Amplified Recirculating Delay Lines as Fiber-optic Decoders in TV Systems

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A novel approach to decoding chrominance signal in amplitude-modulated vestigial-sideband (AM-VSB) television systems is described. The decoding scheme is achieved by means of amplified recirculating delay lines as fiber-optic filters. The technique is experimentally verified by decoding the chrominance components of the UHF channel 21 of G PAL standard.

I. INTRODUCTION

There is a growing interest in fiber-optic signal processing devices due to the great variety of functions they can perform [1, 2]. Among them, their application as filters was previously emphasized and their implementation was reported [3].

On the other hand, subcarrier multiplexing (SCM) is a convenient method of implementing multiple access in a lightwave system. Although conventional SCM receivers demodulate the TV channels in the electrical domain, channel selection has also been achieved using optical prefiltering [4]. After a particular subcarrier has been selected, decoding of the color signal must be accomplished. We present a novel color decoding system in the optical domain, using amplified recirculating delay lines. The technique is experimentally verified by decoding the chrominance signal of a TV channel with the video carrier at 471.25 MHz.

II. OPTICAL DECODING

The standard G of the PAL color system presents the chrominance spectral lines interleaved between luminance lines with a line frequency f_h of 15.625 KHz [5], as can be seen in Fig. 1. These chrominance signals are multiplexed

on a color subcarrier whose frequency falls at 4.43361875 MHz of the video carrier.

Decoding of both chrominance signals U and V can be accomplished by a fiber-optic filter with a FSR (free spectral range) corresponding to the line frequency f_h . If a single amplified recirculating delay line is considered, a loop length L of 13.333 Km is required,

$$FSR = \frac{c}{n_g L}, \quad (1)$$

with c the light speed in vacuum and n_g the group index of the fiber. The minima of the optical filter are located at the frequencies f_m given by

$$f_m = \frac{c}{n_g L} \left(\frac{1}{2} + m \right), \quad (2)$$

where m is an integer number.

The decoding scheme can be achieved with two different configurations of the optical filter, as illustrated in Fig. 2. In Fig. 2a the notch filter configuration output cancels the harmonics of one of the signals to be decoded, located at the frequencies given by Eq. (2), while the other chrominance signal passes through without attenuation apart from the insertion loss of the directional coupler and the low loss of the fiber (0.2 dB/Km at 1.55 μ m).

High rejection levels are obtained by means of adjusting the coupling ratio K of the coupler and the overall gain G^* of the recirculating line. For a notch filter,

$$G^* = \frac{1 - K}{2K - 1}. \quad (3)$$

FIG. 1. Chrominance spectrum (PAL color system) multiplexed on a color subcarrier (F_c), interleaved between luminance spectrum. (---) Spectrum of the luminance signal, (—) spectrum of the chrominance signal V ($F_c \pm ((2n-1)/2)f_h$), and (...) spectrum of the chrominance signal U ($F_c \pm nf_h$).

The difference between maxima and minima amplitude was measured to be >50 dB [3].

No optical amplifier in the delay line is required for this configuration (K variable couplers can be used instead), so a less expensive filter can be achieved.

The outputs in Fig. 2b correspond to a very selective filter which amplifies the harmonics of the selected signal U or V and cancels the harmonics of the other signal. The selected harmonics are at the frequencies given by

$$f_p = \frac{c}{n_g L} (p), \quad (4)$$

where p is an integer number. The rejected harmonics are located at the frequencies given by Eq. (2).

The calculated transfer function of this type of filter is represented in Fig. 3. The parameters are $L = 39.2$ m, $K = 0.586$, and $G^* = 2.399 > 1$. This condition is obtained by adjusting the coupling ratio of the coupler and the gain of the optical amplifier.

Special care must be taken in avoiding oscillations in the filter response. To do so, the following stability condition must be accomplished:

$$G^*(1 - K) < 1. \quad (5)$$

This condition keeps the poles of the transfer function inside the unit circle.

The decoding scheme can be accomplished by the fiber decoder in the baseband signal as in conventional TV receivers. But, for lightwave cable TV systems with optical prefiltering, the decoder can directly operate in the modulated signal as in the measurements reported in this paper.

III. EXPERIMENTAL RESULTS

The amplified recirculating delay line was implemented with a 2×2 , K variable fiber coupler; its loop length was 13.333 Km, comprising 2 m of pigtails, an erbium-doped fiber amplifier (EDFA) pumped at 980 nm with 17 m length and the remainder single mode optical fiber.

