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A Digital Filter Bank based on a Hybrid Modified Improved Coefficient Decimation Method for Cognitive Radio Application

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Abstract

Realization of filter banks (FB) or variable digital filters (VDF) with low complexity to support various operations in multi-standard wireless receivers such as in spectrum sensing and channelization is a challenging task. In this paper, a hybrid modified improved coefficient decimation method (HMICDM) is proposed for the design of a novel filter bank with low implementation cost based on combined improved coefficient decimation method (ICDM), improved modified coefficient decimation method (IMCDM) and coefficient interpolation method (CIM). The proposed filter bank is capable of providing the same number of uniform and non-uniform sub-bands as ICDM but with a lower decimation factor. Individual frequency bands are obtained from the output of HMICDM by the use of suitable masking filters. A design example of the proposed filter bank indicates a 43.1% reduction in the number of multiplications when compared to the convention ICDM. This is however obtained at the expense of increase in architectural size.

Keywords: FIR filter, Filter banks, Cognitive radio.

I. INTRODUCTION

The Filter banks (FB) and variable digital filters (VDF) implemented with finite impulse response (FIR) find extensive applications in cognitive radio processes. Owing to their characteristics of linear phase, ease of implementation and inherent stability, the FIR filters are preferred in communication systems over IIR filters. However, FIR filters with sharp transition bands have a large number of coefficients thereby increasing the computational complexity. Several techniques have been suggested in the literature to realize FIR filter banks with low complexity.

A Cosine Modulated FB (CMFB) was adopted in software-defined radio (SDR) channelizer and used in hearing aid application [1] as well as in cognitive radio [2]. The per-channel structure which use separate digital filters to extract each distinct sub-channel signals, is a direct approach and hence relatively simple. The two main disadvantages of this approach are, first, the technique requires the awareness of each sub-channel bandwidth. Secondly, the number of filter branches increase linearly with the number of received channels [3]. In addition the technique is not efficient when large numbers of channels are to be extracted. The DFTFB has been developed as the replacement of the per-channel approach when the number of channels that need to be extracted is too large. The discrete Fourier transform filter bank (DFTFB) is a modulated FB which is being employed in SDR communication. It consists of a prototype low pass filter followed by DFT operations [4] [5] which enable the technique to effectively utilize the polyphase decompositions of filters. However, the main disadvantage of the DFTFB method is that, it cannot deal with non-uniform sub-channels. As a consequence, distinct channel bandwidths cannot be extracted simultaneously.

The Goertzel filter bank (GFB) was proposed in [6] which is based on the Goertzel algorithm and was aimed at overcoming the stacking channel problem of the DFTFB. However these techniques do not possess multi-standard channelization features. The GFB employs IIR filters and can therefore exhibit instability during reconfiguration. The implementation complexities in all the above mentioned methods are directly proportional to the number of distinct frequency channels that needed to be extracted.

Low complexity FIR filters were designed in [7-9] using two operations. Different multi-band frequency responses were generated using CDM-I operations and the pass-band width of the modal filter varied using CDM-II operations. Based on the CDM, a variety of filter banks with low implementation complexity and multi-standard channelization features have been suggested in literature [10-12].

Multi-stage coefficient decimation filter bank (MS-CDFB) based on CDM-I, CDM-II and frequency response masking (FRM) filters was introduced in [10] for obtaining a uniform filter bank. Non- uniform filter banks based on CDM-II, interpolation and frequency response masking filters were proposed in [11]. Progressive decimation filter bank (PDFB) proposed in [12] to provide both uniform and non-uniform filter banks using CDM-II operation, offer low design and eliminate the re-configurability overhead required in FRM.

In [13], Ambede et al proposed the ICDM-II FB which showed a larger reduction in the number of multiplication complexity over PDFB. However, there is still a need to improve this method in terms of reducing the multiplication operations.

In this paper, a hybrid modified improved coefficient decimation method (HMICDM) is proposed. It is based on the combination of improved coefficient decimation method (ICDM) [14], improved modified coefficient decimation method (IMCDM) and coefficient interpolation method (CIM). It has the advantage of reducing the number of multiplications.

The rest of this paper is organized as follows. Section II presents the theoretical basis of the proposed HMICDM. Section III presents a design example that shows the advantage of the proposed method over ICDM-II FB and the discussion of results. The conclusions and suggestions for further work are drawn in Section IV.

