NEW STEIGLITZ-McBRIDE ADAPTIVE LATTICE NOTCH FILTERS

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Abstract—Two novel adaptive notch filters are presented. The updating algorithms are based on the Steiglitz-McBride error criterion minimization and the basic realizations of the notch filters are all-pass based lattice filters. The proposed realizations represent an extension of a previous ad-hoc scheme for adaptive notch filtering and avoid finding the roots of a high order polynomial to obtain the unknown frequencies of interest. Since the structure is based on the lattice realization, suitable properties with finite length precision realizations can be expected. Computer simulations are included to verify the adaptive filter performance when compared with alternative realizations.

Keywords—Frequency estimation, lattice notch filter, Steiglitz-McBride method.

I. INTRODUCTION

The input signal model $u(n)$ considered in this work is composed of $N$ sinusoids with unknown amplitude $p_k$ and frequency $w_k$, immersed in additive Gaussian noise $r(n)$, written as

$$u(n) = \sum_{k=1}^{M} p_k \sin(w_k n + \phi_k) + r(n),$$

where $\phi_k$ is the corresponding phase of sinusoid $k$.

The problem of estimating the frequencies of multiple sinusoids can be traced back to the Adaptive Line Enhancer (Widrow et al., 1975) where MSE minimization using a k-step FIR prediction filter was the basic structure. The computation of the unknown frequencies requires the evaluation of the roots of the associated polynomial. Other higher precision alternative, with considerable higher complexity, were based in the eigenvalue decomposition of input statistics (Ljung and Soderstrom, 1983). General FIR solutions have proven to be inefficient to recover sinusoids in noise, mainly because the modeling of deep notches requires high order filters.

Due to its natural efficiency IIR based notch filters or their duals, i.e, narrow passband filters with a very selective frequency characteristic, are becoming more attractive for this application. An ideal notch filter transfer function $H(z)$, evaluated on the unit circle, is described by

$$H(e^{jw}) = \begin{cases} 1 & w = w_k \\ 0 & \text{otherwise} \end{cases}.$$ 

Although it is not possible to obtain an exact solution, nice and efficient approximations can be obtained using IIR notch realizations of adequate order. A general IIR notch model, proposed by Nehorai (1985), contemplates a canonical (minimum number of parameters corresponding to each unknown frequency to estimate) direct-form realization of order $2M$. The zeros of the notch filter are located on the unit circle and the module of the poles (at the same radius but, logically, inside $|z| = 1$) is a user defined parameter. The properties and accuracy of this adaptive notch filter have been extensively studied in the literature (Ng, 1987; Stoica and Nehorai, 1988). Despite that classical estimation properties can be related to this model, no direct availability of the estimated frequencies is obtained except by finding the roots of a high-order $(2M)$ polynomial. Alternative realizations using the same model but with a lattice structure were also studied in the past (Cho et al., 1989) with no particular advantages for the multiple sinusoids case. A different notch filter model based on second-order allpass lattice sections, that has interesting numerical properties (Regalia et al., 1988), was presented in Regalia (1991). In this case, individual notch frequencies are independent of the corresponding pole module. This property has shown to be useful to extend the model application, from the single sinusoid recovering, to the multiple sinusoid case of interest.

This work presents a natural extension of the solution in Regalia (1991), that uses either a direct or a factorized allpass lattice realization to deal with the problem of direct availability of the estimated frequencies. In contrast to what was proposed as an ad hoc solution in Regalia (1991), the proposed adaptive notch filter minimizes a well defined criterion, the Steiglitz-McBride (SM) error.

The paper presentation is organized in the following...