DEVELOPMENT OF A CROSSTALK MEASUREMENT TYPE THREE-DIMENSIONAL DIGITAL COLOR DECODER

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Abstract

This paper describes a novel crosstalk measurement type three-dimensional digital Y/C separation model, which will provide the ultimate solution to these problems, and analyzes the characteristics of the separation filters. Further, it realizes the algorithm as hardware and confirms that the picture quality is improved by a rank of 1.5 at a sight distance of 4H over the conventional three-dimensional digital color decoders when various composite color video signals including still images, slowly moving images and moving circular zone plates are input actually.

1. Introduction

Conventional digital color decoders separate and demodulate composite color video signals into component video signals by using two-dimensional Y/C separation circuits or three-dimensional Y/C separation circuits. The former system, however, has some problems such that the resolution is degraded and cross-color, cross-luminance and dot interference can not be removed sufficiently. While, in the latter system where movements are detected in terms of frame differences, if the input is a still image, Y/C separation is completely done through frame comb type filters, but if it is judged as a moving image, Y/C separation is an intra-field two-dimensional operation, and therefore, with an ordinary composite color video signal which involves movements, the same problems as in the former system exist because it retains the aforementioned two-dimensional operation of Y/C separation. However, recently, higher picture quality of television signals has been increasingly demanded and EDTV has been put into practical use, and under these circumstances, cross-color, cross-luminance and dot interference, which are caused by incomplete Y/C separation and determine the picture quality of composite color video signals, have attracted attention as the existing problems to be solved.

2. Three-dimensional Power Spectrum of the Composite Color Video Signal (NTSC)

As shown in Fig. 1, for the composite color video signal of a still image, the Y signal power spectrum is constructed, on the horizontal-vertical spatial frequency axis, as the harmonics synthesis of line spectrums of horizontal and vertical synchronizing frequencies. Moreover, as shown in Fig. 2, the C signal power spectrum is distributed, on the vertical-temporal axis, on flat plains of ±15 Hz, and for the entire spatial-temporal axis, it is characteristic that no Y/C crosstalk appears.

Thus, for the composite color video signal of a still image, Y/C separation can be done completely by using frame comb type or field comb type filters.

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It is seen in Fig. 4 for moving images that unlike in Fig. 2 the power spectrum has a Butterworth spread in the direction of temporal axis so that Y signal and C signal overlap to some extent each other. Therefore, in order to insure sufficient Y/C separation, a proper three-dimensional processing is necessary. It is characteristic that when the composite color video signal involves movements, Y and C spectrums spread enough to cause crosstalk between Y and C signals.

3. Y/C Separation System

3.1 Crosstalk Measuring Filters

In the three-dimensional digital Y/C separation system described in this paper, the crosstalk between Y and C signals mentioned above is noted and the crosstalk between Y and C signals of each pixel is measured by means of field temporal-spatial oblique comb type and intra-field vertical (line) comb type filters, and the field temporal spatial crosstalk is discriminated as to whether it is Y based (potential cross color) or C based (potential cross luminance), and by the resulting control signal, the ratio at which three kinds of Y/C separation filters (1: inter-field temporal-spatial oblique comb type, 2: inter-field vertical (line) comb type, and 3: horizontal band-pass output) are mixed is adaptively controlled. The greatest feature of the new Y/C separation system is the adoption of this method.

The temporal spatial sampling layout of cross talk measuring filters is shown in Fig. 5.

Fig. 5 Layout of sampling points on vertical temporal axis

Fig. 6 shows the pass band characteristics of comb type filters constructed in accordance with the sampling layout mentioned above. By using the field temporal spatial oblique comb type filter and intra-field vertical (line) comb type filter, each Y/C crosstalk is measured. The characteristics of the crosstalk measuring filters in this case are given by

$$\frac{1-e^{2\pi NT}}{2}$$

where T is 263 H for inter-field crosstalk and 1 H for inter-field crosstalk.
The filters in Fig. 6 have null points at carrier points of Y and C, and the crosstalk generating regions construct the pass bands. Thus, the Y/C crosstalk caused by movements in the input composite color signal can be measured accurately. In the circuit of Fig. 7, the output of the field temporal spatial oblique crosstalk measuring filter and the output of the intra-field vertical (line) crosstalk measuring filter, for each pixel, are compared with each other.

\[ F' = \text{Inter-field crosstalk} \]
\[ L = \text{Inter-line crosstalk} \]
\[ T = 263 H \]
\[ T = 1 H \]
\[ F'/L = 263/1 \]

