

PERFORMANCE ANALYSIS OF PULSE SHAPING FILTERS FOR GFDM  
SYSTEMS

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Submitted By

**SURBHI KALSOTRA**

R. No. 801661025

Under Supervision of

**Dr. Hem Dutt Joshi**

Associate Professor



ELECTRONICS AND COMMUNICATION ENGINEERING DEPARTMENT

THAPAR INSTITUTE OF ENGINEERING AND TECHNOLOGY

(A DEEMED TO BE UNIVERSITY), PATIALA, PUNJAB

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## DECLARATION

I, Surbhi Kalsotra hereby declare that the work presented in this thesis entitled "**Performance analysis of pulse shaping filters for GFDM systems**" in partial fulfillment of the requirement for the award of degree of Masters of Engineering submitted at Electronics and Communication Engineering Department of Thapar Institute of Engineering and Technology (Deemed to be university), Patiala is an authentic record of work carried out under the supervision of **Dr. Hem Dutt Joshi (Associate Professor)** Electronics and Communication Engineering Department of Thapar Institute of Engineering and Technology (Deemed to be university), Patiala. The matter presented in this has not been submitted in any other University/Institute for the award of any other degree.

Date: 6/7/18



Surbhi Kalsotra

Roll No: 801661025

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.



Dr. Hemdutt Joshi

Associate Professor

Electronics and Communication Engineering Department

Thapar Institute of Engineering and Technology

(A Deemed To Be University), Patiala, Punjab

Date: 06/7/18

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Surbhi Kalsotra

ME-ECE

801661025

## **ABSTRACT**

During the previous years, the evolution of mobile communication networks has been done in terms of number of users and throughput. But higher throughput will not be enough to address the fifth generation of cellular networks. Cellular systems of the fourth generation (4G) have been optimized to provide high data rates and reliable coverage to mobile users. Cellular systems of the next generation will face more diverse application requirements like the demand for higher data rates exceeding 4G capabilities, battery-driven communication sensors need ultra-low power consumption; and control applications require very short response times. We use a waveform technique called as Generalized Frequency division Multiplexing (GFDM) to achieve these requirements.

Various generations of mobile networks, 5G waveform techniques, standard projects under 5G are discussed. Literature survey has been done by considering papers related with the GFDM technique. From these papers, observations have been drawn and which is used to formulate the problem. Finally the objectives have been drawn in which different pulse shaping filters are used in GFDM technique. Finally, simulation results are computed by using MATLAB R2017a in which symbol error rate performance and out of band emissions power performance have been improved. Finally, the conclusion and the future scope of the work has been discussed.

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## LIST OF ABBREVIATIONS

NTT	Nippon Telegraph and Telephone
FDMA	Frequency Division Multiple Access
GSM	Global System Mobile
TDMA	Time Division Multiple Access
OFDM	Orthogonal Frequency Division Multiplexing
IP	Internet Protocol
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
AI	Artificial Intelligence
CR	Cognitive Radio
DSP	Digital Signal Processing
MTC	Machine Type Communication
WRAN	Wireless Regional Area Network
UHF	Ultra High Frequency
MIMO	Multiple Input Multiple Output
OOB	Out of Band
M2M	Machine-to-Machine
V2V	Vehicle-to-Vehicle
CP	Cyclic Prefix
CFO	Carrier Frequency Offset
FDE	Frequency Domain Equalization
PHY	Physical
PAPR	Peak to Average Power Ratio
FFT	Fast Fourier Transform
IEEE	Institute of Electrical and Electronics Engineers
SNR	Signal-to-Noise Ratio
ISI	Inter Symbol Interference
ICI	Inter Channel Interference
BER	Bit Error Rate

IFFT	Inverse Fast Fourier Transform
STC	Space Time Coding
CSI	Channel State Information
MMSE	Minimum Mean Square Error
PSD	Power Spectral Density
MF	Matched Filter
ZF	Zero Forcing
RC	Raised Cosine
DFT	Discrete Fourier Transform
IDFT	Inverse Discrete Fourier Transform
SIC	Signal Interference Cancellation
QAM	Quadrature Amplitude Modulation
SIR	Signal to Interference Ratio
BTRC	Better than Raised Cosine
FSC	Frequency Selective Channel
TVC	Time Variant Channel
ISP	Improved Sinc Power
BPSK	Binary Phase Shift Keying
GOFDM	Generalized Orthogonal Frequency Division Multiple Access
OFDMA	Orthogonal Frequency Division Multiple Access
SER	Symbol Error Rate
RRC	Root Raised Cosine

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# CHAPTER 1

## INTRODUCTION

### 1.1 OVERVIEW

Generalized Frequency Division Multiplexing (GFDM) is a new 5G multicarrier waveform technique. The main feature of GFDM is the lower out-of-band (OOB) emissions which can be achieved by flexible pulse shaping of subcarriers individually. The thesis work proposed the use of better pulse shaping filters so that symbol error rate (SER) performance can be improved. The different types of pulse shaping filters are used in GFDM having 16-Quadrature Amplitude Modulation (QAM) transmission and SER performance is computed in AWGN and Rayleigh channel. Also, power spectral density (PSD) of the transmitted GFDM signal is also computed.

The thesis report is organized as: Chapter 2 contains the Literature Survey, observations and gaps drawn from this survey and objectives concluded from the identified gaps. Chapter 3 contains the description of the designed GFDM model, Chapter 4 contains the detail about the pulse shaping filters used in the GFDM model. Chapter 5 has the analytical and simulation results. Chapter 6 includes the conclusion drawn from the results and also what further work can be done in this.

### 1.2 EVOLUTION OF WIRELESS COMMUNICATION SYSTEMS

Now-a-days, there is a rapid growth of wireless communication in telecommunication industry. The number of mobile users are increasing exponentially. This rapid growth in total number of mobile users has concluded that the wireless communication is a robust mechanism for data transmission. The increase in success of mobile phones has led to the development of new wireless systems and standards [1].

#### 1.2.1 First Generation Communication system

The first generation (1G) of wireless telephony was introduced in Japan by Nippon Telegraph and Telephone (NTT) in 1979. It was based on analog communication standards. Radio signals used were analog but the connection between telephone system and radio towers was digital. It provides basic but innovative voice transmission. Communication became personal instead of being connected to locations which were fixed. The data rate was around 10kbps and the bandwidth was in between 10 kHz to 30 kHz. The technique used was frequency division multiple access (FDMA) and circuit switching was applied in

this generation [2]. 1G systems need better coverage area, more capacity, security and good spectral efficiency. That's why second generation came into existence.

### **1.2.2 Second Generation Communication system**

The second generation (2G) of wireless telephony was launched on Global System Mobile (GSM) [3] standard in Finland in the year 1991. Unlike 1G, radio signals used here were digital. The use of digital signal between handset and tower had increased the capacity of system in two different ways. Firstly, compressing and multiplexing of voice in digital form was more effective than encodings of analog voice by using various codecs so that more calls could be transmitted in same bandwidth. Secondly, emission of less power from mobiles i.e. cell size should be small for accumulation of more cells in less space. But the transmitted digital signal by phone might not be enough to reach the tower. If lossy compression was used to compress the data, the quality of audio gets reduced. Short messaging services were also introduced which changes the way of communication between people. The telephonic calls and the text messages were digitally encrypted. In 2G systems, data rate was around 300 Kbps having 200 kHz bandwidth [4]. The access technique used was Time Division Multiple Access (TDMA)/FDMA and the switching starts shifting from circuit to packet.

### **1.2.3 Third Generation Communication system**

The third generation (3G) communication system was introduced to provide sufficient data rate for both voice and internet. It integrates mobile access with IP servers. The data rate was around 50 Mbps having 5 MHz bandwidth. The technique used in 3G was CDMA (Code Division Multiple Access) and the switching used was packet switching [3]. 3G is used in GPS (Global Positioning System), location based services, mobile TV, multimedia services, video conferencing, wireless web services etc. This generation has data rates and internet access of mobile almost same in comparison to wired ones at that time.

### **1.2.4 Fourth Generation Communication system**

CDMA technique used in 3G was not sufficient to provide higher data rates [1] and there was a continuous increase in data rate and bandwidth to meet the multimedia requirements. That's why fourth generation (4G) communication system has been introduced. The data rate in 4G is around 100Mbps and reach upto 1Gbps at the downlink due to variable bandwidth of 20, 40 or 70 MHz. Multiplexing technique used in 4G is Orthogonal Frequency Division Multiplexing (OFDM). It is a method by which we can encode data which is in digital form on various carrier frequencies. Sub-carriers used are orthogonal which are closely spaced [2]. They carry data on parallel streams of data. Every sub-carrier is then modulated with the help of modulation scheme whose symbol rate is so that net data rate is same as that of modulation schemes which are of single carrier in the same region of bandwidth. 4G is used in video

conferencing, gaming, high-definition mobile TV, IP telephony, cloud computing, etc. The invention of smart phones having large storage space and better computational capabilities are equipped with high definition cameras and screen turning users into content providers which pushed this system even towards more throughput[5]. LTE and LTE-A are the practical 4G systems.

### **1.3 FIFTH GENERATION (5G) COMMUNICATION SYSTEMS**

In fifth generation (5G) of wireless telephone technology, mobiles can access various technologies of wireless systems at a particular instant of time. The main goal of 5G is to achieve data rate greater than 10Gbps [5]. End to end latency should be at most 1 millisecond i.e. 5 times lower than the latency of 4G. 5G increases the rate of data, reduces the latency (end to end) time, and also improves the area of coverage. These are the properties which are important for most of the applications that are related to the Internet of Things.

#### **1.3.1 Need for 5G**

The 5G system is needed not only for maximum throughput but also includes low latency rate, high spectrum efficiency, less battery usage, good coverage area, increased security, AI capabilities [6], cheaper traffic rates due to lesser infrastructure cost. In 5G systems, new modulation techniques are used.

#### **1.3.2 Development Challenges**

There are various challenges faced in the development of 5G systems. One of the main challenge is the scarcity of the spectrum [6]. The main development challenges in 5G systems are explained below.

- **Cognitive Radio**

Upcoming generations need frequency bands and wider bandwidth per channel. The spectrum has always been the scarce resource in telecommunication industry due to which there is not enough space for new frequency bands. The spectrum availability can be improved by using unlicensed spectrum or spectrum which is previously used for the other services. We use the CR scheme [4] in 5G systems in which the same spectrum is used by different technologies effectively. The CR system detects white spaces of different size, aggregate them making sure that the neighbouring system does not get disturbed by spectrum leakage in adjacent frequency bands.

- **Reconfiguration**

There is interoperability between different networks which is the main reason for 5G success. This allows service provider to select between different wireless area networks [4] and this selection is based on :

1. Type of service needed and the resource availability in access.
2. Properly balance the load by sharing the load with coexisting networks.
3. Sharing of spectrum efficiently.
4. Less blocking probability, congestion control.
5. Increase in capacity and Quality of Service.

- **Network Efficiency**

Low consumption of energy is one of the main requirement for 5G systems. Solar panels of small size can be used to provide power for low energy.

- **Nanotechnology**

By using nanotechnology in mobile phones, they act as intelligent sensors which have use in medicine, communication, safety, transportation etc. There is a need of high speed and increased capacity to interoperate different technologies. So, nanotechnology is used in DSP fabrication [4] which increases the capacity and speed of system.

- **All IP Network**

Internet is open to everyone- developers, viruses, criminals. So, security issues increases which are in need to be solved. All IP network is used in 5G systems to satisfy the needs of cellular communication.

- **Cloud computing**

In cloud computing, data and applications are maintained by using central remote server and internet [4]. In 5G, content is provided by the remote server and cloud computing is used to run applications at any computer without installing the personal files with the help of internet.

## **1.4 5G NETWORK SCENARIOS**

MTC, WRAN, Bit pipe communication and Tactile Internet are the main 5G network scenarios.

### **1.4.1 Machine type Communication (MTC)**

There are various machines and devices are present having sensors in them. They operate automatically and communicate without human intervention [5]. Now-a-days, MTC occurs only for short distances as it

is based on Zigbee and Bluetooth. By increasing the coverage area for MTC, the use of this type of communication increases. The machine can act as whole system with internet only as air interface between the devices or the machine can act as sensors and the whole control system is on cloud.

#### **1.4.2 Wireless Regional Area Network**

In remote areas or less populated areas, there is a problem of lower data rates. For wireless networks, there is a need of small coverage area and licensed frequency bands which are not feasible economically in those areas. So CR technique is used to eradicate this problem in which white spaces of different size are integrated together [5]. Generally, white spaces present in UHF TV bands are used. The increase in latency is not an issue in this scenario but cyclic prefix and cyclic suffix are used properly to avoid ISI.

#### **1.4.3 Bit pipe communication**

Now-a- days, people are demanding to watch their favourite TV shows anywhere and at any time. Mobile phones, tablets, laptops and computers are used to fulfill this demand. The quality of video is high definition and the speed and data rate requirement is increased to get the good quality picture. 3D contents [5] are also accessed using phones. So the data rate needed to be more than 10 Mbps. To achieve the on-going demands, we have to apply MIMO technique, advanced multiplexing methods and dynamic allocation of spectrum. Also, the OOB emissions should be low as CR scheme is used in 5G.

#### **1.4.4 Tactile Internet**

Recently, touch screens are used as input device for mobile phones. In future, different interfaces will integrate together for visual, auditory input. There is a need for interaction of these devices with internet for virtual and augmented reality, gaming, smart house, etc. The latency time [5] should be low around 1ms trip time as the applications under this scenario are real time applications.

### **1.5 5G WAVEFORMS**

MTC and M2M communication [7] requires consumption of power to be low. That's why process of synchronization needs to be strict. So, the orthogonality between the sub-carriers cannot be maintained. In 5G applications like tactile internet and V2V [8], latency time needs to be less which demands for data to be in short bursts. But the spectral efficiency of the OFDM signals having single CP in a symbol is less because of CP insertion which creates problem in 5G applications like WRAN in which the impulse response of channel should have period in microseconds [9]. The spectrum access is dynamic [10] in 5G. But the OFDM [11] signal has high OOB emissions which cause problem in dynamic spectrum access. Also, leakage in spectrum, sensitivity to CFO and limited bandwidth efficiency are present in OFDM due

to CP which is necessary to support FDE. That's why, various schemes of multicarrier are taken into consideration for PHY layer of 5G. The new format of 5G waveforms include:

### **1.5.1 Filter Bank Multi Carrier (FBMC)**

In FBMC [12], rather than pulse shaping the whole band different subcarriers are individually pulse shaped. This type of waveform reduces the OOB emissions. Because of the narrow bandwidth of subcarriers, the length of impulse response of transmit filter is long. So, filter length is four times symbol length. If transmit symbols are large than good spectral efficiency is achieved. So, this type of waveform is not applicable for low latency applications.

### **1.5.2 Generalized Frequency Division Multiplexing (GFDM)**

It is the generalization of OFDM. In GFDM, various blocks are modulated individually. Each block contains multiple subcarriers and each subcarrier has various sub symbols. The pulse shaping of subcarriers are done using circularly shifted filter. This waveform can fulfill various requirements because of its flexibility. So, this waveform is used for 5G PHY layer.

### **1.5.3 Universal Filtered Multi Carrier (UFMC)**

In UFMC [13], a group of subcarriers are filtered so that OOB emissions get reduced. As many subcarriers are covered within the bandwidth of the filter, this waveform can have short impulse response which means good spectral efficiency is achieved in transmissions which is short burst. This waveform does not require any CP and filters can be designed to get a block length which is equal to CP-OFDM. This waveform is sensitive to time misalignment. So, UFMC is not suitable for loose time synchronization applications.

### **1.5.4 Bi-orthogonal Frequency Division Multiplexing (BFDM)**

BFDM [14] uses pulse shapes which are bi-orthogonal to one other both at transmitter as well as receiver side. The system is robust against the frequency dispersion also called as the Doppler effect if the transmitted pulse has good frequency localization. Also, it is robust against the time dispersion also called as multipath if the transmitted pulse has good time-localization. We cannot integrate BFDM with MIMO which is necessary in 5G. For long pulse, efficiency gets reduced for short burst data transmissions which is important in M2M and low latency applications.

## 1.6 GENERALIZED FREQUENCY DIVISION MULTIPLEXING

GFDM is the multiplexing technique proposed for the 5G networks. It is the generalization of OFDM. It is the generalization of digital multi-carrier concept of transceiver. It can be used to exploit white spaces in spectrum for wireless communication. In GFDM, the blocks of data are independently modulated. Every block consists of various sub-carriers and every sub-carrier has various sub symbols [5]. The various sub-carriers used are not orthogonal. The pulse shaping of sub-carriers are done using circularly shifted filter which is shifted in both domains: time as well as frequency. OOB emissions get reduced by this process. The ISI and ICI may arise due to subcarrier filtering. Overhead is small in GFDM block as there is a single CP for a block having various sub symbols. It can be used in the system to improve its spectral efficiency.

- **Features of GFDM**

1. The PAPR is very less in comparison with OFDM.
2. The OOB emissions are very low due to the adjustable nature of filter at the transmitter end.
3. The transmission is block wise due to CP insertion.
4. The equalization process is based on FFT.

- **Advantages of GFDM over OFDM**

OFDM is used mainly because of its robustness in multipath channels [11] and its easy implementation based on FFT algorithms [12]. But the OFDM can address the challenges which are given by 5G networks in limited way.

- In GFDM instead of filtering whole band as in OFDM, we filter each band individually. So there is a large amount of flexibility in the design of GFDM system.
- There is no cyclic prefix in GFDM. So it provides high degree of spectral efficiency.
- Carriers used are non-orthogonal as sub carrier filters are narrow and require long time constant.
- Low out of band emissions.
- Reduced peak to average power ratio.
- Lowers the burden of heavily spectrum fragmentation.
- Low latency needed for many applications such as Tactile Internet.

## **1.7 STANDARDS IN FIFTH GENERATION NETWORKS**

The data rate and speed of 5G technology is expected to increase as billions of users are connected to internet via IoT. The standard projects of 5G under IEEE include [15]:

- **IEEE P802.1 CF**

IEEE P802.1 CF is the “Recommended Practice for Network Reference Model and Functional Description of IEEE 802 Access Network”. This standard is used for interoperability between different networks which are heterogeneous. Such networks need multiple network access technologies, network interface and network subscriptions in only one terminal. Depending on IEEE 802, the design and the usage of access networks is under this standard [16].

- **IEEE P1903.1**

IEEE P1903.1 is the “Standard used for Content Delivery Protocols for Next Generation Service Overlay Network (NGSON). This standard specifies the protocols among CDFE, SRFE, SPDFE, SONFE and CINFE. These protocols are used to deliver the advanced content which aims to provide content discovery and cache, transport QoS control, and content delivery control. It is also context aware and is dynamically adaptive [17].

