AN IMPROVED QUALITY PAL DECODER

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Abstract

The motivations for the final system choices of a commercial improved quality PAL receiver are commented. The receiver is based on fixed spatio-temporal filters for luminance-chrominance separation. The filters were designed according to hardware complexity and subjective performance evaluation and according to three dimensional spectral analysis tests nonstandard in television practice.

1. Introduction

The theoretical advantages of PAL decoding based on digital spatio-temporal filters have long been known [1,2]. In spite of the current spur of interest toward improved quality television [3,4]the implementation of these concepts in actual hardware decoders is up today confined to a few laboratory prototypes and to a handfull of commercial products.

This work describes a commercial PAL decoder based on a fixed set of complementary three dimensional FIR filters for luminance-chrominance separation (hereafter simply referred to as Y/C separation).

The system filters were chosen after extensive experimentation with both the literature solutions and with their original modifications. The filters were compared with respect to: i) hardware complexity; ii) frequency domain analysis of their operation; iii) subjective evaluation of their performance with standard test sequences used in current television practice (e.g., "Girls", "Doll", "Car", etc.). The filter actually adopted in the decoder is an improved 312-line delays filter [1,2] which was found an effective trade-off between visual performance and hardware cost. The motivations for this choice are presented in next section. The hardware scheme is presented and commented in Section 3. Section 4 presents the final remarks.

2. Spatio-temporal filters for luminance chrominance separation

The proposed decoder is based on a complementary set of luminance/chrominance separation filters [1]. Since these filters represent the most critical and qualifying part of the PAL decoder, their comparative examination will be treated in detail.

As well known, Y/C separation can be achieved by the cascade of a vertico-temporal filter with a horizontal bandpass filter without substantial performance loss. (This possibility can be conveniently justified on the basis of the three-dimensional model of the PAL signal [1]). Such a structural semplification is rather useful for hardware implementation based on contemporary field memory technology and it is generally adopted in the filter schemes presented in the literature.

Therefore the considered chrominance separation filters have impulse reponses of type

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$$h(x,y,t) = g_1(x)g_2(y,t)$$

where $g_1(x)$ is a horizontal pass-band filter with passband width 1.3 MHz centered at 284x15625 Hz and $g_2(y,t)$ is a suitable vertico-temporal filter. The most common types of $g_2(y,t)$ kernels encountered in the literature are shown in Fig. 1. The actual coefficients of $g_2(y,t)$ are zero everywhere but on the crossed points where their values is indicated by the corresponding numbers . The coefficients of Fig. 1 refer to the specific chrominance separation filters, considered in the examples of the paper.

Fig. 1 from a) to f) respectively present a line delay (LD) based filter, a frame delay (FD) based filter, a 313-line delays (313 LD) based filter a 312-line delays (312 LD) based filter, a filter suggested by [1], indicated as filter D, and the filter actually adopted in the proposed improved quality receiver, denoted as filter P. All the kernels of Fig. 1 can make for three-dimensional filters of reasonable implementation complexity.

Frequency domain analysis was introduced as a comparison criterion besides hardware feasibility, and the visual performance of the filters that will be subsequently examined. Spectrum analyzers are routinely used with one dimensional signals. Given the complexity of spectrum analyzers for spatio-temporal signals, in television practice frequency domain analysis is used only at a very limited extent, i.e., almost exclusively with special signals called zone plates [5-7]. The frequency domain performance of the filters of Fig. 1 with the most common test sequences was assessed by means of a spectrum analyzer specifically built for television sequences [8].

Fig. 2a shows a frame of test sequence "Cloth" where the camera is slowly panning on the scene from right to left. As an example of the possibilities of the spectrum analyzer, Fig. 2c shows four vertico-temporal sections of the luminance spectum of "Cloth", organized as in Fig. 2b, i.e., taken at horizontal frequencies a) $f_x=0$, b) $f_x = F_{sx}/8$, c) $f_x = F_{sx}/2$ and d) $f_x = 3F_{sx}/8$ (F_{sx} is the horizontal sampling frequency). The motion of the scene is recognizable in the shift of the spectral energy content from section to section).

The spectra of the signals are represented by countour plots associated to pure chrominance information (e.g. green: from the maximum value to -10 dB, blue -10 dB to -20 dB, magenta: from -20 dB to -10 dB, pink: from -30 dB to -40 dB, grey: below -40 dB).

