International Journal of Scientific & Engineering Research Volume 11, Issue 2, February-2020
ISSN 2229-5518

Design of Filter Bank For Multicarrier (FBMC)

Abbas S. Hilal, Manal J. Al-Kindi
Electonic and Communication Engineering Department, College of Engineering,
Al-Nahrain University, Baghdad, Iraq

Abstract—Filter bank multicarrier, FBMC, is a modulation technique to overcome the Inter Carrier Interference (ICI) and Inter Symbol Interference (ISI) that usually occur in OFDM communication systems. The inter carrier interference is a big challenges in network systems. In orthogonal frequency division multiplexing (OFDM), cyclic prefix are used for robustness of signal, but inherently introduce some draw-backs regarding system bandwidth efficiency and then system capacity. FBMC is a modification of OFDM, that provides more efficient bandwidth. In this paper, we implement FBMC with modulation technique OQAM instead of using QAM for better result. QAM modulation is always give a lower spectral efficiency as orthogonality between subcarriers is obtained through a reduction in the frequency domain over-lap. FBMC/OQAM systems there are two main alternatives for its implementation, according to the way the filter bank is implemented. An alternative scheme, named frequency spreading filter bank multicarrier (FS-FBMC), is introduced for multicarrier transmission. It is based on the FFT and closely follows the principle of OFDM, while preserving the key advantages of FBMC, namely the absence of guard time and the spectral separation of the sub-channels. A comparison between the designed FBMC and its equivalent OFDM with IEEE802.11a specifications is carried out in terms of overall system bit error rate, power spectrums density and the implementation complexity of both systems. According the results its has been found that our proposed system give better bit error rate and power spectrum density than OFDM system on the expense of the system computational complexity increase.

Keywords—FBMC, OFDM , OQAM, CP, OOB

◆

IJSER

1 INTRODUCTION

Multicarrier systems are attractive approach to provide useful properties for high data rate wireless communication systems [1],[2].

Orthogonal frequency division multiplexing (OFDM) is a very popular special case of a multicarrier system. OFDM with CP which provides, on one hand, a simple equalization as long as the CP covers the impulse response of the channel. On the other hand, this CP decreases the bandwidth efficiency of the system because of the transmitted redundancy and the considerable levels of out-of-band radiation [3]. OFDM has to face many challenges when considered for adoption in more complex networks. For instance, the use of OFDM in the uplink of multiuser networks, known as OFDMA (orthogonal frequency division multiple access), requires full synchronization of the users signals at the base station input. Such synchronization was found to be very difficult to establish, especially in mobile environments where Doppler shifts of different users are hard to predict/track. Morelli et al. [7] have noted that carrier and timing synchronization represents the most challenging task in OFDMA systems. To combat the problem, some researchers have relaxed on the need for a close to perfect carrier synchronization among users and have proposed multiuser interference cancellation methods [8–9]. These methods are generally very complex to implement. Their implementation increases the receiver complexity by orders of magnitude . Hence, one of the main advantages of OFDM, the low complexity, will be lost. . The poor response of the subcarrier filters in IFFT/FFT of OFDM introduces significant out-of-band (OOB) to other users and also picks up significant ingress noise from them. The same problem appears if one attempts to adopt OFDM for filling in the spectrum holes in cognitive radios. Filter banks can be designed with arbitrarily small side lobes and, therefore, are an ideal choice in multiple access and cognitive radio applications.

Filter Bank MultiCarrier, FBMC is a form of multi-carrier modulation that has its origins within OFDM. It is a development of OFDM and aims to overcome some of the issues, although this comes at the cost of increased signal pro-cessing, FBMC has a much better usage of the available channel capacity and is able to offer higher data rates with-in a given radio spectrum bandwidth, i.e. it has a higher level of spectrum efficiency. To achieve full capacity, offset quadrature amplitude modulation (OQAM) processing is employed. The real and imaginary parts of a complex data symbol are not transmitted simultaneously, as the imagi-nary part is delayed by half the symbol duration.

Several research activities in the last decade suggest to return to the original idea from the late 1960's [4] Chang presented the conditions required for signaling a parallel set of PAM symbol sequences through a bank of overlapping filters within a minimum bandwidth, to transmit PAM symbols in a bandwidth-efficient manner. .Saltzberg [5] ex-tended the idea and showed how Chang's method could be modified for transmission of QAM symbols in a double-sideband- (DSB-) modulated format. In order to keep the bandwidth efficiency of this method similar to that of Chang's signaling Saltzberg noted that the in-phase and quadrature components of each QAM symbol should be time staggered by half a symbol interval. Another key development appeared in [8], where the authors noted that Chang's/Saltzberg's method could be adopted to match channel variations in doubly dispersive channels and, hence, minimize inter symbol interference (ISI) and inter carrier interference (ICI). In [9], performance of OFDM and FBMC is evaluated and output result reveals that FBMC is better than OFDM performance can be improved by using high coding rate. In [10], OFDM and FBMC are designed for multiple access uplinks. Experimental result reveals that the efficiency of OFDM degrades due to loss of orthogonality due to imperfect synchronization between subcarriers whereas in FBMC, orthogonality is maintained automatically between the subcarriers.