- **IEEE 1914.1**

IEEE 1914.1 is the “Standard for Packet-Based Fronthaul Transport Network”. It is used for implementing massive MIMO and for transmission and reception which is multipoint and coordinated. This standard lowers the cost and makes the system more flexible and bandwidth efficient. This standard makes the design and the operation of the network simpler [18].

- **IEEE 1918.1**

IEEE 1918.1 is the “Tactile Internet: Application Scenarios, Definitions and Terminology, Architecture, Functions and Technical Assumption”. This standard is used for the development of the Tactile Internet as 5G. This standard provides low latency time, small transit, and increased security. It provides applications like transportation, mobility, manufacturing, etc which are critical and also provides non-critical applications like events and edutainment [19].

## CHAPTER 2

### LITERATURE SURVEY

#### 2.1 LITERATURE SURVEY

This chapter includes the work done by various researchers in GFDM (Generalized Frequency Division Multiplexing) modulation technique for 5G.

G. Fettweis et al. [20] worked on GFDM scheme which exploit the white spaces in radio frequency spectrum bands. These bands are located very close to the allocated spectrum for wireless data communications. The mechanism for interference reduction is combined with the flexible and simple nature of OFDM. The aim is to see the impact of the non-orthogonal carriers of GFDM which are controlled by the property of selectivity of the transmitter as well as the receiver digital filters. GFDM has lower PAPR compared to OFDM which reduces the implementation cost. The consumption of power also gets reduced. The filtering at the transmitter is adjustable which reduces the OOB radiation. The transmission is block-based using CP insertion and equalization which is based on FFT.

N. Michailow et al. [21] researched about GFDM which gives more flexibility. The data is arranged in the form of blocks where every block has various sub-carriers and every sub-carrier has various sub-symbols. The pulse shaping is applied on individual symbol. It reduces the CP amount when it is compared with the useful data. But single tap FDE is still needed. Tail biting technique is used in order to eliminate the need for periods which are necessary in a conventional system. Interference cancellation techniques are employed to remove ISI and ICI which are introduced by pulse shaping filters. The interference cancellation scheme is used in this paper to provide a significant improvement in BER performance.

I. Gaspar et al. [22] extended his work on GFDM. A transmitter model having less complexity is designed. It reduces the hardware implementation cost. The pulse shaping is applied to individual sub-carriers which reduces the OOB radiation of transmitted signal. GFDM scheme can be implemented by performing less number of computations based on FFT/IFFT algorithms.

A. Festag et al. [5] researched about GFDM which is a modulation technique having the capability to fulfill the needs of 5G networks. The data is transmitted in the form of blocks which are flexible. Every block has various sub-carriers and every sub-carrier has various sub-symbols. The filtering is applied on every sub-carrier. The various techniques are introduced to reduce the OOB radiation. This paper also presents a synchronization method which lowers the spectral emissions. MIMO-GFDM has also been

addressed in this paper for diversity purpose. The analytical and numerical BER of GFDM has been calculated for various channel models and with various iterative linear GFDM demodulators which gives various configurations. These configurations have no disadvantage when compared with the OFDM.

P. Wei et al. [23] worked on removing the ISI and ICI which are introduced in GFDM by pulse shaping filter. The transmitted signal in GFDM modulation technique is in IDGT (Inverse Discrete Gabor Transform) and then DGT (Discrete Gabor Transform) is applied at the receiver to get back the original GFDM signal. Frequency-domain IDGT is considered instead of time-domain IDGT as it helps in the reduction of complexity due to channel equalization. By using frequency domain DGT, the BER performance of GFDM is very near to OFDM at small values of roll off factors. The complexity of the system gets reduced by using LDGT but there is BER degradation which can be improved by increasing the window size. The complexity similar to LDGT is obtained by truncating the frequency domain DGT. The complexity reduction is achieved by this receiver when compared with other receivers.

D. Zhang et al. [24] presented a method for achieving transmit diversity with GFDM. Space time encoding (STC) is a technique to achieve transmit diversity. STC is applied within a block of GFDM to achieve transmit diversity in such a way that latency at PHY layer does not increase when compared with transmission through single antenna. The decoding of a block of GFDM at the receiver is done by using widely linear estimator. This scheme after combining with the MRC (Maximum Ratio Combining) approach decreases the SER when multiple antennas are used at the receiving end. The channel used in this paper is Rayleigh channel.

M. Matthé et al. [25] studied on the performance of various multi-carrier waveforms that can be used in place of OFDM in 5G networks. Filtered OFDM (f-OFDM) and Universal filtered OFDM (UF-OFDM) can achieve lower OOB emissions than OFDM but latency time gets increased in order to achieve this. The degradation of Frame Error Rate (FER) is high while using multipath fading channels. GFDM and FBMC are also investigated. Both waveforms are non-orthogonal and have an extra degree of freedom in time-domain. Lower PAPR and better FER are achieved than OFDM. An implementation of MMSE equalization is proposed in this paper.

H. Ochiai et al [26] presented the theoretical analysis of both in-band and out-of-band distortion performance for OFDM signals with peak cancellation. The closed-form expression of SDR caused by PC is first obtained from which the effect of PC associated with the peak reduced signal is analyzed from the frequency domain perspective. Also, SER degradation caused by PC when transmitted over an AWGN channel is mathematically formulated.

M. Matthé et al. [27] presented an attractive approach to fulfill the reliability issues in the 5G network by combining the flexibility of GFDM with robustness of STC given by S. Alamouti. GFDM and STC

scheme is integrated to give full diversity gain with a very small computational overhead. The code chosen is Reed Solomon code because of its robustness against error bursts and short code words which fit entirely into one frame. The overall system latency is reduced as the decoding is carried out frame-by-frame. The non-iterative Reed Solomon decoder offers a low complexity at the receiver end as compared to the iterative decoding algorithms.

G. Fettweis et al. [28] presented a paper in which the performance of GFDM is evaluated by using different types of pulse shapings. The BER performance in AWGN channels and OOB radiation is the keen interests. The closed form expression of PSD and BER of GFDM with a MF receiver is computed and then it is used for the performance evaluation of the various pulse shaping filters which are used for the shaping of the transmit signal. One guard symbol is used per GFDM block which lowers the OOB radiation created by various filters which are free from ISI after transmission. The OOB radiation is reduced by 46dB as compared to OFDM by using Dirichlet pulse filter. Dirichlet pulse filter is used so that system becomes orthogonal and have similar BER when compared with OFDM. The channel used is AWGN channel. Simulation results show that the RC pulse shaping filter reduces the OOB emissions down to 58dB below OFDM but has an acceptable interference.

M. Lentmaier et al. [29] presented a paper in which the linear system description of transmitter is obtained and then signal is detected by using three different receiver techniques i.e. ZF receiver, MF and MMSE. The bit error rate of these signals are then compared in AWGN and Rayleigh channels. ZF gives the results of BER similar to theoretical BER by removing self created interference. MF receiver gives best results at low SNR, ZF receiver gives best results at high SNR and the MMSE receiver performs the best.

D. Zhang et al. [30] presented a paper in which Orthogonal QAM (OQAM) mapping technique used in GFDM. In this technique, frequency shifts are used. It has a benefit of easy usage of null sub-symbols which reduces the OOB emissions and there is also decrement in the complexity. These benefits can be accomplished by the transfer function of pulse shaping filter in frequency domain. There is a good localization in time in which pilot insertion of symbol is done by limiting the overlapping only to adjacent sub-symbols.

N. Marchetti et al. [31] proposed modulation and demodulation techniques for GFDM systems with lower complexity. The proposed methods exploit the modulation matrix structure. This decreases the computational cost of GFDM but without any degradation in performance. In the transmitter block, DFT and IDFT matrices were used to make the modulation matrix sparse and reduces the computational burden. The ZF, MF and MMSE receivers of lower complexity were designed by the block diagonalization of the involved matrices which reduces the complexity in the matrix inversion and

multiplication operations. A unified demodulator structure based on MF, ZF and MMSE criteria was formulated and closed form expressions for ZF and MMSE receive filters were also derived.

M.A. Islam et al. [32] presented a paper in which performance of GFDM in MIMO is discussed using eight transmit antennas. Transmit diversity is applied instead of STC as it becomes unfeasible for eight antennas. OQAM-GFDM was used which reduces the complexity and OOB emissions. SER performance of OFDM and GFDM is compared. At roll off factor equal to 0.1, OFDM and GFDM have almost same results. From this paper, it can be concluded that GFDM can be used in MIMO environment.

Z. Sharifian et al. [33] proposed a precoder which is independent of data. It minimizes the variance of IP which reduces PAPR without any increment in OOB radiation or BER degradation. The analysis of complexity of various PAPR reducing methods is also given in paper. The proposed precoder has the same BER as that of original GFDMA system. The performance of the proposed precoder is improved while using AWGN channel.

D.W. Lin et al. [34] presented a decomposition which is based on the fourier transform pulse-shaping matrix of GFDM from which some of the properties of GFDM can be accepted. GFDM signals are designed depending on the upper bound on the nullity of the pulse-shaping matrix which is obtained. This is done in order to make sure that GFDM signals do not come in null space.

L.L. Mendes et al. [35] proposed the GFDM modulation technique in which Gabor expansion and transform is used which is finite, discrete and sampled critically. The Gabor analysis terminology and the Balian-Low theorem is used efficiently to calculate the ZF and MMSE receiver filters without any need of inversion of a matrix. This provides the receiver filters for large systems.

R. Datta et al. [36] worked on the techniques to reduce the self created interference. The technique used is double-sided SIC technique. The interference cancellation techniques used in the paper improves the GFDM BER so that it will match with the theoretical BER of OFDM. In GFDM, the self interference is reduced by using basic SIC. It is completely removed by using double sided SIC. GFDM has the flexibility to select the pulse shape due to which the OOB emissions is minimum into the operating frequency.

A. Navarro et al. [37] presented a paper in which a receiver having less complexity is designed for GFDM. This receiver uses filter having sparse representation in the frequency domain. The interference cancellation is done based upon this property. The GFDM performance is also obtained for high order QAM mapping technique. GFDM also offers burst modulation to adjust the future MTC traffic. In the burst modulation, a more flexible PHY is designed. The self-created ICI is there due to non-orthogonality

of sub-carriers which degrades BER performance which can be resolved by SIC techniques at the receiver.

A. Kumar et al. [38] presented a paper in which SER performance of GFDM is evaluated by using various improved nyquist pulse shaping filters in AWGN channel while zero forcing receiver is used. The 16-QAM modulation is applied here. These improved filters have better SER performance in comparison to Root Raised Cosine filter. The SER performance is improved if filters are used along with Meyer auxillary function.

M. Sharique et al. [39] proposed a pulse shaping waveform which reduces the out of band radiation and ICI in the presence of carrier offset. The pulse is formed by combining linearly the two polynomial pulses having decay rates  $t^{-4}$  and  $t^{-5}$ . The resulting pulse is then optimized to reduce bit error rate due to ICI and out of band radiation power.

A. Assalini et al. [40] presents a paper in which two new Nyquist pulses, flipped hyperbolic secant (fsech) and flipped inverse hyperbolic secant (farsech) are proposed which are ISI free and perform better than Raised Cosine pulses in terms of bit error rate. The farsech pulse also perform better than flipped exponential (fexp) pulse.

S. Han et al. [41] presented a paper in which designed filter is optimized for GFDM based on two criterias. Firstly, rate maximization is done by formulating that transmission rate depends on filter coefficients. Dirichlet filters have good transmission rate performance for AWGN channel in the absence of carrier offset whereas in channels including carrier offset non-trivial filters have better rate performance than Dirichlet filters. Secondly, OOB emission minimization is done by proving that power spectral density of GFDM signal depends on filter coefficients. For better results, window function is used along with the filter.

M. Sharique et al. [42] proposed a new family of Nyquist pulses which are time limited and obtained by multiplying the two nyquist pulses in the frequency domain. The roll off factor of proposed pulse depends on two parameters which are optimized to get SIR maximization in the presence of CFO. In this paper, two time-limited pulses multiplied in frequency domain are BTRC and RC pulse and after the optimization of this pulse it is compared with the pulse having the best OOB performance. The proposed pulse has improved SIR performance maintaining the same OOB emissions.

A. Kumar et al. [43] presented a paper in which low cost devices are proposed by using the same clock rate as used in the 4G systems. After that OOB power performance and SER performance of GFDM is studied by using improved nyquist pulse shaping filters. OOB emissions get reduced and SER performance improves by using these pulse shaping filters. SER results are further improved by using

pulse shaping filters with Meyer Auxillary function. SER results are calculated for 16-QAM GFDM transmission in AWGN, FSC and TVC channels in case of ZF receiver.

N.D. Alexandru et al. [44] proposed four new nyquist pulses which are ISI free. This family of pulses have two design parameters a and b which are properly optimized to get these pulses. These pulses outperformed in terms of probability of error when compared with the recent designed pulse.

C.A. Azurdia-Meza et al. [45] proposed a new pulse for baseband digital communication called as IPLCP pulse which is a linear combination pulse. This pulse is applied at both the transmitter side and the receiver side of communication systems and then the system is studied for bit error rate at various values of roll-off factors and timing errors. This pulse has better BER performance than other pulses.

S. Chandan et al. [46] proposed a family of polynomial pulses having decay rate  $t^{-k}$  which is asymptotic for any integer k. These pulses can be flexibly designed for constant value of roll-off factor. These pulses have better performance of SIR than RC and BTRC better than raised cosine pulses. For OFDM systems, this family of pulses helps in reducing ICI.

J.A. Cubillo et al. [47] presented a paper in which a Nyquist –I pulse named as Exponential Linear pulse (ELP) is studied and compared with other pulses. This pulse gives better BER performance but at the cost of increase in OOB emissions when compared with raised cosine pulse. The results of this pulse for BER can further be improved by optimizing the pulse.

C. Estevez et al [48] proposed Sinc Parameteric Linear Combination Pulse (SPLCP) for digital communications. The impulse response and frequency response of this pulse is evaluated in this paper. This pulse has improved BER as compared to other pulses for different roll-off factor values and timing errors. But the OOB emissions get increased by using this pulse.

N.C. Beaulieu et al. [49] proposed a new family of Nyquist-I pulses in this paper. These pulses are based on the parameteric approach and have better BER performance, wider eye opening, smaller distortion in the presence of timing errors when compared with raised cosine pulse.

N.D. Alexandru et al. [50] presented a paper aiming to reduce the ICI power in the devices employing OFDM systems. A new pulse shape named as Phase Modified Sinc Pulse (SM) is proposed which has less ICI power when compared with ISP pulse. There is an increment in the SIR when compared with ISP and other pulses. The expression of BER for OFDM system having BPSK modulation is also derived in AWGN channel and the effect of phase noise and the shape of the pulse used on BER is also studied. The BER performance while using SM pulse is better when compared with other pulses.

A.L. Onofrei et al. [51] proposed two new pulses S1 and S2 in this paper. The results of ICI power, SIR and BER are simulated. The proposed pulses have improved ICI performance and SIR performance when compared with ISP pulse. The BER performance is improved when S1 and S2 pulse shapes are used instead of ISP pulse. The effect of phase noise on BER of OFDM system having BPSK modulation is also studied.

R. Saxena et al. [52] presented a paper in which IMBH pulse shape is applied in the OFDM systems to get better results for ICI and BER. This pulse shape is applied at the receiver side of the system and the results of ICI and BER are simulated. This pulse shaped has improved results for BER and ICI when compared with various pulse shapes like Rectangular, Bartlett, ISP and BTRC. The results are further improved after the optimization of SIR with respect to pulse shape parameters.

H.D. Joshi et al. [53] presented a paper in which the various problems in OFDM systems are studied and the solutions related to these problems are also provided. In this paper, the focus is on the issues like high PAPR and synchronization in time and frequency. To reduce PAPR, clipping and pre-codings are used and synchronization is improved with proper accuracy. With the improvement in these two factors, ICI also gets reduced. In this paper, MBH pulse family is also used at the receiver side in OFDM systems to reduce the ICI.

M.A.M. Albreem et al. [54] presented a paper in which the various generations of communication systems are discussed and then the various challenges are presented like data rates, latency time, bandwidth efficiency, etc. which are not fulfilled by 4G communication systems. These demands are fulfilled by the 5G communication system. Its advantages, development challenges and architecture is also discussed in this paper.

H.A.M. Mourad et al. [55] proposed a new pulse shape in his paper which helps in reducing ICI and increasing SIR ratio. The simulation results of this pulse shape are compared with other pulse shapes like rectangular, raised-cosine, BTRC, similar raised cosine, the double disjoint pulses etc. and a conclusion is drawn that the proposed pulse shape performs better in terms of ICI and SIR ratio than other pulse shapes. Also, the proposed pulse shape depends on a parameter 'n' and when the value of this parameter increases, this pulse shape gives better results but complexity of the pulse shape increases. The side lobe levels of this pulse shape are almost negligible as compared to rectangular pulse shape. That's why this pulse shape helps in decreasing ICI and increasing SIR.

B. Lim et al. [56] presented a paper in which the OFDM and GFDM waveforms are studied with respect to timing offset, CFO and phase noise. Depending on the direction of the offset, the SIR analysis is studied for both GFDM and OFDM in frequency selective channel. GFDM give better results for timing offset and phase noise but it is sensitive to CFO. In this paper, a receiver filter of GFDM is designed and

optimized for SIR maximization to get more robust against CFO. Maximum value of SIR depends on how much system is robust against the CFO and the range of CFO depends on the specifications of the oscillators used and the parameters of the designed system.

M.H. Abbaszadeh et al. [57] proposed a new 5G waveform GOFDM in his paper. In GFDM waveform the sub-carriers used are orthogonal which results in a trade-off between the BER and complexity of the GFDM receivers. In GOFDM, the sub-carriers used are orthogonal. The comparison of BER for GOFDM, GFDM and OFDM waveforms is done in this paper while using AWGN channel and multipath fading channel. There are two configuration cases are taken in this paper which depends on number of sub-carriers, sub-symbols and FDE resolution.

L. Mendes et al. [58] presented a paper in which GFDM system is designed using ZF, MF and MMSE demodulators to reduce the implementation complexity by using circular convolution in the frequency domain. Flexibility of GFDM system is increased by using unitary transforms like Walsh Hadamard, Discrete Hartley, and CAZAC transform. The SER and PAPR performance of GFDM along with the unitary transform are analyzed. The SER performance is same using these transforms and PAPR of CAZAC-GFDM is lowest among the three transforms.

S.K. Bandari et al. [59] presented a paper in which prolate windows are used as pulse shaping filters to reduce ISI and ICI. This multi taper GFDM (MGFDM) lowers the PAPR. PAPR is further reduced by applying wavelet transforms and this MGFDM is called as Wavelet dependent MGFDM (WMGFDM). The results are analyzed using pulse shaping filters: rectangular for OFDM, RRC for GFDM and DPSS for MGFDM and WMGFDM. The wavelet transforms used for WMGFDM are symlets, coiflets, reverse bi-orthogonal, haar, orthogonal, daubechies and discrete meyer. PAPR performance of WMGFDM is better than GFDM and MGFDM. Also, biorthogonal and daubeches performs better than other wavelets. SER performance of WMGFDM is same as that of OFDM and WGFDM but better than GFDM.

