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GHOST CANCELLATION OF ANALOG TV SIGNALS: WITH APPLICATIONS TO IDTV, EDTV, AND HDTV

Jack H. Winters, Ender Ayanoglu, Israel Bar-David, Richard D. Gitlin, and Chih-Lin I

AT&T Bell Laboratories
Holmdel, New Jersey 07733

ABSTRACT

In this paper, we present techniques that can cancel ghosts in received analog TV (for IDTV, EDTV, and HDTV) signals. We utilize the fact that there are short periods of time without the analog signal (the horizontal flyback interval between the lines) to periodically cleanse a finite impulse response (FIR) or an infinite impulse response (IIR) equalizer. This line-by-line processing (cleansing) overcomes the limitations of standard equalizers to allow adequate suppression of ghosts, even with nulls in the spectrum.

1. Introduction

Multipath propagation is a significant source of picture quality degradation in television transmission. The ghosts in the received TV image can be a serious problem with NTSC signals and will be an even more important problem with Improved Definition TV (IDTV), Extended Definition TV (EDTV), and High Definition TV (HDTV) where these ghosts must be removed to realize the full quality improvement.

Numerous techniques (see, e.g., [1]) have been studied for the elimination of ghosts in TV images. For example, deghosting circuitry is commercially available (in Japan) for EDTV that can achieve from 20 to 30 dB of ghost suppression for ghosts up to 6 dB below the main signal level [2]. However, all previously reported techniques are limited in the magnitude or type of ghosts that can be adequately suppressed with analog signals (as in IDTV, EDTV, and most HDTV techniques). In particular, all these techniques fail when there is a null in the channel spectrum. Specifically, with a null, a finite impulse response (FIR) equalizer cannot adequately suppress the ghosts, while an infinite impulse response (IIR) equalizer greatly enhances the noise in the picture.

In this paper, we present a technique that utilizes the fact that there are short periods of time without the analog signal (i.e., the horizontal flyback interval between the lines) to periodically cleanse a finite impulse response (FIR) or an infinite impulse response (IIR) equalizer. This line-by-line processing (cleansing) overcomes the limitations of standard equalizers to allow adequate suppression of ghosts, even with nulls in the spectrum. In combination with other techniques, such as time inversion, preprocessing by conventional equalizers, and adaptive antennas, our technique avoids the problems of conventional equalizers and eliminates the ghosting problem in nearly all TV receivers.

In Section 2 we discuss conventional deghosting techniques and their limitations with continuous-time, analog signals. In Section 3, we show how these limits can be overcome in TV signals by line-by-line processing, and in Section 4 describe applications. Finally, a summary and conclusions are presented in Section 5.

2. Conventional Deghosting Techniques

Figure 1 shows a ghost scenario where both precursor and postcursor ghosts are present. The

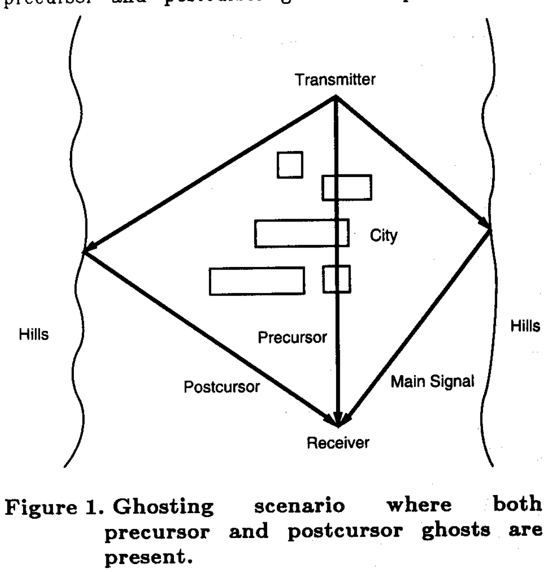

Figure 1. Ghosting scenario where both precursor and postcursor ghosts are present.

line-of-sight signal is attenuated such that it is weaker than a reflected (the strongest/desired) signal, resulting in a precursor ghost. In addition, a weaker signal with greater delay is also present, resulting in a postcursor ghost. Typically, the ghosts are few and widely-spaced with delays ranging from -4 μsec (precursor ghosts) to 37 μsec [3], although the larger ghosts typically have smaller delays. In general, ghosts must be suppressed such that they are 40-50 dB below the main signal in order that they are not noticeable, while noise, because it is random, can be 10 dB higher than the ghosts before it is noticeable.

