PERFORMANCE EVALUATION OF PAPR REDUCTION IN OFDM ANDFBMCUSING COMPANDING TECHNIQUES

A Project report submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY IN

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES (UGC AUTONOMOUS) (*Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC with 'A' Grade*) Sangivalasa, Bheemili mandal, Visakhapatnam. (A.P) 2021-2022.

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ANITS

CERTIFICATE

This is to certify that the project report entitled "**PERFORMANCE EVALUATION OF PAPR REDUCTION IN OFDM AND FBMC USING COMPANDING TECHNIQUES**" submitted by H.S.S. Thushar (318126512021), K. Ranjith Kumar (318126512023), L. Vaishnavi (318126512054), V. Surya Bhavani (318126512057) in partial fulfilment of the requirements for the award of the degree of **Bachelor of Technology** in **Electronics & Communication Engineering** of Andhra University, Visakhapatnam is a record of bona fide work carried out under my guidance and supervision.

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ABSTRACT

Filter bank multicarrier (FBMC) has emerged as the favourite multicarrier communication technique for the fifth-generation communication systems. Since it meets the demand of next generation standards. The achievability of high data rates (10 Gbps) is expected to be attained by the 5G technology. This requires larger bandwidth and efficient usage of the frequency spectrum. In cognitive radio network very low out of band radiation is desired. To overcome the problems of low spectral efficiency and high out of band radiation in orthogonal frequency division multiplexing (OFDM) systems, FBMC is chosen to be a suitable choice. In this project FBMC is used as a waveform candidate for 5G communication. High PAPR is always a problem in multicarrier communication system. FBMC is also a multicarrier communication system, so it also suffers from high PAPR problem. To reduce the PAPR, several PAPR reduction techniques have been proposed over the last few decades. For this scheme simulation is performed to analyse the PAPR performance of FBMC system with various PAPR reduction techniques. All the simulations are performed in MATLAB and it is proved from simulation results that piecewise linear companding technique exhibits better results compared to A-law and μ-law companding techniques.

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LIST OF ABBREVIATIONS

1. FBMC Filter Bank Multi Carrier
2. OFDM Orthogonal Frequency Division Multiplexing
3. ISI Inter Symbol Interference
4. ICI Inter Carrier Interference
5. CFO Carrier Frequency Offset
6. CP Cyclic Prefix
7. AWGN Add White Gaussian Noise
8. FFT Fast Fourier Transform
9. MUX Multiplexer
10. DEMUX Demultiplexer
11. PSD Power Spectral Density
12. 5G Fifth Generations
13. LTE Long Term Evolution
14. CP-OFDM Cyclic Prefix - Orthogonal Frequency Division Multiplexing
15. BER Bit Error Rate
16. SNR Signal to Noise Ratio
17. PAPR Peak to Average Power Ratio
18. MIMO Multiple Input Multiple Output
19. OQAM Offset Quadrature Amplitude Modulation
20. ACE Active Constellation Extension
21. POCS Projection onto Convex Sets
22. SGP Smart Gradient Projection
23. IP Internet Protocol
24. Wi-Fi Wireless Fidelity
25. IFFT Inverse Fast Fourier Transform
26. dB Decibels

27. QPSK	Quadrature Phase Shift Keying
28. S/P	Serial to Parallel Converter
29. AFB	Analysis Filter Bank
30. SFB	Synthesis Filter Bank
31. CFO	Carrier Frequency Offset
32. AMTS	Advance Mobile Telephone Systems
33. IMTS	Improved Mobile Telephone Systems
34. PTT	Push to Talk
35. MTS	Mobile Telephone System

CHAPTER 1

INTRODUCTION

1.1 Literature Survey

Filter Bank Multicarrier Systems has been compared the predominant OFDM systems, providing higher spectral efficiency. The estimation of channels and usage of multiple antennas have been intriguing and the interests associated with FBMC by the real-world testbed measurements are addressed. If the pulse shaping is matched to the channel statistics, the equalizers with one tap are sufficient for implementation practically. For doubly dispersive channels, the closed form solutions for signal to interference ratio are derived to make the system more robust.

WafaKhrouf et al. proposed an epitome based on ping pong optimized pulse shaping (POPS) as a coercive method for the generation of multicarrier waveforms such as in the filter bank multicarrier (FBMC/OQAM) scheme, assuring the favourable signal to interference plus noise ratio (SINR) at the receiving end. The investigations are based on the designing of multicarrier transmissions over the channels having strong delay spread and are apace time variant. The reduction in ICI and ISI levels achieved after applying the POPS paradigm is prominent. The analytical results for the SINR have been studied and the performance metrics of the FBMC/OQAM turned out to be better with those for the FBMC/QAM modulation for some parameters.

A proposal for a parallel equalization structure was put forward in this work for compensation of channel frequency selectivity by Francois Rottenberg et al. The effective implementation of FBMC/OQAM systems have been studied in the presence of doubly dispersive channel. Due to the enhanced selectivity of channel in time and frequency, it is observed that it spifflicates the orthogonality in symbols leading to distorted signal at the receiver. In this work, the authors have performed investigations on the time and frequency selectivity of the channel.

Ali JasimRamadhan discussed the prototype filter designed for the fifth generation Filter Bank Multicarrier systems implementation. The shortcomings occurred in the former technologies led to increased latency and enhanced symbol lengths without affecting channel capacity.

Bidyalaxmi Devi Tensub et al.provides an overview of the multicarrier modulation schemes competent enough to meet the requirements of the future telecommunication areas. It discussed the techniques dominating the wireless communications till now and their downsides. The technology approaching to the implementation of filter banks in which Fast Fourier Transforms forms the basis for the development of sub bands being processed.

DaimingQuetal. presented an approach for tail shortening applied on the FBMC/OQAM symbols, leading to the spectrum being more spectrally efficient.

Han Wang et al. proposed a hybrid PAPR reduction scheme which constituting of partial transmit sequence and tone reservation for FBMC/OQAM systems.

In FBMC system, the signal with high spectral containment will be used to reduce the sidelobes of each subcarrier frequency. FBMC gives better bandwidth efficiency than OFDM from the paper “Improvement of FBMC over OFDM in terms of PSD and BER”,byA.Lakshmi Narayana, faculty of electronics and communication engineering, Anil Neerukonda Institute of Technology and Sciences, Andhra Pradesh, says that the power spectral density is more in FBMC system comparatively than OFDM system. Also, out of FBMC and OFDM, FBMC has high PAPR. From the paper “The potential of FBMC over OFDM for the Future 5G Mobile Communication Technology”, by A.N. Ibrahim, M.F.L. Abdullahi, who were the faculty of electrical and electronics engineering, University Tun Hussein Onn Malaysia, that SNR is more in FBMC than OFDM and BER is less in FBMC than OFDM.

1.2 Overview:

The demand for high data services is gained more importance in present generation. As we all know, data transmission is of 2 types i.e., wireless and wired medium. These data services must be very reliable for transmission of data even in harsh environment. Most of this transmission systems experience degradation such as noise, large attenuation, time variance, multipath non-linearity. Multi-carrier modulation technique is a physical layer technique that has gained a lot of importance in present days due to its robustness. In multi-carrier modulation, the most commonly used technique is OFDM (Orthogonal Frequency Division Multiplexing), FBMC (Filter Bank Multicarrier), which has recently become very popular in wireless communication. There is a great demand of advance communication and according to it there should be high data rate in addition to both efficiency and low bit error rate.

Filter Bank Multicarrier with Offset Quadrature Amplitude Modulation System (FBMC/OQAM) as one of the many new waveforms is proposed for the next wireless communication system (5G). The FBMC system is a multicarrier modulation scheme with relaxed orthogonally, increased frequency efficiency, improved shape and low out-of-band interference inherent in FBMC/OQAM techniques. In OFDM, entire band is separated, but in FBMC, each sub-carrier is shifted independently. When carriers are modulated using FBMC, side lobes are removed and gives clear outcomes.

The main drawback of FBMC/OQAM system is a high Peak to Average Power Ratio (PAPR) of the transmitted signal. To overcome that, many researchers proposed schemes to reduce PAPR for FBMC system. Active Constellation Extensions (ACE) with projection onto convex sets (POCS) and smart gradient projection (SGP), are used for reducing PAPR of FBMC system. But they increase the average power transmitted leading to a decrease in the power efficiency and degrading the bit error rate (BER) performance as well as they require more implementation complexity.

Nonlinear Companding is one of the best PAPR reduction techniques used in multicarrier modulation due to less complexity and good bit error rate BER. The companding function is used in order to attenuate the high peaks and amplify the low amplitudes. At the receiver, the inverse companding function is applied in order to recover the original signal. Moreover, by choosing proper companding parameters, the average transmitted power can be kept unchanged after companding. In this paper, we used different nonlinear companding techniques to reduce PAPR of FBMC system. The companding techniques used are μ-law and A-law and piecewise linear companding.

1.3 Organization of the Project:

The project report is organised in six chapters. It starts from the introduction. The current Chapter 1 introduces the project and gives a brief description of Filter Bank Multi Carrier compared to Orthogonal Frequency Division Multiplexing technique. Chapter 2 provides the brief idea about the 5G Communication and it gives the introduction to the 5G. Chapter 3 gives the detailed working of the Filter Bank Multi Carrier and detailed study of the block diagram. Chapter 4 talks about the Non-Linear companding techniques i.e., about A law, μlaw, piecewise linear companding and also about PAPR(Peak to Average Power Ratio). Chapter 5 talks about the introduction to MATLAB. Chapter 6 gives the Result, Conclusion and Future scope of 5G technology.

CHAPTER 2

INTRODUCTION TO 5G COMMUNICATION

2.1 Introduction:

5G is the Fifth-Generation technology. It has many advanced features potential enough to solve many of the problems of our mundane life. It is beneficial for the government, as it can make governance easier; for the students, as it can make available the advanced courses, classes, and materials online; it is easier for the common people as well, as it can facilitate them on the internet everywhere. So, this tutorial is divided into various chapters and describes the 5G technology, its applications, challenges, etc.

Radio technologies have evidenced a rapid and multidirectional evolution with the launch of the analogue cellular systems in the 1980s. Thereafter, digital wireless communication systems are consistently on a mission to fulfil the growing need of human beings (1G, 2G …4G, or now 5G).

Fig. 2.1 Introduction to 5G Communication.

2.2 What is 5G Technology?

5G is the fifth generation of cellular technology. It is designed to increase speed, reduce latency, and improve flexibility of wireless services. 5G technology has a theoretical peak speed of 20 Gbps, while the peak speed of 4G is only 1 Gbps.

5G also promises lower latency, which can improve the performance of business applications as well as other digital experiences (such as online gaming, videoconferencing, and self-driving cars).

Then — how is 5G different from the previous one (especially 4G)? The answer is — it is not only the increase in bitrate made 5G distinct from the 4G, but rather 5G is also advanced in terms of –

- High increased peak bit rate
- Larger data volume per unit area (i.e., high system spectral efficiency)
- High capacity to allow more devices connectivity concurrently and instantaneously
- Lower battery consumption
- Better connectivity irrespective of the geographic region, in which you are
- Larger number of supporting devices
- Lower cost of infrastructural development
- Higher reliability of the communications

As researchers say, with the wide range of bandwidth radio channels, it is able to support the speed up to 10 Gbps, the 5G Wi-Fi technology will offer contiguous and consistent coverage-wider area mobility in true sense.

2.2.1 Evolution of Mobile Networks:

Mobile communication technology has made it possible for people to connect and communicate in remote parts of the world where even electricity cannot be taken for granted. Mobile communication technologies developed from supporting analogvoice only to powerful systems that provided countless of different applications to billions of consumers.

Below figure shows the timeline of various networking communication technologies categorized into 'Generations'. Subsequently, the digital wireless communication systems are consistently on a delegation to achieve the growing need of human beings.

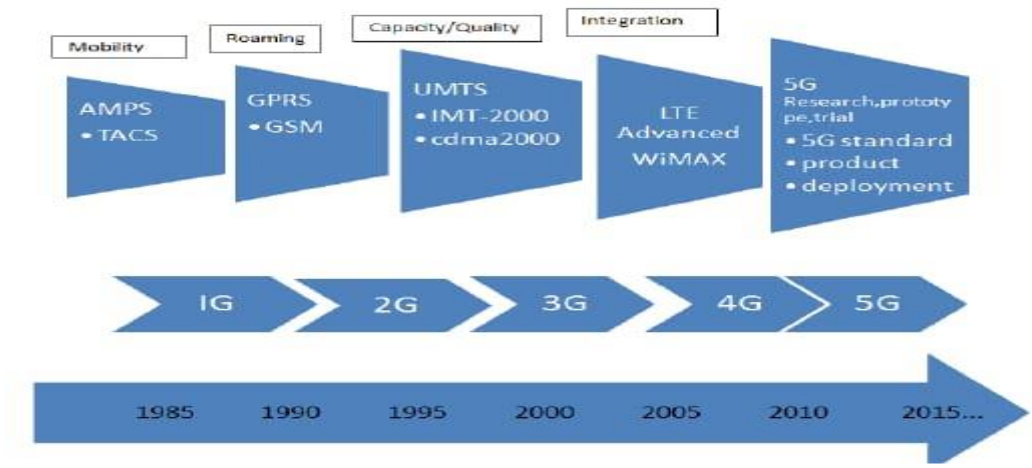

Fig. 2.2 Evolution of mobile networks.

