MEASUREMENT DIFFERENCES WITH VARIOUS CHROMINANCE TO LUMINANCE GAIN AND PHASE TECHNIQUES

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ABSTRACT

When evaluating chrominance to luminance gain and delay inequalities, there are various techniques that can be used. Chrominance to luminance gain can be evaluated using a multiburst signal, (Sin x)/x signal, or 12.5T modulated Sin^2 pulse signal. However, each of these techniques will yield different results for similar parameters tested. This paper will present an empirical and analytical study on the differences between the various C/L measurement techniques.

INTRODUCTION

Chrominance to luminance (C/L) gain and delay inequalities are classified as linear distortions. Linear distortions are those which are not affected by signal amplitude. Basically, C/L gain inequality is defined as the difference in gain of the chrominance components compared to the gain of the luminance components as they pass though a television system. Similarly, C/L delay inequality is defined as the difference in time between the chrominance and luminance signal components as they propagate through a television system.

When viewed on a television receiver, delay distortion will cause color smearing or bleeding at the transitions in a picture. Figure 1 depicts C/L delay distortion in which the chrominance components are delayed with respect to the luminance components. Visually, C/L gain distortion can be seen as incorrect color saturation. Chrominance to luminance gain error's are caused by color peaking or attenuation in the video signal.

In television receivers C/L delay is on the order of approximately 170 nanoseconds. This delay is a result of the modulated video signal passing through the television's SAW filter and other supporting circuits. By design (compliance with FCC standards), video modulators used in cable television systems compensate for inherent C/L delays in television receivers by advancing the chrominance components 170 nanoseconds with respect to the luminance components.

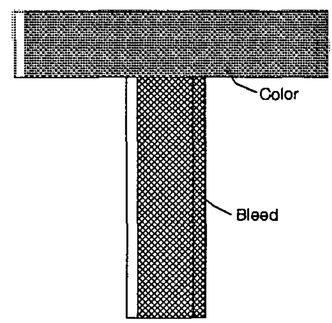

Fig 1. Visual Effect of C/L Time Delay

The standard cable transmission media used for transmitting video signals from the video modulator to television receiver usually does not contribute to C/L distortion. However, when a settop converter is in line with this media, C/L inequalities could exist. As a result of the video processing being performed in baseband converters, chrominance to luminance inequalities may be higher in baseband converters than in RF converters. Settop converters need to be designed for minimum C/L inequalities.

Verification of chrominance to luminance gain and delay distortion can be evaluated using a modulated 12.5T Sin^2 pulse, (Sin x)/x signal, or multiburst signal (gain only). However, for the same measurement the three techniques will produce three different results.

The reason for these differences can best be understood by reviewing the measurement methods. Afterwards a theory for these differences will be formulated.

MEASUREMENT METHODS

Modulate 12.5T Sine-Squared Pulse

The modulated 12.5T $\sin^2$ pulse is probably the more common method used for evaluating C/L inequalities. The main advantage for using the modulated 12.5T $\sin^2$ pulse is that it allows for easy evaluation in the time domain of both C/L gain and delay inequalities with a single signal. The magnitude and direction of either C/L gain or delay distortion can be determined by evaluating the baseline distortion of the 12.5T pulse. The baseline of the pulse will be flat if no distortion exists. However, as gain and delay distortion is introduced, the baseline will be affected in different ways. A single peak either above or below the baseline indicates the presence of C/L gain error only. Symmetrical peaks above and below the baseline indicates the presence of C/L delay error only. A combination of both C/L gain and delay error will result in non-symmetrical peaks above and below the 12.5T pulse baseline. Figure 2 depicts the effects of several types of C/L distortions.