Information of the type of Fig. 2c (which is available for every considered test sequences) together with the three dimensional frequency response of the filter allows to analyze the filtering operation in the frequency domain.

Fig. 3 shows the four vertico-temporal sections of Fig. 2b of the frequency response magnitude of $h(x,y,t)=g_1(x)g_2(y,t)$ relative to kernel $g_2(y,t)$ of Fig. 1a.

Fig. 4a shows the superposition of the transfer function of the chrominance filter of Fig. 3 with the luminance spectrum of "Cloth". Spectral analysis is very effective in order to explain the visual effects typical of delay line filters. Fig. 4a helps justifying the a dramatic loss of vertical resolution not only with horizontal motion as in the case of sequence "Cloth", but also with still scenes. Fig. 4 shows that such an effect is due to the vertical filtering of the middle part of the luminance spectrum.

As the chrominance filter is the complementary of the luminance one, this feature produces considerable cross-colour as a counterpart.

Let us note that vertical motion, being associated to vertical shifts of the spectral energy content would lead to worse separation effects with respect to conventional decoding (as it pushes the luminance energy pick right into the pass-band of the chrominance filter).

The kernel h(x,y,t) relative to the frame delay (FD) filter of Fig. 1d, has a behavior dual to that of the LD filter with respect to vertical and temporal resolution, and with respect to vertical and horizontal motion as shown in Fig. 4b. Subjective evaluation confirms that the inadequacy of the LD filter with respect to high vertical frequencies is comparable with the inadequacy of the FD filter with respect to high temporal frequencies. The FD filter performs very well with still scenes, however it is highly unsatisfactory with moving scenes, even at very slow motion. On the converse the performance of the LD filter (unsuited to deal with common vertical energy content) is rather insensitive to motion, as its temporal bandwidth is unlimited. The relatively satisfactory behaviour of the LD filter with moving scenes is related to the fact that the eye's average response in such a context is more sensitive to the temporal energy content than to vertical details.

Fig. 4c shows that the h(x,y,t) kernel associated to the 313-line delays based filter of Fig. 1c, can be seen as a trade-off between the kernels of the FD and LD filters, with respect to spatial resolution and motion. As a rule of thumb the temporal resolution of the 313-LD based filter is approximately twice that of the FD filter and its vertical resolution is twice that of the LD filter, with the understanding that the filter bands have the diagonal structure of Fig. 4c.

Fig. 4d refers to the kernel associated to the 312-LD based filter, which is conceptually dual to the 312-LD based filter.
However the vertical and temporal resolution of the former are practically twice those of the latter, as a consequence of the geometrical disposition of the chrominance repetition centers [1]. The visual tests reflect these characteristics of the filter transfer functions.

An indesirable feature of the two just examined diagonal filter structures is the equal bandwidth partition between chrominance and luminance, which does not account for the actual spectral energy content and visual importance of the two signals.

Fig. 4e refers to the kernel h(x,y,t) obtained from the so called filter D of Fig. 1e [1]. Filter D is obtained from the convolution of the impulse responses of filters 312 LD with 313 LD. Fig. 4e shows how the chrominance pass-bands nicely surround the chrominance repetition centers. The subjective filter performance is typically rather satisfactory, except for the "hanging dots" effect appearing at the edges of differently coloured regions. Such an effect is due to residual energy at chrominance subcarrier frequency in the luminance signal and it is shown in Fig. 5a. The geometry of the impulse response of filter D leads to the most demanding hardware structure among the considered set of filters.

Filter P of Fig. 1f, is a compromise between the various filtering solutions above examined. Filter P retains the hardware simplicity of the 312-line delays structure, however differently from the 312 LD filter of Fig. 1d it allows for a luminance passband wider than the chrominance one. This feature, shown by the frequency response magnitude sections of Fig. 4f, leads to a better luminance-chrominance balance, as a more restricted chrominance passband is appropriate with respect to the typical chrominance energy contents and it is visually satisfactory. The vertical step response of filter P (characterized by a rising time shorter than that of filter D) makes for a generally satisfactory behaviour with respect to the "hanging dots" effect, as shown in Fig. 5b.

