

EXPLOITING THE CYCLOSTATIONARITY OF RADAR CHIRP SIGNALS WITH TIME-VARYING FILTERS

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- Ability to exploit time-varying cyclostationarity with TV-FRESH filter
- TV-FRESH applies weights in a periodic nature, improving upon FRESH filters
- Gives a 5 dB gain in simulated results over traditional filters

Cyclostationary Signals

$$R_x(t, \tau) = \sum_{\alpha} R_x^{\alpha}(\tau) e^{j2\pi\alpha t},$$

$$R_x^{\alpha}(\tau) = \lim_{T \rightarrow \infty} \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} x\left(t + \frac{\tau}{2}\right) x^*\left(t - \frac{\tau}{2}\right) e^{-j2\pi\alpha t} dt.$$

Cyclostationarity of Chirp Radar

$$c(t) = \sum_{\infty} e^{j2\pi f_c(t-mT_c)^2} q(t-mT_c),$$

$$\alpha = \frac{n}{T_s T_c}, \quad n = 0, \pm 1, \pm 2, \dots, \frac{T_s T_c}{2},$$

$$\beta = \frac{p}{T_s T_c}, \quad p = 0, \pm 1, \pm 2, \dots, \frac{T_s T_c}{2}.$$

MMSE Filter Design Equations

$$S_{d_c, x_p}^{\alpha_{c,p,k}} \left(f - \frac{\alpha_{c,p,k}}{2} \right) = \sum_{b=0}^{B-1} \left[\sum_{u=0}^{U_{c,b}-1} G_{c,b,u}(f) S_{x_c, x_b}^{\alpha_{c,p,k} - \alpha_{c,b,u}} \left(f - \frac{\alpha_{c,p,k} + \alpha_{c,b,u}}{2} \right) + \sum_{v=0}^{V_{c,b}-1} H_{c,b,v}(f) S_{x_c, x_b}^{\beta_{c,b,v} - \alpha_{c,p,k}} \left(f - \frac{\beta_{c,b,v} + \alpha_{c,p,k}}{2} \right) \right]^*$$

$$p = 0, 1, \dots, B-1; \quad k = 0, 1, \dots, U_{c,p}-1,$$

$$S_{d_c, x_m}^{\beta_{c,m,n}} \left(f - \frac{\beta_{c,m,n}}{2} \right) = \sum_{b=0}^{B-1} \left[\sum_{u=0}^{U_{c,b}-1} G_{c,b,u}(f) S_{x_c, x_b}^{\beta_{c,m,n} - \alpha_{c,b,u}} \left(f - \frac{\beta_{c,m,n} + \alpha_{c,b,u}}{2} \right) + \sum_{v=0}^{V_{c,b}-1} H_{c,b,v}(f) S_{x_c, x_b}^{\beta_{c,m,n} - \beta_{c,b,v}} \left(-f + \frac{\beta_{c,m,n} + \beta_{c,b,v}}{2} \right) \right]$$

$$m = 0, 1, \dots, B-1; \quad n = 0, 1, \dots, V_{c,m}-1.$$

TV-FRESH Filter and MMSE Weight Derivation

$$\hat{D}_{l,c}(f) = \sum_{b=0}^{B-1} \left[\sum_{u=0}^{U_{c,b}-1} G_{c,b,u}(f) X_{l,b}(f - \alpha_{c,b,u}) + \sum_{v=0}^{V_{c,b}-1} H_{c,b,v}(f) X_{l,b}^*(f - \beta_{c,b,v}) \right]$$