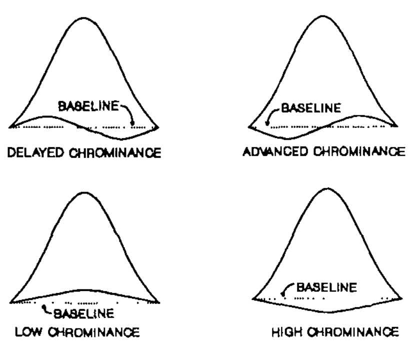

Fig. 2 12.5T Pulse C/L Gain And Phase Distortion Variations

Mathematically, the 12.5T modulated $\sin^2$ pulse can be expressed in the time domain as follows,

$$g(t) = \sin^2(w_m)t \cdot \sin(w_c)t + G \cdot \sin^2(w_m + \phi)t \qquad (1)$$

Where: $g(t) = 0$ when $g(t) > 3.125$ microseconds, $wc = 2 \cdot \pi \cdot 3.58 \cdot 10^6$ rad/sec (chrominance carrier), $wm = 2 \cdot \pi \cdot 160 \cdot 10^3$ rad/sec (luminance modulation), G = C/L gain error, and ϕ = C/L delay $\cdot$ wm.

Expanded, equation 1 becomes,

$$\begin{aligned} g(t) = {} & .5 \cdot \sin(w_c)t - .25 \cdot G \cdot \sin[(w_c + 2 \cdot w_m)t + 2 \cdot \phi] - \\ & .25 \cdot G \cdot \sin[(w_c - 2 \cdot w_m)t - 2 \cdot \phi] + \\ & .5 - .5 \cdot \cos(2 \cdot w_m)t \end{aligned} \qquad (2)$$

The wonderful aspect regarding this signal is that a low frequency reference pulse is transmitted with the modulated chrominance signal. This low frequency reference pulse is expressed in equation 2 as $.5 + .5 \cdot \cos(2 \cdot wm)t$. Inspection of equation 1, clearly shows how the composite signal's baseline is affected as C/L gain or delay vary. For example, figure 3 shows equation 1 plotted for a C/L gain and delay error equal to 0dB and 0 seconds respectively. Figure 4 shows equation 1 plotted for a C/L gain error equal to -2dB and a C/L delay error equal to 150ns.

The spectral distribution of a modulated 12.5T $\sin^2$ pulse can be determined by taking the Fourier integral of equation 1. The Fourier integral is given by,

$$g(t) = \int_0^{\frac{1}{2f_m}} [\sin(\omega_m t)^2 \sin(\omega_c t) + \sin(\omega_m t)^2]\, e^{-j\omega t} dt \qquad (3)$$

Where the upper limit of integration, $1/(2 \cdot fm)$, is used to limit the time function's signal to only one $\sin^2$ pulse.

Figure 5 shows the spectral distribution of this Fourier transformation. Notice that the total luminance signal spans a weighted bandwidth from 0 to 640 KHz. Similarly, the total signal distribution around the chrominance signal spans a weighted bandwidth of ± 640 KHz, either side of 3.58 MHz. Mathematically, C/L gain can be determined the following equation,

$$C/L\ gain = \int_0^{.64\,Mhz} |A(f)|\, \left| \int_0^{\frac{1}{2}f_m} f(t)\, e^{-j\omega t}\, dt \right| df - \int_{2.94\,Mhz}^{4.22\,Mhz} |A(f)|\, \left| \int_0^{\frac{1}{2f_m}} f(t)\, e^{-j\omega t}\, dt \right| df$$

Where: $f(t) = \sin(\omega_m t)^2 \sin(\omega_c t) + \sin(\omega_m t)^2$

(4)

Where $|A(f)|$ is the magnitude of the frequency response of the device under evaluation.

