Uniform and Nonuniform Filter Banks Design Based on Fusion Optimization

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Abstract

One of the important schemes for modern communication is Filter Bank Multi-Carrier with Offset Quadrature Amplitude Modulation (FBMC/ OQAM), as it provides better spectral efficiency with small inter-symbol and inter-carrier interference specially in data fusion platforms. Unfortunately, the design of filter banks in FBMC is difficult and complex to achieve the requirement due to complexity of handling the data fusion issues. This paper presents a proposed method to design a uniform and nonuniform filter banks using a data fusion optimization technique. The design process represented as an objective function describes the amplitude in the stop band, and the goal is to minimize the objective function. Different examples are provided to illustrate the efficiency of the proposed design method.

Keywords: filter bank; FIR filter; optimization; data fusion

1. Introduction

FBMC is a digital multicarrier modulation technique; it offers many benefits, such as the reduction of inter symbolic interference (ISI) and intercarrier interference (ICI), which may be introduced when utilizing channels with varying gain in their frequency band [1-3]. FBMC is a technique that provides many advantages in data fusion applications. When compared with the Orthogonal Frequency Division Multiplexing (OFDM) technology, the Frequency-Band-Mixed-Carrier (FBMC) technique has a greater spectral efficiency [4]. This is a significant additional benefit of FBMC. In a conventional FBMC transceiver, an offset quadrature amplitude modulation (OQAM) modulator is followed by a synthesis filter bank (SFB) in the transmitter. This arrangement is dependent on polyphase filters, as shown in figure 1.

An analysis filter bank (AFB) and an OQAM demodulator are also included in the receiver of this system [5]. The SFB algorithm was implemented by utilizing the FFT processor first, then the polyphase network (PPN). At the same time, the AFB algorithm was implemented by first using the PPN, then using the FFT processor.

PPN is an acronym for a set of filters with a finite impulse response (FIR), which, when combined, produce the impulse response of a prototype filter [6]. As shown in Figure 1, the PPN in the SFB of the transmitter is composed of N different FIR filters. After the output of each FIR filter comes an up sampler and a delay unit, which totals N/2.To create the transmitter signal, the results of all of the

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filters are added together, and the PPN in the AFB of the receiver is comprised of delay units, down samplers (N/2), N FIR filters, and an FFT processor.
The implementation of FFT, IFFT, and FIR filters in an FBMC transceiver calls for a large number of multipliers and adders, which contributes to an increase in the complexity of the system, increases the amount of power that is consumed, and slows down the overall transmission speed [7].

