal), where J0 is the principal component representing the frequency as a function of the amplitude of the video signal. J1 is the first-order lower sideband, also referred to as chroma band, which is situated at 4.43 MHz from the principal component J0, 4.43 MHz being the frequency of the chrominance carrier in the PAL video signal, and J2 is the second-order sideband which is mirror-inverted (see ref. 6) relative to the frequency zero-point. In the LV PAL format two frequency-modulated audio carriers of 0.683 and 1.066 MHz are added to this signal.
The amplitude of the sound carriers is chosen as -26 dB relative to the main carrier.

Figure 3a shows the spectrum of an NTSC video signal which is frequency-modulated on an 8.1 MHz carrier. Since the chrominance carrier in an NTSC signal has a frequency of 3.58 MHz, the lower sidebands J1 and J2 are now spaced at distances of 3.58 and 7.16 MHz, respectively. In the NTSC video format the audio signals are added as FM carriers at 2.3 and 2.8 MHz. The basic idea of the addition of digital audio, which will be explained in detail in the following, is to use the low-end frequency range up to 1.75 MHz. We may therefore conclude that, unlike the case of PAL, the analog carriers can even remain in the case of NTSC, so that compatibility with analog sound is possible.

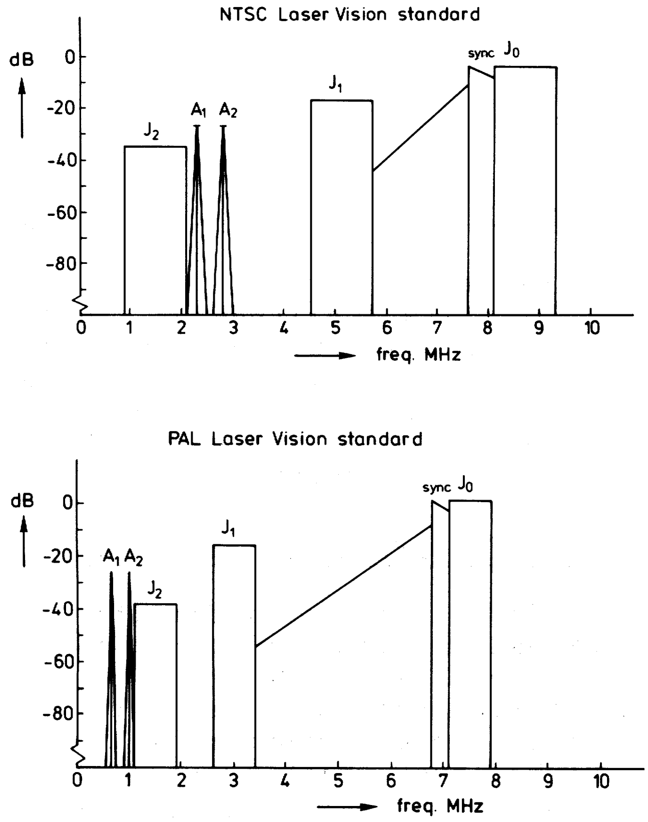

Figure 3a/b.
Frequency spectra of the NTSC (a) and PAL (b) LaserVision video formats.

The interference caused by the second order sideband J2, found in this low-end frequency range, has to be removed.
An example of an embodiment of such a system is given in ref. 7. The method (see fig. 4) is basically a compensation method. The chroma band is filtered out from the composite video signal. By means of a squarer circuit and bandpass filtering the second harmonic is generated. This frequency-doubled chroma signal is now added with the correct phase and amplitude to the original composite video signal. After frequency-modulation the chroma J2 component will be cancelled.