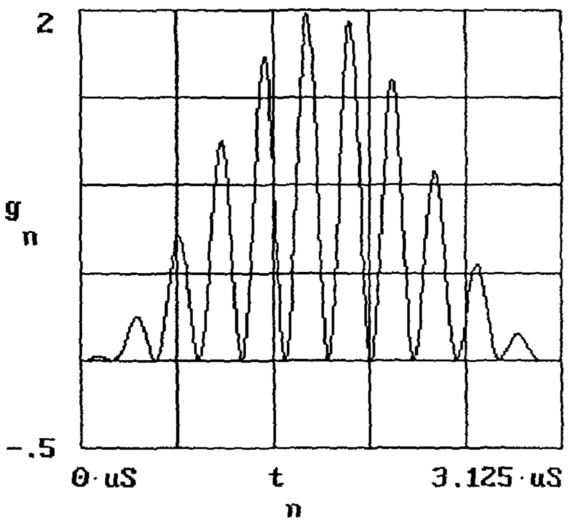

Fig. 3 Simulated 12.5T pulse With No C/L Gain Error

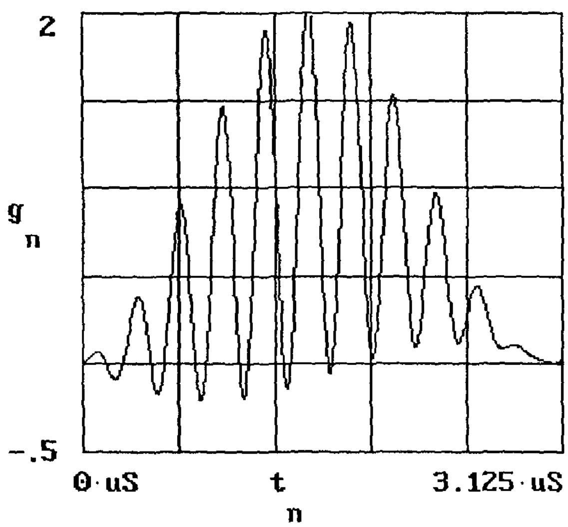

Fig. 4 Simulated 12.5T Pulse With C/L Gain And Delay Error

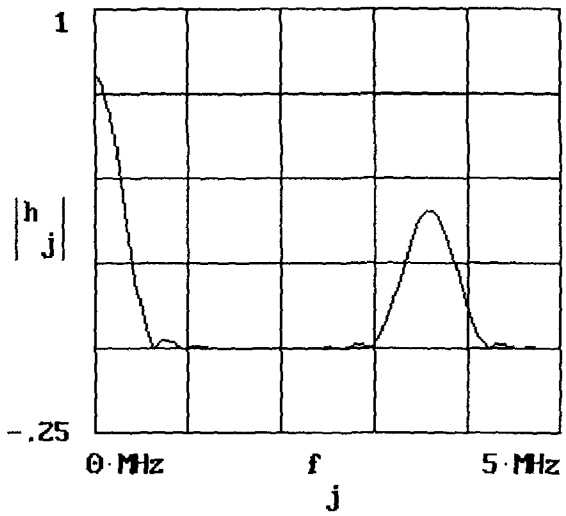

Fig. 5 Spectral Distribution Of A Modulated 12.5T Sin^2 Pulse

(Sin x)/x Pulse

The (Sin x)/x pulse has an extraordinary property which allows one to analyze the complete frequency response of a communication system with a single pulse. The (Sin x)/x pulse produces a flat and continuous frequency spectrum from 0 Hz to approximately the reciprocal of the pulse width. The Fourier transformation of this signal can be shown by the following equation,

$$h(t) = \int_{-\infty}^{\infty} \frac{\sin(\omega_m t)}{\omega_m t} e^{-j\omega t}\, dt \tag{5}$$

The (Sin x)/x pulse is shown in both the time and frequency domain in figures 6 and 7 respectively. If a 210 nanosecond (Sin x)/x pulse is transmitted at intervals of the horizontal scanning frequency (f_H), the frequency spectrum will contain equal amplitude harmonics of f_H up to 4.75 MHz. The described (Sin x)/x test signal which is available on several video generators is shown in figure 8.