Table I rates in seven quality ranks the visual performance of the Y/C separation of the filters of Fig. 1, versus that of conventional analog PAL decoding.
No symbol indicates comparable visual performance, while the plus or the minus symbols are respectively associated with better or worse performance quality according to the rule shown in Table I. In order to correctly read Table I it should be noted that entry "motion" is to be interpreted with respect to all the other entries of the same column. More precisely if no symbol is assigned at this entry, it means that the quality of the visual cues reported by the Table applies to still as well as to moving sequences.
On the contrary if some minus symbols appears at entry motion, it means that the quality of the visual cues reported by the Table applies only to still sequences and it has to be appropriately

scaled (according to the number of minus symbols) in order to be referred to moving scenes. The presence of the plus symbol has to be similarly interpreted, except in the sense of a visual quality improvement with moving sequences.
It can be readily seen that Table I supports and extends concepts pointed out by the frequency domain analysis.

Subjective evaluations indicate that filter FD performs rather well with still pictures but it leaves a lot to be desired in presence of motion. Filter P has been preferred over the others, apart from its relative hardware simplicity, because its performance with moving imagery is quite acceptable and it is not affected by the ringing and subcarrier residual problems of the other filters.

3. Implementation considerations

A fully digital PAL decoder based on filter P for luminance-chrominance separation has been implemented in three prototypes. A version of this product targeted to professional PAL decoding is presently under developpment.

Fig. 6 shows the decoder scheme. In the prototypes filter P is implemented with commercial field memories and dedicated PLA's.
The horizontal filter $g_1(x)$ and the two low-pass filters operating on the U and V signals respectively are implemented via dedicated commercial fast signal processors.

The professional PAL decoder under developpment is a full integrated version (except for the field memories) of the scheme of Fig. 6 and it is provided both with analog R, G, B, and Y, U, V monitoring outputs and with numerical parallel output according to standard CCIR 656.

4. Conclusions

This paper summarizes the work which led to the design of a commercial improved quality PAL decoder.

The emphasis of the presentation is on the spatio-temporal filters to use for luminance/chrominance separation. The various solutions presented by the literature were carefully examined and compared with respect to hardware complexity and both visual and spectral performance.

As subjective evaluations typically represent information rather delicate to obtain and difficult to document it was found effective to integrate such data with the spectral performance of the filters with typical PAL test sequences.This kind of frequency domain analysis, not standard in current television practice, was performed by an "ad hoc" spectrum analyzer built for television sequences [8].

The examination led to modify the literature solutions into new filters of which the filter actually adopted in the decoder, filter P, is an example.

Specific points of interest of the paper are: the demonstration of the practical feasibility of nontrivial spatio-temporal filters into commercial PAL decoders; the use of nonconventional frequency domain analysis as an effective performace assessement tool for television systems.

Acknowledgement

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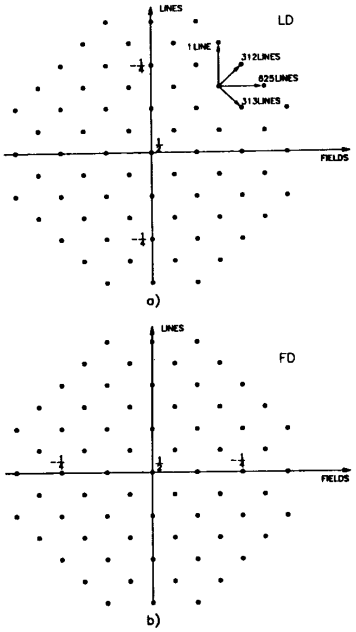


