Digital Audio Modulation in the PAL and NTSC Optical Video Disk Coding Formats*

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An extension of the current optical video disk format that includes a digital audio signal is presented. 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 is described, which permits the realization of a compatible system. For the PAL and SECAM video formats the feasibility of digital audio is shown, but it cannot be combined with the analog audio carriers.

0 INTRODUCTION

In the current optical video disk 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 [1]–[3].

The maximum audio signal-to-noise ratio of the optical 525-line NTSC format at present attainable is aproximately 70 dB, which includes a 15-dB improvement by the CX noise reduction system [3]. In the 625-line PAL and SECAM formats of the optical disk the audio signal is approximately 10 dB superior to that in the NTSC optical format.

An improvement in audio quality seems possible only by going digital. For example, the 16-bit linear quantization used in the Compact Disc digital audio system format [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 dropouts. 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 optical video disk 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 optical 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 optical coding format. In Section 2 we describe the experimental results obtained with actual disks.

1 REQUIREMENTS TO BE MET BY DIGITAL AUDIO MODULATION SYSTEMS IN THE OPTICAL FORMATS

In this section we describe the optical 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 optical formats.

1.1 Description of the Optical Coding Formats

The signal format of current NTSC and PAL optical disk is a two-level signal (high-frequency), which is frequency-modulated, after preemphasis, 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 high-frequency signal by the two frequency-modulated audio carriers. Fig. 1 shows a block diagram of the signal

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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. Fig. 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.

Fig. 3(b) shows the spectrum of a PAL video signal which is frequency-modulated on a carrier of 7.1 MHz (that is, the frequency corresponding to the black level of the video signal), where J_0 is the principal component representing the frequency as a function of the amplitude of the video signal. J_1 is the first-order lower sideband, also referred to as chroma band, which is situated at 4.43 MHz from the principal component J_0, 4.43 MHz being the frequency of the chrominance carrier in the PAL video signal, and J_2 is the second-order sideband which is mirror-inverted [6] relative to the frequency zero point. In the optical 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.

Fig. 3(a) 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 J_1 and J_2 are now spaced at distances of 3.58 and 7.16 MHz, respectively. In the NTSC video format the audio signals are added as frequency-modulated 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 in the case of PAL, the analog carriers can even remain in the case of NTSC, so that compatibility with analog sound is possible.

The interference caused by the second-order sideband J_2, found in this low-end frequency range, has to be removed. An example of an embodiment of such a system is given in [7]. The method (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 J_2 component will be canceled.

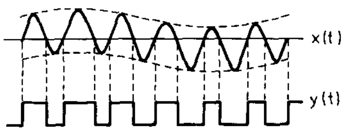


Fig. 1. Generation of modulator signal. The sum signal is limited so that a pulse-width- and frequency-modulated two-level signal results.

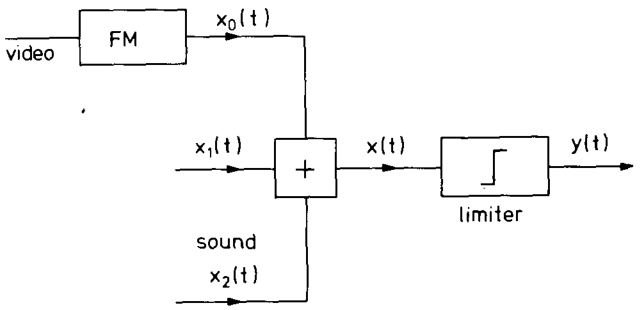
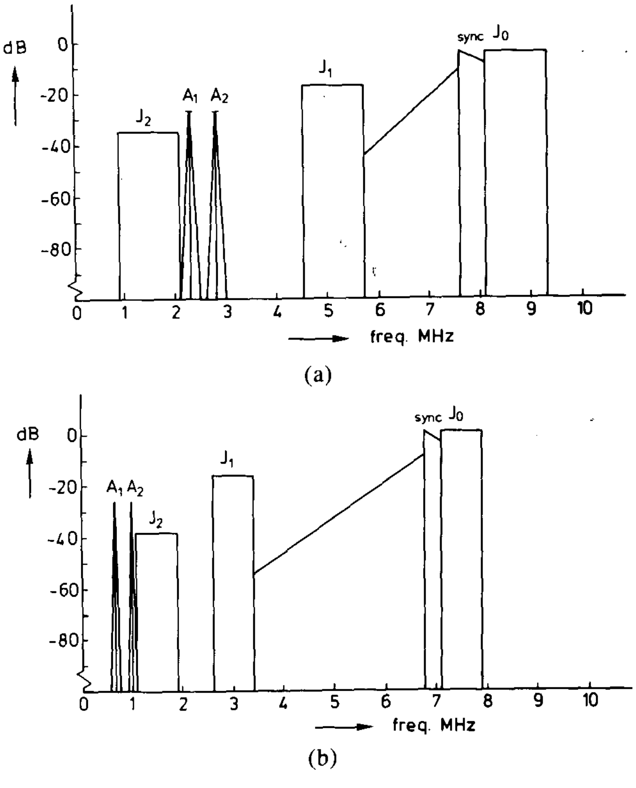


