Luminance-Chrominance Gain Equalizer
based on Bernstein Polynomials

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Abstract: - This paper presents a linear luminance-chrominance gain equalizer for compensating the linear chrominance gain distortion in color TV transmission system. The proposed equalizer was implemented based on Bernstein polynomials. As it is known, the Bernstein type filter has flexible parameters to adjust the circuit performance for the best results. In addition, the modulated 20T sine-squared pulse test signal is generated for testing the proposed equalizer, which can be measured all three types of the linear distortion. As the results, the proposed equalizer is also proved to be efficient in equalizing both the low gain and the high gain chrominance distortions without degraded its phase characteristics.

Key-Words: - Bernstein Polynomials, Chrominance Signal, Luminance Signal, Modulated 20T Sine-squared Pulse, Video Equalizer, Video Test Signal.

1 Introduction

In color TV transmission system, a composite video signal is used to modulate the RF signal distributed as normal broadcast TV. This composite video signal is generally composed of the luminance signal and chrominance signal. It has the limit of frequency spectrum occupy both the low frequency and the high frequency bands. It will certainly have more problems at high frequency bands. In other words, the level and time are unequal between the luminance signal and chrominance signal after it passed through a system. Consequently, the appearance of picture will be affected with incorrect color saturation and hue. For this reason, the color TV transmission system has to solve the problem in order to transmit the TV signal to the home receivers without degradation of picture quality. This mentioned problem is the linear chrominance distortions which compose of three types; the chrominance gain distortion, the chrominance delay distortion, and the chrominance gain & delay distortions [1-2]. In addition, the linear chrominance distortions can be revealed by a special of the modulated 20T sine-squared pulse test signal which affects the baseline of pulse [1], [3]. This pulse has several advantages. For example, it is easy to generate and it can measure all three types of the linear chrominance distortions. In practice, this pulse is placed in the vertical blanking interval on line 17 for testing the TV signals [4-5].

Many authors have proposed different design methods to implement the analog filter which was applied to analog equalizer, including a Transconductor-capacitor [6-8], CMOS gate driving a distributed RLC line [9], MO-OTA [10], and Double-layer RC distributed [11]. The approximation of the linear phase analog filters becomes an important problem which must be solved for video applications. In [6], a Transconductor-capacitor topology was connected by the all-pass biquads in cascade to solve the problem. In [9] solved the problem by a CMOS gate driving a distributed RLC line. Then, the optimization algorithms based on CMOS multiple-output OTA was used [10].

The first approach of the video equalizer has been proposed in [12]. The designing method was implemented by active uniformly distributed RC (URC) filter [13-14]. The results showed that the transition band was narrower than [11]. Then, an active distributed MOSFET transistor has been presented in [15]. It obtained the smaller circuit than [13-14]. However, the problem still occurred that it was the non-maximally flat group delay which caused the delay error. Therefore, the non-minimum phase and Generalize Bessel Polynomial (G.B.P) have been used for the transfer function design. Moreover, the phase compensating circuit for flat group delay adjustment must be increased by the video gain equalizer. Thus, the video gain equalizer is much more complicated. Unfortunately, the
solution of the group delay error is still not complete and large circuit. For this season, the paper proposes the design of the gain equalizer which can correct the linear chrominance gain inequality without the effect of the delay error.

This paper focuses on the design of a linear luminance-chrominance gain equalizer based on Bernstein polynomials. An implementation with Bernstein filter is shown that the gain equalizer transfer function can be obtained with appropriated parameters. The proposed equalizer can correct both the high gain and low gain chrominance distortions without relative delay distortion. Then the modulated 20T sine-squared pulse test signal is used for testing the results of measurement. The experimental results show in good performance.

The rest of the paper is organized as follows. In Section 2, we described three types of the linear chrominance distortions with the modulated 20T sine-squared pulse test signal. The design of linear luminance-chrominance gain equalizer based on Bernstein polynomials is presented in Section 3. Then, Section 4 shows the simulation and experimental results of the proposed equalizer. Finally, the conclusion is given in Section 5.

