PEAK-TO-PEAK AVERAGE POWER RATIO REDUCTION IN ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING SYSTEM USING THE COMBINATION OF COMAPNDING AND PRE-CODING TECHNIQUES

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By

OOI XIN KAI

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LIST OF ABBREVIATIONS

OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak-to-Average Power Ratio
4G	Fourth Generation
ISI	Inter Symbol Interference
HPA	High Power Amplifier
SQRT	Square-Rooting Companding Technique
CP	Cycle Prefix
FFT	Fast Fourier Transform
CFO	Carrier Frequency Offset
ICI	Inter-Carrier Interference
CCDF	Complimentary Cumulative Distribution Function
PTS	Partial Transmit Sequence
SLM	Selective Mapping
BER	Bit Error Rate
DCT	Discrete Cosine Transform
WHT	Walsh-Hadamard Transform
FWHT	Fast Walsh-Hadamard Transform
PSK	Phase-Shifts Keying
ASK	Amplitude-Shift Keying

PENGURANGAN PAPR DALAM SISTEM OFDM DENGAN MENGGUNA KOMBINASI TEKNIK COMPANDING DAN TEKNIK PRA-CODING

ABSTRAK

Kekerapan Ortogon Division Multiplexing (OFDM) telah digunakan secara meluas dalam bidang aplikasi komunikasi tanpa wayar. Namun, kelemahan utama untuk sistem OFDM adalah nisbah kuasa puncak kepada purata (PAPR). PAPR adalah salah satu masalah yang paling penting dalam OFDM apabila fasa bebas daripada subpembawa sering akan menggabungkan membina. PAPR tinggi mengurangkan kecekapan sistem dan meningkatkan kerumitan sistem. Dalam projek ini, teknik utama yang digunakan untuk mengurangkan PAPR yang tinggi dalam sistem OFDM adalah companding undang μ dan companding eksponen. Algoritma kedua-dua teknik comapnding akan diperkenalkan kemudian. Teknik pra-coding akan disiasat untuk bergabung dengan algoritma yang companding undang μ dan companding eksponen untuk meningkatkan pengurangan PAPR. Beberapa teknik companding bertambah baik telah direka buntuk untuk menyelesaikan masalah ini, termasuk DCT companding undang μ, FWHT companding undang μ, DCT companding eksponen dan FWHT companding eksponen. Teknik kombinasi yang dicadangkan telah disimulasikan dengan Matlab untuk menyiasat keputusan tentang pengurangan PAPR dan BER. Prestasi teknik kombinasi yang dicadangkan telah dianalisis

dan dibincangkan. Bagi pelaksanaan pengurangan PAPR mengenai teknik kombinasi yang dicadangkan, teknik yang terbaik adalah teknik DCT companding undang μ disebabkan oleh peningkatan tertinggi dalam PAPR, iaitu 2,044 (31.16%) dengan modulasi QPSK pada N = 64. Untuk prestasi daripada BER, nilai BER daripada teknik DCT companding undang μ (0,2288) dan teknik FWHT companding undang μ (0,2357) adalah lebih tinggi daripada teknik- teknik eksponen.

PAPR REDUCTION IN OFDM SYSTEM USING THE COMBINATION OF COMAPNDING AND PRE-CODING TECHNIQUES

ABSTRACT

An orthogonal Frequency Division Multiplexing (OFDM) system has been widely used in the field of wireless communication application. However, there is a major drawback for OFDM systems which is high Peak to Average Power Ratio (PAPR). PAPR is one of the most important problems in OFDM when the independent phase of the subcarrier will often combine constructively. High PAPR reduces the system efficiency and increases the system complexity. In this project, the main technique used to reduce the high PAPR in OFDM system are μ-law companding and exponential companding. The algorithm of the both techniques will be introduced. Pre-coding technique will be investigated to combine with the algorithm of the μ-law companding and exponential companding to improve the PAPR reduction. DCT μ-law companding, FWHT μ-law companding, DCT exponential companding and FWHT exponential companding have been designed to reduce the problem of high PAPR. The proposed combined techniques had been simulated by Matlab software to investigate the result about the reduction of PAPR and Bit Error Ratio (BER). For the performance of PAPR reduction about the proposed combined techniques, the best technique is DCT μ-Law Companding Technique due to its highest improvement in PAPR, which is 2.044 (31.16%)

with modulation of QPSK at N = 64. For the performance of BER, the BER of the DCT μ-law companding technique (0.2288) and FWHT μ-Law companding technique (0.2357) is significantly higher than exponential techniques.

CHAPTER 1

INTRODUCTION

1.1 Background

The orthogonal frequency division multiplexing (OFDM) is a technique for multicarrier modulation scheme in both wireless and wired communication systems for the transmission of multimedia data. However, there is a major drawback for OFDM systems which is high Peak-to-Average Power Ratio (PAPR). This paper proposes the method about the combination of companding and pre-coding technique for PAPR reduction of OFDM system.

In this era of moderation, OFDM systems has been widely used in the field of wireless communication application such as DSL Internet access, power line networks, wireless networks, and Fourth Generation (4G) mobile communications. It is a fact that OFDM systems are effective in the field of wireless communication application. OFDM is an efficient modulation technique due to its high data rate, high spectral efficiency and mitigating wireless impairments.

OFDM basically operates on the principle of splitting high rate data stream into several low rate streams being transmitted simultaneously over a number of subcarriers [1]. One of the main advantages of OFDM system is no Inter Symbol Interference (ISI) due to that of many subcarriers enables much longer symbol duration which makes the signal more robust to multipath dispersion.