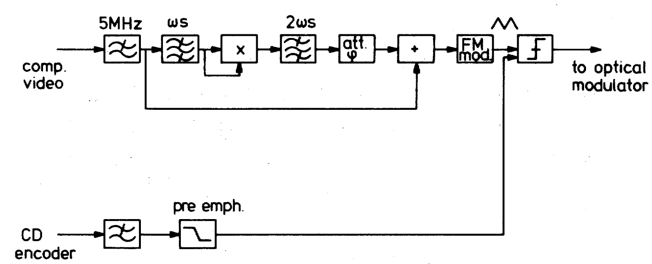

Figure 4.
An example of the compensation of the second-order side band J2.

1.2. Picture quality

To find the effect of a pulse-width modulation of the carrier on the picture quality we designed the experimental set-up shown in Figure 5. The video modulator supplies a composite PAL video signal to the frequency modulator. The sinewave from the signal generator is fed to the pulse-width input of the modulator. The frequency and pulse-width modulated carrier passes a circuit which simulates the frequency roll-off of the optical read-out system. The video signal can be

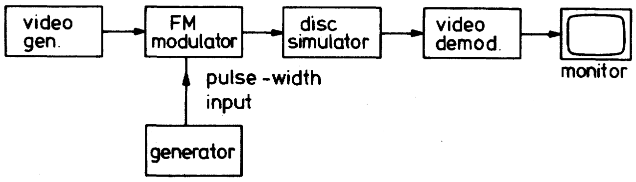

Figure 5.
Block diagram of the experimental set-up to study the influence of pulse-width modulation on the picture quality.

studied with a video demodulator and a video monitor. An informal panel examined the effect of the pulse-width modulation on the picture quality as a function of the amplitude and frequency of the signal. We determined the pulse-width level at which it became just visible in the video picture. To achieve the maximum visibility of the disturbance of the pulse-width modulation, the frequencies of the generator were chosen at even multiples of the line frequency (15625 Hz for PAL).

The disturbance in the video signal is caused by the second order sideband of the pulse-width modulation.

Figure 6 gives the maximum pulse-width level that can be allowed as a function of the generator frequency. The graph shows that the influence remains fairly constant up to approximately 1.5 MHz and increases rapidly above this frequency, due to direct interference in the video FM spectrum. The vertical amplitude axis is given relative to the amplitude of the main carrier. Figure 6 illustrates that with a maximum signal level pulse-width modulation may be applied when the signal is passed through a lowpass filter with a cut-off frequency in the range from 1.5 to 2 MHz.

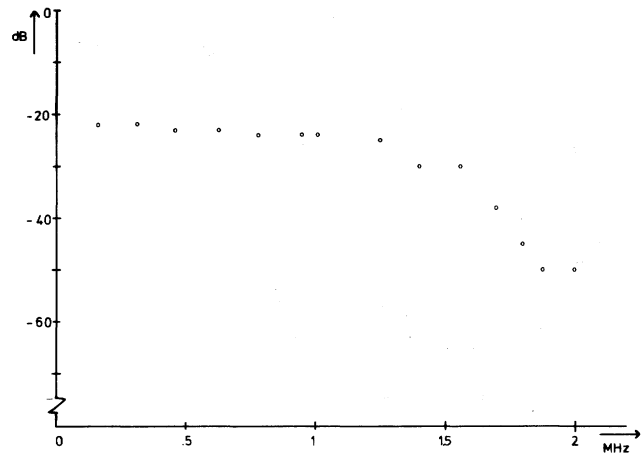

Figure 6.
Relative amplitude of sinusoidal pulse-width modulation when it becomes just visible in the picture. The video decoder is an unmodified model LV 720, Mk-1 PAL decoder.

