Design and Performance Evaluation of Lattice Daubechies Wavelet Filter Banks for Less Complex Cognitive Transceivers

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ABSTRACT

Wavelet Packet Based Multicarrier Modulation (WPMCM) system uses usually a prototype filter bank multicarrier. The Daubechies-D10 filter bank (D10FB) is the basic framework of multicarrier modulation (MCM) transceiver system. In this paper, Lattice structures of exact Daubechies-D10 wavelet filter are adopted to design a prototybe filter bank realized for a proposed structure of WPMCM transceiver system. Magnitude and phase responses of the exact Daubechies-D10 LPF and the proposed structure are compared. They are nearly the same in the passband with improved roll-off characteristics of the magnitude response of the proposed. Whilefrom the results, it appears that the proposed WPMCM structure possess low speed of operation, less complexity and less power consumption.It is also noticed from SNR comparison, that the performance evaluation of the proposed WPMCM transceiver system is a moderate between other two previously issued structures.

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1. INTRODUCTION

In the last few decades, wireless applications have been expanding. This progress calls for further radio spectrum. However this radio spectrum is a limited resource and it becomes saturated. The spectrum was statically distributed under fixed spectrum access policy. National Telecommunication and Information Administration's (NTIA) allocates the spectrum frequency and demonstrates how the radio spectrum has been licensed and separated into number of bands where each band is specified to different services, such as mobile telephone, radio, television and others [1],[2].

Furthermore, it looks like that there is no much space to append any new services, except when some of the available licenses are suspended. Therefore in order to hold this issue and the discrepancy between spectrum rareness and spectrum underutilization, a smart wireless communication system called cognitive radio (CR) is invented to allocate frequency spectrums and utilized optimally. Licensed users (LUs) in most wireless communication applications utilize frequency spectrums inefficiently and portions of frequency spectrums are not used. These portions is called spectrum holes. That's why CR has planned that these spectrum holes must be shared with unlicensed users (UUs) in the absence of LUs [3].

This paper is organized as follows: Section 1 explains an introduction to the issue to be solved in this paper. Theoretical bases of multicarrier systems such as OFDM and WPMCM are introduced in section 2 with the comparison of their performance and properties. Section 2 also provides the foundation of the traditional WPMCM system. Filter bank structures for analysis and synthesis to assure perfect reconstructionconditions, are also contained. This

section also shows the Lattice structure for wavelet filter bank be used to design the prototype filter. Section 3 givesa literature review for lattice structure.

In section 4, the proposed filter bank design model is adopted from the prototype lattice Daubechies-D10 wavelet filters. Section 5, shows many results and comparisons. The resulting magnitude and phase filter responses are included for the designed prototype filter and the deviation between responses of the exact and those of the proposed structures. Acomplixitycomparisionis is also illustrated between the exact D10FB and the proposed filter bank. In addition, performance evaluation of three types of lattice wavelet filter bank studied according to BER vs. noise variance under several types of modulation schema for AWGN and Rayleigh fading channels are are also considered. Finally, section 6 concludes this paper.

2. MULTICARRIER MODULATION SYSTEMS

Orthogonal frequency division multiplex OFDM based system was recommended to be the greatest candidate for CR transmission [4]. Recently wavelet packet filter bank system is investigated as a multicarrier modulation system (MCM). Such a system is called wavelet packet multicarrier modulation (WPMCM) andnominated as an attractive alternative multicarrier modulation technique for CR based systems. WPMCM has many interesting features such as, adaptability, flexibility, moderate complexity, side lobes suppression, spectrum efficiently, and has many advantages over the traditional Fast Fourier Transform FFT based OFDM systems [5].

The greater disadvantage of the OFDM is that the FFT process in OFDM decomposes the signals into sines and cosines, which cause high side lobes as a consequence of rectangular window application. Furthermore, the pulse shaping function used to modulate each subcarrier spreads to infinity in the frequency domain. By contrast, the wavelet packet transforms (WPTs) have extensive basis functions and can give power spectral density (PSD) with a higher degree of side lobes prevention. The long wavelet basis in WPMCM can allow for better frequency localization of subcarriers [6]. Regardless, the length of wavelet basis is much longer than the interval of a symbol causes some overlap in the time domain while preserving their orthogonality. Also, WPMCM progress robustness to carrier frequency offsets and timing offsets. Thus, WPT in WPMCM can progress a manner of functioning

against channel effects. Consequently, there is no need of cyclic prefix to attenuate the inter-symbol interference (ISI) which is a major disadvantage in the OFDM that causes bandwidth inefficiency, where the total bandwidth sacrifices by about 20% to 25% of it for cyclic prefix[7], [8].

Thus WPMCM gives great orthogonality between subcarriers and takes advantage of fixing up the imperfection in bandwidth wastage by having admirable spectral containment. Furthermore, WPMCM can be realized in a faster model and processed by less-complex computations, leading to some decrease in transmission power. In addition, WPMCM has the advantage of analysing signals in WPT by representing them in time-frequency domain rather than just the frequency domain as in FFT. That's why WPMCM has come out as admirable candidates for MCM in CR wireless communication systems [5],[9].

WPMCM transceiver system utilizes inverse wavelet packet transform (IWPT) at the transmitter side and WPT at the receiver side. At the receiver, the essential parts of WPMCM is a pair of quadrature mirror filters (QMFs), {h[n], g[n]} half-band low and high pass analysis filter, respectively. On the other side, at the transmitter, it has a pair of quadrature mirror filters {p[n], q[n]} half-band low and high pass synthesis filter, that are applied to create the wavelet packet carriers for modulation of data. The half-band low and high pass analysis filter with L length of each filter must satisfy the following condition[10]:

$$g[n]=(-1)^n h[L-n-1] \qquad (1)$$

In addition to fulfil perfect reconstruction (PR), the pair of analysis and synthesis filter banks must be assure three specific conditions:

$$G[z]=H[-z]$$
$$P[z]=H[z]$$
and
$$Q[z]=-H[-z] \qquad (2)$$

These conditions are due to presence the mirror image symmetry around the frequency $\omega=\pi/2$ in the middle of both QMF bank $H(e^{j\omega})$ and $G(e^{j\omega})$ as characterized in Fig. 1 [11].

Moreover realizing both orthonormality properties and PR, the analysis and synthesis filters must fulfil the following two conditions [11]:

$$H[-z]P[z]+ G[z]Q[z]=0 \qquad (3)$$
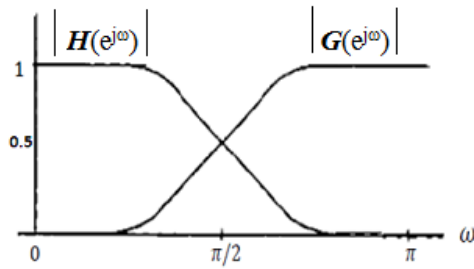and

$$H[z]P[z]+ G[z]Q[z]=2z^{(-1)} \quad (4)$$

Fig. 1 Frequency responses of QM analysis filters,[11].

Fig. 2 explains the classical WPMCM structure of a transceiver with three-stage decomposition (8 channels)[12]. In this figure WPT is utilized in WPMCM. Therefore WPT uses multi-resolution technique by which different frequencies are analysed with different resolutions. Filter banks in WPT are used to divide the signal into a set of sub-band signals and change the resolution of that signal. So, using a multi-scale filter bank will analyse each sub-band signal with a resolution corresponds to its scale. That is the measuring of quantity of detail information in the signal. Accordingly, the up-sampling and down-sampling operations are employed to change the scale in the signal as seen in Fig. 2[13],[14].

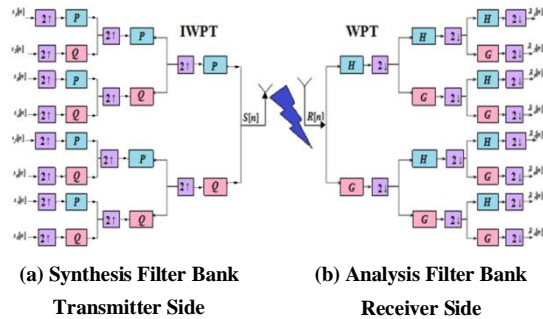**(a) Synthesis Filter Bank Transmitter Side**   **(b) Analysis Filter Bank Receiver Side**

Fig. 2 WPMCM transceiver system for three-stage decomposition (8 channels) [12].

The IWPT is realised by WP synthesis filter bank which joins different parallel streams into a sole signal $S[n]$. After transmiting $S[n]$, WPT is implemented using WP analysis filter banks at the receiver. So the composite signal is separated into simpler compounds, as shown in Fig. 2.

In WPMCM transceiver system all modulation signals can be comprised of a sum of modulated wavelet packet coefficients $\zeta_l^p[n]$ weighted with complex data $a_{u,k}$, known as multicarrier symbols. The signal $S[n]$ can be expressed as follows [15]:

$$S[n] = \sum_u \sum_{k=0}^{N-1} a_{u,k} \zeta_{log_2(N)}^k (n - uN) \quad (5)$$

In Equation (5) every wavelet packet coefficient $\zeta_l^p[n]$ is computed as in the following two equations by convolving h and g filters with the wavelet packet coefficients from a prior level. This convolution process is performed again for all wavelet packets until attaining the desired resolution. This process is demonstrated clearly in wavelet packet analysis and is well explained in Fig.2 (b) in *Ref.* [15].

$$\zeta_{l+1}^{2p}[n] = \sqrt{2} \sum_k h[k] \zeta_l^p[2n-k] \quad (6)$$

$$\zeta_{l+1}^{2p+1}[n] = \sqrt{2} \sum_k g[k] \zeta_l^p[2n-k] \quad (7)$$

With a reversed recurrent method, a wavelet packets synthesis filter bank can reconstruct the wavelet packets as follows:

$$\zeta_l^{2p}[n] = \sum_k h[k] \zeta_{l+1}^{2p}[2n-k] + \sum_k g[k] \zeta_{l+1}^{2p}[2n-k] \quad (8)$$

This reconstruction is called wavelet packet synthesis which illustrated in Fig. 2(a)[15]. The whole framework of the WPMCM transceiver system is described in Fig. 3.
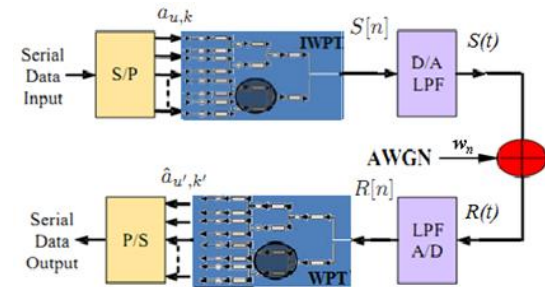

Fig. 3 WPMCM transceiver system framework.

When number of channels is increased, the complexity of whole system will be increased in an aprximate exponential rate with base 2.This expensive issue must be resolved. In this paper, a new WPMCM-transceiver system structure is designed using a novel type of wavelet FIR filter bank called Lattice Daubechies Wavelet Filter Bank (LDWFB). The essential framework of such filter bank is realised in this paper with less-complexity.

Lattice structure will achieve less complexity goal due to the fact that it can be accomplished using two adders, two multipliers and one delay in each of analysis and synthesis trans-multiplexer lattice wavelet unit, where α_i is the value of the lattice coefficient at the ith stage of trans-multiplexer lattice unit, as depicted in Fig. 4. Thus, lattice structure of wavelet filter banks introduces a new tool for constructing

trans-multiplexer model. In such model, a filter bank can be constructed from multiple stages of trans-multiplexer lattice wavelet units. Where parallel data channels should be multiplexed into one signal, transmitted and then reconstructed using synthesis and analysis lattice wavelet filter banks, respectively [16].
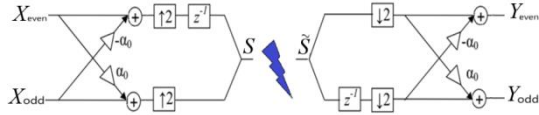

Fig. 4 First unit of synthesis and analysis trans-multiplexer lattice wavelet[16].

In this paper, the WPMCM system needs a filter bank multicarrier (FBMC) in model. Where FBMC is accomplished by orthogonal and QMF. The proposed filter banks is designed and realized as Lattice Daubechies-based transceivers. The Daubechies Wavelet filter banks (DFB) are used as the essential framework of such FIR filter banks and are adopted from Daubechies-D10 wavelet filter that are implemented in lattice structure filter bank, which will be used here in the design of a Daubechies wavelet multicarrier DWMCM transceiver system. Where trans-multiplexer configuration for analysis filter bank in the receiver and synthesis filter bank in the transmitter to simulate a dual channel filter bank.

The most significant characteristic of DFBs is power symmetric. Power symmetric filter banks are allowed to be realized using lattice structures [17]. Where lattice structures are readily to implement [18]. Also in high degree parallelism the power symmetric filter banks can save together regularity and modularity, which causing high throughput. So the LDWFB are designed and realized in this paper which must have a real coefficients that satisfy the condition [19]:

$$|H(e^{jw})|^2 + |G(e^{jw})|^2 = 1 \qquad \text{for all w} \qquad (9)$$

In addition, the polyphase structure can be stand in by a lattice structure. Fig. 4 shows the construction of wavelet filter bank using lattice structure in trans-multiplexer model.

LDWFBs are designed to approximately satisfy the perfect reconstruction PR conditions. First design the filters' polyphaseof the analysis filter Bank as below [20]:

$$H[z] = H_{even}[z^2] + z^{-1}H_{odd}[z^2] \qquad (10)$$

$$G[z] = G_{even}[z^2] + z^{-1}G_{odd}[z^2] \qquad (11)$$

Then the polyphase matrix $A_P$of the specified analysis filter Bank is as follow:

$$A_P[z] = \begin{bmatrix} H_{even}[z] & H_{odd}[z] \\ G_{even}[z] & G_{odd}[z] \end{bmatrix} \qquad (12)$$

The transfer function in matrix form for the polyphase structure of LDWFB at the receiver side inWPMCM transceiver system will be:

$$S[z] = A_P[z]X[z] \qquad (13)$$

$$\begin{bmatrix} S_{even} \\ S_{odd} \end{bmatrix} = \begin{bmatrix} H_{even}[z] & H_{odd}[z] \\ G_{even}[z] & G_{odd}[z] \end{bmatrix} \begin{bmatrix} X_{even} \\ X_{odd} \end{bmatrix} \qquad (14)$$

where X_{even} and X_{odd} are used to denote the even and odd terms of input X, respectively. AndS_{even} and S_{odd} are used to denote the even and odd terms of output S, respectively as depicted in Fig. 4.

3. LITERATURE REVIEW

Considerable researches has been publishedin this area and numerouslattice structures available in literature [11],[21]-[28].

In 1999, C. Goh*et al.*[21], used lattice structure to design two channel perfect reconstruction-quadrature mirror filter banks (PR-QMFB) by an efficient weighted least squares algorithm. The filter bank design problem was devised as a weighted least square problem with regards to the lattice coefficients. Theweighted minimaxlattice coefficients was optimizes by iterative algorithm with only small number iterations. The lattice structure PR-QMFBs applied filters possesingstopband attenuation exceeding 100dB, with stopband ripple control.

In 2007, V. Herrero*et al.*[22], used folded lattice architecture where one filtering unit used to performs n-octaves levels of performing one-Dimentional (1-D)Daubechies DWT operations. This was accompleshed by folding the outputs to the input n-1 times. The design was produced using the VIRTEX V100 hardware chip.

In 2013, J. M. Abdul-Jabbar and Z. Z. H. Altaei[11], designed and implemented discrete wavelet multi-tone (DWMT) transmission system using IIR wavelet filter banks. Bireciprocal lattice wave digital filters (BLWDFs) were implemented in an approximate linear phase designed of 11th order IIR wavelet filter bank for DWMT transmission systems. Again, in 2014, J. M. Abdul-Jabbar and R. W. Hamad[23], used lattice structure to design an efficient FIR filter bank. The lattice FIR filter bank coefficients were designed to simulate a 1[st]order Gaussian derivative. Lattice and polyphase FIR filter were implemented and designed for 5[th]order QRS-like filter banks for fuzzy classification ofECG signals. The QRS-like FIR filter bank is realized

to extract as much information as possible to classify different cardiac diseases in QRS wave.

In 2015, also J. M. Abdul-Jabbar, and O. N.Saadi[24], designed a linear phase IIR filter. The coefficients of the designed filter were fulfilled by simulating the FIR response of *Ref.*[23]. A least square method solution is used to minimize the error between transfer responses of their design and that of*Ref.*[23]. This minimization was simulated with a three intelligent computation algorithms.Bireciprocal lattice wave digital filters (WDFs) were implemented in a sufficient linear phase design of 5thorder IIR wavelet filter bank for QRS complex detection.

In 2017, J. Lee and C. Ciou[25], designed and simulated a lattice structure of two-dimensional (2-D) two channel quincunx quadrature mirror filter QMF banks (QQMFBs), which utilized 2-Drecursive symmetric half-plane (SHP) digital all-pass lattice (DAL) filters. This 2-D SHP QQMFB has a promising 2-D DC half-band property that permits nearby half of the 2-D recursive SHP DALF's coefficients to be zero. The simulation results evidence the efficient of the designed 2-D recursive SHP DALFs in Lattice-Form as copmerasion to 2-D SHP DALFs in the Direct-Form which desgined in *Ref.* [26].

Again in 2017, A. Hamamoto,*et al.*[27], proposed multidimensional linear phase biorthogonal filter bank (MD LPBOFB) using a lattice structure with higher order feasible (HOF) building blocks.MD HOF building blocks fulfill both the linear phase and perfect reconstruction conditions. HOF structure is compared with a cascade of traditional order-1 structure in terms of the number of parameters, cost and coding gain. The HOF structure defeats the complixity and the cost for MD LPBOFBs designing, but sacrifices the coding gain.

In 2020, S. A. Al-Kishawi,*et al.*[28], designed a WPMCM system. The concept is employed to fulfill a design with near perfect reconstruction (NPR) and less-complex system realization. Bi-reciprocal lattice all-pass digital filter banks (BLAPDFBs) was implemented for NPR of 4th order IIR wavelet filter bank for WPMCM system. The foundation of IIR filter banks are Quadrature Mirror and half-band filter bank which based on the model established in Ref. [23].

4. THE PROPOSED LATTICE DAUBECHIES-D10 FILTER BANK (LD-10FB) MODEL

The LPF and HPF equations of the Daubechies-D10 wavelet filter bank are[29]:

$$H[z] = \sum_k h_k z^{-k} = h_0 + h_1 z^{-1} + h_2 z^{-2} + h_3 z^{-3} + h_4 z^{-4} + h_5 z^{-5} + h_6 z^{-6} + h_7 z^{-7} + h_8 z^{-8} + h_9 z^{-9} \quad (15)$$

$$G[z] = zH[-z^{-1}] = -h_9 + h_8 z^{-1} - h_7 z^{-2} + h_6 z^{-3} - h_5 z^{-4} + h_4 z^{-5} - h_3 z^{-6} + h_2 z^{-7} - h_1 z^{-8} + h_0 z^{-9} \quad (16)$$

where the Daubechies-D10 coefficients are [30]:
$h_0 \cong 0.22641898$, $h_1 \cong 0.85394354$
$h_2 \cong 1.02432694$, $h_3 \cong 0.19576696$
$h_4 \cong -0.34265671$, $h_5 \cong -0.04560113$
$h_6 \cong 0.10970265$, $h_7 \cong -0.00882680$
$h_8 \cong -0.01779187$, $h_9 \cong 4.71742793e-3$
(17)

The magnitude and phase responses of $H[z]$ the Daubechies-D10 wavelet LPF are mapped in Fig. 5(a) & (b).

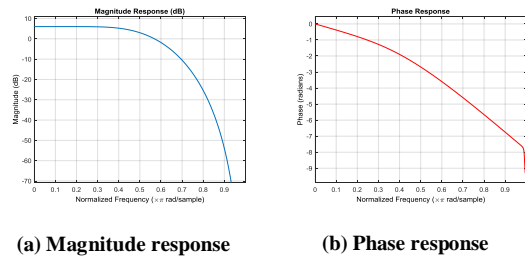(a) Magnitude response   (b) Phase response

Fig. 5 The Frequency Response of the Daubechies-D10 wavelet LPF.

To calculate the corresponding polyphase matrix $A_P[z]$, $H[z]$ and $G[z]$ are separated into even and odd parts. So it will be:

$$A_P[z] = \begin{bmatrix} h_0 + h_2 z^{-1} + h_4 z^{-2} + h_6 z^{-3} + h_8 z^{-4} & h_1 + h_3 z^{-1} + h_5 z^{-2} + h_7 z^{-3} + h_9 z^{-4} \\ -h_9 - h_7 z^{-1} - h_5 z^{-2} - h_3 z^{-3} - h_1 z^{-4} & h_8 + h_6 z^{-1} + h_4 z^{-2} + h_2 z^{-3} + h_0 z^{-4} \end{bmatrix} \quad (18)$$

In consequence of Fig. 6, the polyphase matrix of lattice will be as follows:

$$A_L[z] = \begin{bmatrix} k_1\beta & k_2\beta \\ l_1\beta & -l_2\beta \end{bmatrix} \quad (19)$$

Synthesis Filter Bank   **Analysis Filter Bank**
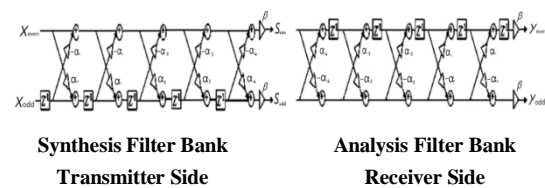**Transmitter Side**   **Receiver Side**

Fig. 6 The analysis and synthesis sides of the LD-10FB.

In Fig. 6, it can be observed the difference between the analysis and synthesis filter banks, the delay element is removed from the beginning of the lower branch in synthesis side to the end of the upper branch of the analysis side. Also it can be noticed the coefficient in the first analysis stage becomes the last synthesis one, in addition

the coefficient α_i stays in its arrange on the two sub branches but with reversed signs. This is as a result of the time reversal of the analysis side required to be accomplished in the synthesis side so that fulfil the perfect reconstruction condition.

By comparing equations (18) and (19) it conclude:

$$
\begin{aligned}
k_1 = 1 &- \alpha_0\alpha_1 z^{-1} - \alpha_0\alpha_2 z^{-2} - \alpha_0\alpha_3 z^{-3} \\
&- \alpha_0\alpha_4 z^{-4} - \alpha_1\alpha_2 z^{-1} \\
&- \alpha_1\alpha_3 z^{-2} - \alpha_1\alpha_4 z^{-3} \\
&- \alpha_2\alpha_3 z^{-1} - \alpha_2\alpha_4 z^{-2} \\
&- \alpha_3\alpha_4 z^{-1} + \alpha_0\alpha_1\alpha_2\alpha_3 z^{-2} \\
&+ \alpha_0\alpha_1\alpha_2\alpha_4 z^{-3} \\
&+ \alpha_0\alpha_1\alpha_3\alpha_4 z^{-2} \\
&+ \alpha_0\alpha_2\alpha_3\alpha_4 z^{-3} \\
&+ \alpha_1\alpha_2\alpha_3\alpha_4 z^{-2}
\end{aligned}
$$

$$(20)$$

$$
\begin{aligned}
k_2 = &-\alpha_0\alpha_1 z^{-1} - \alpha_2 z^{-2} - \alpha_3 z^{-3} - \alpha_4 z^{-4} + \\
&\alpha_0\alpha_1\alpha_2 z^{-1} + \alpha_0\alpha_1\alpha_3 z^{-2} + \alpha_0\alpha_1\alpha_4 z^{-3} + \\
&\alpha_1\alpha_2\alpha_3 z^{-2} + \alpha_1\alpha_2\alpha_4 z^{-3} + \alpha_2\alpha_3\alpha_4 z^{-3} - \\
&\alpha_0\alpha_1\alpha_2\alpha_3\alpha_4 z^{-2} + \alpha_0\alpha_2\alpha_3 z^{-1} + \alpha_0\alpha_2\alpha_4 z^{-2} + \\
&\alpha_0\alpha_3\alpha_4 z^{-1} + \alpha_1\alpha_3\alpha_4 z^{-2} (21)
\end{aligned}
$$

$$
\begin{aligned}
l_1 = &\alpha_0 z^{-4} + \alpha_1 z^{-3} + \alpha_2 z^{-2} + \alpha_3 z^{-1} + \alpha_4 - \\
&\alpha_0\alpha_1\alpha_2 z^{-3} - \alpha_0\alpha_1\alpha_3 z^{-2} - \alpha_0\alpha_1\alpha_4 z^{-1} - \\
&\alpha_0\alpha_2\alpha_3 z^{-3} - \alpha_0\alpha_2\alpha_4 z^{-2} - \alpha_0\alpha_3\alpha_4 z^{-3} - \\
&\alpha_1\alpha_2\alpha_3 z^{-2} - \alpha_1\alpha_2\alpha_4 z^{-1} - \alpha_1\alpha_3\alpha_4 z^{-2} - \\
&\alpha_2\alpha_3\alpha_4 z^{-1} + \alpha_0\alpha_1\alpha_2\alpha_3\alpha_4 z^{-2} \qquad (22)
\end{aligned}
$$

$$
\begin{aligned}
l_2 = &z^{-4} - \alpha_0\alpha_1 z^{-3} - \alpha_0\alpha_2 z^{-2} - \alpha_0\alpha_3 z^{-1} \\
&- \alpha_0\alpha_4 - \alpha_1\alpha_2 z^{-3} - \alpha_1\alpha_3 z^{-2} \\
&- \alpha_1\alpha_4 z^{-1} - \alpha_2\alpha_3 z^{-3} \\
&- \alpha_2\alpha_4 z^{-2} - \alpha_3\alpha_4 z^{-3} \\
&+ \alpha_0\alpha_1\alpha_2\alpha_3 z^{-2} \\
&+ \alpha_0\alpha_1\alpha_2\alpha_4 z^{-1} \\
&+ \alpha_0\alpha_1\alpha_3\alpha_4 z^{-2} \\
&+ \alpha_0\alpha_2\alpha_3\alpha_4 z^{-1} \\
&+ \alpha_1\alpha_2\alpha_3\alpha_4 z^{-2}
\end{aligned}
$$

$$(23)$$

By solving the four concluded equations, the values of lattice coefficients α_i and the value of scaling gain β will be as follows:

$\alpha_0 = $ -2.62151901, $\alpha_1 = $ 0.491024153
$\alpha_2 = $ -0.09215124, $\alpha_3 = $ -0.0455492168
$\alpha_4 = $ -0.02083495, $\beta = $ 0.22641898.

$$(24)$$

5. RESULTSANDCOMPARISONS
5.1 RESPONSE COMPARISON

The resulting magnitude and phase responses of the designed Lattice Daubechies Wavelet LPF are plotted in Fig.7(a) & (b), respectively. It can be noticed that there is an improvement in the transition band between the original Daubechies-D10 filter and the proposed lattice Daubechies-D10 filter as is evident in Figs.

6(a) and 7(a). Also it is clear that Fig. 7(b) demonstrates an approximate linear phase processing, especially in passband region.

The passband deviations (maximumandaverageerrors) between responses of the exact Daubechies-D10 LPF and the proposed structure Lattice Daubechies LPF are given in Table 1. It is clear that the two responses of exact and proposed are similar, with a slight difference.
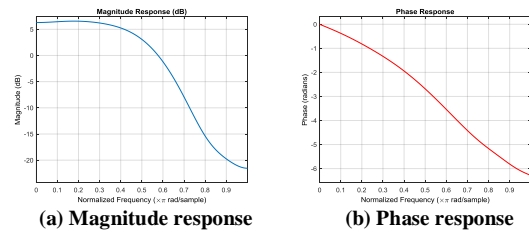

(a) Magnitude response   **(b) Phase response**

Fig. 7 The Frequency Response of the designed Lattice Daubechies LPF.

Table 1:Resulting errorsin the frequency response.

Response	Max. Error	Average Error
Magnitude	0.1426103444489	0.0984621032193
Phase	3.2944287763970	1.5926780405617

5.2 COMPLEXITY COMPARISON

Table 2 show the complexity comparison between exact structure D10FB and the proposed lattice D10FB in either analysis side or synthesis side. This dominates both; the improvement in speed of the filtering operation, and the reduction in complexity of the proposed structure, and hence reducing the power consumption.

Table 2: ComplixityComperasion

	Exact D10FB	LatticeD10FB
Adder	18	10
Multiplier	20	12
Delay	18	5

5.3 PERFORMANCE EVALUATION OFWPMCM TRANSCEIVER SYSTEM

The objective of this subsection is to simulate the WPMCM transceiver system in order to evaluate the system performance based on the effect of various communication channels. Different modulation schemes are covered throughout simulation, and bit error rate (BER) is evaluated for the WPMCM transceiver system

under different channel noise models such as, AWGN and Fading Rayleigh channels.

In all simulations, the values of BERare compared according to noise variance for several MCM transceiver systems based on three different lattice structures. The first, MCM transceiver systems, isbased on the structure of lattice FIR filter bank designed by*Ref*.[23], the second is theWPMCM transceiver system based on Bi-reciprocal lattice wave discrete wavelet IIR filter banks proposed by [28] and the third is based on the proposed structure LD-10FB. Also this simulation covers several types of modulation schema, such as BPSK, QPSK, 4FSK and M-QAM (for M=4,8,16,64)realized intwo types of channels; AWGN channel andRayleigh fading channel.
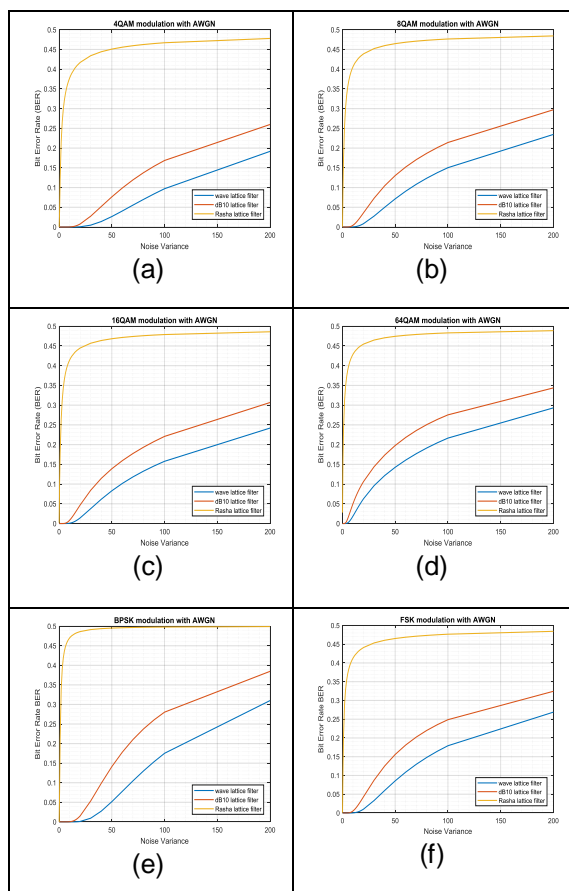

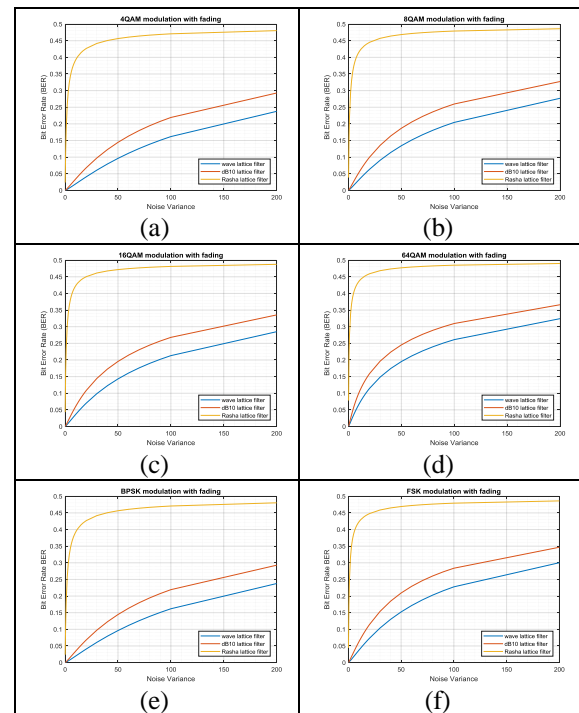Fig. 8 BER vs. noise variance for AWGN channel.

Fig. 9 BER vs. noise variance for Rayleigh fading channel.

Figures (8) and (9) show the performance evaluation of the three WPMCM transceiver systems in AWGN channel and Rayleigh fading channel, respectivelyfor all adopted types of modulation.

Regarding Fig. 8 (a),(b), (c) and (d) it can seen that as the modulation order increases BER increases too. Also Rayleigh fading channel achieved the same result, and it is shown in Figure 9 (a),(b), (c) and (d).

In additionFigs. 8 and 9 show that the BER for M-QAM, BPSK and FSK over a AWGN channel is less than that achieved in Rayleigh fading channel.

Finally, it can be concluded from all Figs.8 and 9 that the best performance from the three WPMCM transceiver system is that based on Bi-reciprocal lattice wave discrete wavelet filter banks proposed by[28] and the system of worst performace is the exact lattice FIR filter bank designed by [23]. While the performaceof the proposed structure LD-10FBis a moderate between the two.

All the results explained in this paper are established on computer simulation executed using MATLAB R2017b.

6. CONCLUSION

Lattice structures of exact Daubechies-D10 wavelet filter have been used to design prototybe filter bank realizedfor WPMCM transceiver system. Magnitude and phase responses of the

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exact Daubechies-D10 LPF and the proposed structurearenearly similar in the passband with improved roll-off characteristics of the magnitude response of the proposed. In addition, the proposed structure had possess low speed of operation, less complexity and less power consumption.

From BER comparisons, it had been noticed that the performance evaluation of the proposed WPMCM transceiver systemmoderate between other two previously issued structures.

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تصميم وتقييم أداء أجراف مرشحات Daubechies المويجية المتشابكة القليلة التعقيد لمرسلات ومستقبلات الاتصالات الإدراكية

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الملخص

عادةً ما يستخدم نظام WPMCM نظامًا متعدد الناقلات لمرشح النموذج الأولي. إنمرشحات التصفية (D10FB) Daubechies-D10 هي الإطار الأساسي لنظام الإرسال والاستقبال متعدد التشكيلMCM . في هذا البحث، تم اعتماد هياكل متشابكةللمرشح المويجي Daubechies-D10 لتصميم جرف مرشح أولي تم إستخدامه للبنية المقترحة لنظام الإرسال والاستقبال.WPMCM تمت مقارنة استجابات السعة والطور لـ Daubechies-D10 LPF والهيكل المقترح. وهي متشابهة تقريبًا في نطاق التمرير مع خصائص انسيابية محسنة لاستجابة المقدار المقترح. من النتائج ، يبدو أن هيكل WPMCM المقترح يمتلك سرعة تشغيل منخفضة ، أقل تعقيدًا واستهلاكًا أقل للطاقة.

يلاحظ أيضًا من مقارنة BER ، أن تقييم أداء نظام الإرسال والاستقبال WPMCM المقترح هو متوسط بين هيكليين سابقين تم إستعراضهما.

الكلمات الدالة:

OFDM؛ نظام الإرسال والاستقبال الإدراكي WPMCM؛ المرشح المويجيDaubechies-D10؛ التعقيد القليل؛ BER.