Ghost suppression at the receiver can be accomplished by passing the received signal through a filter with a transfer function that is the inverse of the channel response. Exact inversion of the channel can be obtained by an IIR equalizer, as shown in Figure 2 for a K tap equalizer, while an approximate channel inverse can be achieved by an FIR equalizer, as shown in Figure 3.

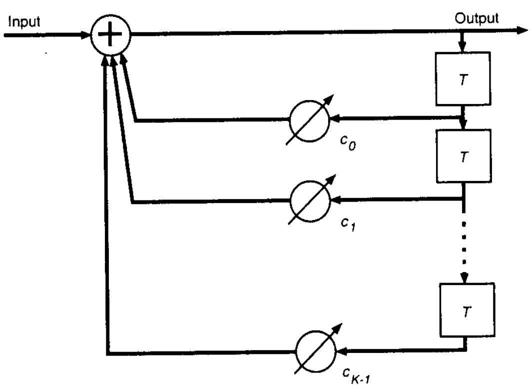

Figure 2. Block diagram of a feedback tapped delay line equalizer (IIR filter) with K taps.

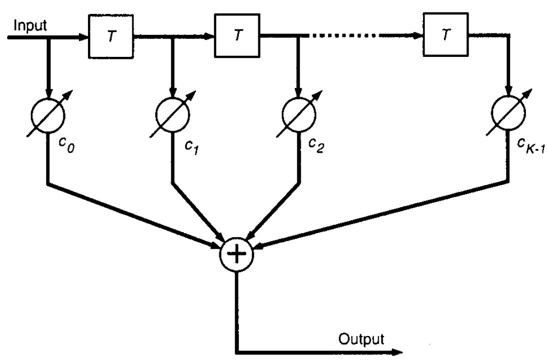

Figure 3. Block diagram of a tapped delay line equalizer (FIR filter) with K taps.

The IIR equalizer uses taps over the interval of ghost delays to suppress from one up to an arbitrary number of ghosts. However, because of the feedback, as the feedback coefficients, c_i's, increase in magnitude (i.e., the zeroes of the channel response polynomial approach the unit circle - with large postcursor ghosts), the noise level in the output increases (noise enhancement) and when the coefficients are too large (when the zeroes are outside the unit circle - with precursor ghosts), the IIR is unstable. On the other hand, the FIR, because of its feedforward structure, has limited noise enhancement and is always stable. However, in eliminating ghosts with delays within the span of its taps (which is typically much larger than the interval of ghost delays) it produces residual ghosts outside this span. As the level of ghosts increases (i.e., as the zeroes of the channel response approach the unit circle), the level of the residual ghosts becomes too high. Thus, both the FIR and IIR equalizers have unsatisfactory performance (ghost suppression or noise enhancement) as the zeros of the channel transfer function approach the unit circle. This can occur with a single ghost (reflection) with large magnitude (e.g., with a nonabsorbing reflector such as most buildings), or with multiple ghosts even when they are weaker than the desired signal. Thus, current techniques fail to adequately suppress ghosts in many cases [5] (28% of the cases in one study [4]).

3. Line-By-Line Processing

We assumed above that the TV signal was a continuous analog signal; however, the NTSC TV signal has a dead time during the horizontal flyback interval (11.2 μsec). Let us restrict our attention to the case where the total ghost delay variation is less than the horizontal flyback interval. That is, the maximum precursor delay τ_{pre} plus the maximum postcursor delay τ_{post} is less than the horizontal flyback interval. In this case, all the information needed to determine a line is contained in the samples from τ_{pre} before to τ_{post} after the line, and no other nondeterministic signals are in these samples. Of course, any deterministic signals in the horizontal flyback interval are in these samples, but since these signals are known *a priori* (or their exact received level can easily be determined), they can be subtracted out.

