# FEEDBACK INTERFERENCE CANCELLER WITH PRE-WHITENING FILTERS FOR ATSC EQUALIZATION DIGITAL ON-CHANNEL REPEATERS

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## ABSTRACT

The combination of the Equalization Digital On-Channel Repeater (EDOCR) and the Feedback Interference Canceller (FIC) may be considered as a good solution for re-broadcasting recovered DTV signals with high power after the reception of distorted weak signals. However, the adoption of the FIC distorts spectrum edge which hinders the EDOCR's synchronization. This is because the FIC cannot eliminate the feedback around the carrier pilot and the edge of the spectrum clearly. To overcome this obstacle, an FIC with the pilot-free reference (PFR) was proposed but an additional cost for the PFR was too prohibitive to be implemented. Therefore we propose an FIC with pre-whitening filters (PWFs) which help the FIC estimate the feedback channel accurately. The proposed FIC with the PWFs eliminates the spectrum distortion clearly and suppresses the feedback signal more powerfully with a little additional cost compared to the FIC with the PFR.

***Index Terms*—**DTV, EDOCR, FIC, spectrum distortion, pre-whitening filters

## 1. INTRODUCTION

Recently single frequency networks (SFNs) have been considered for the ATSC DTV services [1-3]. Combining the Equalization Digital On-Channel Repeater (EDOCR) with the Feedback Interference Canceller (FIC) is an interesting issue for organizing SFNs. Since the EDOCR makes a high-quality of re-transmitted signal and the FIC enhances the re-transmission signal power, the combined system gives a near optimal solution for re-broadcasting distorted weak DTV signals [4-9].

However, there is a crucial problem that the spectrum around the carrier pilot and the edge of the FIC output signal is significantly distorted when adopting the FIC to the EDOCR. Spectrum distortion makes the EDOCR's operation difficult by disturbing the carrier and timing recovery which are preceded before the equalization process. This disaster comes from the reason that the FIC cannot estimate the feedback channel properly because of the strong carrier pilot and band-limited characteristic of the ATSC DTV signal. The spectrum distortion is an important research issue to be solved for combining the EDOCR and the FIC

To solve the spectrum distortion, a FIC with the pilot-free reference (PFR) which estimates the spectrum around the carrier pilot properly was proposed [10]. However an additional implementation cost for the PFR increases dramatically, developers hesitate to choose the FIC with the PFR as a partner of the EDOCR. In aspect of minimizing the implementation cost, a pre-whitening filter (PWF) which can eliminate the spectrum distortion may be considered as an alternative to the PFR. The FIC with PWFs has no spectrum distortion, better feedback cancelling performance and an affordable implementation cost.

The rest of this paper is organized as follows: In section 2, the conventional FIC and the FIC with the PFR are introduced briefly and the proposed FIC with PWFs is discussed in section 3. The simulation results are shown in section 4 and the paper is concluded in section 5.

## 2. PREVIOUS WORKS

### 2.1. Conventional Feedback Interference Canceller

The conventional FIC has been widely used in the field of acoustic signal processing. The conventional FIC estimates the feedback channel by cross-correlating the output signal of the repeater and the feedback signal. Estimated feedback channel information is updated to the adaptive filter by Least Mean Square (LMS) algorithm and the replica of the feedback signal is generated by inner product of adaptive filter coefficients and reference signal vector. The feedback signal is simply removed by subtracting this replica signal from the input signal of the repeater.

As the feedback cancellation process is iterated, the adaptive filter estimates the feedback channel more accurately and thus suppresses the residual feedback signal

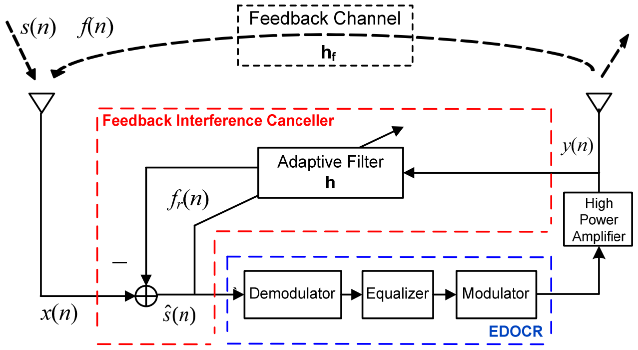


Fig. 1. The simplified blocks of the combined system: the EDOCR and the conventional FIC.

