Signal Processing 89 (2009) 1550–1556

Contents lists available at ScienceDirect

Signal Processing

journal homepage: www.elsevier.com/locate/sigpro

# Area and power efficient mismatched filters based on sidelobe inversion

Indranil Sarkar *, Thomas Poonnen, Adly T. Fam

*Department of Electrical Engineering, The State University of New York at Buffalo, NY 14260, USA*

ARTICLE INFO

*Article history:*
Received 13 October 2008
Received in revised form
16 January 2009
Accepted 16 February 2009
Available online 5 March 2009

*Keywords:*
Barker codes
Compound Barker codes
Mismatched filter
Sidelobe suppression

ABSTRACT

A computationally efficient mismatched filter comprised of a matched filter in cascade with a multi-stage filter based on sidelobe inversion is proposed. For this approach to work, the given code has to satisfy certain conditions as derived in this work. For the proposed filter to be of practical significance, the given autocorrelation must have a computationally efficient representation including the case of sparse and/or small integer valued sidelobes such as in Barker codes. When implemented in VLSI, significantly smaller chip area and less power are required compared to the length-optimal filters achieving comparable sidelobe suppression.

© 2009 Elsevier B.V. All rights reserved.

## 1. Introduction

Pulse compression codes are designed such that the transmitted energy is uniformly spread in time while the autocorrelation function (ACF) has most of its energy in the mainlobe. Upon matched filtering of such codes, the output is their ACF. The peak sidelobe level (PSL) in the ACF of any good code is required to be as low as possible. Barker codes have the least PSL (of unity magnitude) among all biphase codes. In most applications, it is desirable to reduce the sidelobes further. This is achieved via mismatched filters.

Mismatched filters for sidelobe suppression based on both IIR and FIR filters have been investigated in the literature as discussed in [1]. FIR filters constitute the main body of research in sidelobe suppression filters. FIR mismatched filters have been proposed as either direct design [2–4] or as a sidelobe suppression (SLS) filter in cascade with a matched filter [5–7]. Among these filters, the ones proposed in [2,3] are length-optimal filters, i.e. they produce the best possible sidelobe suppression for a given filter length. Since all their coefficients are optimized, they require $N$ multipliers and $N-1$ adders for a filter of length $N$.

In this work, we propose mismatched filters based on sidelobe inversion and demonstrate their suitability for very large scale integration (VLSI) implementation. To achieve the same sidelobe suppression as the length optimal filters, the filters are considerably longer. However for codes with certain desirable sidelobe structures, such as in the cases of odd length Barker codes, the proposed filters require significantly fewer adders and multipliers per output. This also translates to significantly reduced chip-area and lower power consumption. In most applications, the physical time delay corresponding to the increased latency is of little significance. Recently, computationally efficient multiplicative mismatched filters were proposed by two of the authors for Barker [8,9] and compound Barker [10] codes. A comparative performance of the proposed filter with that of the length-optimal and multiplicative filters [9] is presented in Fig. 1. In this plot, all the three filters achieve comparable sidelobe suppression for the Barker code of length 13 in the range of 50–60 dB. The minimum PSL optimal filter performs the

* Corresponding author. Tel.: +1 716 400 2591; fax: +1 716 645 3656.
*E-mail addresses:* sarkar@fr.com (I. Sarkar), tpoonnen@eng.buffalo.edu (T. Poonnen), afam@eng.buffalo.edu (A.T. Fam).

0165-1684/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.sigpro.2009.02.018

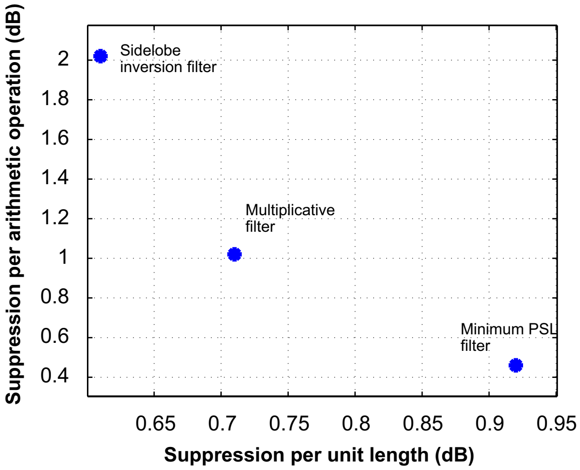


**Fig. 1.** Trade off between latency and computational efficiency of the proposed filters and length-optimal ones for the Barker code of length 13.

best in terms of suppression per unit length while having the least suppression per arithmetic operation. On the other hand, the sidelobe inversion filter produces the best suppression per arithmetic operation while having the longest filter length. The multiplicative filter [9] represents a compromise between the two extremes as shown in Fig. 1.