Fig. 2. Principle of pulse-width modulation. $x(t)$—input signal to limiter; $y(t)$—resulting two-level output signal.

1.2 Picture Quality

To find the effect of a pulse-width modulation of the carrier on the picture quality we designed the experimental setup shown in Fig. 5. The video modulator supplies a composite PAL video signal to the frequency modulator. The sine wave 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 rolloff of the optical readout system. The video signal can be 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 (15 625 Hz for PAL). The disturbance in the video signal is caused by the second-order sideband of the pulse-width modulation.



(a)

(b)

Fig. 3. Frequency spectra of optical video formats. (a) NTSC. (b) PAL.

Fig. 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 frequency-modulated spectrum. The vertical amplitude axis is given relative to the amplitude of the main carrier.

Fig. 6 illustrates that with a maximum signal level pulse-width modulation may be applied when the signal is passed through a low-pass filter with a cut-off frequency in the range of 1.5–2 MHz.

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 read out the video disk. Since a comparatively weak signal strength is desirable for the coding of the digital audio signal (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 of 100 kHz to 1 MHz, in particular at 500 kHz, because at approximately 500 kHz the eight-to-fourteen modulation (EFM) spectrum (EFM is the modulation system used in the Compact Disc) exhibits a maximum and rolls off below this frequency [8]–[10]. Fig. 7 shows the frequency diagram of a suitable low-frequency preemphasis filter. The roll-off frequency is situated at 500 kHz. Below this frequency the signal is boosted by 6 dB per octave, which is easy to achieve. The crossover frequency at which the characteristic becomes flat again (in the present example 30 kHz) is determined by the visibility limit (Fig. 6) and its possible influence on control systems such as the radial tracking. During our experiments we found a preemphasis of 23 dB an optimal choice.

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. Fig. 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 low-pass-filtered with a cut-off frequency of approximately 1.75 MHz. After the low-frequency preemphasis the signal is applied to the pulse-width input of the video modulator. Fig. 8 holds functionally for both the NTSC and the 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. Fig. 9 depicts the resulting spectra in both the NTSC and the PAL formats.

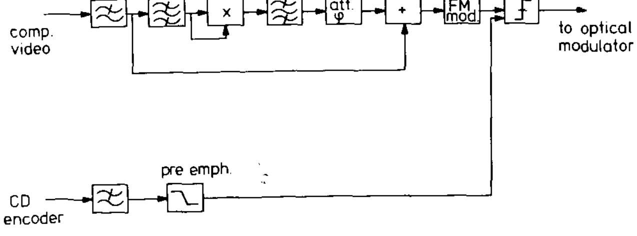


Fig. 4. Example of compensation of second-order sideband J_2.

Fig. 10 shows the block diagram of the decoder. The digital audio signal can be reconstructed easily by deemphasis and low-pass 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 needs no functional changes with respect to the current one.

2 EXPERIMENTS

The digital audio signal can be disturbed by different sources. These disturbances may originate from:

1) Irregularities on the video disk surface
2) Birefringence of the disk substrate
3) Crosstalk.