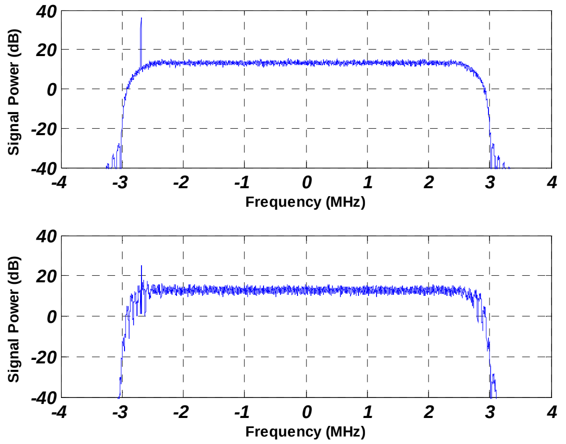


Fig. 2. Spectra of the originally transmitted signal (top) and the conventional FIC output (bottom)

in the recovered signal more powerfully. Considering the successful reception of the EDOCR, the FIC should suppress the feedback signal power at least -4dB below the main transmitted signal power. This minimum feedback cancelling requirement is due to the capability of the equalizer of the existing EDOCR [4, 5].

Fig. 1 shows the simplified blocks of the EDOCR with the conventional FIC. To investigate the feedback cancelling procedure in detail, we will use notations depicted in Fig. 1. Let $s(n)$ be the main transmitted signal and $f(n)$ be the feedback signal of the repeater, then the input signal of the repeater $x(n)$ is as follows;

$$x(n) = s(n) + f(n) = s(n) + \mathbf{h}^*_f(n) * \mathbf{y}(n)\ , \qquad (1)$$

where $\mathbf{h}_f(n)$ is the real feedback channel vector between the transmit antenna and the receive antenna and $\mathbf{y}(n)$ denotes a reference signal vector which consists of the output signal of the repeater. The FIC generates the feedback replica by

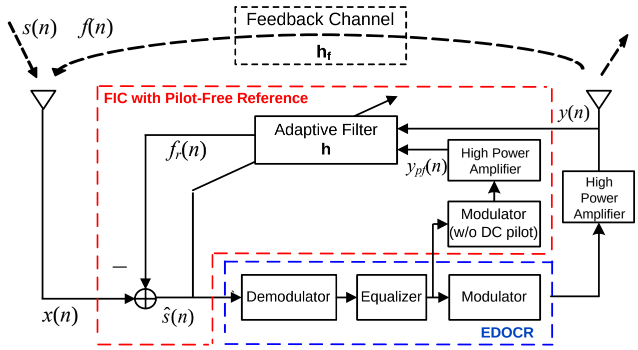


Fig. 3. The simplified blocks of the combined system: the EDOCR and the FIC with the PFR.

$$f_r(n) = \mathbf{h}^*(n) * \mathbf{y}(n)\ , \qquad (2)$$

then subtracts it from the FIC input to remove feedback,

$$\hat{s}(n) = x(n) - f_r(n)\ . \qquad (3)$$

The adaptive filter are updated by the LMS algorithm simply,

$$\mathbf{h}(n+1) = \mathbf{h}(n) + \mu\hat{s}^*(n)\mathbf{y}(n)\ . \qquad (4)$$

where $\mu$ is a step-size which determines the convergence speed and the steady-state performance of the FIC.

If the step-size is properly selected, the FIC can effectively suppress the feedback signal and meets the minimum feedback cancelling requirement. The crucial problem, however, occurs around the carrier pilot and the edge of the spectrum of the recovered signal. Fig. 2 shows the spectra of the main transmitted signal and the recovered signal. It can be easily seen that there is severe distortion around the carrier pilot and edge of the spectrum. Synchronization circuits of the existing EDOCR do not work owing to this spectrum distortion hence the EDOCR cannot process the FIC's output signal.

