SIGNAL MATCHED FILTER BANKS:
Design, Characterization and Process Modeling

by

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Dedicated to

*My mother **Ratnmala***
*wife **Manjusha,***
*son **Viraj,** and*
*daughter **Vaishnavi,***
who are everything in my life..

CERTIFICATE

This is to certify that the thesis entitled **"Signal Matched Filter Banks: Design, Characterization and Process Modeling"** being submitted by Mr. Sanjay Laxmikant Nalbalwar to the Indian Institute of Technology Delhi, India for the award of the **Doctor of Philosophy** in Electrical Engineering, is a bonafide research work carried out by him. He has worked under our guidance and supervision.

To the best of our knowledge the thesis has reached the requisite standard. The results presented in this thesis have not been submitted in part or full to any other university or institution for award of any degree or diploma.

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Sanjay Nalbalwar

ABSTRACT

Optimum signal representation is one of the most critical components in any signal processing application. Multiscale, multirate modeling and discrete wavelet transform are assuming increasing importance for the purpose because of their ability to represent a wide class of signals/processes. The modeling, in the multirate framework, is intrinsically related to the subband coding. The signal dependent, optimum subband coding, is linked to a notion of signal matched filter bank, where one would like energy to be concentrated in as fewer channels (and hence subbands) as possible. The focus of this thesis is on the estimation of signal matched filter bank. The thesis addresses the issues of estimating signal matched filter bank for deterministic as well as stochastic signal cases. The problem, in fact, is broken down into two parts: (i) Estimation of signal matched analysis bank and (ii) Estimation of signal matched synthesis bank and solved separately. In addition to a signal matched filter bank, a multiscale model, for generation of self-similar and cyclostationary process, is also presented. The thesis also proposes a linear phase characterization of non-uniform filter bank. This result, though not directly related to signal-matched filter bank problem, was obtained as a spin-off while deeply investigating non-uniform filter bank.

In this thesis, we begin with a precise mathematical formulation of the problem of whitening analysis bank and define the concept of signal matched analysis filter bank (SMAFB). This is an entirely new formulation and forms the basis for all the approaches, optimal or suboptimal, developed in the thesis. Further, we observe that the problem of estimating signal matched M-band, analysis side, multirate filter bank, has same mathematical form as the problem of finding whitening filter for a vector auto-regressive

process. Also, it is well known that the latter problem can be efficiently solved using circular lattice algorithm. Therefore we present a precise mathematical equivalence between the circular lattice filter and multirate filter bank. This is one of the main contributions of this thesis. Using this equivalence we present an algorithm for the estimation of an M-band signal matched analysis filter bank (SMAFB).

The above approach, though optimal in MMSE sense, suffers from two disadvantages: first, it is an indirect approach and secondly, extension of design strategy to nonuniform filter bank is not straightforward. We also present a number of approaches, though suboptimum in nature, have their own advantages and limitations.

The suboptimal approaches, which are presented in this thesis, include : M-band UFB using DFT based approach and its extension to dyadic NUFB, M-channel UFB using Nyquist (M) filter approach, M-channel Pseudo-QMF bank using cosine modulation approach and M-channel NUFB using predictor approach. Relative merits/demerits of all these approaches are also presented with respect to computational complexity, FIR/IIR filters, causal/noncausal filters, stability, and uniform/non-uniform band and subband coding gain.

The second issue, considered here, is the design of signal matched synthesis filter bank (SMSFB). The first issue mentioned above, provides only the analysis side of the filter bank in terms of signal/signal statistics. One of the approaches to obtain the synthesis part of the filter bank could be by means of PRFB theory. Such a filter bank (the composition of analysis bank followed by synthesis bank), in the strict sense, cannot be called signal matched filter bank (SMFB). Also, when one is dealing with a particular signal or signal class, the design needs to ensure perfect reconstruction for this signal or signal class only and not for all the finite power/energy signals. We propose a concept of multirate linear combiner (MRLC). As an application of this concept we propose an approach for the design of signal matched synthesis filter bank (SMSFB). We also propose, as a second application of MRLC, a multiscale model for the generation of self-similar and cyclostationary processes.

We also explore the linear phase property for nonuniform filter bank. This property has been extensively studied earlier for UFB. This is extended to obtain a similar property for nonuniform filter banks, which helps to characterize the linear phase NUFB. We have obtained the constraints on filter length, the condition on decimation factors and required number of symmetric and anti-symmetric filters which ensure linear phase NUFB. These results can be used by the designer of linear phase NUFB to reduce the search space and design time.

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