I. Gaspar et al. [60] presented a paper in which two approaches are given for the coexistence of 4G and 5G. The 5G waveform can use same clock as used by LTE. In first approach, GFDM is in proper alignment with LTE grid which reduces the latency 15 times and in second approach, GFDM is used as secondary system which reduces the latency 10 times. In this paper, a new way of generating the GFDM signal is also given.

N. Michailow et al. [61] presented a paper in which GFDM is studied for 5G systems and different waveform techniques like OFDM, SC-FDE, SC-FDM are compared. After that PAPR is compared of different waveform schemes. OFDMA has poor performance and GFDMA has better performance than other waveform techniques.

## **2.2 OBSERVATIONS**

From the work done by various researchers on the modulation technique used in 5G, the various observations have been drawn:

- In GFDM system, the sub-carriers used are non-orthogonal to fulfill the need of low power consumption but this leads to an increase in ISI and ICI.
- The receiver of GFDM system is very complex. New techniques are introduced to reduce the complexity of receiver but this causes a degradation in the SER performance of the GFDM system.
- SER and OOB emissions depends on the coefficients of pulse shaping filters used in the GFDM system and their performance can be improved by using improved pulse shaping filters.

## **2.3 STATEMENT OF PROBLEM BASED ON OBSERVATIONS**

With the help of observations drawn in the previous sections, it has been found that there are many problems such as ISI, ICI, high complexity at the receiver end of GFDM and the degradation of SNR while reducing the latency time which is one of the most important feature required in 5G cellular networks. Due to these issues, the probability of taking correct decision at the receiver end decreases and hence, the SER performance also degrades. PSD and SER of the GFDM system depends on the coefficients of pulse shaping filters used. So, SER and OOB power performance can be improved by selecting the pulse shaping filters wisely.

## **2.4 OBJECTIVES**

From the above observations, following objectives has been drawn.

- To study the characteristics of various pulse shaping filters used in the GFDM.
- To analyze and compare the PSD performance of GFDM in AWGN and Rayleigh channel by using various pulse shaping filters.
- To analyze and compare the SER performance of GFDM in AWGN and Rayleigh channel by using various pulse shaping filters.

## CHAPTER 3

### GFDM SYSTEM MODEL

GFDM is the multiplexing technique proposed for 5G networks which is used to exploit spectrum white spaces by using CR scheme [23]. White spaces are the vacant frequency bands present in already used spectrum and by using CR scheme the frequency ranges of varying size are aggregate together keeping in mind that the neighbouring system does not get affected by the spectral leakage in the adjacent frequency bands.

In the proposed work, the improved pulse shaping filters are applied in the GFDM modulator and then the comparison of PSD and SER is done while using 16-QAM transmission technique over AWGN and Rayleigh channel. The lower OOB emissions and improved SER performance can be achieved by using the flexible pulse shaping. The software used for the implementation of GFDM system is the MATLAB software.

In GFDM, the data symbols are transmitted in the form of blocks. Each data block contains  $K$  sub-carriers and each sub-carrier is further divided into  $M$  sub-symbols as shown in Figure 3.1. The sub-carriers used are not orthogonal to each other. The pulse shaping of sub-carriers are performed using filter shifted in both domains: time and frequency. OOB emissions get reduced by this process. There is only single CP used for a GFDM block which increases ICI and ISI.

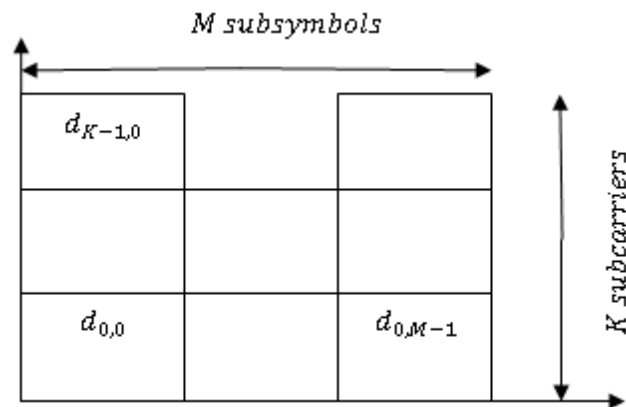


Figure 3.1 Division of sub-carriers and sub-symbols in GFDM.

The GFDM block diagram is shown in Figure 3.2. There are three main parts in GFDM: transmitter, channel and receiver which are divided into various blocks [5]. Let's study each block in detail.

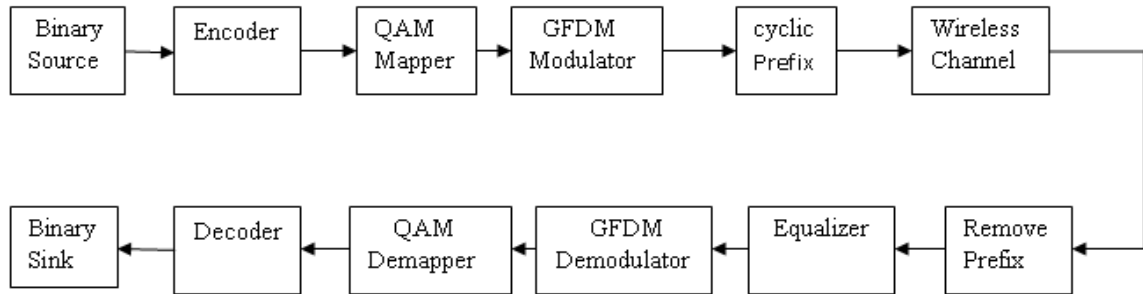


Figure 3.2 Block diagram of GFDM.

### 3.1 GFDM TRANSMITTER

In the transmitter part of GFDM, various operations are performed: data generation, encoding, mapping, modulation, adding CP which are explained below.

#### 3.1.1 Binary Source

The binary source generates the data in the binary form (i.e. '1' and '0'). This binary data is represented by vector  $\mathbf{b}$  and give as an input to the encoder.

#### 3.1.2 Encoder

The binary data is given as an input to the encoder which splits the higher bit rate stream into lower bit rate streams. The encoded output,  $\mathbf{b}_e$  is then given as an input to the QAM mapper.

#### 3.1.3 QAM Mapper

The encoded output is applied as an input to the QAM mapper which takes its values from  $2^\mu$  complex constellation where  $\mu$  is the order of modulation. The mapped data vector,  $\mathbf{d}$  having  $N \times 1$  elements is given as an input to the GFDM modulator.

#### 3.1.4 GFDM Modulator

The block diagram of GFDM modulator is shown in Figure3.3. In the GFDM modulator, various operations are performed on the data vector,  $\mathbf{d}$  which are explained in the subsequent sections.

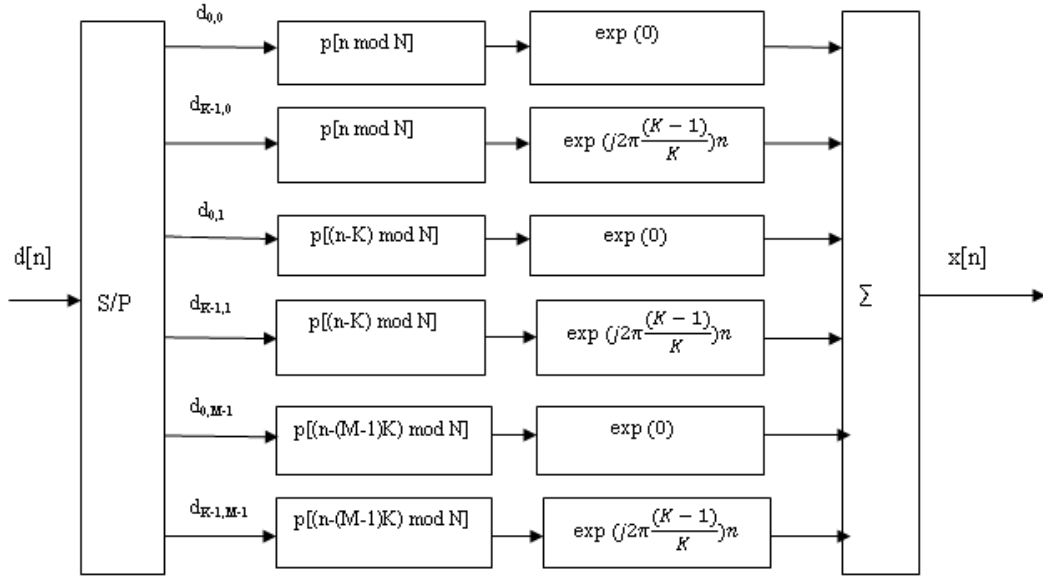


Figure 3.3 GFDM Modulator

### 3.1.4.1 Serial-to-Parallel Conversion

By using serial-to-parallel converter, the mapped data is decomposed into  $K$  sub-carriers having  $M$  sub-symbols each as given,  $\mathbf{d} = [d_0 d_1 \dots d_{K-1}]^T$  and  $\mathbf{d}_{k,m} = [d_{k,0} d_{k,1} \dots d_{k,M-1}]^T$ . The  $\mathbf{d}_{k,m}$  is the data transmitted on the  $k$ th sub-carrier and in the  $m$ th sub-symbol of the block and  $N=KM$  is the total symbols present in a GFDM block.

### 3.1.4.2 Pulse Shaping

After serial-to-parallel conversion, pulse shaping operation is performed on each data symbol separately as represented by the equation

$$p_{k,m}[n] = p[(n - mK) \bmod N] e^{\frac{j2\pi kn}{K}} \quad (3.1)$$

where  $n$  is the sampling index,  $p[n]$  is the pulse shaping used and  $p_{k,m}[n]$  is the pulse shaping filter,  $p[n]$  after shifting in both time and frequency domain. In this shifted version of pulse shaping filter, complex exponential performs shifting in frequency domain and modulo operation performs shifting in time domain.

### 3.1.4.3 Superposition

The transmit samples( $x$ ) are attained by superpositioning the transmitted symbols

$$x[n] = \sum_{k=0}^{K-1} \sum_{m=0}^{M-1} p_{k,m} [n] d_{k,m}, \quad n = 0, 1, \dots, N - 1 \quad (3.2)$$

or by collecting the pulse shaping samples in a vector say,  $p_{k,m} = (p_{k,m}[0], p_{k,m}[1], \dots, p_{k,m}[N])^T$ , we can rewrite the equation(2) in matrix notation as

$$x = Bd \quad (3.3)$$

where  $B$  is a  $KM \times KM$  transmitter modulation matrix as given by the equation

$$B = [p_{0,0} \dots p_{K-1,0}, p_{0,1} \dots p_{K-1,M-1}] \quad (3.4)$$

### 3.1.5 Cyclic Prefix

After modulation of the transmitted signal, cyclic prefix is added at the end of the GFDM block. The length of the CP is equal to  $K/4$  that is, one-fourth of the number of sub-carriers used. The transmitted signal after the addition of the CP is given by the equation

$$x_{cp} = [x(N - N_{cp} : N - 1)^T \ x^T] \quad (3.5)$$

The above signal is then transmitted through the wireless channel.

## 3.2 CHANNEL

The transmitted signal is transmitted over a wireless channel. The signal is transmitted through channel having AWGN noise and Rayleigh fading channel.

## 3.3 GFDM RECEIVER

The transmitted signal is then reached at the receiver side after passing through the wireless channel. The received signal is given as

$$y = Hx_{cp} + w \quad (3.6)$$

in which H represents the channel matrix which is a convolution matrix having total elements equal to  $(N + N_{cp} + N_{ch} - 1) \times (N + N_{cp})$ . The channel impulse response is given as  $h = [h_0 \dots \dots \dots h_{N_{ch}-1}]^T$  where  $N_{ch}$  is the length of the channel and w is the AWGN noise.

For channel having AWGN noise, H equals to 1. So, the equation (3.6) becomes

$$y_{cp} = x_{cp} + w \quad (3.7)$$

For Rayleigh fading channel, we find the convolution of impulse response,  $h$  and data vector,  $x_{cp}$  and then the output after convolution is added to AWGN noise and is given by the equation

$$y_{cp} = h\theta x_{cp} + w \quad (3.8)$$

where  $\theta$  denotes the circular convolution.

The signal after the addition of AWGN noise is received at the receiver side.

There are various operations performed at the receiver end of the GFDM system model which are explained below.

### 3.3.1 Remove Prefix

From the received signal, CP is removed first. The signal after the removal of CP is given by the equation

$$y = y_{cp}(N_{cp}:N_{cp} + N - 1) \quad (3.9)$$

### 3.3.2 Equalizer

When a signal transmitted through channel, it gets distorted due to ISI. The equalizer is used to get the desired signal back by removing the distortion caused due to channel. It preserves both frequency component and actual shape of the signal. In this GFDM model, zero forcing equalization is performed. The received signal after equalization is given by

$$z = H^{-1}Hx + H^{-1}w = x + w_n \quad (3.10)$$

### 3.3.3 GFDM Demodulator

After equalization, linear demodulation is performed. The receiver used for this type of demodulation is of three types: Zero Forcing (ZF) receiver, Matched Filter (MF) receiver, Minimum mean square error (MMSE) receiver.

#### 3.3.3.1 Zero Forcing Receivers

This type of receiver removes self interference at the receiver end but there is a possible noise enhancement which has an effect on SER performance. As noise enhancement depends upon pulse shaping, so we can improve the SER performance by properly designing the pulse shape.

In this receiver, evaluate a matrix  $B_{ZF}$  such that  $B_{ZF}B = I$  in which I is the identity matrix and matrix  $B_{ZF}$  is given as

$$B_{ZF} = (B^H B)^{-1} B^H \quad (3.11)$$

where  $B^H$  is the Hermitian transpose of matrix, B.

#### 3.3.3.2 Matched Filter Receiver

This receiver maximizes the signal-to-noise ratio (SNR) but introduces a self-interference when transmit pulse applied is non-orthogonal. In this receiver, evaluate a matrix  $B_{MF}$  such that  $B_{MF}B = I$  in which I is the identity matrix and matrix  $B_{MF}$  is given as

$$B_{MF} = B^H \quad (3.12)$$

where  $B^H$  is the hermitian transpose of matrix,B.

#### 3.3.3.3 Minimum Mean Square Error Receiver

This receiver gives a trade-off between noise enhancement and self-interference. In this receiver evaluate a matrix  $B_{MMSE}$  such that

$$B_{MMSE} = \left( \frac{\sigma_n^2}{\sigma_d^2} I + B^H B \right)^{-1} B^H \quad (3.13)$$

In this GFDM model, linear demodulation is performed using ZF receiver as given by the equation

$$d_r = B_{ZF} z = B_{ZF} (Bd + w_n) \quad (3.14)$$

where,  $B_{ZF} = B^{-1}$  which is a  $MK \times MK$  receiver matrix.

ZF receiver completely removes self interference but noise enhancement is introduced. The Noise Enhancement factor (NEF) denoted by  $\xi$  causes reduction in signal-to-noise ratio (SNR) while using ZF receiver.

$$\xi = \sum_{n=0}^{MK-1} |[B_{ZF}]_{k,n}|^2 \quad (3.15)$$

It is same for every value of k.

### 3.3.4 QAM De-mapper

The demodulated output,  $d_r$  is given as an input to the QAM de-mapper which reverse the process of QAM mapper. It converts the received data symbols into data bits.

### 3.3.5 Decoder

The QAM de-mapper output is given as an input to the decoder which converts the different lower bit rate streams into single higher bit rate stream.

### 3.3.6 Binary Sink

The decoded output is then taken as the final received data which is same as the input data if there are no errors occur in the process.

This above model is used to find PSD and SER of GFDM while using improved pulse shaping filters for different values of roll-off factor. The channels used in the model are of two types: AWGN and Rayleigh channel.

## CHAPTER 4

### PULSE SHAPING FILTERS

The transmitted signal is of higher rate and if the signal bandwidth becomes more than the channel bandwidth then ISI occurs in the signal. The pulse shaping is done to reduce the ISI added due to distortion of the signal while transmitting through the channel [39]. Also, it changes the shape of the waveform of the signal which is transmitted so that the signal can be used in a better way for its purpose. Generally, the pulse shaping occurs after the modulation technique. It is done at the transmitter side and detected at the receiver side. The received signal is sampled at an optimum point so that the probability of getting an accurate decision gets increased. It is done only when these pulse shapes do not interfere with each other at the sampling point. For minimum interference, the pulses other than desired pulse should have zero crossing at the optimum sampling point. Also pulse shape is designed such that the decay of the amplitude is fast outside the time interval of the pulse. It is necessary as in real systems due to timing jitter, there is a shift in the sample point which introduces errors [43].

The pulse shaping filter  $p[.]$  used in the GFDM have a greater impact on the spectral properties of the signal. The nyquist pulse shape have a periodic zero values in the time domain at the multiples of the symbol period [38]. In square root nyquist filter, the symmetry condition is fulfilled by squaring the frequency coefficients. So, a square root filter is used both at transmitter and receiver side in digital communication system.

#### 4.1 RAISED COSINE FILTER

RC filter is the pulse shaping filter used to minimize the ISI. The impulse response of this filter as given in [62] is given by the equation

$$p_{RC}(t) = \text{sinc}\left(\frac{t}{T}\right) \frac{\cos(2\pi\alpha t)}{1 - (2\alpha t/T)^2} \quad (4.1)$$

In this pulse shaping filter,  $\alpha$  is the roll off factor and  $T$  is the transmission symbol period. The asymptotic decay rate of this pulse shaping filter is  $t^{-3}$ . Figure 4.7 shows the impulse response of this filter at  $\alpha$  equal to 0.1, 0.5 and 0.9.

