A luminance notch filter for preventing color crosstalk attenuates a SECAM luminance signal using digital filtering techniques. The luminance notch filter includes a band-pass filter centered at the chrominance band that is operable to receive the input luminance signal and provide a band-pass filtered luminance signal. The band-pass filtered luminance signal is transformed by a non-linear operator and the transformed luminance signal is subtracted from the input luminance signal delayed by a delay element to provide a notch filtered luminance signal.
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NON-LINEAR DIGITAL NOTCH FILTER
FOR SECAM VIDEO ENCODER

BACKGROUND OF THE INVENTION

Color television systems encode "luminance" (brightness) and "chrominance" (hue) information signals in a composite television signal. The luminance signal is equal to a sum of weighted intensity values of the primary hues (red, blue, green). A pair of chrominance signals contain color information consisting of the corresponding differences between the intensities of the red and blue and the luminance signal. In the SECAM ("sequential color and memory") standard, the composite signal containing the luminance and chrominance information is provided in frequency modulated form. The composite SECAM signal comprises a luminance signal in one frequency band and sequentially alternating, frequency modulated chrominance signals in an adjacent, partially overlapping frequency band. The luminance spectrum extends from 0 to 6 MHZ. The chrominance information modulates a subcarrier having a frequency swing that extends from 3.9 to 4.75 MHZ. Interference between the luminance signal and the chrominance signals, a phenomenon known as "color crosstalk", can occur due to the overlapping frequency bands. This color crosstalk can cause receiver error characterized by a scrambled video image at the receiver.

The SECAM standard specifies attenuation of the amplitude of luminance components located in the overlapping part of the luminance spectrum in order to reduce color crosstalk. Such filtering is specified to have a nonlinear response that depends on the amplitude of the luminance signal in the chrominance bandwidth.
Known analog notch filters use a classical passive filter with a set of diodes providing the nonlinear response. Another analog approach uses amplitude thresholding in response to repetitive high luminance signal levels to operate an anti-crosstalk trap circuit.

5 SUMMARY OF THE INVENTION

In modern video equipment, the SECAM encoding is performed directly from the digital video components using integrated DSP techniques, usually in a single chip. In such systems, analog implementations of the notch filter are not favored because the digital video components would need to be converted to analog components, filtered, converted back to digital components, encoded digitally to the SECAM format, and converted again to analog composite video.

The present invention provides a luminance notch filter that uses digital filtering techniques to attenuate the overlapping part of the luminance signal, that is, in the chrominance signal passband. The digital filter of the present approach provides filtering directly on the digital video components prior to being forwarded to a digital SECAM encoder. The present approach also minimizes the amount of digital logic required, in particular the number of multipliers.

Accordingly, a luminance notch filter for use in a television transmission system having a source of luminance signals comprises a digital band-pass filter centered at the chrominance passband that is operable to receive the input luminance signal and provide a band-pass filtered luminance signal. The band-pass filtered luminance signal is transformed by a non-linear operator and the transformed luminance signal is subtracted from the input luminance signal delayed by a delay element to provide a notch filtered luminance signal reduced in the overlapping part of the signal.

According to an aspect of the apparatus, the digital band-pass filter includes first and second legs which are coupled to each other at respective input ends. At least the second leg of the first and second legs has one or more all-pass sections selected such
that the phase of the first leg is approximately \((1+2n)\pi\) more than the phase of the second leg at a passband frequency and approximately \(2n\pi\) at other frequencies. A subtractor coupled to an output end of the first and second legs subtracts a second leg output from a first leg output to provide a passband frequency response. In an embodiment, the first leg includes a pair of cascaded delay elements and the second leg includes a pair of cascaded second-order all-pass sections.

The luminance notch filter of the present invention is particularly useful in systems that convert digital source signals, such as MPEG ("Moving Pictures Expert Group") signals, to SECAM standard signals. Accordingly, a SECAM television signal transmission system includes an MPEG decoder, a luminance notch filter and a SECAM encoder. The MPEG decoder decodes an MPEG video stream to provide a luminance signal and first and second chrominance signals. The luminance notch filter includes a digital band-pass filter centered at the chrominance passband that receives the luminance signal and provides a band-pass filtered luminance signal. A non-linear operator transforms the band-pass filtered luminance signal and a subtractor subtracts the transformed luminance signal from the received luminance signal delayed by a delay element to provide a notch filtered luminance signal. The SECAM encoder receives the notch filtered luminance signal and the chrominance signals to encode a SECAM output signal.
BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

FIG. 1 is a schematic block diagram of a television transmission system in accordance with the present system.

