COMB FILTER TECHNIQUES IN PAL DECODING

Introduction

Some deficiences in the pictures produced by a standard PAL decoder are described. The defects arise mainly from the difficulty in separating the luminance and chrominance components and result in **cross-colour** which causes flashes of spurious colour in areas of fine detail and **cross luminance** which appears as crawling dots on vertical coloured edges.

The problems are particularly annoying when the decoded signal is to be re-encoded as happens in some types of synchroniser, for example, because the original sub-carrier components can then interfere with the new sub-carrier used in the re-encoding process.

Comb-filter techniques using line-period delays can improve the separation of luminance and chrominance in a decoder but produce other defects which are noticeable with certain types of picture information and for the best results an adaptive system is used where the form of filtering is selected according to the nature of the picture content in order to achieve the best compromise.

A simplified description of a typical adaptive comb-filter decoder is given; it uses analogue techniques.

The use of **field-period** delays can give improved performance, but although ultrasonic quartz delays of field duration have been produced it is most convenient to use digital techniques.

A PAL decoder using digital techniques throughout and incorporating two field delays is described briefly. In this case **line-locked** sampling is employed at the EBU standard of 13.5MHz in order to simplify the production of EBU standard digital YUV outputs.

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1. THE PERFORMANCE OF A SIMPLE PAL DECODER

1.1 A Demonstration Picture

To illustrate the performance and defects of a decoder consider the picture in fig. 1.1(a) which contains:

i. Coloured patches giving vertical (1) and horizontal (2) coloured edges.

ii. Gratings, that is patterns of fine lines with various spacings.

   a. vertical lines (3) having high-frequency luminance components which however are the same on each line.

   b. horizontal lines (4) having luminance components which differ from line-to-line but are of only low frequency.

   c. diagonal lines (5) which have high frequency luminance components but which also differ from line-to-line.

1.2 Picture Defects Arising in Simple PAL Decoding

The elements of a simple PAL decoder are shown in fig. 1.2 and the defects arising from the principle of allowing the luminance and chrominance signals to share the same frequency band are well known and illustrated in fig. 1.1(b). It is assumed that the decoder is correctly adjusted and that there are no differential phase errors.

1.3 Some Possible Compromises in a Simple PAL Decoder

1.3.1 Increasing the bandwidth of the "notch" in the luminance channel reduces the crawling dot pattern on coloured vertical edges but reduces the sharpness of <u>all</u> vertical edges and patterns.

1.3.2 Reducing the chrominance bandwidth in the decoder can reduce the "fine" cross-colour, but the only useful solution is to filter out from the luminance channel all components near to sub-carrier prior to coding. The resulting sharpness reduction may only be noticed by the monochrome viewer because the colour decoder removes some of these components anyway.

1.3.3 It may be noticed that these defects are largely absent if the signal is from a "colour-under" video tape system such as VHS or U-matic, because of the restricted chrominance and luminance bandwidths: but so unfortunately is much of the sharpness of the picture.

Fig. 1.1.(c) shows for comparison the performance of a comb-filter decoder using one-line delays. Although there is considerable improvement some extra defects are introduced. The best compromise is an adaptive decoder which automatically switches rapidly between the two forms according to the picture content.

2. A LINE-DELAY COMB-FILTER DECODER

2.1 The Delay Lines

The PAL input is passed through two delay lines each of precisely one line period, 64.00μs so that three signals are simultaneously available, undelayed and delayed one and two line periods. These signals will be called 0H, 1H and 2H respectively. They are represented at A, B and C in fig. 2.1 in the way that they might appear at a particular instant on vector scopes using the 1H signal (which forms the "main" output) as a reference.

The following points must be noted.

i. The 1H signal represents the "middle" line.

ii. The 0H and 2H signals represent the lines below and above and can be though of as the "outer" lines.

iii. The three consecutive line of signal are assumed to be carrying the same picture information.

iv. The delays are precisely one line in duration and therefore give a phase shift of 283 3/4 + 1/625 cycles at sub-carrier frequency; the 1/625 component can be ignored in this case.

v. The U signal is shifted by 90° by the action of each delay line.

vi. The V signal is inverted by VAS on lines 0H and 2H. (one line period later the V signals on 1H will be inverted and the diagrams could equally well have been drawn this way).

vii. The luminance component would not normally be shown on such a diagram because it would not normally form a stationary vector but whatever it is it will have the same form on all three lines if they carry the same picture information.

The suffixes e.g. U_0 U_1 U_2 etc. indicate the number of line periods of delay which has been applied to each signal.

The delay lines must cover the whole video band (unlike those in PAL-D decoders which need pass only the chrominance signal) and amplitude modulation of a 30MHz carrier is typically used.

2.2 The Action of the Comb Filter if the Same Picture is Present on Three Consecutive Lines

Note: The phasor diagrams of fig. 2.1 will be valid for all conditions but if the same picture is present on all three lines considered then the lengths of V_0, V_1 and V_2 will be equal, as will the lengths of U_0, U_1, U_2, and Y_0, Y_1 and Y_2.