The setup is shown in Fig. 4. A CW LD output of $1.5 \mu\text{m}$ externally modulated was launched onto the optical filter. The output was analyzed in a RF spectrum analyzer. The work undertaken involved two different intensity modulation schemes of the LD.

For measuring the transfer function of the optical filter, a sinusoidal signal from the tracking generator of the RF spectrum analyzer should be used, marked as (2) in Fig. 4. On the other hand, if we are interested in the decoded V chrominance signal, the modulation should be performed by a TV pattern generator, labeled (1) in Fig. 4.

UHF channel 21 of the G PAL standard was selected for this experiment, so the video carrier was at 471.25 MHz. The color subcarrier is located at 475.6836 MHz. The pattern chosen was D2, so higher intensity appears in the chrominance signals to be decoded. The optical filter was adjusted to cancel the U signal, as can be seen in Fig. 5. The actual suppression of this signal after passing through the filter can also be shown in this figure.

FIG. 2. Chrominance optical decoding system. (a) U (...) and V (—) decoded signals when a notch optical filter configuration is considered. (b) U (...) and V (—) decoded signals when a selective optical filter configuration is considered.

FIG. 3. Calculated transfer function of a high selective-high blocking band optical filter. The parameters of the amplified recirculating delay line are $L = 39.2$ m, $K = 0.586$, and $G^* = 2.399 > 1$.

The optical filter operating as a selective filter for the U signal (Fig. 2b) was also implemented and measured. The results obtained correspond to Fig. 5b, where the spectra of the output and input signals appear.

IV. DISCUSSION

The limitations of the present experimental arrangement are due to relatively low input signals reinforced by the losses due to splices and connectors.

Incoherent processing reported here allows us to avoid environmentally sensitive coherent optical interference effects. The effects of temperature variation on the free spectral range of the filter are given by

$$\frac{\partial FSR}{\partial T} = -\frac{c}{n_g L} \left[\alpha_T + \frac{\partial n}{\partial T} \right], \quad (6)$$

where α_T is the linear thermal expansion coefficient, so $\alpha_T L = \partial L / \partial T$.

Using typical values for silica fibers of $\alpha_T = 8 \times 10^{-17}/^\circ\text{C}$, $\partial n / \partial T = 1 \times 10^{-5}/^\circ\text{C}$ and $n = 1.44$, the second term of Eq. (6) is small compared to the first term. For a fiber 13.333 Km long, allowing a FSR variation of 8 Hz, the maximum allowable temperature range will be approximately 50°C .

Bandwidths up to GHz, no spurious delays, and high dynamic ranges are other attractive features of these decod-

ers in comparison with typical PAL chrominance delay lines. A performance comparison of the proposed filter and existing (nonoptical) decoders is reported in Table 1.

V. CONCLUSIONS

A novel chrominance decoding system has been theoretically described and experimental results are reported. The decoding scheme can be accomplished by the fiber decoder in the baseband signal as in conventional TV receivers or directly in the modulated optical signal in lightwave cable TV systems with optical prefiltering.

The fiber decoder is an amplified recirculating delay line.

FIG. 4. Experimental setup.

FIG. 5. Measurements: (a) Transfer function of the notch optical filter and system output. (b) Input and output of the system when a selective optical filter is considered.

Its performance would be further improved by minimizing the losses. A more complex filter configuration can lead to higher rejection ratios between the decoded signals.

Performance comparison with typical nonoptical decoders was reported. Despite the fiber decoder's bulky size and relative high cost compared to nonoptical decoders, its higher bandwidths, low loss, and operation in the optical

domain are attractive features. Its size can be reduced if an integrated Fabry-Perot scheme is considered at the expense of loss increases.

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TABLE 1

Performance Comparison of the Proposed Filter and Existing (Nonoptical) Filters

Decoder	Nonoptical	Optical
Center frequency	4.433619 MHz	475.6836 MHz
Bandwidth	3.4–5.2 MHz	>GHz
Phase delay time 1/FSR	63.943 μ s ($\pm$ 5 ns)	63.99 μ s ($\pm$ 20 ns)
Variation in delay over range 10°C–60°C	<5 ns	<20 ns
Typical insertion loss	9 dB	2.6 dB at 1.55 μ m
Spurious delay	<28 dB	<50 dB

Note. Data are from Ref. [5].