Control system based on:
Small: Inter-field comb type (large weight)
Large: Horizontal band-pass (large weight)

Fig. 7 Block diagram for the measurement of crosstalk measuring filters

However, for an all spatial frequency pattern which involves movements such as a fountain zone plate image, the aforementioned two kinds of crosstalk measuring filters alone are insufficient and result in degraded picture quality as shown in Photo 1.
The degradation in this case is caused because the crosstalk measuring filters are not completely three-dimensionalized, that is, the inter-field temporal-spatial oblique crosstalk filters are not provided with a function to discriminate the measured crosstalk as to whether it is Y based (potential cross color) or C based (potential cross luminance). On the other hand, the horizontal frequency component of the C based crosstalk has been known to be near the subcarrier frequency, and therefore, it is possible to do crosstalk evaluation by placing a horizontal frequency detector in the interference path. This crosstalk evaluation method is very effective to determine which Y/C separation filter is most suited for the contents of the instantaneous spectrum of the composite signal.

3.2 Horizontal Frequency Detection Algorithm

The algorithm of the afore-mentioned new third crosstalk evaluating filter is described below. For the derivation of this algorithm, refer to Appendix.

Now, let \( S(t) \) be a temporal domain sine wave of frequency \( f \) Hz, assume that in order to prevent aliasing of \( S(t) \), sampling is done at \( f_s \) Hz in the range of \( f_{ck} >> 2f \), and let \( S(nT) \) denote the sampled signal as the result, where \( n \) is an integer and \( T=1/f_s \) second.

Let the three consecutive samples of \( S(nT) \) be as follows:

\[
S_1 = A \sin (\omega t + \phi_1) \\
S_2 = A \sin (\omega t + \phi_1 + \phi_s) \\
S_3 = A \sin (\omega t + \phi_1 + 2\phi_s)
\]

where \( A \) is the amplitude of the sine wave, \( \omega = 2\pi f \), \( \phi_1 \) is an arbitrary phase shift with respect to the first sample, and \( \phi_s \) is the phase change of the sine wave for one clock period and

\[
\phi_s = \frac{2\pi f}{f_{ck}}
\]

In order to derive the frequency detection algorithm, assume that \( A, \omega \) and \( \phi \) are unknown. By algebraic rearrangement of Eqs. (1) through (3), we can derive the necessary and sufficient condition for Eq. (4). This condition is given by

\[
S_1 - 2S_2 \cos \phi_s + S_3 = 0
\]

For the derivation of this equation, refer to Appendix.

A practical configuration in accordance with Eq. (5) is the trap FIR filter shown in Fig. 9.

This filter has the following amplitude characteristics.

\[
y = e^{-j2\pi f_{ck}} - 2 \cos \phi_s + e^{j2\pi f_{ck}} \\
= 2(\cos \omega T - \cos \phi_s)
\]

As shown in Fig. 10, the amplitude characteristic crosses the axis of \( Y=0 \) at frequency \( f \) Hz.

The fact that when a non-zero signal is applied to the filter input, no output is provided indicates that the frequency of the input signal is \( f \) Hz.

In this algorithm, the frequency detector operates best as such in the domain of \( f_{ck}/4 \) where \( 2 \cos \omega T \) is steepest (actually, it works effectively in the range of \( 0 < f < f_{ck}/2 \)).

This frequency detection algorithm is used for the third \( f_s \) detection filter of Fig. 7 in this crosstalk measurement type three-dimensional digital color decoder. It is just the novel and most important part in the whole Y/C separation circuits. It makes it possible to discriminate the output of the field temporal-spatial oblique crosstalk measuring filter as to the whether it is Y based (potential cross color) or C based (potential cross luminance), and hence to measure the complete three-dimensional crosstalk on the temporal-spatial and thereby remedy the degraded picture quality in Photo 1.
3.3 Y/C Separation Filter

The Y/C separation three-dimensional filter shares the temporal-spatial sampling point in Fig. 5 with the afore-mentioned cross color measuring filter.

Fig. 11 and Fig. 12 show the configuration of the inter-field temporal-spatial oblique Y/C separation filter and the intra-field vertical (line) comb type filter, respectively.

Fig. 11 NTSC, block diagram of the temporal-spatial oblique comb filter

Fig. 12 NTSC, block diagram of the intra-field vertical comb filter

The two kinds of filters having the above characteristics are combined with the horizontal band-pass filter, and the output signals from the resulting three kinds of Y/C separation filters are adaptively controlled by using the control data generated from the measured crosstalk values described in the preceding paragraph, and then they are synthesized to result in color signal (C). On the other hand, luminance signal (Y) can be obtained by deriving this C signal from the input composite color signal which is in the same timing.