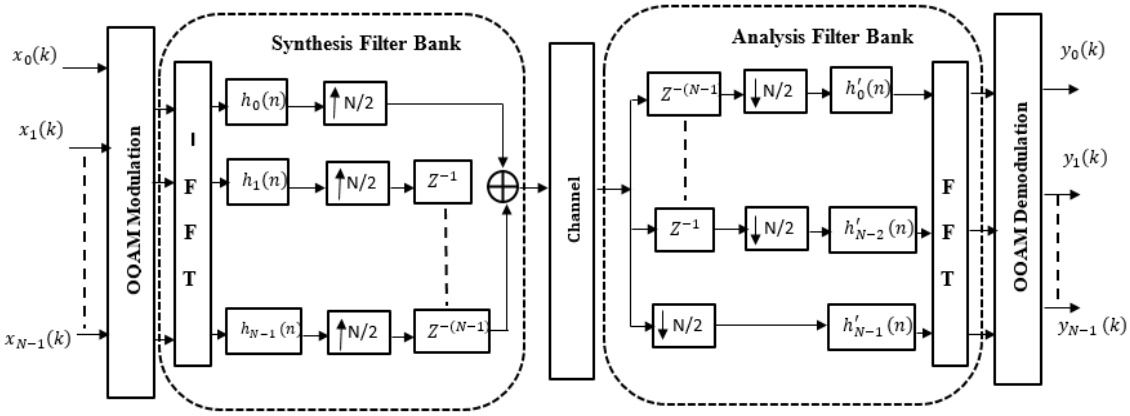

Figure1: FBMC and OFDM systems frequency responses

Perfect Reconstruction (PR) is a must-have for every well-designed filter bank, which, as the name implies, ensures that the signal is not tainted in any way by the filter bank. There are two primary types of filter banks: uniform filter banks, in which all sampling rates (are the same) are uniform, and nonuniform filter banks, in which at least one sampling rate is different from the rest. This paper will describe a method for designing uniform and nonuniform filter banks. The technique relies on minimizing a performance index that considers both the Magnitude Response of the Analysis Filters (MRAF) and the amount the reconstruction deviates from being ideal. That's much like the strategy described in [15, 20]. The PR conditions are written as a single linear equation system for FIR analysis and synthesis filters. In contrast, the MRAF is reported as the square root of a quadratic function. By analyzing the PR condition in the z-domain, a new set of linear equations can be derived, providing a different formulation than those found in, say, [15, 20, or 23]. You can use the described method to create uniform and nonuniform filter banks.

2. Related Work

Many strategies for designing a filter bank with consistent characteristics have been offered [8–14]. In general, we can classify these methods into two categories. In the first category, all filters can be made from the prototype design. Nguyen's [8] suggestion to create a prototype filter using local optimization is an engaging example of this class of methods. All the significant aliasing terms are eliminated through the derivation of the constraints. After then, cosine-modulated versions of the prototype filter are what we use to derive the analysis and synthesis filters. When it comes to the second group, they take a more unified approach by creating all of the filters at once. However, data fusion complexity is not considered.

Nayebi et al. [14] proposed a powerful approach to this problem by deriving a closed-form relation between the input and output of the filter bank in the time domain. For PR to be achieved, the output must be a slowed-down version of the input. We develop the time-domain necessary and sufficient criteria for PR based on this constraint. After that, an optimization problem was constructed to build the filter bank. The cost function was made up of two terms: the first connected to the PR requirements, and the second accomplished the necessary frequency specifications for the filters. The optimization yields the filters used for synthesis and analysis. Nonuniform multi-rate filter banks were studied theoretically in [15]. It was proven that PR can be attained if a collection of sample rates is compatible, which means that the rates satisfy certain criteria.PR for the suitable set can be understood in a nutshell by noting that all aliasing components can be paired up and cancelled.

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Achieving flawless reconstruction is impossible if the sample rates do not constitute a compatible set [15]. Prototype-based designs [18, 21] and the one where all filters are built concurrently [19, 22] are the two primary groupings that may be used to categorize the methods used to design nonuniform filter banks that have compatible sample sets. Nayebi et al. [19], building on their earlier work in [15], suggested one of the approaches in the second category.

Matrix-based sampling operators, which theoretically express down-sampling and up sampling blocks, were invented so that a closed-form relation could be found between input and output in the time-domain. For the purpose of formulating the PR condition, these operators can be employed to derive the input-output relation. The filter bank was then designed using optimization, as in [14]. In contrast, Ho et al. [22] presented an approach in which the goal is to reduce the total ripple energy across all of the filters while still meeting the requirements for PR error (distortion and aliasing) and filter frequency. As a semi-infinite quadratic programming issue, the design challenge was reduced to its bare minimum with the use of a dual parameterization approach. If there is a solution to the problem, it will be unique and the global minimum because the problem is convex. If the sampling set is congruent and the length of all filters is large enough, then, as mentioned in [22], there is a unique solution. Ho et al. [23] presented an effective solution for solving this semi-infinite programming by taking advantage of constraint optimization approaches, significantly speeding up the design process.

In mathematical programming, the goal is to pick the one thing that meets the most criteria out of a set of possibilities. Mathematics has been interested in the creation of optimization problem solution methods for millennia. Optimization problems emerge in all quantitative areas, from computer science and engineering to operations research and economics[24-37].

3. Design of Filter Bank

Analysis filters are used in filter banks to divide a signal into many frequencies sub-bands, which can subsequently be processed independently of one another. Therefore, analysis filters H k (z) must follow certain frequency requirements. The goal here is to create a filter bank whose Magnitude Response of the Analysis Filters (MRAF) meets specific criteria. To maximize the number of degrees of freedom for a given value of N, we shall focus on the MRAF and neglect the phase response of the separate analytical filters. Even if not every individual filter in the design has a linear phase, the PR criteria ensure that the filter bank as a whole does. The magnitude response of the k^{th} FIR analysis filter with coefficients $h_k = \left[h_{k,0}, h_{k,1}, \ldots\ldots h_{k,N-1}\right]^T$ at the frequency ω can be obtained as the square root of a quadratic function:

$$\left|\boldsymbol{H_k}(\boldsymbol{e^{j\omega}})\right| = \left|\sum_{i=0}^{N-1} \boldsymbol{h_{k,i}} \boldsymbol{e^{-j(i\omega)}}\right| = \sqrt{\boldsymbol{h_k^H} \boldsymbol{\Re}(\boldsymbol{\omega}) \boldsymbol{h_k}} \qquad (1)$$

were

$$\boldsymbol{\Re}(\boldsymbol{\omega}) = \begin{bmatrix} 1 & cos(\omega) & cos(2\omega) & \ldots & cos(N-1)\omega \\ cos(\omega) & 1 & cos(\omega) & \ldots & cos(N-2)\omega \\ cos(2\omega) & cos(\omega) & 1 & \ldots & cos(N-3)\omega \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ cos(N-1)\omega & cos(N-2)\omega & cos(N-3)\omega & \ldots & 1 \end{bmatrix}$$

A. Problem formulation

The optimization problem can be formulated as a minimization of J with respect to synthesis filters' coefficients f (while analysis filters are fixed):

$$J_f = w_f \sum_{k=1}^{K} \sum_{i=1}^{p} \left|\sqrt{f_k^H \Re(\omega_i) f_k} - \gamma_k^f(\omega_i)\right|^2 \qquad (2)$$

or with respect to analysis filters' coefficients h (while synthesis filters are fixed):

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$$J_h = w_h \sum_{k=1}^{K} \sum_{i=1}^{p} \left| \sqrt{h_k^H \Re(\omega_i) h_k} - \gamma_k^h (\omega_i) \right|^2 \qquad (3)$$

Where
w_f, w_h : weights of objective functions for analysis filter and synthesis filter respectively.
$\gamma_k^{(f)}(\omega)$ and $\gamma_k^{(h)}(\omega)$: are the desired magnitude response for the k^{th} analysis and synthesis filters at specified normalized frequencies ω_i $(0 \leq \omega_i \leq \pi)$.

The Proposed Algorithm is shown in Figure 2. The proposed algorithm, and its implementation as a Matlab function, can be used to design all types of filter banks.

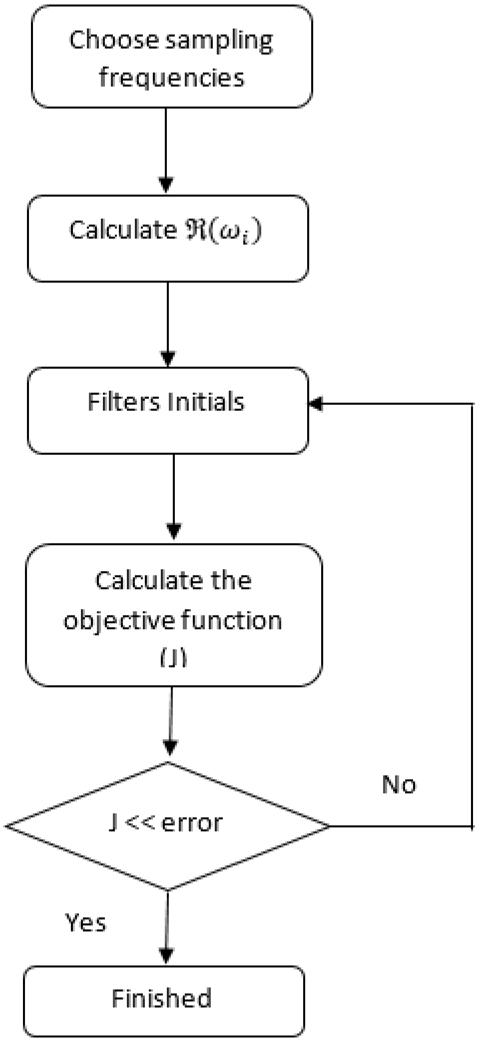

Figure 2: Proposed algorithm

4. Simulation Results

Various filter banks can be designed with the help of the proposed approach, which has been implemented as a Matlab function.

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A) Uniform filter bank

For n={2,2}, a two FIR filters are connected. The length of the filters is set to 60. The amplitude of the distortion is shown in fig. 3 The filter frequency response is shown in fig. 4.