Adding the 0H and 2H delayed signals causes any luminance which is the same on both lines to add but any chrominance will be shifted by 180° by the action of the two delay lines and will cancel giving luminances only as at D in fig. 2.1.

> Note: This alone is not a good method of separating luminance because it is derived from the "outer" lines only and vertical resolution would be reduced.

Subtracting this from the main 1H signal gives just U_1 and V_1 the "middle line" chrominance at E.

> Note: This is not a perfect chrominance signal because it would contain U/V cross-talk if $U_0 \neq U_0$ or $V_0 \neq V_2$ because in this case U components would appear in the V phase and vice versa.

Subtracting the 0H from the 2H signal gives cancellation of luminance whereas the chrominance signals add. This "outer line" chrominance at F unfortunately has the opposite VAS to the middle line chrominance at E but this can be reversed by a "PAL modifier" (See next section). Which brings the "outer lines" and "middle lines" chrominance into phase. They can then be added to the "middle line chrominance" to give the "combed" chrominance signal at H which can be subtracted from the main 1H signal to remove its chrominance leaving the luminance intact as at J.

2.3 The PAL Modifier

The purpose of this circuit is to reverse the direction of VAS on a PAL chrominance signal. The principle is shown in fig. 2.2.

The PAL chrominance, which can be thought of as a signal at f_{sc} but varying phase and hence varying slightly in frequency, is applied to the first input of a multiplier, the second input of which is carefully phased carrier at 2 f_{sc}.

The output of the multipler will be sum and difference components at $2f_{sc}$ + chrominance (about 13.3MHz) and $2f_{sc}$ - chrominance component. (i.e. about 4.43MHz)

If the chrominance input were at a frequency slightly greater than f_{sc} (i.e. advancing in phase) then the difference component would be slightly lower than f_{sc} (i.e. retarding in phase) and vice versa. If viewed on a vectorscope the output would therefore appear to be the mirror image of the input, the position of the "mirror" would depend on the phase of the $2f_{sc}$ carrier.
An effect of this circuit is therefore to reverse the phase rotation hence the VAS of the input, the phase of the output can be adjusted by adjustment of the phase of the $2f_{sc}$ input.

The principle is not new and was described by Bruch in 1966 as an aid in decoding the proposed PAL signal.

3. CHROMINANCE SEPARATION AND DECODING WITH A LINE-DELAY COMB FILTER

(see fig. 3.1)

The same one-line delays can be used as for the luminance filtering. The outer line chrominance F is shifted in phase by 90° at K to bring it into phase with the middle line chrominance E.

Adding signals at E and K gives L, the U signal with luminance and V components cancelled. Subtracting E and K gives the V signal at M. These two signals are demodulated in the normal way to yield B-Y and R-Y respectively.

4. PERFORMANCE OF THE LINE-DELAY COMB FILTER DECODER

4.1 Chrominance Rejection on the Luminance Signal

Examination of J, the luminance output in fig. 2.1 shows that the chrominance is eliminated if $V_0 = V_1 = V_2$ and $U_0 = U_1 = U_2$. this will be true for cases where the same signal is present on 3 consecutive lines and therefore the crawling dot pattern on vertical coloured edges is eliminated, 6 on fig. 1.1.c.

At horizontal coloured edges however, the colouring signals will not be equal on successive lines and there will be uncancelled chrominance giving a crawling dot pattern at 1 in fig. 1.1.c. Remember that the normal chrominance rejection notch would not be used.

4.2 Luminance Sharpness

Because there is no luminance notch filter there is no loss of sharpness of vertical lines and edges, 6 and 8 in fig. 1.1

The simplified version of J at J' shows that the luminance output is a mixture of 0H and 1H contributions so it might appear that vertical resolution suffers but the horizontal lines at 9 in fig. 1.1 contain no high-frequency components and are rejected by the chrominance band pass filter so the luminance is simply the 1H signal in this region of the picture: it is only the chrominance band that the luminance signal becomes a mixture of the 0H and 1H luminance.

A problem arises with fine diagonal picture lines as at 10 . Here, although there is no chrominance signal there are luminance components which are within the chrominance band, but they are not identical on successive lines and therefore Y_2 and Y_0 may differ in phase. This results in a loss of diagonal resolution.

4.3 Luminance Aliasing

A further problem is aliasing causing patterns on diagonal picture lines as at 11 in fig. 1.1.c. The PAL modifier circuit, it may be remembered, has the effect of inverting frequencies about f_{sc} therefore a luminance component at say 3.43MHz would appear at 5.43MHz and vice versa. In addition when applied to the non-linear transfer characteristic of the picture tube a further intermodulation would occur yielding 2.0MHz in this case.

This aliasing does not occur on the vertical gratings because here $Y_0 = Y_2$ and the luminance components cancel at the input to the PAL modifier. Neither does it occur on the horizontal gratings because these contain no components within the pass-band of the chrominance filter.

4.4 Chrominance Decoding

Examination of L in fig. 3.1 shows complete cancellation of luminance components if these are identical on three successive lines so cross colour associated with fine vertical lines on the picture is eliminated (12 in fig. 1.1.c).

