GHOST CANCELLATION FOR CABLE HEADENDS

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Abstract

Multipath reception, of ghosting, has been a significant problem with broadcast NTSC television. Recent activity has resulted in the establishment of the Koo Ghost Cancellation Reference (GCR) signal as the American standard[1]. A new product which uses this signal has been developed for cable headends. Its use gives a significant improvement in picture quality for subscribers. This paper will discuss the new GCR standard and a practical system developed which uses this signal.

Introduction

The GCR needs to meet many specific requirements for high quality ghost cancellation. To meet these needs a new class of signals where developed. These signals have many important properties of which high energy and flat spectrum are most significant.

The processing algorithm in the receiver must make maximum use of the GCR properties to get high quality and cost effective cancellation. The GCR does not mandate a particular processing but certain properties such as flat spectrum and flat time domain envelope which were developed as desirable transmission characteristics also allow for efficient processing at the receiver. The algorithm presented below was developed to process GCR with a fixed point DSP and very efficient algorithms and hardware. The processing at the receiver must be able to handle the wide variety of the channel characteristics possible. This is best done if one algorithm is used regardless of the type of channel distortion. Some of the different aspects of distortion include distinct ghosts, smeared ghosts, inphase ghosts, quadrature ghosts, pre ghosts, post ghosts, distortion and smearing of the main signal, demodulation phase offsets, and sampling phase offsets. To have an algorithm change for different channel distortions would not be realistic given the number of different types of distortions and the multitude of combinations in which they can occur.

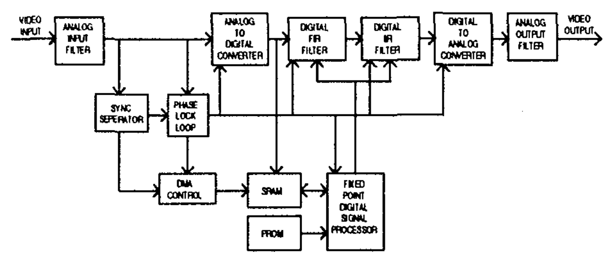


Figure 1 Ghost Cancellation System

The overall system is shown in Figure 1. The digital filter allows flexibility in the placement of the multipliers in its FIR and IIR parts. The architecture has been optimized for ghost cancellation balancing complexity, chip size, cancellation quality, and ghost statistics.

The remaining part of the hardware includes the analog input filter, analog output filter, analog to digital converter, digital to analog converter, sync separator, PLL, RAM, ROM, DSP, and programmable logic devices for controlling the GCR capturing. All of these are standard parts.

This system must work equally well in broadcast and cable environments without knowledge in the receiver in which environment it is located. The extensive testing done by broadcasters[2][3][4] and the cable industry[5] shows the effectiveness of the system.

GCR Signal

The GCR is defined by the following equations[6][7]

$$f(t) = \frac{1}{2\pi}\int_{0}^{\Omega}\left[A\cos\left(b\omega^2\right) + Aj\sin\left(b\omega^2\right)\right]W(\omega)e^{j\omega t}d\omega$$

$$+\frac{1}{2\pi}\int_{-\Omega}^{0}\left[A\cos\left(b\omega^2\right) - Aj\sin\left(b\omega^2\right)\right]W(\omega)e^{j\omega t}d\omega$$

$$W(\omega) = \int_{-t_1}^{t_1}\left(\frac{1}{2\pi}\int_{-\Omega_1}^{\Omega_1}e^{j\gamma t}d\gamma\right)\left(\frac{1}{2}+\frac{1}{2}\cos(ct)\right)e^{-j\omega t}dt$$

where A, b, Ω, t_1, c, Ω_1 are real parameters. These equations were formulated to have specific properties required to properly characterize the transmission channel. These include:

- **High signal energy**. High signal energy allows good characterization of the channel and high speed cancellation in a noisy environment.
- **Flat spectrum**. Flat spectrum allows complete and high quality equalization of the entire video signal.
- **Smooth phase characteristic**. Smooth phase minimizes sensitively to many distortions.
- **Non-cyclic Property.** non-cyclic property is extremely important for ghost/echo cancellation and channel equalization.
- **Windowed $\frac{\sin(x)}{x}$ auto correlation**. This is a widely used function and it can easily be processed by many existing algorithms and processing methods.
- **Flat time domain envelope**. A flat time domain envelope maximizes transmitted power and minimizes nonlinear and clipping distortions.
- **Short time duration**. A short time duration minimizes the impact on VBI resources.
- **No limit to cancellation range**. Range of cancellation should be an option of broadcasters and receiver manufactures.
- **Properties insensitive to digital processing**. Video is an analog signal whose properties should be unrelated to digital processing of that signal. This includes digital sampling rate and data lengths in FFTs.
- **Signal should not mandate processing at receiver**. A range of ghost cancellation products from the professional level to the consumer level will be made. Flexibility in processing at the receiver will allow each product to meet the cost and quality requirements of each market. Flexibility in processing allows the quality of cancellation to improve as new signal processing algorithms are developed.
- **Qualitative indicator of transmission distortion**. The envelope of the signal is sensitive to multipath reception. The envelope of the signal allows a visual indication of the existence of a channel distortion transfer function.