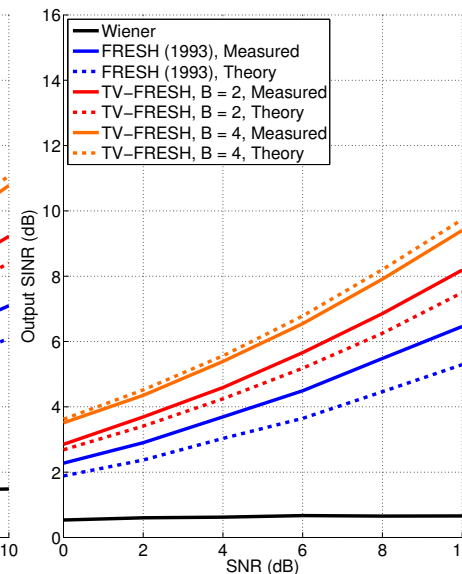
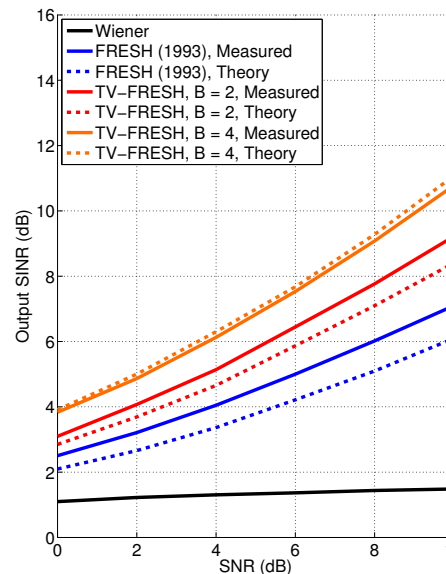
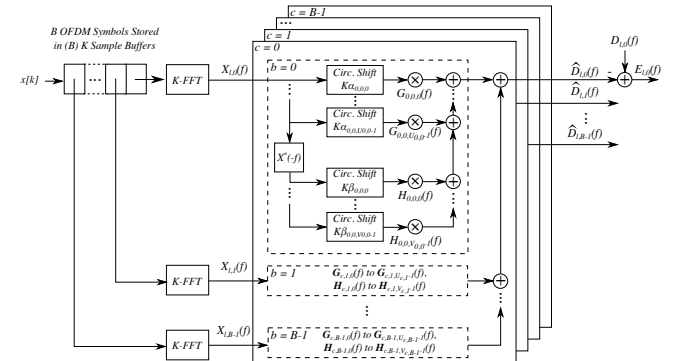
$$E_{l,c}(f) = D_{l,c}(f) - \hat{D}_{l,c}(f),$$

$$\mathbb{E} \{ E_{l,c}(f) X_{l,p}^*(f - \alpha_{c,p,k}) \} = 0,$$

$$\mathbb{E} \{ E_{l,c}(f) X_{l,m}(-f + \beta_{c,m,n}) \} = 0.$$

$$\frac{\partial}{\partial G_{c,p,k}^*} \mathbb{E} \{ E_{l,c}(f) E_{l,c}^*(f) \} = 0,$$

$$\frac{\partial}{\partial H_{c,m,n}} \mathbb{E} \{ E_{l,c}(f) E_{l,c}^*(f) \} = 0.$$



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ABSTRACT
A time-varying filter is proposed which improves by 5 dB upon traditional FRESH and Wiener filters when rejecting a pulsed radar signal. The filter is a time-varying FRESH (TV-FRESH) filter, which applies different sets of filter weights in a periodic manner, with the same periodicity of the received signal. Matching the periodicity of the filter to that of the signal improves the efficiency of interference suppression and the estimate of the desired signal. The simulated results show mitigating the interference from a radar signal in an Orthogonal Frequency Division Multiplexing (OFDM) signal.

Index Terms— cyclostationary, radar, TV-FRESH, OFDM, filter.

1. INTRODUCTION
This paper proposes a novel filtering structure which is able to exploit the cyclostationarity of signals with time-varying statistics. The motivating example is a pulsed radar signal interfering with an OFDM signal, a situation which will become more common due to spectrum sharing [1]. The filter proposed in this paper shows a 5 dB improvement over both the FRESH filter and the Wiener filter.

The proposed filter is a time-varying FRESH (TV-FRESH) filter, which exploits the cyclostationarity of the received signal and applies different sets of filter weights in a periodic manner, similar to a polyphase filter bank. The periodicity of the radar signaling, including its chirp rate and its Pulse Repetition Frequency (PRF), are incorporated into the filter, a capability unique to the TV-FRESH filter.

The novelty of the paper is described in the following list:

- The TV-FRESH filter creates the ability to exploit time-varying cyclostationarity.
- The filter structure applies weights in a periodic nature, improving upon existing FRESH filters.
- Gives a 5 dB gain in simulated results over traditional filters.

The work of M. Carrick and J. H. Reed was supported in part by the National Science Foundation under grant CNS-1442821.

2. BACKGROUND
In this section background material is given on cyclostationary signals and FRESH filtering.

2.1. Cyclostationary Signals
The cyclic autocorrelation function (CAF) is used to determine second-order periodicity of frequency as is present within [1].

$$R_{xx}^{\alpha}(\tau) = \lim_{T \rightarrow \infty} \frac{1}{T} \int_{-\frac{T}{2}}^{\frac{T}{2}} x\left(t + \frac{\tau}{2}\right) x^*\left(t - \frac{\tau}{2}\right) e^{-j2\pi\alpha t} dt. \quad (1)$$

$$R_{xx}^{\alpha}(\tau) = \sum_{k=-\infty}^{\infty} S_{xx}^{\alpha}(k) e^{j2\pi k \tau}. \quad (2)$$

2017 5th IEEE Global Conference on Signal and Information Processing

November 14–16, 2017
Montreal, Canada

