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# Performance Evaluation of oF DM and Prototype FBMC-OQAM Cognitive Radio under constraints of variable Overlapping factors

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**ABSTRACT:** To fully realize the potential of CR networks, there is a need to draw the attention of the research community for developing advanced, context-based and innovative methodologies, techniques and algorithms for the Performance Enhancement of Filter Bank Multicarrier based Cognitive Radio under fading channel Environment. The present section deals with Comparatative Performance Evaluation of OFDM and Prototype FBMC Cognitive Radio. One can see that with decrease in the number of subcarriers, FBMC obtains more spectral efficiency gain over OFDM which surely indicates the more applicability of FBMC for the CR system with small size of spectrum holes. Simulation Results show that FBMC can attain higher channel capacity than OFDM due to low spectral leakage of its prototype filter.

**Index Terms:** OFDM, FBMC, Filter-Bank, Cognitive radio.

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## I. INTRODUCTION

Cognitive radio being an intelligent wireless communication system is able to dynamically adjust its transmission characteristics, hence it is treated as a possible remedy for getting rid of spectrum scarcity problem by enhancing the spectrum efficiency using multicarrier communication techniques [1].Multicarrier communication techniques lead to better resource allocation strategies among different secondary users, as primary and secondary user bands persist side by side. With Different Wireless Multiple Access Technologies, the mean mutual interference between the two systems is considered a important factor to evaluate the performance of both the networks. OFDM based CR system is vulnerable to more interference to the PUs due to large side lobes in its filter frequency response. The inclusion of Cyclic Prefix in each OFDM symbol degrades the system capacity. This drastic leakage effect which is predominant in different frequency sub bands bears a negative impact on the performance of FFT based spectrum sensing. So, to curtail this leakage problem in OFDM, a very tight synchronization problem needs to be imposed at the cognitive radio system network level. Filter bank Multicarrier which is basically an OFDM with OQAM pre and post processing in the analysis and synthesis filter banks, need not require any Cyclic prefix extension as it can overcome the spectral leakage problem by reducing the sidelobes of each subcarrier resulting in increased spectral efficiency. Various methods for spectrum sensing using filter bank approach found in literature show the earlier workers making use of Welch Spectral Periodogram technique and Thomson Multitaper method and Lagrangian Multiplier Approach etc have been discussed[2][3].The transmit power of each subcarrier should be varied according to the channel condition and the location of the subcarriers w.r.t Primary user spectrum.The CR system can use the non-active and active Primary User bands as long as the total power and other interference constraints are satisfied.

## II. SYSTEM MODEL

The CR system frequency spectrum is divided into N subcarriers each having a $\delta f$ bandwidth.The side by side frequency distribution of PUs and SUs can be taken for study under consideration.The frequency bands that have been occupied are active PU bands while other vacant PU bands are the spectral holes or white spaces which cognitive or unwanted secondary users can occupy.Various performance parameters of interest here can be total transmit power,spectral distance between the subcarriers and the channel gain under interference constraints.The interference power introduced by the $l^{th}$ PU signal in the band of $i^{th}$ subcarrier can be explained as

$I_i(d_i,P_{PUl})=\int y_i^2\psi_l(e^{jw})d\omega$...........................................Eq.1[4]

where $\psi_l(e^{jw})$ is the power spectrum density of PU signal and $y_i$ is the channel gain between $i^{th}$ subcarrier and $l^{th}$ PU signal.The Power Spectrum Density depends upon the multicarrier technique applied.The Power spectral densities of OFDM and FBMC are discussed mathematically in the section ahead.

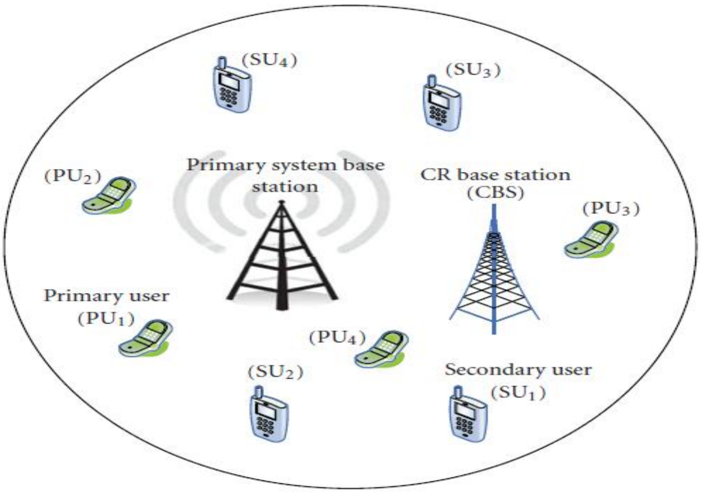


**Figure.1** Cognitive Radio Network[5]

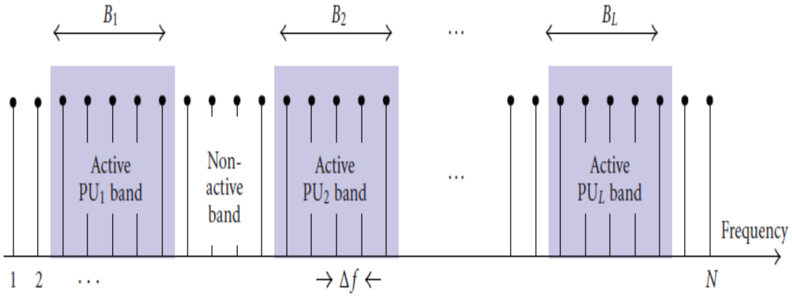


**Figure.2** Frequency Distribution of Active and Non Active Primary User Bands[6].

### 2.1 Power Spectral Density of OFDM

The OFDM symbol is formed by taking IDFT to a set of complex input symbols $X_k$ with addition of Cyclic-Prefix.Mathematically,$x(n)=\sum\sum X_{k,w}g_T(n-wT)e^{j2\pi(n-wT-C)k/N}$.Eq.2
where k is a set of data subcarrier indices varying from 0 to N-1.,N is IDFT size,C is the length of Cyclic Prefix in different samples,T=C+N is the total length of OFDM symbol in number of samples.The OFDM power spectral density is given by [6]

$\Phi_{OFDM}(f)=(\sigma_x^2/T)\sum G_T(f-k/N)^2$............................................Eq.3

$G_T(f)$ is the Fourier Transform of $g_T(n)$, $\sigma_x^2$ is the variance of zero mean and uncorrelated input symbols.

2.2 Power Spectral Density of FBMC.

Each subcarrier in FBMC system is modulated with a staggered –offset QAM.The primary idea is to transmit real valued symbols instead of transmitting complex valued symbols.Orthogonality between the adjacent subcarriers is achieved due to time staggering of in-phase and quadrature phase components of these symbols.The modulator and demodulator are implemented with the help of Transmultiplexer filter bank structure comprising of synthesis and analysis filter banks.Basically,the filters in these synthesis and analysis filter bank are obtained by frequency shifts of a single prototype filter.The FBMC is expressed mathematically as

$x(n)=\sum\sum a_{k,w}h(n-w\tau_0)e^{j2\pi}(k/N)^n e^{j\phi k,w}$............................Eq.4 where k is a set of subcarrier indices,h is pulse shape,$\phi_{k,w}$ is phase term,τ is FBMC Symbol duration, $a_{k,w}$ are the real symbols obtained from complex QAM symbols having a zero mean and finite variance $\sigma_x^2$.The power spectral density of FBMC is expressed by the relation[7]

$\phi_{FBMC}=(\sigma_r^2/\tau_0)\sum H(f-k/N)^2$..........................................Eq.5

H(f) is frequency response of prototype filter with coefficients h[n] with n=0,.....W-1 where W=KN and K is the length of each individual polyphase component,it is also called as Overlapping factor.It is assumed that prototype filter coefficients have even symmetry around $(KN/2)^{th}$ coefficient and first coefficient is zero[7].Hence,

$H(f)=h[W/2]+2\sum h[(W/2)-r]\cos(2\pi fr)$.........................Eq.6

Interference incurred by one subcarrier is equal to sum of interference incurred for all the time slots when a burst of individual complex symbols is transmitted.The important thing in doing subcarrier assignment in the multiuser case is the allocation of bandwidth.

2.3.Ofdm/Fbmc Subchannel Processing

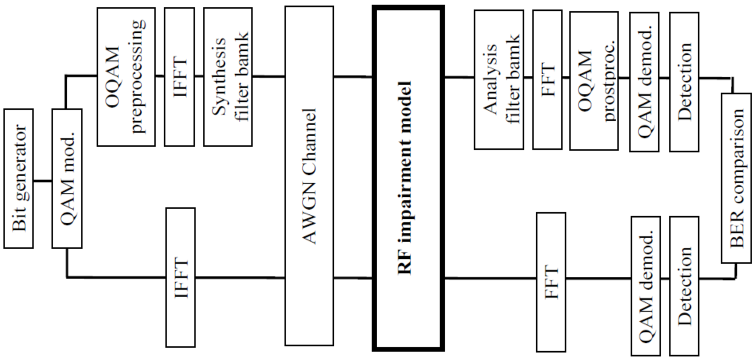


**Figure.3** Block Diagram of FBMC/OFDM Baseband Simulation Framework for RF Impairments[8]

The prototype filter should have several essential characteristics like linear-phase Nyquist filter with unity roll-off, to minimize delay and complexity, transmission zeros at the frequencies which are integer multiples of the subchannel spacing,for independent and accurate channel measurements,attenuation increasing with frequency, to offer increasing level of protection from/to primary users in cognitive radio.With these constraints, the main flexibility parameters in the system design are the number of subchannels, and the overlapping factor, which determines the total number of filter coefficients, and the option for partial filter bank design, for example to equip a low rate user in uplink in an efficient manner.The Mirabassi Martin Filter Coefficients[9] have been taken in PHYDAS Report have been taken under consideration in the present study.FBMC with K=4 is designed in PhyDAS Project .FBMCs which are frequency localized prototype filters suffer from minimal intercell interference. Large part of the assigned spectrum is underutilized while the increasing number of wireless multimedia applications lead to spectrum scarcity.Cognitive radio is an option to utilize non used parts of the spectrum that actually are assigned to primary services.The benefits of cognitive radio are clear in the emergency situations.Current emergency services rely much on the public networks.This is not reliable in public networks where the public networks get overloaded.The major limitation of emergency network needs a lot of radio resources.The idea of applying Cognitive Radio to the emergency networks is to alleviate this spectrum shortage problem by dynamically accessing the free spectrum resources.Cognitive Radio is able to work in different frequency bands and various wireless channels and supports multimedia services such as voice, data and video.A reconfigurable radio architecture is proposed to enable the evolution from the traditional software defined radio to Cognitive Radio.The present study puts its focus on Performance Enhancement of Filter Bank Multicarrier (FBMC) based Cognitive Radio (CR) in adaptive, opportunistic, autonomic domain under different strategic conditions of wireless environment.By introducing the techniques to improve the spectral efficiency one can minimize the spectrum underutilization, hence improving the overall performance of FBMC based CR. There is a need to modify the characteristics of FBMC for better performance of cognitive radio system.