In [11] the review of FBMC techniques and compare them with OFDM in various applications. We note that most of the advantages of FBMC originate from the fact that, by de-sign, the nonadjacent subcarriers in this modulation are separated al-most perfectly through a bank of well-designed filters. OFDM, on the other hand, was originally designed with a great emphasis on a low-complexity implementation. Much of the low complexity of OFDM is due to a fundamental assumption: subcarrier signals are a set of perfectly synchronized orthogonal tones. These tones are generated at the transmitter using an IFFT block, and they are separated at the receiver through an FFT block. In [12] the author present a derivation of FBMC systems that reveals the relationships among different forms of FBMC. A method of designing FBMC systems for a near-optimum performance in doubly dispersive channels is presented and its superior performance over OFDM is shown. In [16] the author made a fair comparison between OFDM to Filter Bank Multi-Carrier (FBMC) which offers much better spectral properties. There exist different variants of FBMC, but they will mainly focus on Offset Quadrature Amplitude Modulation (OQAM) be-cause it provides the highest spectral efficiency, and per-form real-world tested measurements at a carrier frequency of 2.5 GHz (outdoor-to-indoor, 150 m link distance) and 60 GHz (indoor-to-indoor, 5 m link distance).

IN our work ,we implement FBMC with modulation technique OQAM instead of using QAM for better result. QAM modulation is always give a lower spectral efficiency as orthogonality between subcarriers is obtained through a reduction in the frequency domain overlap, while OQAM modulation give a result orthogonality in the real domain only, which guarantees maximum spectral efficiency for that purpose we use OQAM modulation in our work. we follow the specifications of IEEE 802.11a to design our sys-tem. In this paper , we compare the designed FBMC system with OFDM system which has the same specifications. The comparison involves the bit error rate, for subcarrier spectrum and systems complexity. It has been found that our proposed system give better bit error rate and power spectrum density than OFDM system, but it gives significant increment in complexity as described in section 4

2 SYSTEM MODEL

We follow IEEE 802.11a specifications to implement the communication system in Fig. 1, which contains FBMC transmitter and receiver. Following main processing blocks: OQAM preprocessing, spreading frequency filter (SFF) and IFFT. The FBMC receiver main processing block OQAM post–processing, de-spreading frequency filter (DFF) and FFT

2.1 FBMC transmitter

At the transmitter side, Inverse fast Fourier transform is used as a modulator. The modulation symbol map is used to generate 16QAM modulated electrical signals, and then the modulation symbol de-mapper demodulates the signals according to that which type of. modulation is incorporated. Preprocessing block converts the QAM symbols into OQAM.

The conversion of QAM symbols into OQAM process, involve an inherent increase in the sample rate by a factor of 2.The conversion process is shown in Fig. 3. The converted real sequence is multiplied by multiplication sequence, Θ(m,n), [14], where

$$\Theta(m,n) = e^{j\frac{\pi}{2}(m+n)} = J^{(m+n)} \qquad (1)$$

m is subcarrier and n is symbol interval .

The main difference when compared to the existing OFDM system and FBMC system is that while in OFDM systems an IFFT connected with Cyclic Prefixing (CP) is used, in FBMC this is replaced by a synthesis filter bank. This change allows it to present better performance than its multicarrier emulators, due to the ability to perform per subcarrier filtering, as shown Fig.1 and 2 .

2.2 FBMC Receiver

At the receiver side, output of transmitter used as an input of receiver and preceded further. As shown figure 1 . we used serial to parallel conversion, in which data sequences changes from serial to parallel. In which analysis FFT are used. By using this filters the process of decomposition performed by the filter bank. Analysis Filter Bank (AFB) is used in demodulator part. The outputs of the parallel branches are the OQAM symbols which must go through OQAM-post processing which reverses the procedure, this conversion leading to complex-valued output signals and their sampling rates are 2x lower than before the conversion, as shown fig 4. where:

$$\Theta^{*}_{m,n} = e^{-j\frac{\pi}{2}(m+n)} = -j^{(m+n)} \qquad (2)$$

3 SPREADING FREQUENCY FILITER (SFF)

There are two main alternatives for FBMC/OQAM systems implementation, according to the way the filter bank is implemented. If the filter bank is implemented making use of an inverse FFT operation, followed by a poly-phase network the

IJSER

system corresponds to the PPN-FBMC alternative. If it is generated through frequency spreading followed by an inverse FFT operation performed in the frequency domain then it is an FS-FBMC system..