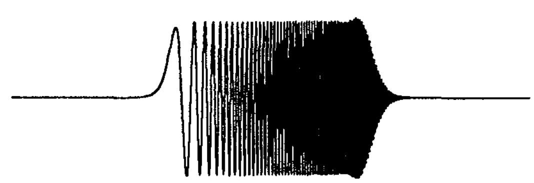


Figure 2 GCR Signal

Figure 3 GCR Spectrum

The GCR is transmitted in an eight field sequence of changing polarity (+,-,+,-,-,+,-,+) on a 30 IRE pedestal. The GCR spans from -10 IRE to +70 IRE.

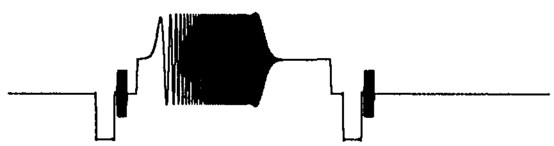


Figure 4 Positive GCR And Video

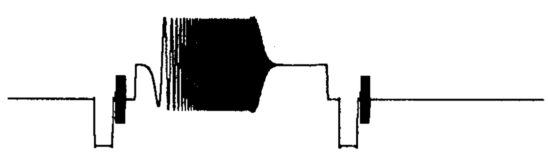


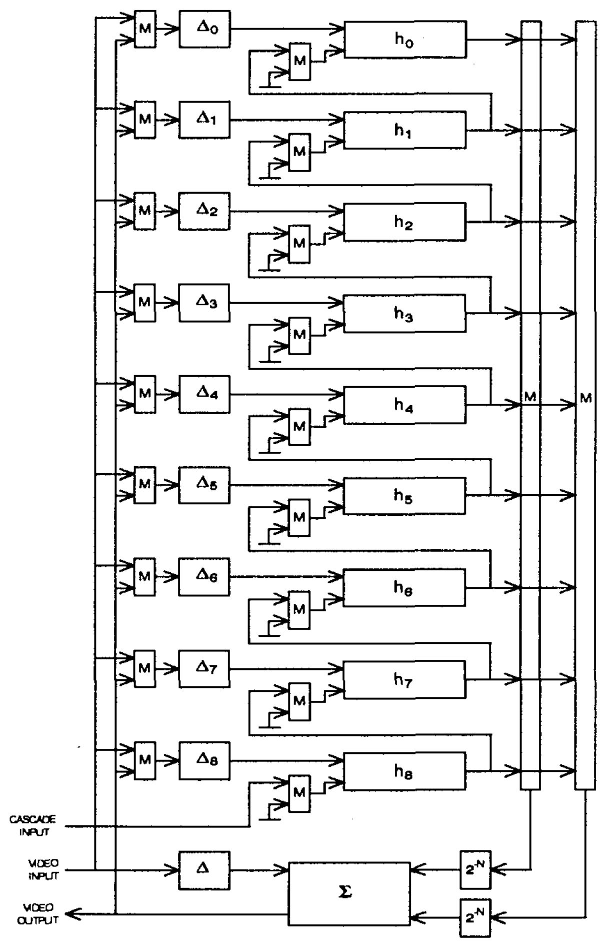
Figure 5 Negative GCR And Video

As stated above the GCR does not mandate particular processing. The description that follows is for the system currently implemented and is only one of many possible filters and algorithms.

Digital Filter

The digital filter of the ghost cancellation system consists of two custom filter chips[8]. Figure 6 shows the filter architecture. Each chip has nine sections of twenty tap transversal filters with programmable delays. In the first chip the filter sections have the flexibility to be placed dynamically anywhere in either the FIR or IIR filters. The filter sections of the second chip can be placed at any time delay in the IIR filter. The FIR filter is used to cancel pre ghosts, main signal distortion, and close post ghosts. The IIR filter is used to cancel post ghosts.