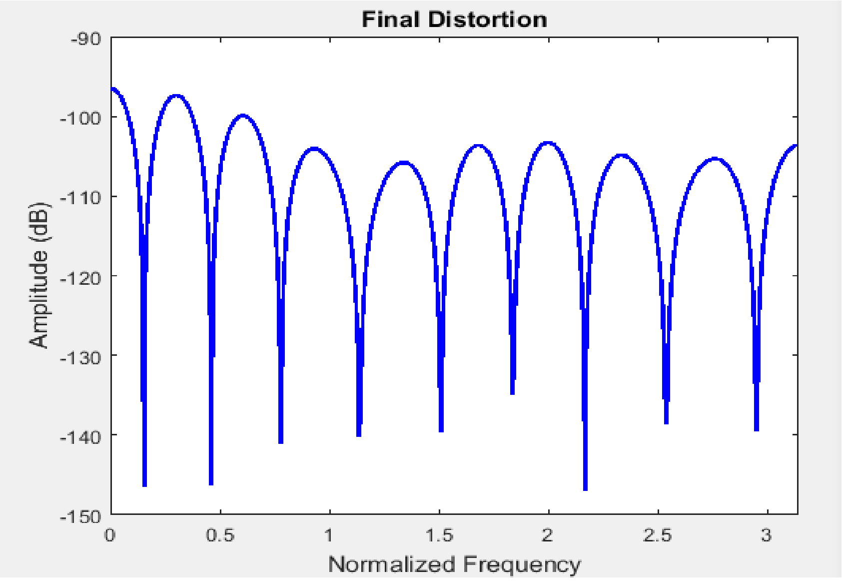

Figure 3: Amplitude of final distortion

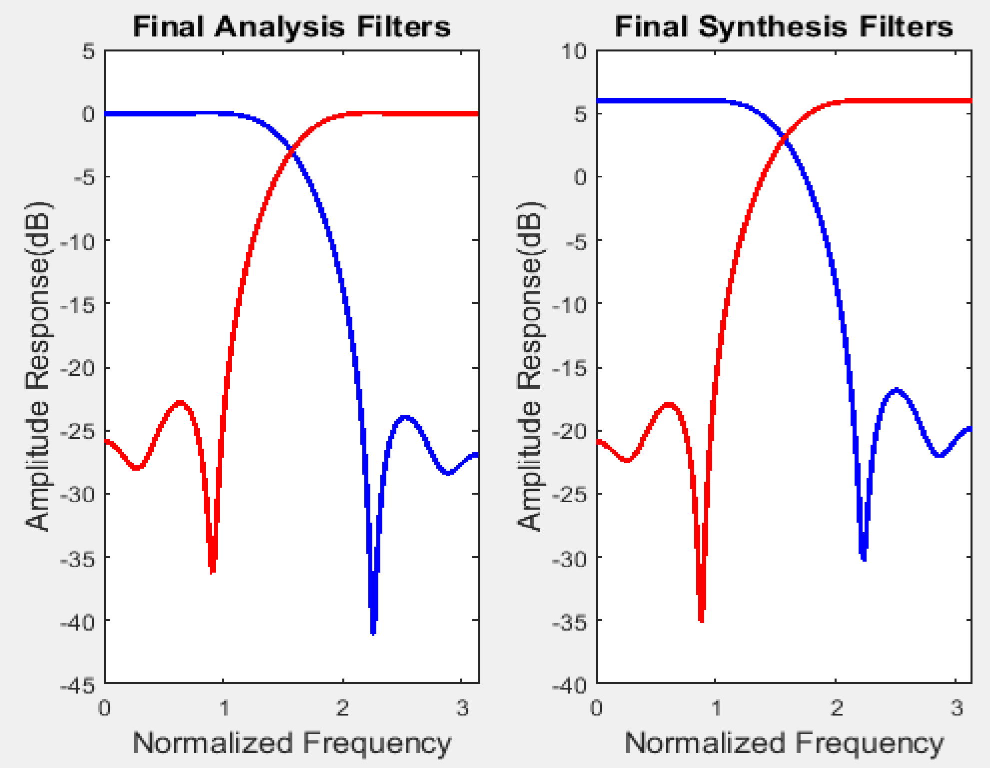

Figure 4: frequency response of final analysis filters and final synthesis filters

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From Fig. 3, it can be seen that the distortion is almost below -95 dB which is technically considered almost zero for many applications. For n = {2,2,2}, a three FIR filters are connected. The distortion amplitude is shown in fig. 5 The filter frequency response is shown in fig. 6.