### 2.3.1 FBMC Subchannel Processing

In the FBMC applications, the use of critically sampled Analysis Filter Bank (AFB) would be problematic,since the aliasing effects would make it difficult to compensate the imperfections of the transmission channel.Therefore, a factor of two oversampling is commonly applied in the subchannel processing sections.The Interpolation and Decimation Factors of 3,5 and 8 can also be taken under consideration for the present study.In the considered filter bank models,the useful data symbols are carried alternatively by real and imaginary parts of the complex-valued subcarrier sequences.By using the whole complex samples in subchannel processing in the receiver,effectively 2x oversampling is obtained.At the end of the subchannel processing sections, the needed real/imaginary parts are selected to get a critically sampled sequence for detection.It is also noticed that the signals with even numbered subchannels are nicely centered around zero frequency i.e.they have a baseband format.On the other hand, the signals with odd numbered subchannels are centered around.This would results in two different kinds of sub channel processing sections.It is possible to frequency shift all odd numbered subchannel signals around zero frequency by adding a simple extra term to both pre and post multipliers.Hence,all sub channel processing sections can work using baseband signal format.

#### 2.3.1.1 FBMC Transmission Scheme

Filter Bank Multicarrier (FBMC) technique is an enhancement to conventional OFDM scheme.The difference between them is that FFT is complemented by a set of digital filters known as polyphase network in FBMC approach while in OFDM approach, a cyclic prefix is inserted after FFT.The drivers for FBMC approach originate from two characteristics mainly time domain and frequency domain. In the time domain, the Cyclic

Prefix is avoided which allows for full use of radiated power and achieves an increase in bit rate which can be significant.In the frequency domain,the leakage is very small and users can exploit independent groups of sub channels,in a unsynchronized context.In the transmitter and receiver,a filter bank is obtained by adding to a FFT, a specific signal processing module, the polyphase network,the number M of the filters in the bank is the size of FFT and the system is said to have M subchannels.The filters are frequency shifted versions of prototype low pass filter,satisfying nyquist criteria.There are different approaches for design of such filters[10].

### 2.3.1.2. Model Structure of Transmultiplexer

The core of FBMC/OQAM system is a critically sampled Transmultiplexer(TMUX) configuration shown in Fig.4.The main processing blocks are OQAM pre-processing, Synthesis Filter Bank (SFB), Analysis Filter Bank (AFB) and OQAM post-processing.The transmission channel is typically assumed to be ideal with $C(z) = 1$ when analyzing and designing TMUX systems because the channel equalization problem is handled separately.In order to guarantee down sampling at correct phase (at the maximum points of the received pulses), an extra delay $z^{-D}$, with $D$ depending on length of prototype filter

$Lp=KM+1-D$………………………………………..Eq.7

has to be included either to the Synthesis Filter Bank(SFB) output or Analysis Filter Bank (AFB) input .Based on Eq.(5.3), the required extra delay in the TMUX system is $z^{-2}$.A simple implementation method for this delay is to insert an additional zero coefficient to the beginning of the impulse response of the optimized prototype filter.

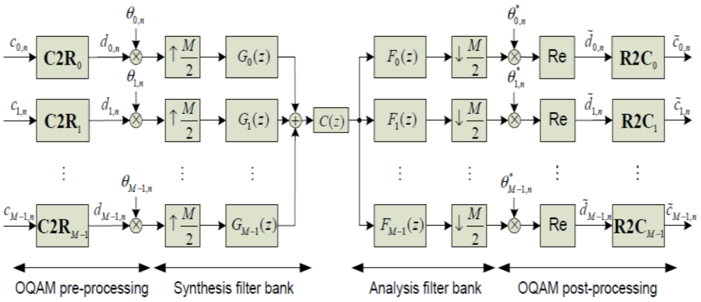


**Figure 4.** Block diagram of FBMC–OQAM Processing:TMUX Configuration[11]

### 2.3.1.3 Synthesis and Analysis Filter Bank

In the SFB,the input signals are first up sampled by $M/2$ and then filtered with synthesis filters $Gk(z)$.The SFB output signal is formed when all sub signals are added together.In the AFB, the input signal is first filtered by analysis filters $Fk(z)$ and these signals are then down sampled by a factor of $M/2$ to form output signals.The presented TMUX system can be considered to be critically sampled because the sample rate (counted in terms of real-valued samples) of the SFB output (AFB input) is equal to the sum of the sample rates of the sub channel signals $dk;n$ ($\tilde{d}k;n$).In the case of chosen class of complex modulated filter banks, all sub channel filters can be generated from a single real-valued linear-phase FIR low pass prototype filter $p[m]$ by using exponential modulation as follows [11].

$F_k[m]=p[m]e^{j2\pi k/M(m-(Lp-1/2))}$…………………….........Eq.8

$H_k(m)=F^*_k[L_p-1-m]=p[m]e^{j(2\pi k/M(m-(Lp-1/2))}$...................Eq.9

where $k = 0;1....M -1$ and $m = 0;1.....Lp -1$.Due to the modulation function, the resulting sub channel filters also have a linear phase.The magnitude response of the prototype filter is divided into three types of regions: the pass band region is $[0; \omega_p]$, the stop band region is $[\omega_s;p]$, and the gap between these two is called as the transition band. The band edges can be given as follows $\omega_p = (1-\alpha)\pi/M$ and $\omega_s = (1+\alpha)\pi/ M$ ,where α is the roll off factor that defines how much adjacent sub channels are overlapping.A typical choice is $\alpha = 1:0$, which means that the transition bands of a sub channel end at the centers of the adjacent sub channels.OQAM pre processing and post processing operation involves complex to real and real to complex conversion of the two symbols.In the first operation, there is an increase in sample rate by a factor of two while in the later case there is a decrease in the sample rate by a factor of two.The FBMC system uses a specially designed Filter Bank Structure.At first, the complex modulation values are spread over several carriers and filtered by a certain prototype filter which indicates that a larger FFT is required to make the transmission signal as clear from Fig.4.The spectral band efficiency of this filter bank is more beneficial as compared to the conventional OFDM signal approach.Using an offset QAM as the modulation technique in which the data values are transmitted with a time shift of half symbol duration and no data rate loss occurring, prior to transmission,the symbols overlapping occurs to separate them at the receiver to minimize the effect of ISI and obey the Nyquist Criteria.In FBMC,no Cyclic Prefix needs to be used to compensate for channel induced ISI and ICI.The tedious signal processing is applied along with channel equalization, that is why the FBMC Polyphase filter bank approach reduces all earlier signal processing requirements[12,13].

## III. FREQUENCY SAMPLING DESIGN TECHNIQUE

The prototype filter can be designed to fulfill Perfect Reconstruction (PR) conditions or to provide Near Perfect Reconstruction (NPR) characteristics. However, it is worth emphasizing that the PR property is exactly obtained only in the case of ideal transmission channel. Therefore, it is sufficient that interferences that originate from the filter bank structure are small enough compared to the residual interferences due to transmission channel. In addition, NPR prototype filters can provide higher stop band attenuation than their equal-length PR counterparts.A straightforward way to design NPR prototype filters is to directly optimize the impulse response coefficients.An evident drawback of this approach is that the number of filter coefficients increases dramatically when designing filters banks with high number of sub channels ($M > 64$).Another approach is to use e.g.frequency sampling technique [14] or windowing based techniques[15].In these methods, prototype filter coefficients can be given using a closed-form representation that includes only a few adjustable design parameters. This section concentrates on the frequency sampling design technique.The impulse response coefficients of a filter are obtained when the desired frequency response, which is sampled on a $KM$ uniformly spaced frequency points $\omega_k = 2\pi k/KM$, is inverse Fourier transformed [14].The resulting closed-form representation for a real-valued symmetric FIR prototype filter has been given as Matlab code.
FBMCCOM=6*(M*2+(M.*($\log_2$(M)-3)+4)+K*M*2) Eq.10 is the complexity function for FBMC/OQAM with polyphase structure.FBMC=6*M.*M*K……………………Eq.11 denotes the complexity function for FBMC/OQAM without polyphase structure[16].

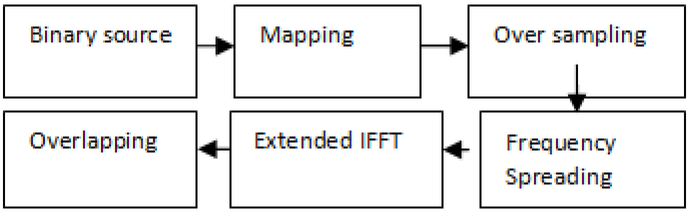


**Figure.5.** Block diagram of FBMC Modulation scheme[17]

$x_n=\sum X_k e^{j2\pi nk/N}$ ………………………………………Eq.12 where $0<n<N-1$ and $0<k<N-1$

In the above block diagram, the modulation and demodulation can be performed by applying IFFT and FFT.The time domain samples of FBMC symbol can be represented by the Eq.12 showing the relation of N point IFFT where $X_k$ is the complex modulation data for subcarrier with index k.Prior to the transmission, a CP is appended or added to each symbol. By adding cyclic prefix,ISI is reduced but at the cost of reduced effective data rate of the system as well.In the typical design structure of FBMC, the complex modulation values are spread over several carriers and ultimately filtered by a prototype filter. The system performance of FBMC is evaluated via BER as function of SNR.The SNR is defined as $SNR_{dB}=10\log_{10}(E_s/N_0)=10\log_{10}(E_bN_cM/OVNN_0)$………Eq.13 as CP is absent here.$E_b$ is bit energy,$N_0$ is noise variance,N is the number of subcarriers available, $N_c$ is number of subcarriers used.OV is oversampling ratio and M is the number of bits transmitted by one subcarrier.The Performance analysis of effect of change of bits transmitted by one sub carrier.i.e.M(64,128,256,512,1024,2048,4096) in our present study is done at different values of overlapping factor K (K=2,4,6,8).