II. THEORETICAL BASIS OF THE PROPOSED ALGORITHM

This new method consists of three stages. In the first stage, a modal filter also referred to as a prototype filter is designed. In the second stage, the coefficient decimation operations are performed on the modal filter. Lastly, the coefficient interpolation operations are performed on the modified modal filter. When performing the technique, (ML^2) sub-bands are obtained as demonstrated in section III.

In the coefficient decimation method (CDM), the modified filter coefficients in the frequency domain are obtained from:

$$H_1(e^{j\omega}) = \frac{1}{M}\sum_{k=0}^{M-1} H\left(e^{j\left(\omega-\frac{(2\pi k)}{M}\right)}\right) \tag{1}$$

Where $0 \leq k \leq M\text{-}1$

The filters obtained after performing the CDM-I operations consist of the same size of pass bands and transition bands and the same filter order as in the low-pass FIR prototype filter.

The pass bands and transition bands of the obtained filters when performing CDM-II operations are M times that of the low-pass FIR prototype filter. The order of the obtained filters after performing CDM-II operations are $1/M$ times that of the low-pass FIR prototype filter. This is because all the zeros obtained after performing CDM-I operations are discarded and the reserved taps are group together.

In the modified coefficient decimation method (MCDM) [14], multi-band frequency responses with center frequencies of the sub-bands located at the integer multiples of π/M are obtained. The Fourier transform of the modified filter taps is given by:

$$H_2(e^{j\omega}) = \frac{1}{M}\sum_{k=0}^{M-1} H\left(e^{j\left(\omega-\frac{\pi(2k+1)}{M}\right)}\right) \tag{2}$$

Similar to the second operation of CDM, the order of the filters after performing MCDM-II operations are $(1/M)$ times that of the low-pass FIR prototype filter.

Improved modified coefficient decimation method (IMCDM) is introduced in [15] whereby, if the decimation factor is M, then every M^{th} tap of the low-pass FIR filter is retained. All other taps are replaced by zeros. The sign of every two retained taps are reversed. As a result of this operation, the multi-band frequency response of an FIR filter is obtained with center frequencies at $\frac{2\pi(k+\frac{1}{4})}{M}$, where k is an integer ranging from 0 to $M\text{-}1$. If $H(e^{j\omega})$ denotes the Fourier transform of the prototype filter coefficients, then the Fourier transform of the modified filter coefficients is given by:

$$H_3(e^{j\omega}) = \frac{1}{M}\sum_{k=0}^{M-1} H\left(e^{j\left(\omega-\frac{2\pi(k+\frac{1}{4})}{M}\right)}\right) \tag{3}$$

After performing IMCDM-II operations, the pass band filters are obtained with the similar pass bands and transition bands size as in the CDM-II process.

When having the same size of prototype filter order number and the same of decimation factor value. The corresponding MCDM-II, CDM-II and IMCDM-II operations are mathematically related as follows:

$$h_2(n) = (-1)^n h_1(n) \quad \text{for } n=0, 1, 2 \ldots N \tag{4}$$

$$h_3(n) = (-1)^n h_2(n) \quad \text{for } n=0, 2, 4 \ldots N \tag{5}$$

$$h_3(n) = (-1)^n h_2(n) \quad \text{for } n=1, 3, 5 \ldots N \tag{6}$$

The combination of IMCDM, CDM and MCDM is termed the modified improved coefficient decimation method (MICDM).

The technique to synthesize FIR filters with sharp transition bands also referred to as the coefficient interpolation method (CIM) was suggested in [16-18]. If this method is applied to the MICDM, then the resulting filter is termed HMICDM and will have properties which contain many sparse coefficients. Thus, a wide transition-band filter with low complexity will be used in making filters for extracting individual desired frequency bands [19]. The technique simply adds $L\text{-}1$ zeros between every two coefficients of the modified filter where L denote the interpolation factor.

III. COMPUTER SIMULATION RESULTS AND DISCUSSION

The advantages of HMICDM based filter bank over ICDM based filter bank are discussed with the help of an illustrative example as given below.