### 2.2. Feedback Interference Canceller with the Pilot-Free Reference

To overcome the spectrum distortion caused by the carrier pilot and band-limited characteristic of ATSC DTV signals, the FIC with the pilot-free reference (PFR) was proposed [10]. The simplified structure of the FIC with the PFR is shown in Fig. 3. The feedback cancelling procedure is identical to that of the conventional FIC except for the adaptive filter update. The adaptive filter coefficients are updated by

$$\mathbf{h}(n+1) = \mathbf{h}(n) + \mu\hat{s}^*(n)\mathbf{y}_{pf}(n)\ . \qquad (5)$$

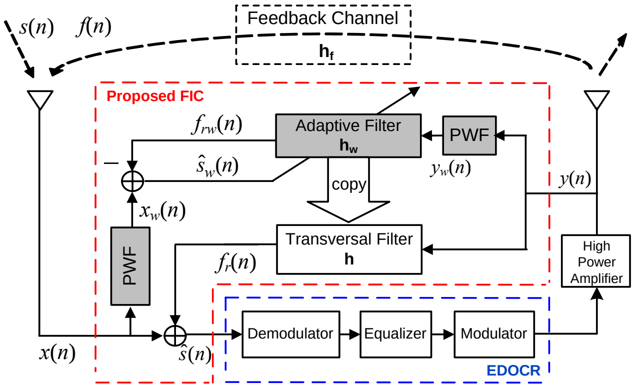


Fig. 4. The simplified blocks of the combined system: the EDOCR and the proposed FIC with PWFs.

Table I. Simulation Parameters

| Parameters | Specifications |
|---|---|
| Feedback signal power | + 20 dB to main signal power |
| Feedback signal delay | 0.45 $\mu s$ to repeater output |
| Gain increasing speed | 0.0116 sec to +20dB |
| Adaptive filter length | 40 baseband taps |
| Pre-whitening filter length | 40 baseband taps |

$\mathbf{y}_{pf}(n)$ denotes the pilot-free reference vector which is generated by subtracting the DC pilot at the modulation block of the EDOCR and passing an additional analog devices including D/A converter, HPA and so on.

The FIC with the PFR performs more exact feedback channel estimation and compensates the spectrum distortion around the pilot. However an extra line for the PFR needs the same digital/analog devices used in main signal-path line and also modification of the existing EDOCR. These prohibitive additional implementation costs are obstacles for adopting the FIC with the PFR to the EDOCR.

## 3. PROPOSED METHOD

Since the above-mentioned FIC compensates the spectrum distortion around the carrier pilot by using the PFR, we can reach the conclusion that the same result may be obtained if we remove the carrier pilot in reference signals. A pre-whitening filter (PWF) also suppresses the carrier pilot in reference signals by de-correlating the input signal hence the PWF may be considered as an alternative to the PFR [9, 11-12]. Contrary to the FIC with the PFR, the PWF is realized in FIC circuits internally and does not need a large hardware resource.

Fig. 4 shows the simplified blocks of the EDOR with the proposed FIC. The feedback cancelling process is also identical to that of the conventional FIC except for the feedback channel estimation in the whitened-signal domain. To perform feedback channel estimation in whitened-signal

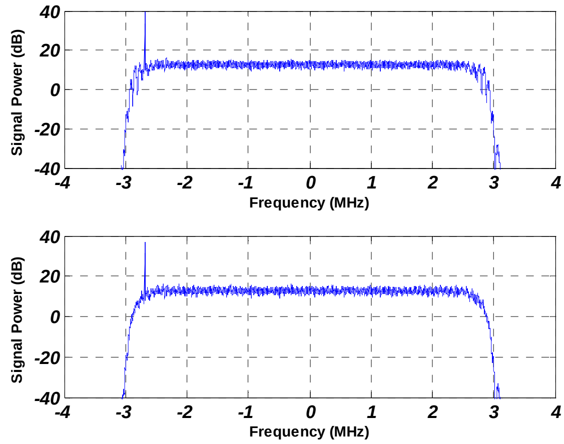


Fig. 5. Spectra of the FIC with the PFR output (top) and the FIC with PWFs output (bottom)