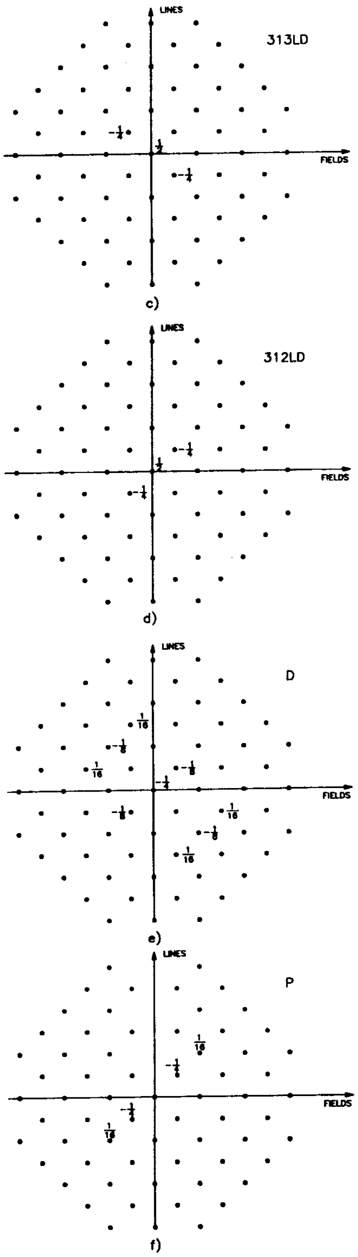
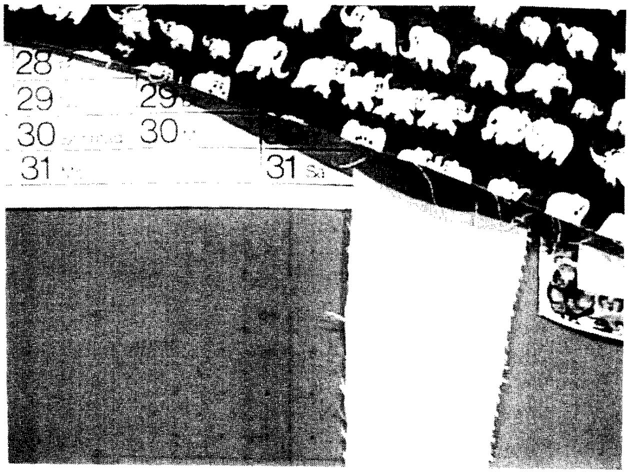
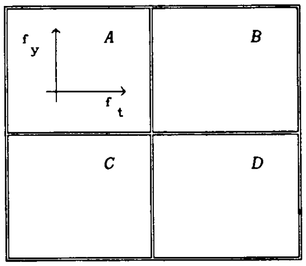


Fig. 1 Chrominance filters: a) LD based filter; b) FD based filter; c) 313 LD based filter; d) 312 LD based filter; e) filter D; f) filter P.



a)



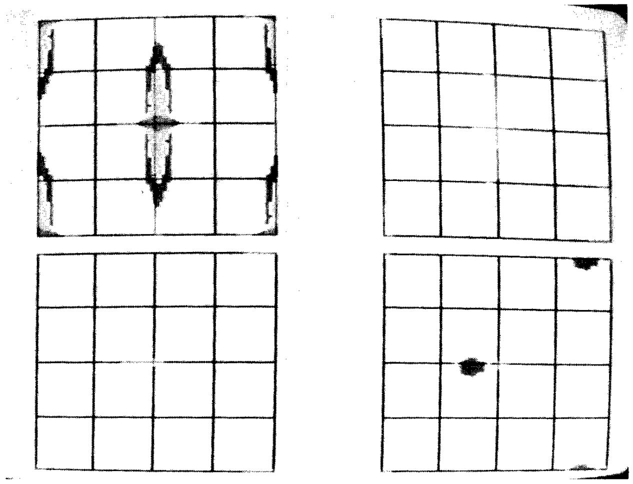
b)

$A : f_x = 0$

$B : f_x = \frac{1}{8} F_{sx}$

$C : f_x = \frac{1}{4} F_{sx}$

$D : f_x = \frac{3}{8} F_{sx}$



c)

Fig. 2

a) Frame of test sequence "Cloth" (courtesy of Centro Ricerche RAI, Torino);

b) vertico-temporal sections organization;

c) vertico-temporal sections of the luminance spectrum.

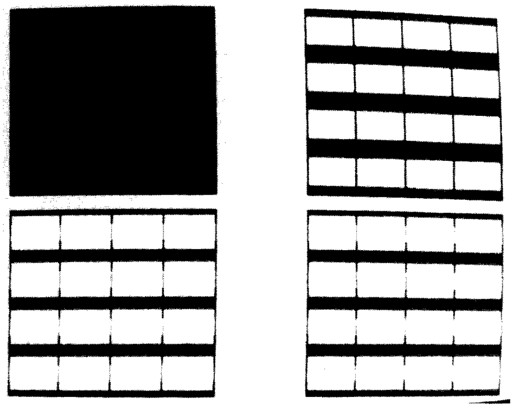


Fig. 3 Vertico-temporal sections of the magnitude of the h(x,y,t) relative to the kernel of Fig. 1a.