In this project, two types of companding techniques which are μ-law companding and exponential companding will be used to reduce the high PAPR in OFDM system. The companding technique used will be improved by the combination with other companding techniques such as pre-coding technique and clipping technique to improve the overall reduction of PAPR.

1.2 Problem Statement

Recently, the usage for multimedia wireless communication applications have grown tremendously and it leads to research attention from academics, researchers and industries in the field of wireless communication. The transmitted signal of OFDM exhibits a high Peak-To-Average Power Ratio (PAPR). High PAPR occurs due to large envelope fluctuations in OFDM signal which requires a highly linear high power amplifier (HPA).

High PAPR is one of the most important problems in OFDM and it will reduce the system efficiency and increase the system complexity. The high PAPR problem is more significant in the near future due to the high usage of mobile device where the efficiency of power amplifier is more critical with the mobile device of limited battery power.

For this work, combined technique has been proposed to reduce the high PAPR in OFDM system. The effect of the combination of companding technique and pre-coding technique for PAPR reduction in OFDM system will be investigated.

1.3 Objectives

1. To develop the method about the combination of companding technique and pre-coding technique for PAPR reduction in OFDM system.
2. To analyse the result of the reduction of PAPR by using the combination of companding technique and pre-coding technique.

1.4 Project Scope

In this project, companding technique is used as the main technique to reduce the PAPR in OFDM system. There are many types of companding technique, such as A-law companding, are μ-law companding, exponential companding, companding using airy function**,** square-rooting companding technique (SQRT) and others.

Two types of companding techniques which are μ-law companding and exponential companding will be used to reduce the high PAPR in OFDM system in this project. The companding technique used will be combined with other PAPR reduction techniques such as pre-coding technique and clipping technique to improve the overall reduction of PAPR.

This project solely focused on the theoretical justification and simulation of companding technique for PAPR reduction of OFDM system. In this project, QPSK, 16-QAM and 64-QAM are used as modulation scheme. The performance of the companding technique for PAPR reduction of OFDM system will be analysed based on the simulation result.

1.5 Thesis Organization

This report consists of five chapters. Chapter 2 will present the literature review about the overview of Orthogonal Frequency Division Multiplexing (OFDM), the overview of Peak to average power ratio (PAPR), the introduction of PAPR reduction technique, μ -Law companding, exponential companding, pre-coding technique and combination of μ -Law companding and pre-coding technique.

Chapter 3 will present the steps and methods for this project. First, the project implementation flow will be discussed and the project implementation flow chart will be shown. After that, the parameters used in PAPR reduction techniques will control the output of the simulation result. Then, the important steps in project design of combination of companding technique and pre-coding technique will be discussed. Next, project requirement will be reviewed and a summary will be made lastly.

Chapter 4 will present the result and discussion based on the simulation of the proposed combination of companding technique and pre-coding technique. The performance of PAPR and BER about the combination of companding technique and pre-coding technique will be investigated.

Lastly, Chapter 5 will presents about the conclusion, limitations and future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will present an overview of Orthogonal Frequency Division Multiplexing (OFDM), peak-to-average power ratio (PAPR), the introduction of PAPR reduction technique, μ -Law companding, exponential companding, pre-coding techniques, the combination of pre-coding and μ -law companding techniques and summary.

2.2 Orthogonal Frequency Division Multiplexing (OFDM)

Orthogonal Frequency Division Multiplexing (OFDM) has been developed into a popular scheme for common used wideband digital communication applications such as digital television and audio broadcasting, wireless networks, DSL internet access and 4G mobile communications.

For the operation of OFDM, a block of *N* information symbols is transmitted in parallel on *N* subcarriers. An OFDM modulator can be implemented as an IFFT on a block of *N* information symbols followed by cycle prefix (CP) [2].The block diagram of OFDM system as shown in Figure 2.1 [2]. The complex representation of OFDM signal can be expressed as:

$$x\,(k) = \frac{1}{N}\sum_{n=0}^{N-1} X_n e^{\frac{j2\pi nk}{N}} \quad ;\; k = 0,1 \ldots \ldots \ldots, N-1 \qquad (2.1)$$

Where,

X_n is the mapped information data

N is the number of subcarriers

x(k) is the IFFT output signal

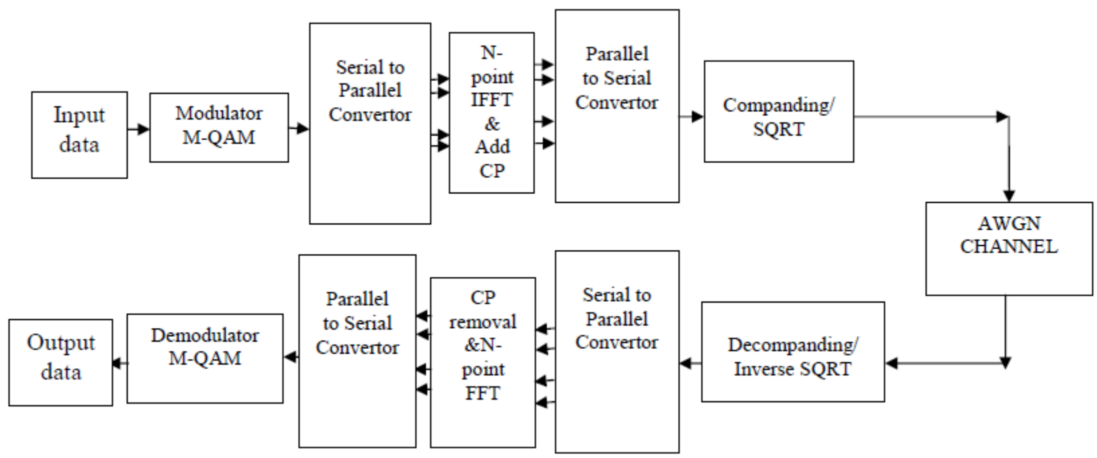

Figure 2.1: Block Diagram of OFDM System [2]

In the OFDM system, the inverse of the transmitter is performed by the receiver. By using the serial to parallel convertor, OFDM data are divided from serial data stream into parallel data sets. Then, the domain samples are converted back into a frequency domain representation by the Fast Fourier Transform (FFT). Thus, magnitudes of the frequency components correspond to original data. Finally, the parallel data are converted by the parallel to serial convertor block into a serial stream to recover the original input data [2].