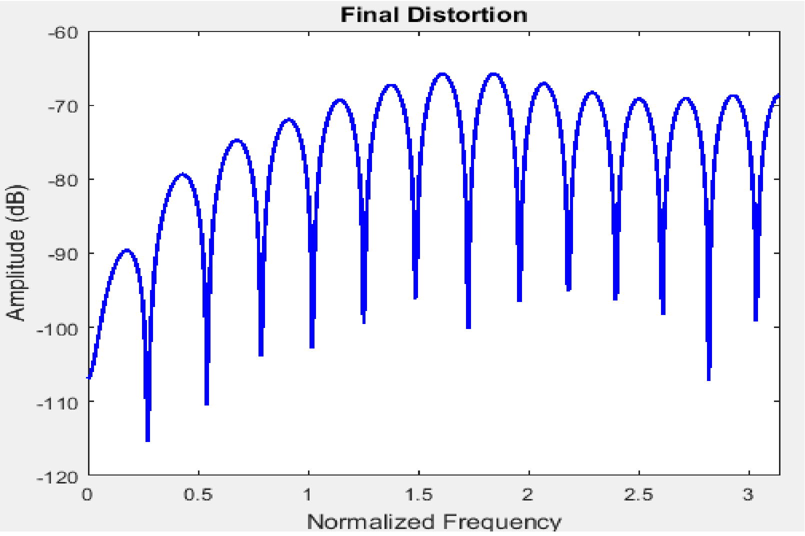

Figure 5: Amplitude of final distortion

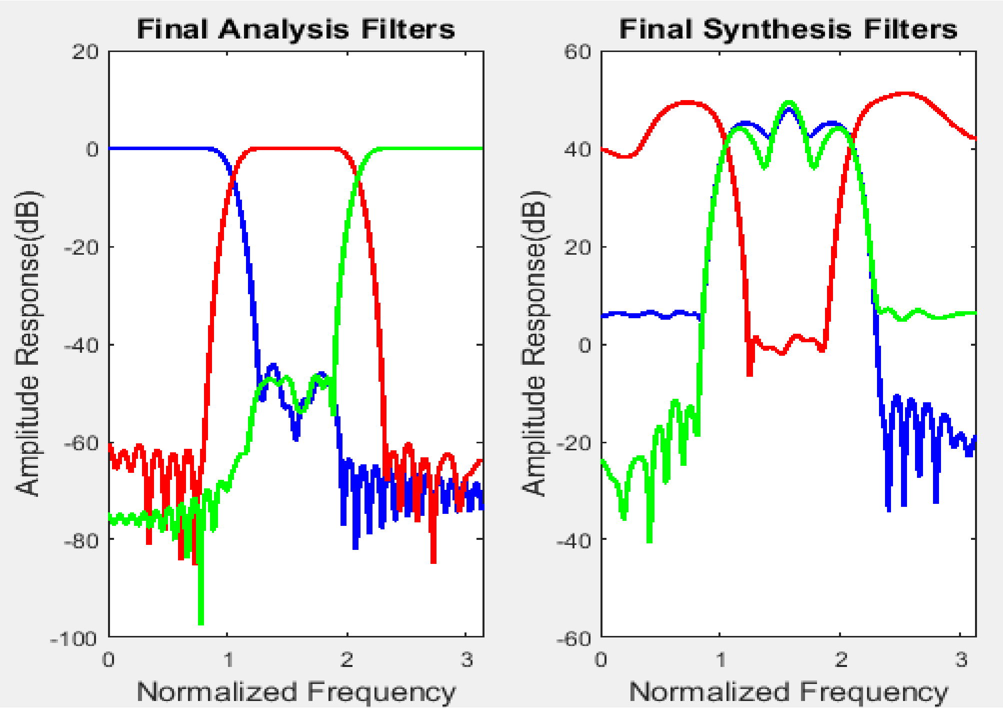

Figure 6: frequency response of final analysis filters and final synthesis filters

From Fig. 5, it can be seen that the distortion is almost below -70 dB which is technically considered almost zero for many applications

B- A non -uniform filter bank

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A non-uniform filter bank n = {2,4,4} is designed using the proposed approach. The length of the filters is set to 64. All distortions are plotted in Fig. 7. The filters' frequency responses are shown in Fig. 8. The

minimum attenuation for the analysis filters is -71.54, -77.22, and -82.35 dB..