In this paper we implement FBMC-OQAM with use spreading frequency filter and we follow the specifications of IEEE 802.11a to design our system. The spreading frequency filter block used in FS-FBMC implementations consists of a filter designed through the frequency sampling technique. Using this technique the number of multicarrier symbols which overlap in the time domain is given by the overlap factor K . With this alternative the prototype filtering is implemented in the frequency domain by using an IFFT of size. The out-put of the IFFT is serialized through the application of an overlap and add operation. In this operation of the IFFT's samples are added together to form to output, when the transient period is finished. The synthesis filter bank, making use of frequency spreading, employed with this filter, when a data symbol is plied to a sub-channel, in fact, it is a set of 7 frequency com-opponents which are fed to the transmission channel. This suggests a direct approach to derive the transmitted signal, namely an inverse FFT combined with an overlap-and-sum scheme. If the system has M sub-channels, the size of the IFFT is . The IFFT-based transmitter is sketched in Fig.5, for K=4. Of course, it is necessary to abide by the rules of FBMC transmission. The first rule is the orthogonality of neighboring sub-channels. Therefore, if the sub-channels with indices "i" and "i+2" are assumed real, the real data symbols and di+2(nM) are multiplied by the coefficients $H_K = (1 \leq K \leq 3)$
and fed to the 7 inputs of the IFFT with indices: iK-3, iK-2, .….,iK+3 and (i+2)K-3, (i+2)K-2,......, (i+2)K+3 , respectively, The output of the IFFT is fed to a parallel-to-serial converter, which delivers the time sample stream for transmission. Since the rate of the multicarrier symbols is 1/M, K IFFT output blocks overlap in the time domain. Thus, K IFFT out-put blocks have to be stored and summed to generate the transmitted stream. for K=4, with the 4 blocks of 4M samples which contribute to the summation that produces the block of M samples applied to the transmission channel.

The implementation of the receiver is based on an extended FFT, of size KM. In that case after serial-to-parallel conversion, the received signal is fed to an FFT of size L = KM, for K=4. The FFT outputs with indices iK-3, ..., iK+3 are weighted by the coefficients and a summation yields the data symbols , actually multiplied by 4, the sum of the squared coefficients. The counterpart of the overlap-and-sum operation of the transmitter is a sliding window in the time domain at the receive side. In fact, the data recovery rests on the following property of the frequency coefficients of the Nyquist filter

$$\frac{1}{N}\sum_{N=-N+1}^{N-1}|H_N|^2 = 1 \qquad (3)$$

where N is multicarrier symbols.

Comparing both the frequency spreading and polyphone network FBMC alternatives it can be concluded that FS-FBMC presents some additional benefits: it has better performance in timing offset compensation and achieves high equalization.

AN additional benefit of this alternative is its flexibility, as various schemes can be implemented for a particular IFFT; a system with K = 4 can be reconfigured into a system with K = 2 with double the subchannels N. These benefits come at the cost of its increased computational complexity when com-pared with PPN-FBMC, due to the introduction of an IFFT block of size K ×N, opposed to a block of size N in PPN-FBMC.

4 SIMULATION RESULTS AND ANALYSIS

A key performance index to evaluate the capacity-approaching is the BER given a received SNR over an AWGN channel. We consider the following parameters (most used in the literature). In this section, we examine the performance of the FBMC and CP-OFDM waveforms and compare the results. Our simulations have been carried out with parameters that are shown in Table 1. For the evaluation, three performance metrics are considered the Power Spectral Density, the Probability of Error and Computational complexity.

Table 1. Simulation Parameters IEEE802.11a

Overall Parameters		
FFT size	NFFT	64
Bit per symbol	m	4
Type of modulation		16QAM
Number of subcarrier	M	52
CP-OFDM Parameters		
Cyclic Prefix	CP-OFDM	16 samples
FBMC Parameters		
Overlapping Factor	k	2,3,4

4.1Computational Complexity

The computational complexity of filter bank structures can be evaluated by calculating the number of real multiplications and additions that are necessary to compute a new length M complex-valued output sequence. However, our analysis is just based on the number of multiplications because it is a known fact that adders are considerably cheaper to implement than multiplies

Table2- Computational Complexities of the Multicarrier system [16]

Multicarrier system	Computational complexity
CP-OFDM	$(\log_2(M)$-3+4/M)
FBMC-OQAM	$(\log_2(\frac{M}{2})$ -3 +8/M) +4K

IJSER

It can be seen that the FBMC more complex than the conventional OFDM, as shown fig. 5. It can also be noticed that the computational complexity of FBMC depends only slightly on the overlapping factor K and M , this is result depended on table2.