2.3 Peak-to-average Power Ratio (PAPR)

Peak-to-average power ratio (PAPR) is a measurement of a waveform calculated from the peak amplitude of the waveform divided by the Average value of the waveform as shown in Figure 2.2 [3]. Large envelope fluctuation in OFDM signal is one of the major drawbacks of OFDM [4] which create difficulties due to the practical communication systems are peak power limited.

Generally, the main usage of PAPR is to characterize the envelope fluctuation of the OFDM signal. OFDM systems need the tight frequency synchronization due to the subcarriers is narrowband in OFDM. In addition to this, the orthogonality between the subcarriers is disturbed by the carrier frequency offset (CFO), and therefore the signal on any particular subcarrier will not remain independent of the remaining subcarriers. This phenomenon is known as inter-carrier interference (ICI), which is a big challenge for error-free demodulation and detection of OFDM symbols [4].

The PAPR for an OFDM signal x[n] is defined as ratio of maximum signal power to average power of signal [1] which is as shown as formulae below:

$$PAPR = 10\log\frac{max|x[n]|^2}{Avg|x[n]|^2} \tag{2.2}$$

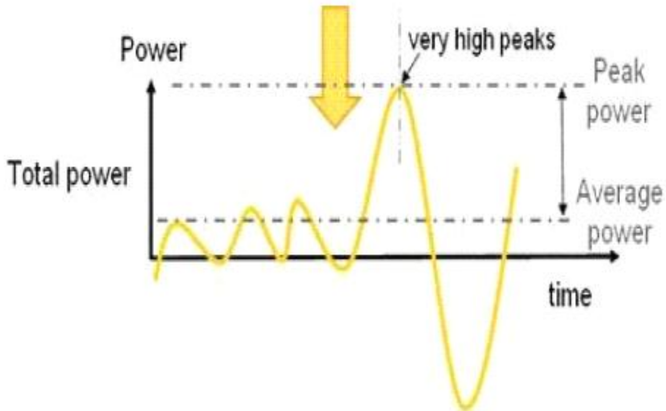

Figure 2.2: Representation of PAPR [3]

After that, the reduction of PAPR is investigated by the complimentary cumulative distribution function (CCDF) which indicates the probability when the PAPR exceeds over a certain threshold. The CCDF of PAPR can be applied to determine the bounds for the minimum number of redundancy bits required to identify the PAPR sequences and evaluate the performance of any PAPR reduction schemes [2]. CCDF can be expressed as:

$$\text{CCDF} = \text{Probability}\ (\text{PAPR} > \text{PAPR}_0) \tag{2.3}$$

Where,

$PAPR_0$ is the threshold level

In simple words, the reduction of PAPR is important to solve the difficulties of OFDM systems. The PAPR reduction techniques will be introduced in the next session.

2.4 PAPR Reduction Techniques

Several PAPR reduction methods have been proposed to solve the main drawbacks of OFDM systems. Based on the proposed schemes, the PAPR reduction methods can be divided into distortion based technique and non-distortion technique.

Distortion based PAPR reduction techniques are the schemes that introduce spectral re-growth belong to distortion based categories which are the most straightforward PAPR reduction methods. The examples of the distortion based PAPR reduction techniques are including clipping, μ-law companding, exponential companding, linear companding transform, and trapezium distribution.

Meanwhile, non-distortion PAPR reduction schemes do not distort the shape of the OFDM signal and therefore no spectral regrowth takes place [4]. The examples of the non-distortion based PAPR reduction techniques are including Coding Technique, PTS (Partial Transmit Sequence) and Selective Mapping (SLM) Scheme.

For this work, the main companding technique used to reduce the high PAPR in OFDM system are μ-law companding and exponential companding. The algorithm of the both techniques will be introduced later. Pre-coding technique will be investigated to combine with the algorithm of the μ-law companding and exponential companding to improve the PAPR reduction.

2.5 µ-Law Companding

The method of companding technique was first proposed in, which employed in classical µ-law (Mu-law) transform and showed effective. Since then many different companding transform with better performance have been published [5]. A µ-law companding technique utilizes µ-law algorithm companding transform by compressing the peak signals and enlarging the small signals for reducing PAPR [6]. An OFDM transmitter based on µ-law companding is depicted in Figure 2.3.