Figure *1* shows the magnitude response of the low-pass FIR prototype filter which is overdesigned to -60 dB of stop band attenuation instead of -55 dB in order to compensate for the effect of the decimation factor *(M)* in stop band attenuation (SA). The filter coefficients are computed using Parks-McClellan algorithm to obtain the desired frequency response with the following specifications:

f_{pass}=1800 Hz, f_{stop}=2000 Hz, $f_{sampling}$=40000 Hz

$$\delta_{pass} = 0.1dB \text{ and } \delta_{stop} = -60\ dB.$$

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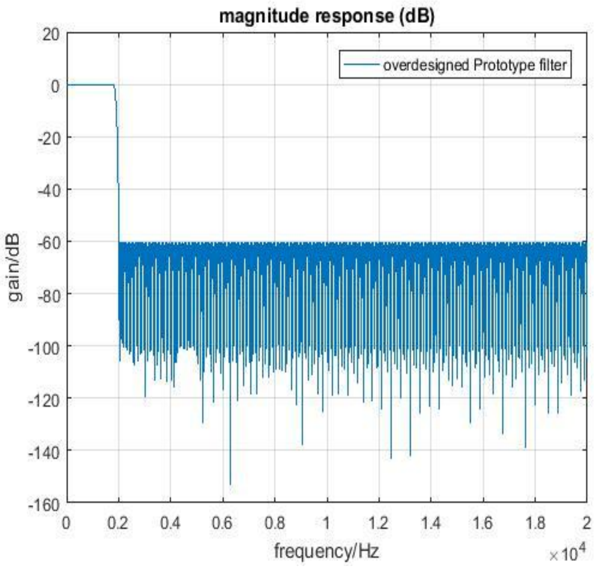

Fig. 1: Prototype filter

Figure *2* and figure *3* show the magnitude responses when performing MICDM-I and ICDM-I operations with $M = 2$ on the prototype filter. It is seen clearly that MICDM-I provide more bands with less decimation factor thus less stop-band attenuation is attained with MICDM-I than in ICDM-I. It can also be noted in table *1* below that the length of the modal filter in MICDM is less than in ICDM which further reduces the power consumption (since power consumption is directly proportional to the number of filter order) and the implementation complexity.

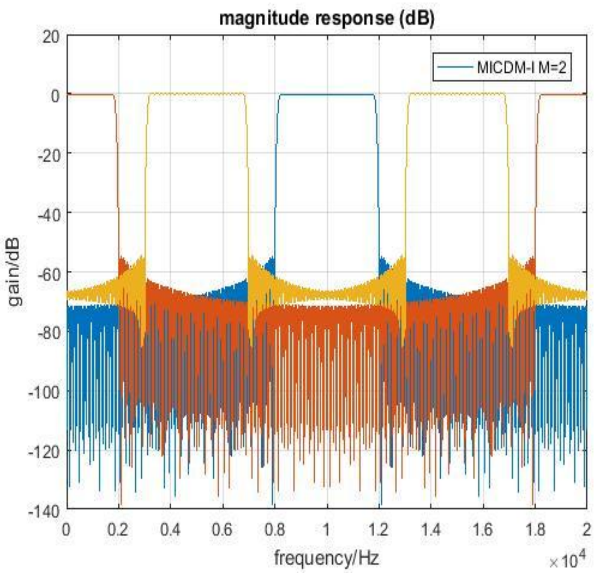

Fig. 2: Magnitude response obtained after performing MICDM-I M=2 on the prototype filter

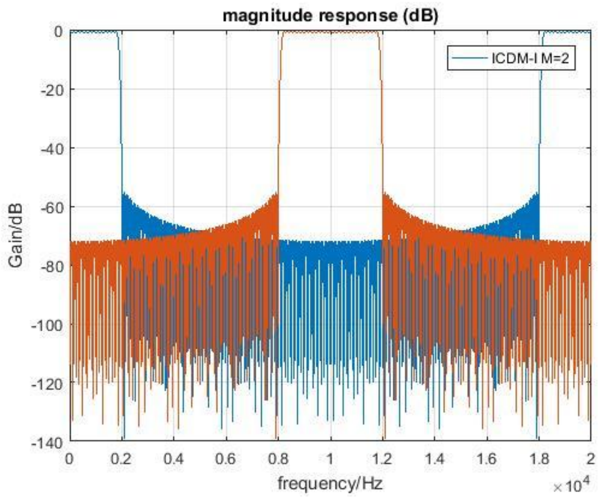

Fig. 3: Magnitude response obtained after performing ICDM-I M=2 on the prototype filter

Suitable masking filters or spectral subtraction can be used to isolate individual sub-bands with identical bandwidths after performing MICDM-I operations. Figure *4* shows the frequency response after performing HMICDM-I with $M = 2$ and L=*2*, where M is the decimation factor and L is the interpolation factor.