3.4 Block Diagram of the Color Decoder

Fig. 15 shows the block diagram of this three-dimensional digital color decoder with special emphasis placed on Y/C separation circuits.
4. Extension to PAL Video Signals

4.1 Temporal-spatial Power Spectrum of PAL Video Signals

Descriptions so far given refer mainly to the Y/C separation processing of NTSC composite color video signals. They can be extended to PAL Video signals as follows.

It is well known that in the PAL color television system the carrier of color difference signal \( u \) is 180° altered in phase by line in order to reduce color transmission distortion DP. As a result, the carrier of color difference signal \( u \) and the carrier of color difference signal \( v \) are offset by 1/2 line with respect to each other and by 1/4 line with respect to \( Y \) signal. The PAL video signal having the relationship of frequency interleaving described above has the temporal-spatial power spectrum as shown in Fig. 16.

These filters can be constructed to have \( T=312 \) H for inter-field crosstalk and \( T=2H \) for intra-field (inter-line) crosstalk in Fig. 7 which refers to NTSC. On the other hand, Y/C separation filters have characteristics as shown in Fig. 18. These filters can be constructed to be 312 H and 2 H, respectively in Fig. 11 and Fig. 12, which refer to NTSC. Since the filter configuration is the same for NTSC and PAL as described above, the new digital color decoder system can be used in either system merely by touch operation.

5. Color Demodulation Circuit

The color signal after Y/C separation is subsequently demodulated through a color demodulation circuit of Fig. 19 into component \( Y \), \( R-Y \) and \( B-Y \) signals.

Throughout the equipment, the system clock frequency is 13.5 MHz which is completely conforming to CCIR Rec-601, and is generated by line locking with the input video signal.
6. Design Specifications for the Crosstalk Measurement Type Three-Dimensional Digital Color Decoder

Table 1 shows the specifications for this digital color decoder in design stage.

<table>
<thead>
<tr>
<th>Item</th>
<th>Specifications</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling frequency</td>
<td>13.5 MHz</td>
<td>NTSC 858×/₉</td>
</tr>
<tr>
<td>Quantization number</td>
<td>8 bit</td>
<td>PAL 864×/₉</td>
</tr>
<tr>
<td>Subcarrier rejection</td>
<td>&gt;45 dB</td>
<td></td>
</tr>
<tr>
<td>Band frequency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>&gt;5.5 MHz</td>
<td></td>
</tr>
<tr>
<td>B−Y</td>
<td>&gt;1.5 MHz</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>&gt;5.5 MHz</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>&gt;5.5 MHz</td>
<td></td>
</tr>
<tr>
<td>S/N</td>
<td>&gt;55 dB</td>
<td></td>
</tr>
<tr>
<td>DG, DP</td>
<td>&lt;2%, 2'</td>
<td></td>
</tr>
<tr>
<td>K-factor</td>
<td>1%</td>
<td>2 T pulse</td>
</tr>
<tr>
<td>Clock jitter</td>
<td>±1 ns max.</td>
<td></td>
</tr>
<tr>
<td>Video input</td>
<td>1.0 Vpp 75 Ω</td>
<td>NTSC/PAL</td>
</tr>
<tr>
<td>Video output</td>
<td>4:2:2:2</td>
<td>Digital Component</td>
</tr>
<tr>
<td></td>
<td>CCIR REC-656</td>
<td>Analog Component</td>
</tr>
<tr>
<td></td>
<td>Y, B−Y, G−Y</td>
<td>Analog Component</td>
</tr>
<tr>
<td></td>
<td>R, G, B</td>
<td></td>
</tr>
<tr>
<td>Size (W × H × D)</td>
<td>425×88×515 mm</td>
<td></td>
</tr>
</tbody>
</table>

After development, it was confirmed by various tests such as zone plate, sweep, color bar, etc. that the development target shown in this table had been achieved successfully.

7. Picture Quality of the Crosstalk Measurement Type Three-Dimensional Digital Color Decoder

7.1 Still Zone Plate Video Signals

When the NTSC still zone plate video signal is input to this digital color decoder, luminance signal (Y) as shown in Photo 2 is output after Y/C separation.