FIG. 2 is a schematic block diagram of an embodiment of a notch filter for use in the system of FIG. 1.

FIG. 3 is a schematic block diagram of a second embodiment of a notch filter for use in the system of FIG. 1.

FIG. 4 is a block diagram of a first-order all-pass structure.

FIG. 5 is a block diagram of a second-order all-pass structure.

FIG. 6 is a block diagram of a second-order band-pass filter for use in the notch filter of FIG. 2.

FIG. 7A illustrates the phase responses of respective legs of the filter of FIG. 6.

FIG. 7B illustrates the frequency response of the filter.

FIG. 8 is a block diagram of a third-order band-pass filter for use in the notch filter of FIG. 2.

FIG. 9A illustrates the phase responses of respective legs of the filter of FIG. 8.

FIG. 9B illustrates the frequency response of the filter.

FIG. 10 is a block diagram of a fourth-order band-pass filter for use in the notch filter of FIG. 2.

FIG. 11A illustrates the phase responses of respective legs of the filter of FIG. 10.

FIG. 11B illustrates the frequency response of the filter.
FIG. 12 is a block diagram of a low-pass filter for use with the notch filter of FIG. 3.

FIG. 13A illustrates the phase responses of respective legs of the filter of FIG. 12. FIG. 13B illustrates the frequency response of the filter.

FIG. 14 is a chart showing frequency response for the notch filter of FIG. 2 using the second-order band-pass filter of FIG. 6.

FIG. 15 is a chart showing frequency response for the notch filter of FIG. 2 using the third-order band-pass filter of FIG. 8.

FIG. 16 is a chart showing frequency response for the notch filter of FIG. 2 using the fourth-order band-pass filter of FIG. 10.

FIG. 17 is a block diagram of an embodiment of a fourth-order notch filter using the present filter design approach.

DETAILED DESCRIPTION OF THE INVENTION

An exemplary color television transmission system 10 in accordance with the present invention is now described with reference to FIG. 1. The system 10 converts MPEG source signals to SECAM standard signals and includes an MPEG decoder 14, a notch filter 22, a delay element 23 and a SECAM encoder 26. The MPEG decoder 14 receives a stream of MPEG video packets on input line 12 and decodes the stream to a digital luminance signal Yi and two digital chrominance signals Cr and Cb on lines 16, 18 and 20 respectively. The luminance signal Yi is processed through the notch filter 22 to provide a filtered luminance signal Yo on line 24. The notch filter 22 attenuates the luminance signal Yo over the chrominance subcarrier frequency band (3.9 to 4.75 MHZ) so as to reduce color crosstalk. Since the filtering induces some delay on the luminance signal, the chrominance signals are delayed through delay element 23 to enable realignment with the filtered luminance. The filtered luminance signal Yo and the delayed chrominance signals Cr, Cb are supplied to the SECAM encoder 26 which encodes the digital video signals into an analog SECAM video output signal on line 28.
The SECAM encoder 26 can be implemented using a Philips Semiconductor model number SAA7182A digital video encoder device, for example.

It should be noted that a digital SECAM notch filter which provides adaptive attenuation based on detected luminance strength is disclosed in U.S. Patent Application No. 09/176,704, filed October 21, 1998 and assigned to the assignee of the present application.