Thus, to deghost one line, we only need to use samples over that line (63.5 μsec or 763 samples for a 12 MHz sampling rate with an analog signal bandwidth of less than 6 MHz). Therefore, the FIR equalizer needs to have a maximum length of 2×52.3 + 11.2 = 115.8 μsec (since, to generate an output sample at a given time, the equalizer combines samples from up to 52.3 μsec before to 52.3 μsec after that time, plus the 11.2 μsec delay variation) or 1398 taps to deghost the line. In practice, we would simply zero the samples in the FIR equalizer (i.e., cleanse the equalizer) at the beginning of each line. Note that with line-by-line processing, as long as the total ghost delay spread is less than 11.2 μsec, the ghosts are completely eliminated (since the residual ghost appears outside the analog signal portion of the line), for any ghost magnitude or location of zeros.

For the IIR equalizer, line-by-line processing has the advantages that it reduces the noise enhancement and can be used to ensure stability. Since, with line-by-line processing, the IIR equalizer is cleansed at the end of each line, the noise enhancement is limited (for zeros inside the unit circle, i.e., a stable conventional IIR equalizer) to that of the FIR equalizer. With line-by-line processing, the IIR equalizer is, of course, always stable. However, with zeros outside the unit circle, the noise enhancement can easily be very large, and the signal levels in the equalizer can saturate the devices in any given implementation. To avoid these problems, we consider the use of spectral factorization, along with time inversion. Specifically, we first factor the channel response $H(z)$ into the product of two polynomials - one with zeros inside ($H^+(z)$) and one with zeros outside ($H^-(z)$) the unit circle. Then, if we pass the received signal through $G^+(z)/H^+(z)$ and pass the time-reversed received signal through $G^-(z)/H^-(z)$, such that $G^+(z)/H^+(z) + G^-(z)/H^-(z) = 1/H(z)$, we can equalize the channel with minimal noise enhancement. A similar technique was proposed in [5]. Note that this requires finding all the roots of the channel response polynomial, which may complicate adaptation (see below). However, with line-by-line processing, the IIR equalizer has the same performance (ghost suppression and noise enhancement) as the FIR equalizer, but requires taps only over the interval of ghost delay (11.2 μsec or 142 taps versus 1398 taps).

Adaptation of the weights to realize the channel inverse for the FIR equalizer can be accomplished using one of numerous techniques, with a suitable reference signal (one example is the GCR signal [2] used in Japan). Figure 4 shows how adaptation of the weights can be achieved using the LMS algorithm [6], one of the simplest techniques and the one most widely used, particularly since it is easy to implement in VLSI. For the IIR equalizer, adaptation of the weights can be carried out in a similar manner as that for the FIR equalizer, e.g., with the LMS algorithm as shown in Figure 4, with the significant difference that the filter weights estimate the channel (not the channel inverse) and these weights are copied into the IIR structure shown in Figure 4c.

Implementation of the algorithm requires a digital signal processor with at least 12 bits of accuracy and $12\times10^6 K$ (or 1.7×10^9 with 142 taps) complex multiplications and additions per second. If we consider the tapped delay line chip by S. Rao [7], which, in its current version, is capable of 360×10^6

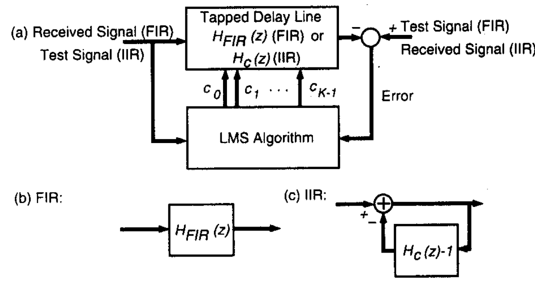

Figure 4. Block diagram of the weight adaptation for FIR and IIR equalizers.

complex multiplications and additions per second on 22 mm^2 of active area, note that with an active area of 105 mm^2 the IIR equalizer can be implemented on one chip. The FIR equalizer would require multiple chips, however.

For ghosts with delays greater than 11.2 μsec, we consider the use of conventional equalization techniques, since ghosts with large delay tend to be weaker (because they are reflected from more distant objects). Specifically, two equalizers would be used, one for nearby and one for more distant ghosts, which is similar to the technique discussed in [8], where an FIR and an IIR filter were used. However, spectral factorization of the channel response, as discussed above for the IIR equalizer, may be required.