**Table.1** Framing Parameters for FBMC Configuration

| Parameter | FBMC | OFDM |
|---|---|---|
| Useful Bandwidth | $10^7$Hz(6,7,8,9,10Mhz) | $10^7$Hz |
| System BW | $2*10^9$Hz | $2*10^9$Hz |
| Number of Carriers | 1024(16-4096,8192,16384) | 1024 |
| Number of Active Carriers | 601 | 601 |
| Cyclic Prefix | Not Applicable | 72samples |
| Carrier Spacing | $15*10^3$ | $15*10^3$ |
| Sampling Rate | $15.36*10^6$Hz | $15.36*10^6$ Hz |
| Sampling Period | $65.1*10^{-9}$seconds | $65.1*10^9$seconds |
| Preamble Symbols in Subframe | 04 | 04 |
| Data Symbols in subframe | 16 | 09 |
| Subframe duration | $1.63*10^{-3}$s | $0.93*10^{-3}$s |
| Overlapping Factor | 4(optimum results)(4,6,8,10) | 2,4,6,8;3,5,7 |

## IV. RESULTS AND DISCUSSION

The impact of the present study of FBMC CR is highlighted through the role of number of sub channels. Readjustment of various parameter levels leads to optimization between different radio environment parameters under varying strategic conditions.The computational complexity of the FBMC cognitive radio is studied under the effect of K,M and Lp. The impact of different constraints on the system performance has been investigated. Data under consideration is snri= -10 to +30db with qam=[2,4,8,16,32,64].Capacity varies logarithmically wrt increasing SNR values from -10dB to +30dB for different modulation techniques in FBMC Cognitive radio under effect of AWGN channel. The present study has its deep impact on Performance Enhancement of Filter Bank Multicarrier Based Cognitive radio under Fading Channel Environment.Figure.6-11 show the frequency response of modified prototype filter at varying values of K.Figure 12 shows that computational complexity increase with rise in number of real multiplications wrt number of subchannels M. Figure 15 shows amplitude versus time plot for FBMC when serial symbol for M array QAM modulation is used at Transmitter fed with digital signal.Figure 16-22 show the Magnitude wrt Frequency plots for FBMC and ODDM –OQAM under constraints of different values of K and M.In Figure .23 the comparatative performance analysis for both OFDM and modified FBMC depicts that Magnitude wrt frequency decays from above 30dB to -52 dB for FBMC whereas the magnitude wrt frequency decay is around 25dB to -39dB at a normalized frequency of 0.12 π radians per sample.Figure 34 and 35 clearly show the trend with reduced guard bands between users at M= 512 with K=2,3,4.Figure .6 and Figure.28 are realized as per the PHYDAS(Physical Layer for Dynamic Spectrum Access) filter specifications.Figure .33 represents the Round off noise power spectrum for FBMC at standard values of K=2,3,4(K=4 being optimum in compliance with earlier P.Martin Mirabassi Filter design).

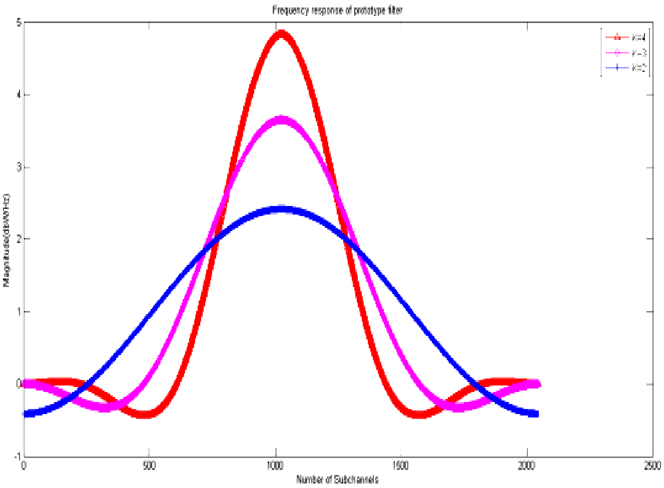


**Figure.6** Frequency Response of FBMC Prototype Filter(compared with P.Martin Mirabassi Filter Coefficients.Fig.36) at K=2,3,4

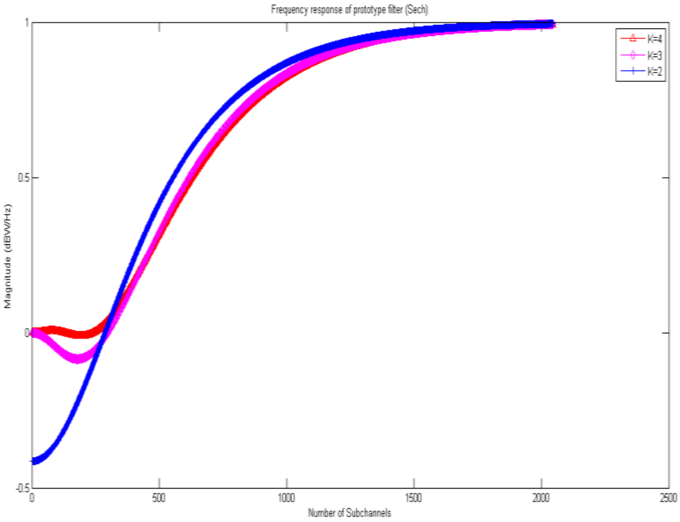


Figure.7 Frequency Response of the Prototype filter (Sech) compared to PHYDAS filter at K=2,3,4

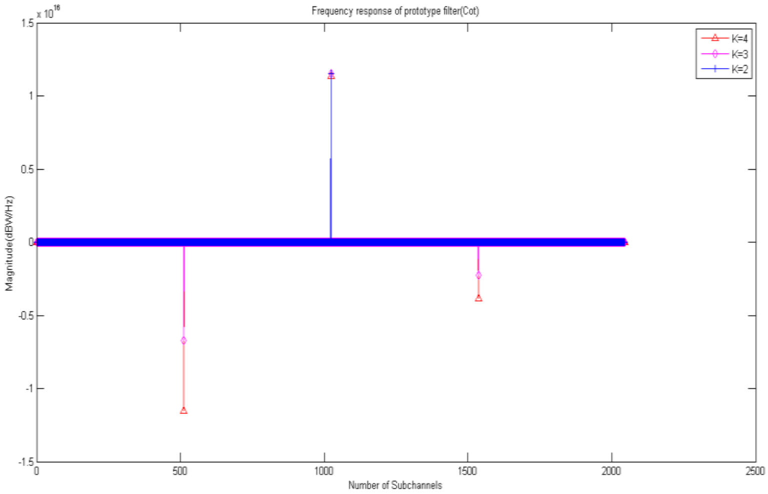


**Figure8** Frequency Response of Modified PHYDAS Prototype filter(Cot) at K=2,3,4

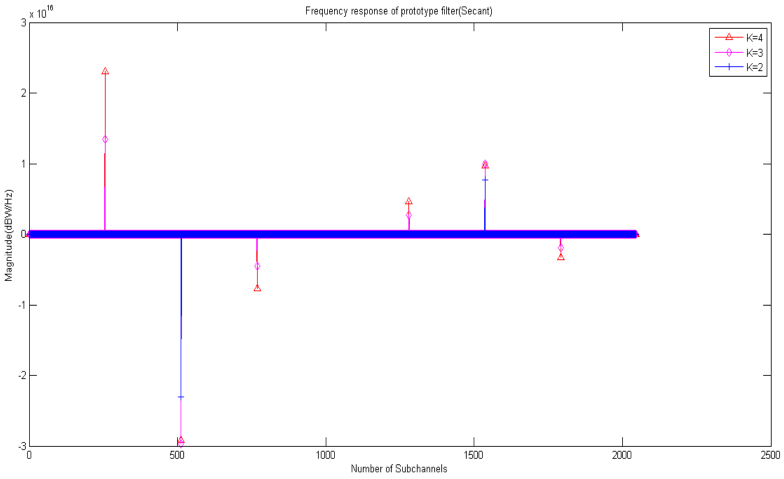


**Figure.9** Frequency Response of Modified Phydas Prototype filter(Secant) at K=2,3,4

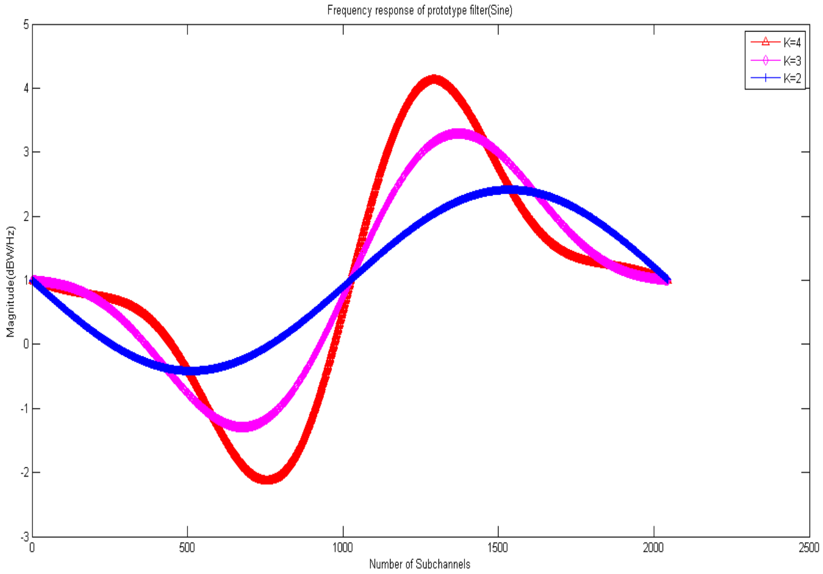


**Figure.10** Frequency Response of Sine variant of Protoype Phydas filter at K=2,3,4

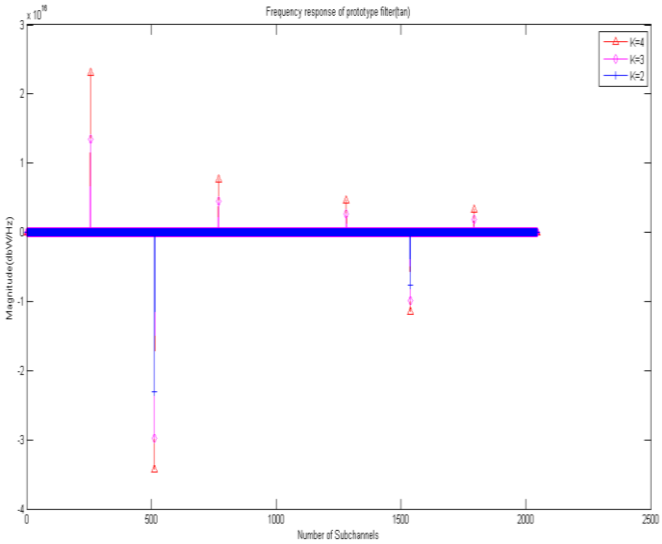


**Figure.11** Magnitude Response w.r.t. number of Subchannels for Prototype filter(tan) at K=2,3,4(Phydas Specifications).