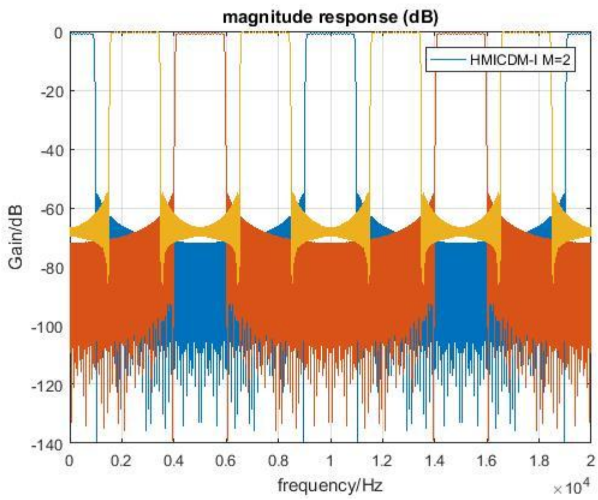

Fig. 4: Magnitude response obtained after performing HMICDM-I M=2, L=2 on the prototype filter

More bands which are in the order of $1/L$ narrower than those in MICDM are found, hence more improvement in the flexibility of filter bank architecture.

Figure *5* and figure *6* shows the same results as figure *4* but with higher decimation factor hence HMICDM employ a prototype filter with less order number which reduces power consumption and implementation complexity.

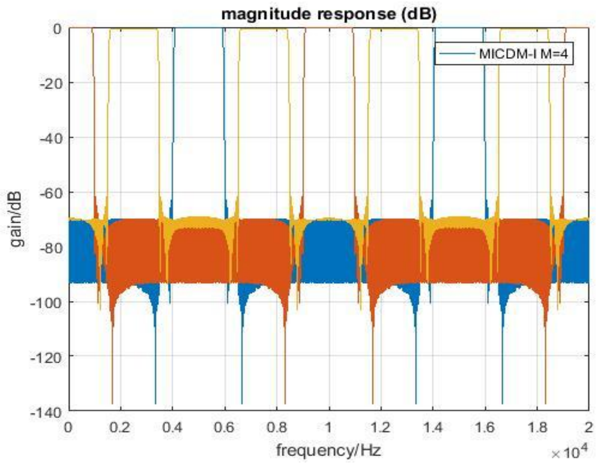

Fig. 5: Magnitude response obtained after performing MICDM-I M=4 on the prototype filter

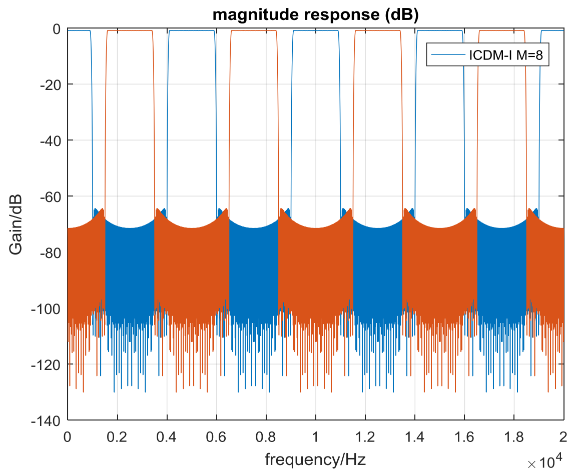

Fig. 6: Magnitude response obtained after performing ICDM-I M=8 on the prototype filter

Table 1: Multiplication complexity comparison to obtain two sub bands

Particulars	ICDM-I M=8	Proposed	
		MICDM-I M=4	HMICDM-I M=2 L=2
Length of modal filter (Lmod)	1248	1176	552
Length of masking filter (Lmask)	300×2=600	300×2=600	250×2=500
Number of multiplication [Lmod/2]+[Lmask/2]	[1248/2]+[600/2]=924	[1176/2]+[600/2]=888	[552/2]+[500/2]=526
Total number of multiplication	924	888	526
Percentage reduction	0%	3.9%	43.1%

Table *1* shows the multiplication complexity of the three methods in the extraction of two uniform frequency bands (5 kHz and 15 kHz) as shown in figure *7*, figure *8* and figure *9*. It is clearly that the proposed method HMICDM gives a 43.1% reduction in the number of multiplication when compared to the conventional ICDM.