First Generation (1G) was introduced in 1980s and provided voice transmissions and bandwidth of 2kbps. 1G is an analog system and comprised of the following technologies which are Advance Mobile Telephone Systems (AMTS), Improved Mobile Telephone Service (IMTS), Push to Talk (PTT) and Mobile Telephone System (MTS). Second Generation (2G) started in 1990s and was commercially launched on the GSM standard which based on digital technology and network infrastructure with the speed up to 14.4kbps. 2G consist of the following technologies which are Global System for Mobile Communication (GSM), Enhanced Data Rates for GSM Evolution (EDGE), Code Division Multiple Access (CDMA) and General Packet Radio Service (GPRS). Third Generation (3G) introduced in 2000s quest for data at higher speeds. It substantiates video calling with the speed up to 2Mbps. 3G comprises of Universal Mobile Telecommunication Systems (UMTS), Wideband CDMA, UBluetooth, High

Speed Downlink Packet Access (HSDPA) and Wireless Local Area Network (WLAN).

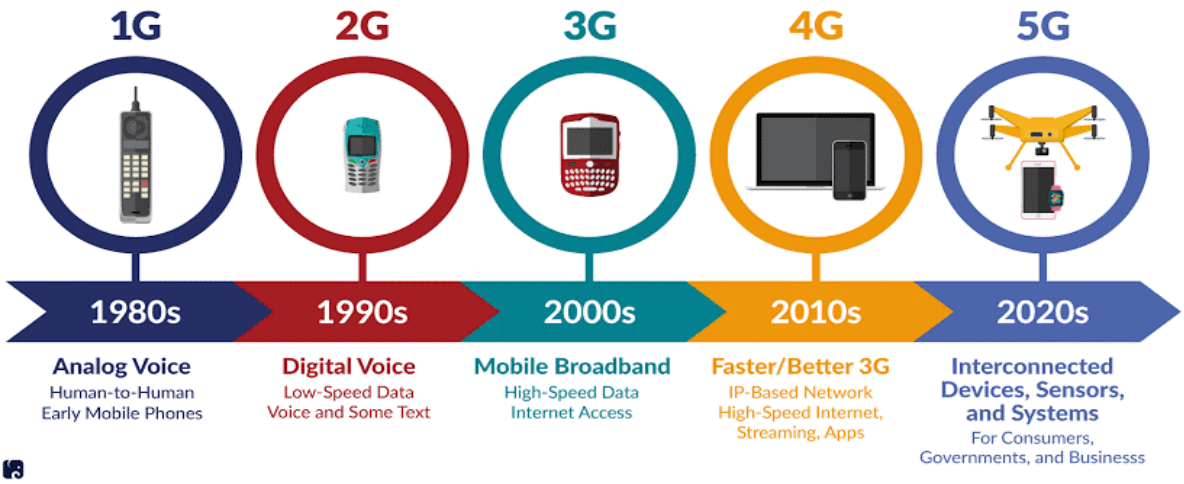

Fig.2.3 showing the timeline of all Previous Generation Techniques.

Fourth Generation (4G) introduced in 2000s. 4G uses the concept of connectivity anywhere, anytime from any kind of devices and it is indeed observed in user behaviour. It supposed to provide 100Mbps to 1Gbps to users and the range of latency between 40ms and 60ms. 4G able to delivering faster and better mobile broadband experiences besides application of mobile web access and the high quality of videos and images. Besides that, 4G LTE were introduced because it is not able to fully reach the range of 4G. The download process, stream and browse faster with better connectivity. It is closer to meet the criteria of standards. Next, LTE-Advanced was introduced which is more progressive of technologies and standards which is capable to deliver faster and bigger data. Besides that, it offers to deliver true speeds of 4G compared to the LTE networks. 4G comprised Long Term Evolution (LTE), Worldwide Interoperability for Microwave Access (WiMAX), Multiple Input Multiple Output (MIMO) smart antenna technologies, Mobile Broadband Wireless Access (MBWA) and Orthogonal Frequency Division Multiplexing (OFDM). Nowadays, there are more powerful laptops and smartphones which is becoming more attractive and demanding advanced multimedia capabilities. This has led to an eruption of wireless mobile devices and services.

2.3 Salient features of 5G:

The salient features of 5G communication are

- Up to 10Gbps data rate - > 10 to 100x speed improvement over 4G and 4.5G networks.
- 1-millisecond latency.
- 1000x bandwidth per unit area.
- Up to 100x number of connected devices per unit area (compared with 4G LTE).
- 99.999% availability.
- 100% coverage.
- 90% reduction in network energy usage.

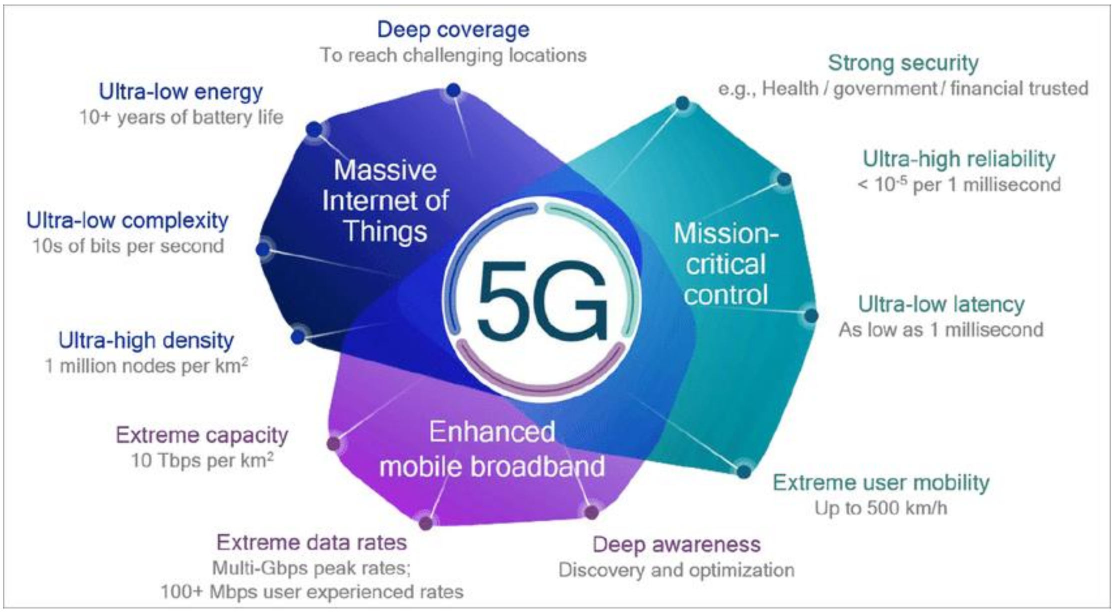

Fig. 2.4 Features of 5G.

2.4Advantages of 5G Communications

1. High speeds

5G works faster on mobile phones and other devices when compared to 4G and 4G LTE. It allows users to download movies, videos, and music in seconds as opposed to minutes. The network has 20 Gbps speed enabling organizations to use the same for services such as automation, advanced web conferencing, etc. A recent survey says that consumers who used 5G saved nearly 23 hours per day in the downloading process.

2. Low latency

5G has low latency when compared to 4G that will support new applications such as AI, IoT, and virtual reality efficiently. Not only that, it enables mobile phone users to open a webpage and browse things without any hassles. Another thing is that it gives ways to access the internet anytime when looking for some important information.

3. Increased capacity

5G has the capacity to deliver up to 100 times more capacity than 4G. It allows companies to switch between cellular and Wi-Fi wireless strategies that will help a lot to experience better performance. Apart from that, it provides methods to access the internet with high efficiency.

4. More bandwidth

One of the main advantages of 5G is that it increases more bandwidth that will help transfer the data as soon as possible. Furthermore, mobile phone users can ensure a faster connection with more bandwidth after choosing a 5G network.

2.4.1 Disadvantages of 5G Technology

1. Limited global coverage

The main disadvantage of 5G is that it has limited global coverage and is available only in specific locations. Only cities can benefit a lot from 5G network and remote areas may not get the coverage it for some years. Moreover, the expenses for setting tower stations are high when compared to other networks.

2. Decreased broadcast distance

Although 5G works fast at high speed, it won't travel as far when compared to 4G. Moreover, tall buildings and trees may block the frequency of the 5G network that will result in various problems. Therefore, it requires more towers for coverage that is time-consuming and expensive. Rain can also cause problems to 5G coverage that needs more protection.

3. Upload speeds

5G technologies allow mobile phone users to ensure high download speeds. On the other hand, the upload speeds are not over 100 Mbps when compared to 4G. Furthermore, mobile phones need better battery technology while using a 5G connection. Many phone users say that they experience more heat on their devices while running 5G.

4. Weakened device batteries

Phones that use a 5G connection will result in a huge battery drain that reduces the lifespan to a large extent. Hence, manufacturers need to invest in new battery technologies to protect the battery from damages and other problems.

2.4.2 Applications of 5G

It will make a unified global standard for all.

- Network availability will be everywhere and will facilitate people to use their computer and such kind of mobile devices anywhere anytime.
- Because of the IPv6 technology, visiting care of mobile IP addresses will be assigned as per the connected network and geographical position.
- Its application will facilitate people to avail radio signal at higher altitude as well
- High-speed mobile network. 5G will revolutionize the mobile experience with a supercharged wireless network, which can support up to 10 to 20 GBPS of data download speed.
- Entertainment and multimedia.
- Internet of Things – Connecting everything.
- Satellite Internet.

2.4.3 Future Scope of 5G

Several researches and discussions are going on across the world among technologists, researchers, academicians, vendors, operators, and governments about the innovations, implementation, viability, and security concerns of 5G.

As proposed, loaded with multiple advanced features starting from the super high speed internet service to smooth ubiquitous service, 5G will unlock many of the problems. However, the question is — in a situation, where the previous technologies (4G and 3G) are still under process and in many parts yet to be started; what will be the future of 5G?

Fig. 2.5 future scope in 5G.

5th generation technology is designed to provide incredible and remarkable data capabilities, unhindered call volumes, and immeasurable data broadcast within the latest mobile operating system. Hence, it is more intelligent technology, which will interconnect the entire world without limits.

Likewise, our world would have universal and uninterrupted access to information, communication, and entertainment that will open a new dimension to our lives and will change our lifestyle meaningfully.

2.4.3 Which countries are using 5G Technology?

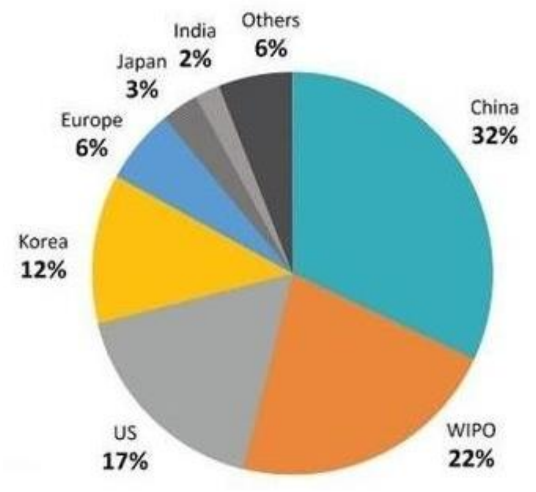

Fig. 2.6 Graphical distribution of 5G Patent Families.

First adopters embracing 5G will gain a competitive edge over the others, and it looks like China is currently leading the way. According to various sources, Asian countries like China, South Korea, Japan, and the US (outside Asia) are investing and building 5G infrastructure.

Since 2015, China has spent the most money on 5G and the amount is about US$24 billion which is more than any other countries. These numbers are momentous, as the potential economic impact of 5G far outweighs the improvements recorded when the industry transitioned from 3G to 4G.

CHAPTER 3

OFDM AND FBMC SYSTEMS

3.1 Orthogonal Frequency Division Multiplexing(OFDM)

In telecommunications, orthogonal frequency-division multiplexing is a type of digital transmission and a method of encoding digital data on multiple carrier frequencies.