1.3. Interference and noise

In optical recording the signal-to-noise ratio at low frequencies (500 kHz) deteriorates as a result of the interference produced by the He-Ne laser which is used to readout the video disc. Since a comparitively weak signal-strength is desirable for the coding of the digital audio signal (see Fig. 6), it is advantageous to boost the signal-strength at low frequencies relative to the signal strength at higher frequencies. A suitable cut-off frequency is situated in the range from 100 kHz to 1 MHz, in particular at 500 kHz, because at approximately 500 kHz the EFM spectrum (EFM is the modulation system used in the Compact Disc) exhibits a maximum and rolls off below this frequency (refs. 8,9,10). Figure 7 shows the frequency diagram of a suitable low-frequency pre-emphasis filter. The roll-off frequency is situated at 500 kHz. Below this frequency the signal is boosted by 6 dB/octave, which is easy to achieve. The cross--over frequency at which the characteristic becomes flat again (in the present example 30 kHz) is determined by the visibility limit (Figure 6) and its possible influence on control systems such as the radial tracking. During our experiments we found a pre-emphasis of 23 dB an optimal choice.

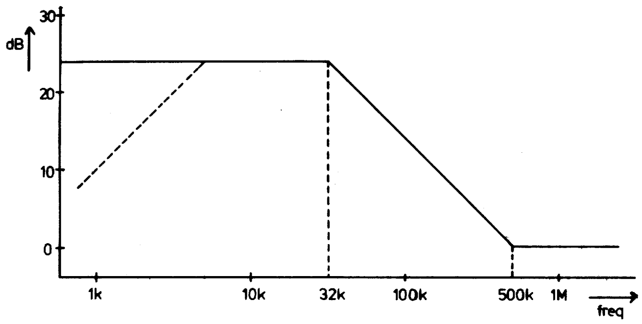

Figure 7.
Amplitude Bode diagram of the pre-emphasis filter.

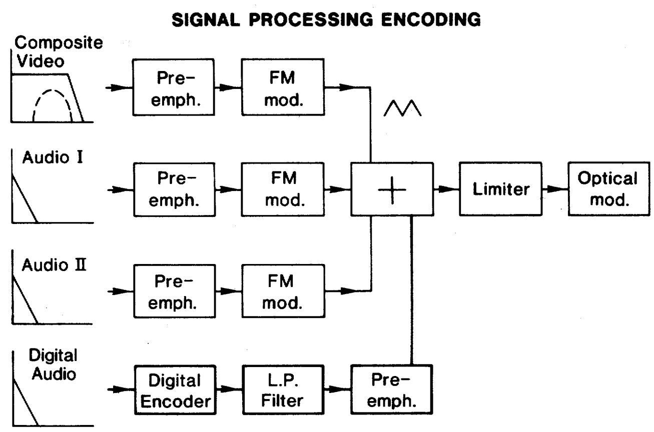

Figure 8.
Block diagram of the combined video and digital audio encoder. The block diagram holds for the PAL and NTSC video formats with some altered parameters. Note, however, that the analog audio carriers have to be removed in the PAL case. The video FM modulator is extended using J2 compensation.

1.4. Complete diagram of encoder and decoder

After the preliminaries of the preceding sections it is now quite easy to draw the block diagram of the complete system. Figure 8 shows the diagram of the combined video and digital audio encoder. We decided to use the Compact Disc encoder as the line encoder. In other words the bit stream supplied to the pulse-width modulation input is bit-to-bit compatible with the normal Compact Disc modulation bit stream. It is clear that this has the advantage of enabling current equipment to be used for encoding and decoding the digital audio signal. Accordingly the digital audio signal is CIRC-encoded and EFM-modulated, and the subcode generator supplied the additional information. The two-level output of the EFM modulator is lowpass--filtered with a cut-off frequency of approximately 1.75 MHz. After the low-frequency pre-emphasis the signal is applied to the pulse-width input of the video modulator. Figure 8 holds functionally for both the NTSC and PAL cases, with of course some altered parameters. Note, however, that in the PAL video format the analog audio carriers have to be removed. The level of the digital audio signal with respect to the main carrier is approximately -22 dB. In Figure 9a/b we have depicted the resulting spectra in both the NTSC (a) and the PAL (b) formats.