4.2 Power Spectram Density (PSD*)*

PSD is represented in dBW/Hz and function of the normalized frequency. We can simply remark here two things, the first one the reduction of PSD in the Out of Band (OOB) region due to the filtering process used in FBMC, this reduction makes this new waveform more robust to the Inter-Carrier Interference, and the effect of the sub-band filtering which divided the overall PSD into a summation of sub-band PSDS. In Figure 6, 7 and 8 the comparison of PSD between CP-OFDM with FBMC for various values of overlapping factor K is shown. Here, it is obviously shown that in FBMC the power in the OOB is very small compared to the power in the corresponding band. So, we can say that the FBMC has the best PSD when compared to the CP-OFDM.

4.3 Bit Error Rate (BER)

A comparison of the probability of error, which is presented by the BER, of OFDM and FBMC to the modulation levels 16QAM modulation. When compared to the CP-OFDM system the FBMC presents a net gain in all cases simulated in our work. That FBMC using 16OQAM has better BER from the CP-OFDM in shown figure 9 with approximately 9 dB at BER=10^{-4} and OFDM is approximation 9dB at BER=10^{-2}. So, as shown figure 10 we can say that FBMC has the best BER when compared to the CP-OFDM.

5 CONCLUSION

In this paper, the implementation of filter bank for multicarrier with modulation OQAM, and filter bank implement spreading frequency filter is studied and presented. We follow IEEE802.11a specification to implement our design system. The first objective was to compare them with the conventional CP-OFDM, The simulation results show that our design in this paper improves parameters and deteriorates other parameters, so we need to take other criteria to choose the waveform for the next generation, like the tail issue, the complexity, the latency, and others. The FBMC improve the PSD but deteriorate the complexity, in the same time the FBMC improve the BER rate.

6 REFERENCES

[1] T. Ihalainen et. al., “Channel equalization in filter bank based multicarrier modulation for wireless communications,” EURASIP Journal on Advances in Signal Process., 2007.

[2] P. Siohan, C. Siclet, and N. Lacaille, “Analysis and design of OFDM/OQAM systems based on filterbank theory,” IEEE Transactions on Signal Processing, vol. 50, no. 5, pp. 1170–1183, May 2002.

[3] Dirk S. Waldhauser, Leonardo G. Baltar and Josef A. Nossek, " Adaptive Equalization for Filter Bank Based Multicarrier Sys-tems",," IEEE Transactions on Signal Processing, pp. 1-4244-1684-4, 2008.

[4] B. Saltzberg, “Performance of an efficient parallel data transmission system,” IEEE Transactions on Communication Technology, vol. 15, no. 6, pp. 805–811, 1967.

[5] M. G. Bellanger and J. L. Daguet, “TDM-FDM transmulti-plexer: digital polyphase and FFT,” IEEE Transactions on Communications, vol. 22, no. 9, pp. 1199–1205, 1974.

[6] B. Hirosaki, “An analysis of automatic equalizers for orthog-onally multiplexed QAM systems,” IEEE Transactions on Communications, vol. 28, no. 1, pp. 73–83, 1980.

[7] B. Hirosaki, “An orthogonally multiplexed qam system using the discrete fourier transform,” IEEE Transactions on Commu-nications, vol. 29, no. 7, pp. 982–989, 1981.

[8] B. Le Floch, M. Alard, and C. Berrou, “Coded orthogonal frequency division multiplex,” Proceedings of the IEEE, vol. 83, no. 6, pp. 982–996, 1995.

[9] Roth k, Baltar L, Faerber M and Nossek J, Performance analysis of FBMC and CP-OFDM in the presence of phase noise, European Conference on Networks and Communications (EuCNC), Oulu, Finland, 2017; 1-5.

[10] Saljoghei A, Gutiérrez F, Perry P, Venkitesh D, Koipillai R and Barry L, Experimental Comparison of FBMC and OFDM for Multiple Access Uplink PON. Journal of Lightwave Technol-ogy 2017; 35 (9): 1595-1604.

[11] B. Farhang-Boroujeny, “OFDM versus filter bank multicar-rier,” IEEE Signal Processing Magazine, vol. 28, no. 3, pp. 92–112, May 2011.

[12] B. Farhang-Boroujeny, “Filter bank multicarrier modula-tion: A waveform candidate for 5G and beyond,” Advances in Electrical Engineering, vol. 2014, December 2014.

[13] Ronald Nissel, Stefan Schwarz, and Markus Rupp, "Filter Bank Multicarrier Modulation Schemes for Future Mobile Communications", IEEE Journal on Selected Areas in Com-munications , May 2017

[14] Ari Viholainen ,Maurice Bellanger and Mathieu Huchard ," Prototype filter and structure optimization", PHYDYAS 2009.

[15] M.Bellanger, D.LeRuyet, D.Roviras, M.Terré T J.Nossek, L.Baltar, Q.Bai, D.Waldhauser ," Prototype filter and structure optimization", PHYDYAS 2010.