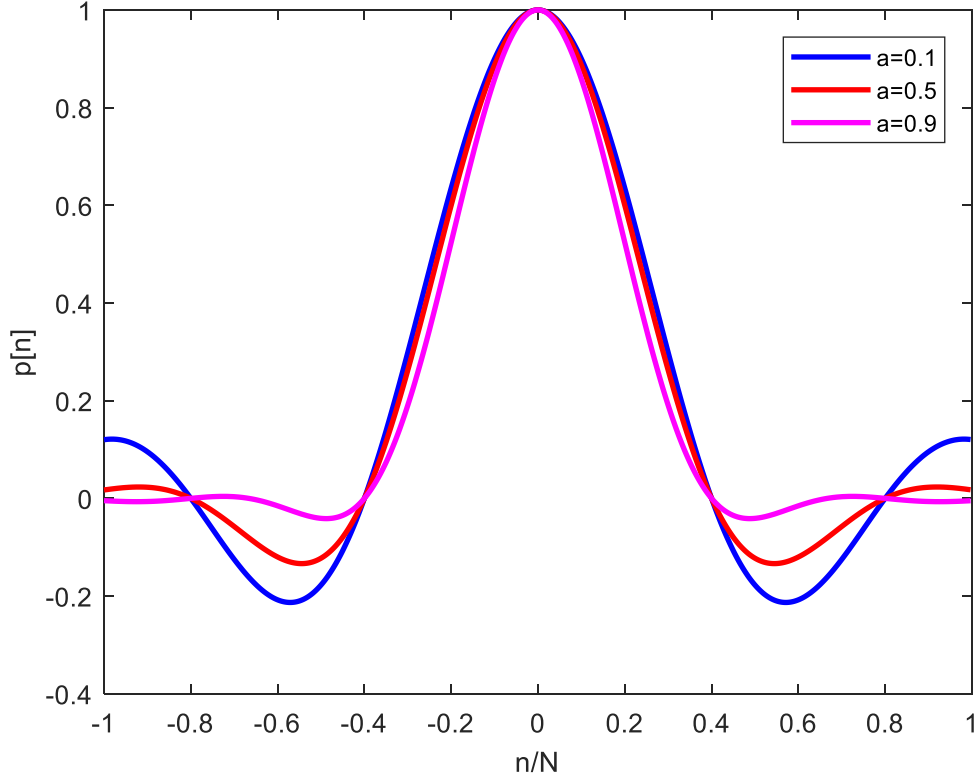


Figure 4.1 Impulse response of RC filter at  $\alpha=0.1, 0.5$  and  $0.9$ .

## 4.2 ROOT RAISED COSINE FILTER

In digital communication, RRC is mostly used as transmit and receive filtering. The equivalent response of these two filters is equal to that of RC filter.

$$i. e. \quad P_{rrc}(f) = \sqrt{|P_{rc}(f)|}$$

The impulse response of RRC is given as

$$p_{rrc}(t) = \frac{\sin\left[\frac{\pi t}{T}(1-\alpha)\right] + \frac{4\alpha t}{T} \cos\left[\frac{\pi t}{T}(1+\alpha)\right]}{\frac{\pi t}{T} \left[1 - \left(\frac{4\alpha t}{T}\right)^2\right]} \quad (4.2)$$

where  $\alpha$  is the roll off factor and  $T$  is the transmission symbol period. The impulse response of this filter is not zero at intervals  $\pm T$ . But at  $\alpha=0$ , the zeros of this filter is at  $\pm T$ . Figure 4.2 shows the impulse response of the RRC pulse shaping filter at  $\alpha$  equal to 0.1, 0.5 and 0.9.

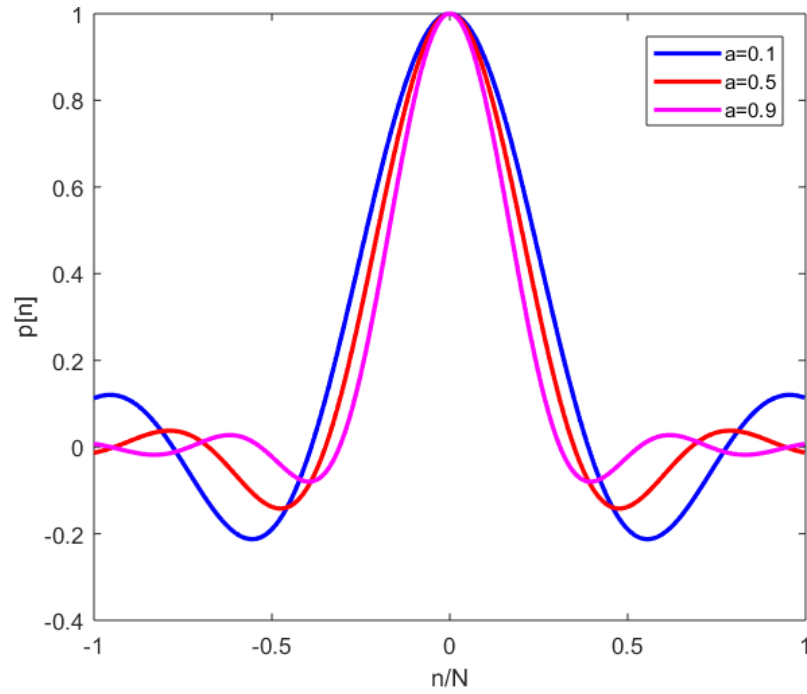


Figure 4.2 Impulse response of RRC filter at  $\alpha=0.1, 0.5$  and  $0.9$ .

### 4.3 BETTER THAN RAISED COSINE FILTER

This pulse shaping filter is given in [63] and the impulse response of this filter is given by the equation

$$p_{BTRC}(t) = \text{sinc}\left(\frac{t}{T}\right) \frac{2\beta t/T \sin(\pi\alpha t/T) + 2 \cos(\pi\alpha t/T) - 1}{1 + (\beta t/T)^2} \quad (4.3)$$

In this pulse shape,  $\alpha$  is the roll off factor,  $T$  is the transmission period and  $\beta = \ln(2)/(\alpha B)$ . The asymptotic decay rate of this pulse is  $t^{-2}$ . Figure 4.6 shows the impulse response of the BTRC pulse shaping filter for  $\alpha$  equal to 0.1, 0.5 and 0.9.

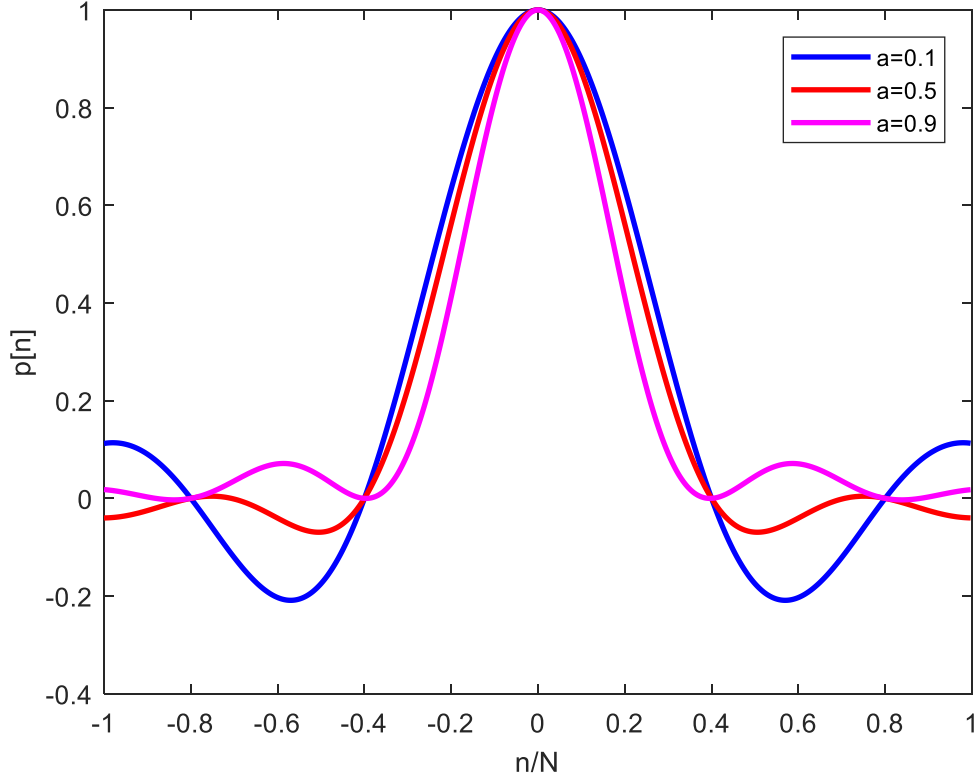


Figure 4.3 Impulse response of BTRC filter at  $\alpha=0.1, 0.5$  and  $0.9$ .

#### 4.4 MODIFIED BARTLETT HANNING FILTER

This pulse shape is given in [64] and the impulse response of this pulse shape is given by the equation

$$p_{MBH}(t) = \text{sinc}\left(\frac{t}{T}\right) \left\{ \left( \frac{2(1-\beta) \cos\left(\frac{\alpha\pi t}{T}\right)}{1 - \left(\frac{2\alpha t}{T}\right)^2} \right) - \left( \frac{(1-2\beta) \sin\left(\frac{\alpha\pi t}{T}\right)}{\left(\frac{\alpha\pi t}{T}\right)} \right) \right\} \quad (4.4)$$

In this pulse shape,  $\alpha$  is the roll-off factor,  $T$  is the transmission period,  $\beta$  is the window shape parameter and the range of  $\beta$  lies between 0.5 and 1.88. Some known pulse shapes are included in table 4.1 under the following condition:

A	B	Pulse Shape
0	0.5 to 1.88	Rectangular Pulse Shape
0 to 1	0.5	RC pulse shape
0 to 1	1	Bartlett pulse shape
1	1	Frank and SOCW pulse shape
0 to 1	1.2	BTRC pulse shape

Table 4.1 Different pulse shapes of MBH pulse family.

Figure 4.4 shows the impulse response of the MBH family at various values of  $\beta$ . As it can be seen from the figure, the main lobe width and side lobe levels are more at  $\beta$  equal to 0.5.

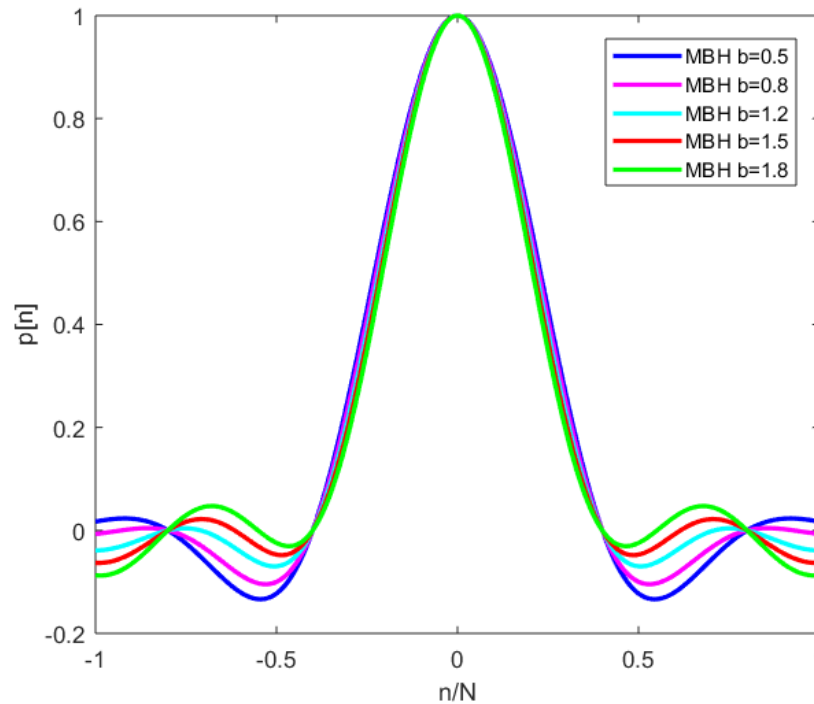


Figure 4.4 Impulse response of MBH family at various values of  $\beta$ .

Figure 4.5 shows the impulse response of the MBH pulse shaping filter at  $\beta$  equal to 0.5 for roll off factor,  $\alpha$  equal to 0.1, 0.5 and 0.9.

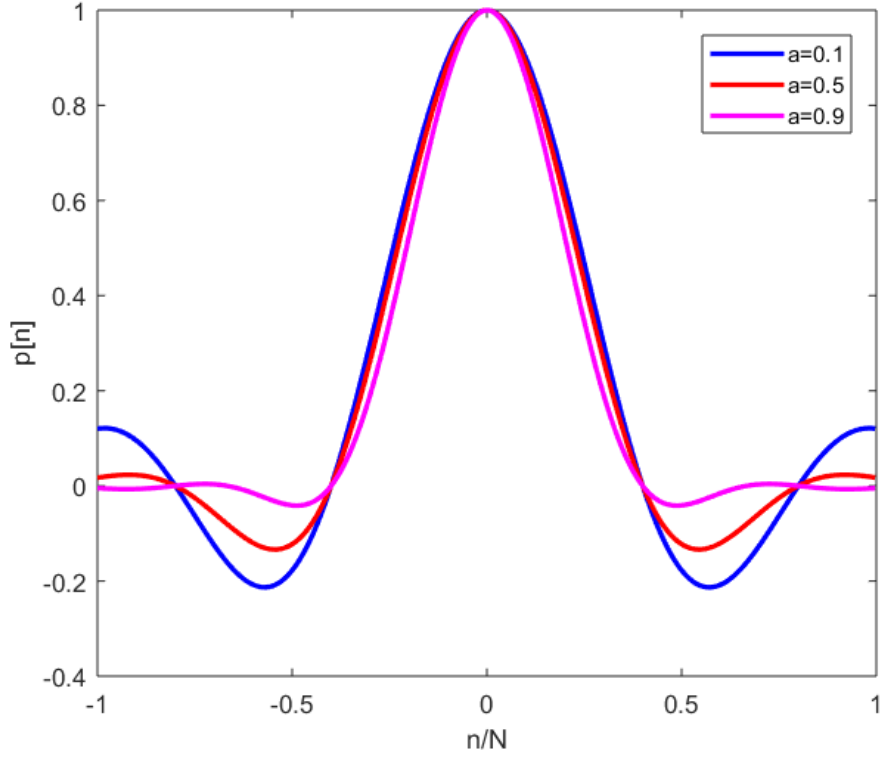


Figure 4.5 Impulse response of MBH pulse family for  $\beta=0.5$  and  $\alpha=0.1, 0.5$  and  $0.9$ .

#### 4.5 FLIPPED HYPERBOLIC SECANT FILTER

This improved nyquist pulse shape is given in [65]. The impulse response is given by the equation

$$p_{FHS}(t) = \frac{1}{T} \text{sinc}\left(\frac{t}{T}\right) \left\{ 8\pi t \sin\left(\frac{\pi\alpha t}{T}\right) \cdot F_1(t) + 2 \cos\left(\frac{\pi\alpha t}{T}\right) [1 - 2F_2(t)] + 4F_3(t) - 1 \right\} \quad (4.5)$$

In above equation

$$F_1(t) = \sum_{k=0}^{\infty} (-1)^k \frac{(2k+1)\gamma}{((2k+1)\gamma)^2 + (2\pi t)^2} \quad (4.6)$$

$$F_2(t) = \sum_{k=0}^{\infty} (-1)^k \frac{(2\pi t)^2}{((2k+1)\gamma)^2 + (2\pi t)^2} \quad (4.7)$$

$$F_3(t) = \sum_{k=0}^{\infty} (-1)^k \frac{(2\pi t)^2}{((2k+1)\gamma)^2 + (2\pi t)^2} e^{-(2k+1)\frac{\alpha\gamma}{2T}}$$

In this pulse shape,  $\gamma = \ln(\sqrt{3} + 2)/(\alpha B)$ ,  $\alpha$  is the roll-off factor,  $B = 1/2T$  is the Nyquist frequency,  $T$  is the transmission period,  $\beta = \ln(2)/(\alpha B)$ . Figure 4.6 shows the impulse response of the flipped hyperbolic secant pulse shaping filter for  $\alpha$  equal to 0.1, 0.5 and 0.9.

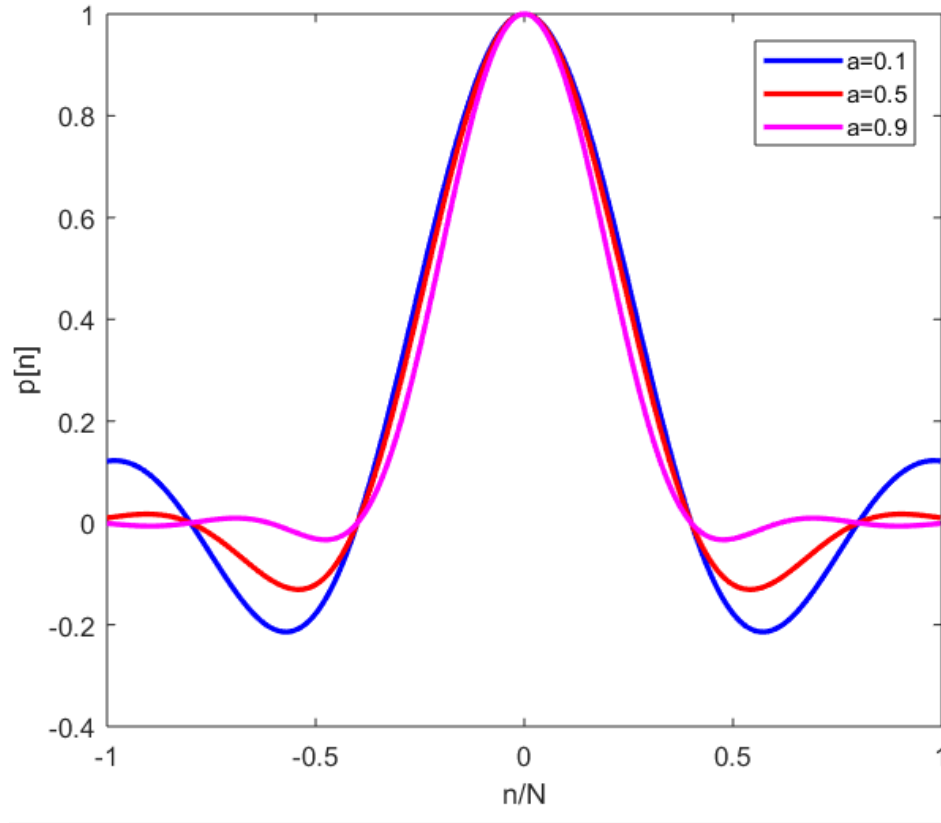


Figure 4.6 Impulse response of flipped hyperbolic secant pulse shaping filter at  $\alpha=0.1, 0.5$  and  $0.9$ .

#### 4.6 IMPROVED SINC POWER (ISP) SHAPING FILTER

This improved pulse is proposed in [66]. The impulse response of this improved pulse is given by the equation

$$p_{ISP}(t) = \exp\left(-a\left(\frac{t}{T}\right)^2\right) \cdot \text{sinc}^n\left(\frac{t}{T}\right)$$

where  $a$  is the designed parameter for the adjustment of the amplitude and  $n$  gives the degree of the sinc function.

Figure 4.7 shows the impulse response of ISP pulse shaping filter at different values of  $a$  and  $n$ . At  $a=0.5$  and  $n=1$ , the ISP pulse has wider main lobe width and side lobe width. So at these parameter values, the SER performance is better. The impulse response of this pulse shape does not depend on roll off factor.