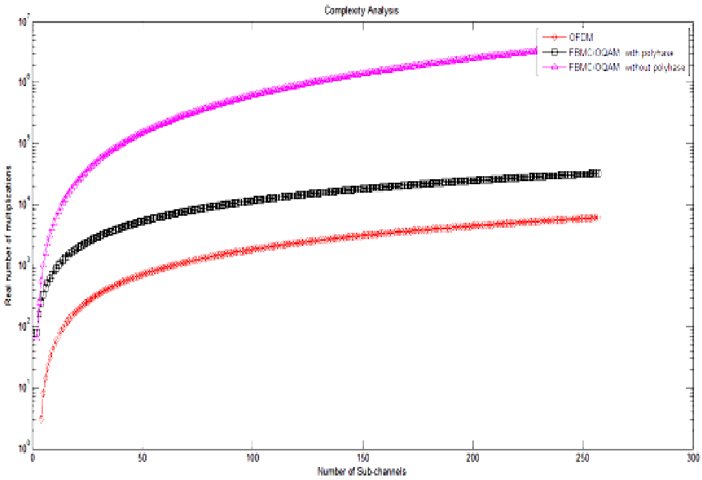


**Figure.12** Comparatative Analysis of Complexity versus Number of Subchannels for FBMC with and without Polyphase technique

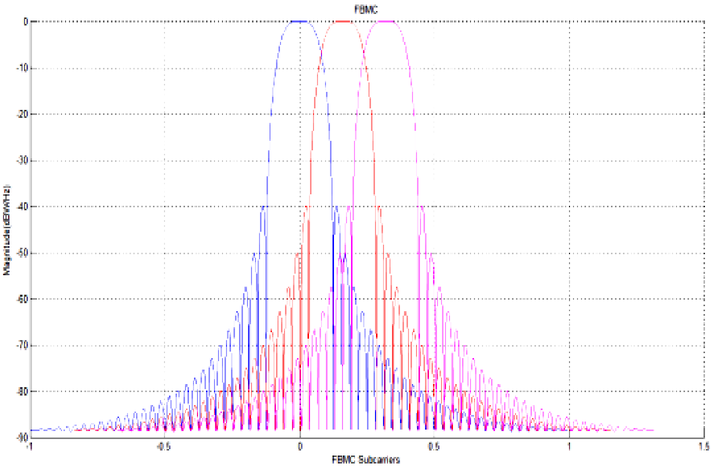


**Figure.13** Magnitude Response of FBMC Subcarriers at K=2,3,4.

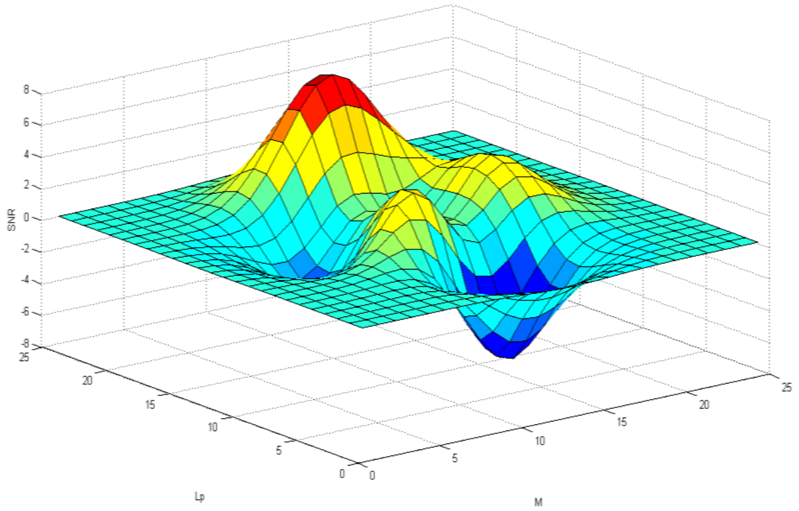


**Figure.14** Surface Plot Between SNR,Lp and M

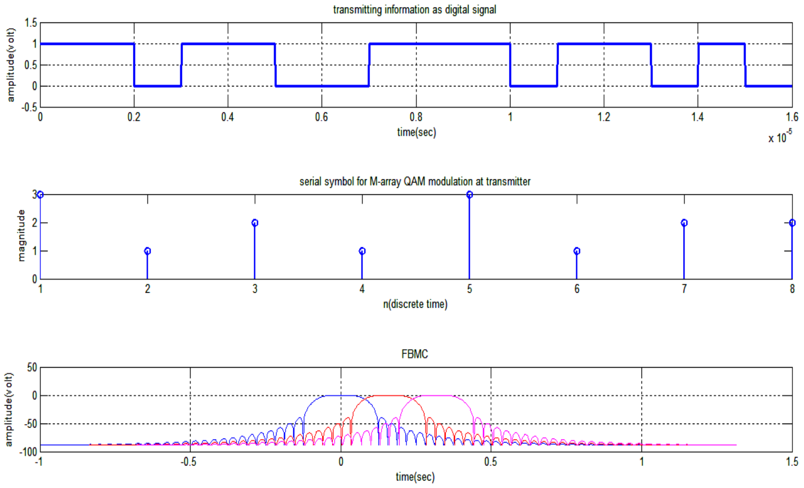


**Figure 15** Amplitude versus time plot for FBMC when serial symbol for M array QAM modulation is used at Transmitter fed with digital signal.