2 Linear Chrominance Distortions

The linear chrominance distortions of the color TV transmission system are caused by the limitation of gain and delay. The linear chrominance distortions can be measured by using the modulated 20T sine-squared pulse test signal with color sub-carrier at 4.43 MHz for PAL system [1], [3]. This pulse test signal can be placed on line 17. The advantage of using the modulated 20T sine-squared pulse test signal is that both gain and delay distortions with a single signal can be evaluated directly. Hence, an experiment proposed here demonstrates the linear chrominance distortions in color TV transmission system by using the modulated 20T sine-squared pulse test signal.

The generation of the modulated 20T sine-squared pulse test signal [12] is shown in Fig. 1. From Fig. 1, beginning with a 20T pulse having the half-amplitude duration (H.A.D) of 2.5 µsec (at point 1) is modulated with the color sub-carrier at 4.43 MHz for PAL system (at point 2), so it obtains the modulated 20T pulse envelope (at point 3). Next, low-pass filter (LPF) was used to eliminate the harmonic currents out of the pulse. An alternative to a signal timing of 20T pulse at point 1 is adapted by using delay network. After that, these two pulses test signal were added together. Hence, the modulated 20T sine-squared pulse test signal is obtained at point 4 and can be defined by

\[
x(t) = \begin{cases} 
\frac{1}{2} & \text{if } |t| \leq \frac{T}{2} \\
0 & \text{otherwise}
\end{cases}
\] (1)

where \( A \) is the magnitude of a modulated 20T sine-squared pulse test signal, \( \tau \) is the delay time, \( T = 0.1 \) µsec, \( \omega_c = 2\pi f_c \), and the color sub-carrier \( f_c = 4.43 \) MHz for PAL system.

The three types of the linear distortions will be discussed in the following sections.

2.1 Chrominance Gain Distortion

The chrominance gain distortion is defined by [2]

\[
A = \frac{1 - (y_1 + y_2 + 2y_1y_2)}{1 + (y_1 + y_2 + 2y_1y_2)}
\] (2)

Hence, \( y_1 \) and \( y_2 \) are the two peaks of the distorted pulse baseline which are normalized by the output pulse height. According to Eq. (1), if \( y_1 \) and \( y_2 \) are 0, then \( A = 1 \) and \( \tau = 0 \). Thus, the undistorted modulated 20T sine-squared pulse test signal is shown in Fig. 2.

Fig. 2. The undistorted modulated 20T sine-squared pulse test signal.

Fig. 2 shows the undistorted modulated 20T sine-squared pulse test signal with the flat baseline. When either \( y_1 \) or \( y_2 \) is 0, then \( A < 1 \) or \( A > 1 \), and \( \tau = 0 \) . Thus the chrominance gain distortion is shown in Fig. 3.
Fig. 3. The chrominance gain distortion.

Fig. 3 shows the modulated 20T sine-squared pulse test signal of a sinusoidal baseline with only one peak referring to chrominance gain distortion. This only one peak signal is defined as \( y \), where \( y = Y/Y_{\text{max}} \). In addition, Fig. 3(a) shows the low gain chrominance distortion with \(-3\) dB. The modulated 20T sine-squared pulse with upward bow of the baseline has the peak height of \( y = 0.171 \). Fig. 3(b) shows the high gain chrominance distortion with \(+3\) dB of the modulated 20T sine-squared pulse with downward bow of the baseline has the peak height of \( y = -0.171 \).