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

2.1 Irregularities on the Video Disk Surface

EFM test sequences (pseudo music) written directly on the disk 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 without preemphasis. The low-frequency disturbances are due to scratches and rapid fluctuations of the reflection coefficient of the video disk. After preemphasis as in Fig. 7, we found bit error rates in the range of 10^{-5}–10^{-6} without the EFM signal being visible in the video picture.

2.2 Birefringence of the Disk Substrate

A source of interference with the EFM signal is the birefringence of the video disk when a He-Ne laser is

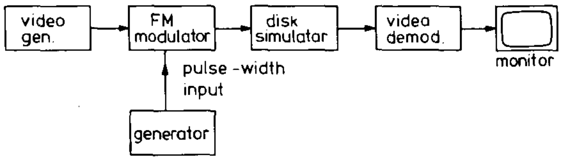


Fig. 5. Block diagram of experimental setup to study influence of pulse-width modulation on picture quality.

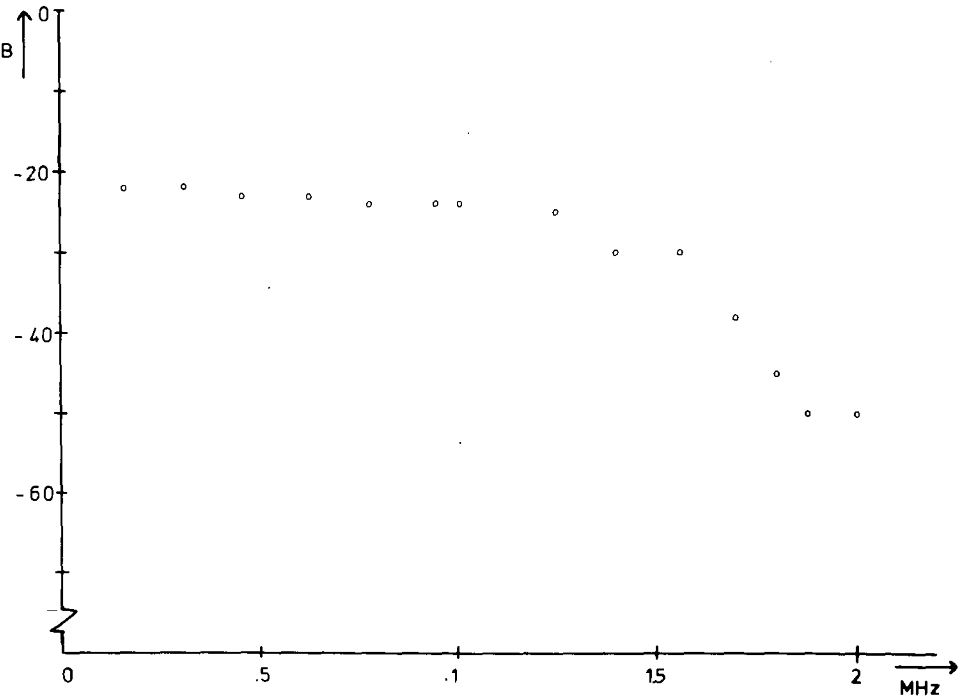


Fig. 6. Relative amplitude of sinusoidal pulse-width modulation when it becomes just visible in picture. Video decoder is unmodified model LV 720, Mk-1 PAL decoder.

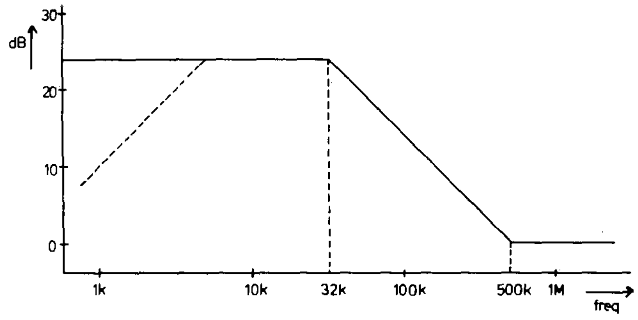


Fig. 7. Amplitude Bode diagram of preemphasis filter.