domain, both the input signal and the reference signal convolve with the PWF on each signal's path. The whitened replica is generated by

$$f_{rw}(n) = \mathbf{h}^*(n) * \mathbf{y}_w(n), \tag{6}$$

where $\mathbf{y}_w(n)$ denotes a whitened reference signal vector which consists of the output signal of the PWF. Then the whitened recovered signal is calculated by

$$\hat{s}_w(n) = x_w(n) - f_{rw}(n). \tag{7}$$

where $x_w(n)$ is the whitened input signal. The adaptive filter coefficients are updated by the LMS algorithm with the whitened recovered signal and the whitened reference vector as follows,

$$\mathbf{h}(n+1) = \mathbf{h}(n) + \mu\hat{s}_w^*(n)\mathbf{y}_w(n). \tag{8}$$

Estimated adaptive filter coefficients are copied to the transversal filter and the FIC removes the feedback signal using eq. (2), (3) in real signal domain. Because the PWF eliminates all negative causes of ATSC DTV signals for feedback channel estimation, the proposed FIC suppresses the feedback successfully without any spectrum distortion.

## 4. SIMULATION RESULTS

We analyzed the performance of the proposed FIC with PWFs by comparing to that of the conventional FIC in two aspects: spectrum distortion and feedback cancelling performance. All of parameters associated with simulations, such as power of the feedback signal, adaptive filter length, pre-whitening filter length and so forth, are summarized in Table I. Fig. 5 shows output signal spectrum of each FIC.

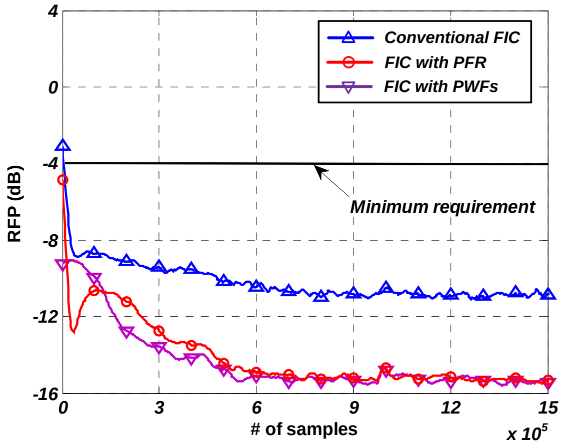


Fig. 6. RFP curves of all FICs

The FIC with the PFR preserves the carrier pilot perfectly but there is still the distortion in the spectrum edge. On the contrary, the proposed FIC maintains the carrier pilot satisfactorily and removes the spectrum edge distortion clearly.

The measuring index of the feedback cancelling performance is a residual feedback power (RFP), which means the remaining feedback signal power in the recovered signal. The RFP is defined by

$$RFP = 10\log_{10}\left(\frac{E[e(n)e^*(n)]}{E[s(n)s^*(n)]}\right) \quad (9)$$

where $e(n)$ is a difference between the main signal s($n$) and the recovered signal $\hat{s}(n)$. Fig. 6 shows the RFP curves of each FIC. All of FICs have a sufficient performance beyond the minimum feedback cancelling requirement of the existing EDOCR but the proposed FIC has the most powerful feedback cancelling performance.

## 5. CONCLUSIONS

We proposed a feedback interference canceller (FIC) with pre-whitening filters (PWFs) to compensate for the spectrum distortion which causes a critical problem in the synchronization of the EDOCR. The proposed FIC can remove the spectrum distortion and suppress the feedback signal more powerfully than previous FICs. It is expected that the proposed FIC with PWFs can contribute to the commercialization of the advanced system and the coverage extension of ATSC services.

## ACKNOWLEDGEMENT

This work was supported by the IT R&D program of MKE/KCC/KEIT. [KI002067, Development of transmission efficiency enhancement technology for terrestrial DTV system]

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