### 2.2 Chrominance Delay Distortion

The chrominance delay distortion is defined by

\[
\tau = \frac{T_0}{\pi} \cos^{-1} \left[ 1 + \frac{8y_1y_2}{1 - (y_1 + y_2)^2} \right] 
\]  
(3)

If \((y_1 + y_2)^2 << 1\), Eq. (3) can be rewritten as

\[
\tau \approx \frac{4T_0}{\pi} \sqrt{-y_1y_2} 
\]  
(4)

When \( y_1 = -y_2 \), then \( A = 1 \), and \( \tau > 0 \). Thus, the chrominance delay distortion is shown in Fig. 4.

Fig. 4. The chrominance delay distortion.

Fig. 4 shows the modulated 20T sine-squared pulse test signal of a sinusoidal shape with a symmetrical baseline of positive peak and negative peak which refers to chrominance gain & delay distortions. There are four different types of chrominance gain & delay distortions; the low gain chrominance distortion \( A = -3 \) dB with positive chrominance delay distortion \( \tau = +300 \) nsec and with negative chrominance delay distortion \( \tau = -300 \) nsec are shown in Fig. 5(a) and Fig. 5(b). The high gain chrominance distortion \( A = +3 \) dB with positive chrominance delay distortion \( \tau = +300 \) nsec and with negative chrominance delay distortion \( \tau = -300 \) nsec are shown in Fig. 5(c) and Fig. 5(d).

### 3 Luminance-Chrominance Gain Equalizer

#### 3.1 The Bernstein Polynomials

The \( n^{\text{th}} \) \((n \geq 1)\) Bernstein polynomials, \( f(x) \) be defined in the interval \([0, 1]\), is given by [16], [17]

\[
B_n(f; x) = \sum_{i=0}^{n} \binom{n}{i} f(i/n) (1-x)^{n-i} x^i 
\]  
(5)
For \( i = 0,1,\ldots,n \) where \( \binom{n}{i} = \frac{n!}{i!(n-i)!} \).

Considering the approximation of a low pass function as shown in Fig. 6, then we get

\[
 f \left( \frac{i}{n} \right) = \begin{cases} 
 1, & 0 \leq i \leq n - K \\
 0, & n - K + 1 \leq i \leq n 
\end{cases}
\]

(6)

where \( K \) is the number of successive discrete points at the zero values function.

Considering the approximation of a low pass function, let us approximate it by choosing a magnitude-squared function \( |N(j\omega)|^2 \), then it is related by

\[
 |N(j\omega)|^2 = \frac{H_0}{1 + \varepsilon^2 B^2(j\omega)}
\]

(12)

The result of magnitude-squared function has the form as

\[
 |N(j\omega)|^2 = \frac{H_0 \cdot (1 + \omega^2)^{2n}}{(1 + \omega^2)^{2n} + \varepsilon^2 \omega^4} \sum_{i=0}^{n-K} \left( \binom{n}{i} \left( \frac{1}{\omega} \right)^{2i} \right)^2
\]

(13)

As the result of selecting the locations of the poles and the zeros of \( |N(j\omega)|^2 \) in the left-hand-side of s-plane, the transfer function is stability and has minimum-phase. Thus the transfer function is defined as Eq. (14).

\[
 N(s) = a_0 + a_1 s + a_2 s^2 + \ldots + a_{n-1} s^{n-1} + a_n s^n
\]

\[
 b_0 + b_1 s + b_2 s^2 + \ldots + b_{n-1} s^{n-1} + b_n s^n
\]

(14)

To sum up, there are three parameters that affect the magnitude and phase characteristics of \( N(s); n, K \), and \( \varepsilon \).

3.2 The Bernstein Filter

Let us assume the parameters for the magnitude-squared low-pass function of the fourth order Bernstein filter are the parameters chosen are \( n = 2 \) and \( K = 1 \), we obtain

\[
 |N(s)|^2 = \frac{H_0^2 \cdot (1 - s^2)^4}{(1 + \varepsilon^2) s^2 + (4 - 4\varepsilon^2) s^4 + (6 + 4\varepsilon^4) s^6 - 4s^2 + 1}
\]

(15)

where \( H_0 \) is the variable constant for magnitude.