There will be less or no reduction of cross-colour on diagonal lines in the picture because in these cases the luminance component will not be the same on the three lines and will not cancel at L and M.

It can also be seen that the U components are taken from 3 successive lines: providing the three lines are of the same colour then the V components cancel but the U components are added and this gives some improvement in chrominance signal-to-noise ratio and cross colour rejection on plain coloured areas when compared with a conventional decoder. The same sort of results apply to the V signal at L.

The comb filter chrominance decoding performs poorly on horizontal coloured edges (7 in fig. 1.1.c) however: there is some loss of vertical colour resolution and V/U cross-talk will occur where $V_0 \neq V_2$, this will give the usual PAL colour flicker.

4.5 Comb Failure Conditions with Two Line-Delays

The comb filter will not be beneficial whenever the picture information differs on three successive lines. If the picture has a horizontal edge as in 2 in fig. 1.1.(a) then two lines on each field will be incorrect, i.e. 4 lines per picture.

5. THE ADAPTIVE COMB-FILTER DECODER

5.1 Comb Failure Detection - luminance channel, see fig. 2.1

In general it could be said that the comb filter gives much improved luminance separation when compared with a simple notch, but gives serious defects in certain areas of typical pictures, viz. sub-carrier dot patterns on horizontal coloured edges and loss of resolution and patterning on fine diagonal lines.

It is preferable that for just these areas of the picture the comb filter is switched off and a simple notch filter is substituted. These ares of the picture can be detected and a "comb fail" signal produced whenever either:

i. the middle line chrominance signal E is very different from the "modified" outer lines chrominance G, i.e. $1H \neq \frac{0H + 2H}{2}$

or

ii. the hf content is very different on the 0H and 2H signals. Note that by looking at A and C in fig. 2.1 it can be seen that these signals will not be identical even when the picture information is the same on lines 0H and 2H because of the phase reversal of the chrominance relative to the luminance. The picture difference is therefore detected by rectifying the hf content of the signals prior to the comparison.

If either of the above difference signals rise above a preset threshold level then the comb filter is switched off and a 4.43MHz notch filter is inserted in the luminance path. The setting of the threshold levels is determined by subjective appraisal.

Switching to and from the comb-filter mode can take place in less than 1μs.

5.2 Chrominance Decoding see fig. 3.1

Conventional simple chrominance decoding gives perfectly adequate results except for cross-colour, and this only occurs when there is signifcant luminance information in the chrominance frequency band.

The chrominance section therefore normally operates in the simple decoding mode except when much high frequency content is detected in the separated luminance signal. While this occurs the decoder is switched to the comb-filter mode.

6. THE USE OF FIELD-DELAY COMB-FILTERS

6.1 Figure 6.1 shows the use of two delays of 312 line periods each. The normal method of implementing such delays is by RAM storage and for this the video must first be converted to digital form and it is convenient, therefore, to use digital techniques throughout such a decoder.

This has been done in the BBC CD2M/546 where the input is sampled at 13.5MHz, line-locked, in order that the YUV outputs can conform to the EBU standard of 13.5, 6.75, 6.75MHz sampling rates for such signals.

The burst-locked oscillator, demodulating multipliers, filters and blanking stages all operate with digital signals at a clock rate of 13.5MHz but perform identical functions to their analogue counterparts.

This decoder gives excellent chrominance-luminance separation and adaptive techniques are not used except that

i. for monochrome inputs a full band luminance signal is produced

ii. if the input is non-mathematical PAL (that is without the normal correlation of the sub-carrier from field to field) then the comb filter may give poor results and simple complementary filtering is then selected.

The decoder is expensive but includes the cost of three A-D converters if used as part of a synchroniser or effects unit.

6.2 Operation of the Field-Delay Comb-filter, see fig. 6.1
The delays are each 312 lines, slightly less than one field. Fig. 6.1 shows the situation when, for example line no. 100 is emerging from the second delay. Line no. 412 will be emerging from the first delay and line no. 724 entering the first. These lines are from three successive fields but they occupy adjacent positions on the picture as shown at H.

Because the delays are an even number of lines, the signals at A, B and C will have the same VAS polarity and, because the lines are closely spaced on the picture they will carry similar picture information providing the scene is stationary. The subcarrier however will be shifted by 180° by each delay because if $f_{sc} = (283\ 3/4 + 1/625) f_h$ then 312 lines represents

$312 \times (283\ 3/4 + 1/625) = 88530.4992$ cycles of sub-carrier - this is virtually n + 1/2 cycles.

COMB FILTER TECHNIQUES IN PAL DECODING

Using the same notation as before ie. that U_0 U_1 U_2 etc. represent undelayed, once delayed and twice delayed signal components the separated chrominance and luminance signals are shown at F and G respectively.

6.3 Performance of the dual 312 line delay decoder

In the chrominance signal at F it can be seen that there is no U/V separation and this requires accurate phasing of the U and V demodulators as in a smple PAL decoder and phase errors will cause "Hanover Bar" effects. On the other hand there is no inherent U/V crosstalk even on horizontal coloured edges in the picture.