[16] Jintae Kim, Yosub Park, Sungwoo Weon, Jinkyo Jeong, Sooyong Choi, and Daesik Hong," A New Filter-Bank Multicarri-er System: The Linearly Processed FBMC System", IEEE 2018

[17] YongJu Won, JongGyu Oh, JinSeop Lee, and JoonTae Kim. A Study of an Iterative Channel Estimation Scheme of FS-FBMC System. Wireless Communications and Mobile Compu-ting, 2017:e6784142, 2017.

IJSER

7 FIGURES

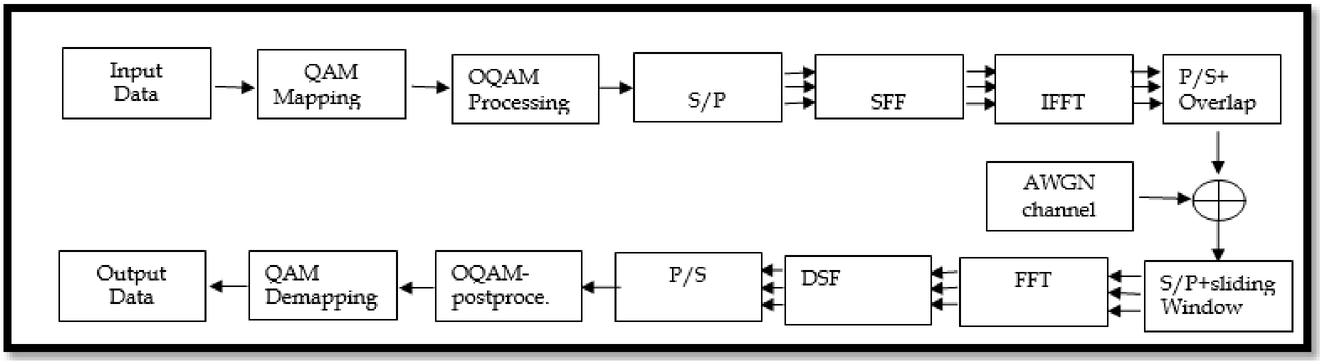
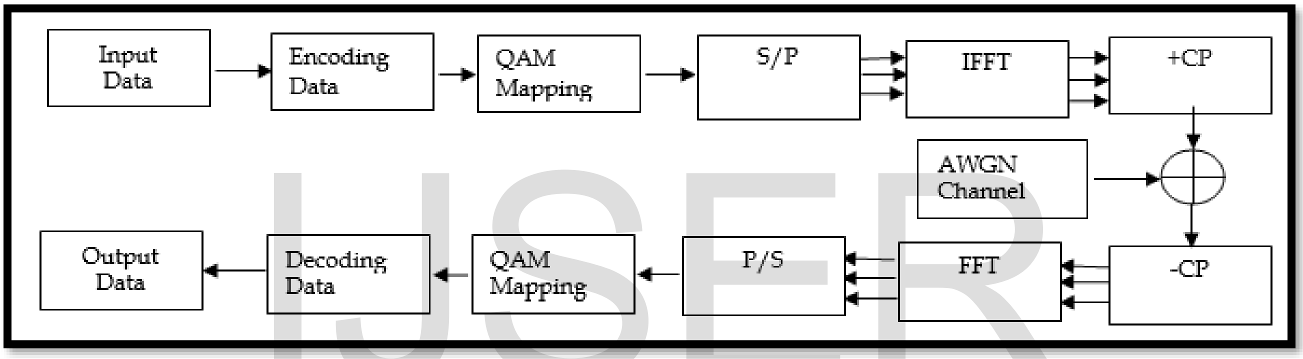