To analyze Bernstein filter in more details, let us consider the following example cases.

Example 1: To examine the magnitude characteristic of the low-pass of the fourth order Bernstein filter, we choose \( \varepsilon = 0.1 \), \( \varepsilon = 1 \), \( \varepsilon = 10 \), and \( \varepsilon = 100 \). Then the variable constant \( H_0 \) is selected to achieve the magnitude at 7.5 for all conditions. Fig. 7 shows the comparison magnitude characteristics of the low-pass of the fourth order Bernstein filter. It can be concluded that the transfer functions have MAXFLAT magnitude in the pass-band. In addition, the attenuation in the stop-band can be changed depends on \( \varepsilon \). Hence, the Bernstein filter can be applied in control systems such as the compensating circuits.
3.3 Design Procedure

The design begins with the substitution of the characteristic function of Bernstein polynomials into the low-pass transfer function. Then Eq. (13) is known as low-pass of the $n^{th}$ order Bernstein filter, replacing $\omega$ by $s / j$. By choosing the value of these parameters $n = 2$, $K = 1$, and $\epsilon = 10$, we obtain the magnitude-squared low-pass function of the fourth order Bernstein filter as

$$|N(s)|^2 = \frac{H_0^2 \cdot (1 - s^2)^4}{10001s^8 - 40004s^6 + 40006s^4 - 4s^2 + 1}$$ (16)
Next step, Eq. (16) was applied to the gain equalizer transfer function at ±1 dB, ±2 dB, and ±3 dB. A simple approach for gain equalizer transfer function is given by [18]

\[
|H(s)|^2 = 1 + |N(s)|^2
\]  

(17)

For stability and minimum-phase, we select the poles and zeros in the left-hand-side of s-plane. We obtain a low-pass transfer function of the fourth order Bernstein filter as

\[
H(s) = \frac{1.1218s^4 + 10.2761s^3 + 44.8216s^2 + 97.5048s + 101}{s^4 + 9.4021s^3 + 42.1995s^2 + 94.4897s + 101}
\]  

(18)

The high gain equalizer transfer functions are obtained by means of a low-pass to high-pass transformation. Therefore, the high gain equalizer transfer functions are at ±1 dB, ±2 dB, and ±3 dB according to the following

\[
H(s)_{1,db} = \frac{1.2589s^4 + 11.2356s^3 + 47.6215s^2 + 100.6386s + 101}{s^4 + 9.4021s^3 + 42.1995s^2 + 94.4897s + 101}
\]  

(19)

\[
H(s)_{2,db} = \frac{1.4102s^4 + 12.2699s^3 + 50.5584s^2 + 103.8389s + 101}{s^4 + 9.4021s^3 + 42.1995s^2 + 94.4897s + 101}
\]  

(20)

\[
H(s)_{3,db} = \frac{6.2027s^4 + 6.3337s^3 + 85.155s^2 + 73.633s + 71.6202}{s^4 + 8.7607s^3 + 35.8515s^2 + 73.633s + 71.6202}
\]  

(21)

Moreover, the low gain equalizer transfer functions are obtained by means of a low-pass to low-pass transformation. Hence, the low gain equalizer transfer functions are at −1 dB, −2 dB, and −3 dB according to the following

\[
H(s)_{1,-db} = \frac{0.8914s^4 + 8.3810s^3 + 37.6166s^2 + 84.2280s + 90.0313}{s^4 + 9.1601s^3 + 39.9539s^2 + 86.9156s + 90.0313}
\]  

(22)

\[
H(s)_{2,-db} = \frac{0.7944s^4 + 7.4686s^3 + 33.5216s^2 + 75.0587s + 80.2303}{s^4 + 8.9251s^3 + 37.8285s^2 + 79.9432s + 80.2303}
\]  

(23)

\[
H(s)_{3,-db} = \frac{0.7991s^4 + 6.6671s^3 + 29.9241s^2 + 67.0037s + 71.6202}{s^4 + 8.7607s^3 + 35.8515s^2 + 73.633s + 71.6202}
\]  

(24)

The magnitude characteristic of the high gain and the low gain equalizer transfer functions at ±1 dB, ±2 dB, and ±3 dB are plotted in Fig. 12. According to the simulation results, the proposed equalizer can enhance or compress the chrominance gain distortion in color TV transmission system with color sub-carrier at 4.43 MHz for PAL system [20].