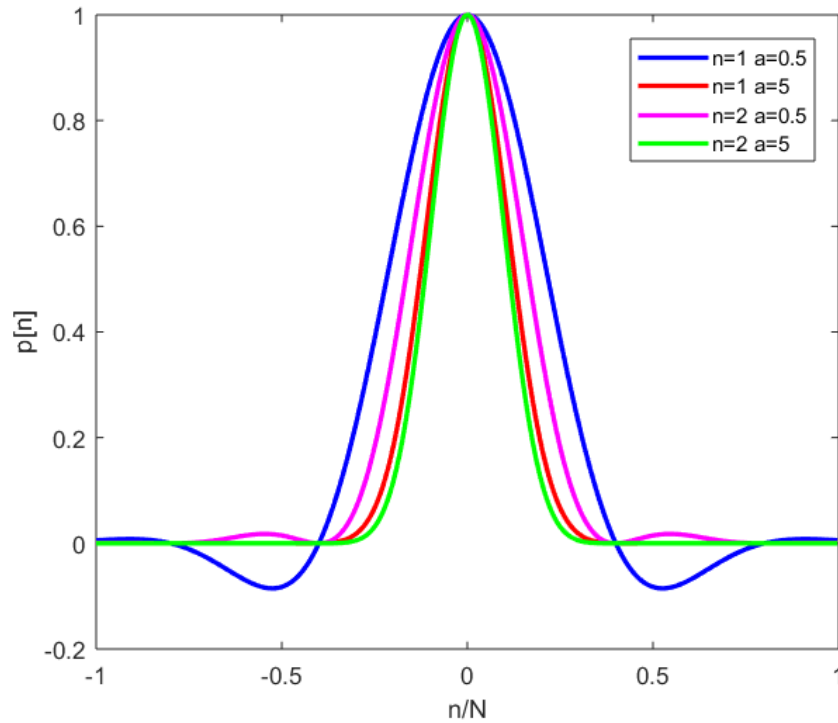


Figure 4.7 Impulse response of ISP pulse shaping filter at different values of  $a$  and  $n$ .

#### 4.7 PHASE MODIFIED SINC PULSE (SM)

This pulse shape is proposed in [51] and the impulse response of this pulse shape is given by the equation

$$p_{PMSP}(t) = \exp(-a(t/T)^2) \left( \frac{\sin((\pi t - b \sin(c\pi t))/T)}{(\pi t - b \sin(c\pi t))/T} \right)^n \quad (4.10)$$

In this equation,  $T$  is the transmission period,  $a$  is used for amplitude control,  $b$  and  $c$  are used for phase control and  $n$  is the degree of sinc function. Figure 4.8 shows the impulse response of SM pulse shaping filter at different values of  $a$  and  $n$ . The value of  $b$  and  $c$  are taken as 0.25 and 2. At  $a=0.25$  and  $n=1$ , the

SM pulse has wider main lobe width and side lobe width. So at these parameter values, the SER performance is better. The impulse response of this pulse shape does not depend on roll off factor.

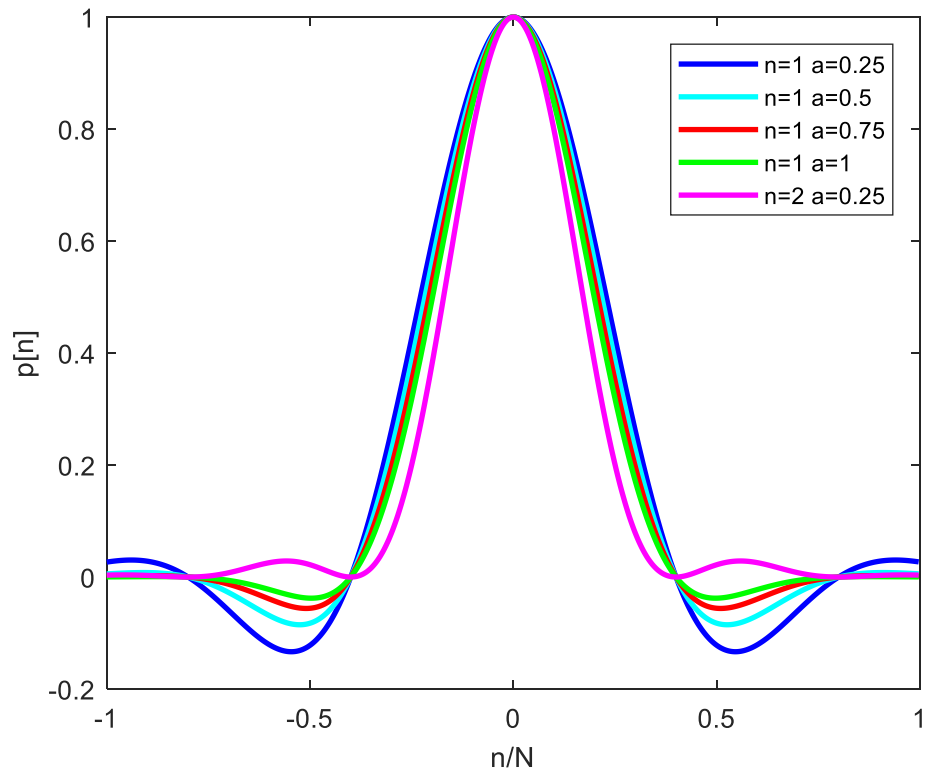


Figure 4.8 Impulse response of PMSP pulse shaping filter at different values of a and n.

## CHAPTER 5

### RESULTS AND DISCUSSIONS

This chapter contains the simulation results of the impulse response of the pulse shaping filters used in the GFDM model at various roll off factor values, PSD and SER of the GFDM using different pulse shaping filters. The simulation results and analytical results of SER are calculated using AWGN channel and Rayleigh channel and at various values of roll off factor. The simulation results are obtained using software MATLAB 2017a. The parameters used for the computation of results are given in Table 5.1.

Sub-symbols (M)	5
Sub-carriers (K)	128
Mapping	16-QAM
Roll off factor ( $\alpha$ )	0.1, 0.5 and 0.9
Cyclic Prefix (CP) length	32
Channel	AWGN and Rayleigh

Table 5.1 Simulation Parameters

#### 5.1 PULSE SHAPING FILTERS ANALYSIS

The different types of pulse shaping filters are used in the GFDM model and then analysis of coefficients of pulse shaping filters is done on the PSD and the SER performance.

Figure 5.1 shows the impulse response of pulse shaping filters at roll off factor,  $\alpha$  equal to 0.1. All pulse shaping filters have almost equal main lobe width but ISP and PMSP pulse shaping filter has lower side lobe levels and the remaining pulse shaping filters have almost equal side lobe levels. Figure 5.2 shows the impulse response of pulse shaping filters at roll off factor,  $\alpha$  equal to 0.5. The RRC pulse shaping filter has narrow main lobe width than other pulse shaping filters used. RC and FHS pulse shaping filters have almost same impulse response. Their main lobe widths are almost equal. The BTRC pulse shaping filter has lowest side lobe levels whereas the RRC pulse shaping filter has highest side lobe levels. Figure 5.3 shows the impulse response of pulse shaping filters at roll off factor,  $\alpha$  equal to 0.9. The RRC pulse shaping filter has narrow main lobe width than other pulse shaping filters used. ISP and PMSP pulse

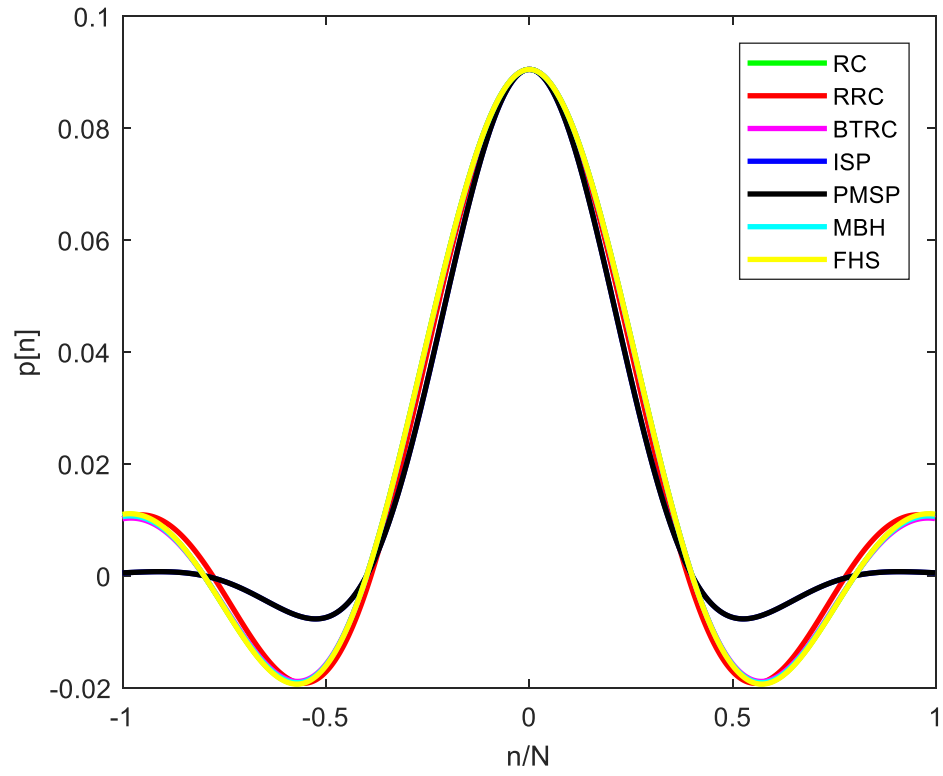


Figure 5.1 Impulse response of pulse shaping filters at  $\alpha=0.1$ .

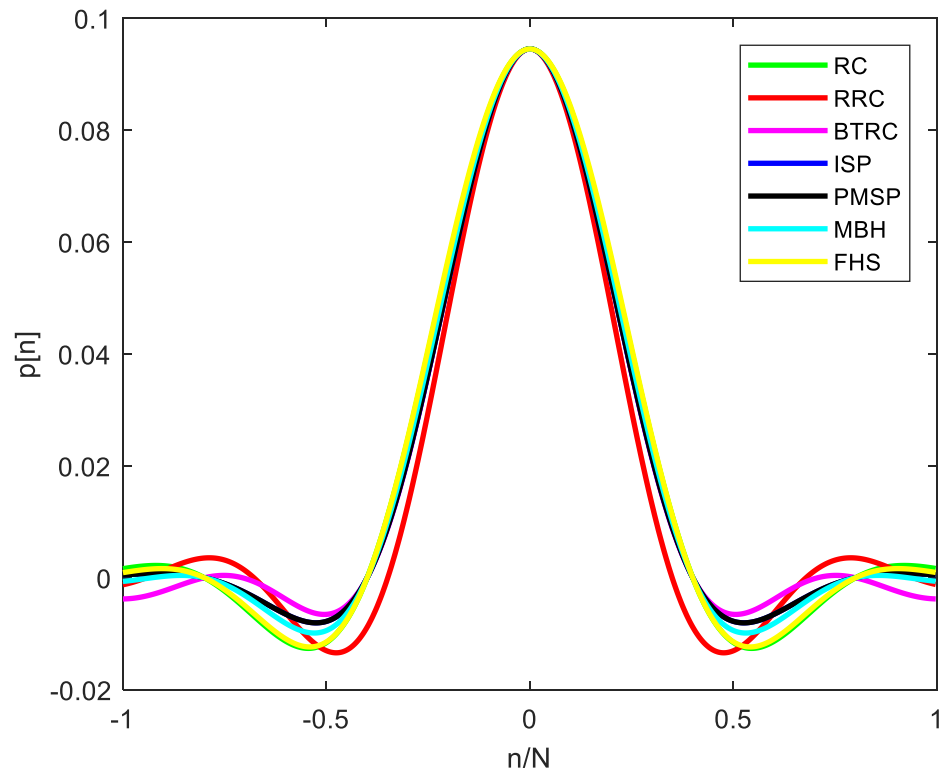


Figure 5.2 Impulse response of pulse shaping filters at  $\alpha=0.5$ .

shaping filter has wider main lobe width. The ISP and PMSP pulse shaping filter has higher side lobe levels whereas the BTRC pulse shaping filter has lower side lobe levels.

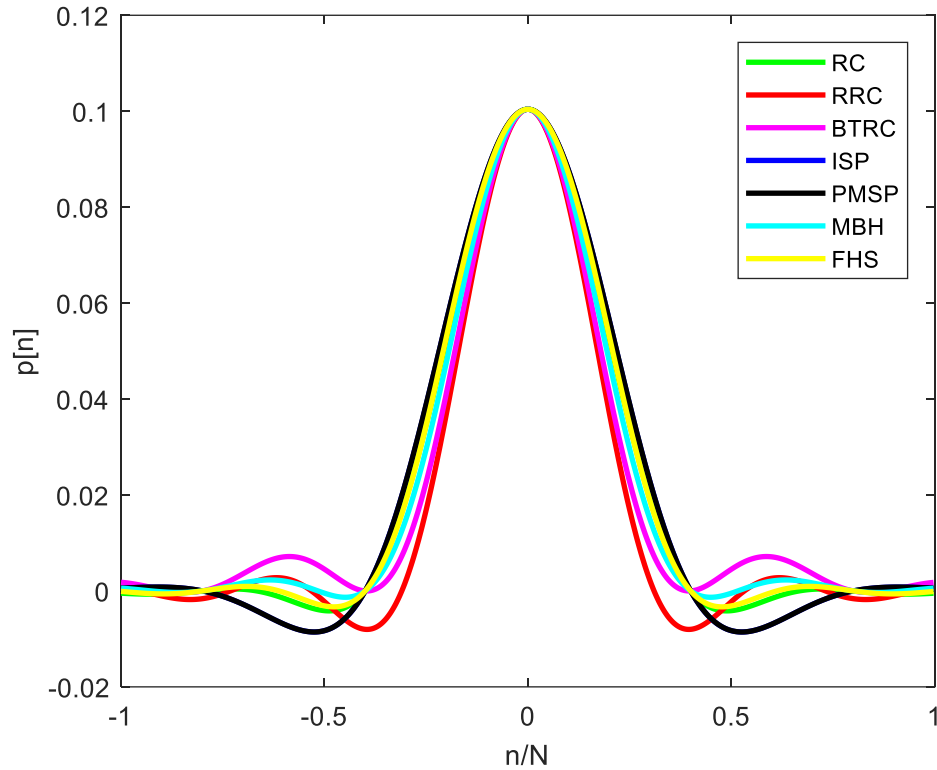


Figure 5.3 Impulse response of pulse shaping filters at  $\alpha=0.9$ .

- **MBH Pulse Family Analysis**

The impulse response of MBH pulse shaping filter is analysed for different values of  $\beta$  and  $\alpha$ . Figure 5.4 shows the impulse response of MBH family for various values of  $\beta$  at  $\alpha$  equal to 0.1. The MBH pulses have almost same impulse response for different values of  $\beta$ .

Figure 5.5 shows the impulse response of the MBH family for various values of  $\beta$  at  $\alpha$  equal to 0.5. As value of  $\beta$  increases, the main lobe width and side lobe levels increases. For  $\beta$  equal to 0.5 MBH pulse shaping filter has wider main lobe width and higher side lobe levels. For  $\beta$  equal to 1.8 MBH pulse shaping filter has narrow main lobe width and lower side lobe levels. There is a very minute difference in main lobe width at various values of  $\beta$  for roll off factor,  $\alpha$  equal to 0.5.

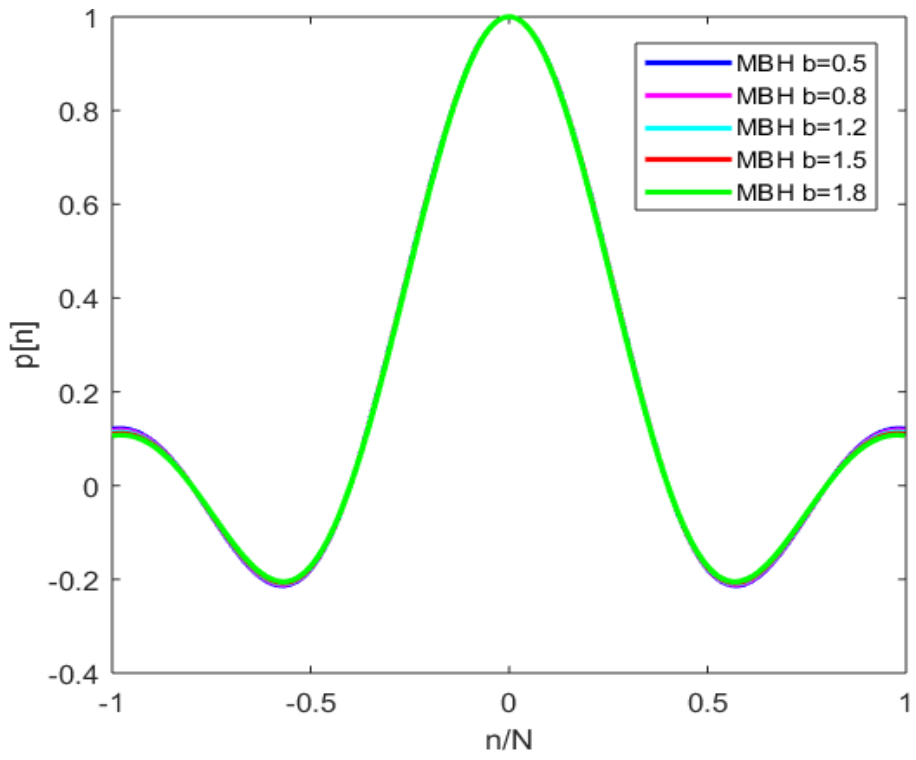


Figure 5.4 Impulse response of MBH family at  $\alpha$  equal to 0.1.

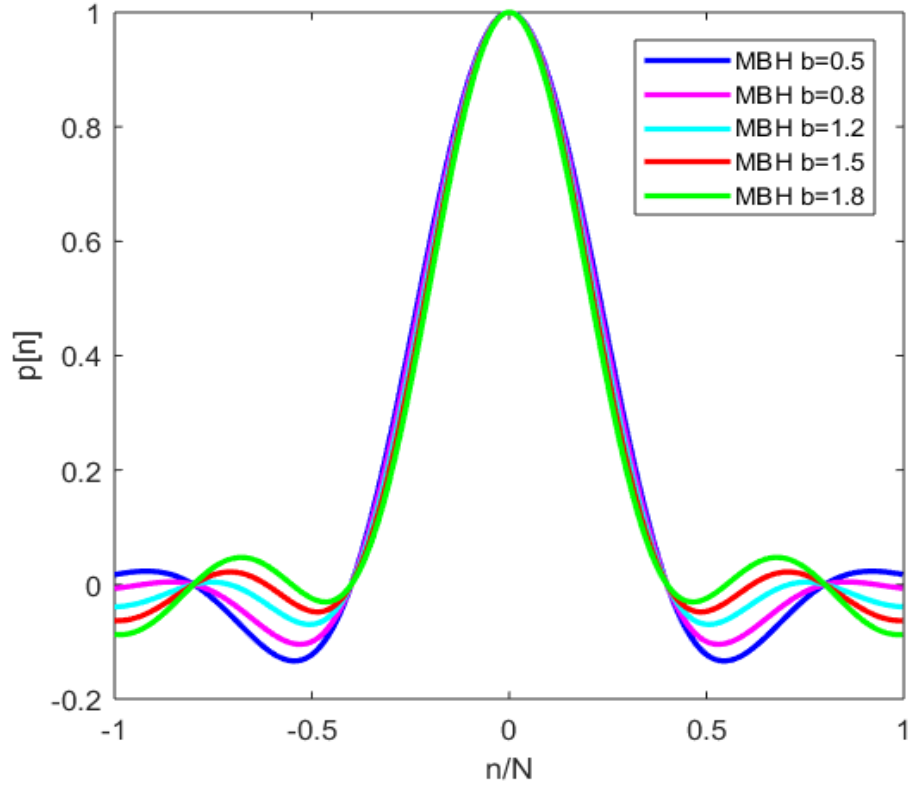


Figure 5.5 Impulse response of MBH family at  $\alpha$  equal to 0.5.