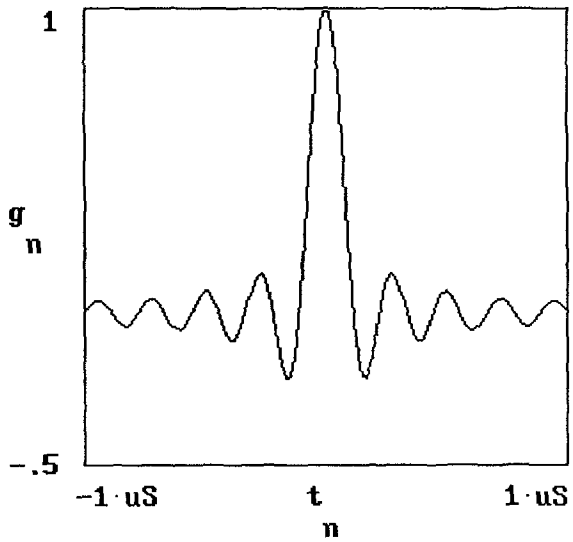

Fig. 6 Time Domain Response Of A (Sin x)/x Pulse

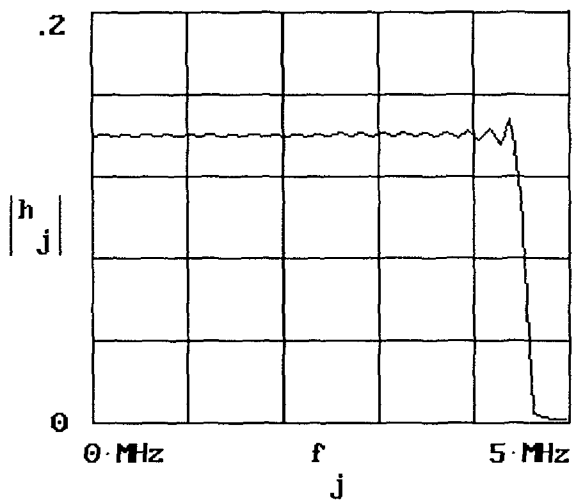

Fig. 7 Frequency Domain Response Of a (Sin x)/x Pulse

Analysis of response using the (Sin x)/x signal is done with a spectrum analyzer or special video analyzer. When using a spectrum analyzer, the only information obtainable is amplitude vs. frequency. However, there are instruments available that will display both amplitude and group delay as a function of frequency from approximately 220 KHz to 4.5 MHz. Using these instruments and choosing the proper frequency points, C/L gain and delay distortion can be determined.

Mathematically, C/L gain when using the (Sin x)/x pulse is determined as follows,

$$C/L\ gain = \int_{.22\,Mhz - BW}^{.22\,Mhz + BW} |A(f)|\ \left|\int_{-\infty}^{\infty} \left[\frac{\sin(\omega_m t)}{\omega_m t}\right] e^{-j\omega t}\, dt\right| df - \int_{3.58\,Mhz - BW}^{3.58\,Mhz + BW} |A(f)|\ \left|\int_{-\infty}^{\infty} \left[\frac{\sin(\omega_m t)}{\omega_m t}\right] e^{-j\omega t}\, dt\right| df \quad (6)$$

Where |A(f)| is the magnitude of the frequency response of the device under evaluation and BW is equal to 1/2 the bandwidth of the measurement system. Similarly, C/L delay can be determined as follows,

$$C/L\ delay = \frac{d}{df_{220\,KHz}} ARG(A(f))\ ARG\left[\int_{-\infty}^{\infty} \left[\frac{\sin(\omega_m t)}{\omega_m t}\right] e^{-j\omega t}\, dt\right] - \frac{d}{df_{3.58\,MHz}} ARG(A(f))\ ARG\left[\int_{-\infty}^{\infty} \left[\frac{\sin(\omega_m t)}{\omega_m t}\right] e^{-j\omega t}\, dt\right] \quad (7)$$

Where Arg( ) is a function for the phase response, which is equal to the arc tangent of the imaginary part of the Fourier integral of f(t) divided by the real part of the Fourier integral of f(t). Similarly, Arg(A(f)) is the phase response as a function of frequency for the device under test.

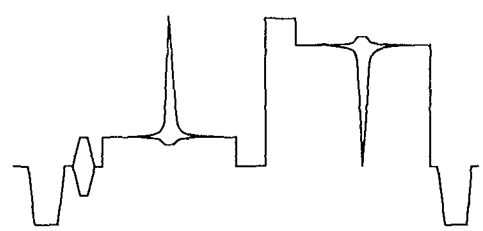

Fig. 8 Typical (Sin x)/x Signal

Multiburst Signal

The multiburst signal is unlike the 12.5T pulse and (Sin x)/x pulse which took advantage of their Fourier components and/or modulation theory to generate the frequency components at which gain and delay are mathematically analyzed. The multiburst signal consist of 6 frequency packets ranging from .5 MHz to 4.1 MHz. A typical multiburst signal is shown in figure 9. Chrominance to luminance gain measurements are made by comparing the response of the 3.58 MHz packet to the response of the 500 KHz packet. Alternatively, all packet amplitudes may be measured with respect to the bar amplitude, yielding a lower frequency reference. Automated measuring equipment using the multiburst is inconsistent in the reference used, even among different software revisions of the same equipment.