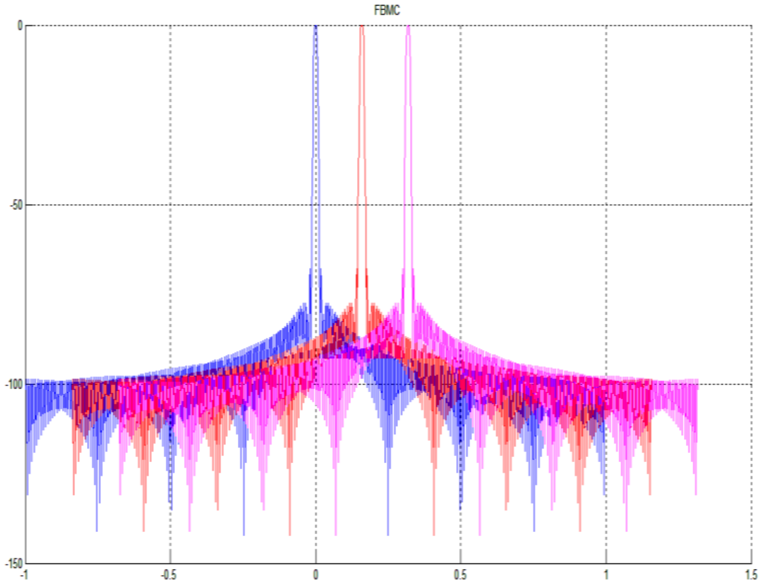


**Figure.16.**Magnitude.w.r.t.Frequency-response.of.FBMCPrototype.filter.at.K=3.with.M=256.

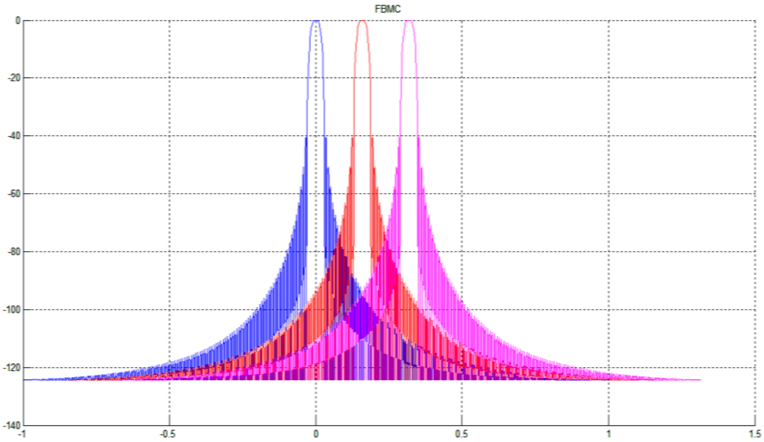


**Figure.17.**Magnitude w.r.t. Frequency Response of FBMC Prototype Filter at K=4 with M=64subchannels(subcarriers).

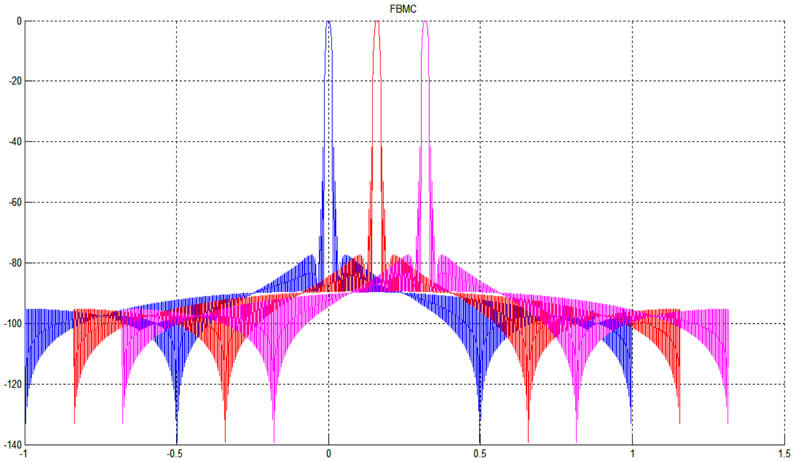


**Figure.18** Magnitude w.r.t. Frequency.Response of FBMC Prototype Filter at K=8 with M=64subchannels(subcarriers)

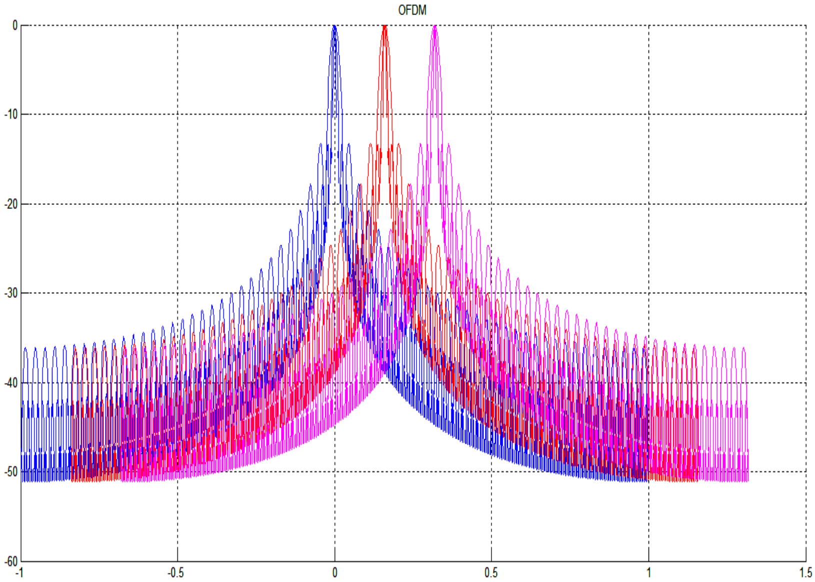


**Figure19** Magnitude w.r.t Frequency Response of OFDM at K=4 with M=64 number of subchannels(subcarriers).

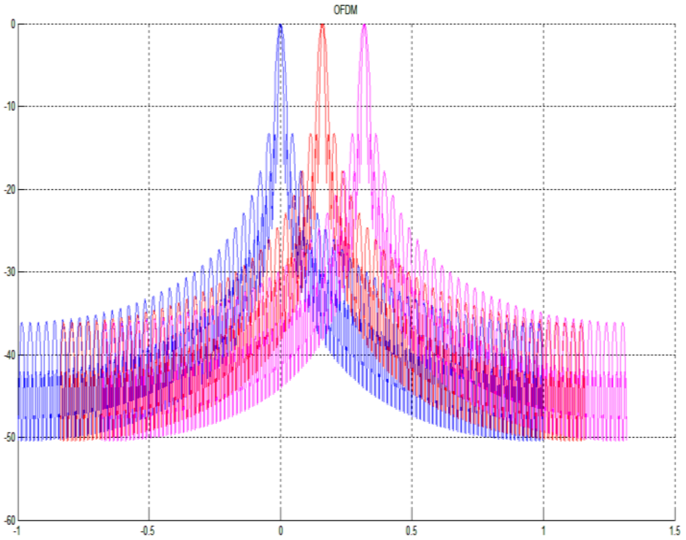


**Figure.20** Magnitude w.r.t. Frequency Response of OFDM at K=8 with M=64 subchannels

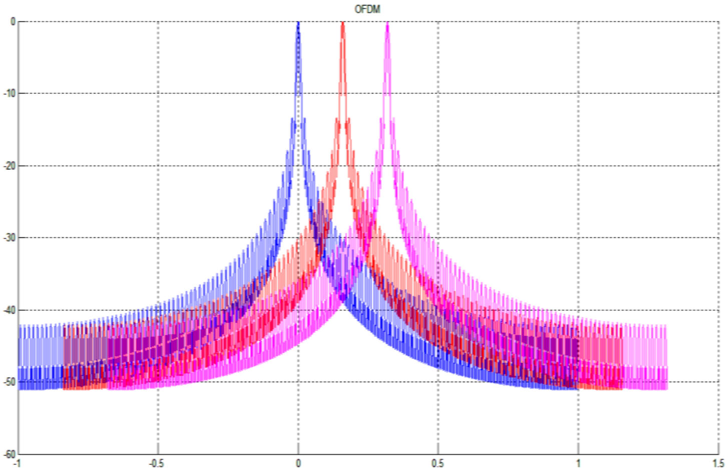


**Figure.21** Magnitude w.r.t. Frequency Response of OFDM at K=3 with M=128 subchannels

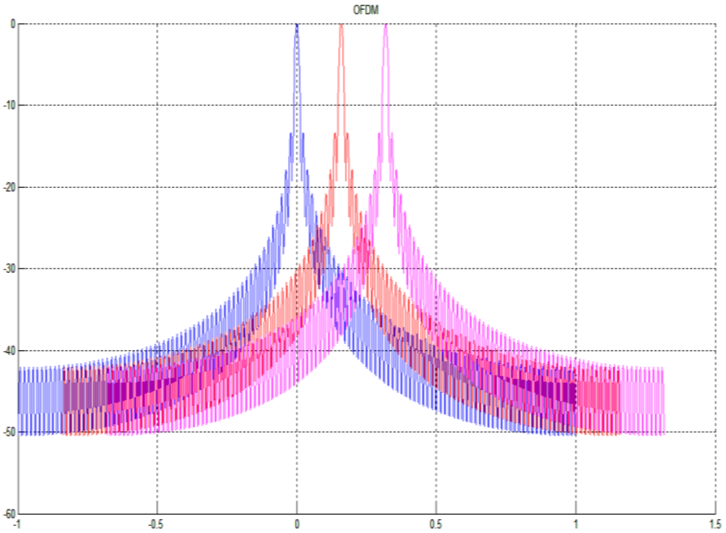


**Figure.22**Magnitude w.r.t Frequency Response of OFDM at K=4 with M=128 subchannels

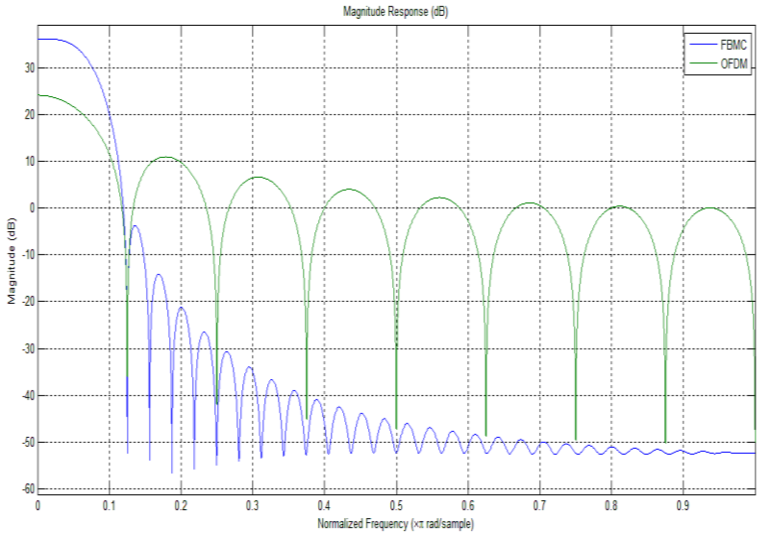


**Figure.23** Magnitude wrt Normalized Frequency Response of OFDM and FBMC

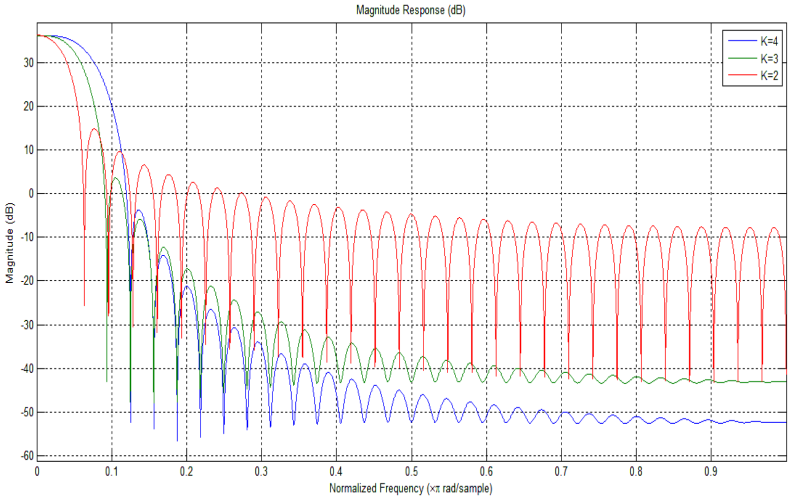


**Figure.24** Magnitude wrt Normalized Frequency Response of FBMC Prototype Filter at K=2,3,4

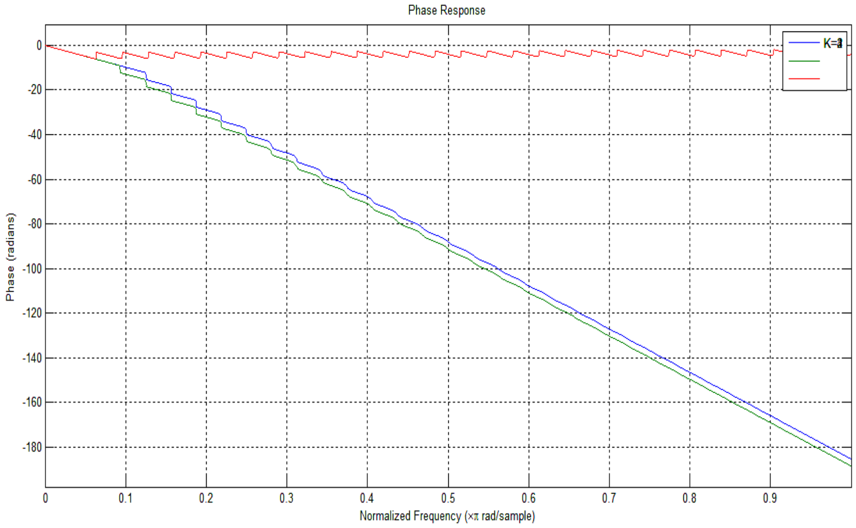


**Figure.25** Phase Response w.r.t Normalized Frequency at K=2,3,4 for FBMC Prototype Filter

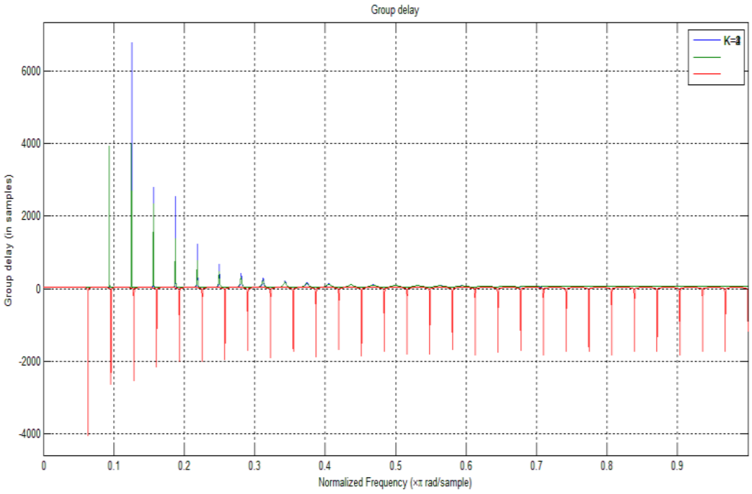


**Figure26** Group Delay(in samples) w.r.t Normalized Frequency for FBMC Prototype Filter at K=2,3,4.

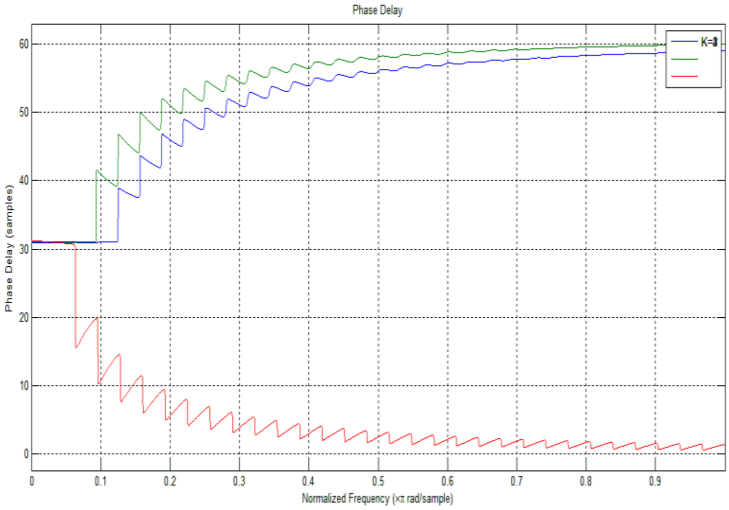