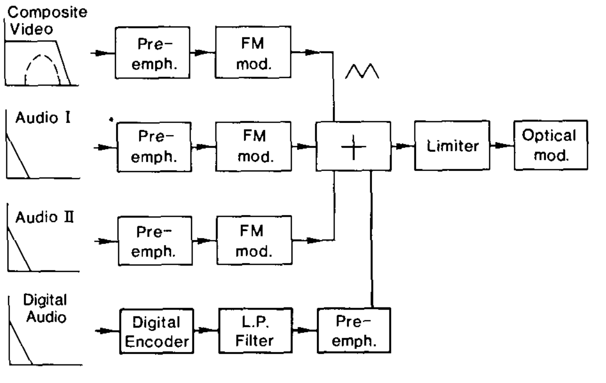
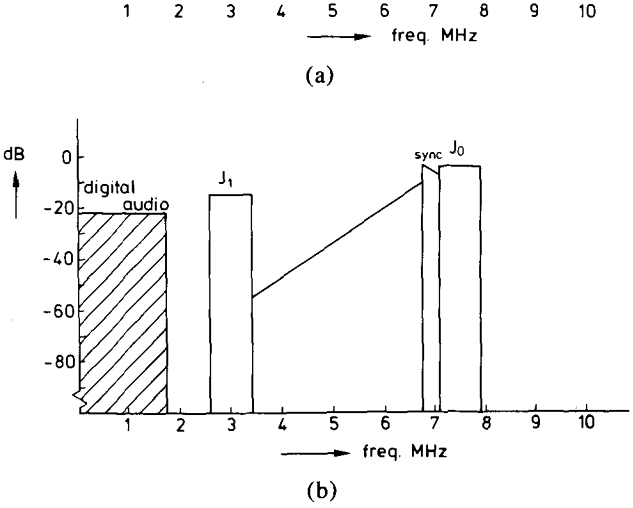


Fig. 8. Block diagram of combined video and digital audio encoder. The block diagram holds for PAL and NTSC video formats with some altered parameters. Note, however, that the analog audio carriers have to be removed in the PAL case. The video frequency modulator is extended using J_2 compensation.



(a)

(b)

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

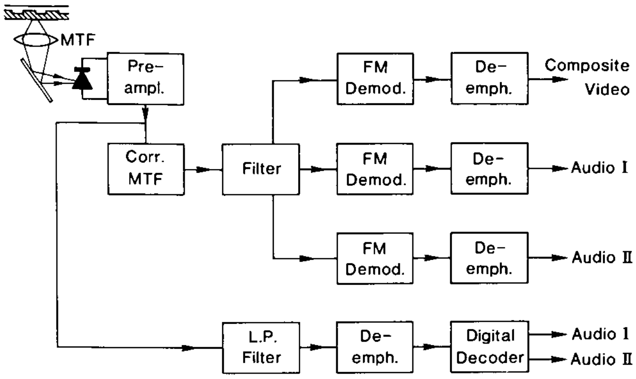


Fig. 10. Block diagram of decoder. The EFM signal is simply reconstructed by deemphasis and low-pass filtering.

used for readout. The birefringence of the measured disks reached up to 25°, resulting in a certain fraction of light intensity being reflected by the disk, but not reflected to the signal detector by the polarizing beam splitter and hence fed back toward 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 disk rotating at a speed of n revolutions per second the fundamental frequency f is

$$f = \frac{2sn}{\lambda}$$

where s is the total stroke of the nonflat disk and λ the wavelength of the He-Ne laser. At $s = 2$ mm, $\lambda = 633$ nm, and $n = 25$ r/s this frequency equals 160 kHz.

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

With deliberately warped test disks we found amplitude variations at frequencies up to 350 kHz. We measured the maximum tolerable birefringence of the disk 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 disks 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 disk player around the optical axis. Our measurements showed that the bit error rates of the EFM pseudo music signal, at a level of −26 dB, are not seriously perturbed by the birefringence of the disk up to 30°.

2.3 Crosstalk

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

3 CONCLUSIONS

The current optical video disk system can be combined with digital audio according to the Compact Disc audio system, fulfilling the requirements that (1) the digital audio signal be not visible in the video picture, and (2) the digital audio signal can be read out well within the limits of the CIRC error-correction system, even with disturbing influences originating from imperfections of the disk and/or the readout 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 be reconstructed easily by filtering and decoding by the EFM and CIRC decoder.

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Mr. Hoogendijk's biography was not available at press time.