Frequency-Domain Equalization for Distributed Terrestrial DTV Transmission Environments

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Abstract—This paper presents a frequency-domain direct-inversion equalization method for DTV receivers to deal with 0 dB ghosts. To secure the existence of a channel inverse, channel-matched filtering and noncausal filtering are performed prior to equalization. Simulation results show that the proposed method has a comparable performance to the ideal DFE.

I. INTRODUCTION

Decision feedback equalizers (DFEs) have been commonly used in Advanced Television Systems Committee (ATSC) digital television (DTV) receivers. However, under severe channels, such as a 0 dB ghost channel or a single frequency network (SFN) channel, the DFE frequently suffers from the unstable convergence due to the error propagation caused by decision errors. To compensate for this problem, various methods have been proposed [1], [2]. In [1], a trellis decoder (TD) was used for a decision device instead of the conventional slicer to reduce error propagation caused by incorrect decision. Channel-matched filtering method proposed in [2] showed an outstanding performance because it provided a key to deal with 0-dB ghost channel even for 8-VSB signals. However, most of such trials are based on time-domain decision-feedback equalization and thus can not be free from the error propagation problem.

To solve this problem, we first tried to escape from the conventional time-domain decision feedback scheme. Frequency-domain equalization (FDE) with direct inversion occurred to us as a good alternative. To achieve this, however, a channel to be equalized should be minimum phase but most severe channels are nonminimum phase. Fortunately, we have found in [3] that nonminimum-phase channels can be changed into approximately minimum-phase ones by noncausal filtering when the second largest path has up to approximately 7/10th the magnitude of the main path. Since a 0 dB ghost channel does not satisfy such a premise, we needed to find how to make it satisfied. This was easily solved by channel-matched filtering presented in [2]. In this paper, we present a FDE method developed through the above mentioned trials. Since the proposed method can use a block-based computation based on the fast Fourier transform (FFT) instead of convolution in time domain, it provides a reduced computational complexity as well as stable high performance equalization.

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II. PROPOSED FDE METHOD

The optimal equalizer in the sense of the zero-forcing criterion is simply an inverse of a channel [4]. However, if the channel condition is severe, the inverse corresponding to the channel mostly does not exist or the channel has spectral nulls. In such a case, the equalization with the inverse of the channel causes noise enhancement and may have infinitely large coefficients for some frequencies.

To cope with this problem, we employ a noncausal filter operating in reversed time [3]. The noncausal filter turns nonminimum-phase channels into approximately minimum-phase channels when the second largest path of the channel impulse response (CIR) has up to approximately 7/10th the magnitude of the largest path [3]. Severe channels, such as a 0 dB ghost channel and an SFN channel, do not generally satisfy the constraint on the magnitude of multipath. We solve this problem by introducing a channel-matched filter. The channel-matched filter (CMF) changes the channel property by enhancing the amplitude of the highest level (main path) [2].

If we obtain a minimum-phase channel after the channel-matched filtering and the noncausal filtering, it is possible to produce the inverse of the given channel in frequency domain by the simple numerical inversion of each channel coefficient. Fig. 1 shows the simplified block diagram of the proposed method. The equalization is simply done by multiplying the FFT data of the output of the noncausal filter and the coefficients of the frequency-domain equalizer. This filtering process leads us to the reduction of the computational complexity because the convolution in time domain is replaced with the multiplication in frequency domain. This reduction effect becomes remarkable as the number of taps increases.

III. SIMULATION RESULTS

We performed computer simulations to verify the performance of our proposed frequency-domain equalizer for ATSC DTV receivers. The channel profile used for this simulation was Brazil channel D which is the indoor channel or SFN channel used for the Laboratory Test in Brazil [5].

Fig. 2(a) shows the impulse response of the baseband equivalent VSB channel corresponding to the Brazil channel D when the carrier frequency is 473 MHz. Fig. 2(b) shows the
combined response of the channel and the CMF. It can be seen that the amplitude of the highest level (main path) is enhanced by more than 6 dB, and thus the magnitude constraint for the application of noncausal filtering becomes satisfied. Fig. 2(c) shows the impulse response filtered by the noncausal filter obtained after one-iteration procedure [3]. The pre-ghosts shown in Fig. 2(b) are almost disappeared after noncausal filtering and thus the impulse response of the filtered channel becomes approximately nonminimum phase.

Fig. 3 shows the coefficients of the inverse system for each response shown in Fig. 2 by doing inverse-FFT for each inverse obtained in frequency domain. We can find that the coefficients of the inverses of the original channel (Fig. 3(a)) and the filtered channel by the CMF (Fig. 3(b)) do not converge and they can not be covered with finite number of taps. On the other hand, the coefficients of the inverse of the filtered channel by the CMF and the noncausal filter (Fig. 3(c)) converge. This means that it is enough to equalize the filtered channel with finite number of taps. In the proposed method, using the coefficients obtained by numerical inversion of each frequency-domain coefficient of the inverse of the filtered channel shown in Fig. 2(c), we performed FDE with the overlap-save method as shown in Fig. 1.

By comparing the symbol-error rates (SER) of various equalization schemes, we verified the superiority of the proposed method. For comparison, we used a conventional DFE and a DFE with the CMF, and the ideal DFE. All DFEs were adapted in time domain using the RLS algorithm in the field sync segment and the stop-and-go algorithm in the data segments. To reduce the error propagation of the DFEs with and without the CMF, we adopted an intelligent slicer presented in [1]. Fig. 4 shows the SER curves for each DFE and the proposed method under the Brazil channel D given in Fig. 2(a). Even at low SNR values, the proposed method shows a comparable performance to the ideal DFE.

IV. CONCLUSION

This paper presented a direct-inversion FDE method for conquering severe channels, such as an SFN channel or severe indoor channels. To secure the direct inversion, the CMF and the noncausal filter were employed. Since the proposed method has a comparable performance to the ideal DFE and provides the reduced computational complexity due to the frequency-domain filtering, it is expected that it may play an important role in implementing DTV SFN and thus save frequency resources.

REFERENCES