Luminance rejection will not be complete unless $Y_0 = Y_1 = Y_2$ and cross colour can occur, for example, at the top and bottom of a vertical grating but this affects only one line per field in such areas whereas with line-based comb filters two consecutive lines are incorrect.

In the separated luminance signal the luminance is averaged over three picture lines. Loss of diagonal resolution is less than in the two line-delay comb arrangement and the chrominance rejection on horizontal colour boundaries, (6) in fig. 1.1.c, only fails for one line per field.

6.4 Movement rendering

The signal is averaged over three successive fields. If the scene contains movement, therefore, there may be dot patterning on moving edges (poor chrominance rejection) or smearing of moving detail (loss of chrominance-band luminance). There may also be cross-colour in moving areas of fine detail due to poor luminance rejection.

If an adaptive system were used it could switch to simple decoding if movement between fields were detected. This is currently thought unnecessary with this type of decoder however.

7. HANDLING OF NON-STANDARD PAL INPUTS

A basic problem with all comb-filters is that their action depends on the delays being exactly related to both the line period and the sub-carrier frequency. With a non-standard input either or both of these may be incorrect. The case where the exact PAL csc/sync frequency relationship is not maintained is known as "non-mathematical PAL" and it is this which causes particular problems in the field-delay decoder.

In the design considered the sampling of the video and clocking of the delay units is with line-frequency-locked pulses. The delays will always be 312 line duration but the sub-carrier relationships between the undelayed and delayed signals might be incorrect. If for example the 25Hz offset in the PAL colour subcarrier frequency were omitted, the comb filter action would fail totally: there would be no chrominance output and no suppression of chrominance on the luminance output.

This would also happen if the field duration varied by as little as half a cycle of sub-carrier and so it is essential to switch to simple decoding in the presence of non-mathematical PAL or excessive timing jitter of sync relative to sub-carrier.

The line-delay based comb filter is less affected by non-standard inputs. The delays are usually analogue and have a fixed time duration so, because the sub-carrier frequency must in practice be within a tight frequency tolerance, the chrominance separation is usually satisfactory. Luminance rejection could be inferior if the sync frequency is significantly incorrect which can occur in non time-base-corrected outputs of video cassette machines.

8. THE BALD DECODER

The simple decoder is something called a bald decoder to distinguish from the other types because, as has waggishly been pointed out, it doesn't use a comb.

9. THE COMPLEMENTARY FILTER DECODER

In this design the pass band of the chrominance filter matches exactly the stop band of the luminance notch filter.

The idea is that high frequency signals may travel via the chrominance path and be decoded (causing cross-colour) but if the signal is subsequently re-encoded they would be re-converted back to the original luminance components. This does not strictly apply however unless the new subcarrier matches the original both in frequency and phase.

Complementary filtering is not a good idea for receiver decoders, it gives no special benefit and adequate chrominance bandwidth would involve excessive loss of luminance detail.