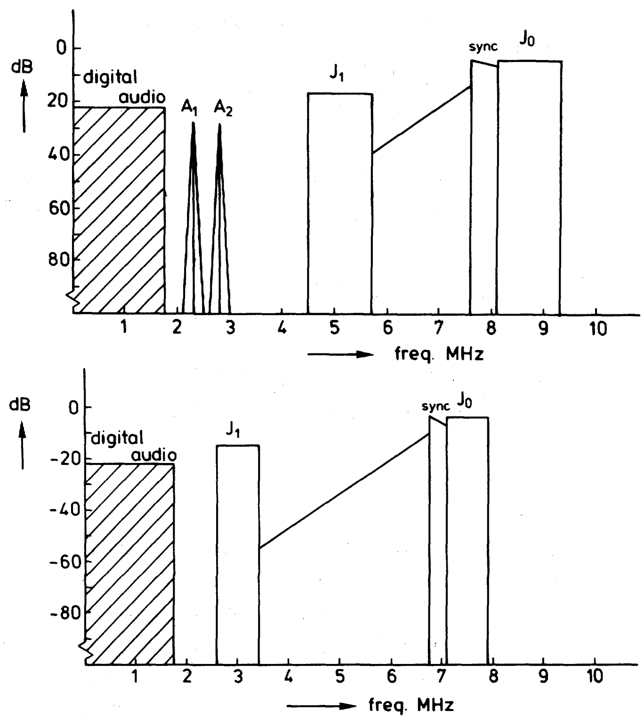

Figure 9 a/b.
Spectra of the combined digital audio and the NTSC (a) and PAL (b) video formats.

Figure 10 shows the block diagram of the decoder. The digital audio signal can easily be reconstructed by de-emphasis and lowpass filtering. The low-pass filter cut-off frequency is 1.75 MHz. After this filtering the signal is passed to a normal Compact Disc decoder which eventually supplies the audio signal.
The video decoder does not need any functional changes with respect to the current one.

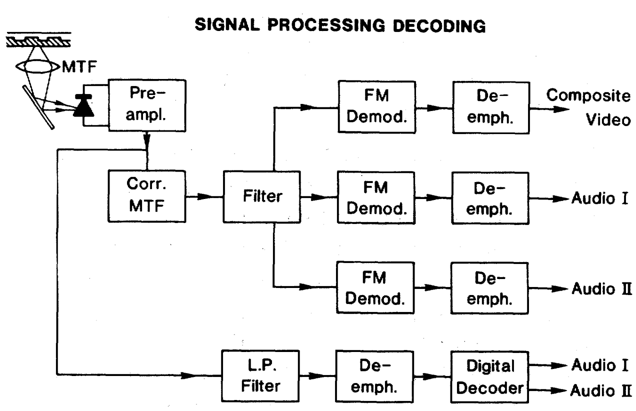

Figure 10.
Block diagram of the decoder. The EFM signal is simply reconstructed by de-emphasis and lowpass filtering.

2. Experiments

The digital audio signal can be disturbed by different sources. These disturbances may originate from:
1. irregularities on the video disc surface,
2. birefringence of the disc substrate,
3. crosstalk.

We recorded many experimental discs (NTSC and PAL) to measure the effect of these sources of interference.

2.1. Irregularities on the video disc surface

EFM tests sequences (pseudo music) written directly on the disc as a pulse-width modulation of the pits, with levels varying from -30 to -20 dB with respect to the main carrier, are hardly detectable with sufficient bit error rate (BER) without pre-emphasis. The low--frequency disturbance are due to scratches and rapid fluctuations of the reflection coefficient of the video disc. After pre-emphasis as in Figure 7 we found BERs in the range 10^{-5}-10^{-6} without the EFM signal being visible in the video picture.