Although, not as intriguing as the 12.5T $\sin^2$ pulse or (Sin x)/x signal, C/L gain for the multiburst signal can be shown as,

$$C/L\ gain = \int_{.5\ Mhz - BW}^{.5\ Mhz + BW} |A(f)|\ \left|\int_0^{\frac{4}{f_m}} \sin(\omega_m t)\, e^{-j\omega t}\, dt\right| df - \int_{3.58\ Mhz - BW}^{3.58\ Mhz + BW} |A(f)|\ \left|\int_0^{\frac{16}{f_m}} \sin(\omega_c t)\, e^{-j\omega t}\, dt\right| df \qquad (8)$$

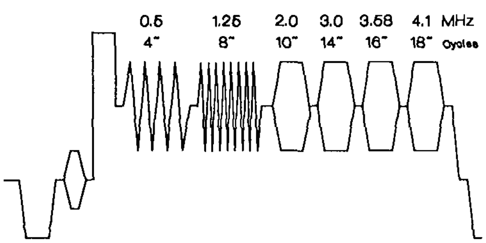

Fig. 9 Typical Multiburst Signal

MEASUREMENT DIFFERENCE THEORY

Figure 10 shows the spectral distribution of 3 C/L gain measurement methods superimposed on one plot. It should be noted that the amplitude of the individual responses are not absolute, but only relative values. In addition only the 500 KHz and 3.58 MHz components of the multiburst are shown.

The 12.5T pulse measurement is a comparison of the weighted average of the total response, A(f) · Fourier integral of the 12.5T pulse, around the color subcarrier, with the weighted average of the total 12.5T pulse response in the first 640 KHz of the luminance spectrum.

The (Sin x)/x waveform has a spectrum that is flat over the entire TV spectrum. The measurement made with it is more of a spot measure of the total response, A(f) · Fourier integral of (Sin x)/x pulse, at the color subcarrier, compared with the response at about 220 KHz.

The multiburst measurement is made by comparing the response of the color subcarrier with the response at 500 KHz, or with the low frequency bar. Other frequencies are also produced, but are not shown in figure 10.

If the gain, $|A(f)|$, of the device under test is flat from 0 Hz to 640 KHz and flat ± 640 KHz around the color subcarrier, all three measurement methods would produce the same results for C/L gain. The same reasoning is true for C/L delay if the delay is linear over the same frequency bands mentioned above. Now consider what happens when the overall baseband response of a typical baseband converter is taken into account. It is not unusual for a baseband converter to have the response shown in figure 11. Particularly, notice the response ± 640 KHz on either side 3.58 Mhz, expanded in figure 12. Since, the 12.5T pulse uses this entire spectrum for C/L gain determination, the results will obviously be different than (Sin x)/x's point measurement at 3.58 Mhz. The same will be true when comparing the results of the 12.5T pulse against the multiburst method. Using the example of the STT response shown in figure 11, the 12.5T pulse will measure less chrominance than either the (Sin x)/x or multiburst approach. The actual difference between the 12.5T method and (Sin x)/x method around 3.58 MHz can be shown as,

$$C/L\ gain = \int_{3.58\ Mhz - BW}^{3.58\ Mhz + BW} |A(f)|\ \left|\int_{-\infty}^{\infty} \left[\frac{\sin(\omega_m t)}{\omega_m t}\right] e^{-j\omega t}\, dt\right| df - \int_{2.94\ Mhz}^{4.22\ Mhz} |A(f)|\ \left|\int_0^{\frac{1}{2f_m}} f(t)\, e^{-j\omega t}\, dt\right| df$$

$$Where:\ f(t) = \sin(\omega_m t)^2 \sin(\omega_c t) + \sin(\omega_m t)^2 \qquad (9)$$

Equation 10 does not take into account the device's response within the first 600 KHz. It is important not to ignore this spectrum. Even though, not as great a contributor as the response around 3.58 MHZ, both the test equipment demodulator and device demodulator showed a fair amount of roll off from DC to 640 KHz. Therefore, the actual difference between any C/L measurement method must use the complete C/L gain or delay equations discused in the previous sections.