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29th January 1985

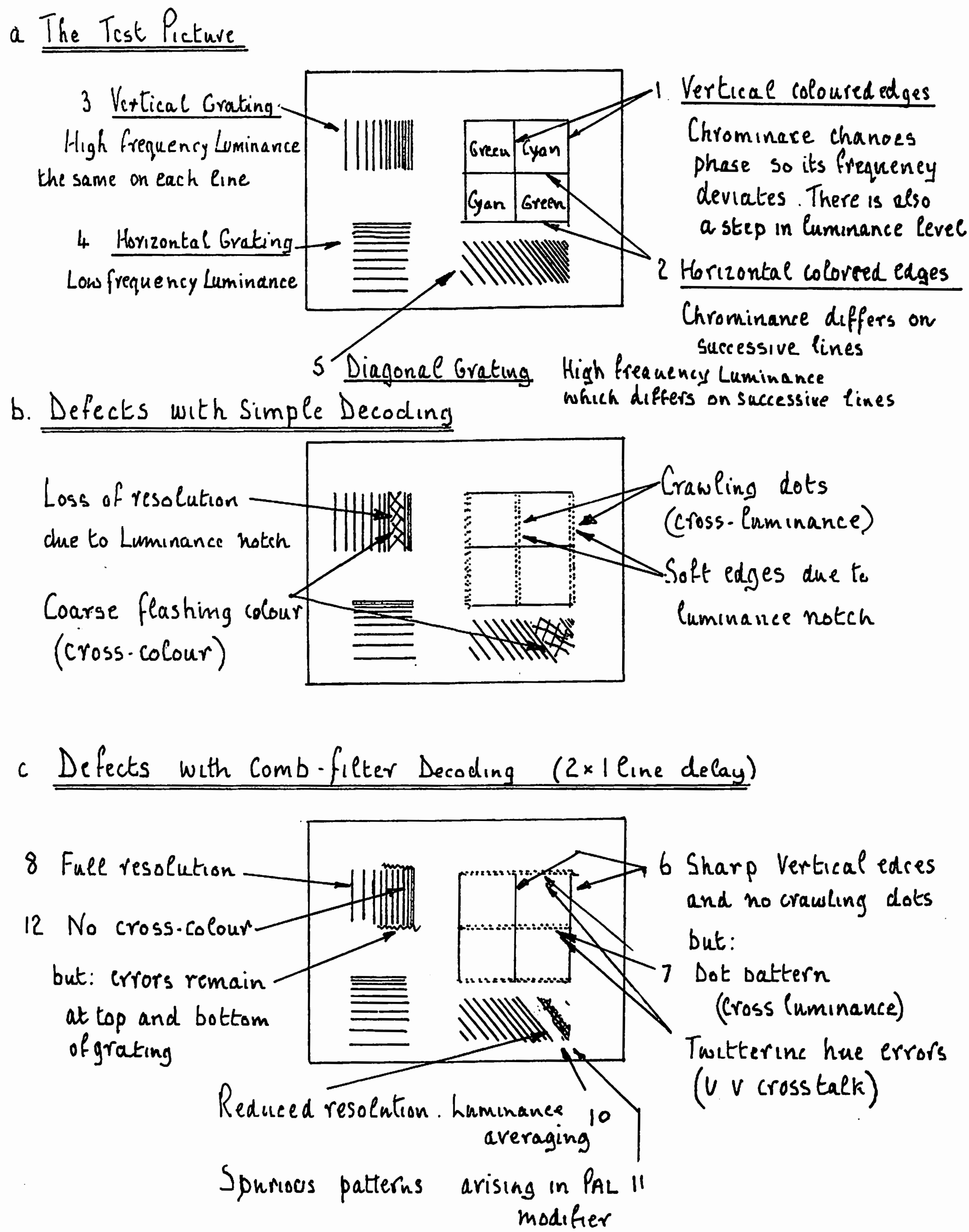


Fig 1.1 De-coding Defects in a PAL picture

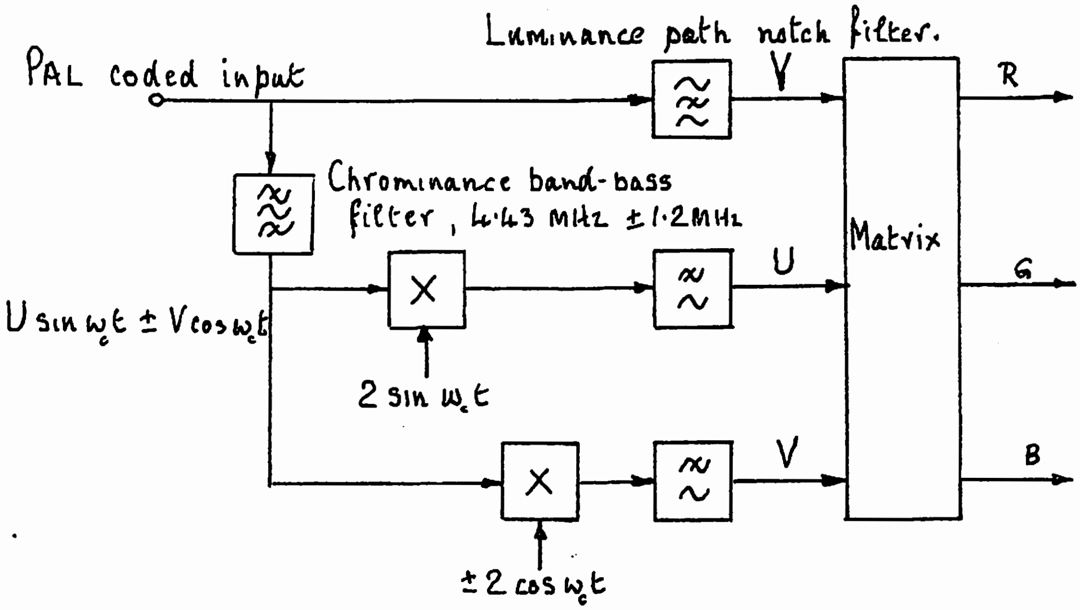


Fig 1.2 Elements of a simple PAL decoder.