**Figure.27** Phase Delay(samples) versus Normalized Frequency for FBMC Prototype Filter at K=2,3,4.

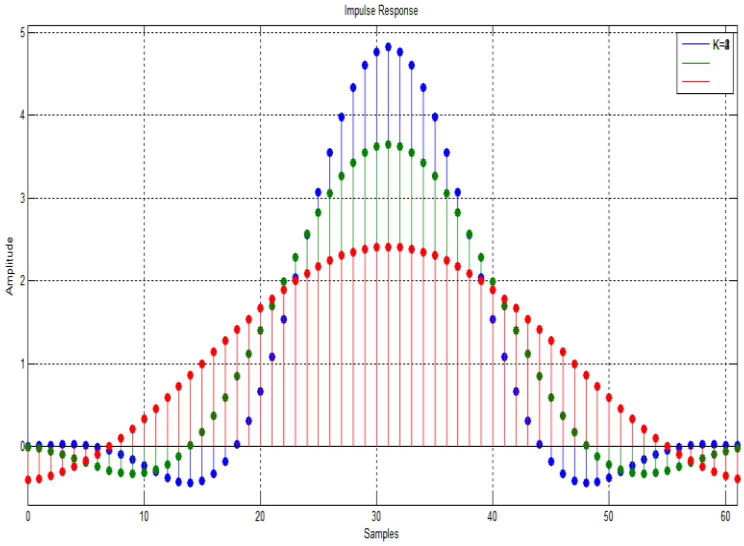


**Figure.28** Impulse Response of FBMC Prototype Filter at K=2,3,4 (in compliance with Phydas Filter Specifications)validated through comparison.

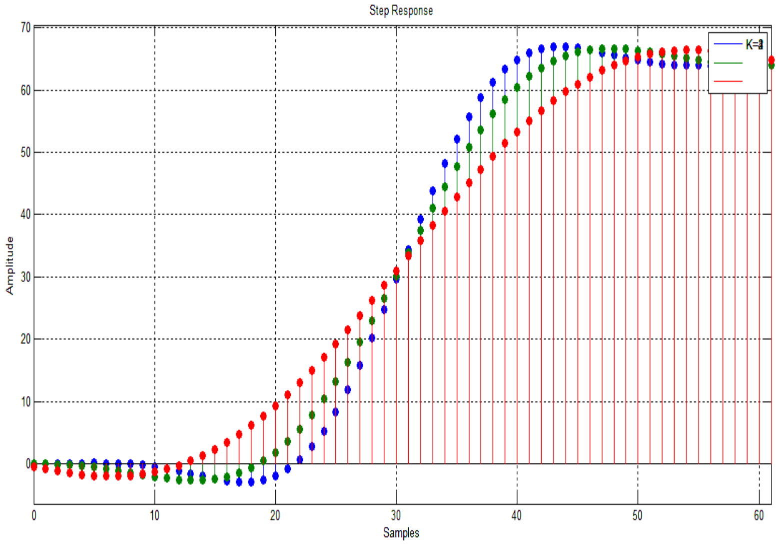


**Figure.29** Step Response of FBMC Prototype Filter at K=2,3,4

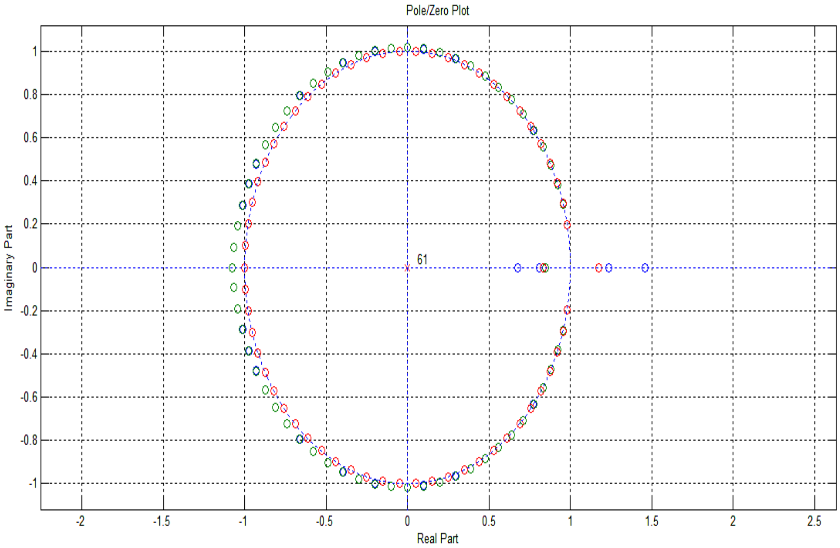
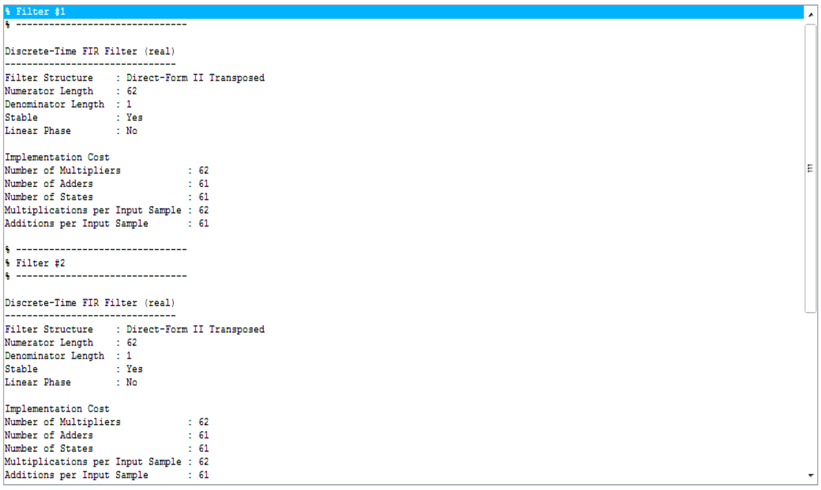


**Figure.30** Pole/Zero Plot of FBMC Prototype Filter design



```
% Filter #1
% ------------------------------

Discrete-Time FIR Filter (real)
-------------------------------
Filter Structure    : Direct-Form II Transposed
Numerator Length    : 62
Denominator Length  : 1
Stable              : Yes
Linear Phase        : No

Implementation Cost
Number of Multipliers            : 62
Number of Adders                 : 61
Number of States                 : 61
Multiplications per Input Sample : 62
Additions per Input Sample       : 61

% ------------------------------
% Filter #2
% ------------------------------

Discrete-Time FIR Filter (real)
-------------------------------
Filter Structure    : Direct-Form II Transposed
Numerator Length    : 62
Denominator Length  : 1
Stable              : Yes
Linear Phase        : No

Implementation Cost
Number of Multipliers            : 62
Number of Adders                 : 61
Number of States                 : 61
Multiplications per Input Sample : 62
Additions per Input Sample       : 61
```