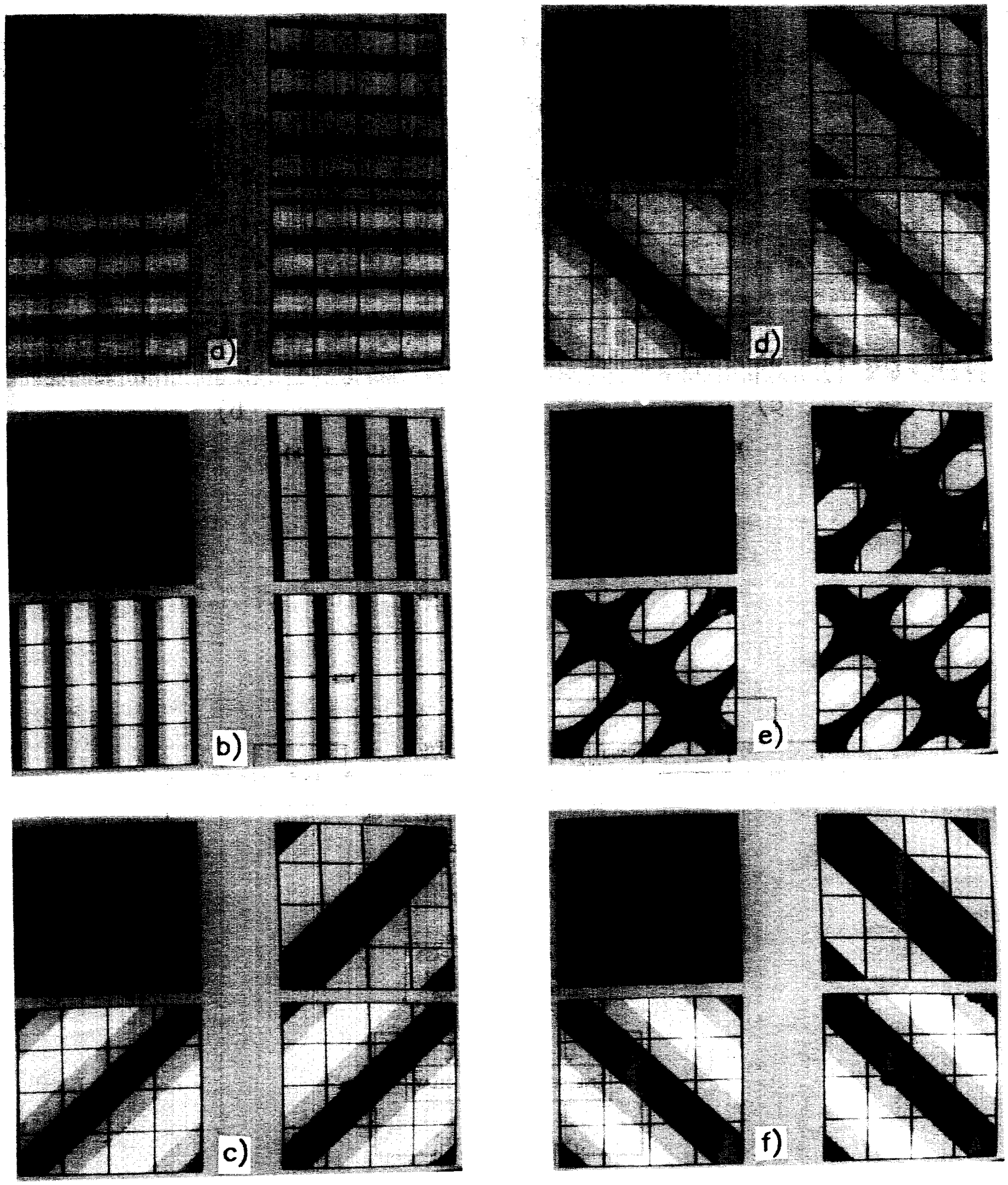
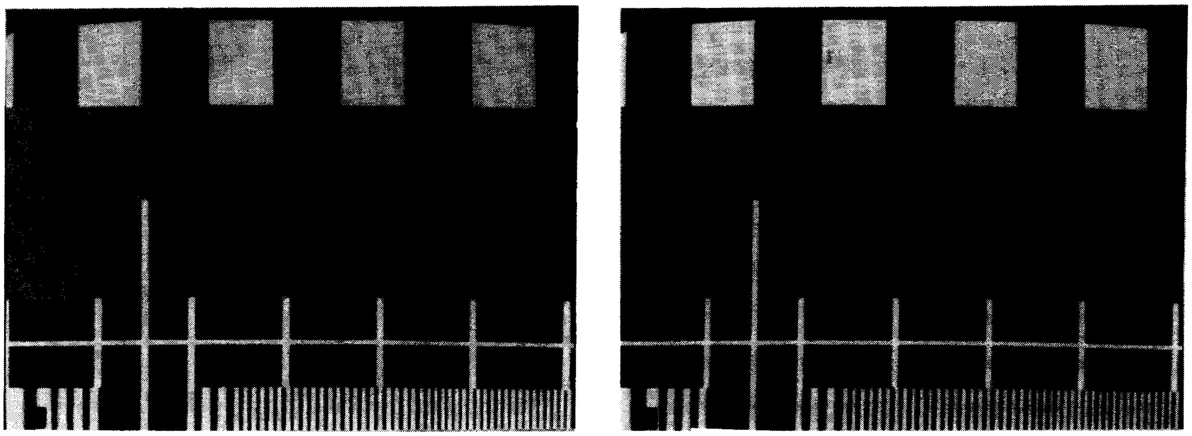