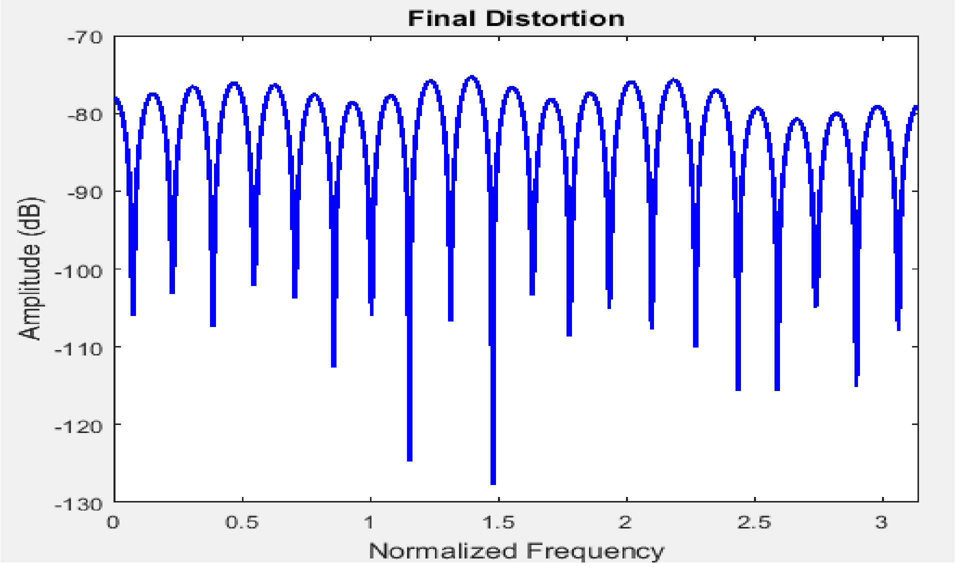

Figure 7: Amplitude of final distortion

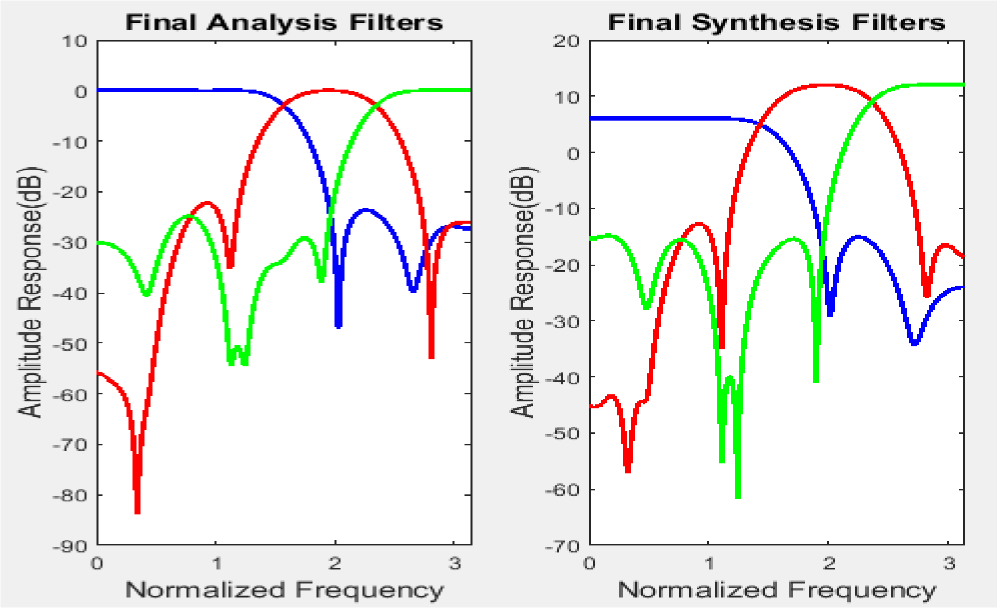

Figure 8: frequency response of final analysis filters and final synthesis filters

5. Conclusion

To solve the filter bank design challenge for data fusion applications, we used a dual-quadratic function formulation, where we minimised the energy in the filters' stopband area and the PR condition. While there may be ripple within the filter bank if the condition on the ripple in the passband is relaxed, the output should be ripple-free if the PR is met. The proposed design technique is shown to be extremely fast and efficient in simulations involving both uniform and nonuniform high-order filter banks, as well as compatible and incompatible sample set scenarios.

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