**Figure.31** Discrete Time II Transposed Discrete Time FIR Filter Structure Information

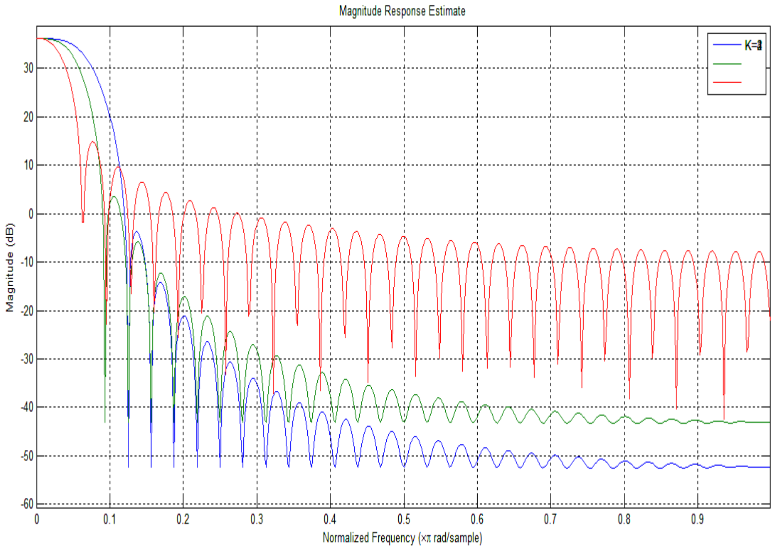


**Figure.32** Magnitude Response Estimate for FBMC Prototype Filter designed at K=2,3,4

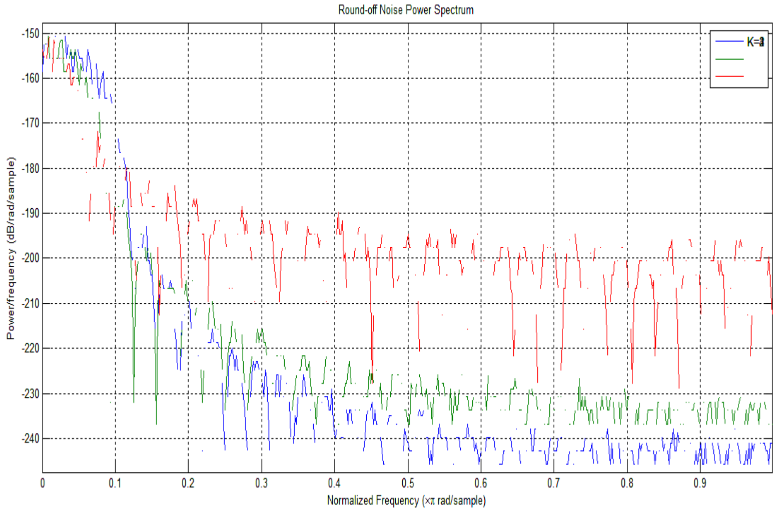


**Figure.33.**Power-Frequency Plot wrt Normalized Frequency(Round Off Noise Power Spectrum) with K=2,3,4

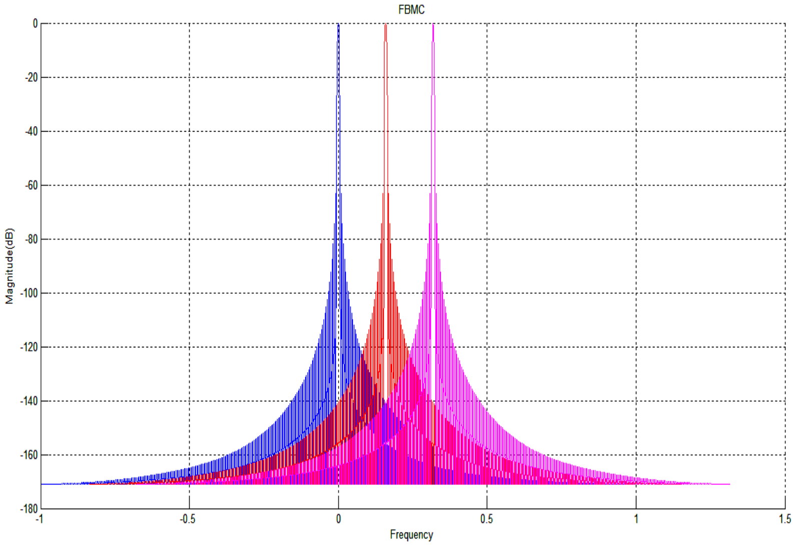


**Figure..34** Magnitude wrt Frequency Plot for FBMC with M=512 subchannels at K=2,3,4

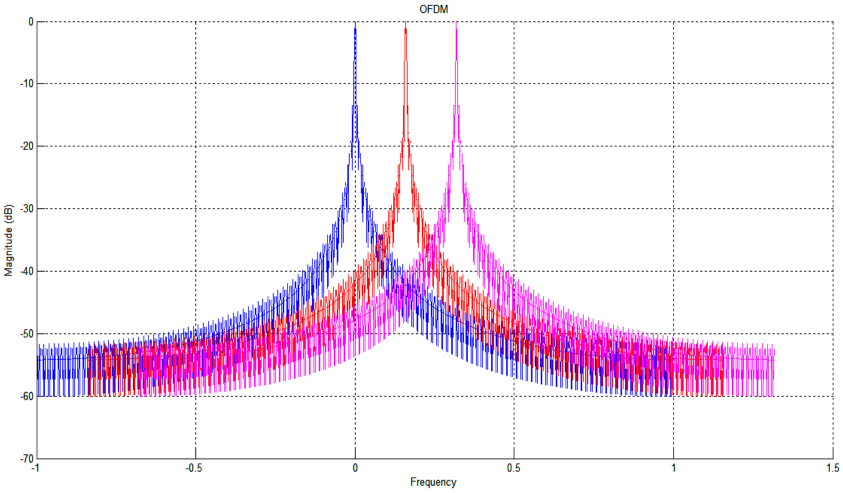


**Figure.35** Magnitude wrt Frequency Plot for OFDM with M=512 subchannels at K=2,3,4.

**Table.2** OFDM-OQAM Gain,Frequency Selectivity,Number of Subcarriers at Fix Coherence BW , Overlapping factor K

| OFDMOQAM Gain(dB) | Frequency Selectivity | Number of Subcarriers (Subchannels M) | Coherence BW(1-2Mhz) | Overlap Factor K |
|---|---|---|---|---|
| -52 to -2dB | -1 to +1.2 | 64 | 1.5 | 4 |
| -50 to -2dB | -1 to +1.25 | 64 | 1.5 | 8 |
| -53 to -1dB | -1to +1.30 | 128 | 1.5 | 3 |
| -50 to 0dB | -1 to +1.35 | 128 | 1.5 | 4 |
| -55 to 0dB | -1 to +1.4 | 512 | 1.5 | 2 |

**Table.**3 FBMC Gain,Frequency Selectivity,Number of Subcarriers at Fix Coherence BW , Overlapping factor K

| FBMC Gain(dB) | Frequency Selectivity | Number of Subcarriers (Subchannels M) | Coherence BW(1-2Mhz) | Overlap Factor K |
|---|---|---|---|---|
| -170 to 0dB | -1 to +0.8 | 512 | 1.5 | 2 |
| -40 to -5dB | -1 to +1.5 | 128 | 1.5 | 4 |
| -120 to-10dB | -1to +1.3 | 256 | 1.5 | 3 |
| -125 to-10dB | -1 to +1.3 | 64 | 1.5 | 4 |
| -95 to -10dB | -1 to +1.3 | 64 | 1.5 | 8 |
| 0to+4.8db (Impulse-Response) | 0 to +62 | 64 | 1.5 | 2 |

Figure.23 shows that the Magnitude response for FBMC Prototype designed,decreases from 35dB to -55db at a Normalized frequency of 0.13 till the side lobe tail of FBMC decays completely at a normalized frequency of 0.98. Fig.24 shows the Magnitude wrt Normalized Frequency Response of FBMC Prototype Filter at K=2,3,4 where,magnitude decays from 35dB to -55dB for K=4,and the magnitude decay for K=3 is from 35db to -42db while the magnitude decay for K=2 starts from a normalized frequency of 35dB to -25dB.Fig.25 shows the Phase Response wrt Normalized frequency for FBMC Prototype Filter where it shown that for K=2 and K=3,the phase starts decaying at a normalized frequency of 0 db to -190dB whereas for K=4,there is a constant phase response throughout the normalized frequency sample range.Fig.26 shows the Group Delay(in samples) wrt Normalized Frequency for FBMC Prototype Filter at K=2,3,4.For K=2 and 3,there is an exponential decay in group delay wrt Normalized frequency while for K=4,there is negative exponential decay in group delay wrt normalized frequency.Fig.27 shows that the Phase delay wrt Normalized frequency from 30 to 15 at 0.05π radians per sample.Fig.28 Impulse Response of FBMC Prototype Filter at K=2,3,4 is in compliance with Phydas Filter Specifications validated through comparison with D5.1 Report[18].Fig.29 shows the Step Response of FBMC Prototype Filter at K=2,3,4.Analytical study shows that the Simulation Performance Analysis of FBMC Filter as Direct Form II Transposed Structure has a Filter Length =N=D*M=1+Filter Order=61+1=62 with Non Linear Phase Response but stable with 62 Number of Multiplications per input sample,61 number of real additions per input sample.Round Off Noise Power Spectrum for FBMC at K=2,3,4 has been shown in Fig.33.

Filter bank based multicarrier systems can be designed to provide better spectral shaping than OFDM systems as this leads to optimum bandwidth efficient multicarrier systems without guard interval.i.e.cyclic prefix.Optimum adaptability to the time and frequency selectivity of the propagation channel is crucial for mobile communication systems.Multicarrier systems provide the possibility to find a tradeoff between robustness against frequency selectivity and time selectivity by adjusting the number of subcarriers.Multicarrier systems can be realized by using Transmultiplexer filter banks.The power spectral density of the input symbol vector of both OFDM and TMUX system is assumed to be white with unity power.Practically,a certain number of subcarriers at the band edges is omitted for data transmission as frequency guard band in order to simplify the subsequent signal processing tasks concerning the band limitation.It has been observed that the power spectral densities of the output signals of each subchannel of the FBMC-TMUX configuration have only overlap with directly adjacent subchannels and separate the other subchannels by the large attenuation characteristics while the power spectral densities for OFDM show large overlap with all other subchannels.The Complex Modulated Transmultiplexer Filter Banks in FBMC subband filters provide an improved spectral shaping as compared to OFDM system.Cognitive radio networks have a promising future and have excellent applications of wireless networks.The adaptive technology naturally presents unique signal processing challenges in cognitive radio domain.The signal processing prospectives of CR have significant impact in CR technology in its performance enhancement.The present section deals with the computer aided simulation and performance analysis of modified FBMC for Physical Layer Cognitive Radio under fading channel scenario.

The use of allocated spectrum varies at different times and over different geographical regions.To overcome the spectrum deficiencies and inefficient utilization of allocated frequencies,it is mandatory to take into consideration the latest communication models by means of which radio frequency spectrum can be utilized wherever the void or white space is available.Here,a comparatative analysis of number of subchannels M on FBMC prototype filter length at fix overlapping factor K=4 has been done by taking BER and Eb/No as performance measuring indicators.Fig.15-Fig.35 show the frequency responses of FBMC Prototype filter at different values of Overlapping Factor K but K=4 is found to satisfy the optimum results.Fig.12 shows that Computational Complexity in terms of number of real multiplications increases with the increase in the number of Subchannels.Fig.28 shows the spread of FBMC subcarriers for certain values corresponding to the FIR low pass prototype filter coefficients that have been taken under present study.We can conclude that this modified FBMC proves to be more efficient with small frequency selectivity as the gain of removed cyclic prefix takes the full effect but with larger frequency selectivity, the FBMC gain decreases. It has been observed that smaller coherence bandwidth results in reduced FBMC gain. The performance evaluation of FBMC CR for physical layer based on orthogonal waveforms under effect of OQAM pre and post processing has been done.