The flexibility in placement of the multipliers is achieved by programmable delay lines and programmable multiplexers. The multiplexers control placement of each twenty tap transversal filter section in either the FIR or IIR filters. The delay lines select the location within the filter. The goal of this flexibility is to have the multipliers where they are needed. While the flexibility does require overhead, analysis indicated that allocating chip area to the overhead was more useful than devoting the same chip area to more multipliers. Architectures based on fixed placement of multipliers have been found to require many more multipliers to achieve the same level of performance.



M = Programmable Multiplexer

Δ_i = Programmable Delay For The i^{th} Section

h_i = 20 Tap Programmable FIR Filter

Figure 6 Digital Filter

Algorithm

Figure 7 outlines the algorithm used and Figures 10 through 16 show an example graphically. The ghosted GCR is first captured into memory. Capturing is done with a circuit based on frame counters to guarantee the alignment of pixels when averaging is done on the data from successive fields. This GCR is then processed by the DSP to remove the color burst, sync, and pair-wise constant signals on the video lines before and after the GCR. This is continued through at least one eight field sequence. The number of eight field sequences captured can either be dependent on the signal-to-noise ratio of the received video or kept constant.

The GCR is then processed to get a channel impulse response model. This is accomplished by cross correlating the received GCR with a stored GCR. Use of cross correlation to get the channel impulse response is possible because the received GCR is the channel impulse response convolved with the transmitted GCR and the auto correlation of the GCR is a windowed $\frac{\sin(x)}{x}$. Therefore the cross correlation output is the channel impulse response with the bandwidth of the GCR. For computation efficiency this step is done in the frequency domain using a FFT of the received GCR, multiplication with the conjugate of the frequency domain representation of the stored GCR, and an inverse FFT of the result. This is all done on a standard fixed point microprocessor with a 16x16 multiplier. The flat time domain envelope and flat frequency domain spectrum of the GCR are the keys to the ability to use a fixed point processor with a FFT of 2048 points. The stored GCR has a slightly wider bandwidth than the transmitted GCR to prevent a double rolloff which would occur in the correlation step if the same bandwidths were used (although it is not absolutely necessary in many echo cancellation signal processing). This is shown in Figure 8. It is important to note that the b parameter in the modified stored GCR is the same as that of the transmitted GCR so that both GCRs have the same phase characteristic. The extra bandwidth preserves the energy in the transition band to allow for a good channel equalization in this region.

When the GCR is present in the transmitted signal, the location and value of the peak of the channel impulse response model can be expected to occur within a small defined region. If the peak is within the expected region the GCR is assumed to be present and the algorithm proceeds normally. If the peak is not within the expected region the GCR is assumed not to be present and the algorithm is restarted without updating the coefficients in the digital filter. The expected region is small so that there is not a significant chance of false detection.

A modified LMS algorithm[9] is then used to adapt the FIR filter. The initial condition of the filter for the adaptation is an impulse. This LMS algorithm averages the gradient estimates over the size of the FIR filter to get the best gradient measurement and updates coefficients only once per loop. Sixteen adaptation loops are performed. The reference used for the LMS algorithm shown in Figure 9 is the cross correlation of the ideal transmitted GCR and the stored GCR.

The IIR filter coefficients are obtained by convolving the FIR filter coefficients with the channel impulse response model. The FIR filter should correct for all pre ghosts, main signal distortion, and close post ghosts. Therefore the output of the convolution contains the main signal and post ghosts. The convolution output after the main signal are the coefficients for the IIR filter. No further adaptations of the IIR filter are required. This single step for the IIR coefficients is desirable because the size of the IIR filter makes multiple adaptations computationally intensive. There is no attempt to check the stability of the IIR filter. Extensive field testing has shown this to be of little value. The IIR filter starts shortly before cutoff point of the FIR to compensate for imperfect behavior of the FIR adaptation at the cutoff point.

Up to this point the processing has assumed a multipliers exist at all locations in time over some interval. Mapping from a idealized filter with multipliers at all locations to a sparse filter which exists in hardware is then accomplished by determining the allocation of the filter sections to either the FIR or IIR filters and determining the delay value for each section. This determination is done using an algorithm placing multipliers at locations where the coefficients are the largest. The coefficient values from the full filter are then copied to the sparse filter. Setting of the shift registers and scaling of the coefficients is done to get maximum use of the dynamic range of the filter while preventing overflows. Finally the coefficients are downloaded to the filter during the vertical interval. The whole process is then restarted with the capture of the GCR signal.