3.1.1 Concept and Process

Orthogonal Frequency Division Multiplexing (OFDM) is one of the modulation types used for current wireless and telecommunications systems. This system used the technique of encoding digital data on multiple carrier frequency and becomes a popular method for wideband digital communication. It is widely used to produce high data rates and combating multipath fading in wireless communication technology. OFDM is already used over the world to attain high data rates which is needed for data intensive applications. It has been used in wireless network, audio broadcasting and 4G mobile communication technology. This modulation format already been used in the WIFI arena (802.11a, 802.11ac, etc.). OFDM use the Cyclic Prefix (CP) which will reduce the overall spectral efficiency. OFDM based on the idea of modulating each data stream on subcarriers and dividing high-bit-rate data stream into several lower bit-rate data. Conventional OFDM makes use of Fast Fourier Transform (FFT) as its basic block. Multicarrier modulation knowing as schemes which able to provide high data rate. Figure 4 shows the frequency response for OFDM which exhibits strong sidelobes due to rectangular windowing. OFDM is a wideband modulation technique which is able to handle with the issues of the multipath reception by transmitting many narrowband overlapping digital signals in parallel in one wide band. It is very useful for communication over channels with frequency selective fading. Nevertheless, it is difficult in handling selective fading in the receiver because of the complicate architecture of the receiver. Besides that, flat fading is easy to combat compared to the frequency selective fading by the use of simple error correction and equalization schemes.

OFDM is based on the principle of multicarrier modulation and is a special case of frequency division multiplexing.

This technique saves up to 50% of the total spectrum than FDM technique and promotes the efficient usage of the available bandwidth.

In OFDM technique, the system bandwidth is divided into sub bands and these sub bands are orthogonal and independent to each other.

OFDM use the Cyclic Prefix(CP) which will reduce the overall spectral efficiency.

The existence of inter carrier interference (ICI) cannot be neglected.

Although OFDM has an edge over FDM, cyclic prefix is used for robustness of signal, but by using cyclic prefix orthogonal frequency division multiplexing has some drawbacks.

To overcome the drawback of OFDM, we make use of Filter Bank Multicarrier (FBMC) since it provides the efficient bandwidth.

3.1.2 BLOCK DIAGRAM OF OFDM

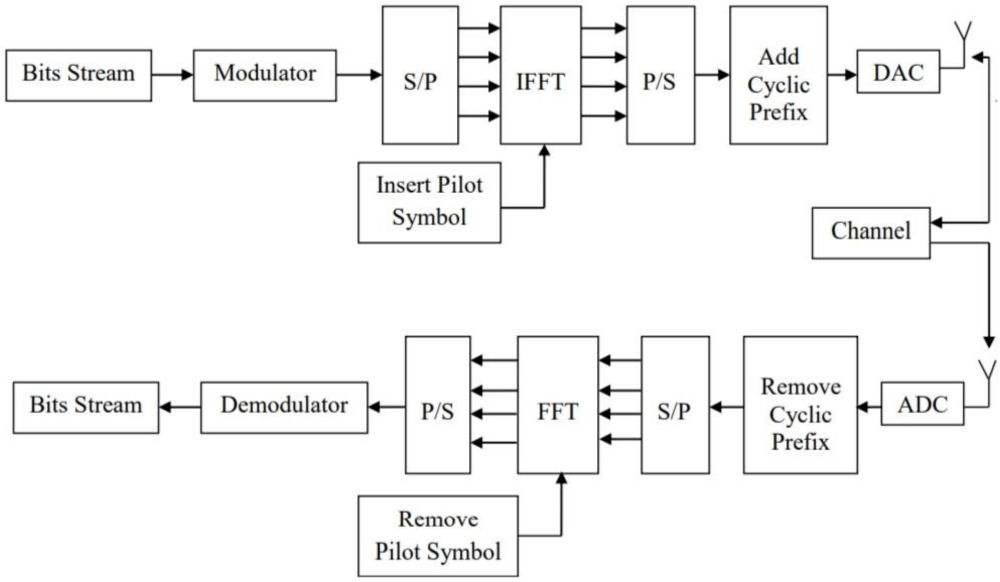

Fig. 3.1 OFDM Block diagram.

3.1.3 CYCLIC PREFIX

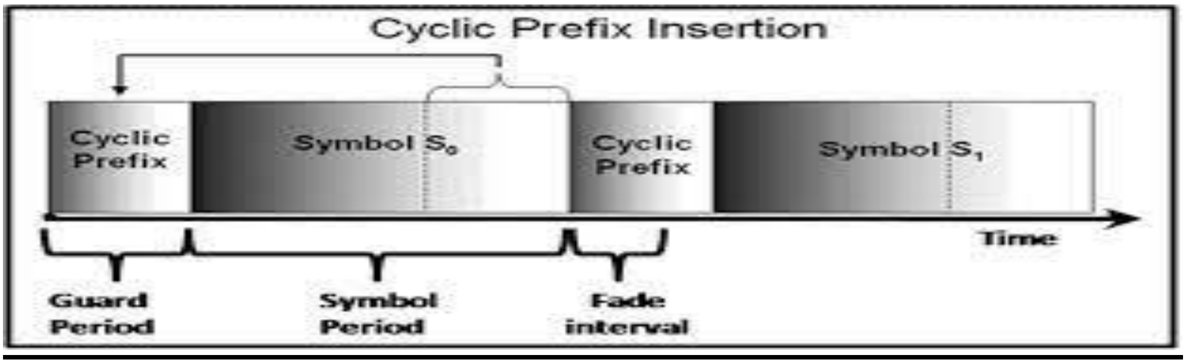

Fig. 3.2 Cyclic Prefix of OFDM.

The cyclic prefix used in Frequency Division Multiplexing schemes including OFDM to primarily act as a guard band between successive symbols to overcome intersymbol interference, ISI.

The cyclic prefix performs two main functions:

- The cyclic prefix provides a guard interval to eliminate intersymbol interference from the previous symbol.
- It repeats the end of the symbol so the linear convolution of a frequency-selective multipath channel can be modeled as circular convolution, which in turn may transform to the frequency domain via a discrete Fourier transform. This approach accommodates simple frequency domain processing, such as channel estimation and equalization.

3.2 Introduction to FBMC

Filter Bank Multicarrier, FBMC is a form of multicarrier modulation in which the carriers are filtered to provide a more spectral efficient form of waveform. Filter Bank Multicarrier, FBMC is a form of multi-carrier modulation that has its origins within OFDM. It is a development of OFDM and aims to overcome some of the issues, although this comes at the cost of increased signal processing.

FBMC has a much better usage of the available channel capacity and is able to offer higher data rates within a given radio spectrum bandwidth, i.e., it has a higher level of spectrum efficiency. Filter bank multicarrier aims to overcome some of the shortcomings that were encountered with OFDM, orthogonal frequency division multiplexing. One of the main shortcomings arises from the fact that OFDM requires the use of what is termed as cyclic prefix. The cyclic prefix is essentially a copy part of a transmitted symbol in OFDM that is appended at the beginning of the next which is considered to be a major drawback and it is eliminated using FBMC. The reason behind the wide usage of the FBMC system are it is a multicarrier modulation scheme with relaxed orthogonality, it has increased frequency efficiency, improved shape, and low out-of-band interference.

3.2.1 Development of FBMC

The use of FBMC and multicarrier modulation in general has come to the fore in recent years as it provides an ideal platform for wireless data communications transmissions.

However, the concept of FBMC technology was first investigated in the mid-1960s during research into methods for reducing interference between closely spaced channels and also avoid the use of cyclic prefix which results in increased complexity. In addition to these other requirements needed to achieve error free data transmission in the presence of interferenceand selective propagation conditions.

Initially the use of FBMC mainly aims at removing cyclic prefix that is used in OFDM but later on it is found that there are some drawbacks such as increased Peak to Average Power Ratio which resulted in power amplifier inefficiency but later on many schemes have been proposed to reduce PAPR which resulted in high efficiency enabling FBMC to be considered for the 5G mobile communications systems which started to be deployed from around 2019. Also, FBMC was adopted for Wi-Fi and a variety of other wireless data systems.

3.2.2 What is FBMC?

FBMC systems are a subclass of Multicarrier (MC) systems. FBMC modulation is a multicarrier modulation method in which a set of synthesis and analysis filters are employed at the transmitter and receiver respectively. The filters use in the FBMC systems are a set of band-pass filters. In this filter, the frequency shifted or modulated versions of a prototype low-pass filter. FBMC offers a better spectral containment than OFDM as the filter bandwidth, so the selectivity is a parameter that can be assorted during low-pass prototype design. Besides that, FBMC gives the better bandwidth efficiency compared to OFDM. This is because, FBMC does not use the CP extension, so it will be attenuated the interferences within and close to the used frequency band efficiently. Next, the FBMC systems are comparatively more resistant to narrowband noise effects.

Figure 3.1 shows the graphical illustration of the FBMC transmitter meanwhile Fig 3.2 shows the graphical illustration of a generic FBMC receiver. At the transmitter as shown in Fig. 3.1, the high-speed input signal will be de-multiplexed into N branches. After that, it will be modulated by the different or same signal constellation as required. The subsequent modulated branches are the unsampled to give N copies. The unsampled data will be sent through the set of synthesis filters gk(n), k=0,1,….,N-1. Next, to produce the transmitted signal s(n), the output of all filters will be summed together. At the receiver as shown in Fig. 3.2, to give N subcarriers of different centre frequencies, the received signal r(n) will be passed through to the bank of analysis filters fk(n),k=0, 1,….,N-1. The signal in every branch will be down sampled by N, demodulated and multiplexed to produce the estimate of the original signal Xr(n).

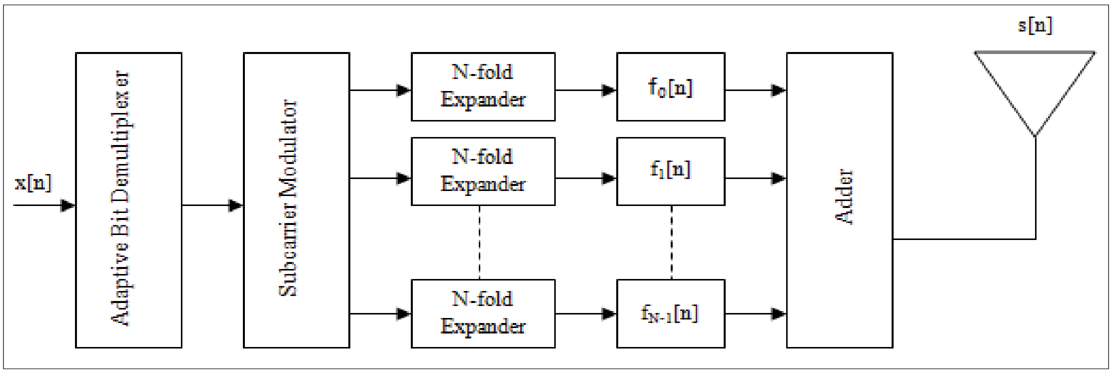

Fig. 3.3The graphical illustration of the FBMC transmitter.

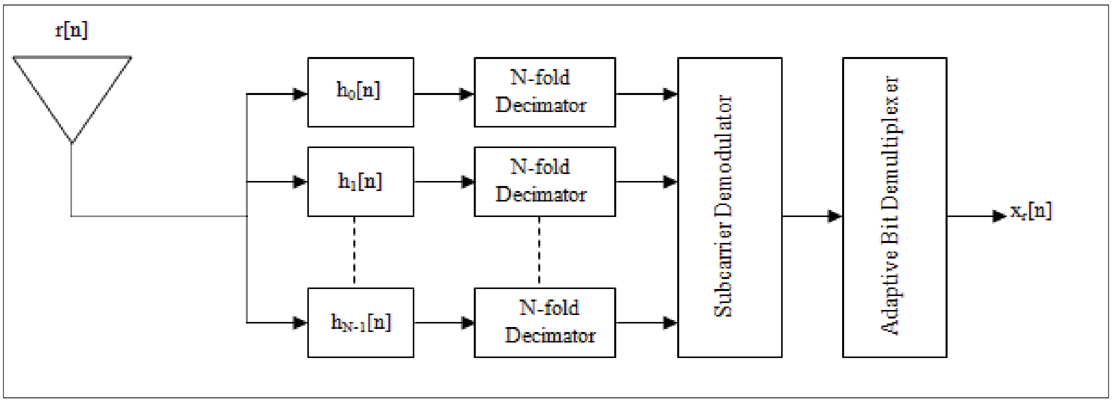

Fig. 3.4The graphical illustration of a generic FBMC receiver.