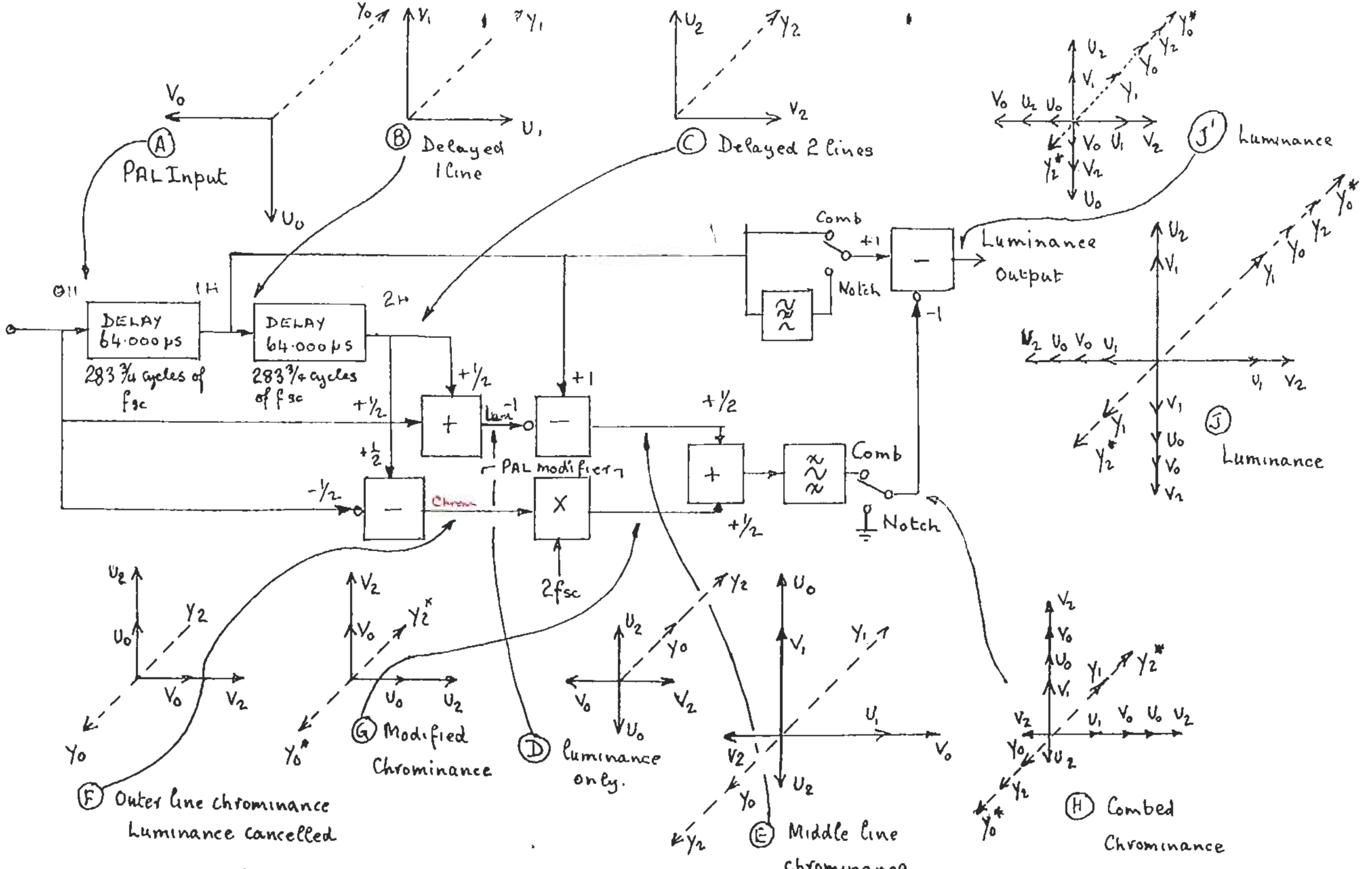
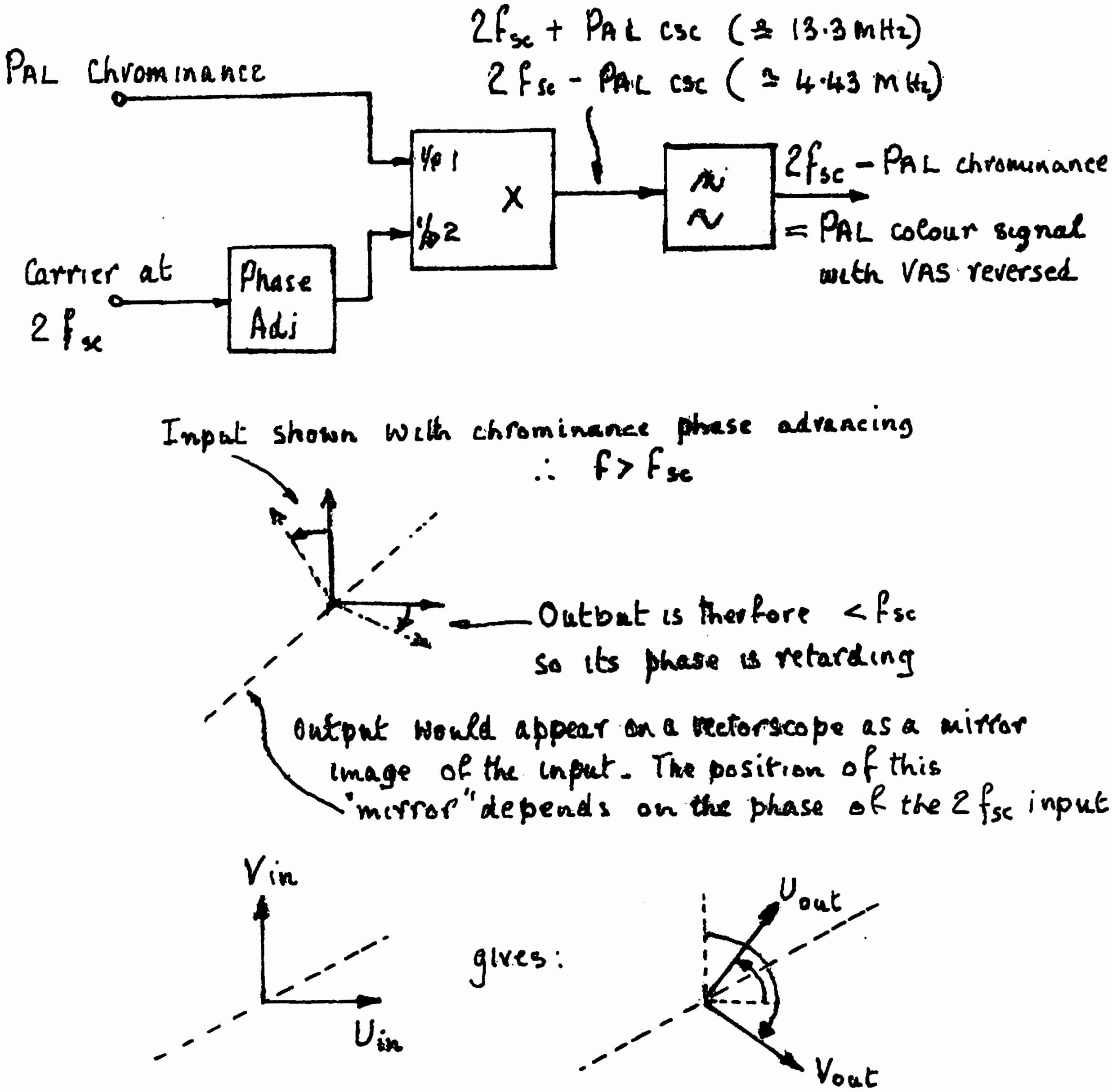