## 2. Description of the filter

Let the incoming code be $X(z)$. Hence the matched filter transfer function is $X(z^{-1})$ and the matched filter output is the ACF given by:

$$R(z) = X(z)X(z^{-1}) \tag{1}$$

$R(z)$ is composed of a mainlobe of height $N$ and sidelobes of peak height 1. For notational purposes, we consider the ACF $R(z)$ to be symmetric around the origin and denote the sidelobes as $S(z)$. In practice, the system should be made causal by adding appropriate delays. $R(z)$ is denoted by:

$$R(z) = N + S(z) \tag{2}$$

The proposed mismatched filter is based on sign inversion of the autocorrelation sidelobes. The transfer function of the first stage of the proposed filter is therefore given by:

$$H_1(z) = N - S(z) \tag{3}$$

The output of the first stage is given by:

$$Y_1(z) = [N + S(z)] \times [N - S(z)] \tag{4}$$

$$= N^2 - [S(z)]^2 \tag{5}$$

If further sidelobe suppression is desired, the sidelobes of $Y_1(z)$ are sign-inverted while keeping the mainlobe as it is. The transfer function of the second stage of the proposed filter is therefore given by:

$$H_2(z) = N^2 + [S(z)]^2 \tag{6}$$

This procedure could be repeated successively to obtain more number of stages of the mismatched filter till the desired sidelobe suppression is achieved. If $k$ stages are used, the transfer function of the $k$th stage is given by:

$$H_k(z) = N^{2^{k-1}} + [S(z)]^{2^{k-1}} \tag{7}$$

for $k = 2, 3, \ldots$. The output of the $k$th stage is given by:

$$Y_k(z) = N^{2^k} - [S(z)]^{2^k} \tag{8}$$

In order for the proposed filtering technique to work, the pulse compression code ACF needs to satisfy certain conditions. These conditions are evaluated next.

### 2.1. Favorable conditions for the proposed filters

Consider the output of the first stage of the sidelobe inversion filter given by Eq. (5). In the time domain, the output is given by:

$$y_1(n) = N^2\delta(n) - [s(n) * s(n)] \tag{9}$$

where $s(n)$ denotes the sidelobes of the ACF in the time domain. In order for the first stage of a filter to work, the mainlobe to peak sidelobe ratio (MSR) at the output should be higher than the MSR of the ACF. Let the peak sidelobe magnitude of the ACF be denoted by $\hat{s}$. Therefore, the necessary and sufficient condition for the filter to work is given by:

$$\frac{N^2 - \sum |s(n)|^2}{\max_{(n>0)}|s(n) * s(n)|} > \frac{N}{\hat{s}} \tag{10}$$

It is straightforward to note that for higher stages of the filter, the MSR at the output should be higher than the MSR at the input for that stage.

For Barker codes, since the peak sidelobe magnitude is unity, the condition for the first stage becomes:

$$\frac{N^2 - \sum |s(n)|^2}{\max_{(n>0)}|s(n) * s(n)|} > \frac{N}{1} \tag{11}$$

The condition is satisfied for Barker codes of length 3, 4, 5, 7, 11 and 13 as shown in Table 1.

Therefore, we observe that for Barker codes, the MSR is improved at the output of the first stage of the sidelobe inversion filter. Based on this observation, we describe multi-stage sidelobe inversion filters for Barker codes in the next section with examples of filters for the important cases of length 13 and 11.

**Table 1**
MSR at the output of first stage for Barker codes.

| Length of Barker code ($N$) | $\sum \lvert s(n)\rvert^2$ | $\max_{(n>0)}\lvert s(n) * s(n)\rvert$ | MSR at output |
|---|---|---|---|
| 3 | 2 | 1 | 7 |
| 4 | 4 | 2 | 6 |
| 5 | 4 | 2 | 10.5 |
| 7 | 6 | 4 | 10.75 |
| 11 | 10 | 8 | 13.875 |
| 13 | 12 | 10 | 15.7 |

Download English Version:

https://daneshyari.com/en/article/563086

Download Persian Version:

https://daneshyari.com/article/563086

Daneshyari.com