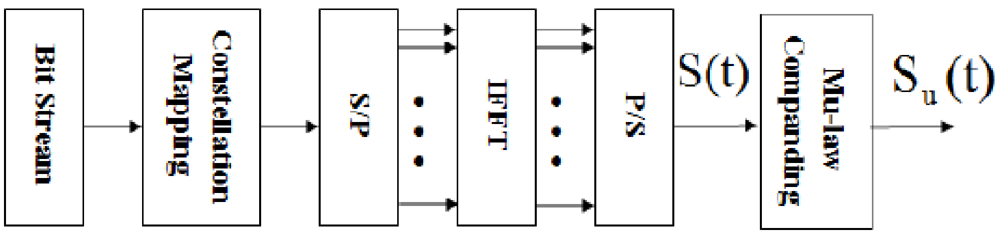

Figure 2.3: Block Diagram of µ -Law Companding Scheme in the OFDM Transmitter. [6]

The signal by utilized µ -law compression characteristic is defined as [6]:

$$S_u(t) = \frac{\ln\left[1 + \mu \frac{|S(t)|}{S_{max}(t)}\right]}{\ln(1+u)} . S_{max}(t). Sgn(S(t)) \tag{2.4}$$

Where,

μ is the µ-law parameter of the compander, which controls the amount of compression

S(t) is instantaneous amplitude of the input

S_{max} (t) is the peak amplitude of *S(t)*

Sgn is a Sign function

2.6 Exponential Companding

J. Tao proposed a new non-linear companding technique, namely exponential companding that can effectively reduce the PAPR of transmitted (companded) OFDM signals by transforming the statistics of the amplitudes of these signals into uniform distribution in 2005 [7]. Figure 2.4 shows the block diagram of a typical OFDM system using the non-linear companding technique for PAPR reduction.

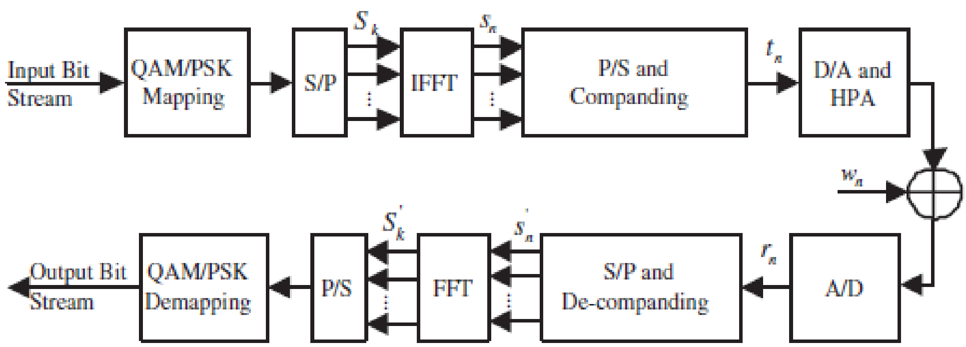

Figure 2.4: OFDM System using Non-linear Companding Technique [7]

Exponential companding technique has the advantage of maintaining a constant average power level. Let $|t_n|^d$, the d^{th} power of the amplitude of companded signal t_n, have a uniform distribution in the interval $[0, \alpha]$. The exponent d is called the degree of a specific exponential companding scheme. The Cumulative Distribution Function (CDF) of $|t_n|^d$ is simply [7] :

$$F_{|t_n|^d} = \frac{x}{\alpha}, \qquad 0 \le x \le \alpha \tag{2.5}$$

Considering the phase of input signals, the companding function *h(x)* is given by [7]:

$$\begin{aligned} \mathrm{h(x)} &= \mathrm{sgn(x)} \mathrm{F^{-1}}_{|t_n|}\left(\mathrm{F}_{|s_n|}(x)\right) \\ &= \mathrm{sgn(x)} \sqrt[d]{\alpha[1-\exp(\frac{x^2}{\sigma^2})]} \end{aligned} \tag{2.6}$$

Where,

sgn(x) is the sign function. The positive constant *α* determines the average power of output signals. In order to keep the input and output signals at the same average power level [7] :

$$\alpha = \left(\frac{\mathrm{E}[|\mathrm{s_n}|^2]}{\mathrm{E}\left[\sqrt[d]{[1-\exp(\frac{|s_n|^2}{\sigma^2})]^2}\right]} \right)^{\frac{d}{2}} \tag{2.7}$$

At the receiver side, the inverse function *h(x)* of is used in decompanding operation is shown [7]:

$$\mathrm{h^{-1}(x)} = sgn(x)\sqrt{-\sigma^2 log_e(1-\frac{x^d}{\alpha})} \tag{2.8}$$

2.7 Pre-coding Techniques

The aim of the pre-coding technique is to reduce the PAPR in the OFDM system. The PAPR reduction must compensate the non-linearities of the HPA having as effect the reduction of the bit error rate (BER) [8]. Figure 2.5 below shows the block scheme of pre-coding technique in OFDM system [8].

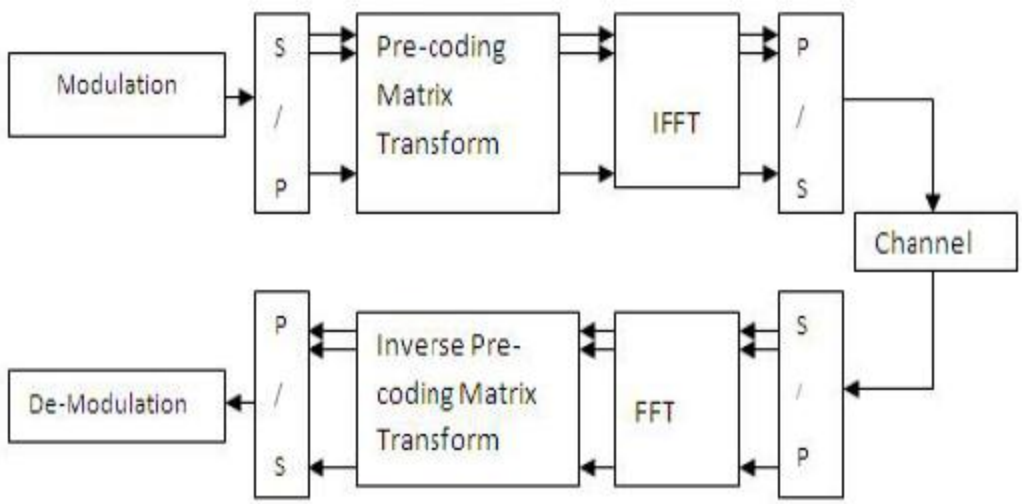

Figure 2.5: Block scheme of Pre-coding technique in OFDM system [8]

There a several types of pre-coding techniques. One of the pre-coding techniques is the discrete cosine transform (DCT). Mathematically, the unitary DCT of an input sequence *x* is [8]:

$$\mathrm{y(k)} = \mathrm{w(k)} \sum_{n=1}^{N} x(n) cos \frac{\pi(2n-1)(k-1)}{2N}, \qquad \mathrm{k} = 1 \ldots \mathrm{N}$$

$$\text{where } \mathrm{w(k)} = \begin{cases} \frac{1}{\sqrt{N}}, & k = 1 \\ \sqrt{\frac{2}{N}}, & 2 \leq k \leq N \end{cases} \qquad (2.9)$$

The Walsh-Hadamard Transform (WHT) is a pre-coding technique that decomposes a signal into set of basic functions. Like the FFT, the Walsh–Hadamard transform has a fast version, the fast Walsh–Hadamard transform (FWHT) which is able to represent signals with sharp discontinuities more accurately using fewer coefficients than the FFT. The FWHT for a signal *x* of length *N* is defined as [8]:

$$y_n = \frac{1}{N}\sum_{i=0}^{N-1} x_i WAL(n.i)$$

$$x_i = \frac{1}{N}\sum_{i=0}^{N-1} y_n WAL(n.i) \tag{2.10}$$

Where

i = 0, 1….N-1 and $WAL(n,i)$ are Walsh functions

2.8 Combination of Pre-coding and μ -Law Companding Techniques

Pre-coding and companding are some of the most efficient techniques to reduce PAPR in OFDM system. In this section, a combinative scheme is proposed by using precoding and μ -Law companding techniques for reducing PAPR. An OFDM transmitter combines precoding approach in frequency domain with μ-Law companding scheme in time domain is shown in Figure 2.6 [9].

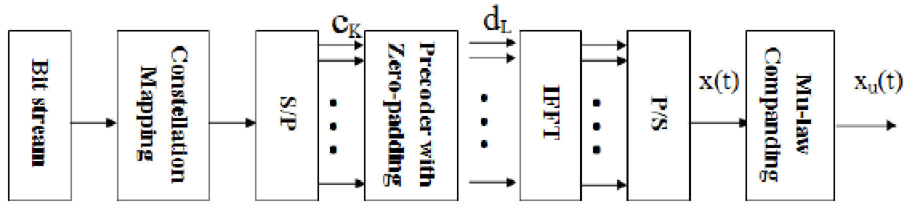

Figure 2.6: Block Scheme of Combination of Pre-coding and μ -Law Companding Technique in OFDM [9]

Figure 2.7 plot the complementary cumulative distribution function (CCDF), which is defined as the probability that the PAPR exceeds a certain threshold $PAPR_0$ for precoding, μ -Law technique, and the combination of precoding with μ -Law technique, respectively[9].

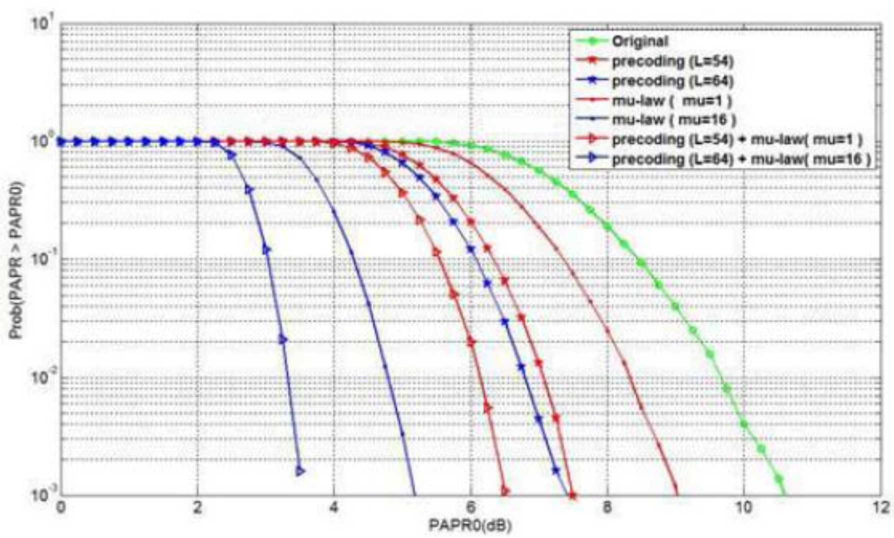

Figure 2.7: Complementary Distribution Function of the PAPR of QPSK-OFDM Signals Using the Pre-coding, μ-Law, and the Combination of Pre-coding and μ-Law Technique, respectively [9]

2.9 Bit Error Ratio (BER)

The performance of BER is obtained by including the noise created during the transmission in channel. BER can be calculated by using following equations [5]. Let $y(t)$ denote the output signal of the compander, $w(t)$ the white Gaussian noise. The received signal can be expressed as:

$$\mathrm{z(t)} = y(t) + w(t) \tag{2.11}$$

The decompanded signal $\check{x}(t)$simply is:

$$\check{\mathrm{x}}(\mathrm{t}) = f^{-1}\,[y(t) + w(t)] \tag{2.12}$$

Using the first order Taylor series expansion,

$$\check{\mathrm{x}}(\mathrm{t}) = x(t) + \frac{df^{-1}(u)}{du}\,|_{u=y(t)}.\, w(t) \tag{2.13}$$

2.10 Summary

From this chapter, the overview of Orthogonal Frequency Division Multiplexing (OFDM), the overview of Peak to average power ratio (PAPR), the introduction of PAPR reduction technique, μ -Law companding, exponential companding, pre-coding techniques, the combination of pre-coding and μ -law companding techniques are presented. It can be summarized that high PAPR is the major drawback of OFDM system. The combination of companding technique and pre-coding technique can be investigated with the pre-coding techniques. BER will be discussed finally. The methodology of the project will be discussed in next chapter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will present the steps and methods for this project. First, the project implementation flow will be discussed and the project implementation flow chart will be shown. After that, the parameters in PAPR reduction techniques which include the modulation scheme, the parameters for companding techniques and the number of subcarriers used. Then, project design of combined companding techniques will be shown. The project requirement will be discuss next. Finally, a summary will be presented.

3.2 Project Implementation Flow

For this project, two types of companding techniques which are μ-law companding and exponential companding will be improved by DCT pre-coding technique to reduce the high PAPR in OFDM. To start the project, the concept of OFDM and PAPR must be researched. Then, the algorithm of companding techniques and pre-coding technique will be investigated. Then, the PAPR reduction techniques will be implementing by using Matlab simulation based on the research before. If the result is acceptable, it will be proceeded to analyse and evaluation session. Figure 3.1 will show the project implementation flow chart.

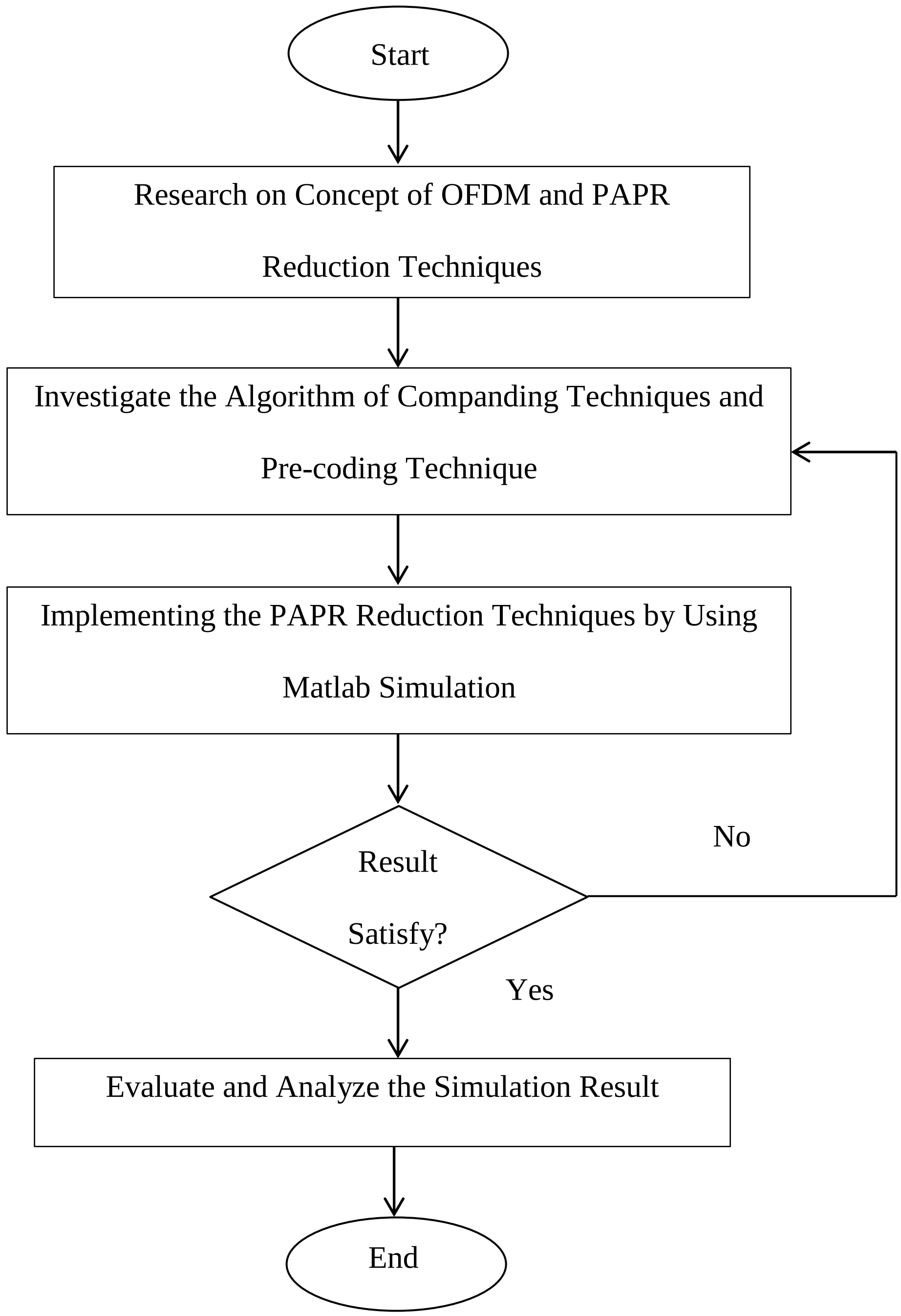

Figure 3.1: Project Implementation Flow Chart

3.3 Project Requirement

This project solely focused on the theoretical justification and simulation of companding technique for PAPR reduction of OFDM system. The simulation of this project is done by using Matlab software to analyze the result of PAPR and BER.

Matlab is a high-performance language for technical computing which integrates computation, visualization, and programming. For this project, QPSK, 16-QAM and 64-QAM are used as modulation scheme. The performance of the companding technique for PAPR reduction of OFDM system will be analyzed based on the simulation result.

3.4 Parameters Used in PAPR Reduction Techniques

Parameters used in PAPR reduction techniques will control the output of the simulation result. The parameters below will be discussed:

1. Modulation scheme
2. Number of subcarriers
3. μ-law parameter for μ-law companding technique
4. d-parameter for exponential companding technique

3.4.1 Modulation Scheme

In this project, QPSK, 16-QAM and 64-QAM are used as modulation scheme. Software Matlab will be used to perform the simulation for these modulation schemes. The performance of the companding technique for PAPR reduction of OFDM system will be analysed based on the simulation result.

QPSK is a form of modulation scheme which uses four phases to construct a QPSK constellation. With four phases, QPSK can encode two bits per symbol, shown in the diagram with Gray coding to minimize the bit error rate (BER). Figure 3.2 below will show the constellation diagram for QPSK.

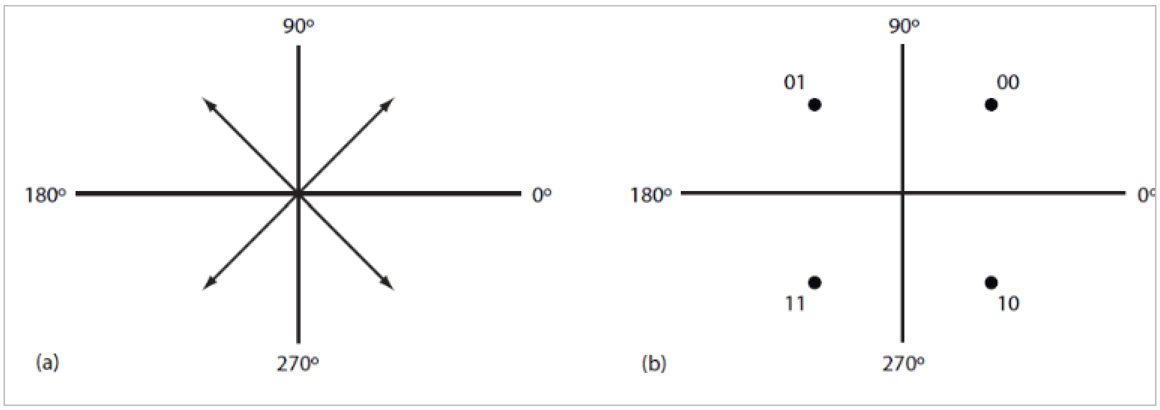

Figure 3.2: Constellation Diagram for QPSK [10]

QAM modulation is a combination of both phase-shifts keying (PSK) and amplitude-shift keying (ASK) which the two carriers in the QAM modulation are shifted in phase by 90 degrees. Figure 3.3 and 3.4 below will show the constellation diagram for 16-QAM and 64-QAM.

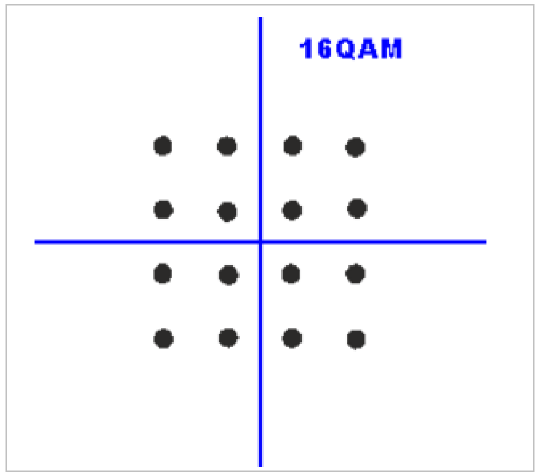

Figure 3.3 Constellation Diagram for 16-QAM [11]

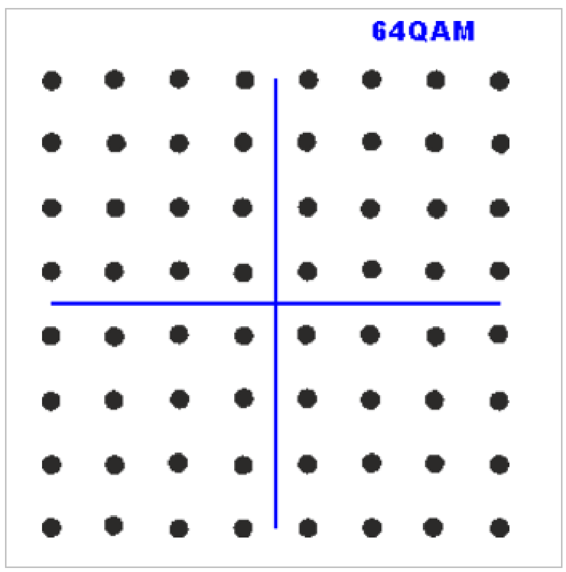

Figure 3.4 Constellation Diagram for 64-QAM [11]

3.4.2 Number of Subcarriers

OFDM system is a channel which divided into many narrower subcarriers. The subcarriers are orthogonal and will not interfere with each other. In other words, the subcarriers are the amount of time the transmitter spends performing IFFT.

The different in number of subcarriers is function for analyze the effect about PAPR in the OFDM system. In this project, the numbers of subcarriers used are 64, 128 and 256. CCDF with varying numbers of subcarriers shows in Figure 3.5 [12].

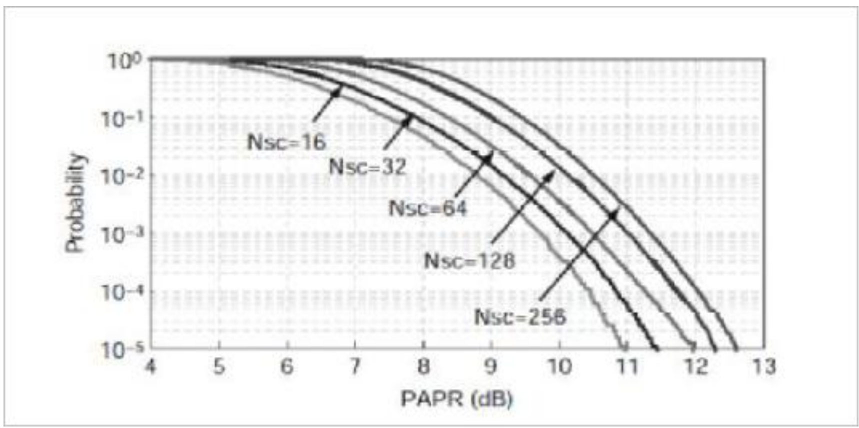

Figure 3.5: CCDF with Varying Numbers of Subcarriers [12]

Subcarriers can be mathematically defined as:

$$S_k(t) = \{\frac{\sin(2\pi k \Delta f t\ ), 0 < t < T, k = 1 \dots N}{0, otherwise} \qquad (3.1)$$

Where Δf are the subcarriers spacing, T is the data symbol period and N is the number of subcarriers. From the Figure 3.5 above, a hypothesis can be made that the PAPR of an OFDM system increase slightly when the number of subcarriers increase.

3.4.3 The μ-law Parameter for μ-Law Companding Technique

The μ-law coefficients of μ-law parameter are responsible for the compression ratio. The value of compression increases with the value of coefficients of μ-law parameter. Companding schemes increase the value of small signals in a way, to bring them in the same level with the high peaks.

For this project, the μ-law compressor parameter chosen for μ-law companding technique is μ=5, which is the nearest to the original OFDM signal. The lower the value of μ-law compressor parameter, the value of PAPR will become higher. Figure 3.6 below shows the μ-law compressor characteristics [12] while Figure 3.7 show the graph of CCDF about the effect of μ-law compressor parameter [13].

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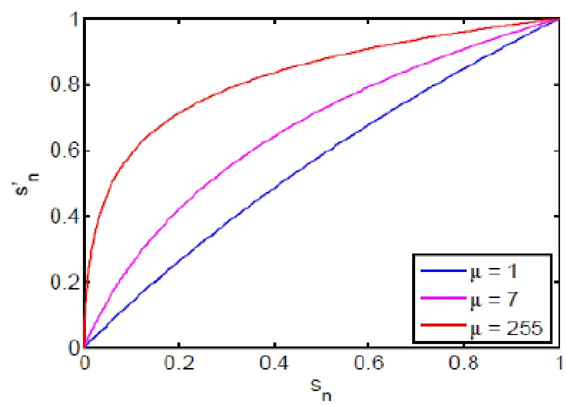

Figure 3.6: Mu-law Compressor Characteristics [12]

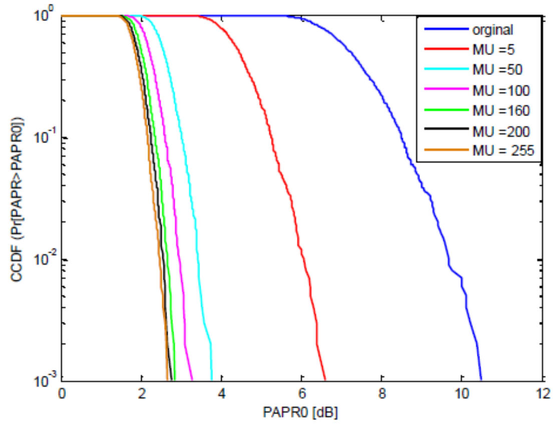

Figure 3.7: Graph of CCDF about the Effect of μ-law Compressor Parameter [13]

3.4.4 The d-Parameter for Exponential Companding Technique

For this project, the d-parameter chosen for exponential companding technique is d=2, which is also the nearest to the original OFDM signal. The higher the value of d-parameter for exponential companding, the value of PAPR will become higher. Figure 3.8 below will show the Graph of CCDF about the effect of d-parameter for exponential companding [13].

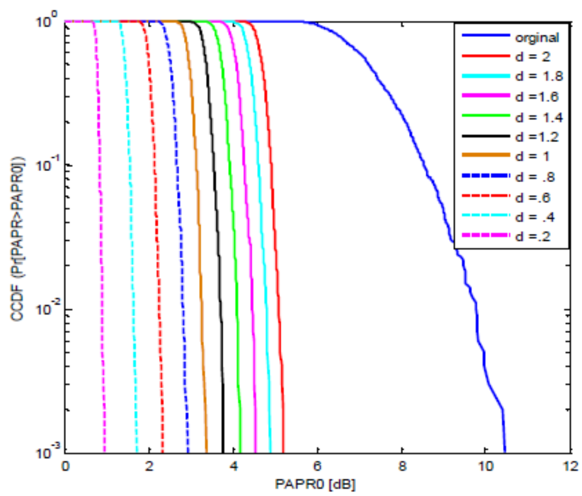

Figure 3.8: Graph of CCDF about the Effect of d-parameter for Exponential Companding [13]