Fig 2.1. Luminance Separation



The phase of the output depends on the phase of the $2f_{sc}$
but note that the sense of the VAS is reversed

Fig 2.2 The PAL Modifier

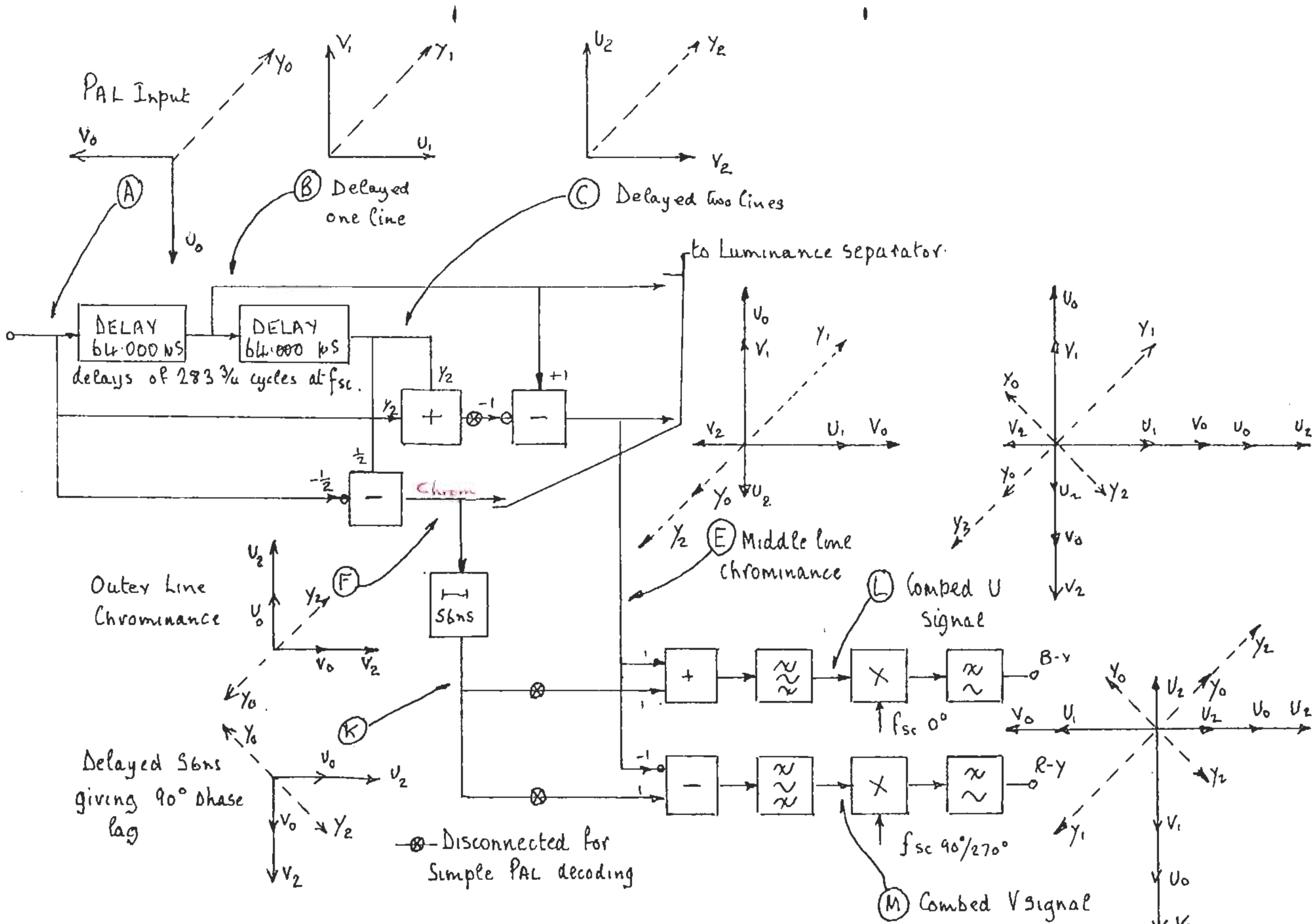


Fig 3.1 Chrominance Decoding 'Line Wise'