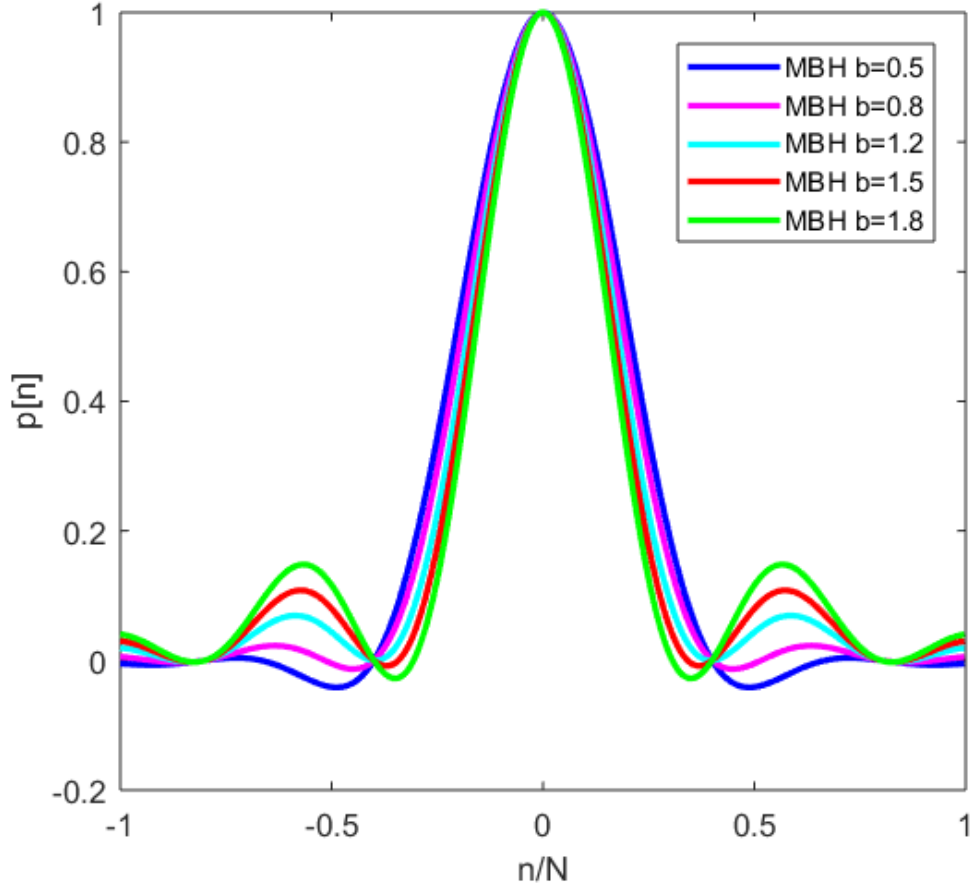


Figure 5.6 Impulse response of MBH family at  $\alpha$  equal to 0.9.

Figure 5.6 shows the impulse response of the MBH pulse family for different values of  $\beta$  at  $\alpha$  equal to 0.9. As value of  $\beta$  increases, the main lobe width and side lobe levels increases. For  $\beta$  equal to 0.5 MBH pulse shaping filter has wider main lobe width and higher side lobe levels. For  $\beta$  equal to 1.8 MBH pulse shaping filter has narrow main lobe width and lower side lobe levels.

## 5.2 POWER SPECTRAL DENSITY ANALYSIS

Power Spectral Density (PSD) is defined as the content of power in the signal versus the frequency range. GFDM signal has coefficient of pulse shaping filters as one of its component. So, OOB emissions can be reduced by selecting the appropriate pulse shaping filter. PSD of the GFDM signal is given by the equation

$$PSD(f) = \lim_{T \rightarrow \infty} \left( \frac{1}{T} E \left\{ |F\{x_{cp}(t)\}|^2 \right\} \right) \quad (5.1)$$

where  $T$  denotes the time period of the signal and  $x_{cp}$  is the transmitted GFDM signal.

The simulation results of PSD using different pulse shaping filters at roll off factor 0.1, 0.5 and 0.9 are calculated. The simulation result of PSD using MBH pulse family is also computed for various values of  $\beta$  at roll off factor equal to 0.5

- **PSD Using Different Pulse Shaping Filters**

Figure 5.7 shows the simulation result of PSD of GFDM signal at  $\alpha$  equal to 0.1. From the result, it is observed that ISP and PMSP pulse shaping has lower OOB emissions whereas RRC pulse shaping has greater OOB emissions as compared to other pulse shaping filters.

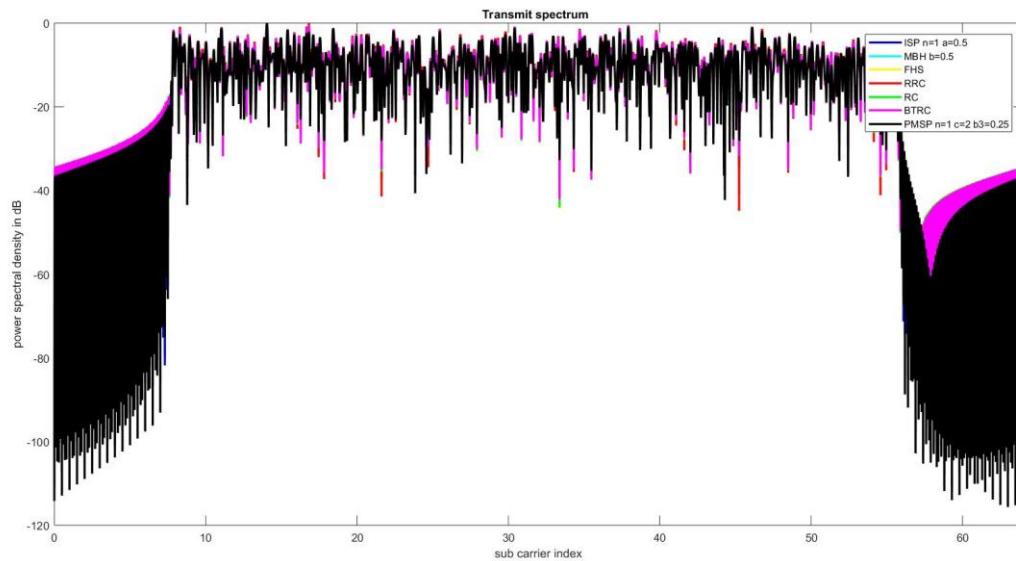


Figure 5.7 PSD of GFDM transmit signal at  $\alpha$  equal to 0.1.

Figure 5.8 shows the simulation result of PSD of GFDM signal at  $\alpha$  equal to 0.5. From the result, it is observed that BTRC pulse shaping has lower OOB emissions and FHS and RC pulse shaping has higher OOB emissions as compared to other pulse shaping filters.

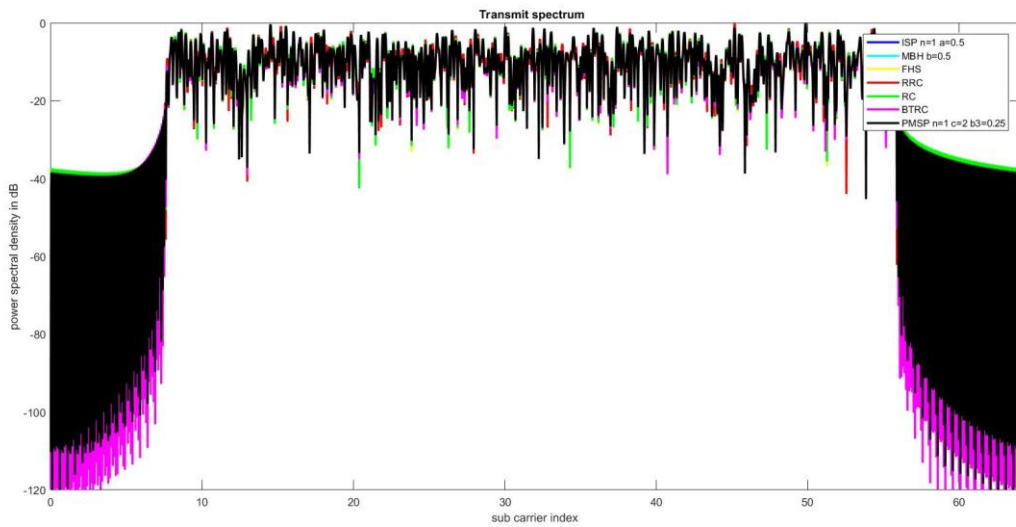


Figure 5.8 PSD of GFDM transmit signal at  $\alpha$  equal to 0.5.

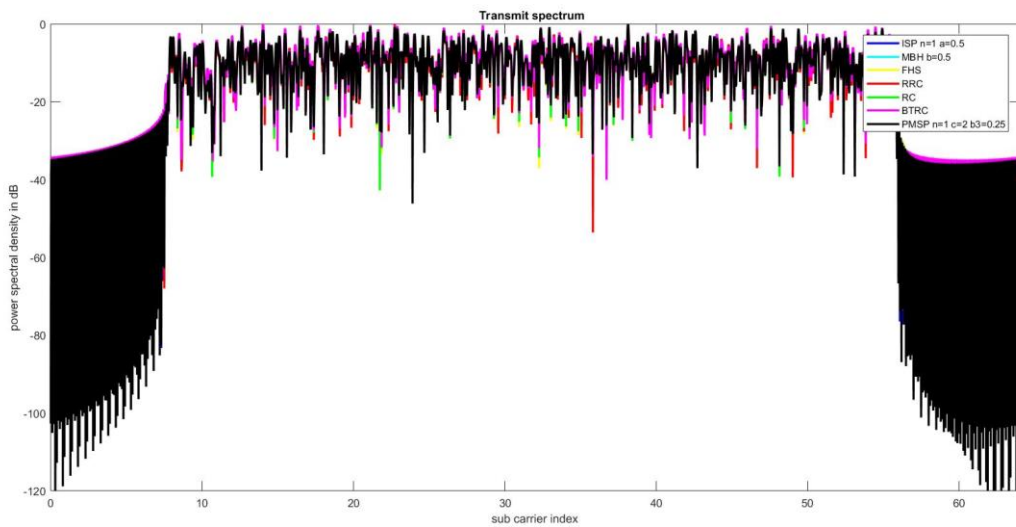


Figure 5.9 PSD of GFDM transmit signal at  $\alpha$  equal to 0.9.

Figure 5.9 shows the simulation result of PSD of GFDM signal at  $\alpha$  equal to 0.9. From the result, it is observed that BTRC pulse shaping has lower OOB emissions and ISP and PMSP pulse shaping has higher OOB emissions as compared to other pulse shaping filters.

- **5.2.2 PSD Using MBH Pulse Family**

Figure 5.10 shows the simulation result of PSD of GFDM transmit signal using MBH pulse family at  $\beta$  equal to 0.5, 0.8, 1.2, 1.5 and 1.8 for  $\alpha$  equal to 0.5. From the result, it has been observed that as value of  $\beta$  increases, the OOB emissions decreases.

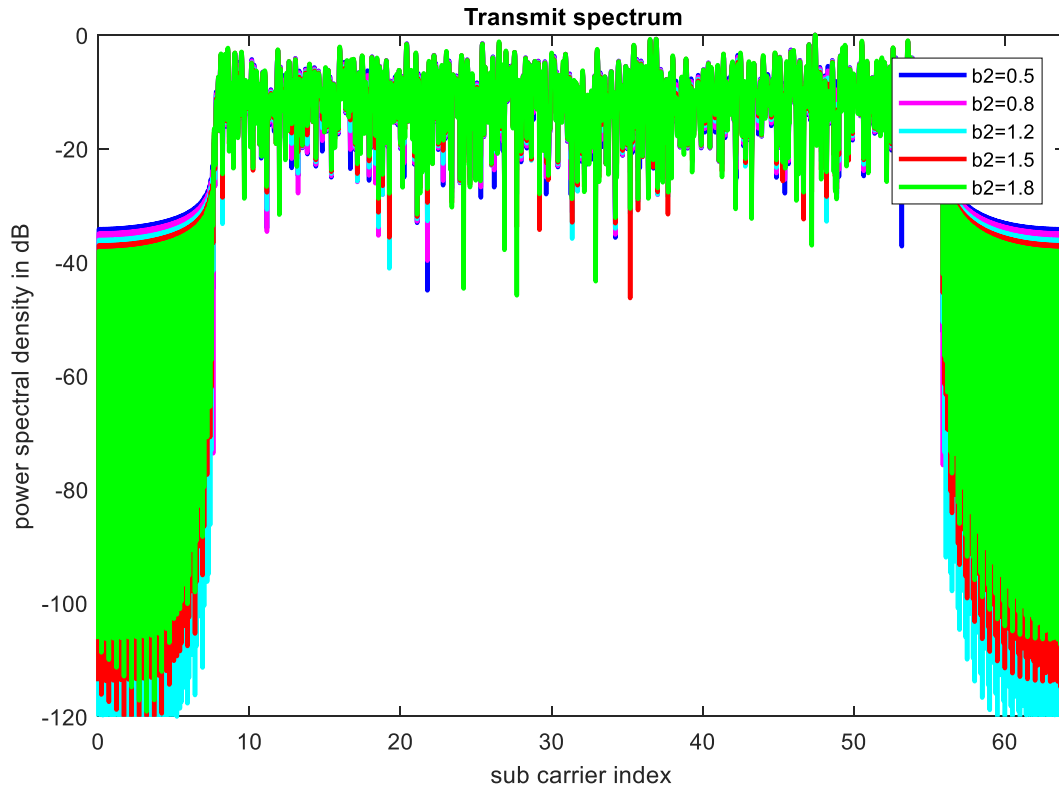


Figure 5.10 PSD of GFDM transmit signal for MBH family at  $\alpha$  equal to 0.5.

### 5.3 SYMBOL ERROR RATE ANALYSIS

SER is defined as the number of symbols in error when the symbols are transmitted through the channel. In the GFDM model, 16-QAM data symbols are transmitted through the AWGN and Rayleigh channel using different pulse shaping filters at various values of roll off factor. The analysis of SER versus  $E_s/N_0$  is done in case of ZF receiver. The analytical expressions of SER in AWGN and Rayleigh channel are also calculated in this section

The ZF receiver eliminates self interference but introduces noise enhancement which depends on the choice of the pulse shaping. The Noise Enhancement factor (NEF) denoted by  $\xi$  which causes reduction in signal-to-noise ratio (SNR) while using ZF receiver is given by the equation

$$\xi = \sum_{n=0}^{MK-1} |[B_{ZF}]_{k,n}|^2 \quad (5.2)$$

It is same for every value of k.

The analytical and simulation results of SER are computed by using different filters at roll-off factor values  $\alpha=0.1, 0.5$  and  $0.9$ . Also SER performance of MBH pulse shaping filter is evaluated separately at  $\beta$  values  $0.5, 0.8, 1.2$  and  $1.5$  at roll-off factor values  $0.5$ .

### 5.3.1 AWGN Channel

NEF adjust the equivalent SNR of GFDM at the receiver side. The mathematical equation of SER performance of GFDM having 16-QAM data transmission is given as:

$$SER_{AWGN} = 2 \left( \frac{k-1}{k} \right) \text{erfc}(\sqrt{\gamma}) - \left( \frac{k-1}{k} \right) \text{erfc}^2(\sqrt{\gamma}) \quad (5.3)$$

where

$$\gamma = \frac{3R_T}{2(2^\mu - 1)} \frac{E_s}{\xi N_0} \quad (5.4)$$

and

$$R_T = \frac{KM}{KM + N_{cp} + N_{cs}} \quad (5.5)$$

$\mu$  is the number of bits per QAM symbol,  $k = \sqrt{2^\mu}$ ,  $N_{cp}$  and the  $N_{cs}$  are the length of cyclic prefix and cyclic suffix.  $E_s$  is the energy per symbol and  $N_0$  is the noise power density.

- **5.3.1.1 SER Analysis Using Different Pulse shaping Filters**

Figure 5.11 shows the analytical result of SER versus  $E_s/N_0$  at  $\alpha$  equal to  $0.1$ . Figure 5.12 shows the simulation results of SER versus  $E_s/N_0$  at  $\alpha$  equal to  $0.1$ . The analytical and simulation results shown in the figures are almost matched. According to the results, all pulse shaping filter have almost equal and better SER performance than ISP and PMSP pulse shaping filters.

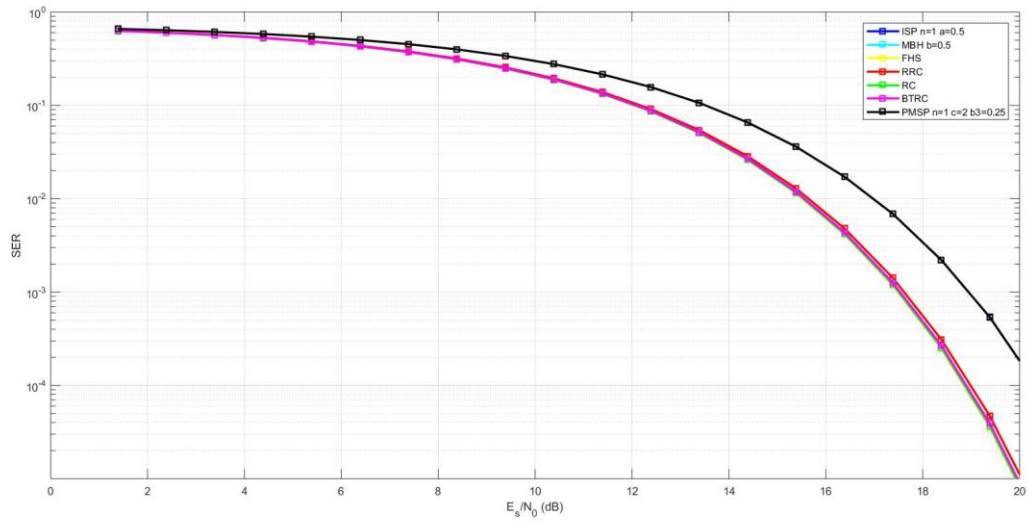


Figure 5.11 Analytical result of SER versus  $E_s/N_0$  at  $\alpha$  equal to 0.1 in AWGN channel.