The digital notch filter of the present invention provides attenuation of the luminance signal using an approach that minimizes the amount of digital logic required, in particular the number of multipliers. An embodiment of the notch filter 22 is shown in the schematic block diagram of FIG. 2. The filter 22 includes band-pass filter 30, non-linear operator 50, delay element 51 and subtractor 52. The filter 22 receives the digital luminance signal Yi in channels 29 and 31. A band-pass filter 30 in channel 29 has a passband \( f_0 \) centered around 4.286 MHz for passing only luminance signal components Yi' that can cause color crosstalk with components in the overlapping chrominance subcarrier frequency band. Note that the passband \( f_0 \) is also the notch frequency of interest for the notch filter. A non-linear operator 50 coupled in series with the band-pass filter 30 transforms the band-pass filtered luminance signal Yi' according to the function

\[
\begin{align*}
\text{if } x < -0.1122 & \quad f(x) = x + 0.1122 \\
\text{if } -0.1122 < x < 0.1122 & \quad f(x) = 0 \\
\text{if } x > 0.1122 & \quad f(x) = x - 0.1122
\end{align*}
\]

The purpose of the non-linear operator is to shape the spectrum of the luminance signal. The function \( f(x) \) is applied to the signal samples \( x(t) \) in the time domain and the shaping of the signal is automatically translated in the frequency domain.

A subtractor 52 subtracts the band-pass filtered luminance signal Yi' transformed by non-linear operator 50 in channel 29 from the input luminance signal Yi in channel
31 delayed by delay element 51 (delay amount = M*delay) to provide a notch filtered luminance output signal 24 having a notch filter characteristic at the passband f₀.

A problem with such a digital filter is the amount of harmonics created by the non-linear operator 50. In an analog design, these harmonics can be easily suppressed by inserting a low-pass filter after the non-linear operator. In the digital domain, the harmonics are aliased in the useful bandwidth, and it is impossible to separate them from the original signal. If the harmonics have too much visual effect on the signal, an alternate embodiment that is more complex may be required.

In this alternate embodiment, shown in FIG. 3, the sampling rate is raised by up-sampler 33 prior to the band-pass filter 30 and the non-linear operator 50. In addition, the output of the non-linear operator 50 is filtered by a low-pass filter 35 before being returned to the original sampling rate by down-sampler 37. This alternate embodiment requires a significantly faster logic and more hardware resources than the preferred embodiment shown in FIG. 2.

Polyphase all-pass filters are used in the present approach in order to minimize the amount of hardware resources required in the digital SECAM notch filter. It is known that polyphase all-pass filters provide excellent characteristics with only a limited number of multipliers. A polyphase all-pass filter is obtained by assembling different sets of all-pass structures and combining the phase response of two or more of such sets. Various frequency responses can be obtained, including the band-pass filter 30 and low-pass filter 35 noted above with respect to FIGs. 2 and 3.

The building blocks of polyphase all-pass filters are delays and well-known all-pass recursive filters having transfer function of the form:

\[ \sum_{n=0}^{N} A_n z^{-n} \]

\[ \sum_{n=0}^{N} A_{N-n} z^{-n} \]
A first-order all-pass structure 100 is shown in FIG. 4. The structure 100 includes a pair of delay elements 102, a pair of adders 104 and a multiplier 106 with coefficient A. A second-order all-pass structure 110 is shown in FIG. 5. The second-order structure includes four delay elements 102, four adders 104 and two multipliers 106 with respective coefficients A and B. The band-pass filter 30 and the low-pass filter 35 noted above in FIGs. 2 and 3 can be made using the all-pass structures shown in FIGs. 4 and 5. The all-pass structures are characterized in the following table:
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>$\phi(0) = 0$</th>
<th>$\phi(\pi) = -\pi$</th>
<th>$\phi(\pi/2) = -\pi$</th>
<th>$\phi(\pi) = -2\pi$</th>
<th>$\phi'(0) = 0$</th>
<th>$\phi'(\pi) = -\pi$</th>
<th>$\phi'(\pi/2) = -\pi$</th>
<th>$\phi'(\pi) = -2\pi$</th>
</tr>
</thead>
</table>

| Phase response | $\phi = e^{-j\omega}$ | $\phi = e^{-j\omega}$ | $\phi = \tan^{-1}\left(\frac{A}{B}\right)$ | $\phi = \tan^{-1}\left(\frac{A}{B}\right)$ | $\phi = \tan^{-1}\left(\frac{A}{B}\right)$ | $\phi = \tan^{-1}\left(\frac{A}{B}\right)$ |

| Structure | $z^{-1}$ | $z^{-2}$ | $\frac{z^{-1} + A}{Az^{-1} + 1}$ | $\frac{z^{-2} + A^2}{Az^{-2} + A^2 + 1}$ | $\frac{z^{-1} + A}{Az^{-1} + 1}$ | $\frac{z^{-2} + A^2}{Az^{-2} + A^2 + 1}$ |

| $z^{-1} + A$ | $Az^{-1} + 1$ | $z^{-2} + A^2 + B$ | $Bz^{-2} + A^2 + 1$ | $A^2 + B$ | $A^2 + B$ |

| $A = \frac{1}{2} + a$ | $B = \frac{1}{2} + a^2$ | $\frac{1}{2} + a^2$ |

| $A^2 + B$ | $A^2 + B$ |

| $z^{-2} + A^2 + B$ | $Bz^{-2} + A^2 + 1$ | $A^2 + B$ | $A^2 + B$ |

| $A^2 + B$ | $A^2 + B$ | $A^2 + B$ | $A^2 + B$ |

| $\theta = \frac{1}{2}$ | $\theta = \frac{1}{2}$ |

| $\omega = \tan^{-1}\left(\frac{A}{B}\right)$ | $\omega = \tan^{-1}\left(\frac{A}{B}\right)$ |

| $\omega = \tan^{-1}\left(\frac{A}{B}\right)$ | $\omega = \tan^{-1}\left(\frac{A}{B}\right)$ |

| $\omega = \tan^{-1}\left(\frac{A}{B}\right)$ | $\omega = \tan^{-1}\left(\frac{A}{B}\right)$ |

| $\omega = \tan^{-1}\left(\frac{A}{B}\right)$ | $\omega = \tan^{-1}\left(\frac{A}{B}\right)$ |

| $\omega = \tan^{-1}\left(\frac{A}{B}\right)$ | $\omega = \tan^{-1}\left(\frac{A}{B}\right)$ |

| $\omega = \tan^{-1}\left(\frac{A}{B}\right)$ | $\omega = \tan^{-1}\left(\frac{A}{B}\right)$ |
To obtain the band-pass filter 30 (FIGs. 2 and 3), different all-pass structures are configured in two sets such that the combined phase of the first set is approximately 
\((1+2n)\pi\) more than the combined phase of the second set at the desired passband frequency \(f_0\) and approximately \(2n\pi\) at all other frequencies. By subtracting the output of the second set from the output of the first set and dividing by 2, the desired frequency response is obtained. The greater the number of all-pass structures contained in each set, the more zeroes can be obtained in the frequency response, thereby getting closer to the required filter specification, e.g., the SECAM notch filter specification.

A simple embodiment of the band-pass filter 30 (FIG. 2) is shown in FIG. 6. In this embodiment, the filter 30A is a second-order filter that includes a straight connection in a first leg 130 and a second-order all-pass structure 110 in a second leg 132. The output of the second leg is subtracted from the output of the first leg at adder 204 and multiplied by multiplier 206. The phase response of the all-pass structure 110 in the second leg 132 is shown in FIG. 7A. The frequency response of the filter 30A is shown in FIG. 7B and given by:

\[
|F(\omega)|^2 = \frac{1 - \cos(\phi(\omega))}{2}
\]

The phase response of the filter 30A is given by:

\[
\angle F(\omega) = \tan^{-1}\left(\frac{-\sin(\phi(\omega))}{1 - \cos(\phi(\omega))}\right)
\]

It should be noted that the only zeroes in the frequency response are at \(\omega=0\) and \(\omega=\pi\).

Referring now to FIG. 8, an embodiment of a third-order band-pass filter is shown. The filter 30B includes a single delay element 202 in first leg 130 and a first-order all-pass structure 100 having phase response \(\phi\), cascaded with a second-order all-
pass structure 110 having phase response $\phi_2$ in second leg 132. The phase responses of the first and second legs are shown in FIG. 9A at lines 220 and 222, respectively. The frequency response of the filter 30B is shown in FIG. 9B and given by:

$$|F(\omega)|^2 = \frac{1 - \cos(\omega + \phi_1(\omega) + \phi_2(\omega))}{2}$$

The phase response of the filter 30B is given by:

$$\angle F(\omega) = \tan^{-1}\left(\frac{-\sin(\omega) - \sin(\phi_1(\omega) + \phi_2(\omega))}{\cos(\phi_1(\omega)) - \cos(\phi_1(\omega) + \phi_2(\omega))}\right)$$

It should be noted that the third-order filter 30B includes three zeroes. In an alternate embodiment of the filter 30B, the first-order all-pass structure 100 with phase response $\phi_1$ is put in the first leg 130 and the delay element 202 is put in the second leg 132. This alternate embodiment has the following characteristics:

$$|F(\omega)|^2 = \frac{1 - \cos(\phi_1(\omega) - \phi_2(\omega) + \omega)}{2}$$

$$\angle F(\omega) = \tan^{-1}\left(\frac{\sin(\phi_1(\omega)) - \sin(\phi_2(\omega) - \omega)}{\cos(\phi_1(\omega)) - \cos(\phi_2(\omega) - \omega)}\right)$$

Referring now to FIG. 10, an embodiment of a fourth-order band-pass filter is shown. The filter 30C includes two delay elements 202 in first leg 130 and two cascaded second-order all-pass structures 110 having respective phase responses $\phi_1$, $\phi_2$.
in second leg 132. The phase responses of the first and second legs are shown in FIG. 11A at lines 224, 226 and 228, respectively. The frequency response of the filter 30C is shown in FIG. 11B and given by:

$$|F(\omega)|^2 = \frac{1 - \cos(2\omega + \phi_1(\omega) + \phi_2(\omega))}{2}$$

The phase response of the filter 30C is given by:

$$\angle F(\omega) = \tan^{-1}\left(\frac{-\sin(2\omega) - \sin(\phi_1(\omega) + \phi_2(\omega))}{\cos(2\omega) - \cos(\phi_1(\omega) + \phi_2(\omega))}\right)$$

It should be noted that the fourth-order filter 30C includes four zeroes. In an alternate embodiment of the filter 30C, the second-order all-pass structure 110 with phase response $\phi_1$ is put in the first leg 130 and the two delay elements 202 are put in the second leg 132. This alternate embodiment has the following characteristics:

$$|F(\omega)|^2 = \frac{1 - \cos(\phi_1(\omega) - \phi_2(\omega) + 2\omega)}{2}$$

$$\angle F(\omega) = \tan^{-1}\left(\frac{\sin(\phi_1(\omega)) - \sin(\phi_2(\omega) - 2\omega)}{\cos(\phi_1(\omega)) - \cos(\phi_2(\omega) - 2\omega)}\right)$$

Following the above design approach, additional zeroes can be added. The cost of each additional zero is a multiplier.

A low-pass filter also can be obtained using the approach of combining the phase responses of two sets of all-pass structures. In particular, the all-pass structures are arranged such that the phase of the first leg of the filter is more or less equal to the
phase of the second leg in the passband, and $\pi$ more than the phase of the second leg in the stop band. Referring now to FIG. 12, an embodiment of a low-pass filter 35 is shown. The filter 35 includes a second-order all-pass structure 110 having phase response $\phi_1$ in first leg 230 and a single delay element 202 cascaded with a second-order all-pass structures 110 having phase response $\phi_1$ in second leg 132. The phase responses of the first and second legs are shown in FIG. 12A at lines 230 and 232, respectively. The frequency response of the filter 35 is shown in FIG. 13B. Note that if the cutoff frequency $\omega_0$ of the filter is exactly $\pi/2$, the coefficient $A$ of the second-order all-pass structure is always zero, which simplifies the implementation of these filters even further.

Having described the building blocks for the SECAM digital notch filter, an approach is now described for determining the value of the various parameters that lead to an overall response for closely matching the SECAM specification. The following description is directed to the filter embodiment shown in FIG. 2 and assumes the effects of harmonics caused by the non-linearity are negligible. The following parameters need to be determined:

- the number of zeroes in the frequency response of the band-pass filter 30
- the optimum values of the coefficients for the all-pass structures of band-pass filter 30
- the number of sampling intervals by which the original signal must be delayed before removing the undesired frequency components

It is difficult to specify the various elements of the filter architecture independently. For example, the shape of the notch is distorted by the phase non-linearity of the band-pass filter 30 when the output of this filter is subtracted from the original signal $Y_i$ at subtractor 52. The amount of distortion depends on the amount of delay on the original signal $Y_i$, and this delay is also dependent on the design of the band-pass filter 30. Therefore, a design algorithm is provided which can take all these parameters into account.
The design algorithm looks for a set of coefficients or parameters that provides a frequency response matching most closely the SECAM specification at certain given points on the frequency axis. There are some constraints that link the coefficients or parameters together, limiting the range of possibilities of the search. These constraints include:

(a) The all-pass structures must be unconditionally stable. This means that the coefficient $A$ in the first-order structures and the parameters $a$ and $t$ in the second-order structures must remain in the range $[-1,1]$.

(b) The frequency response of the band-pass filter 30 must be exactly 1 at the notch frequency 4.286 MHZ. In other words, the phase of the first leg of the filter 30 must be exactly $\pi$ more than the phase of the second leg at that frequency.

(c) The phase response of the band-pass filter 30 at the notch frequency 4.286 MHZ must be equal to the phase response of the delay element 51 on channel 31 associated with the original signal. This is to ensure maximum attenuation at the notch frequency (on the order of -19 dB) when the output of the band-pass filter 30 is subtracted from the delayed original signal at subtractor 52.

A particular design algorithm is as follows:

(1) Select the number $N$ of desired zeroes for the frequency response of the band-pass filter.

(2) Select and arrange the all-pass structures to configure the band-pass filter according the embodiments described above with respect to FIGS. 6, 8 and 10. The filter should have $N$ parameters.

(3) According to the theoretical phase response of this filter, find the number of delays $M$ to be inserted in the path of the original signal in order to fulfill constraint (c).
Select N-1 parameters and scan their values over the range specified by constraint (a).

For each set of parameters, find the remaining Nth parameter that fulfills constraint (b).

For each complete set of N parameters, evaluate the frequency response of the overall design, including the non-linearity, at the corner frequencies 3 MHZ, 3.4 MHZ, 5.4 MHZ and 6 MHZ.

Among all the sets of parameters being tried, find the one that minimizes the difference of the filter response at the corner frequencies with the values -0.2 dB, -3 dB, -3 dB and -1 dB, respectively, which correspond to the SECAM specification.

The algorithm is first tried for N = 2. The band-pass filter is according to the second-order filter 30A in FIG. 6. According to step (3) above:

$$\angle F(\omega_0) = \tan^{-1}\left(\frac{-\sin(\phi(\omega_0))}{1 - \cos(\phi(\omega_0))}\right) = -M\omega_0$$

and since \(\phi(\omega_0) = -\pi\), it is clear that the logical solution for the foregoing is \(M = 0\). Step (4) gives the solution \(A = 0.5732\), \(B = 0.3947\) and the overall frequency response of the corresponding notch filter is shown in FIG. 14. The corner frequency values -0.2 dB, -3 dB, -3 dB and -1 dB are indicated at 302, 304, 306 and 308, respectively. Note that the roll-off before 3 MHZ is quite severe and the response is over 1.5 dB off from the specification at some corner frequencies.

Next the algorithm is tried with N = 3 with the third-order band-pass filter 30B shown in FIG. 8. The phase equalization condition of step (3) becomes:

$$\angle F(\omega_0) = \tan^{-1}\left(\frac{-\sin(\omega_0) - \sin(\phi_1(\omega_0) + \phi_2(\omega_0))}{\cos(\phi(\omega)) - \cos(\phi_1(\omega_0) + \phi_2(\omega_0))}\right) = -M\omega_0$$
and since $\phi_1(\omega_0) + \phi_2(\omega_0) = -\omega_0 - \pi$, then the expression simplifies to:

$$\angle F(\omega_0) = \tan^{-1}\left(\frac{-2\sin\omega_0}{2\cos\omega_0}\right) = -M\omega_0$$

which is easily solved with $M = 1$. Step (4) gives the solution $A = 0.518$ for the first-order all-pass structure and $A = 0.247$, $B = 0.4$ for the second-order all-pass structure.

The overall frequency response for the corresponding notch filter is shown in FIG. 15. Note that the response is within 0.6 dB of the SECAM specification at the selected corner frequencies. Note that the alternate embodiment of the third-order band-pass filter having the delay element in the second leg which was described above cannot be used in this case because it is not possible to equalize the phase of the filter with the phase of a delay as required by step (3).

The algorithm is next tried with $N = 4$ with the fourth-order band-pass filter 30C shown in FIG. 10. Phase equalization in step (3) leads to $M = 2$ and the parameters optimized by the algorithm in step (4) are $A = 0.863$, $B = 0.275$ for the first second-order all-pass structure and $A = -0.0204$, $B = 0.458$ for the second second-order all-pass structure. The frequency response for the corresponding notch filter is given in FIG. 16. Note that the response is within 0.27 dB of the SECAM specification at the selected corner frequencies. This fourth-order band-pass filter offers excellent performance at a reasonable cost.

FIG. 17 shows an 8-bit fixed point embodiment of a fourth-order notch filter 22A as designed using the preceding algorithm for $N = 4$. Note that for this filter 22A the parameters are given as $A = 35/128$, $B = 55/64$ and $A = -3/128$, $B = 59/128$ for the respective second-order all-pass structures. An additional benefit of the polyphase all-pass approach is that there is no accumulation in any of the delay elements. That is, each delay element always carries a delayed or a phase-shifted version of the input
signal. Therefore, the delay elements need only be sized to the dimension of the input signal, e.g., 8 bits.

While this invention has been particularly shown and described with references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.
CLAIMS

What is claimed is:

1. A luminance notch filter for use in a television transmission system having a
   source of a luminance signal, the filter comprising:
      a first channel and a second channel, each channel receiving the
      luminance signal;
      a delay element in the first channel for delaying the luminance signal to
      provide a delayed luminance signal;
      a digital band-pass filter in the second channel operable to receive the
      luminance signal and to provide a band-pass filtered luminance signal;
      a non-linear operator for transforming the band-pass filtered luminance
      signal according to a non-linear function to provide a transformed luminance
      signal; and
      a subtractor for subtracting the transformed luminance signal in the
      second channel from the delayed luminance signal in the first channel to provide
      a notch filtered luminance signal.

2. The luminance notch filter of Claim 1 wherein the digital band-pass filter
   comprises:
      first and second legs coupled to each other at respective input ends;
      at least the second leg of the first and second legs having at least one all-
      pass section, the at least one all-pass section selected such that the phase of the
      first leg is approximately \((1+2n)\pi\) more than the phase of the second leg at a
      passband frequency and approximately \(2n\pi\) at other frequencies;
a subtractor coupled to an output end of the first and second legs for subtracting a second leg output from a first leg output to provide a passband frequency response.

3. The luminance notch filter of Claim 2 wherein the second leg includes an all-pass section comprising a second-order all-pass section.

4. The luminance notch filter of Claim 2 wherein the first leg includes a delay element and the second leg includes a first-order all-pass section cascaded with a second-order all-pass section.

5. The luminance notch filter of Claim 2 wherein the first leg includes a pair of cascaded delay elements and the second leg includes a pair of cascaded second-order all-pass sections.

6. The luminance notch filter of Claim 2 further comprising:
   an up-sampler coupled to the input of the digital band-pass filter for oversampling the luminance signal to provide an oversampled luminance signal to the digital band-pass filter;
   a digital low-pass filter coupled to the output of the non-linear operator for low-pass filtering the transformed luminance signal in the second channel; and
   a down-sampler coupled between the output of the digital low-pass filter and the subtractor for downsampling the filtered luminance signal.
7. The luminance notch filter of Claim 6 wherein the digital low-pass filter comprises:
first and second legs coupled to each other at respective input ends;
the first leg having a second-order all-pass section and the second leg
having a delay element cascaded with a second-order all-pass section, the all-
pass sections selected such that the phase of the first leg is approximately equal
to the phase of the second leg in a pass band and approximately $\pi$ more than the
phase of the second leg in a stop band;
a subtractor coupled to an output end of the first and second legs for
subtracting a second leg output from a first leg output to provide a low-pass
frequency response.