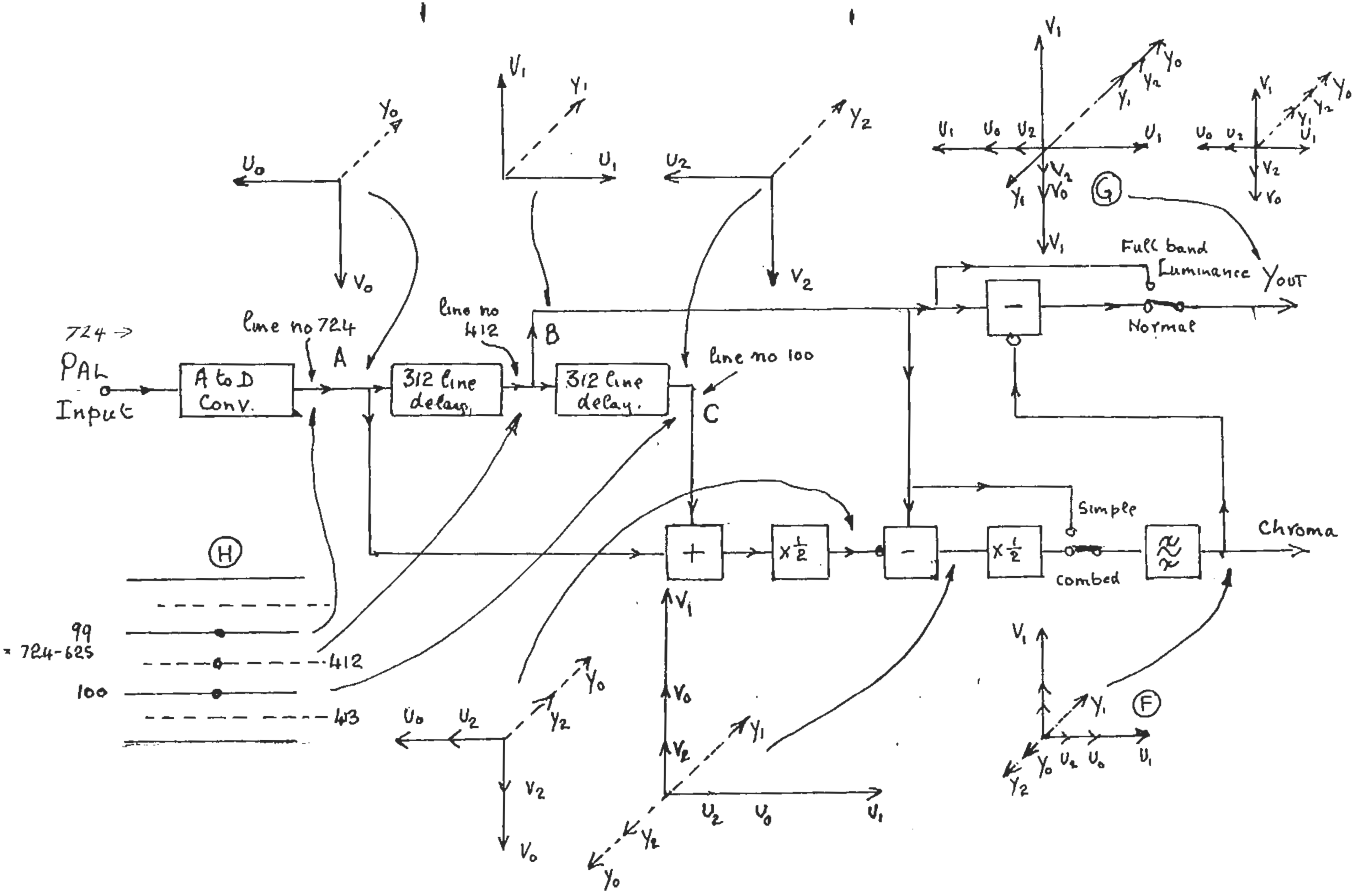


Fig 4.1 COMB FILTER WITH TWO 312 LINE DELAYS

i.e.. Field Wise :

Principees
of 2 line comb!

Consider Three Successive Lines of a PAL signal. as they would be displayed on a monochrome monitor.