For large ghosts with large delays, we consider the following solution. Since such ghosts are generated by large, distant objects, these reflectors will occupy only a small spatial angle from the point of view of the receiving antenna. In general, such ghosts can be reduced in magnitude by adjusting the receive antenna so that its pattern is very weak in the direction of the main reflections. Since the location of these large objects (such as buildings or mountains) usually would be fixed, only a one time adjustment would be required. Simple rabbit ears can be adjusted to suppress strong ghosts. Indeed, this is the method recommended for suppression of large ghosts so that standard FIR or IIR filters give adequate ghost suppression [4]. In severe cases, adaptive antennas can be used to suppress the large ghosts [6]. Adaptive antennas can be used in combination with line-by-line processing, and even preprocessors using conventional FIR or IIR equalizers, to eliminate all types of ghosts.

Figure 5 shows a block diagram of the ghost cancellation technique incorporating the major features discussed above.

4. Applications

For conventional NTSC receivers, our techniques can be implemented as a box, connected between the antenna or cable input to the TV (set-top

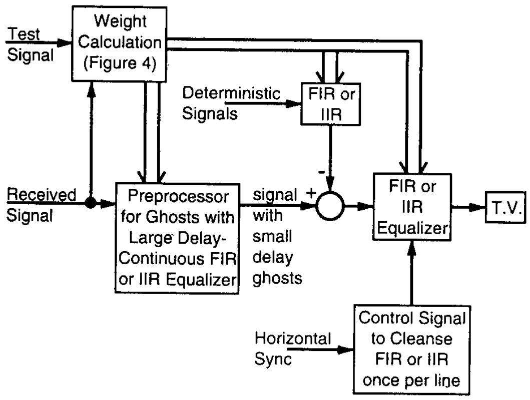

Figure 5. Block diagram of the ghost canceler.

ghost cancellation tuners are commercially available in Japan [2,4]). The box consists of an A/D, one or more digital chips, and a D/A (plus required frequency translation circuitry). For IDTV or EDTV, since digital signals are used within the TV, our techniques can be implemented by simply incorporating the digital chip(s) in the TV.

For HDTV, the application and need for our techniques depends on the HDTV format. If the HDTV format consists only of digital signals, then our techniques may not be needed, since conventional equalization techniques such as decision feedback equalization can be used. However, since most HDTV proposals use a mixture of digital and analog signals, our techniques would be advantageous for deghosting the analog portion of the signal in all ghosting scenarios. In particular, most existing HDTV systems, such as the MUSE system in Japan and MAC system in Europe, use analog video encoding with sub-Nyquist rate sampling. Although these systems use digital processing which eliminates the need for horizontal flyback intervals, clock synchronization is critical, and therefore synchronization pulses are periodically (once per line in MUSE) inserted into the signal. Since these are known signals transmitted without the analog signal, line-by-line processing can be used, with the allowable ghost delay depending on the duration of the synchronization pulses.

For the spectrum-compatible HDTV systems under study in the U.S., the NTSC signal can be deghosted by line-by-line processing as before, while the augmented signal, which typically contains analog samples and synchronization pulses (as in MUSE) can be deghosted by line-by-line processing, again with the allowable ghost delay depending on the duration of the synchronization pulses. For example, in the Zenith HDTV proposal, synchronization pulses are sent once per line with a duration of about 2 μsec under consideration. Finally, we note that simple changes in HDTV signals may be possible that could allow for longer periods without the analog signal and thereby allow our techniques to eliminate large ghosts with even longer delays in these systems.

5. Conclusions

In this paper, we discussed the ghost problem for analog TV, and described the limitations of conventional FIR and IIR equalizers. Specifically, as the zeros of the channel response approach the unit circle, a fixed length FIR equalizer cannot adequately suppress the ghosts, while an IIR equalizer will have too much noise enhancement and become unstable. We then showed how by using line-by-line processing with time inversion these limits can be avoided, using an FIR or IIR equalizer to adequately suppress ghosts without significant noise enhancement in all cases, as long as the ghost duration is less than the period without the analog signal - 11.2 μsec in NTSC. For ghosts with larger delays, we discussed the use of a conventional IIR or FIR equalizer as a preprocessor to eliminate the small ghosts and adaptive antennas to eliminate the large ghosts. Thus, with these techniques, the ghosting problem can be eliminated in nearly all TV receivers.

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