Fig. 4 Effects of the chrominance filters of Fig. 1 on the luminance spectrum of Fig. 2c.



a) b)

Fig. 5 Hanging dots effect for: a) filter D; b) filter P.

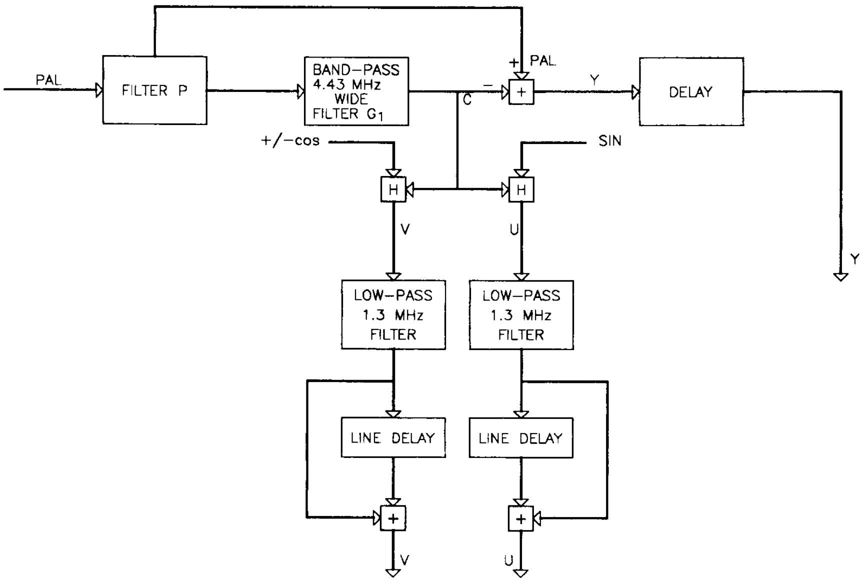
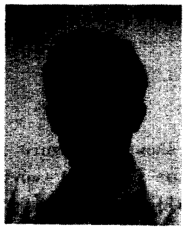


Fig. 6 Digital PAL decoder scheme.

Table I

	FD	LD	312LD	313LD	D	P
LUMINANCE RESOLUTION	+++	−	++	+	++	++
CROSS−COLOUR	+++		+	+	++	++
CROSS−LUMINANCE	+++		+	+	+	+
SUBCARRIER RESIDUAL	++	−	−	−	−−	
RINGING	+++	−			−	
MOTION	−−−	+		−	−	

BIOGRAPHIES



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