Figure 1 FBMC system



IJSER

Figure 2 OFDM system

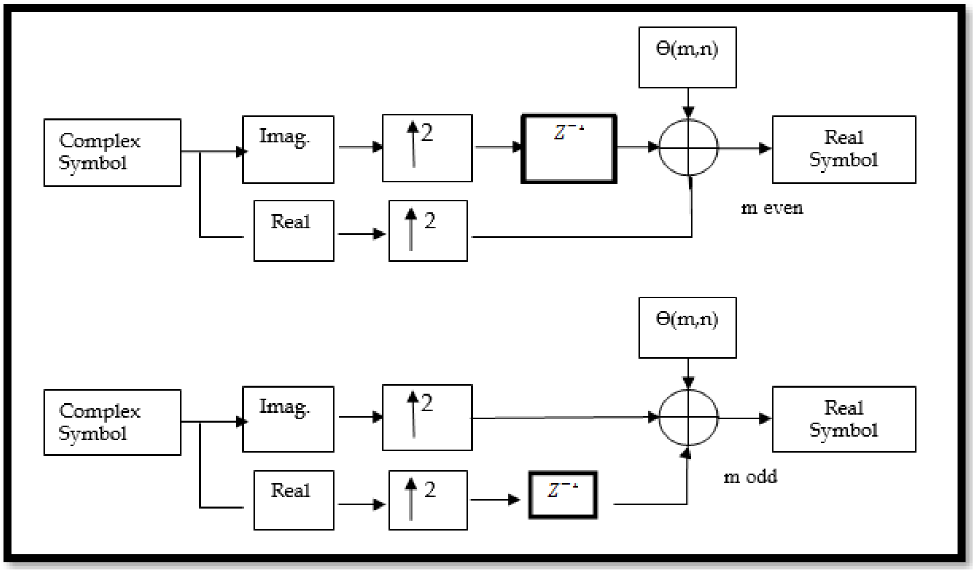
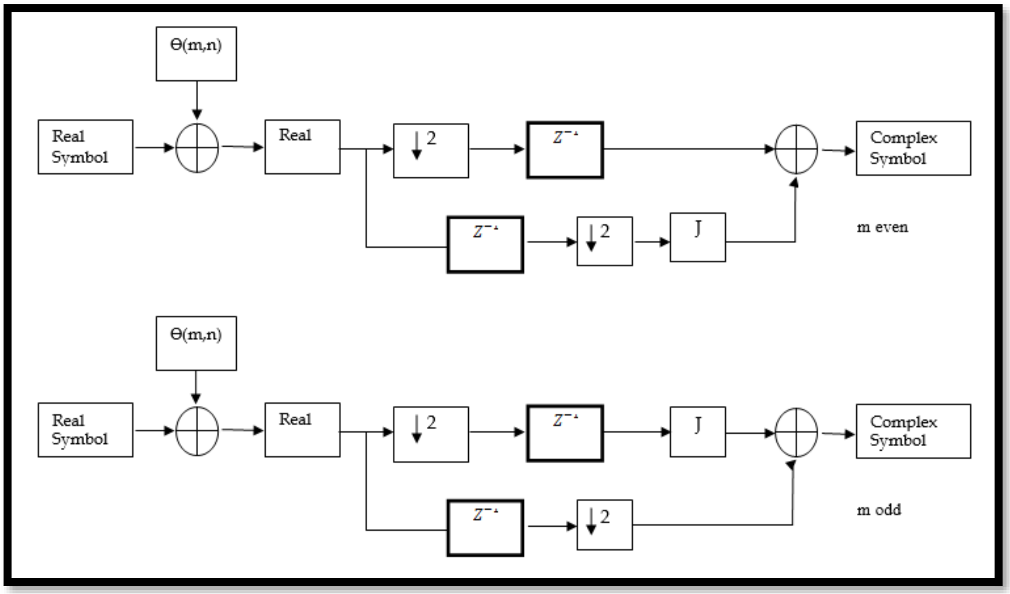


Figure 3 OQAM pre-processing for m odd & even



IJSER

Figure 4 OQAM pre-processing for m odd & even

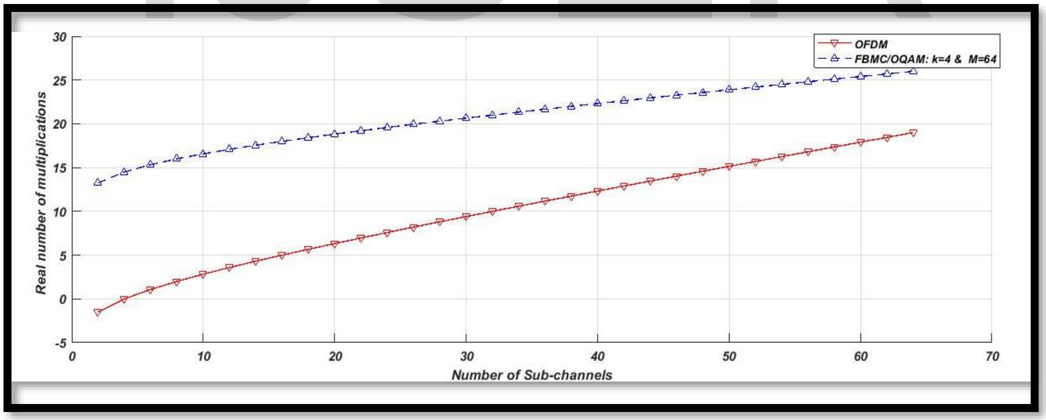
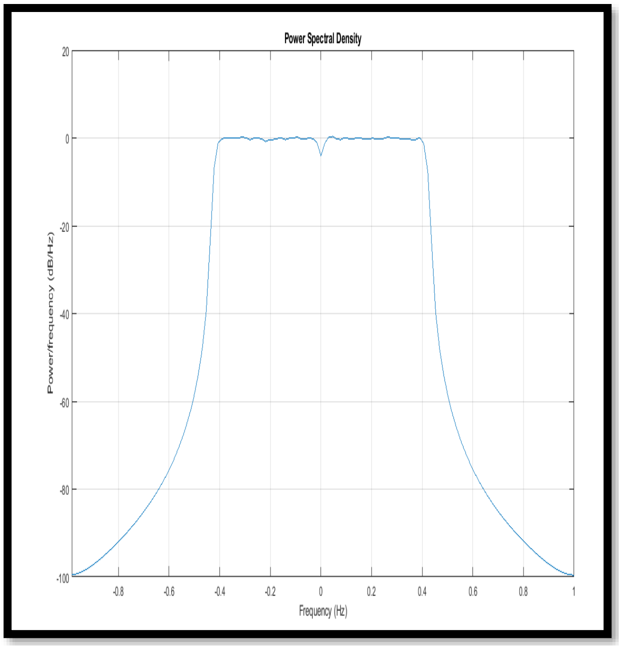