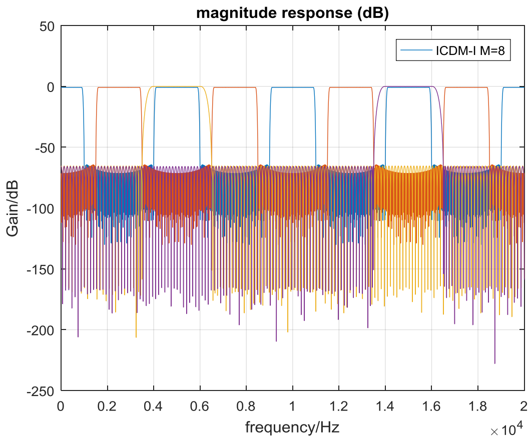

Fig. 7: Extraction of 5 kHz and 15 kHz frequency bands using ICDM-I M=8 and suitable FRM

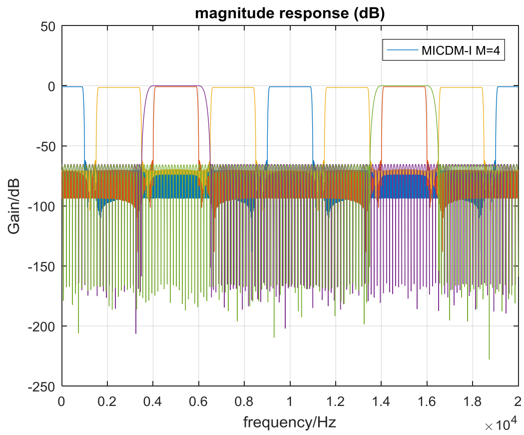

Fig. 8: Extraction of 5 kHz and 15 kHz frequency bands using MICDM-I M=4 and suitable FRM

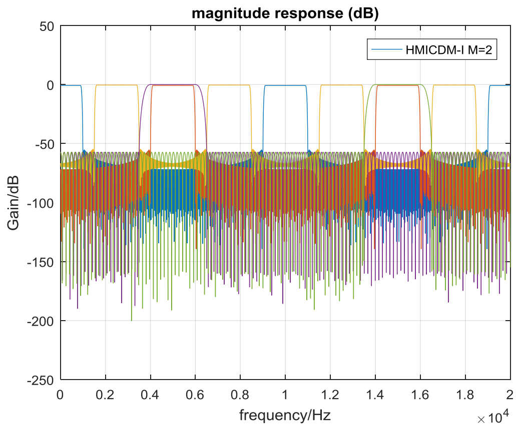

Fig. 9: Extraction of 5 kHz and 15 kHz frequency bands using HMICDM-I M=8 and suitable FRM

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V. CONCLUSION

In this paper, a new method has been proposed for the design of FIR filter banks (FBs) with low complexity and power consumption based on the hybrid modified improved coefficient decimation method (HMICDM). It has been demonstrated that, the HMICDM-I based FB exhibits a significant reduction in complexity over the conventional ICDM-I. The design example indicate that the proposed method offers a 43.1% reduction in multiplication complexity when compared to the ICDM-I method. For this reason the HMICDM-I based FB could be the better choice multi-standard channelization.

REFERENCES

[1] S. Kalathil and E. Elias, "Efficient design of non-uniform cosine modulated filter banks for digital hearing aids", AEU-International Journal of Electronics and Communications, vol. 69, pp. 1314–1320, 2015

[2] S. C. Prema and D. S. Rani, "CMFB for spectrum detection and utilization in CR applications", 2015 International Conference on Computing and Network Communications (CoCoNet), *pp*. 511-515, *Trivandrum, India,* Dec 2015.

[3] S. J. Darak, A. P. Vinod and E. M. K. Lai, "A low complexity reconfigurable non-uniform filter bank for channelization in multi-standard wireless communication receivers," Journal of Signal Processing Systems for Signal Image and Video Technology, vol.68 (1) pp.95–111, Jul 2012

[4] F. Sheikh and B. Bing, "Cognitive spectrum sensing and detection using polyphase DFT filter banks," in Proceeding of the IEEE Consumer Communications and networking conference, pp. 973–977, *Las Vegas, Nevada, USA*, Jan. 2008.