![Photo 2 Regenerated Y signal of a still zone plate image](image)

As seen in this photo, cross color-free, dot interference-free video signals are obtained from inter-field comb type filters.

7.2 Moving Zone Plate Video Signals

When the NTSC video signal which involves a fountain zone plate image is input to the digital color decoder, Y signal as shown in Photo 2 is output after Y/C separation.

![Photo 3 NTSC, regenerated Y signal of a fountain zone plate image](image)

This photo is free from any flaws caused by maldiscrimination in Photo 1. Even with the input signal of a moving image, Y/C separation is done accurately and ideal characteristics almost free from cross color and other interferences are obtained. Further, the use of inter-field comb type filters prevents generation of any interference such as frame lag. Moreover, in the evaluation with horizontally moving zone plates, moving images of black-white oblique striped patterns, etc., any interference such as cross color was not noticed. With ordinary video signals, the picture quality was improved by a rank of 1.5 at a sight distance of 4 H over the conventional three-dimensional digital color decoders. Photo 4 shows regenerated Y signal after separation of a horizontally moving zone plate image.

![Photo 4 NTSC, regenerated Y signal of a horizontally moving zone plate image](image)

8. Conclusion

For the composite video signal, an ingenious way of frequency interleaving multiplex is applied for effective utilization of frequency. However, it is very difficult to separate Y/C spectrums completely, and in the receivers for demodulated NTSC video signals or PAL video signals, cross color, cross luminance and dot interference occur and cause the picture quality to be degraded. These problems existed to be solved.

The new digital color decoder system presented in this paper offers a reasonable solution to these problems. The authors believe that it has established a form of high picture quality reception and high picture quality decoding. If it is realized in smaller size and lighter weight and is applied to home receivers in the future, it will be possible to enjoy significantly improved picture quality.
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APPENDIX

\[ S_1 = A \sin (\omega t + \phi_1) \]
\[ S_2 = A \sin (\omega t + \phi_1 + \phi_2) \]
\[ S_3 = A \sin (\omega t + \phi_1 + 2\phi_2) \]

\[ S_y = A \sin ((\omega t + \phi_1) \cos \phi_3 + A \cos (\omega t + \phi_1 + \phi_2) \sin \phi_3 \]
\[ = S_2 \cos \phi_3 + \sqrt{A^2 - S_2^2} \sin \phi_3 \]

Similarly,
\[ S_2 = S_1 \cos \phi_3 + \sqrt{A^2 - S_1^2} \sin \phi_3 \]
\[ A^2 = \frac{1}{\sin^2 \phi_3} (S_2 - S_1 \cos \phi_3)^2 + S_1^2 \]
\[ S_3 = S_2 \cos \phi_3 + \sqrt{S_2^2 - S_1^2 (S_2 - S_1 \cos \phi_3)^2} \sin \phi_3 \]
\[ = S_2 \cos \phi_3 + \sqrt{(S_1 - S_2 \cos \phi_3)^2} \sin \phi_3 \]
\[ = S_2 \cos \phi_3 + (S_1 - S_2 \cos \phi_3) \cos \phi_3 \]

Here, if the positive sign is taken, then \( S_y = S_1 \). This is the natural result of the following relation and has no meaning.

\[ \cos \phi_3 = \cos (-\phi_3) \]

Moreover, it corresponds to the fact that the phase change from \( S_2 \) to \( S_3 \) is equal in magnitude but reverse in direction to the phase change from \( S_1 \) to \( S_2 \). That is,
\[ S_3 = A \sin (\omega t + \phi_1 + \phi_3 - \phi_2) = S_1 \]

Here, if the negative sign is taken, then
\[ S_2 - 2S_1 \cos \phi_3 + S_3 = 0 \]

This is the result being sought.

REFERENCES


Shin-etsu Ito was born in Akita Prefecture, Japan, on March 21, 1950. He received the B.S. E.E. degree from the University of Akita, in 1974. In the same year, he joined NHK (Japan Broadcasting Corporation), Japan, and through the Engineering Department of the Production Engineering Bureau, he moved in 1982 to the Program Facilities Department of the Engineering Headquarters where he was engaged in the design and development of digital data transmission apparatus and computer communication systems. In 1984, he turned to the Development Engineering Department of the same Headquarters, and since then, has been engaged in the design and development mainly of digital video signal processing systems, digital magnetic recording systems, satellite digital transmission systems, etc. Mr. Ito is a member of IEEE of U.S.A., SMPTE of U.S.A., IEICE of Japan, and ITEJ of Japan.

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