After substituting the measured STT response for |A(f)| the predicted difference equals -1.2dB. This delta is very close to the actual measured delta shown in table 1.

It is very important to note, that depending on the response of the converter or demodulator being evaluated, the difference in magnitude and polarity of the C/L inequalities measured will vary. Table 2 shows actual measured results of an off air demodulator and two baseband converters. In this evaluation, the 12.5T method measured higher chrominance gain for the demodulator than for the baseband converters.

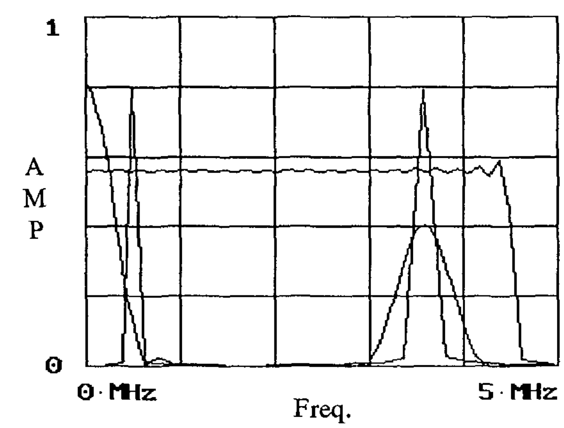

Fig. 10 Measurement Comparison

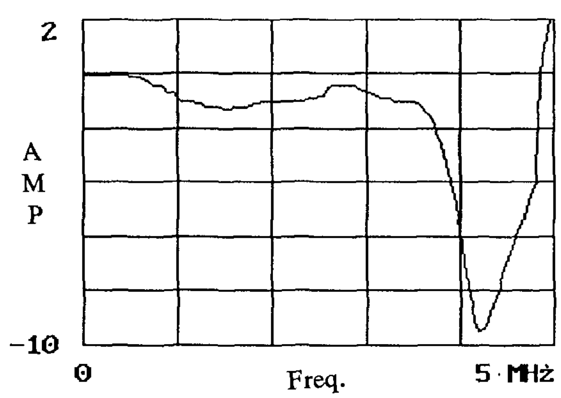

Fig. 11 Example Demodulator Response

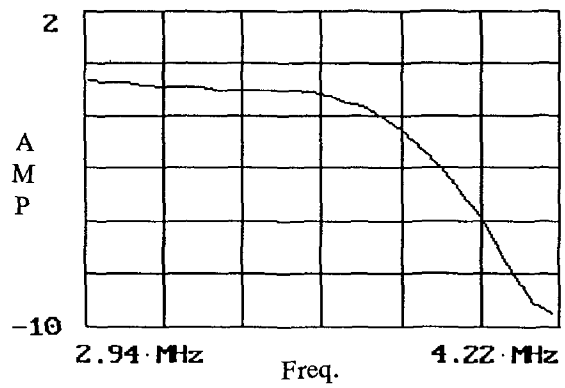

Fig. 12 Expanded Example Demodulator Response

Measurement Method	Gain (dB)	Delay (nS)
(Sin x)/x	-0.3	73
12.5T	-1.6	34
Multiburst	-1.0	
Δ(Sin x)/x & 12.5T	-1.3	-39

Table 1 Video Demodulator And Baseband Converter

CONCLUSION

As was shown mathematically and empirically, the C/L results obtained between the different C/L measurement techniques will vary depending on the response of the system being measured. This investigation is not suggesting that one method is better than another, only that they are different. However, when analyzing converter C/L inequalities, it is important that consistency in the measurement technique be used.

REFERENCES

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Measurement Method	Demod		Converter #1		Converter #2	
	Gain (dB)	Delay (nS)	Gain (dB)	Delay (nS)	Gain (dB)	Delay (nS)
(Sin x)/x	-.5	1	-.6	44	-1.0	79
12.5T	+.19	34	-1.45	34.7	-1.17	62.5
Multiburst	-.12		-.87		-.87	
(Sin x)/x - 12.5T	.69	33	.85	9.3	.17	16.5

Table 2 Comparison Between C/L Measurement Methods