[5] D. Lee, D. Kim and C. M. Lim, "Performance analysis of frequency hopping satellite communication system reducing the transient response of Polyphase DFT filter", The 20th Asia-Pacific Conference on Communications (APCC), pp. 199-202, Pattaya, Thailand, Oct. 2014.

[6] T. Hentschel, "Channelization for software defined base stations," Annales des Telecommunications, vol. 57, no. 5-6, pp. 386-420, March 2002

[7] R. Mahesh and A. P. Vinod, "Coefficient decimation approach for realizing reconfigurable finite impulse response filters," in Proceeding of the IEEE ISCAS, Washington, DC USA, pp. 81–84, May 2008.

[8] R. Mahesh and A. P. Vinod, "A low-complexity flexible spectrum sensing scheme for mobile cognitive radio terminals," IEEE Transactions Circuits Systems II, Express Briefs, vol. 58, no. 6, pp. 371–375, Jun. 2011.

[9] R. Mahesh and A. P. Vinod, "Low complexity flexible filter banks for uniform and non-uniform channelization in software radios using coefficient decimation," IET Circuits, Devices & Systems, vol.5, no.3, pp. 232-242, May 2011.

[10] M. Lin, A. P. Vinod and C. M. S. See, "A new flexible filter bank for low complexity spectrum sensing in cognitive radios," Journal of Signal Processing Systems for Signal, Image and Video Technology, Springer, vol. 62, no. 2, pp. 205-215, 2011

[11] K. G. Smitha and A. P. Vinod, "A new low power reconfigurable decimation-interpolation and masking based filter architecture for channel adaptation in cognitive radio handsets," Physical Communication, Elsevier, vol. 2, no. 1–2, pp. 47-57, March–June 2009

[12] M. Lin, A. P. Vinod and C. M. S. See, " Progressive decimation filter banks for variable resolution spectrum sensing in cognitive radios," 2010 IEEE 17th International Conference on Telecommunications, ICT 2010, pp. 857-863, Doha, Qatar, April 2010

[13] Ambede, A. P. Vinod and A. S. Madhukumar, "Design of a Low Complexity Filter Bank Satisfying LDACS1 Spectral Mask Specifications for Base-Station Receivers in Air-Ground Communications," IEEE/AIAA 35th Digital Avionics Systems Conference (DASC), Sacramento, California, USA, Sept. 2016

[14] A. Ambede, K. G. Smitha, and A. P. Vinod, "A Modified Coefficient Decimation Method to Realize Low Complexity FIR Filters with Enhanced Frequency Response Flexibility and Pass-band Resolution," 35th International Conference on Telecommunications and Signal Processing (TSP), pp. 658-661, Prague, Czech Republic, July 2012

[15] B. Mgawe and E. Mwangi, "An Improved Modified Coefficient Decimation Method to Realize Low Complexity Reconfigurable FIR Filters For Cognitive Radio", Proceedings of ISER 135th International Conference, pp. 81-84, St Petersburg, Russian Federation, July 2018.

[16] A. Ambede, S. Shreejith, A. P. Vinod and S. A. Fahmy, "Design and Realization of Variable Digital Filters for Software-Defined Radio Channelizers Using an Improved Coefficient Decimation Method", Circuits and Systems II: Express Briefs IEEE Transactions on, vol. 63, pp. 59-63, 2016, ISSN 1549-7747.

[17] R. Mahesh and A. P. Vinod, "Frequency Response Masking based Reconfigurable Channel Filters for Software Radio Receivers," IEEE International Symposium on Circuits and Systems, pp. 2518-2521, *New Orleans USA*, May 2007

[18] W. Zhang, Q. Du, Q. Ji and T. Chen, "Unified FRM-based complex modulated filter bank structure with low complexity," IET Electronics Letters, Vol. 54, pp. 18-20, 01 February 2018

[19] T. Sinha and J. Bhaumik, "Designing of sharp transition low pass FIR filter using multistage FRM approach," Devices for integrated circuit (DevIC), pp. 414-418, Kalyani, India, March 2017.