Figure 5 Number of real multiplications as a function of number of subchannels in the case of OFDM & FBMC K=4 & M=64



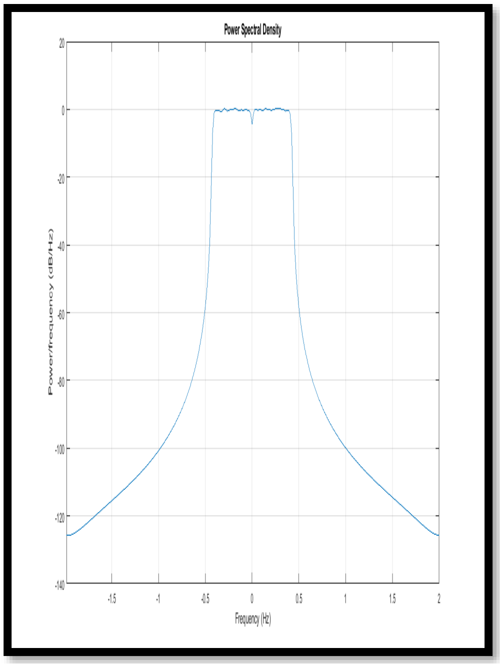


Figure 6 PSD for FBMC at K=2

Figure 7 PSD for FBMC at K =4

IJSER

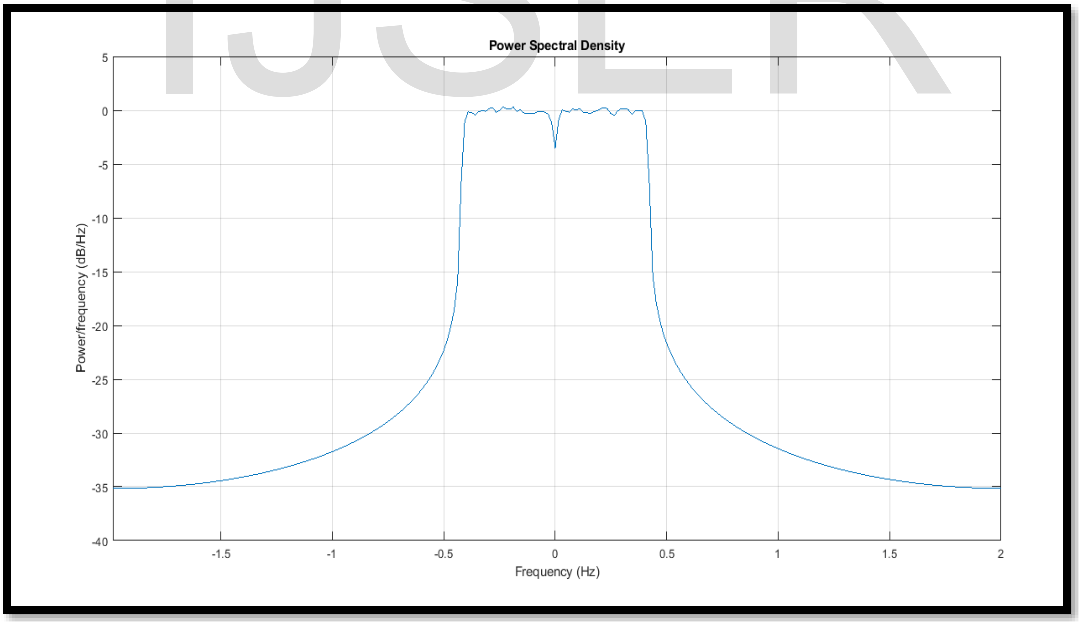
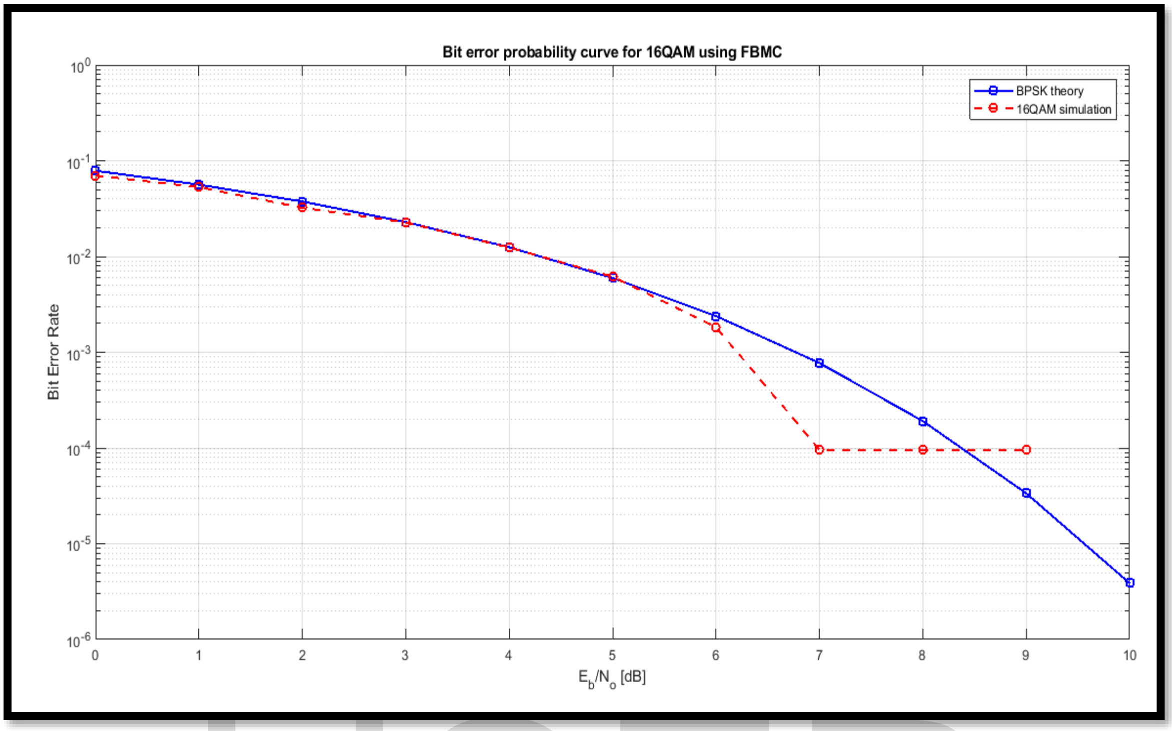