2.2. Birefringence of the disc substrate

A source of interference with the EFM signal is the birefringence of the video disc when a He-Ne laser is used for read-out. The birefringence of the measured discs reached up to 25°, resulting in a certain fraction of light intensity being reflected by the disc, but not reflected to the signal detector by the polarizing beam splitter and hence fed back towards the laser. The frequency of the light-intensity modulation due to this laser feedback depends on the frequency at which the length of the optical light path changes. For a disc rotating at a speed of n rev/sec the fundamental frequency f is

$$f = 2sn/\lambda$$

where s is the total stroke of the unflat disc and λ the wavelength of the He-Ne laser. At s=2 mm, λ = 633 nm and n=25 rev/sec this frequency equals 160 kHz.

Other unflat modes of the disc may cause higher harmonics. In practical situations unflat discs can give amplitude modulations of the light output of the He-Ne laser at frequencies up to 500 kHz.

With deliberately warped test discs we found amplitude variations at frequencies up to 350 kHz. We measured the maximum tolerable birefringence of the disc substrate, where the digital audio signal is just disturbed (the appearance of interpolations and mutes in the decoder). The effect of birefringence of the test discs can be increased by increasing the amount of light fed back to the laser. This can be obtained by a rotation of the quarter-wave plate in the video disc player round the optical axis. Our measurements showed that the BER of the EFM pseudo music signal, at a level of -26 dB, are not seriously perturbed by the birefringence of the disc up to 30°.

c. Crosstalk

Another possible source of interference with the EFM signal is crosstalk due to an obliqueness of the disc substrate relative to the perpendicular position of the optical axis of the read-out objective lens in the video disc player. At the nominal track pitch of 1.67 microns and at skew angles, in the radial as well in the tangential direction, up to 1° we were unable to measure any increase of the BER of the EFM test sequences (written at levels varying from -26 to -20 dB).

3. Conclusions

The current LaserVision video disc system can be combined with digital audio according to the Compact Disc Audio System, fulfilling the requirements that:
a) the digital audio signal is not visible in the video picture, and b) the digital audio signal can be readout well within the limits of the CIRC error correction system, even with disturbing influences originating from imperfections of the disc and/or the read-out system.

Contrary to the case with PAL, the analog carriers can even remain in the case of NTSC, so that compatibility with analog sound is possible.

The digital audio signal can easily be reconstructed by filtering and decoding by the EFM and CIRC decoder.

nm Eindhoven, June 1983

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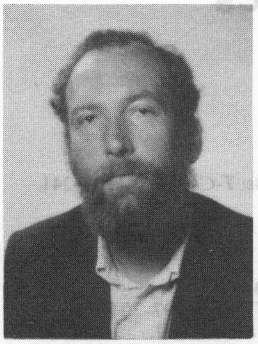
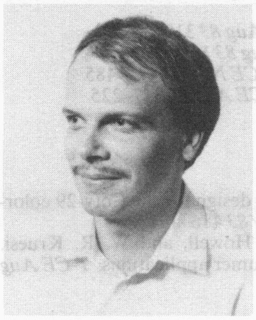
BIOGRAPHIES



Kees A. Schouhamer Immink joined the Philips' Research Laboratories (Eindhoven) in 1968. He obtained after a part time study a master's degree in electronics at the Eindhoven University of Technology. He then joined the Measurement and Control group of the Philips's lab to study the servo systems of the LaserVision system. In 1979 he reinforced the optical disc recording group to design channel codes for the Compact Disc Digital Audio System.

His present interests are modulation systems for magneto-optical and magnetic recording.



Joost Kahlman was born in Tilburg, the Netherlands in 1956. He received the B.Sc. degree in electronics in Eindhoven in 1979. He joined the Philips Research Laboratories in 1980 after serving the Dutch army. He is now engaged in the design of modulation systems for optical disc systems.

Ad H. Hoogendijk, a member of the Main Industry Group Audio, N.V. Philips' Gloeilampenfabrieken, Eindhoven, the Netherlands, received a bachelor's degree in electronics in 1959. At the present time his responsibility is audio and video signal processing for the LaserVision video disc system. Between 1963 and 1972 he performed similar work for VCR and other video tape recorders.