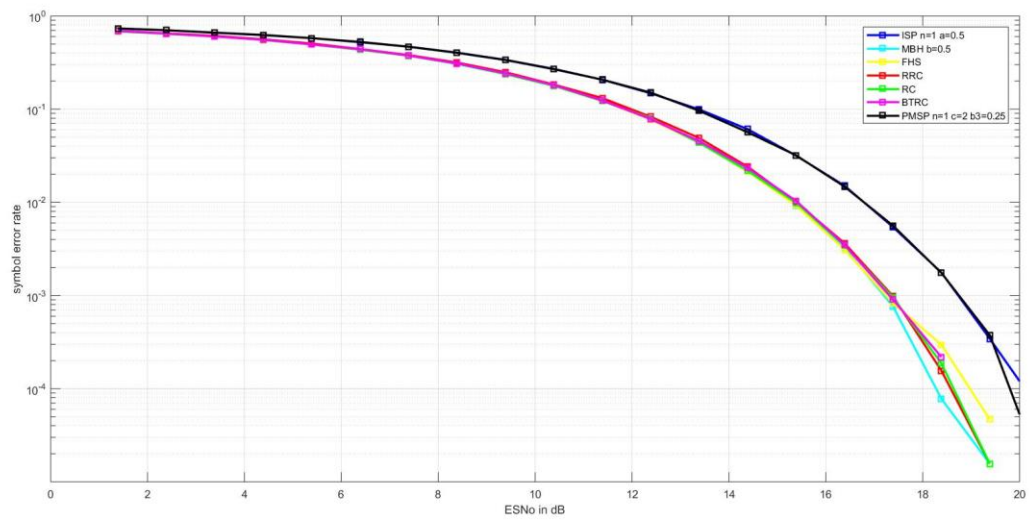


Figure 5.12 Simulation result of SER versus  $E_s/N_0$  at  $\alpha$  equal to 0.1 in AWGN channel.

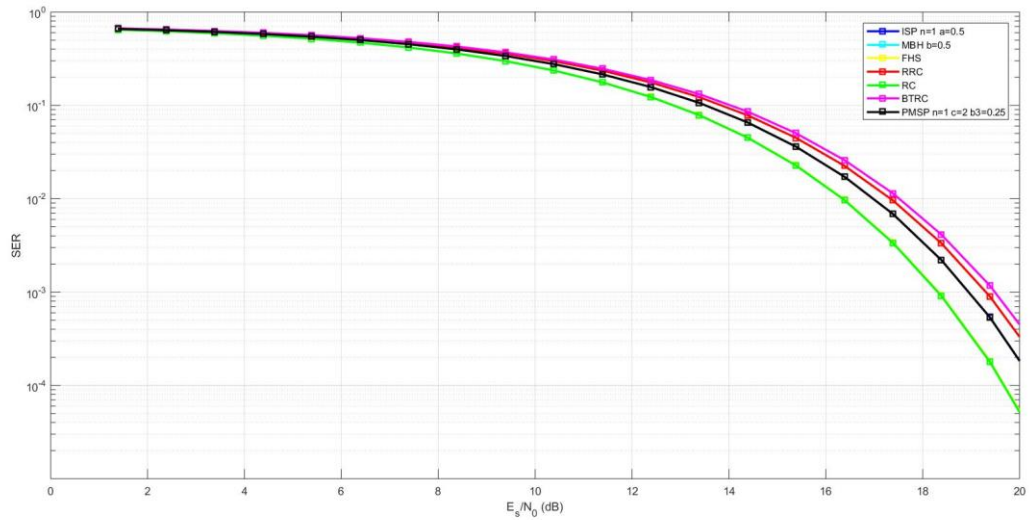


Figure 5.13 Analytical results of SER versus  $E_s/N_0$  at  $\alpha$  equal to 0.5 in AWGN channel.

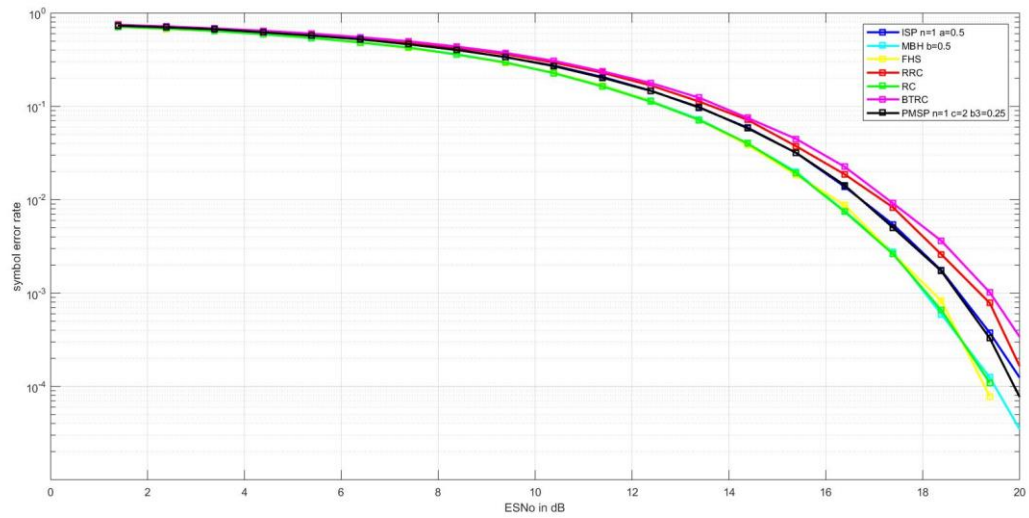


Figure 5.14 Simulation results of SER versus  $E_s/N_0$  at  $\alpha$  equal to 0.5 in AWGN channel.

Figure 5.13 shows the analytical result of SER versus  $E_s/N_0$  at  $\alpha$  equal to 0.5. Figure 5.14 shows the simulation result of SER versus  $E_s/N_0$  at  $\alpha$  equal to 0.5. The analytical and simulation results shown in the figures are almost matched. According to the results, FHS, RC and MBH pulse shaping filter have better SER performance than other pulse shaping filters. BTRC pulse shaping filter has poor SER performance.

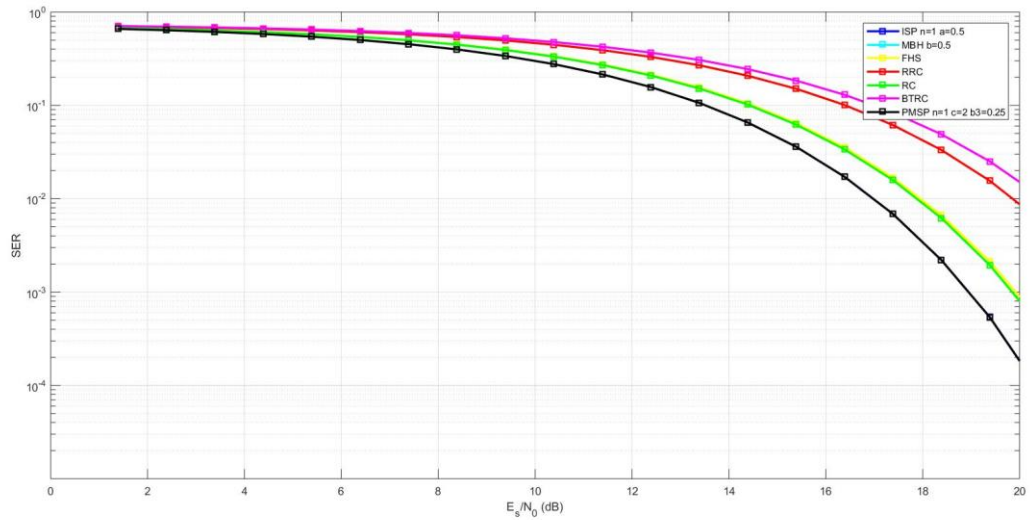


Figure 5.15 Analytical results of SER versus  $E_s/N_0$  at  $\alpha$  equal to 0.9 in AWGN channel.

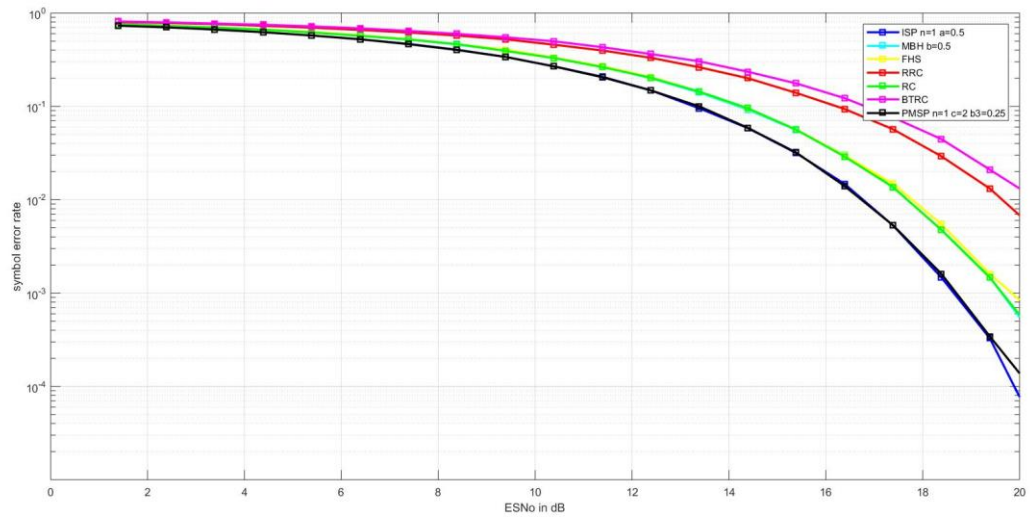


Figure 5.16 Simulation results of SER versus  $E_s/N_0$  at  $\alpha$  equal to 0.9 in AWGN channel.

Figure 5.15 shows the analytical result of SER versus  $E_s/N_0$  at  $\alpha$  equal to 0.9. Figure 5.16 shows the simulation results of SER versus  $E_s/N_0$  at  $\alpha$  equal to 0.9. The analytical and simulation results shown in the figures are almost matched. According to the results, ISP and PMSP pulse shaping filter have better SER performance than other pulse shaping filters.

- **SER Analysis using MBH pulse family**

Figure 5.17 shows the analytical result of SER versus  $E_s/N_0$  at  $\alpha$  equal to 0.5. Figure 5.18 shows the simulation results of SER versus  $E_s/N_0$  at  $\alpha$  equal to 0.5. The analytical and simulation results shown in the figures are almost matched. According to the results, MBH pulse shaping filter at  $\beta$  equal to 0.5 has better SER performance.

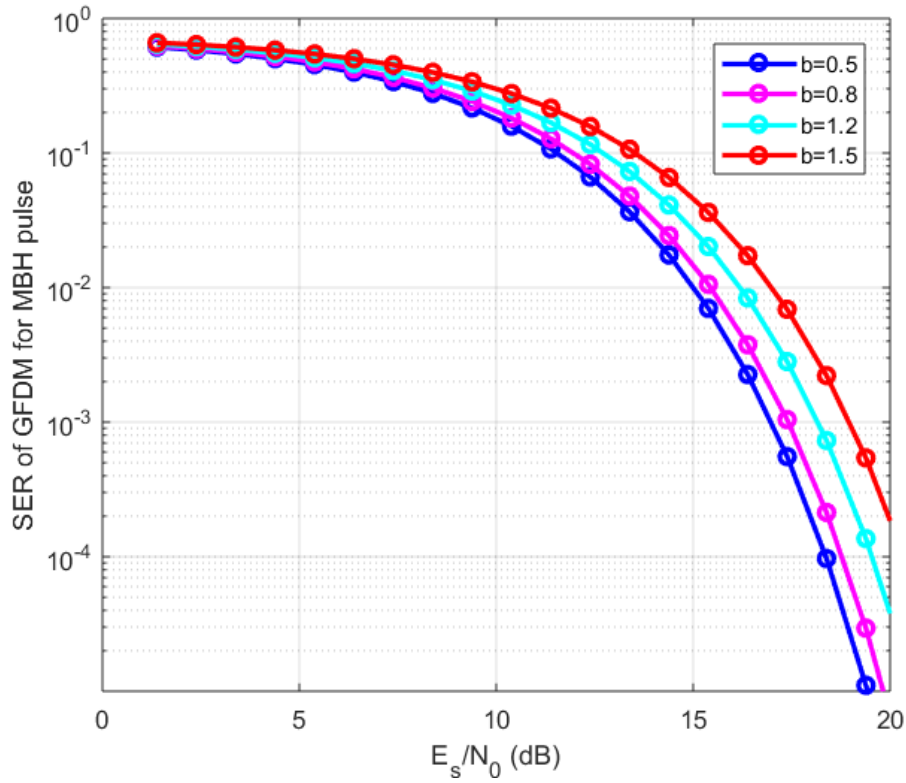


Figure 5.17 Analytical results of SER versus  $E_s/N_0$  using MBH at  $\alpha$  equal to 0.5 in AWGN channel.

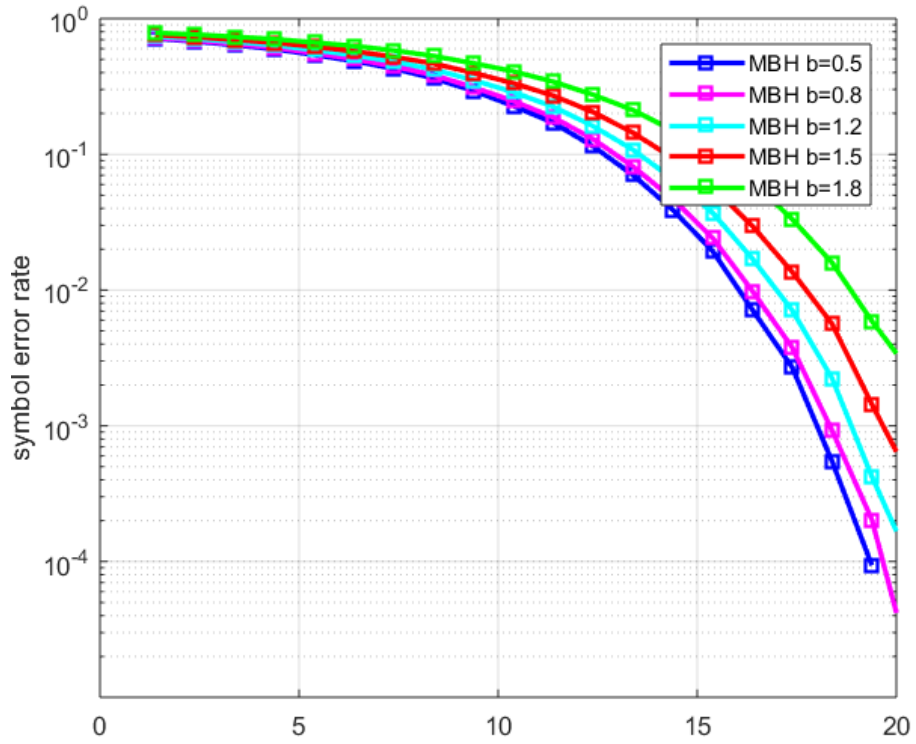


Figure 5.18 Simulation results of SER versus  $E_s/N_0$  using MBH at  $\alpha$  equal to 0.5 in AWGN channel.

### 5.3.2 Rayleigh Fading Channel

SER performance of GFDM having 16-QAM data transmission over Rayleigh channel is given by the equation

$$SER_{RAY} = 2 \left( \frac{k-1}{k} \right) \left( 1 - \sqrt{\frac{\gamma_r}{1+\gamma_r}} \right) - \left( \frac{k-1}{k} \right)^2 \left[ 1 - \frac{4}{\pi} \sqrt{\frac{\gamma_r}{1+\gamma_r}} \arctan \left( \sqrt{\frac{1+\gamma_r}{\gamma_r}} \right) \right] \quad (5.6)$$

where

$$\gamma_r = \frac{3R_T}{4(2^\mu - 1)} \frac{E_s}{\xi N_0} \quad (5.7)$$

Instantaneous SNR and Instantaneous SER are random variables. So, average SER is a very important factor to study the performance of the system.

- SER Analysis Using Different Pulse shaping Filters

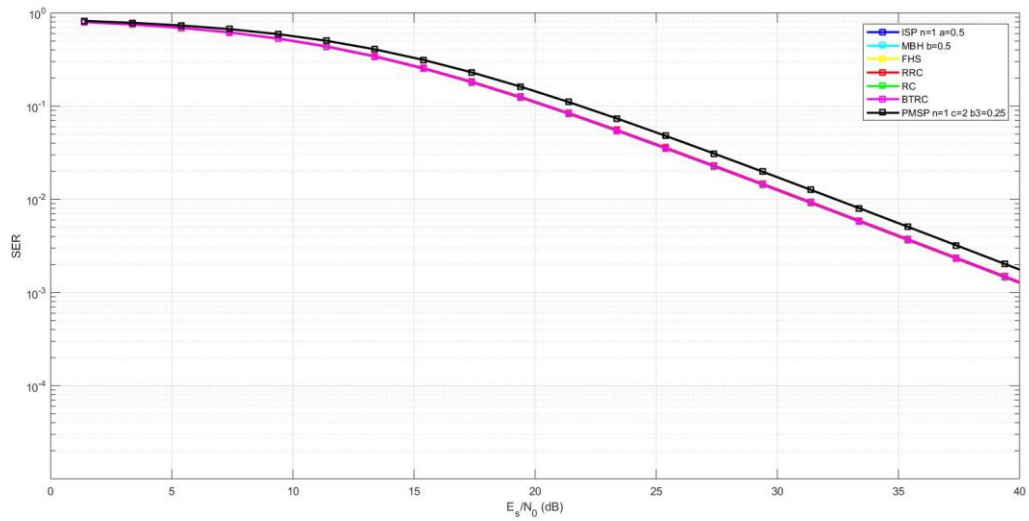


Figure 5.19 Analytical results of SER for  $\alpha$  equal to 0.1 in Rayleigh channel.