3.2 How data can travel in FBMC

The traditional format for sending data over a radio channel is to send it serially, one bit after another. This relies on a single channel and any interference on that single frequency can disrupt the whole transmission.

FBMC adopts a different approach. First the data is transmitted in parallel across the various subcarriers and then there is a shift of half the inverse of the sub-channel between the real part and the imaginary part of a complex symbol such that there is staggering of in-phase and quadrature-phase components in both time and frequency domains, hence, orthogonality is maintained within the real and imaginary domains separately.

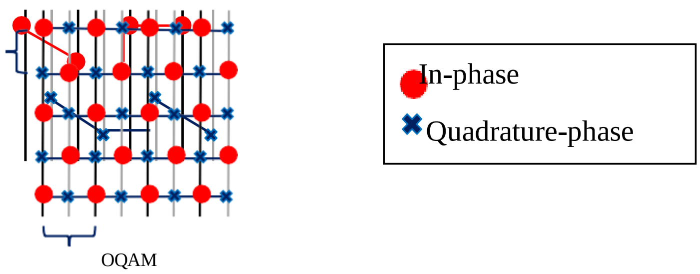

Fig. 3.5OQAM signalling.

The distribution of data with an offset introduced between the real and imaginary parts has some further advantages. Due to the presence of offset the inter symbol interference and inter carrier interference can be eliminated to some extent. By performing proper post processing at the receiver enables us to reconstruct the data.

3.3 Block Diagram of FBMC

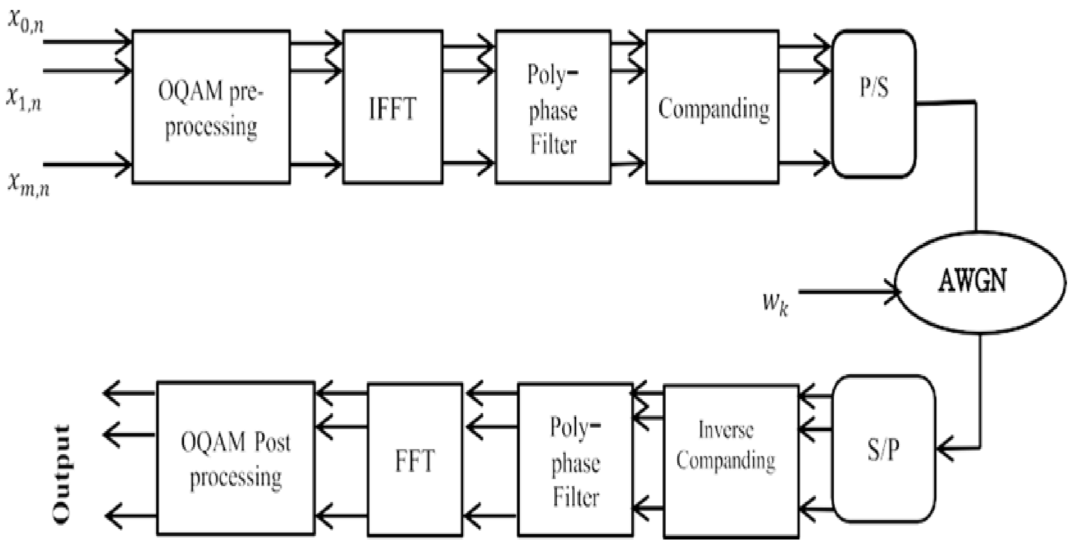

Fig. 3.6Proposed Transceiver Structure of FBMC with Companding.

3.3.1 OQAM Pre-Processing

The function of OQAM pre-processing is to take the serial to parallel converted data that is obtained from the random generator and then perform the quadrature amplitude modulation which results in complex data, and then there is a shift of half the inverse of the sub-channel between the real part and the imaginary part of a complex symbol such that there is staggering of in-phase and quadrature-phase components in both time and frequency domains the output of the OQAM pre-processing is then passed through the IFFT block.

3.3.2 IFFT-Frequency-Domain to Time Domain Conversion

The orthogonality of the subcarrier is maintained and the frequency domain signals are converted into a time domain and the generation of real-output signal is achieved by arranging the conjugate of sub-carrier. In this stage the techniques like IFFT Mapping, zero mapping and selector bank are included to overcome the problem of length of subcarrier and bin size.

3.3.3 Polyphase Network

In order to fix the size of FFT some additional processing is required, called as polyphase network. The prototype filter is defined as a set of coefficients and the relationship between input and output sequences, which is:

$$y(n) = \sum_{i=0}^{L-1} h_i x(n-i) \tag{3.1}$$

The filter impulse response, of length L, is the sequence of coefficients hh_i the frequency response is expressed by:

$$H(f) = \sum_{i=0}^{L-1} h_i \, e^{-j_{2\pi} if} \tag{3.2}$$

The filter has linear phase if the coefficients are symmetrical and, in this case, the delay is:

$$\tau = \frac{L-1}{2} \tag{3.3}$$

In digital signal processing, and particularly in digital filtering, it is customary to use the Z- transfer function, which generalizes the frequency response and is defined by:

$$H(Z) = \sum_{i=0}^{L-1} h_i z^{-i} \tag{3.4}$$

The filter frequency response is the restriction of the Z-transfer function to the unit circle, i.e., it is obtained by letting Z = $e^{j^2 \pi f}$.

Now, if we assume, as in the previous section, that the filter length is a product of two factors.

L = K.M, the sequence of filter coefficients can be decomposed into M interleaved sequences of K coefficients and the Z-transfer function can be expressed as a double summation.

It turns out that each individual filter element has a frequency response of a phase shifter hence the name of polyphase decomposition and polyphase network for the complete set.

Now, turning to the filter bank in the transmitter, which is generated by shifting the response of the prototype filter on the frequency axis, a global Z-transfer function can be derived Shifting the frequency response of the filter function H (f) by 1/M on the frequency axis leads to the function:

$$B(f) = H(f-1/M) \quad (3.5)$$

The key point here is that the functions H (Z^M) are not affected by the frequency shift. Then, considering all the shifts by multiples of 1/M and the associated filters, and letting W = $e^{-j2\pi}/_M$, a matrix equation is obtained which is the inverse discrete Fourier transform and all the filters in the bank have the same filter elements.

In the implementation, the transmitter output is the sum of the outputs of the filters of the bank. Thus, the processing associated with the filter elements H (Z^M) can be carried out after the summation which is performed by the IDFT.

The same scheme applies to the filter bank in the receiver. The difference is that the frequency shifts are multiples of –1/M and the discrete Fourier transform (DFT) replaces the IFFT. In fact, for each sub-channel, the signal of interest is shifted around the frequency origin and filtered. Again, the filter elements are the same for all the filters in the bank and, since it is the sum of the sub-channel signals which is received, the processing can be common and the separation of the signals can take place afterwards, with the help of the DFT.

3.3.4 Companding and De-Companding

The output of the polyphase network will result in high PAPR(Peak to Average Ratio) at the transmitter end which results in increased battery consumption and decreases power amplifier efficiency, for example if PAPR is 10dB and if we want to pass a signal with power 0.2W then the power amplifier must be able to handle a peak power 2W in order to reduce the PAPR we use companding techniques which uses a companding function and if the input is less than the amplification of the input takes place whereas if the input if small then the attenuation takes place. At the receiver the reverse process takes place by using De-companding function in order to reproduce the original data.

3.3.5 Parallel to Serial Conversion

The final stage in the implementation must undo the first stage. A switch is used to time- division multiplex the four individual bit signals into a single sequence.

3.3.6 AWGN Channel

Additive white Gaussian Noise (AWGN) is a basic noise model used in Information theory to imitate the effect of many random processes that occur in nature.

The term additive white Gaussian noise (AWGN) originates due to the following reasons.

Additive: The noise is additive, i.e., the received signal is equal to the transmitted signal plus noise. This gives the most widely used equality in communication systems which is shown in Figure below.

$$r(t)=s(t)+w(t)(1)(1)r(t)=s(t)+w(t) \quad (3.6)$$

Moreover, this noise is statistically independent of the signal. Remember that the above equation is highly simplified due to neglecting every single imperfection a Tx signal encounters, except the noise itself.

White: Just like the white colour which is composed of all frequencies in the visible spectrum, white noise refers to the idea that it has uniform power across the whole frequency band. As a consequence, the Power Spectral Density (PSD) of white noise is constant for all frequencies ranging from $-\infty-\infty$ to $+\infty+\infty$.

Nyquist investigated the properties of thermal noise and showed that its power spectral density is equal to $k\times Tk\times T$, where kk is a constant and TT is the temperature in Kelvin. As a consequence, the noise power is directly proportional to the equivalent temperature at the receiver.

Gaussian: The probability distribution of the noise samples is Gaussian with a zero mean, i.e., in time domain, the samples can acquire both positive and negative values and in addition, the values close to zero have a higher chance of occurrence while the values far away from zero are less likely to appear,this is shown in figure. As a result, the time domain average of a large number of noise samples is equal to zero.

In reality, the ideal flat spectrum from $-\infty-\infty$ to $+\infty+\infty$ is true for the frequencies of interest in wireless communications (a few kHz to hundreds of GHz) but not for higher frequencies. Nevertheless, every wireless communication system involves filtering that removes most of the noise energy outside the spectral band occupied by our desired signal. Consequently filtering, it is not possible to distinguish whether spectrum was ideally flat.

3.3.7 Serial to Parallel Conversion

The main function of serial to parallel converter is to convert the serial data parallelly. The parallel data is transmitted by assigning a unique word to each of the subcarriers. Once the symbol has been allocated to each of the subcarriers then they are phased mapped according to the modulating scheme. Digital Modulation Scheme used in FBMC Transmitter.

It is one of the advantages of FBMC that different modulation schemes can be applied to each sub channel depending on channel condition, data rate, robustness, and throughput and channel bandwidth. There could be different modulation schemes applied specified by complex numbers i.e., QPSK, 16 QAM. Modulation to FBMC sub channels can be made adaptive after getting information and estimation of channel at transmitter.

3.3.8 FFT: Time Domain to Frequency Domain Conversion

FBMC distributes the data over a large number of carriers at different frequencies. This spacing provides the orthogonality which prevents the receivers from seeing the wrong frequencies. In contrast to other multi-carriers' techniques, like OFDM, FBMC prevents the Inter Symbol Interference (ISI) by using a poly-phase network is the key features of FBMC is the IFFT/FFT pair. These two mathematical tools are used to transform several signals on different carriers from the frequency domain to the time-domain in the IFFT (or FFT-1) and from the time-domain to the frequency-domain in the FFT.

3.3.9 OQAM Post-Processing

The main function of OQAM post-processing is to separate the alternate real and imaginary parts which are separated by an offset when passed through the transmitter and then demodulation process takes place which results in the desired data at the receiver end.

3.4 Key Features of FBMC

- In the FBMC system, the signal with high spectral containment will be used to reduce the sidelobes of each subcarrier frequency.
- The subcarriers are orthogonal to each other.
- The FBMC system offers more robustness to the time and frequency offset.
- The FBMC system offers more frequency spectral efficiency

3.6 Differences between FBMC and OFDM

OFDM and FBMC known as the multicarrier techniques which is the data symbols will be transmitted simultaneously over the multiple frequency subcarriers. Their nature of multicarrier signals gives in-build support for frequency selective link/rank adoption. The main difference between OFDM and FBMC is the pulse shaping applied at each subcarrier. Most of the wireless mobile communication technology that was developed today is based on OFDM. FBMC is an advancement of OFDM. The basic change in the FBMC system is the replacement of the CP in OFDM with the multicarrier system based on filter bank [24], the inverse Fast Fourier transform (IFFT) and the input of the Cyclic Prefix was replaced by the synthesis filter bank (SFB). Meanwhile for the output of the Cyclic Prefix and Fast Fourier transform (FFT) was replaced by the analysis filter bank (AFB). The frequency spectrums of the subcarriers in the OFDM system are overlapped with the minimum frequency spacing. Besides that, the orthogonality was reached between the different of the subcarriers. The input stream was split into parallel data streams using the serial to parallel data converter (S/P). Subsequently, to generate time sequence of the streams, it will be passed into an IFFT block. The symbol time sequences of the OFDM system will be extended by adding CP. The digital signal produced and converted into analog form before it has been transmitted over the channel. FBMC overcomes the weakness of the OFDM system. In the FBMC system, it produced a well localized subchannel in both frequency and time domain by adding a generalized pulse shaping filters. There is no CP needed in the FBMC system, so it provided more effective use of the radio resources and have more spectral containment signals. Filter bank can be defined as an array of the N filters that will be processed the N input signals to generate N outputs. There are two types of the filter bank in this system which is analysis filter bank (AFB) and synthesis filter bank (SFB). In the AFB, the input of N filter is connected together. Besides that, the system in analogous manner that can be assumed as an analyser to the input signal based on each filter characteristics. Meanwhile in the SFB, the outputs of the filter array will be added and a new signal will be synthesized. The synthesized analysis configuration known as transmultiplexer and will be applied in the multicarrier communication systems. Figure 9 shows the frequency response for OFDM and FBMC. Based on this figure, it shows the major impact to the transmission data. The energy was concentrated within the frequency range of a single subcarrier for the FBMC systems, meanwhile in the OFDM system shows the rather strong sidelobes due to rectangular windowing.Hence, we conclude that FBMC is relatively more efficient when compared with OFDM and it has major advantages which overcome the drawback of OFDM system and it is quite useful for next generation technology such as 5G and many more, the reason behind its success is efficient use of data and complexity is less when compared with other multiplexing techniques.