Figure 8 PSD for OFDM



IJSER

Figure 9 BER of FBMC

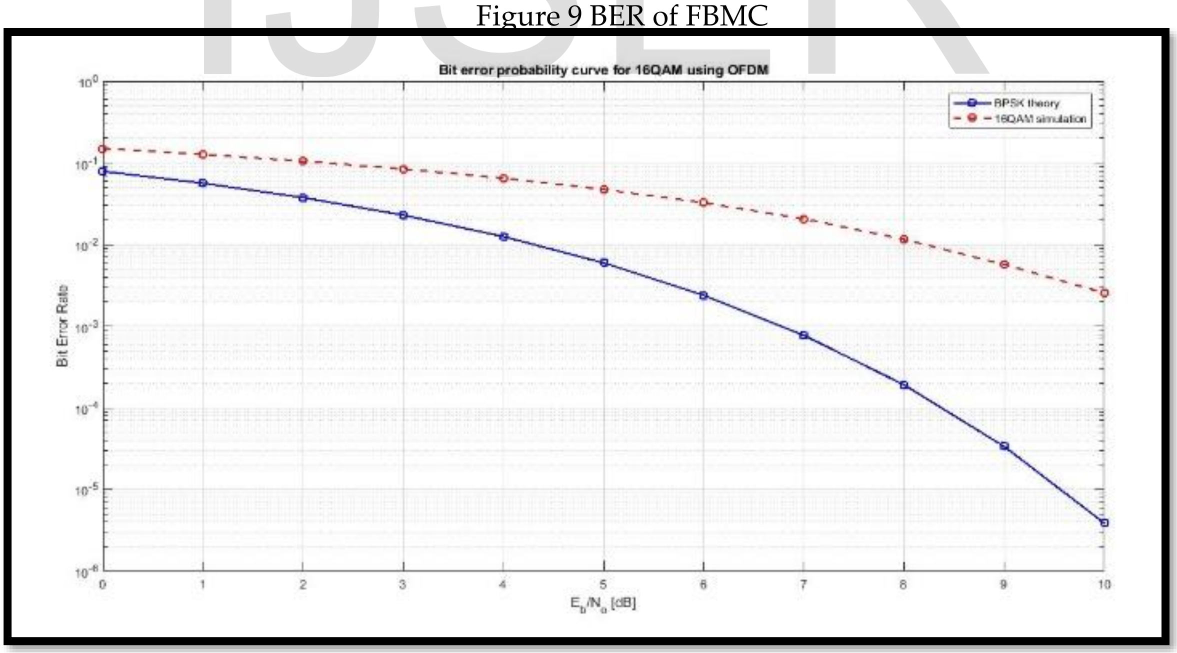


Figure 10 BER of OFDM

IJSER