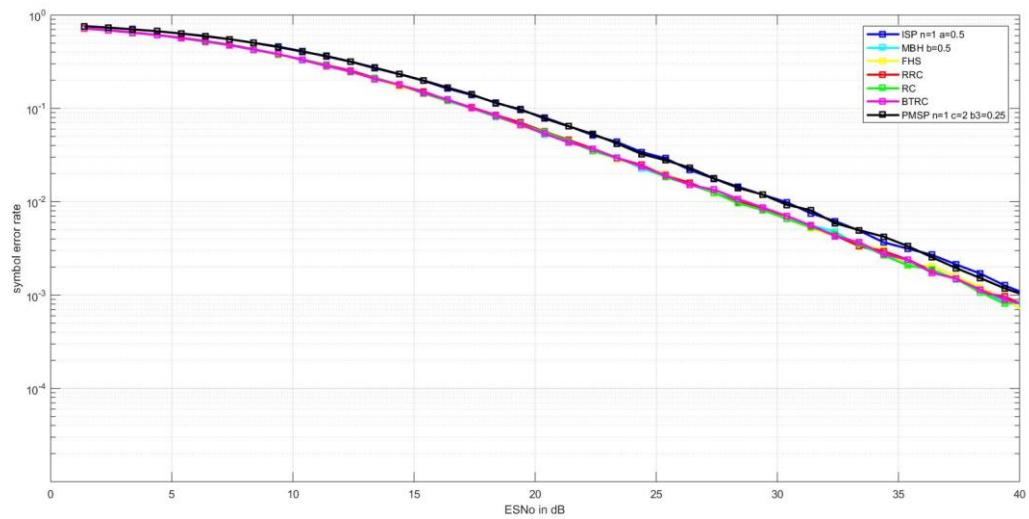


Figure 5.20 Simulation results of SER for  $\alpha$  equal to 0.1 in Rayleigh channel.

Figure 5.19 shows the analytical results of SER using different pulse shaping filters for  $\alpha$  equal to 0.1 in Rayleigh channel. Figure 5.20 shows the simulation results of SER using different pulse shaping filters for  $\alpha$  equal to 0.1 in Rayleigh channel. The analytical and simulation results shown in the figures are almost matched. According to the results, all pulse shaping filter have almost equal and better SER performance than ISP and PMSP pulse shaping filters.

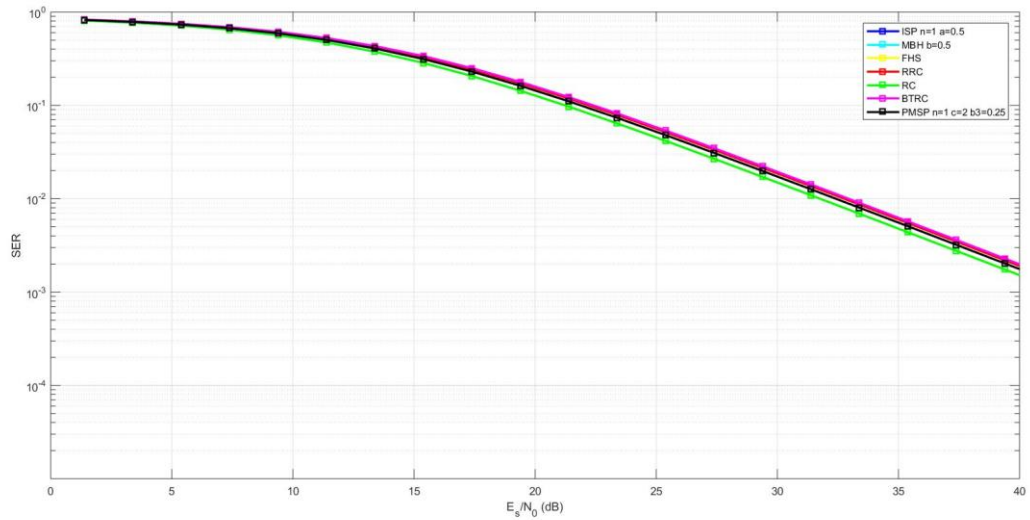


Figure 5.21 Analytical results of SER for  $\alpha$  equal to 0.5 in Rayleigh channel.

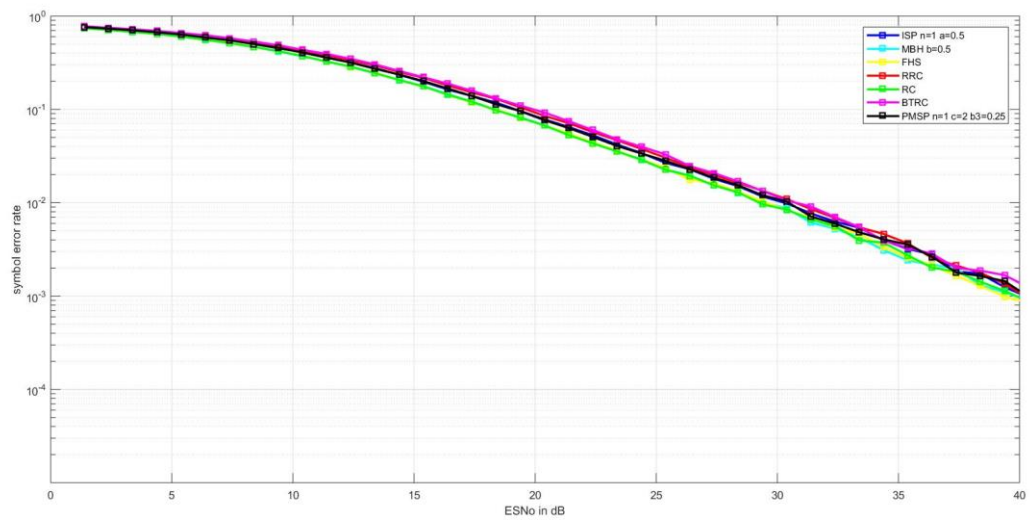


Figure 5.22 Simulation results of SER for  $\alpha$  equal to 0.5 in Rayleigh channel.

Figure 5.21 shows the analytical results of SER using different pulse shaping filters for  $\alpha$  equal to 0.5 in Rayleigh channel. Figure 5.22 shows the simulation results of SER using different pulse shaping filters for  $\alpha$  equal to 0.5 in Rayleigh channel. The analytical and simulation results shown in the figures are almost matched. From the results RC, FHS and MBH pulse shaping filter has better SER performance.

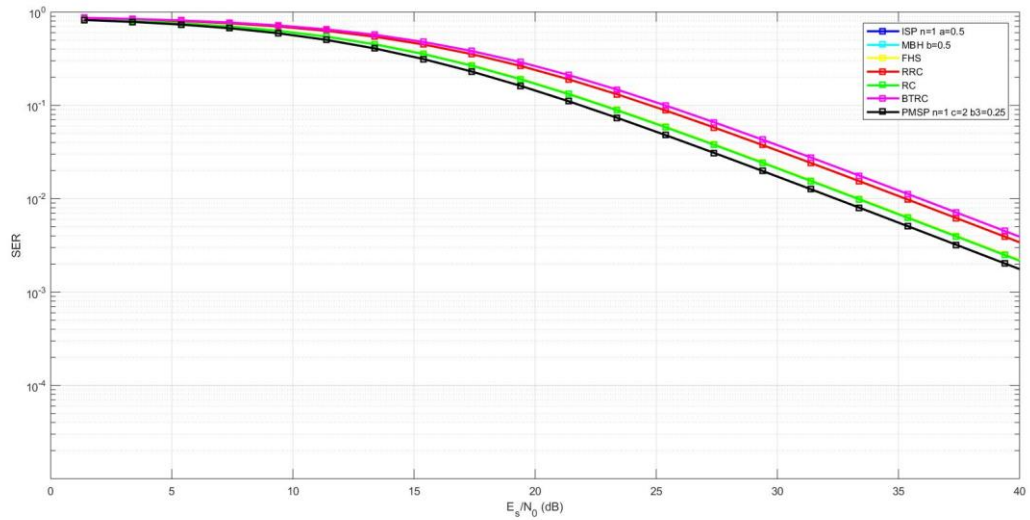


Figure 5.23 Analytical results of SER for  $\alpha$  equal to 0.9 in Rayleigh channel.

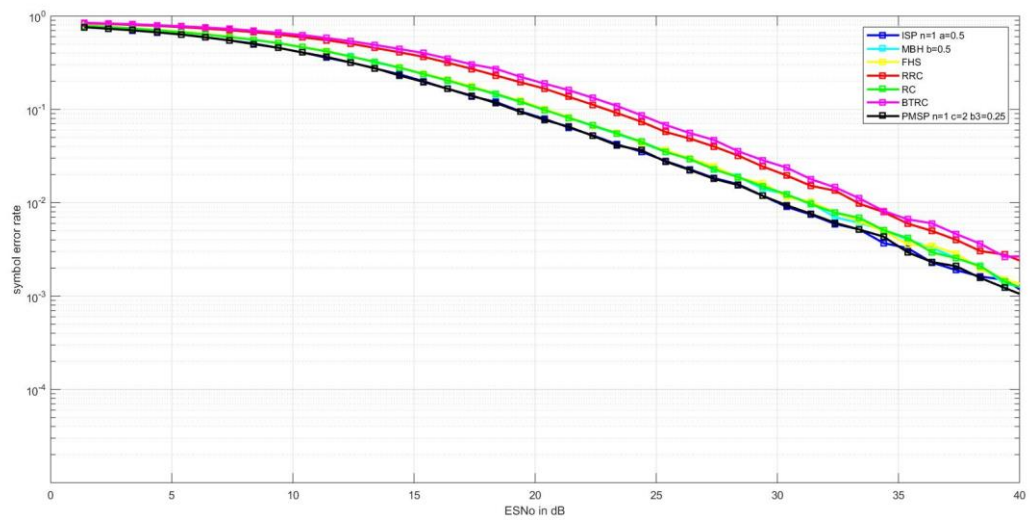


Figure 5.24 Simulation results of SER for  $\alpha$  equal to 0.9 in Rayleigh channel.

Figure 5.23 shows the analytical results of SER using different pulse shaping filters for  $\alpha$  equal to 0.9 in Rayleigh channel. Figure 5.24 shows the simulation results of SER using different pulse shaping filters for  $\alpha$  equal to 0.9 in Rayleigh channel. The analytical and simulation results are almost matched. From the results, it is analyzed that ISP and PMSP pulse shaping filter having degree,  $n=1$  and designed parameter  $a=0.5$  has better SER performance than other pulse shaping filters.

- **SER Analysis using MBH pulse family**

Figure 5.25 shows the analytical results of SER using MBH family for  $\alpha$  equal to 0.5 in Rayleigh channel and Figure 5.26 shows the simulation results of SER using MBH family for  $\alpha$  equal to 0.5 in Rayleigh channel. The analytical results and simulation results are almost matched. From the results, it is analyzed that MBH pulse shaping filter having  $\beta$  equal to 0.5 has better SER performance for  $\alpha$  equal to 0.5.

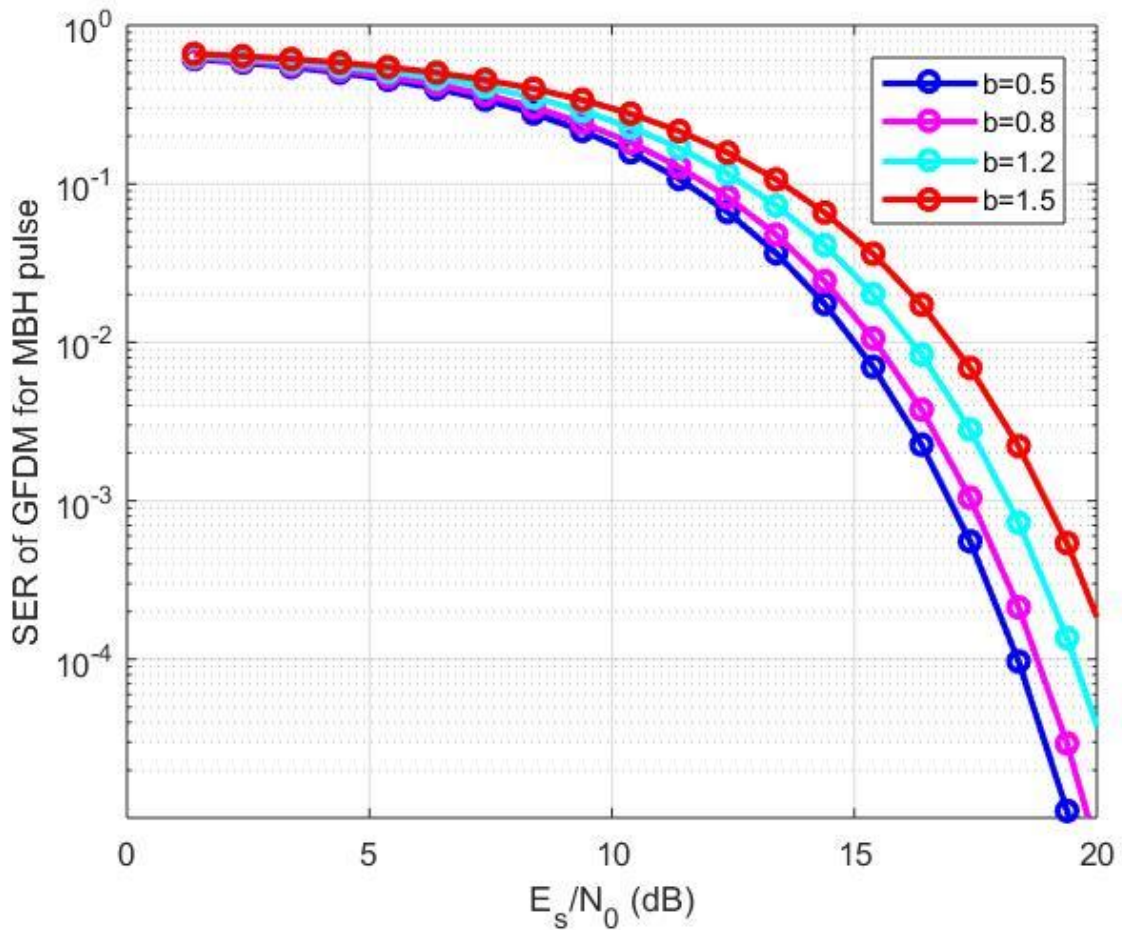


Figure 5.25 Analytical results of SER using MBH for  $\alpha$  equal to 0.5 in Rayleigh channel.

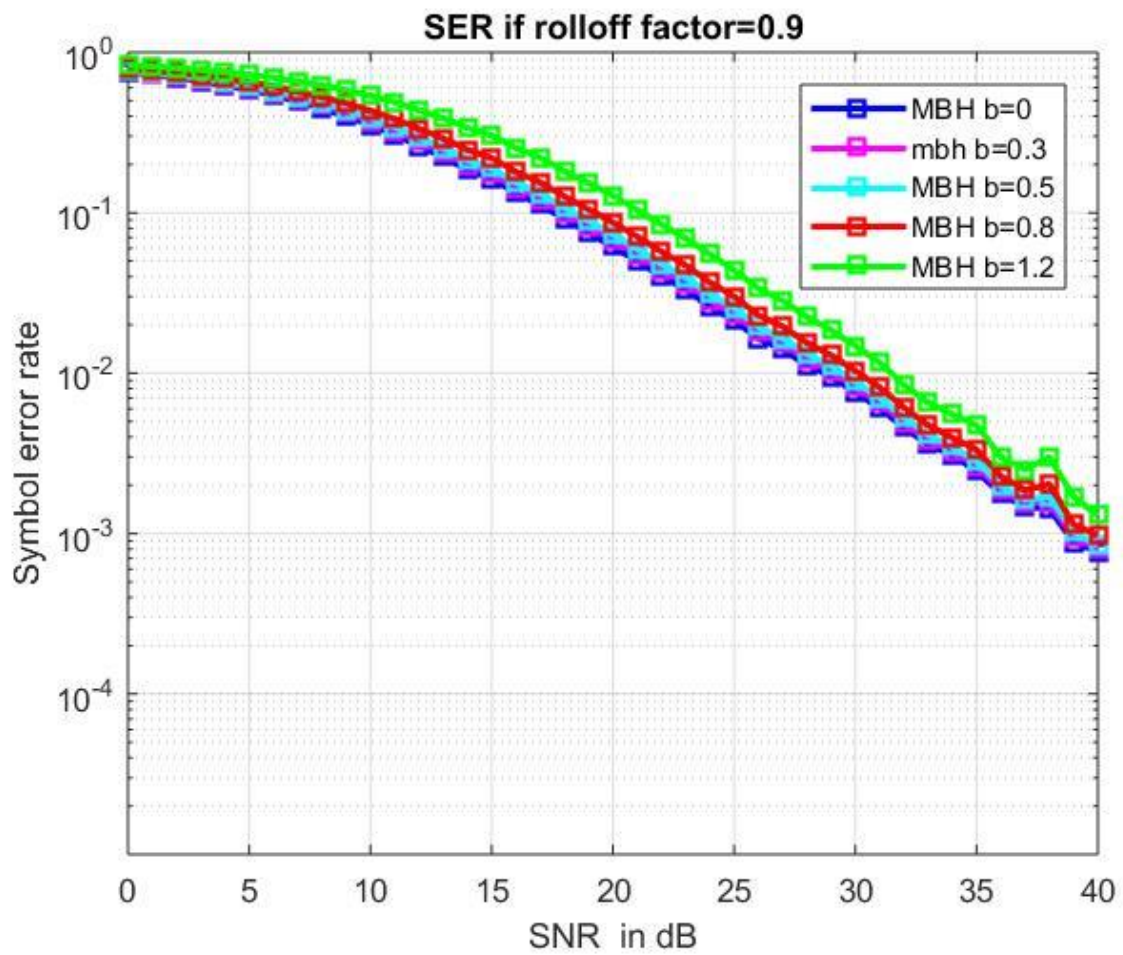


Figure 5.26 Simulation results of SER using MBH family for  $\alpha$  equal to 0.5 in Rayleigh channel.

## CHAPTER 6

### CONCLUSION AND FUTURE SCOPE

The various objectives of the thesis work have been achieved. The study of GFDM system model is also done. From the work done by the various researchers, observations are made and then the gaps are identified. After that, the objective of the thesis work is concluded. The comparison of the impulse response of the pulse shaping filters at various values of roll off factor values is made. The comparison of SER and PSD of GFDM using different pulse shaping filters has been made. Also, the effect of value of  $\beta$  on PSD and SER performance of in case of MBH pulse family has been studied. From the results it has been concluded that as side lobe levels of pulse shaping filter increases SER performance improves while OOB performance degrades. For MBH pulse family, as value of  $\beta$  increases, side lobe level decreases and so the SER performance degrades but OOB power performance improves. So, there is a trade off between the OOB power performance and SER performance. Simulation results are computed using MATLAB2017a. This work can be extended by using proper optimization techniques to find the pulse shaping filter having good OOB power performance and SER performance.

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# PERFORMANCE ANALYSIS OF PULSE SHAPING FILTERS FOR GFDM SYSTEMS

*by* Surbhi Kalsotra

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SURBHI KALSOTRA

R. No. 801661025

Under Supervision of

**Dr. Hem Dutt Joshi**

Associate Professor



THAPAR INSTITUTE  
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