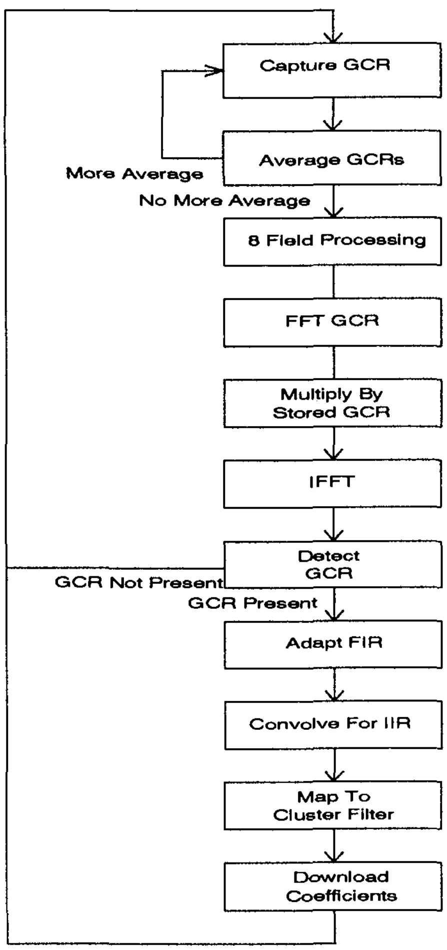


Figure 7 Flowchart Of Algorithm

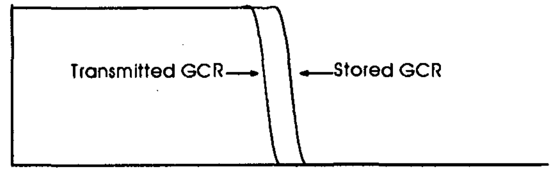


Figure 8 GCR Spectrum

Figure 9 LMS Reference

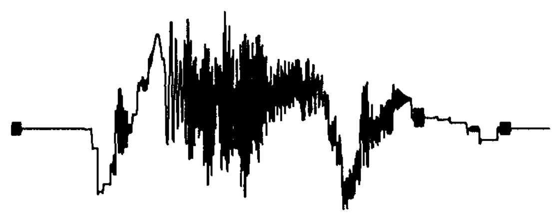


Figure 10 Ghosted GCR And Video

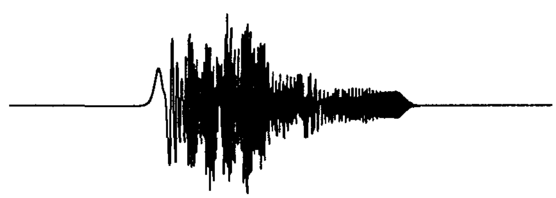


Figure 11 Ghosted GCR

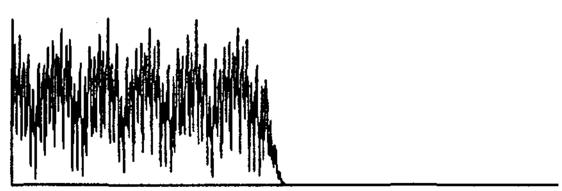


Figure 12 Spectrum Of Received GCR

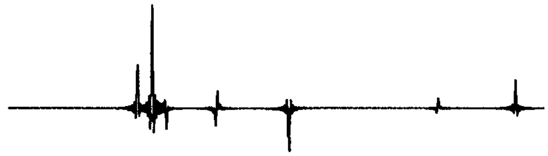


Figure 13 Channel Impulse Response

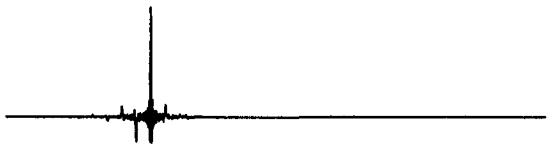


Figure 14 FIR Coefficients

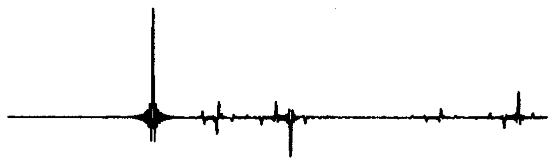


Figure 15 Convolution Output

Figure 16 IIR Coefficients

Conclusion

The GCR is a unique signal was designed to meet the specific requirements of ghost cancellation of television. The performance of the ghost cancellation system using this signal has been found to be excellent. The flexibility in allocating filter sections to any location in the filters has been key to getting high performance from the filter resources. The flatness of the spectrum of the high energy GCR has been found indispensable in allowing the algorithm to be implemented in a fixed point processor while maintaining high quality and high speed ghost cancellation. The theoretical basis of the algorithm which makes no assumptions about the characteristic of the channel except linearity allows the algorithm to perform effectively over a wide variety of channel characteristics.

References

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