After that, we propose the idea of luminance-chrominance gain equalizer in order to compensate the high gain and the low gain chrominance distortions as shown in Fig. 13. In general, the modulated 20T sine-squared pulse test signal with color sub-carrier at 4.43 MHz was used for testing the color TV transmission system. The input signals are the distorted modulated 20T sine-squared pulse test signals. The input signals have been through the luminance-chrominance gain equalizer for compensating the chrominance gain distortion. The results of a design of the luminance-chrominance gain equalizer indicated that the output signals obtained as the modulated 20T sine-squared pulse test signal without the gain chrominance distortion. There are four different cases of the input signals to describe in more details.

Case 1: The input signal has the low gain chrominance distortion at −3 dB as shown in Fig. 3 (a). It is compensated with the luminance-chrominance gain equalizer at line 2. Hence, the chrominance gain signal must be equally enhanced to the luminance gain signal. Then we obtain the undistorted modulated 20T sine-squared pulse test signal with the flat baseline as shown in Fig. 2.

Case 2: The input signal has the high gain chrominance distortion at +3 dB as shown in Fig. 3 (b). It must be compensated with the luminance-chrominance gain equalizer at −3 dB in line 3. Therefore, the chrominance gain signal must be equally enhanced to the luminance gain signal.
Then, we obtain the undistorted modulated 20T sine-squared pulse test signal with the flat baseline as shown in Fig. 2.

Case 3: The input signal has the low gain chrominance distortion $A = -3\, \text{dB}$ with the negative chrominance delay distortion $\tau = -300\, \text{nsec}$ as shown in Fig. 5(a). It is compensated with the luminance-chrominance gain equalizer at $+3\, \text{dB}$ in line 2. So, the output signal only remains the negative chrominance delay distortion without the chrominance gain distortion as shown in Fig. 4(a).

Case 4: The input signal has the high gain chrominance distortion $A = +3\, \text{dB}$ with the positive chrominance delay distortion $\tau = +300\, \text{nsec}$ as shown in Fig. 5(b). It is compensated with the luminance-chrominance gain equalizer at $-3\, \text{dB}$ in line 3. Hence, the output signal only remains the negative chrominance delay distortion without the chrominance gain distortion as shown in Fig. 4(b).

### 4 The Simulation and Experimental Results

This section illustrates the design of a realizable equalizer circuits by using PSpice and the experimental results of the luminance-chrominance gain equalizer. Let us start with a design of luminance-chrominance gain equalizer by using PSpice. There are the steps as follows; firstly, we produced the generation circuits of a modulated 20T sine-squared pulse test signal at $\pm 1\, \text{dB}$, $\pm 2\, \text{dB}$, and $\pm 3\, \text{dB}$ with the variable resistor $R_1$ as shown in Fig. 14.

![Fig. 14. Generator circuit of the modulated 20T sine-squared pulse test signal.](image)

Secondly, the design of the gain equalizer transfer functions in the section 3.3 brings to a synthesis with active networks which are at $\pm 1\, \text{dB}$, $\pm 2\, \text{dB}$, and $\pm 3\, \text{dB}$. In the simulation, the input signal is provided by the generator circuit of the modulated 20T sine-squared pulse. For instance, if input signal has the high gain chrominance distortion at $+3\, \text{dB}$ then the generator circuit must set the variable resistor of $R_1 = 0.7079\, \Omega$ as shown in Fig. 15(a). Conversely, if input signal has the low gain chrominance distortion at $-3\, \text{dB}$, then the generator circuit must set the variable resistor $R_1 = 1.4126\, \Omega$ as shown in Fig. 15(b).