8. The luminance notch filter of Claim 1 wherein the digital band-pass filter comprises:
first and second legs coupled to each other at respective input ends;
the first and second legs each having any combination of all-pass
sections and delay elements selected such that the phase of the first leg is
approximately $(1+2n)^{\pi}$ more than the phase of the second leg at a passband
frequency and approximately $2n\pi$ at other frequencies;
a subtractor coupled to an output end of the first and second legs for
subtracting a second leg output from a first leg output to provide a passband
frequency response.

9. A SECAM television signal transmission system comprising:
an MPEG decoder for decoding an MPEG video stream to provide a
luminance signal and first and second chrominance signals;
a luminance notch filter comprising a digital band-pass filter operable to
receive the luminance signal and to provide a band-pass filtered luminance
signal; a non-linear operator for transforming the band-pass filtered luminance signal according to a non-linear function to provide a transformed luminance signal; a subtractor for subtracting the transformed luminance signal from the luminance signal to provide a notch filtered luminance signal; and 

a SECAM encoder for receiving the notch filtered luminance signal and the first and second chrominance signals and for encoding a SECAM output signal.

10. The SECAM television signal transmission system of Claim 9 wherein the digital band-pass filter comprises:

first and second legs coupled to each other at respective input ends;

at least the second leg of the first and second legs having at least one all-pass section, the at least one all-pass section selected such that the phase of the first leg is approximately $(1+2n)\pi$ more than the phase of the second leg at a passband frequency and approximately $2n\pi$ at other frequencies;

15 a subtractor coupled to an output end of the first and second legs for subtracting a second leg output from a first leg output to provide a passband frequency response.

11. The SECAM television signal transmission system of Claim 10 wherein the first leg includes a pair of cascaded delay elements and the second leg includes a pair of cascaded second-order all-pass sections.

12. A method for filtering a luminance signal, the method comprising:

digitally band-pass filtering the luminance signal to provide a band-pass filtered luminance signal having signal components in a preselected frequency spectrum;
transforming the band-pass filtered luminance signal according to a non-linear function to provide a transformed luminance signal;
subtracting the transformed luminance signal from the luminance signal to provide a notch filtered luminance signal.

13. The method of Claim 12 wherein band-pass filtering comprises:
coupling the luminance signal to first and second filter legs wherein at least the second leg of the first and second legs has at least one all-pass section, the at least one all-pass section selected such that the phase of the first leg is approximately \((1+2n)\pi\) more than the phase of the second leg at a passband frequency and approximately \(2n\pi\) at other frequencies;
subtracting a second leg output from a first leg output to provide a passband frequency response.

14. A luminance notch filter for use in a television system, the filter comprising:
means for digitally band-pass filtering the luminance signal to provide a band-pass filtered luminance signal having signal components in a preselected frequency spectrum;
means for transforming the band-pass filtered luminance signal according to a non-linear function to provide a transformed luminance signal;
means for subtracting the transformed luminance signal from the luminance signal to provide a notch filtered luminance signal.

15. The luminance notch filter of Claim 14 wherein the means for band-pass filtering comprises a polyphase all-pass filter.

16. A method for designing a digital notch filter having a digital band-pass filter in a second channel centered at a notch frequency that is operable to receive a source
signal and provide a band-pass filtered source signal which is subtracted from a delayed source signal in a first channel to provide a notch filtered source signal, the method comprising:

selecting a desired number of zeroes $N$ for the frequency response of the band-pass filter;

selecting and arranging all-pass sections in first and second legs of the band-pass filter such that the band-pass filter has $N$ all-pass parameters;

determining a number of delay elements $M$ to insert in the first channel such that the phase response of the band-pass filter at the notch frequency is equal to the phase response of the delay elements $M$;

selecting $N-1$ of the $N$ parameters and scanning parameter values over a fixed range to determine the remaining $N^{th}$ parameter such that the phase of the first leg of the band-pass filter is approximately $(1+2n)\pi$ more than the phase of the second leg at the notch frequency and approximately $2n\pi$ at other frequencies.

17. The method of Claim 16 further comprising for each set of $N$ parameters evaluating the frequency response of the notch filter at one or more corner frequencies.

18. The method of Claim 17 wherein evaluating the frequency response is relative to a SECAM notch filter specification.
A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H04N9/64 H04N9/78

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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