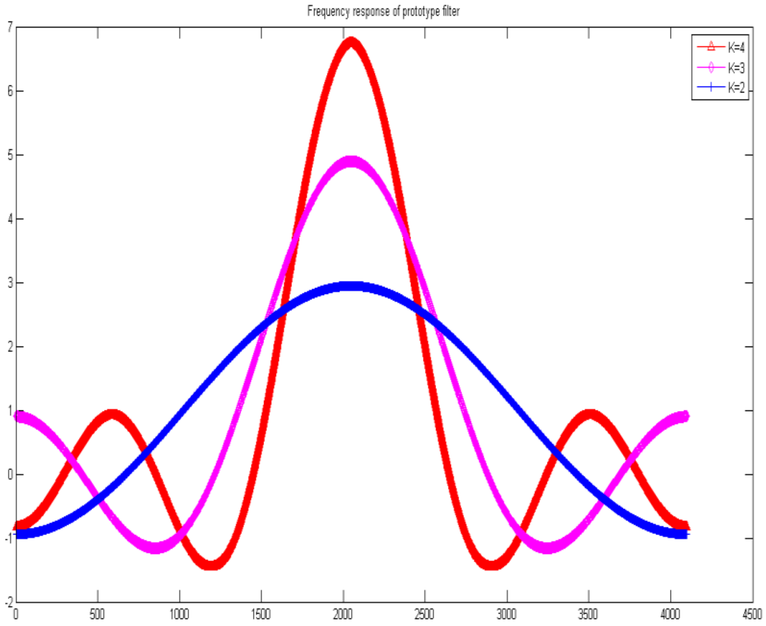


**Figure.36** Frequency Response of Prototype Filter(Corresponding to Martin Mirabassi Filter Coefficients)K=2,3,4;M=4096

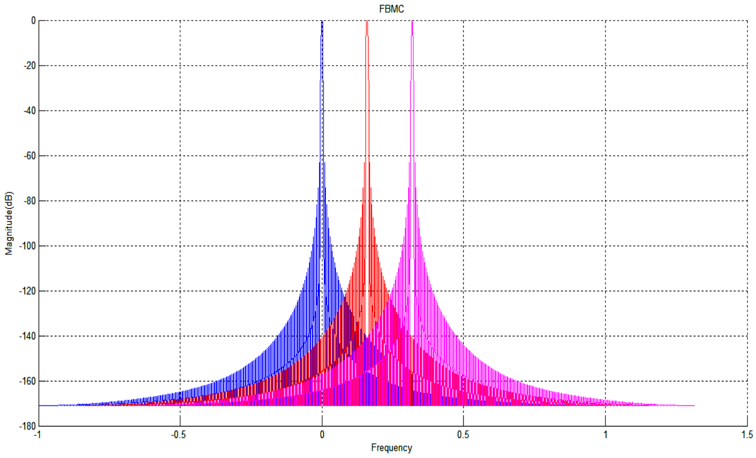


**Figure.37** Magnitude wrt Freq for FBMC at N=384 subcarriers;K=4

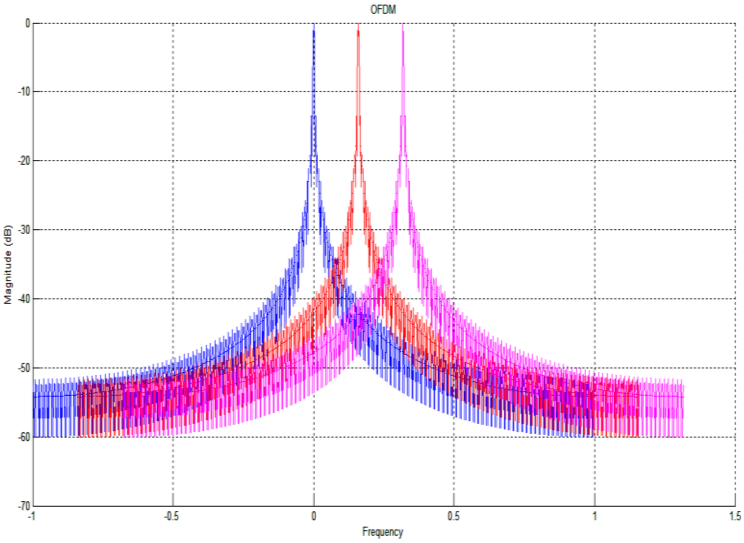


**Figure.38.**Magnitude wrt Frequency Plot for OFDM at N=384 subcarriers;K=4

The present study has left its impact on FBMC cognitive radio under pervasive and ubiquitous wireless communication scenario for next generation communication systems[24-36]. 5.Conclusion: The time varying nature of wireless channels such multipath-fading makes it difficult for the rf design engineers to satisfy the ever growing demands of mobile users in terms of data rate and spectral efficiency.The limited radio spectrum and limitation on the processing power availability in the portable handheld unit of mobile users are important constraints in wireless system designLimited usable radio frequencies and current rigid frequency allocation policies have resulted in the apparent scarcity of the radio spectrum even though the overall spectrum occupancy is still very low. Cognitive radios offer the promise of enabling the future wireless world by increasing spectrum efficiency through dynamic spectrum access. In dynamic spectrum access, the secondary users access the underutilized primary user spectrum opportunities such that the interference to the primary users is under allowed limits. Spectrum sensing is a key enabler for cognitive radios. Sensing provides awareness about radio environment so that spectrum opportunities can be efficiently reused to limit the interference to the primary users. A Comparatative Performance Analysis of Phydas Prototype filter with modifications achieved through P.Martin Mirabassi Filter Coefficients at K=2,3and 4 for N=384,512 subcarriers has been done which shows the stopband behaviour and frequency selectivity as the performance parameters of interest in the present study. An efficient FBMC-TMUX Prototype filter having minimum stopband attenuation and good transition band response is deemed good from reconstructed output point of view. The overall performance of good prototype filter design using multirate approach depends upon complex modulated filter bank. The study can be extended to the wireless networks through the application of efficient filter banks which can be further helpful for analysis and design of future wireless radio technologies .

6. Impact of the Present Study

The outcome of research done will be helpful in detecting the interference at primary receiver and reliability of detection in Cognitive cycle of CR system.The Spread Spectrum Detection in terms of Power and with wide frequency range hidden in the noise can be done. The most of the CR will have to autonomously work in multiservice, multitechnology and multiuser environment by adapting to the different parameters under different conditions.Vertical and Horizontal sharing of radio spectrum will be possible to some extent with efficient spectrum space opportunities, spectrum mobility and transmission power control.The present study will be useful for optimum selection of hardware components which will minimize circuit complexity and cost and less chances of interference.FBMC based CR network performance will improve with the application of multirate signal processing in wireless communication.Better Radio Resource Management will be possible as the Congestion in ISM bands which adversely affects the quality of communication will be reduced by Dynamic Spectrum Access based CR network.The study is useful to improve the performance of CR system under different signal impairments,channel modulation techniques for Physical layer CR.The Computer Modelling and Simulation of Interference Analysis by using different techniques in Physical layer CR wireless environment has led to the improvement in terms of Gain for Channel Capacity and Spectral efficiency with minimum BER and least Power Requirements.The CR spectral analysis for system capacity and increased spectrum usage has a profound impact on ubiquitous and pervasive soft communication environment.The present study is useful in the future planning of Wireless Mobile Communication Networks (extendable to Wireless Sensor Networks) by achieving the flexibility in the user data rates in different radio frequency environment.Better Utilization of available spectrum rf bandwidth is possible by reduction of multiple access interference,a major factor in system capacity and quality of communication at a minimum power level.The present study is useful to enhance the communication quality,coverage area and security of FBMC based Cognitive radio network. The presented results can be used for capacity ,coverage and quality analysis. It works on a trade-off algorithm of channel capacity,spectral efficiency,BER,Power,Interference,BW,SNR(Eb/No),Overlapping-Factor/Prototype filter length,Number of Subchannels used,power spectral density, interpolation ,decimation,single channel/multi channel sub band processing through multirate filter banks in a TMUX configuration).So,this study is useful for CR wireless network planning,optimization with various mobile distributions and different services.The present study has its deep impact on analysis of nonlinear spectral regrowth in FBMC -CR study on time and frequency synchronization with FBMC is possible.FBMC as expected is more efficient with small frequency selectivity,as the gain of removing cyclic prefix is that with larger frequency selectivity,the gains that can be expected from using FBMC become slightly smaller.

## V. FUTURE SCOPE OF THE PRESENT WORK

The work in this thesis is helpful in developing the link level and system level simulation for $5^{th}$ Generation Wireless network. C-OQAM is enabler for next generation Cognitive radio network.The modular features of this system allow its expansion to incorporate more realistic models and computationally efficient algorithms.Performance Comparison of (FBMC) proposed with its variants to be modified in future can be done.The Comparative Performance Analysis of Cognitive Radio under Different Modulation and Coding Techniques using advanced Transform Techniques can be done.With the support of Real Time Workshop or PhySim or Network Simulator platform and simulink will allow the use of signal processing hardware/FPGA Implementation to complement the host processor.Rayleigh,Rician,Nakagami,Weibull fading channels are available to replace AWGN and Binary Symmetric channel models to simulate the system under mobility radio channel.Performance higher than optimal can be achieved by incorporating more influential parameters of interest in system level simulation models using adaptive signal processing approach.Attempts should be made to develop newer models of CR on Lab View,System View within SNR range for Cognitive radio operation -5dB to +40dB.Radio Spectrum Management at Physical Layer CR still may not provide sufficient BW.Spectrum Sensing in Cognitive radio under Media Access Control Layer of OSI Model can be done as Spectrum Sensing Cognitive Radio Enhancement to ProTOMAC(Proactive Transmit Opportunity Detection at MAC Layer).The work can be extended to develop algorithms which further enhance coordination among cells,high cell edge throughput,high network coverage and higher interference suppression in a cognitive radio network.

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