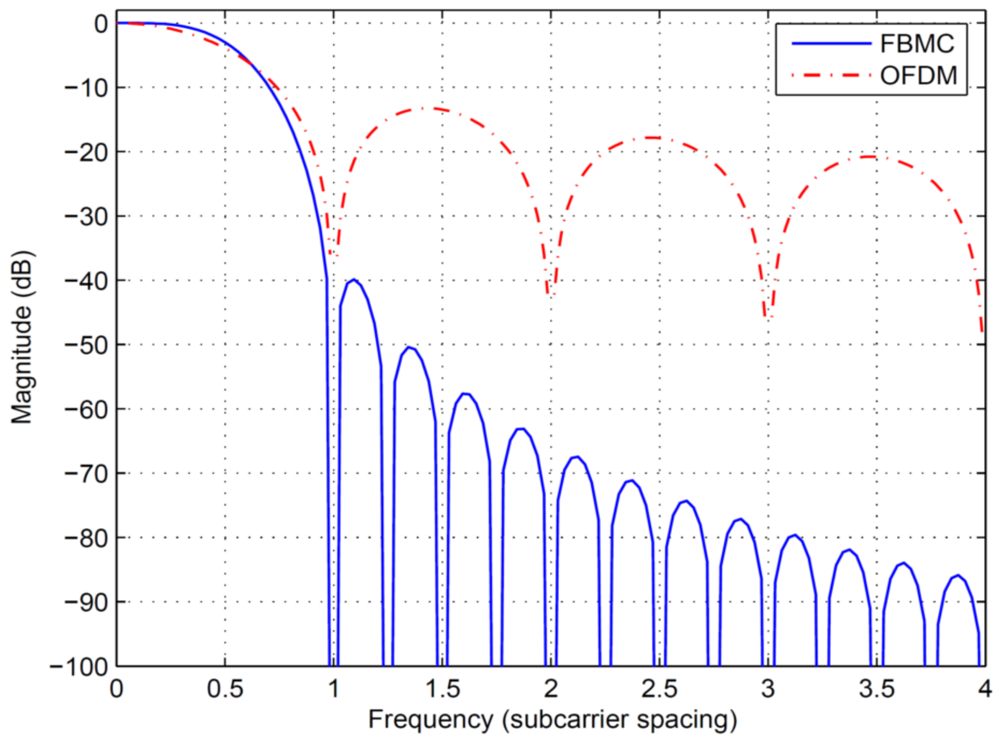

Fig. 3.7Frequency Response of FBMC and OFDM.

In the OFDM system, CP extension required, so it reduces the bandwidth efficiency, but in the FBMC system, CPare not required and hence conserves the bandwidth. Besides that, OFDM is very sensitive to the carrier frequencyoffset (CFO). Meanwhile for the FBMC system, it less sensitive, so it performs significantly with the increase ofthe consumer mobile network, it shows that the FBMC system improves in performance compared to OFDMas shown in Fig.3.3.

3.7 Advantages of FBMC system

- FBMC is able to provide a spectrum efficient and more selective system.
- The cyclic prefix, CP required for OFDM is not needed thereby freeing up more space for real data.
- The FBMC system offers more robustness to the time and frequency offset.

- Provide robust narrowband jammers.

3.7.1 Disadvantages of FBMC System

- The use of MIMP with FBMC is very complicated and as a result few systems have investigated the use of these two techniques together.
- The design of wide bandwidth and high dynamic range systems with FBMC provides some significant RF development challenges.
- FBMC is more complicated than OFDM it introduces an overhead in overlapping symbols in the filter bank in the time domain.

CHAPTER 4

COMPANDING TECHNIQUES

4.1 PEAK TO AVERAGE POWER RATIO (PAPR):

During transmission, the summation of modulated subcarrier values may lead to a huge value as compared to sample's average value, which causes a 'peak' in the output. When the sinusoids having zero phase difference between each other get added up lead to a significantly high peak power with regards to each signal's power. When there are large number of variations in the amplitudes of the multipath signals transmitted, there is a need for non-linear power amplifiers. Therefore, power loss is more. The power value of peak, called peak power for a sinusoidal signal has an amplitude value equivalent to the maximum value for the envelope.

It is defined as the ratio of the maximum power of the sample to the average power of the sample. In addition to this, high PAPR is resulted as an outcome when the different subcarriers are out of phase with each other.

$$(dB) = 10log10(maxiT \leq t \leq (i-1)\ T|S(t)|\ 2\ E[|S(t)|\ 2]). \qquad (4.1)$$

Where$i$ = 0, 1, $M + \beta - 1$, $E[|S(t)|\ 2]$ represents the expectation value.

4.2 PAPR REDUCTION TECHNIQUES

Nowadays, reducing PAPR has become pivotal for the multicarrier systems. Various PAPR reductiontechniques have been introduced so far for the MCM systems. The fundamental classification forminimization of PAPR can be done as follows:

• Distorted Signal Techniques

• Non-Distortion based Signal Techniques

The techniques causing power loss and distortion in the original signal after processing it with reduction technique, are termed as signal distortion techniques. These schemes are responsible for initiating the spectral regrowth phenomenon in multicarrier systems. This in turn, deteriorates the spectrum causing distorted signals.

While, if the PAPR is reduced using the reduction methods in order that the original signal remains unaffected and there occurs no loss of power, are called as non-distorted signal techniques. Some of them are discussed below:

• Clipping and Filtering

• Companding

• Selected Mapping (SLM)

• Tone Reservation (TR)

• Tone Injection (TI)

• Active Constellation Extension (ACE)

• Partial Transmit Sequence (PTS)

4.3 Introduction to Non-Linear Companding

Nonlinear Companding is a special type of clipping scheme used to provide great PAPR reduction with better BER performance and less implementation complexity required to build the system. The companding transforms enlarge the small signals while compressing the large signals to increase the immunity of small signals from noise and interference. The companding function is applied at the transmitter to compand the output signals using strict monotone function and at the receiver, the inverse companding function is used to recover the signal in the receiver. Different nonlinear companding techniques have been discussed below.

4.3.1 Applications of Companding

Companding is used in digital telephony systems, compressing before input to an analog-to-digital converter, and then expanding after a digital-to-analog converter. This is equivalent to using a non-linear ADC as in a T-carrier telephone system that implements A-law or μ-law companding. This method is also used in digital file formats for better signal-to-noise ratio (SNR) at lower bit depths. For example, a linearly encoded 16-bit PCM signal can be converted to an 8-bit WAV or AU file while maintaining a decent SNR by compressing before the transition to 8-bit and expanding after conversion back to 16-bit. This is effectively a form of lossy audio data compression.

Professional wireless microphones do this since the dynamic range of the microphone audio signal itself is larger than the dynamic range provided by radio transmission. Companding also reduces the noise and crosstalk levels at the receiver.

Companders are used in concert audio systems and in some noise reduction schemes.

4.3.2 Working

The electronic circuit that does this is called a compander and works by compressing or expanding the dynamic range of an analog electronic signal such as sound recorded by a microphone. One variety is a triplet of amplifiers: a logarithmic amplifier, followed by a variable-gain linear amplifier and an exponential amplifier. Such a triplet has the property that its output voltage is proportional to the input voltage raised to an adjustable power.

Companded quantization is the combination of three functional building blocks – namely, a (continuous-domain) signal dynamic range compressor, a limited-range uniform quantizer, and a (continuous-domain) signal dynamic range expander that inverts the compressor function. This type of quantization is frequently used in telephony systems.

In practice, companders are designed to operate according to relatively simple dynamic range compressor functions that are designed to be suitable for implementation using simple analog electronic circuits. The two most popular compander functions used for telecommunications are the A-law and μ-law functions.

4.3.3 Crest Factor

Crest factor is a parameter of a waveform, such as alternating current or sound, showing the ratio of peak values to the effective value. In other words, crest factor indicates how extreme the peaks are in a waveform. Crest factor 1 indicates no peaks, such as direct current or a square wave. Higher crest factors indicate peaks, for example sound waves tend to have high crest factors.

Crest factor is the peak amplitude of the waveform divided by the RMS value of the waveform.

The peak-to-average power ratio (PAPR) is the peak amplitude squared (giving the peak power) divided by the RMS value squared (giving the average power). It is the square of the crest factor.

When expressed in decibels, crest factor and PAPR are equivalent, due to the way decibels are calculated for power ratios vs amplitude ratios.

Crest factor and PAPR are therefore dimensionless quantities. While the crest factor is defined as a positive real number, in commercial products it is also commonly stated as the ratio of two whole numbers, e.g., 2:1. The PAPR is most used in signal processing applications. As it is a power ratio, it is normally expressed in decibels (dB). The crest factor of the test signal is a fairly important issue in loudspeaker testing standards; in this context it is usually expressed in dB.

The minimum possible crest factor is 1, 1:1 or 0 dB.

4.4A-LAW Companding

We know that in the companding technique, the compression of OFDM signals at the transmitter and expansion at the receiver. In this companding method, the compressor characteristic is piecewise, made up of a linear segment for low level inputs and a logarithmic segment for high level inputs. A-law compressor characteristics for different values of A. Corresponding to A=1, we observe that the characteristic is linear (no compression) which corresponds to a uniform quantization. A-law has mid riser at the origin. Hence it contains non-zero value. The practically used value of "A" is 87.6. The A-law companding is used for PCM telephone systems.

The linear segment of the characteristic is for low level inputs whereas the logarithmic segment is for high level inputs andit is mathematically expressed.

The reason for this encoding is that the wide dynamic range of speech does not lend itself well to efficient linear digital encoding. A-law encoding effectively reduces the dynamic range of the signal, thereby increasing the coding efficiency and resulting in a signal-to-distortion ratio that is superior to that obtained by linear encoding for a given number of bits.

The A -LAW companding function which is applied to the end of the transmitter is given by:

$$h(s_k) = u(A)\,\mathrm{sgn}(s_k)\{\,A|s_k|/1+\ln(A), \quad \text{if } |s_k|<|s_k|\max/A \qquad (4.2)$$

$$h(s_k) = u(A)\,\mathrm{sgn}(s_k)\{1+\ln(A|s_k|)/1+\ln(|A|), \text{if} |s_k|>=|s_k|\max/A$$

Where the A value tells us about the order of companding level at the transmitter side, where k(A) is normalization constant. To recover the original signal, the De companding function is used at the receiver side which is given by

$$h(r_k) = k (A)^\wedge (-1) sgn(r_k) \{ |r_k|(1+\ln(A))/A \quad \text{if, } |r_k| < |r_k|max/1+\ln(A) \quad (4.3)$$

$$h(r_k) = k (A)^\wedge (-1) sgn(r_k) \{exp (|r_k|(1+\ln(A)))/A \quad \text{if, } |r_k| > |r_k|max/1+\ln(A)$$

Where k(A) is normalization constant.

4.5 μ-Law Companding

In the μ-law companding, the compressor characteristic is piecewise, made up of a linear segment for low level inputs and a logarithmic segment for high level inputs. μ-Law compressor characteristics for different values of μ. Higher the value of μ, more is the compression. Corresponding to μ=0, we observe that the characteristic is linear (no compression) which corresponds to a uniform quantization. μ-Law has mid tread at the origin. Hence it contains zero value. The practically used value of "μ" is 255. The μ-law companding is used for speech & music signals. This μ-law companding technique is used in United States (U.S.), Canada, Japan, etc. The early BELL digital transmission system uses a 7-bit PCM Coder with μ=100. But the most recent digital transmission system uses an 8-bit PCM code with the value of μ=255. Where the μratio is used to control the order of companding level at the transmitter side, where u(μ) is normalization constant.

The μ- LAW companding function which is applied to the end of the transmitter is given by

$$h (s_k) = u(\mu) \text{ sgn } (s_k) \ln (1+ \mu| s_k|)/\ln(1+ \mu) \quad (4.4)$$

Where the μratio tells us about the order of companding level at the transmitter side, where u(μ) is normalization constant. To recover the original signal, the De companding function is used at the receiver side which is given by:

$$h(r_k) = u (\mu)^\wedge (-1) sgn(r_k)(1/ \mu) ((1+ \mu) ^\wedge|r_k | -1) \quad (4.5)$$

4.6PIECEWISE LINEAR COMPANDING

Wang first proposed the μ − law companding scheme based on speech processing. However,theμ−lawcompanding schemereducesPAPRattheexpenseofanincreaseintheaverage signal power. Later, another important nonlinear companding scheme namely exponential companding (EC) was developed in, which can obtain better PAPR reduction by transforming the distribution of OFDM signals while maintaining the average signal power constant. Recently, proposes a new nonlinear companding scheme by transforming the Gaussian distributed signal into a distribution form with a linear piecewise function. Though, the nonlinear companding schemes can reduce PAPR effectively, the computational complexity of nonlinear companding is fairly high. In, a low-complexity linear companding transform (LCT) was introduced to reduce peak power by linearly transforming the small and large signal amplitudes with different scales. However, the average signal power cannot be kept at the same level for the input and output of LCT. Besides, as LCT does not have one-to-one mapping, additional side information was needed in the decompanding operation. To maintain the average signal power constant and to obtain a one-to-one mapping, the two-piecewise companding (TPWC) scheme investigated intransforms small amplitudes with a scale and large amplitudes with both a scale and a shift. It is apparent that companding transform is an extra operation after the modulation of OFDM signals, thus companding schemes reduce PAPR at the expense of generating companding distortion. Hence, it is important for the design of companding transform aiming at minimizing the impact of companding distortion on the bit error rate (BER) performance**.**

When the original signal $x_n$is companded with a given peak amplitude A_c, the proposed companding scheme shown in Fig. 5 clips the signals with amplitudes over A_c for peak power reduction, and linearly transforms the signals with amplitudes close to A_c for power compensation. Then, the companding function of the proposed companding scheme is: (4.5)

$$h(x) = \begin{cases} x & |x| \le A_i \\ kx + (1-k)A_c & A_i < |x| \le A_c , \\ sgn(x)A_c & |x| > A_c \end{cases}$$

where $sgn(x)$ is the sign function.

Consequently, the decompanding function at the receiver is

$$h^{-1}(x) = \begin{cases} x & |x| \le A_i \\ (x - (1-k)A_c) \,/k & (1-k)A_c < |x| \le A_c , \\ sgn(x)A_c & |x| > A_c \end{cases} \quad (4.6)$$

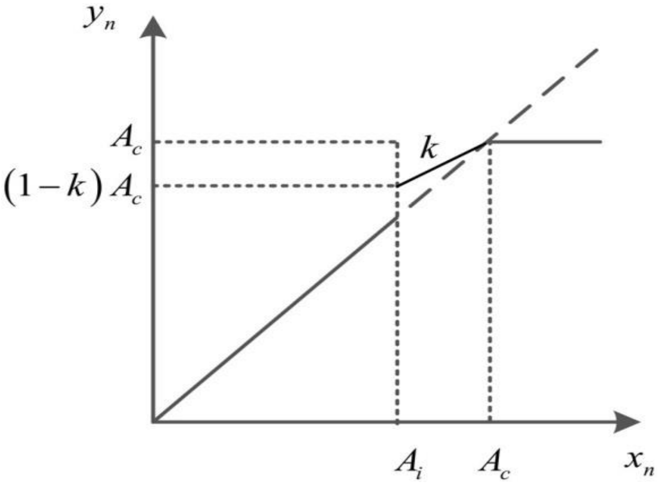

Fig. 4.1Proposed linear companding transform.

It is obvious that the proposed companding transform is specified by parameters A_c, A_i and k. A_c is the peak amplitude of the companded signals. As the average signal power is maintained constant, then according to the definition of PAPR, the PAPR value of the proposed scheme that can be achieved theoretically is determined by A_c. With a pre-set theoretical PAPR value, A_c can be determined as $A_c = \sigma_x 10^{PAPRpreset20}$. With determined A_c, parameters A_i and k can be obtained by solving:

$$= A^{A_i c}(kx + (1-k)A_c)^2 f|x_n|(x)dx + \int_{A_c}^{\infty} A_c^2 f(x)dx$$

$$= \int_{A_i}^{\infty} x^2 f|x_n|(x)dx. \quad (4.5)$$

4.7 Consequences of Companding

In companding, the rate of compression depends on the values of compression parameters μ and A of the equations presented in the section "Logarithmic Companding Curves". Greater the value of compression parameters, higher is the rate of compression.

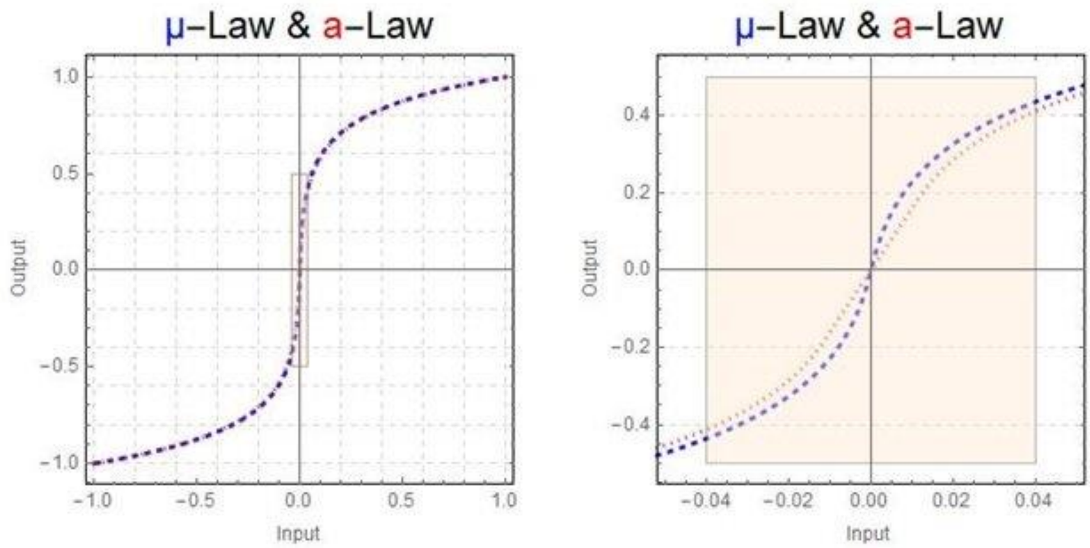

Fig.4.2 Compression curves for different values of compression parameters in (a) μ-law (b) A-law.

Higher compression rates imply greater non-linearity in quantization, which means there is a better representation of lower amplitude signals (using a greater number of bits) compared to higher amplitude ones. This indicates that, in a companded signal, the quantization error will be at its minimum at low levels and will gradually increase with an increase in the level of the input signal (PDF). In addition, the smaller the quantization interval, the better the signal-to-quantization noise ratio (SQNR). Thismeans companding increases the SQNR at low-level signals while degrading it for higher amplitude ones (PDF).

The scenario well suits the demand for telephone systems which primarily transmit human speech wherein low amplitude quieter phonemes occur more frequently when compared to high amplitude louder phonemes (PDF). A direct consequence of this is an improvement in the quality of the audible signal, as we would have accounted for the sensitivity issues posed by the human ear.

CHAPTER 5

MATLAB

5.1 Introduction to MATLAB

MATLAB is a high-performance accent for abstruse computing. It integrates computation, visualization, and programming in an easy-to-use ambiance area problems and solutions are bidding in accustomed algebraic notation. Typical uses include

- Math and ciphering
- Algorithm development
- Data accretion
- Modeling simulation, and prototyping
- Data analysis, exploration, and accommodation
- Scientific and engineering cartoon
- Application development, including graphical user interface building

MATLAB is an alternate arrangement whose basal abstracts aspect is an arrangement that does not crave dimensioning. This allows you to break abounding abstruse accretion problems abnormally those with cast and agent formulations, in atom of the time it would yield to address affairs in a scale non alternate docent such as C.The name MATLAB stands for cast laboratory MATLAB has acquired over an icon of years with a scribe from abounding users. In university environments, it is the accepted advisory apparatus for anterior and Avant Garde courses in mathematics, engineering, and science. In industry, MATLAB is the apparatus of best for high-productivity research, development, and analysis.

MATLAB actualizes the ancestors of add-on application-specific solutions alleged toolboxes. Very important to a lot of users of MATLAB, toolboxes acquiesce you to apprentice and administer specialized technology Toolboxes are absolute collections of MATLAB functions (M-files) that extend the MATLAB ambiance to break accurate classes of problems. Areas in which toolboxes are accessible cover arresting processing, ascendancy systems, neural networks, down-covered logic, wavelets, simulation, and abounding others.

5.2 The MATLAB System

The MATLAB arrangement consists of 6 capital parts:

5.2.1 Development Environment

This is the set of accoutrement and accessories that advise you to use MATLAB functions and files. Abounding of these accoutrements are graphical user interfaces. It includes the MATLAB desktop and Command Window, a command history, an editor and debugger, and browsers for examination help, the workspace, files, and the seek path.

5.2.2 The MATLAB Algebraic Function

This is an all-inclusive accumulating of computational algorithms alignment from elementary functions like sum, sine, cosine, and circuitous arithmetic, to added adult functions like cast inverse, cast eigenvalues, Bessel functions, and fast Fourier transforms.

5.2.3 The MATLAB Language

This is a high-level matrix/array accent with ascendant breeze statements, functions, abstracts structures, input/output, and acquisitive programming features. It allows both programming in the small to rapidly actualize quick and bedraggled departure programs and programming in the large to actualize complete ample and circuitous appliance programs.

5.2.4 Graphics

MATLAB has all-encompassing accessories for announcement vectors and matrices as graphs, as able-bodied as annotating and pressing these graphs. It includes high-level functions for two-dimensional and three-dimensional abstracts visualization, angel processing, animation and presentation graphics it as well includes low-level functions that acquiesce you to absolutely adapt the actualization of cartoon as able-bodied at to body complete graphical user interfaces on your MATLAB applications.

5.2.5 The MATLAB Appliance Affairs Interface (API)

This is a library that allows you to address C and Fortran programs that collaborate with MATLAB. It includes accessories for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational engine, and for account and autograph MAT-files.

5.2.6 MATLAB Desktop

MATLAB Desktop is the capital MATLAB appliance window. The desktop contains 6 sub windows, the command window, the workspace browser, the accepted agenda window, the command history window, and one or added amour windows, which are apparent alone if the user displays a graphic.

The command window is the area the user types MATLAB commands and expressions at the alert) and area the achievement of those commands is displayed MATLAB defines the workspace as the set of variables that the user creates in a plan session the workspace browser shows these variables and some advice about them. Double beat on a capricious in the workspacebrowser launches the Management Editor, which can be acclimated to access advice and assets instances adapt assertive backdrop of the variable.

The accepted Agenda tab aloft the workspace tab shows the capacity of the accepted directory, whose aisle is apparent in the accepted agenda window. For example, in the windows operating arrangement the aisle ability be as follows: CAMATLAB Work, advertence that agenda work" a subdirectory of the capital agenda "MATLAB"; which is installed in drive C, beat on the arrow in the accepted agenda window shown anaccount of afresh acclimated paths Beat on the button to the appropriate of the window allows the user to change the accepted directory.

MATLAB is a deck aisle to accretion M-files and added MATLAB accompanying files, which are adapted in directories in the computer book system, any book run in MATLAB has to abide in the accepted agenda or in an agenda that is on seek path. By default, the files supplied with MATLAB and algebraic works toolboxes are included in the seek path. The easiest way to see which directories are on the seek path.

The easiest way to see which directories are anon the seek path, or to add or adapt a seck path, in to baddest set aisle from the Book card the desktop, and again use the set aisle chat box It is acceptable conveyance to add any frequently acclimated directories to the seek aisle to abstain again accepting the change the accepted directory

The Command History Window contains an almanac of the commands a user has entered in the command window. Including both accepted and antecedent MATLAB sessions, previously entered MATLAB commands can be allowed and re executed from the command history window by appropriate heat on a command or arrangement of commands.

This activity launches a card from which to baddest assorted options in accession to active the commands. This is advantageous to baddest assorted options in accession to active the commands. This is an advantageous affection if experimenting with assorted commands in a plan session.

5.2.7 Using the MATLAB Editor to actualize M-Files

The MATLAB editor is both an argument editor specialized for creating M-files and a graphical MATLAB debugger. The editor can arise in a window by itself, or it can be a sub window in the desktop M-files are denoted by the addendum m, as in pixel up m. The MATLAB editor window bus abundant pull-down airheaded for tasks such as saving, viewing and debugging files Because it performs some simple checks and as well uses blush to differentiate amid assorted elements of code, this argument editor is recommended as the apparatus of best for autograph and alteration M-functions. To access the editor. Blazon adapter at the alert opens the M-file filename m in an editor window, accessible for editing as acclaimed earlier, the book has to be in the accepted directory, or in an agenda in the seck path.

5.2.8 Getting Help

The arch way to get advice online is to use the MATLAB advice browser opened as an abstract window either by beating on the catechism mark attribute() on the desktop toolbar, or by accounting advice browser at the alien in the command window. The advice Browser is a web browser chip into the MATLAB desktop that displays a Hypertext Markup Language (HTML) document. The Advice Browser consists of two panes, the advice navigator pane, acclimated to accretion information, and the affectation pane, acclimated to appearance the information Self- explanatory tabs added than navigator area is acclimated to accomplish a search.

5.3 Communication

The Communications Arrangement Toolbox provides algorithms and accoutrement for the design, simulation, and assay of communications systems. These capabilities are provided by the MATLAB function, MATLAB Arrangement objects and Simulink block. The arrangement toolbox includes algorithms to antecedent coding, access coding, interleaving modulation equalization, synchronization, and access modelling, Accoutrement are provided for bit absurdity amount analysis, breeding eye and afterlife diagrams, and visualizing access characteristics. The arrangement toolbox as well provides adaptive algorithms that let you archetypal activating communications systems that use OFDM. OFDMA, and MIMO techniques. Algorithm's abutment fixed-point abstracts accession and C or HDL cipher generation.

5.4 Key Features

Algorithms for designing the concrete band of communications systems, including antecedent coding access coding, interleaving modulation, access models. MIMO equalization and synchronization.

- GPU-enabled Arrangement tar for computationally accelerated algorithms such as Turbo, LDPC, and Viterbi decoders Alternate accommodation tools, including eye diagrams, constellations and access drop functions
- Graphical apparatus for comparing the apish bit absurdity amount of an arrangement with analytical results.
- Access models, including AWGN. Multipath Rayleigh Fading. Rician Fading.MIMO Multipath Fading, and LTE MIMO Multipath Fading
- Basal RF impairments, including nonlinearity, actualization noise, thermal noiseand actualization and abundance offsets
- Algorithms accessible as MATLAB function MATLAB Arrangement objects, and Simulink blocks
- Abutment for fixed-point clay and C and HDL cipher generation

5.5 System Design

The architecture and simulation of a communications arrangement requires allegory its acknowledgment to the babble and arrest inherent in real world environments, belief its behaviour appliance graphical and quantitative means, and free whether the consistent achievement meets standards of acceptability. Communications Arrangement Toolbox accoutrements an array of tasks for communications arrangement architecture and simulation. Abounding of the functions, Arrangement objects and blocks in the arrangement toolbox accomplish computations associated with an accurate basic of a communications system, such as a demodulator or equalizer. Added capabilities are advised for accommodation or analysis.

5.6 System Characterization

The arrangement toolbox offers several accepted methods for quantitatively anecdotic arrangement performance:

- Bit absurdity amount (BER) computations
- Adjoining access ability arrangement (ACPR) measurements
- Absurdity agent consequence (EVM) measurements
- Accentuation absurdity arrangement (MER) measurements

Because BER computations are axiological to the assumption of any communications system. The arrangement toolbox provides the afterward accoutrement and capabilities for configuring BER analysis scenarios.

5.7 BER

BER apparatus - A graphical user interface that enables you to BER achievement of communications systems. You can assay achievement visa simulation-based, semi analytic, or abstract approach. Error Amount Analysis Console - A MATLAB article that runs simulations for communications systems to measure absurdity amount performance It supports specified analysis credibility and bearing of parametric achievement plots and surfaces Accelerated achievement can be accomplished if active on a multicore accretion platform.

Multicore and GPU dispatch - An adequacy provided by Parallel Accretion Toolbox that enables you to advance simulation achievement appliance multicore and GPU accoutrements aural your computer. Distributed accretion and billow accretion abutment Capabilities provided by Parallel Accretion Toolbox and MATLAB

Distributed Accretion Server that accredit you to advantage the accretion ability of your server farms and the Amazon EC2 Web service.

5.8 Performance Visualization

The arrangement toolbox provides the afterward capabilities for visualizing arrangement performance: Access accommodation apparatus -For visualizing the characteristics of a crumbling access Eye diagrams and arresting after life besprinkle plots- For a qualitative, beheld compassionate of arrangement behaviour that enables you to accomplish antecedent architecture decisions Signal aisle plots - For a connected account of the signal's aisle amid accommodation points.

BER plots - For visualizing quantitative BER achievement of an architecture candidate, parameterized by metrics such as SNR and fixed-point char size.

5.9 Analog and Digital Modulation

Analog and digital modulation techniques encode the information stream into a signal that is suitable for transmission Communications System Toolbox provides a number of modulation and corresponding demodulation capabilities. These capabilities are available as MATLAB functions and objects MATLAB System objects and Simulink blocks Modulation types provided by the toolbox are

Analog: AM, FM, PM, SSB, and DSBSC.

Digital: FSK, PSK, BPSK, DPSK, OQPSK, MSK, PAM, QAM and TCM.

5.10 Source and Channel Coding

The Communications System Toolbox provides source and channel coding capabilities that let you develop and evaluate communications architectures quickly enabling you to explore what if scenarios and avoid the need to create coding capabilities from scratch.

5.10.1 Source Coding

Source coding, also known as quantization or signal formatting is a way of processing data in order system toolbar provides a variety of types of algorithms for implementing source coding and decoding, including

- Quantizing
- Companding(μ- law and A-law)
- Differential pulse code modulation (DPCM)
- Huffman coding
- Arithmetic coding

5.10.2 Channel Coding

To combat the effects of noise and channel corruption, the system toolbox provides block and convolutional coding and decoding techniques to implement error detection and correction. For simple error detection with no inherent correction, a cycleredundancy check capability is also available Channel coding capabilities provided by the system toolbox include:

- BCH encoder and decoder
- Reed-Solomon encoder and decoder
- LDPC encoder and decoder
- Convolutional encoder and Viterbi decoder
- Orthogonal space-time block code (OSTBC) (encoder and decoder for MIMO channels)
- Turbo encoder and decoder examples.

CHAPTER 6

SIMULATION RESULTS

6.1 Power Spectral Density (PSD)

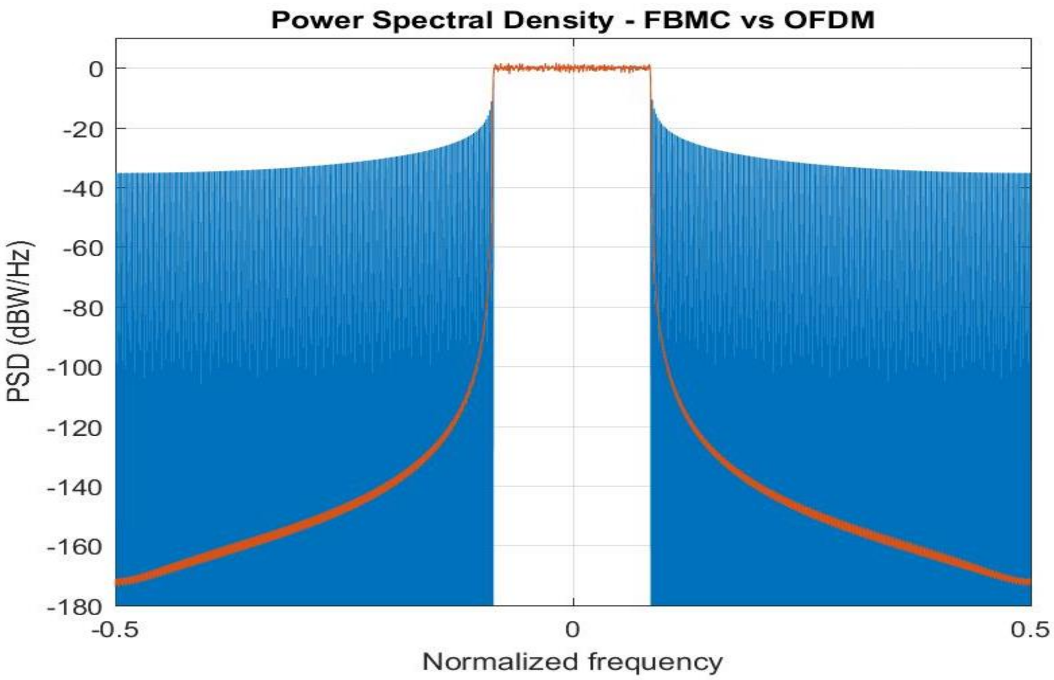

Fig.6.1 Power Spectral Density.

Power Spectral Density helps to display the strength of the energy variation as a function. It shows, at which point the variation of frequency is weaker. The PSD computation is done through the FFT method. Integration of PSD provides the energy of the specific frequency range.

PSD= Energy (w)/Frequency (Hz)

From the above figure, it is found that CP-OFDM spectrum in the out of band is -35 dB/ MHz whereas for FBMC it is of -170 dB/ MHz's therefore, spectrum leakage will be less felt when we use FBMC.

6.2 Peak Power to Average Power in FBMC System

The highest peak to average power ratio is the main disadvantage of the multicarrier modulation techniques the input data stream is subdivided into many sub streams. This sub streams are called sub carriers. The subcarriers are modulated (Independently) at different carrier frequencies and it produces a high PAPR for transmission purpose added up simultaneously. The peak power of a signal is produced when N number of signals are added in the same phase. The peak power of a signal is produced when N times the average power of the signal. So, the PAPR value is very high in the multicarrier signals.

The Peak to Average Power Ratio is expressed a (6.1)

$$PAPR_{dB} = 10\log\left(\frac{max[x(t)x^*(t)]}{E[x(t)x^*(t)]}\right)$$

Here, |X(t)| is the amplitude of the X(t) and E is the expectation of the signal.

Schemes	PAPR (dB)
FBMC without using Companding	14.1016
FBMC using μ-law Companding	4.868
FBMC using A-law Companding	10.2285
FBMC using piece-wiseLinear Companding	3.9701

Table- 1 PAPR in FBMC with Different Companding

Table 1 depicts the PAPR at CCDF= 10^-3 for the different companding techniques. From Table 1, we can observe that for μ-law companding, results in greater reduction of PAPR by about 9.2336dB when compared with the original FBMC system at 10^-3 complementary cumulative distribution function (CCDF) and for A-law companding, the PAPR is reduced by about 3.8731 dB at 10^-3 of the complementary cumulative distribution function (CCDF).

6.2.1 CCDF vsPAPR (dB) plots in FBMC System with different companding techniques

Complementary Cumulative Distribution Function is useful to study the opposite question and ask how often the random variable is above a particular level. This is called the complementary cumulative distribution function (CCDF) or simply the tail distribution or exceedance.

This has applications in statistical hypothesis testing, for example, because the one-sided p-value is the probability of observing a test statistic at least as extreme as the one observed. Thus, provided that the test statistic, T, has a continuous distribution, the one-sided p-value is simply given by the CCDF, one of the most popular applications of cumulative distribution function is standard normal table, also called the unit normal table or Z table, is the value of cumulative distribution function of the normal distribution. It is very useful to use Z-table not only for probabilities below a value which is the original application of cumulative distribution function, but also above and/or between values on standard normal distribution, and it was further extended to any normal distribution.

The complementary accumulative distribution function (CCDF) is used to tell the percentage of time that the power is greater than or equal to a certain value. The complementary cumulative distribution function (CCDF) is also used to obtain the PAPR value.

$CCDF = Prob\ (PAPR > X_0)$

Where X_0 is the threshold

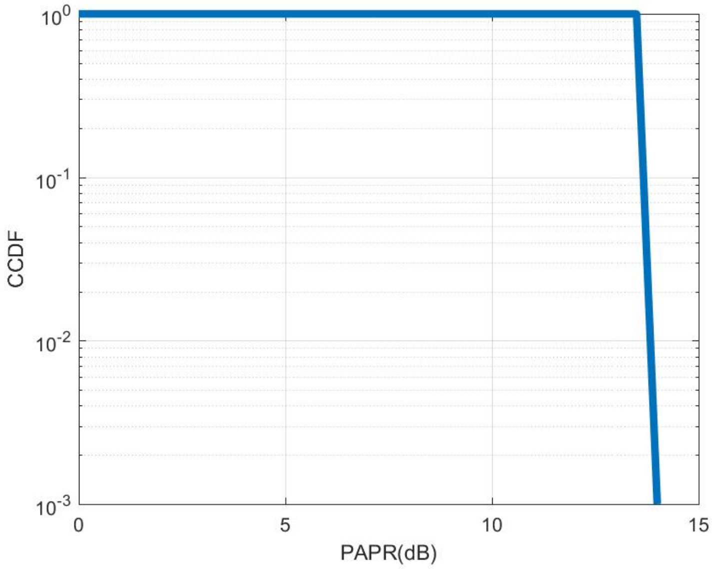

Fig. 6.2 Conventional FBMC.

Above figure shows us the PAPR in FBMC system without using companding at Complementary Cumulative Distribution Function= 10^-3.

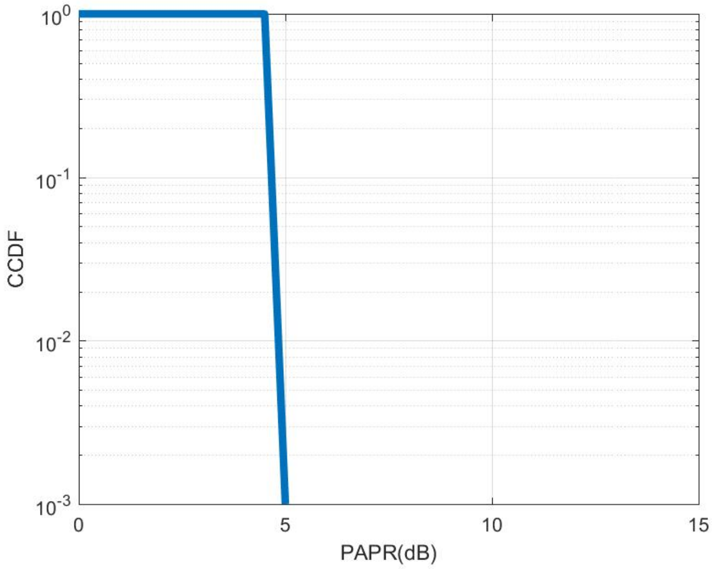

Fig. 6.3 FBMC with μlaw Companding.

Above figure shows us the PAPR in FBMC system using μ −law companding at Complementary Cumulative Distribution Function= 10^-3. The figure clearly shows us that their drastic reduction in the PAPR value when compared with the Figure.

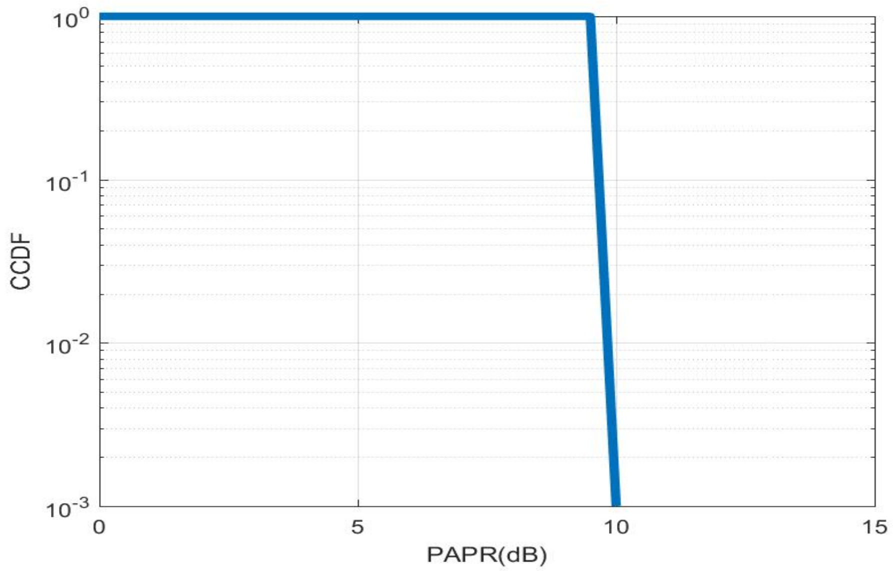

Fig. 6.4 FBMC with A law Companding.

Above figure shows us the PAPR in FBMC system using A-law companding at Complementary Cumulative Distribution Function= 10^-3.

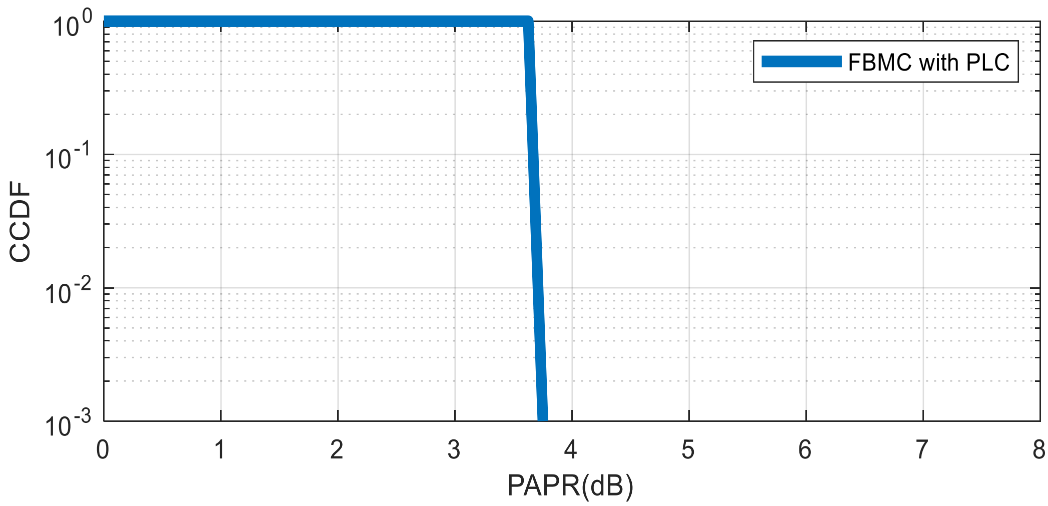

Fig. 6.5 FBMC with piecewise linear Companding.

Above figure shows us the PAPR in FBMC system using Piecewise Linear companding at Complementary Cumulative Distribution Function= 10^-3.

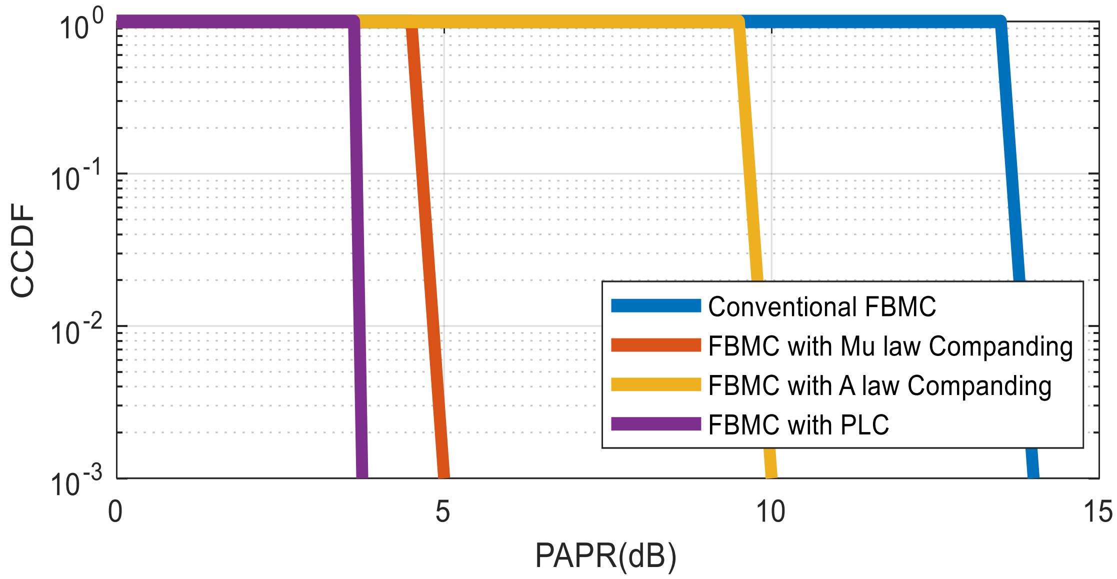

Fig 6.6 FBMC with different Companding.

Above figure shows us the combined plot of the above graphs which clearly state that with the help of nonlinear companding techniques we can effectively reduce the PAPR in FBMC system.

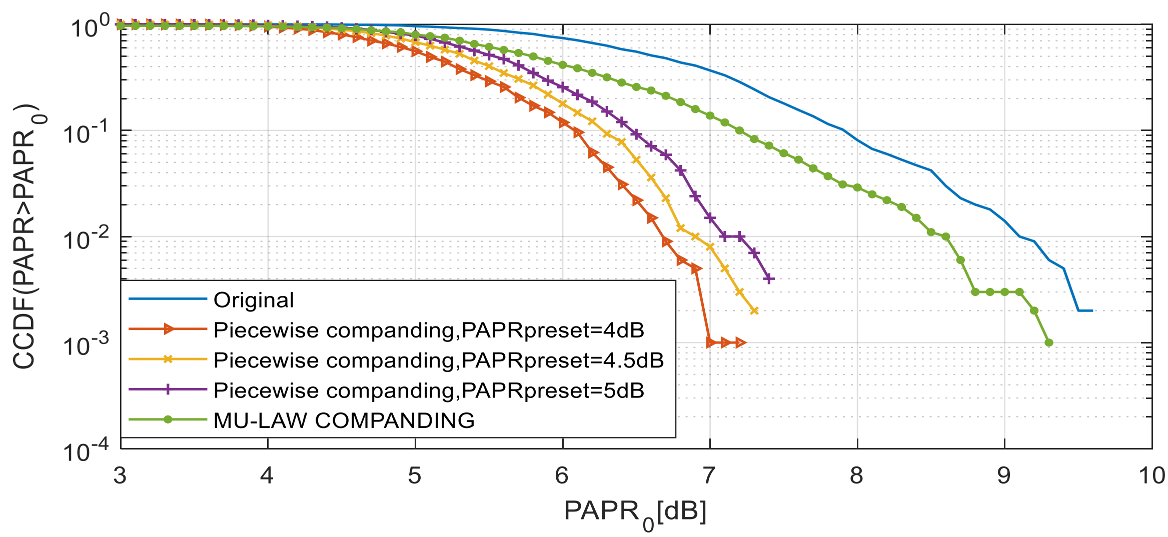

Fig 6.7OFDM with different companding techniques.

Above figure shows us the PAPR in OFDM system using different types companding at Complementary Cumulative Distribution Function= 10^-3.

In summary, simulation results above demonstrate that the proposed $\mu -$law companding scheme can offer better performances with respect to PAPR reduction, BER performance, and out of band radiation.

CHAPTER 7

CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

FBMC/OQAM is one of the best waveforms used for the next wireless communication systems 5G, due to providing good spectral efficiency and low out-of-band emission. The filtering process is used to reduce the Out of Band sidelobe leakage; it provides a better spectrum operation when compared to OFDM and also provides a better ICI robustness. In this work, we comparatively analyse the system performance at different nonlinear companding techniques to reduce a PAPR of FBMC/OQAM system. The tried techniques are a μ −law, A-law companding and piecewise linear companding schemes. The computer simulation results verified that the piecewise linear companding scheme offers more efficient PAPR reduction, PSD performances than the others referred schemes.

The high PAPR value which is a major drawback can be eliminated effectively using nonlinear companding paving the path for the use of FBMC in 5G communication.

PAPR in FBMC when using A-law companding is reduced by 3.8731 when compared to FBMC without companding.

PAPR in FBMC when using μ-law companding is reduced by 9.2336 when compared to FBMC without companding.

PAPR in FBMC when using piecewise linear law companding is reduced by 10.2016 when compared to FBMC without companding.

7.2 Future Scope

The biggest thing that will happen in the mobile communication industry is the advent of 5G mobile communication technology which is on track for launch in 2020 in conjunction with the Olympic Games in Tokyo. 5G mobile communications is the next step in the transformation communication technology. The competence of 5G mobile communication must broaden far beyond those of previous generations to facilitate connectivity for a wide range of applications. These capabilities consist of very low latency, ultra-high reliability and very high achievable data rates. Besides that, the consumers will be able to download a 1080p HD movie to their mobile phone in about one second and also 50GB video games within a minute with this 5G mobile communication technology.

FBMC is a new waveform technique having few advantages over OFDM for future 5G mobile communication technology and the fundamental change of this technology is the replacement of the OFDM with a multicarrier system based on filter bank at the receiver and transmitter. Besides that, the CP extension required and therefore reduces bandwidth efficiency in OFDM. OFDM is very sensitive to the carrier frequency offset meanwhile in FBMC is less sensitive so it performs better with the increase of the mobile consumers.

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