Simulation of OFDM and Performance Analysis of PAPR Reduction Technique

Major Project Report

Submitted in partial fulfillment of the requirements

for the degree of

Master of Technology

in

Electronics and Communication Engineering

(Communication Engineering)

By

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Declaration

This is to certify that

i) The thesis comprises my original work towards the degree of Master of Technology in Communication Engineering at Nirma University and has not been submitted elsewhere for a degree.

ii) Due acknowledgement has been made in the text to all other material used.

Zala Dharmendrasinh D.

Certificate

This is to certify that the Major Project entitled **"Simulation of OFDM and Performance Analysis of PAPR Reduction Technique"** submitted by **Zala Dharmendrasinh Dasharathsinh (08MECC18)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in Electronics & Communication (Communication) of Nirma University, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of our knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

Date: Place: Ahmedabad

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- Zala Dharmendrasinh D.
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Abstract

OFDM (Orthogonal Frequency Division Multiplexing) technology has become a priority in the mobile communication due to its feature of partitioning the available bandwidth into sub-channels with much lower bandwidth. The report contains an introduction to multi-carrier modulation which emphasizes on OFDM followed by its mathematical and qualitative description. The MATLAB software is used for the simulations of the OFDM where the various parameters are analyzed. Moreover the results for M-PSK, M-QAM and the e ect of symbol period are calculated.

The second phase describes the PAPR (Peak to Average Power Ratio) -reduction techniques, which demonstrates Selected Mapping (SLM) and Partial Transmit Sequences (PTS) techniques. In an SLM system, an OFDM symbol is mapped to a set of quasi-independent equivalent symbols and then the lowest-PAR symbol is selected for transmission. In the PTS the PAPR reduction process is made more e cient by varying the number of phase sequences and the length of block size. Here for both techniques number of sub blocks and phase sequences are changed and results are obtained using MATLAB Software.

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Chapter 1

Introduction

1.1 Introduction

With the rapid growth of digital communication in recent years, the need for high-speed data transmission has increased. Often, these services require very reliable data transmission over very harsh environments and must meet much constraints such as finite transmit power and efficient Bandwidth. A common problem found in high speed communication is inter-symbol interference (ISI). In a wireless communication system the signal reflects from large objects such as mountains or buildings, the receiver sees more than one copy of the signal. In communication terminology, this is called multipath. There are many methods proposed to combat the ISI. Multicarrier modulation techniques including orthogonal frequency division multiplexing (OFDM) are among.

The main idea behind OFDM is that since low-rate modulations (i.e. modulations with relatively long symbols compared to the channel time characteristics) are less sensitive to multipath, it should be better to send a number of low rate streams in parallel than sending one high rate waveform. Orthogonal frequency division multiplexing is a telecommunications technology that is the foundation of most next-generation, or

4G wireless Internet services. Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier transmission technique whose history dates back to the mid-1960s. Although the concept of OFDM has been around for a long time, it has only recently been recognized and adopted as an effective technique for high-speed bidirectional wireless data transfer 802.11a, DAB (Digital Audio Broadcasting), DVB-T (Digital Video Broadcasting) are some of the new emerging standards that use OFDM. This is because of the following reasons. Firstly, OFDM is very immune to channel imperfections. Secondly, OFDM uses bandwidth very efficiently, i.e. it uses lesser bandwidth than traditional modulation schemes to transmit at a particular rate. And lastly, OFDM can be implemented using DSP techniques on fast and low cost embedded devices which have become easily available over the last few decades.

One of the major drawbacks of multicarrier transmission is the high peak-to-average power ratio (PAPR) of the transmit signal. If the peak transmit power is limited by either regulatory or application constraints, the effect is to reduce the average power allowed under multicarrier transmission relative to that under constant power modulation techniques. This in turn reduces the range of multicarrier transmission. Moreover, to prevent spectral growth of the multicarrier signal in the form of intermodulation among subcarriers and out-of-band radiation, the transmit power amplifier must be operated in its linear region (i.e., with a large input back off), where the power conversion is inefficient. This may have a deleterious effect on battery lifetime in mobile applications. In many low-cost applications, the drawback of high PAPR may outweigh all the potential benefits of multicarrier transmission systems.
In fact, the PAPR problem also arises in many cases other than multicarrier transmission. Typically, the PAPR is not an issue with constant amplitude signals. With no constant amplitude signals, however, it is important to deal with the PAPR of those signals. For example, a DS-CDMA signal suffers from the PAPR problem especially in the downlink because it is the sum of the signals for many users. In this article, however, we limit our attention to the PAPR problem in multicarrier transmission

only.

1.1.1 Objective of the Project

This project will focus on Orthogonal Frequency Division Multiplexing (OFDM) simulation and PAPR reduction technique. In this project, OFDM system will be simulated using MATLAB toolbox Simulink. Simulink model is prepared using this toolbox and parameter flow diagram analyzed. Also describes the SLM and PTS method to remove PAPR problem of OFDM. Code for the both technique is implemented and examine with different parameter.

1.1.2 Out line of the Project

1) Second chapter describes general concepts and evolution of ofdm system. It gives mathematical description of each blocks and representation with block diagrams. It also describes advantages and disadvantages of the system and describes PAPR problem. Also shows CCDF of PAPR.

2) Third chapter describes proposed algorithm here in this paper. It shows simulink model of OFDM and description of each block used in this model with diagram and variable representation. It also SLM and PTS techniques, used to remove PAPR problem of OFDM.

3) Chapter fourth shows result of generated simulink model and result of PAPR reduction techniques. For simulink model it shows flow diagram of transmitter and receiver also with scattering and cancelation diagrams. This chapter includes result of SLM and PTS techniques with changing parameter like number of phase sequence and number of sub blocks.

4) Chapter five includes summary work and conclusion. It includes possible future work in simulink model with different changing parameters and also can improve PAPR result using coding techniques.

1.1.3 Gantt Chart for Project

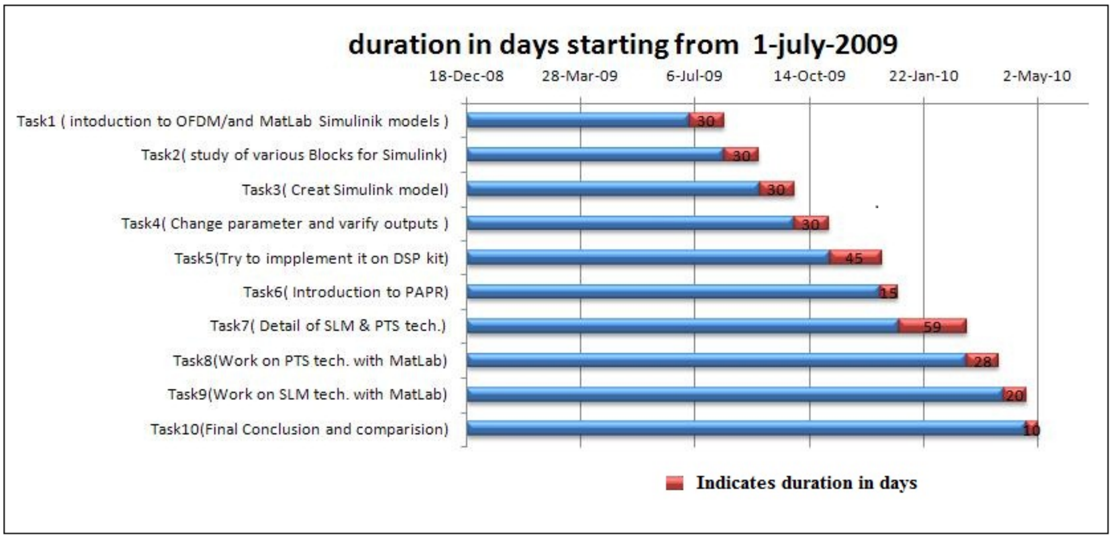


Figure 1.1: Gantt Chart

Chapter 2

OFDM System

In an ideal radio channel, the received signal would consist of only a single direct path signal, which would be a perfect reconstruction of the transmitted signal. However in a real channel, the signal is modified during transmission in the channel. In wireless communication, multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. Causes of multipath include atmospheric ducting, refraction, reflection from terrestrial objects, such as mountains and buildings as shown in figure 2.1. In multipath propagation transmitted signal that have experienced difference in attenuation, delay and phase noise while traveling from the source to the receiver. The main problem with reception of radio signals is fading. Also, there are intersymbol interference (ISI), shadowing, and interference [1].

2.1 Evolution of OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is an alternative wireless modulation technology to CDMA. OFDM has the potential to surpass the capacity of CDMA systems and provide the wireless access method for 4G systems. OFDM is a

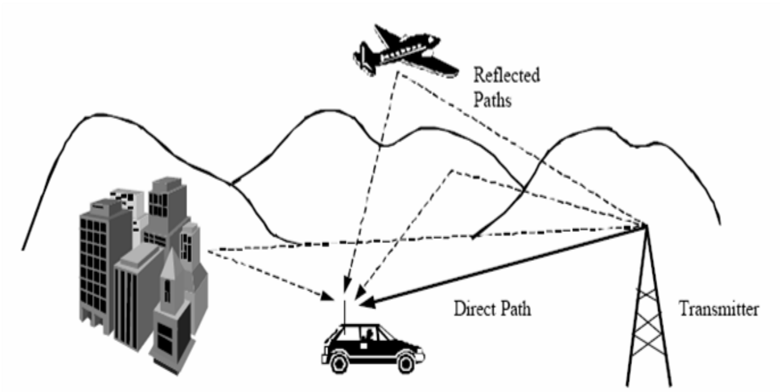


Figure 2.1: Multipath Effects[4]

modulation scheme that allows digital data to be efficiently and reliably transmitted over a radio channel, even in multipath environments. The name OFDM is derived from the fact that the digital data is sent using many carriers, each of a different frequency (Frequency Division Multiplexing) and these carriers are orthogonal to each other, hence Orthogonal Frequency Division Multiplexing [4].
The origins of OFDM development started in the late 1950's with the introduction of Frequency Division Multiplexing (FDM) for data communications. In 1966 Chang patented the structure of OFDM and published the concept of using orthogonal overlapping multi-tone signals for data communications. In 1971 Weinstein introduced the idea of using a Discrete Fourier Transform (DFT) for implementation of the generation and reception of OFDM signals, eliminating the requirement for banks of analog subcarriers oscillators. This presented an opportunity for an easy implementation of OFDM, especially with the use of Fast Fourier Transforms (FFT), which are an efficient implementation of the DFT [3]. This suggested that the easiest implementation of OFDM is with the use of Digital Signal Processing (DSP), which can implement FFT algorithms. It is only recently that the advances in integrated circuit technology have made the implementation of OFDM cost effective. It wasn't until the late 1980's that work began on the development of OFDM for commercial use, with the introduction of the Digital Audio Broadcasting (DAB) system. In 1995 U.K and Sweden replace FM audio broadcasting to DAB, which provides high quality digital

audio and information.

2.2 General Concepts of OFDM

Signals are orthogonal if they are mutually independent of each other. Orthogonality is a property that allows multiple information signals to be transmitted perfectly over a common channel and detected, without interference. Loss of orthogonality results in blurring between these information signals and degradation in communications. Many common multiplexing schemes are inherently orthogonal. Time Division Multiplexing (TDM) allows transmission of multiple information signals over a single channel by assigning unique time slots to each separate information signal. The main concept of OFDM is orthogonality of the subcarriers. Mathematically a set of function will be orthogonal if

$$\begin{aligned} \int_a^b \psi_p \psi_q * (t) dt &= k \;\; if \;\; p = q \\ &= 0 \;\; if \;\; p \neq q \end{aligned} \tag{2.1}$$

Where * denotes the complex conjugate. There are many sets of orthogonal functions, the most famous of which are the complex exponential which form the basis of the Fourier transform.

$$\varphi_k(t) = e^{jw_k t} \tag{2.2}$$

with

$$w_k(t) = w_0 + (2\pi K / T_s)$$

The orthogonality of these function make them good candidates for OFDM transmission and suggest the DFT as a method for generating the transmition waveform. The aim of the OFDM is to divide the wide frequency selective channel into multiple flat fading channels. The carrier can be thought of as sinusoids or exponentials of the form Spaced W/ N Hz apart, where W is the available bandwidth. Each carrier is scaled by a complex constellation value Xnm from the input data; the subscript n =0,1,2,..., N-1 corresponds to the Index number of the carrier, and m is the index of the entire OFDM symbol, or frame. The constellation points most commonly come from M-ary Phase Shift Keying (M-PSK) Or M-ary Quadrature Amplitude Modulation (M-QAM), but almost any mapping works. The scaled carriers are then summed to yield the time waveform to be transmitted over the channel as mentioned in equation

$$s_m\left(t\right) = \sum_{n=0}^{N-1} x_{nm} \emptyset_n (t - mT) \tag{2.3}$$

An infinite sequence of OFDM symbols or frames is a just a position of all the individual OFDM symbols and we drop the index m to give

$$\begin{aligned} s\left(t\right) &= \sum_{m=-\infty}^{\infty} s_m(t) && (2.4) \\ &= \sum_{m=-\infty}^{m=+\infty} \sum_{n=0}^{N-1} x_{nm\emptyset_n}(t - mT) && (2.5) \end{aligned}$$

Since it is a rectangular pulse modulated on the carrier frequencies kW/N for k = 0, 1, 2,, N-1 [6].

2.2.1 OFDM Spectrum

Another way to way to view the orthogonality property of OFDM signals is to look at its Spectrum. In the frequency domain each OFDM subcarriers has a sinc, sin(x)/x, frequency response, as shown in Figure 2.2 sinc shape has a narrow main lobe, with many side-lobes that decay slowly with the magnitude of the frequency difference away from the centre. Each carrier has a peak at the centre frequency and nulls evenly spaced with a frequency gap equal to the carrier spacing. The orthogonal nature of the transmission is a result of the peak of each subcarriers corresponding to the nulls of all other subcarriers.

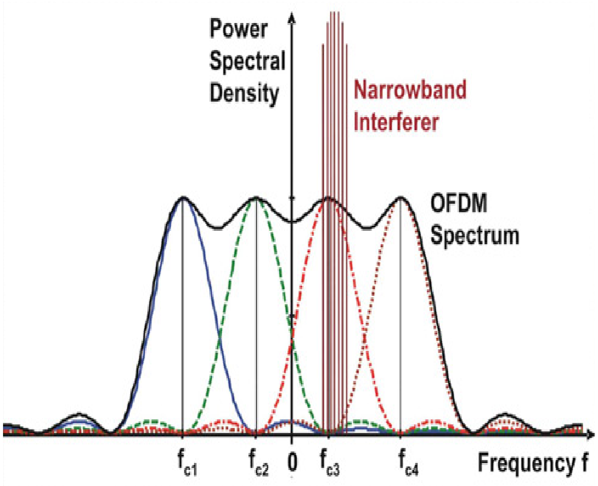


Figure 2.2: OFDM Spectrum[3]

2.2.2 The Discrete Fourier Transform

Two primary methods for separating carriers in OFDM have been evaluated during its development. The earliest one used actual filters to separate the bands, and suffered form the difficulty of implementing filters with sharp band edges. The second and most promising method uses base band processing, wherein both transmitter and receiver can be implemented using the Discrete Fourier Transform (DFT). Each carrier in the OFDM System can be written in the form

$$s_{nm}\left(t\right) = X_{nm}e^{i2\pi f_c t} \tag{2.6}$$

Where is the complex magnitude corresponding to the nth sub-carrier in the mth OFDM symbol and is nonzero over the time period $(m-1)T_s < t < mT_s$, where T_s is the symbol period. This allows us to write the equation for the OFDM symbol as the complex continues time average of the carrier for a given m as

$$S_{nm}(t) = (1/N)\sum_{n=0}^{N-1} X_{nm}e^{j2\prod f_n t} \tag{2.7}$$

where

$$f_n = \ f_0 + n\triangle f$$

With f_0 as the base frequency, and Δf as the sub-carrier spacing. Without loss of generality, let f_0=0. Substituting for and sampling the equation for the OFDM symbol at a frequency of 1/T result in

$$S_m(kT) = \left(\frac{1}{N}\right)\sum_{n=0}^{N-1} X_m e^{(j2\prod n\Delta f)kT} \tag{2.8}$$

It is convenient at this point to take N samples over the period of one data symbol, yielding the relationship T_s = NT. Comparing the above equation with the general form of IDFT given by

$$g\left(kT\right) = \frac{1}{N}\sum_{n=0}^{N-1} G(\frac{n}{NT})e^{j2\pi nk/N} \tag{2.9}$$

We see that complex function of n is no more than the definition of the signal sampled in the frequency domain and s(kT) is the domain representation. Due to the relationship between Fourier transform and the discrete Fourier transform

$$G\left(n\right) = G\big(e^{jw}\big)_{w=\frac{2\pi n}{N}} \tag{2.10}$$

The two equations are equivalent if

$$\Delta f = (1/NT) = 1/T_S$$

Which is the condition required for orthogonality. The OFDM can be defined by using Fourier transform. The benefit using the DFT is that it can be calculated cheaply and easily using Fast Fourier Transform (FFT) [6]

2.3 Block Diagram of OFDM Transmitter

OFDM signals are typically generated digitally due to the difficulty in creating large banks of phase lock oscillators and receivers in the analog domain. The Transmitter Receiver Block Diagram is shown in figure 2.3

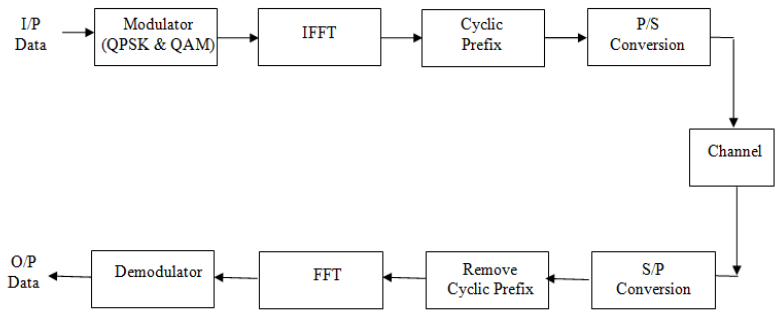


Figure 2.3: OFDM Transreceiver[2]

The transmitter section converts digital data to be transmitted, into a mapping of sub carrier amplitude and phase. It then transforms this spectral representation of the data into the time domain using an Inverse Discrete Fourier Transform (IDFT). The Inverse Fast Fourier Transform (IFFT) performs the same operations as an IDFT, except that it is much more computationally efficiency, and so is used in all practical systems. In order to transmit the OFDM signal the calculated time domain signal is then mixed up to the required frequency. The receiver performs the reverse operation of the transmitter.

2.3.1 Serial to Parallel Converter

Data to be transmitted is typically in the form of a serial data stream. In OFDM, each symbol typically transmits 40 - 4000 bits, and so a serial to parallel conversion stage is needed to convert the input serial bit stream to the data to be transmitted in each OFDM symbol. The data allocated to each symbol depends on the modulation scheme used and the number of subcarriers. For example, for a subcarriers modulation of 16-QAM each subcarriers carries 4 bits of data, and so for a transmission using 100 subcarriers the number of bits per symbol would be 400.

2.4 Subcarrier Modulation

Once each subcarrier has been allocated bits for transmission, they are mapped using a modulation scheme to a subcarriers amplitude, phase, which is represented by a complex In-phase and Quadrature-phase (IQ) vector. Figure 2.4 shows an example of subcarriers modulation mapping.

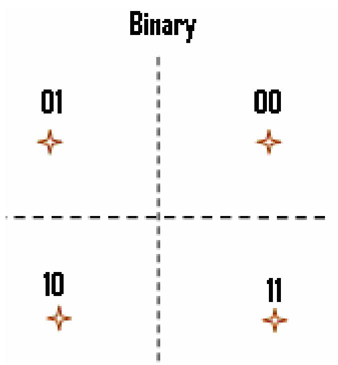


Figure 2.4: QPSK Constellation

This example shows QPSK which maps 2 bits for each symbol. Each combination of the 2 bits of data corresponds to a unique IQ vector, shown as a dot on the figure. A large number of modulation schemes are available allowing the number of bits transmitted per carrier per symbol to be varied. In the receiver, mapping the received IQ vector back to the data word performs subcarriers demodulation. During transmission, noise and distortion becomes added to the signal due to thermal noise, signal power reduction and imperfect channel equalization. For each received IQ vector the receiver has to estimate the most likely original transmission vector. This is achieved by finding the transmission vector that is closest to the received.

2.4.1 Frequency to Time Domain Conversion (IFFT)

After the subcarriers modulation stage each of the data subcarriers is set to amplitude and phase based on the data being sent and the modulation scheme. This sets up the OFDM signal in the frequency domain, also known as IFFT mapping. An IFFT is then used to convert this signal to the time domain, allowing it to be transmitted. In the frequency domain, before applying the IFFT, each of the discrete samples of the FFT corresponds to individual subcarriers. Most of the subcarriers are modulated with data. The outer subcarriers are unmodulated and set to zero amplitude. These subcarriers are also known as virtual carriers. These zero subcarriers provide a frequency guard band before the nyquist frequency and effectively act as an interpolation of the signal and allows for a realistic roll off in the analog anti-aliasing reconstruction filters[3]. If IFFT mapping is a type of conjugate symmetry than signal generated from IFFT is real type, otherwise it is a complex signal. Depends on application IFFT mapping is applied.

2.4.2 Cyclic Prefix

The effect of ISI on an OFDM signal can be further improved by the addition of a guard period to the start of each symbol. This guard period is a cyclic copy that extends the length of the symbol waveform. Each subcarrier, in the data section of the symbol, (i.e. the OFDM symbol with no guard period added, which is equal to the length of the IFFT size used to generate the signal) has an integer number of cycles. Because of this, placing copies of the symbol end-to-end results in a continuous signal, with no discontinuities at the joins. Thus by copying the end of a symbol and appending this to the start results in a longer symbol time. Figure 2.5 shows the insertion of a guard period. Adding a guard period lowers the symbol rate, however it does not affect the subcarrier spacing seen by the receiver. The guard period adds time overhead, decreasing the overall spectral efficiency of the system.

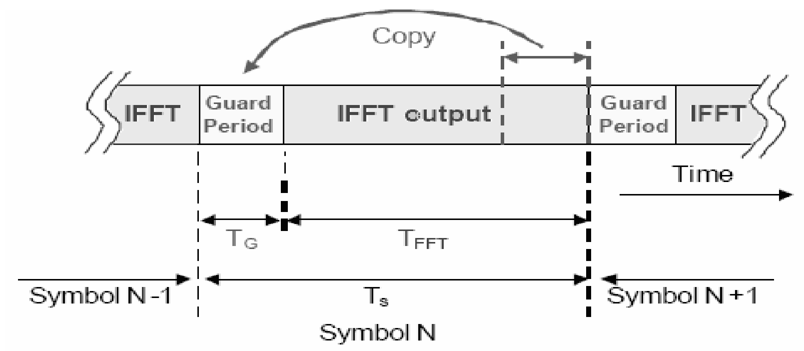


Figure 2.5: Insertion Guard Interval[3]

Guard duration should be longer than channel delay spread. The addition of guard period removes most of the effects of ISI; however in practice, multipath components tend to decay slowly with time, resulting in some ISI even when a relatively long guard period is used.

The output of the OFDM modulator generates a base band signal, which must be mixed up to the required transmission frequency. The receiver performs the reverse operation of the transmitter, mixing the RF signal to base band for processing, then using a Fast Fourier Transform (FFT) to analyze the signal in the frequency domain. The amplitude and phase of the subcarriers is then picked out and converted back to digital data. The IFFT and the FFT are complementary function and the most appropriate term depends on whether the signal is being received or generated.

2.4.3 Key Elements of Design

Once the channel bandwidth, guard interval and data throughout put is fixed a few key elements can be determined.

1) Symbol duration

   Symbol duration affects the carrier spacing and coding latency. In practice, carrier offset and phase stability may affect how close two carriers can be placed. If the application is for the mobile reception, the carrier spacing must be large enough to make the Doppler shift negligible. Generally, the useful symbol duration should be chosen so that the channel is stable for the duration of a symbol.

2) Number of subcarriers

   The number of subcarriers can be determined based on the channel bandwidth, data throughput and useful symbol duration. The carriers are spaced by the reciprocal of the useful symbol duration. The number of carriers corresponds to the number of complex points being processed in FFT.

3) Modulation scheme

   The modulation scheme used in an OFDM system can be selected based on the requirement of power spectrum efficiency. In general, the selection of modulation scheme applying to each subchannel depends solely on the compromise between the data rate requirement and transmission robustness.

2.5 Advantages and Disadvantages of OFDM:

2.5.1 Advantages

1) Makes efficient use of the spectrum by allowing overlap.

2) By dividing the channel into narrowband flat fading sub channels, OFDM is more resistant to frequency selective fading than single carrier systems are.

3) Eliminates ISI and IFI through use of a cyclic prefix.

4) Using adequate channel coding and interleaving one can recover symbols lost due to the frequency selectivity of the channel

5) Channel equalization becomes simpler than by using adaptive equalization techniques with single carrier systems

6) It is possible to use maximum likelihood decoding with reasonable complexity.

7) OFDM is computationally efficient by using FFT techniques to implement the modulation and demodulation functions.

8) It is less sensitive to sample timing offsets than single carrier systems.

9) Provides good protection against co channel interference and impulsive parasitic noise.

2.5.2 Disadvantages

1) The OFDM signal has a noise like amplitude with a very large dynamic range, therefore it requires RF power amplifiers with a high peak to average power ratio.

2) It is more sensitive to carrier frequency offset and drift than single carrier systems are due to leakage of the DFT.

2.6 Peak to Average Power Ratio (in OFDM)

One of the major drawbacks of OFDM is the high peak-to-average power ratio (PAPR) of the transmit signal. If the peak transmit power is limited by either regulatory or application constraints, the effect is to reduce the average power allowed under multicarrier transmission relative to that under constant power modulation techniques. This in turn reduces the range of multicarrier transmission. Moreover, to prevent spectral growth of the multicarrier signal in the form of intermodulation among subcarriers and out-of-band radiation, the transmit power amplifier must be operated in its linear region (i.e., with a large input back off), where the power conversion is inefficient. This may have a deleterious effect on battery lifetime in mobile applications. In many low-cost applications, the drawback of high PAPR may outweigh all the potential benefits of multicarrier transmission systems.

In fact, the PAPR problem also arises in many cases other than multicarrier transmission. Typically, the PAPR is not an issue with constant amplitude signals. With no constant amplitude signals, however, it is important to deal with the PAPR of those signals. For example, a DS-CDMA signal suffers from the PAPR problem especially in the downlink because it is the sum of the signals for many users.

The PAPR of an OFDM signal can be defined as,

$$PAPR = \frac{Peak\ Amplitude\ of\ the\ Signal}{Average\ value\ of\ the\ Signal}$$

$$\mathrm{PAPR}\{\mathrm{x}\} = \frac{\max|\mathrm{x}|^2}{\mathrm{E}[\,|\mathrm{x}|^2\,]}$$

where x be any signal representation (critically sampled baseband, oversampled baseband, continuous-time passband, etc.) defined over one symbol period. Figure 2.6 below illustrates what the amplitudes of one symbol could look like for a particular symbol that exhibits a large peak.

2.6.1 The PAPR of Multicarrier Signal

A multicarrier signal is the sum of many independent signals modulated onto subchannels of equal bandwidth. Let us denote the collection of all data symbols Xn, n = 0, 1, , N - 1, as a vector $X = [X_0, X_1, ..., X_{N-1}]^T$ that will be termed a data

Figure 2.6: Amplitude of an OFDM Symbol for N=256

block. The complex baseband representation of a multicarrier signal consisting of N subcarriers is given by Where $j = \sqrt{-1}$ Δf is the subcarrier spacing, and NT denotes the useful data block period. In OFDM

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \cdot e^{j2\prod n\Delta ft}, 0 \leq t < NT$$

the subcarriers are chosen to be orthogonal $i.e., \Delta f = 1/NT$ The PAPR of the transmit signal is defined as

$$PAPR = \frac{\max_{0 \leq t \leq NT} |x(t)|^2}{1/NT \cdot \int_0^{NT} |x(t)|^2 dt}$$

an approximation will be made in that only NL equidistant samples of x(t) will be considered where L is an integer that is larger than or equal to 1. These "L-times oversampled" time-domain signal samples are represented as a vector $X = [x0, x1, ..., x_{NL-1}]^T$ and obtained as

$$\mathrm{x_k = x(k \cdot T/L)} = \frac{1}{\sqrt{\mathrm{N}}} \sum_{\mathrm{n=0}}^{\mathrm{N-1}} \begin{array}{l} \mathrm{X_n \cdot e^{j2\prod kn\Delta fT/L}}, \\ \mathrm{k = 0, 1, ...NL - 1} \end{array}$$

It can be seen that the sequence X_k can be interpreted as the inverse discrete Fourier transform (IDFT) of data block X with (L - 1)N zero padding. It is well known that the PAPR of the continuous-time signal cannot be obtained precisely by the use of

Nyquist rate sampling, which corresponds to the case of L = 1. It is shown that L = 4 can provide sufficiently accurate PAPR results [10]. The PAPR computed from the L time oversampled time domain signal samples is given by

$$\mathrm{PAPR} = \frac{\max\limits_{0\leq \mathrm{k}\leq \mathrm{NL}-1} |\mathrm{x_k}|^2}{\mathrm{E}[|\mathrm{x_k}|^2]},$$

where E[.] denotes expectation.

2.6.2 The CCDF of PAPR

The cumulative distribution function (CDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques. In the literature, the complementary CDF (CCDF) is commonly used instead of the CDF itself. The CCDF of the PAPR denotes the probability that the PAPR of a data block exceeds a given threshold.From the central limit theorem, the real and imaginary parts of the time domain signal samples follow Gaussian distributions, each with a mean of zero and a variance of 0.5 for a multicarrier signal with a large number of subcarriers. Hence, the amplitude of a multicarrier signal has a Rayleigh distribution, while the power distribution becomes a central chi-square distribution with two degrees of freedom. The CDF of the amplitude of a signal sample is given by **F(z) = 1 - exp(z)**.

What we want to derive is the CCDF of the PAPR of a data block. The CCDF of the PAPR of a data block with Nyquist rate sampling is derived as

$$\begin{aligned} P(PAPR > z) &= 1 - P(PAPR \leq z) && (2.11)\\ &= 1 - F(z)^N && (2.12)\\ &= 1 - (1 - \exp(-z))^N && (2.13) \end{aligned}$$

This expression assumes that the N time domain signal samples are mutually independent and uncorrelated. This is not true, however, when oversampling is applied.

Also, this expression is not accurate for a small number of subcarriers since a Gaussian assumption does not hold in this case. Therefore, there have been many attempts to derive more accurate distribution of PAPR.

Chapter 3

The Proposed Algorithm

This chapter describes the process for modeling the OFDM transmission and receiver system. The software selected to develop the model has been MATLAB and its simulation toolbox Simulink. The name MATLAB stands for matrix laboratory. The OFDM system was modeled using MATLAB/Simulink to allow various parameters of the system to be varied and tested. The reason to select them is because MATLAB is a very common software tool for engineering. It is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment. MATLAB is the tool of choice for high productivity research, development, and analysis. Even more, a large number of libraries and toolboxes, mainly in the fields of communications and digital signal processing, are offered by Simulink. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. The complete model layout is going to be exposed in this chapter. The way to represent the blocks is going to follow the data stream. It is started with the data source and it is ended with the error rate calculation block used to get some results. Some simulation parameters can be changed in the model in order to view different results.

This chapter also Describes PAPR reduction Techniques to reduce value of PAPR in OFDM. Selected Mapping (SLM) and Partial Transmit Sequence (PTS) are used in system for higher performance.

3.1 Layout of the System

The simulink model is shown in figure 3.1 It consists of

1) Binary data source generator at 1 Mbps rate

2) Data mapping QPSK modulator

3) Zero padding for IFFT mapping(Real or complex output), 24 subcarriers, one symbol per sub carrier, two bits per symbol(because of QPSK)

4) IFFT 64 point

5) Cyclic prefix of 16 sample(IFFT/4)

6) Channel (AWGN, Multipath)

7) Receiver side reverse process of transmitter like FFT, Data demapping QPSK demodulator

3.2 OFDM Model Description

The system model is shown in figure 3.1. A brief description of each block and subsystem is described afterwards.

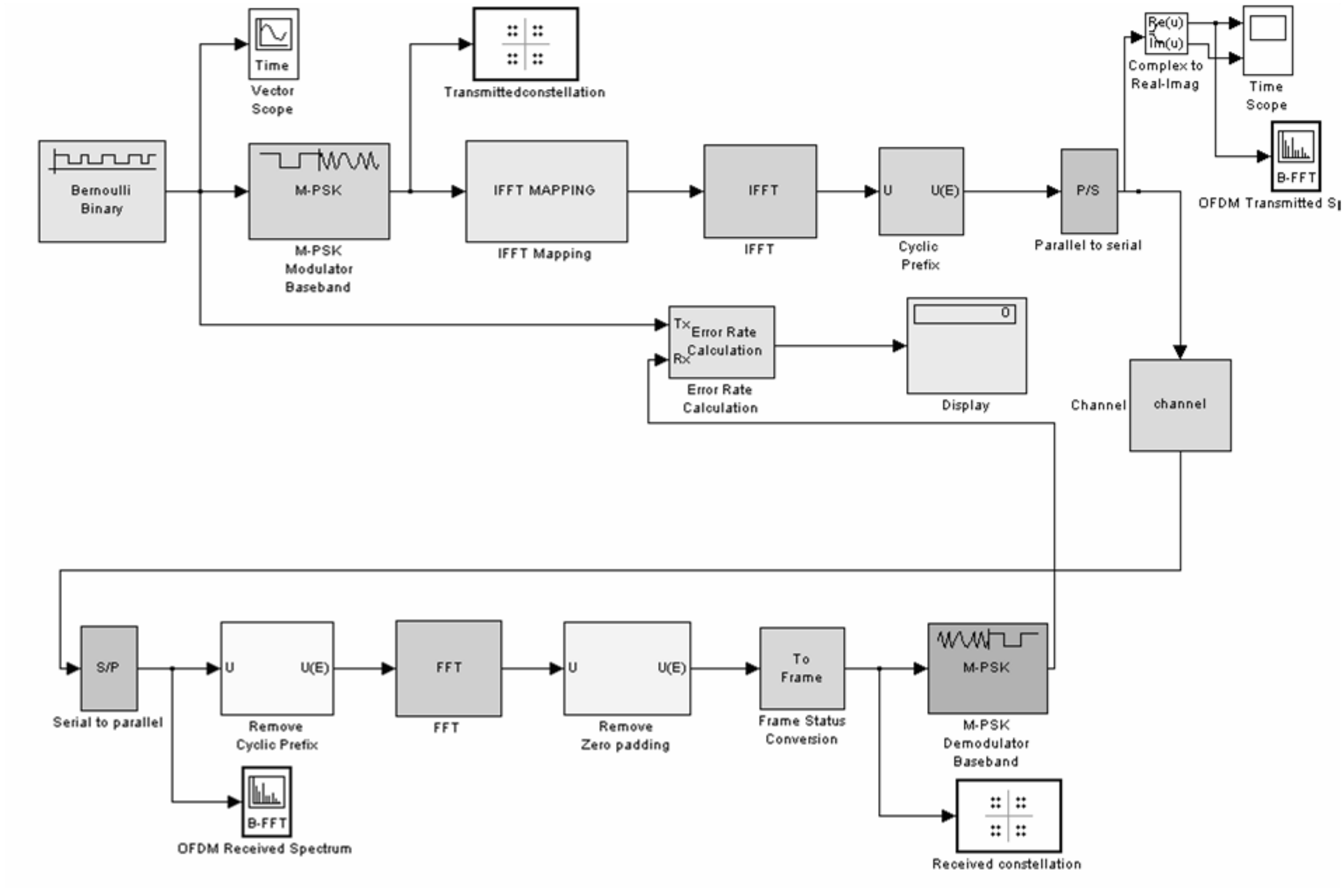


Figure 3.1: OFDM Transreceiver Simulink Model

3.2.1 Binary Data Source

The Binary input data is random generated with a Bernoulli Binary Generator block from communication block set. In frame based output 48 samples per frame are used and for a 1 M bits/s data rate (1/sample time). The block window is shown in 3.2

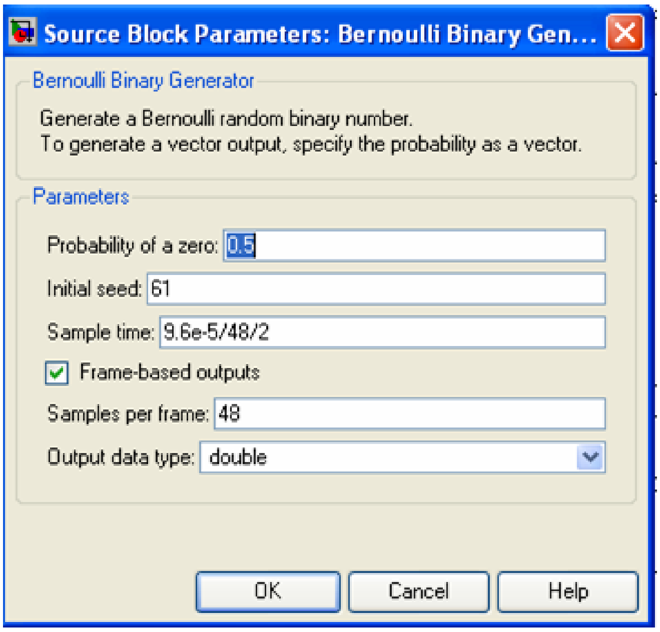


Figure 3.2: Binary Source Generator Block Window

3.2.2 Data Mapping- QPSK Modulation

Modulation is the process by which information signals, analog or digital, are transformed into waveforms suitable for transmission across the channel. Hence, digital modulation is the process by which digital information is transformed into digital waveforms. The M-PSK block selected from communication block set as shown in figure 3.3.

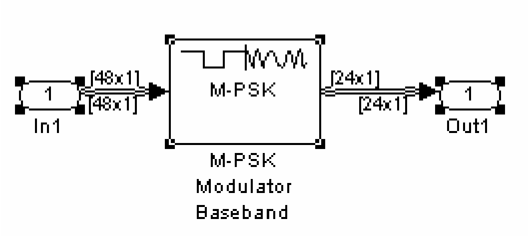


Figure 3.3: Data Mapping Block

The binary serial input data shall be divided into groups of 2(number of bits per symbol) bits and converted into complex number representing 4-PSK. In QPSK symbol 0, 1, 2, 3 mapped as 0.7071+0.7071j, -0.7071+0.7071j, -0.7071-0.7071j, 0.7071-0.7071j. The constellation plot various mapping is shown in figure in figure 3.4 and 3.5 In M -PSK modulator block change the value of M , 4 , 8, 16, 32, 64, 256,...,etc and mapped bits into symbol.

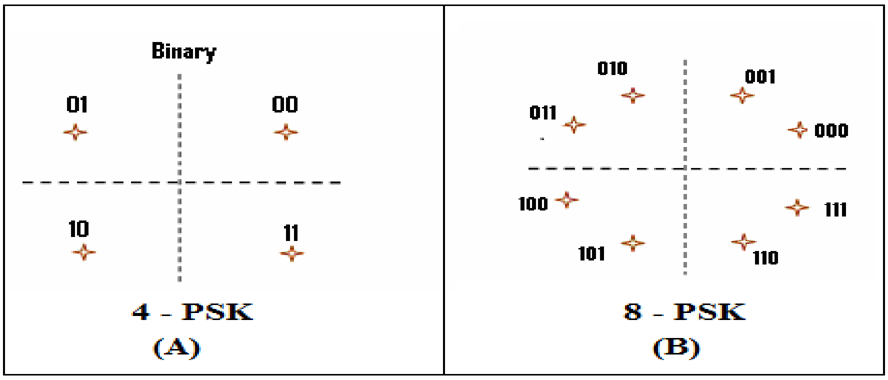


Figure 3.4: Constellation Diagram of (A)4- PSK (B)8-PSK

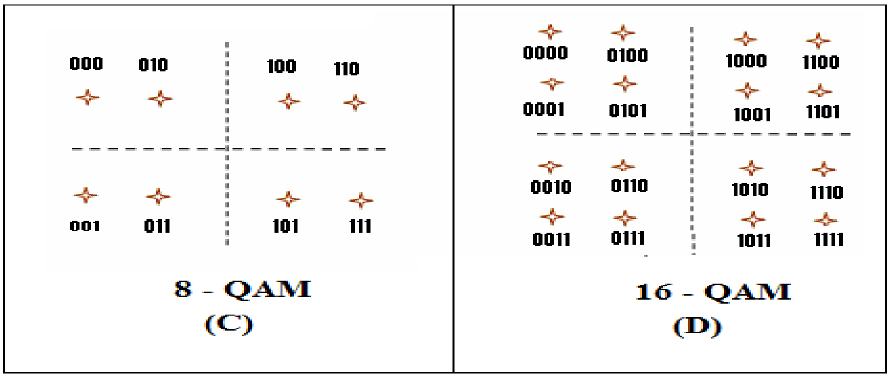


Figure 3.5: Constellation Diagram of (C)8-QAM (D)16 QAM

3.2.3 IFFT Mapping / IFFT

As in this design one sub carrier is allocate for one QPSK symbol. The block diagram IFFT mapping is shown in figure 3.6. For IFFT mapping zero pad and selector blocks are assigning. Zero pads append zeros to the input signal and the selector block reorders the sub carriers. Depend on Zero pad block we can design 32 point, 64 point, 128 point FFT etc.

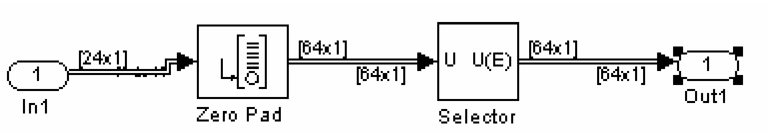


Figure 3.6: Simulink Block for IFFT Mapping

A 64 point IFFT is used; the coefficient 1 to 12 are mapped to the same number IFFT inputs, while the coefficient -12 to -1 are copied into IFFT inputs 50 to 63. The rest of the inputs 13 to 51 and the 0(dc) input are set to zero. These subcarriers can be arranging in desired order using selector block. This is shown in figure 3.7.

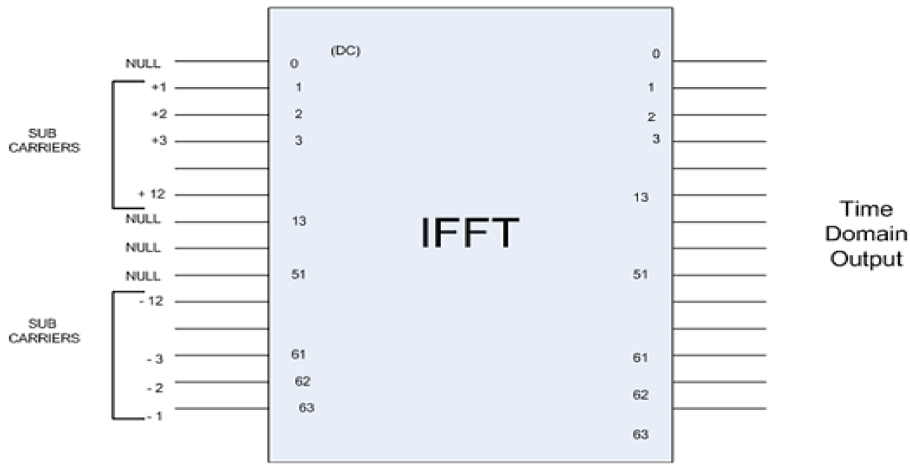


Figure 3.7: IFFT Mapping

After performing an IFFT, the output is cyclically extended to the desired length.

3.2.4 Cyclic Prefix

A selector block as shown in figure 3.8 is used for implementing cyclic prefix in the simulink model. The last 16 sub carriers are copied into the beginning of the OFDM symbols. The cyclic prefix preserves orthogonality between sub-carriers. To avoid the ISI, cyclic prefix duration should be larger than transmission duration of the symbol.

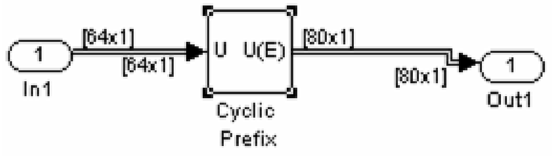


Figure 3.8: Simulink Block for Cyclic Prefix

3.2.5 Parallel to Serial Converter

Output of cyclic prefix is applied to unbuffer block for parallel to serial converter as shown in figure 3.9. To keep data transmission frame based add the block Frame status conversion and in block window select frame based.

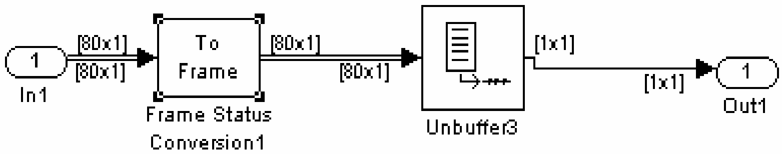


Figure 3.9: Parallel to Serial Converter Block

3.2.6 Channel

In communication block set different Channel blocks like AWGN channel Multipath Raleigh fading channel, Rican fading channel etc. are available. The AWGN Channel block shown in figure 3.10 adds white Gaussian noise to a real or complex input signal. When the input signal is real, this block adds real Gaussian noise and produces real output signal. When the input signal is complex, this block adds complex Gaussian noise and produces a complex output signal. In this block window we can change the value of SNR, Eb/No etc depends on selection.

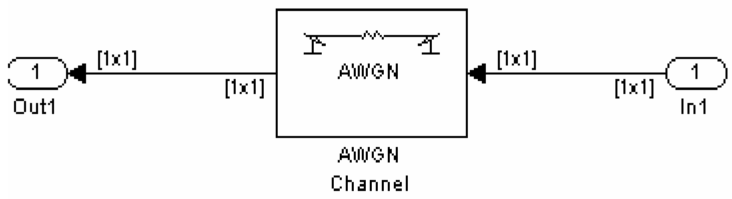


Figure 3.10: AWGN Channel Block

The Multipath Rayleigh Fading Channel block implements a base band simulation of a multipath Rayleigh fading propagation channel. This block is useful for modeling mobile wireless communication systems below. This block accepts only frame-based complex signals at its input. To work with sample-based inputs, use the Frame conversion block of the Signal Processing block set to reformat the signal. Relative motion between the transmitter and receiver causes Doppler shifts in the signal frequency. In the block's parameter dialog, the Delay vector specifies the time delay for each path. Gain vector specifies the gain for each path.

3.2.7 Receiver

The OFDM receiver performs the following task described briefly.

1) Serial to parallel

   The signal is converted from serial to parallel converter using buffer block as shown in figure 3.11. The Buffer block redistributes the input samples to a new frame size.

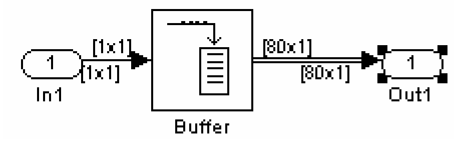


Figure 3.11: Serial to Parallel Converter

2) Remove Cyclic prefix added in the transmission side.(Using selector block)

3) FFT(blocks shown in figure 3.12)

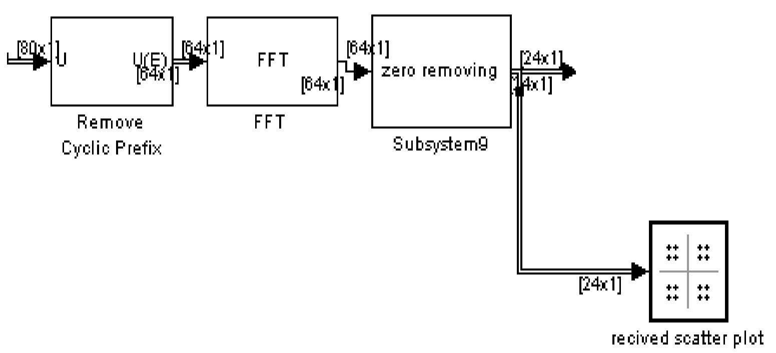


Figure 3.12: Cyclic Prefix Remover

4) Remove the zeros added for the FFT and reorder the subcarriers (subsystem of zero removing is shown in figure (3.13)

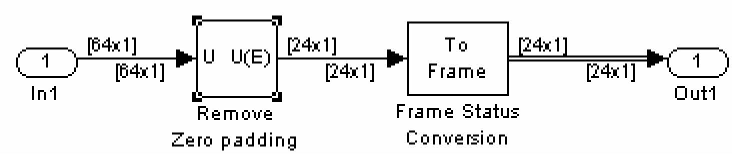


Figure 3.13: Zero Removing Subsystem

5) Demapping of data

The receiver side demapping can be performed by M-PSK demodulator. In this block select the parameter M array same as in transmitter.

3.2.8 Error Rate Calculation

The Error Rate Calculation block compares input data from a transmitter with input data from a receiver. It calculates the error rate as a running statistic by dividing the total number of unequal pairs of data elements by the total number of input data elements from one source as shown in figure 3.14. One can use this block to compute either symbol or bit error rate because it does not consider the magnitude of the difference between input data elements. If the inputs are bits, the block computes the bit error rate. If the inputs are symbols, it computes the symbol error rate. The input ports marked Tx and Rx accept transmitted and received signals respectively. The Tx and Rx signals must share the same sampling rate.

This block produces a vector of length three whose entries correspond to:

1) The error rate (BER- bit error rate)

2) The total number of errors, i.e., the comparisons between unequal elements

3) The total number of comparisons that the block made

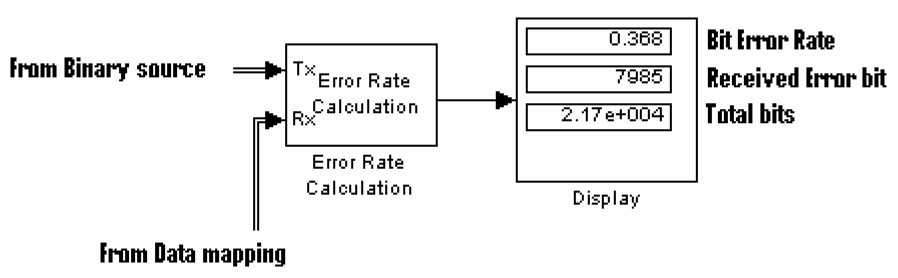


Figure 3.14: Error Rate Calculations with Display

3.3 PAPR Reduction Techniques

1) Signal Scrambling techniques

- All variations on how to scramble the codes to decrease the PAPR.
- Coding techniques , Block Coding, Selective Level Mapping (SLM) and Partial Transmit Sequences (PTS) .

2) Signal Distortion techniques

- Reduce high peaks directly by distorting the signal prior to amplification.
- Clipping , peak windowing, peak cancelation, Peak power suppression, weighted multicarrier transmission, companding .

3.3.1 The Partial Transmit Sequence (PTS)

In the PTS technique, an input data block of N symbols is partitioned into disjoint sub blocks. The sub carriers in each sub block are weighted by a phase factor for that sub block. The phase factors are selected such that the PAPR of the signal is minimized.

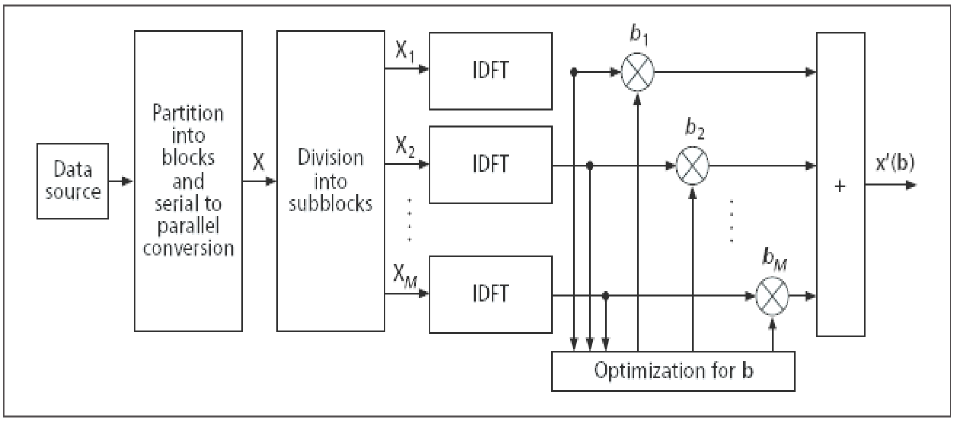


Figure 3.15: PTS Technique

Figure 3.15 shows the block diagram of the PTS technique. In the ordinary PTS technique[8] input data block X is partitioned into M disjoint subblocks $Xm = [X_{m,0}, X_{m,1}, ..., X_{m,N-1}]^T$, m=1,2,,M such that $\sum_{m=1}^{M} X_m = X$ and the subblocks are combined to minimize the PAPR in the time domain. The L-times oversampled time domain signal of Xm, m = 1, 2, , M, is denoted $x_m = [x_{m,0}, x_{m,1}, ..., x_{m,N-1}]^T \cdot$ $x_m, m = 1, 2, ..., M$ is obtained by taking an IDFT of length NL on Xm concatenated with (L - 1)N zeros. These are called the partial transmit sequences. Complex phase factors $b_m = e^{j\phi_m}, m = 1, 2, ..., M,$, are introduced to combine the PTSs. The set of phase factors is denoted as a vector $b = [b_1, b_2, ..., b_M]^T$ The time domain signal after combining is given by $x'(b) = \sum_{m=1}^{M} b_m \cdot x_m$, where $x'(b) = [x'_0(b), x'_1(b), ...x'_{NL-1}(b)]^T$ The objective is to find the set of phase factors that minimizes the PAPR. Minimization of PAPR is related to the minimization of

$$\max_{0 \leq k \leq NL-1} |X'_k(b)|$$

In general, the selection of the phase factors is limited to a set with a finite number of elements to reduce the search complexity. The set of allowed phase factors is written as $P = \{e^{j2\prod l/W} | l = 0, 1, ..., W - 1\}$, where W is the number of allowed phase factors. In addition, we can set $b_1 = 1$ without any loss of performance. So, we should perform an exhaustive search for (M - 1) phase factors. Hence W^{M-1} sets of phase factors are searched to find the optimum set of phase factors. The search complexity increases exponentially with the number of subblocks M.

PTS needs M IDFT operations for each data block, and the number of required side information bits is $\lfloor \log_2 W^{M-1} \rfloor$, where $\lfloor y \rfloor$ denotes the smallest integer that does not exceed y. The amount of PAPR reduction depends on the number of subblocks M and the number of allowed phase factors W. Another factor that may affect the PAPR reduction performance in PTS is the subblock partitioning, which is the method of division of the subcarriers into multiple disjoint subblocks. There are three kinds of subblock partitioning schemes: adjacent, interleaved, and pseudo-random partitioning[7]. Among them, pseudo-random partitioning has been found to be the best choice. The PTS technique works with an arbitrary number of subcarriers and any modulation scheme. As mentioned above, the ordinary PTS technique has exponentially increasing search complexity. To reduce the search complexity, various techniques have been suggested. In iterations for updating the set of phase factors are stopped once the PAPR drops below a preset threshold [5]. In various methods to reduce the number of iterations are presented. These methods achieve significant reduction in search complexity with marginal PAPR performance degradation.

3.3.2 The Selected Mapping Technique

In the SLM technique, the transmitter generates a set of sufficiently different candidate data blocks, all representing the same information as the original data block, and selects the most favorable for transmission[8]. A block diagram of the SLM technique is shown in Fig. 3.16

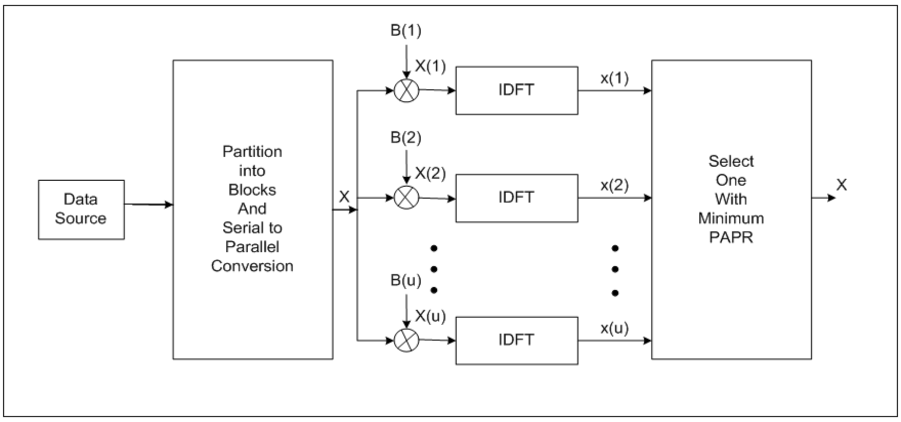


Figure 3.16: SLM Technique

Each data block is multiplied by U different phase sequences, each of length N $B^{(u)} = [b_{u,0}, b_{u,1}, ..., b_{u,N-1}]^T$, u=1,2,,u resulting in U modified data blocks. To include the unmodified data block in the set of modified data blocks, we set $B^{(1)}$ as the all-one vector of length N. Let us denote the modified data block for the uth phase sequence sequence $X(u) = [X_0 b_{u,0}, X_1 b_{u,1}, ..., X_{N-1} b_{u,N-1}]^T$, u = 1, 2, , U. After applying SLM to X, the multicarrier signal becomes

$$X^{(u)}(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n b_{u,n} \cdot e^{j2\Pi n \Delta f t}, 0 \leq t \leq NT$$

Among the modified data blocks $X^{(u)}$ u=1,2,,U, the one with the lowest PAPR is selected for transmission. Information about the selected phase sequence should be transmitted to the receiver as side information. At the receiver, the reverse operation is performed to recover the original data block. For implementation, the SLM technique needs U-IDFT operations, and the number of required side information bits is $\lfloor \log_2 U \rfloor$ for each data block. This approach is applicable with all types of modulation and any number of subcarriers. The amount of PAPR reduction for SLM depends on the number of phase sequences U and the design of the phase sequences.

Chapter 4

Simulation Result

Once finished the design and implementation of the OFDM Transreceiver using simulink, it is time to perform some analysis and comment the obtained results. The next figures show the results of the Simulations..

4.1 Data Flow for Transreceiver

In simulink model data can be visualized by add the block To Workspace after each block. The data value after each block of transmitter is shown in Workspace.
Now in Workspace toolbar using plot selection we can plot all values in different plot pattern.

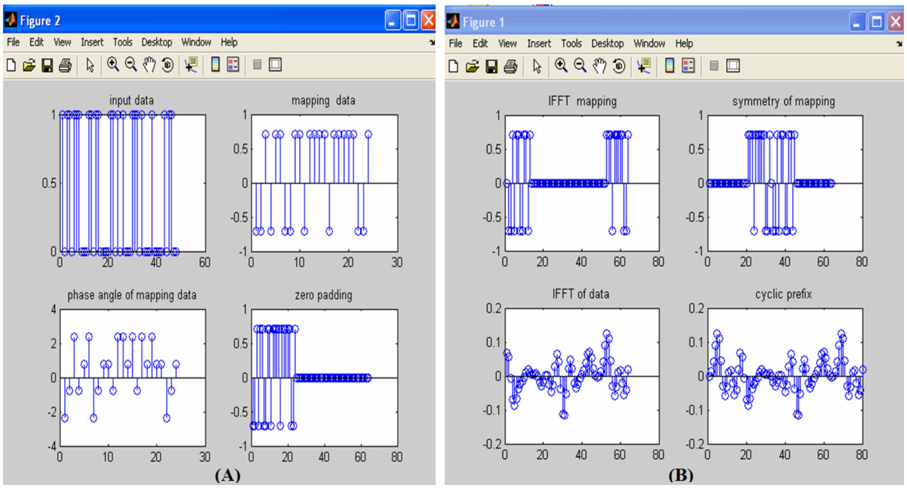


Figure 4.1: (A),(B) OFDM Transmitter Data Plot for One Symbol

The figure 4.1 [A, B] shows the plot of data vs time which conveys complete flow for the transmitter. Mapping of IFFT and addition of cyclic prefix is shown clearly.

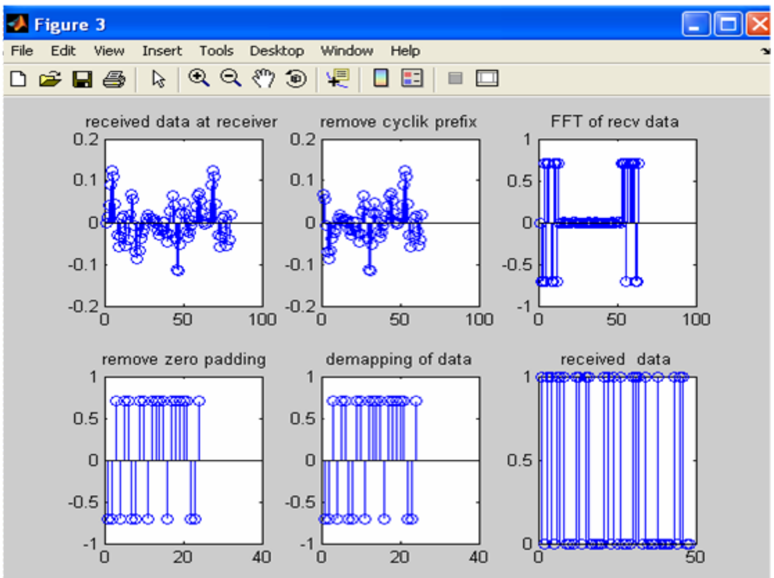


Figure 4.2: Receiver Data Plot

The figure 4.2 shows the data vs time graph which shows the complete data flow of receiver section.

4.1.1 OFDM Signal

The Time domain output signal can be visualized by addition of Time scope in model. OFDM signal Real part and for imaginary part is shown in figure 4.3. One OFDM symbol consists 16 samples for guard band and 64 point FFT

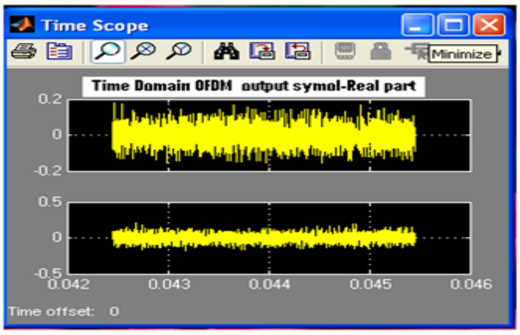


Figure 4.3: OFDM Time Domain Signal Real Part and Imaginary Part

The transmitted OFDM spectrum is shown in figure 4.4.

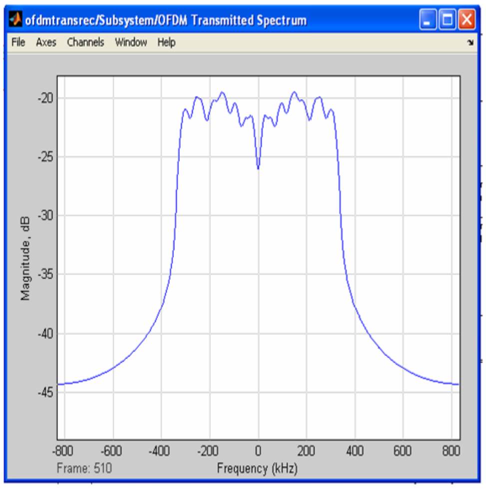


Figure 4.4: OFDM Transmitted Signal Spectrum

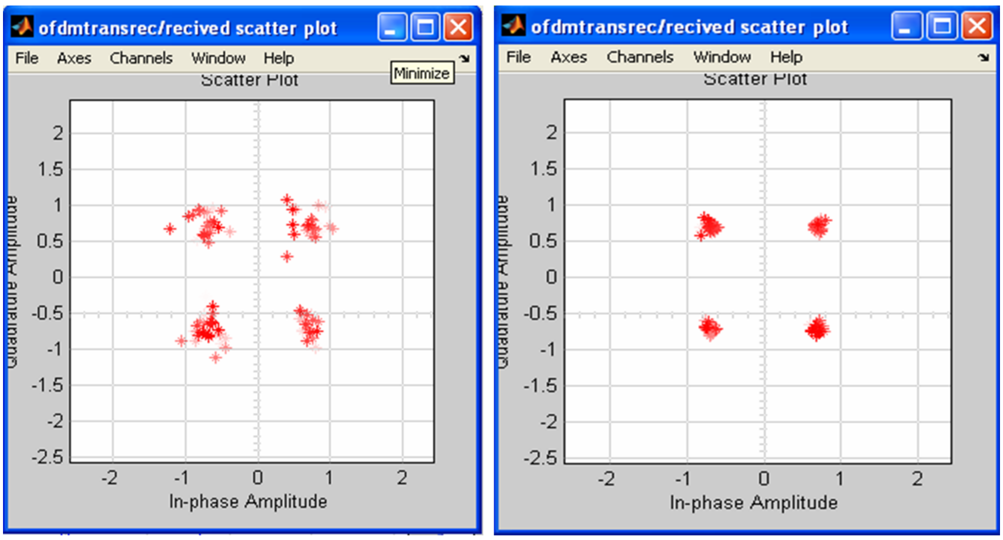
The transmitted OFDM spectrum is shown in figure 4.4., where zero frequency and frequency peaks at both side are seen clearly.

4.2 Effect of Variation in E_b/N_0

The received signal can be affected by change the value of signal power in AWGN channel[9]. The signal quality will be better for higher signal to noise ratio.

4.2.1 Received Constellation Plot

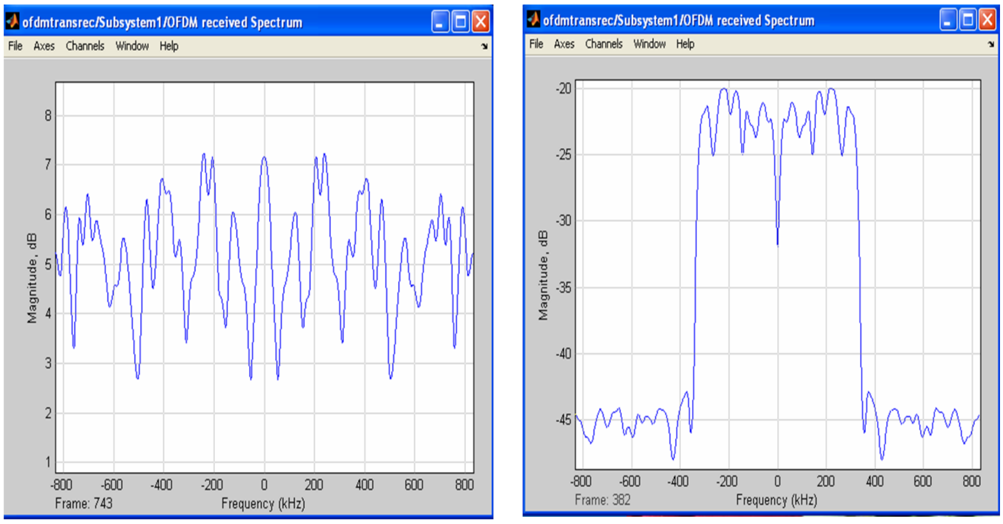
For different value of E_b/N_0 the constellation diagram at receiver is shown in figure 4.5. Points at 50dB value are seen more clearly as compared to the points at 40dB; hence at higher value of E_b/N_0 less error are present in the system. As noise increases the constellation point gets more blurred and it is difficult to detect it correctly.



(A) (B)

Figure 4.5: (A),(B) Received Constellation at E_b/N_0 40db, 50db

4.2.2 Received OFDM Spectrum



(A) (B)

Figure 4.6: Received spectrum (A) at E_b/N_0 =0db (B) at E_b/N_0 =50 db

The Figure 4.6 [A] shows that at Eb=N0=0 dB the data is not clearly visible and the Figure 4.6 [B] shows that for Eb=N0=50 dB the data is clearly visible.

4.2.3 BER Performance of Proposed OFDM Model

Figure 4.7 Shows BER result for this discribes ofdm model.

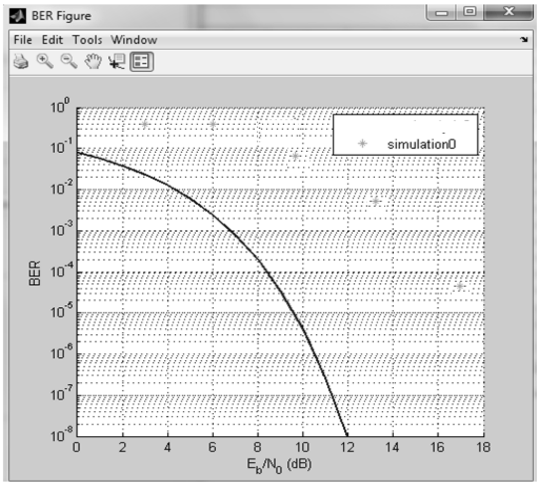


Figure 4.7: BER Performance of OFDM Model

This BER performance for OFDM Model taken from BERTool in MATLAB. BERTool is an interactive GUI for analyzing communication systems' bit error rate. Using this tool the result for BER is compared with its theoretical value. Dark line represents the theoretical value and the result of developed OFDM simulink model is shown. The plot of the points with the sign of + shows the BER performance of the OFDM model. Both the line and the plot of the points as mentioned above relatively shows the BER performance of the OFDM model.

4.2.4 Effecet of Symbol Period

In simulink model BER performance can be obtained by changing the value of Symbol Period. In AWGN channel block window we can change symbol period for the model and can get output response.

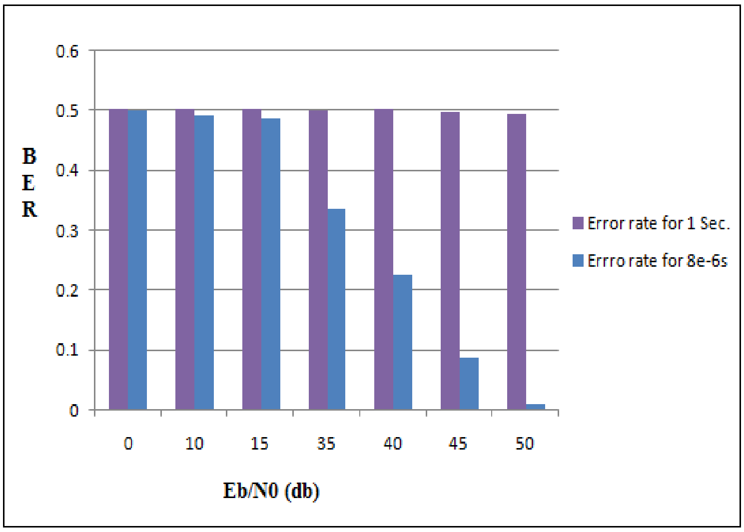


Figure 4.8: BER Performances for Change in Symbol Period

E_b/N_0	Error rate(1 sec)	Error rate(8e-6s)reduced bitrate
0	0.5011	0.498
10	0.5010	0.4917
15	0.5009	0.4841
35	0.4995	0.3341
40	0.49983	0.2232
45	0.4964	0.0872
50	0.4926	0.007854

Table I: Output Result for Changing Symbol Period

The above results conveys that BER value for 1 sec period is higher as compared to symbol period for 8 micro sec where increase in symbol time corresponds to increase in error rates.

4.2.5 BER Performance of M-PSK

In simulink model BER performance can be obtained by change the value of Eb/No in AWGN channel block window and Note the reading of error rate calculation Display. The bit error rate BER deteriorates more rapidly as the Eb/No drops, it can be seen in the next graphic figure 4.8.

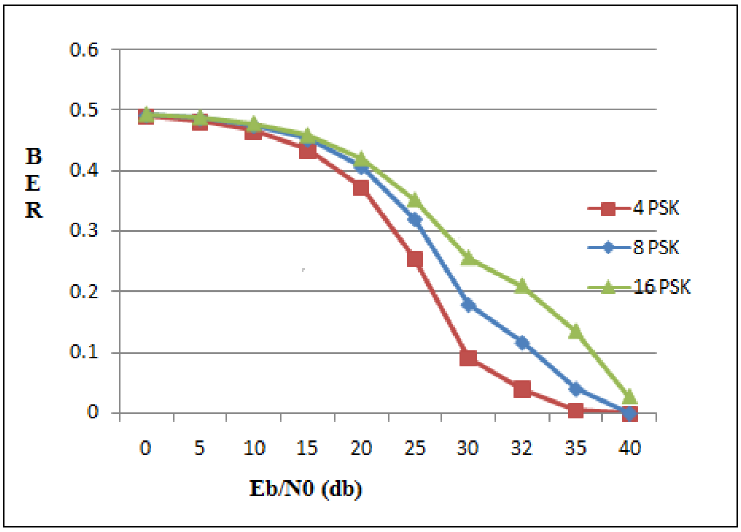


Figure 4.9: BER Performances for M-PSK

E_b/N_0	BER OF 4-PSK	BER OF 8-PSK	BER OF 16-PSK
0	0.4902	0.493	0.4944
5	0.4817	0.4873	0.489
10	0.4657	0.4757	0.4789
15	0.4347	0.4528	0.4596
20	0.373	0.4077	0.4211
25	0.2549	0.3215	0.3533
30	0.09082	0.1802	0.2571
32	0.03983	0.1174	0.2112

Table II: Output Result for PSK

4.2.6 BER Performance for M-QAM

For QAM mapping BER performance is shown in Figure 4.9.

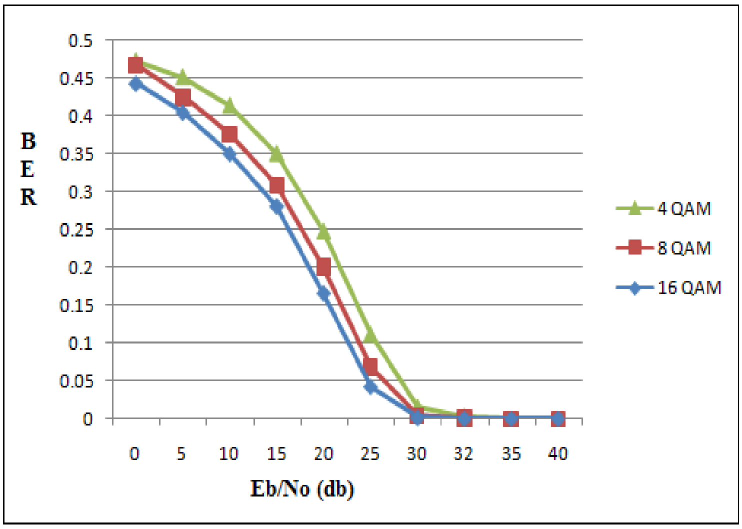


Figure 4.10: BER Performances for M-QAM

E_b/N_0	BER OF 4-QAM	BER OF 8-QAM	BER OF 16-QAM
0	0.4714	0.4663	0.4427
5	0.4503	0.4244	0.4043
10	0.413	0.3754	0.35
15	0.3498	0.308	0.2806
20	0.2474	0.2003	0.1658
25	0.1118	0.06816	0.0423
30	0.0153	0.004189	0.0012
32	0.003224	0.000426	0

Table III: Output Results for QAM

From the above simulation results of the comparison of BER for M-PSK and M-QAM, it is recommended to use high level constellation for the overall capacity to be higher with the only drawback of the points being closer, which results in transmission less robust to the errors.

4.3 PAPR Reduction Techniques

Result for PAPR reduction technique is shown in this section.

4.3.1 CCDF of PAPR by PTS

The figure 4.11 shows that 1.1 dB reduction is possible from the graph of the original signal having the PAPR of 10.9 dB and similar signal using PTS technique having the PAPR of 9.8 dB.

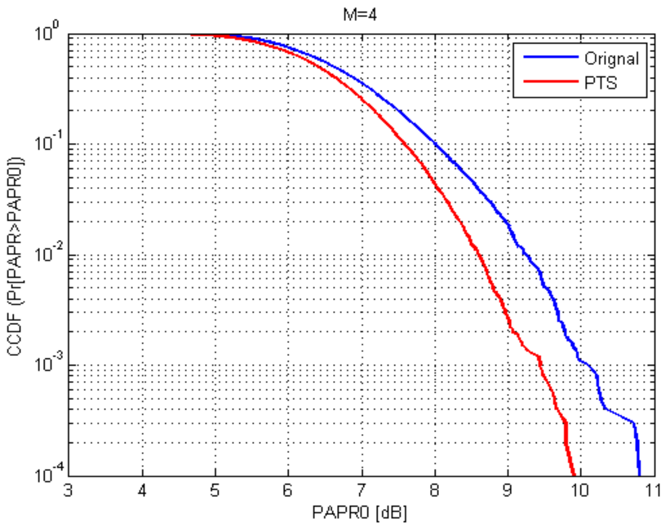


Figure 4.11: CCDF of PAPR by PTS

The following simulation result shows that PAPR is reduced to 1.6dB after increasing the number of phase sequences from 16 to 36. Also, PAPR is reduced to 1.9dB after increasing the number of input data block from 4 to 8.

1) By changing no. of Sub-block and no. of Phase-sequence.

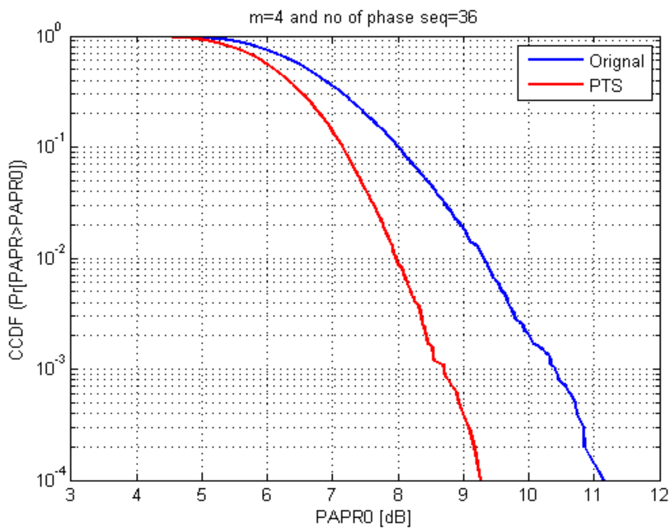


Figure 4.12: CCDF of PAPR by PTS

2) For Different Value of Sub-blocks

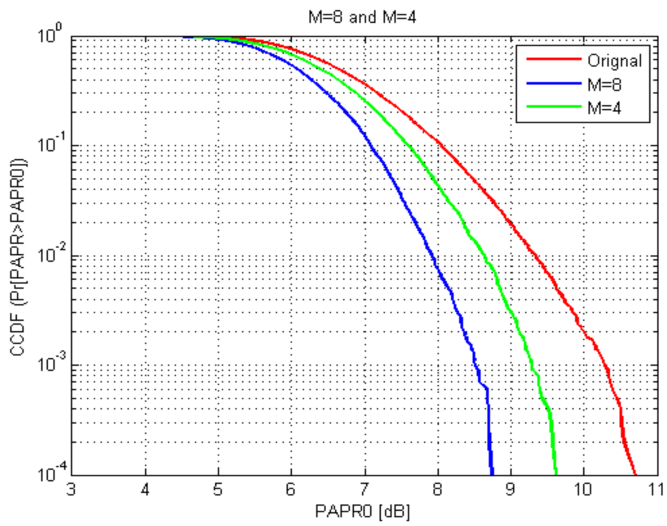


Figure 4.13: CCDF of PAPR by PTS for Various M

4.3.2 CCDF for Selective Mapping Technique

1) For Single Value of N

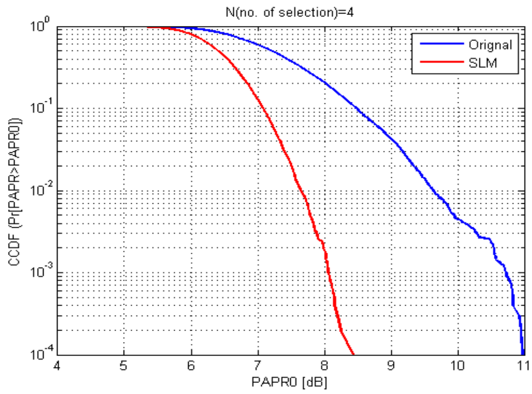


Figure 4.14: CCDF of PAPR for SLM

2.4 dB reduction is achieved with this technique as the value of PAPR for original signal is 11 dB as compared to the similar signal with SLM technique having PAPR of 8.6 dB.

2) For Different Value of N

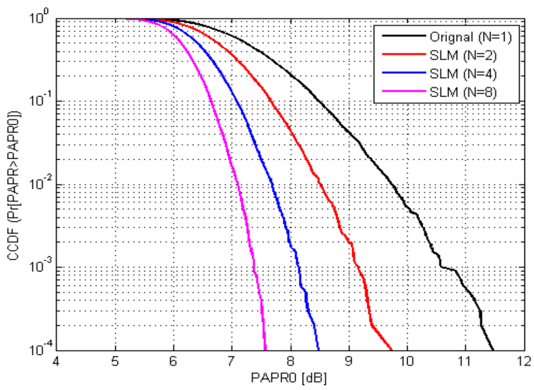


Figure 4.15: CCDF of PAPR for Different Value of N

Result shows as no. of selection for phase sequence is increases from 2 to 8 PAPR decreases upto 2.1dB.

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

The thesis describes the concept of OFDM simulation and PAPR reduction using SLM and PTS techniques. The developed simulink model for baseband OFDM is used for various analysis and comparisons

From the Simulink model

- It is recommended to use high level constellation for the overall capacity to be higher with the only drawback of the points being closer, which results in transmission less robust to the errors.
- The BER value for 1 sec period is higher as compared to symbol period for 8 micro sec where increase in symbol time corresponds to increase in error rates.

From simulation results

- PAPR reduction with PTS technique is 1.1 db for input symbols. This reduction can be increased by increasing the number of phase sequences and number of sub-blocks. The simulation result shows that PAPR is reduced to 1.6dB after increasing the number of phase sequences from 16 to 36. Also, PAPR is reduced to 1.9dB after increasing the number of input data block from 4 to 8.

- PAPR reduction with SLM technique is 2.4dB for the input symbol. This reduction in PAPR with SLM can be increased by increasing the number of phase sequences. Increase in phase number from 2 to 8 results in reduction of PAPR up to 2.1 dB.

SLM reduces large PAPR as compared to the PTS with the only drawbacks which are:

- The complexity of the SLM
- Loss of PAPR which is sometimes caused due to the selection of critical samples in the OFDM symbol.

5.2 Future Scope

Future expansions for this project could include:

1) If the simulink model runs successfully on the DSP kit having two wireless modems data transmission and reception are possible where a wireless link is established.

2) The need for side information transmission with the OFDM signals can be eliminated using the BSLM (Blind Selected Mapping) method after some research work.

3) More reduction is PAPR can be achieved by using different encoding and block coding techniques.

Appendix A

List of Abbreviations

OFDM	Orthogonal Frequency Division Multyplexing
IFFT	Frequency to Time Domain Conversion
PAPR	Peak to Average Power Ratio
CCDF	Complementary Cumulative Distribution function
CDF	Complementary Cumulative Distribution
PTS	Partial Transmit Sequence
SLM	Selected Mapping Technique
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
FFT	Fast Fourier Transform
CDMA	Code Division Multiple Access
DSP	Digital Signal Processing
DAB	Digital Audio Broadcasting
DVB	Digital Video Broadcasting
BSLM	Blind Selected Mapping
IDFT	Inverse Discrete Fourier Transform

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