![Fig. 15. The distorted modulated 20T sine-squared pulse test signal at $\pm 3\, \text{dB}$.](image)

The final step is the simulation of the gain equalizer which is designed with the fourth order Bernstein
filter. Fig. 16(a) shows the high gain equalizer at +3 dB which can compress the gain chrominance signal at −3 dB equaling to the gain luminance signal. Consequently, the output signal obtains as the undistorted modulated 20T sine-squared pulse test signal with the flat baseline. Fig. 16(b) shows a comparison of the input signal with $A = +3$ dB (top) and the output signal from the simulation (bottom).

In contrast, the low gain equalizer at −3 dB can enhance the gain chrominance signal at +3 dB equaling to the gain luminance signal as shown in Fig. 17(a). Fig. 17(b) shows a comparison of the input signal with $A = -3$ dB (top) and the output signal with the flat baseline from the simulation (bottom).

In addition, a luminance-chrominance gain equalizer circuits are implemented at +1 dB, ±2 dB, and ±3 dB as demonstrated in Fig. 18. From the experiment, the undistorted modulated 20T sine-squared pulse test signal was provided by the TSG 271 PAL TV Generator. Then this pulse has been through the luminance-chrominance gain equalizer. Also, the Oscilloscope is used to display the output signal. An experimental test of luminance-chrominance gain equalizer is shown in Fig. 19. Hereby, if input signal passes through the luminance-chrominance gain equalizer at only +2 dB, we obtain the output signal as Fig. 20(a).

Fig. 20(a) demonstrates the output signal from the experiment, which is the modulated 20T sine-squared pulse test signal with the high gain chrominance distortion at +2 dB. Moreover, the gain chrominance distortion can be read from the Oscilloscope display. In this case, the Oscilloscope is calibrated VOLTS/DIV = 0.2 and TIME/DIV = 1 µsec. From Fig. 20(a), we get $Y = 0.1240$, $Y_{\text{max}} = 1.08$, $y = 0.1148$, then $A = 1.2594$ or $A \approx +2$ dB. On the other hand, Fig. 20(b) shows the case of input signal passes through the luminance-chrominance gain equalizer at only −2 dB. We get $Y = 0.1$, $Y_{\text{max}} = 0.9$, $y = 0.1111$, then $A = 0.7999$ or $A \approx -2$ dB.

![Fig. 18. A luminance-chrominance gain equalizers.](image)

![Fig. 19. An experimental test of luminance-chrominance gain equalizer.](image)

![Fig. 20. The output signals from the experiment.](image)
5 Conclusion
The design of linear luminance-chrominance gain equalizer based on Bernstein polynomials is presented, in order to compensate the low gain and the high gain distortions in color TV transmission system. A luminance-chrominance gain equalizer was implemented with the fourth order Bernstein filter with chosen parameters as \( n = 2, K = 1 \), and \( \varepsilon = 10 \). Additionally, the Bernstein filter has more advantages. For example, the transfer function has MAXFLAT magnitude in the pass-band. The attenuation in the stop-band can be adjusted depends on \( \varepsilon \). Moreover, with appropriated parameter of Bernstein filter, it is shown that the phase response is better than does Bessel-Thomson filter.

A luminance-chrominance gain equalizer was realized at \( \pm 1 \text{dB}, \pm 2 \text{dB}, \) and \( \pm 3 \text{dB} \). As the simulation results, the proposed equalizer can enhance or compress the chrominance gain inequality. The modulated 20T sine-squared pulse test signal was used for testing the performance of proposed equalizer. The simulation and experimental results are in good agreement with the measured results.

References: