PAPR PERFORMANCE ANALYSIS FOR COMBINATION OF SELECTIVE MAPPING (SLM) AND EXPONENTIAL COMPANDING TECHNIQUE

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PAPR PERFORMANCE ANALYSIS FOR COMBINATION OF SELECTIVE MAPPING (SLM) AND EXPONENTIAL COMPANDING TECHNIQUE

by

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LIST OF ABBREVIATIONS

BER	Bit Error Rate
CCDF	Complementary Cumulative Distributive Function
CF	Clipping and Filtering
COFDM	Coded Orthogonal Frequency Division Multiplexing
DQPSK	Differential Quadrature Phase Shift Key
FFT	Fast Fourier Transform
IFFT	Invert Fast Fourier Transform
MSLM	Modified Selective Mapping
OFDM	Orthogonal Frequency Division Multiplexing
PAPR	Peak Average Power Ratio
PTS	Partial Transmit Sequence
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Key
SLM	Selective Mapping

ANALISIS PRESTASI PAPR UNTUK KOMBINASI PEMETAAN SELECTIVE (SLM) DAN EKSPONEN COMPANDING TECHNIQUE

ABSTRAK

OFDM adalah skim penghantaran multicarrier yang meningkatkan kadar penghantaran data. Walau bagaimanapun, OFDM mempunyai masalah PAPR tinggi yang boleh menyebabkan herotan isyarat. Skim pengurangan PAPR dikenali sebagai SLM-Exp telah diperkenalkan dalam projek ini untuk mengatasi masalah PAPR tinggi OFDM. Untuk menilai prestasi PAPR SLM-Exp, skim SLM-Exp bersama-sama dengan SLM-Mu dan Exponential telah disimulasi dalam MATLAB untuk menilai PAPR di 1×10^{-3} CCDF plot. Prestasi PAPR SLM-Exp telah berbanding dengan SLM-Mu, dan skim Exponential dengan bilangan subpembawa, turutan fasa dan skim modulasi diubah. Bilangan kebimbangan subpembawa dalam projek ini adalah 64, 128, 256, dan 1512. Bilangan urutan fasa kebimbangan dalam projek ini adalah 8, 16 dan 32. Untuk skim modulasi, QPSK, 16 QAM, dan 64 QAM adalah dalam pertimbangan di projek ini. Hasil kajian menunjukkan bahawa nilai PAPR SLM-Exp di 1×10^{-3} CCDF plot adalah lebih baik daripada SLM-Mu dari 0.53dB ke 2.31dB dan 0.10dB ke 0.61dB untuk skim Exponential apabila bilangan subpembawa berubah. Keputusan juga menunjuk bahawa prestasi PAPR SLM-Exp adalah lebih baik daripada SLM-Mu dari 0.99dB ke 1.63dB apabila nombor jujukan fasa berubah.

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ABSTRACT

OFDM was a multicarrier transmission scheme that increase data transmission rate. However, OFDM has high PAPR problem which can cause signal distortion. A PAPR reduction scheme known as SLM-Exp was introduce in this project to overcome high PAPR problem of OFDM. To evaluate the PAPR performance of SLM-Exp, SLM-Exp scheme along with SLM-Mu and Exponential were simulated in MATLAB for PAPR value at 1×10^{-3} of CCDF plot. PAPR performance of SLM-Exp was compare with SLM-Mu, and Exponential scheme as number of subcarrier, phase sequence and modulation scheme varied. The number of subcarrier concern in this project were 64, 128, 256, and 512. Number of phase sequence concern in this project were 8, 16 and 32. For modulation scheme, QPSK, 16 QAM, and 64 QAM were concern in this project. The result shows that PAPR value of SLM-Exp at 1×10^{-3} of CCDF plot was better than SLM-Mu by 0.53dB to 2.31dB and 0.10dB to 0.61dB for Exponential scheme as number of subcarrier varied. Result also shows that PAPR performance of SLM-Exp is better than SLM-Mu by 0.99dB to 1.63dB as number of phase sequence varied.

CHAPTER 1

INTRODCUTION

The chapter 1 of this report discuss the background of OFDM. Then, problem statement about the current combination of PAPR reduction scheme. After that, objective of this project follows by the scope of the project, and chapter organization of the report.

1.1 Project Background

OFDM was multicarrier transmission scheme used for both wireless and wired communication. In multicarrier transmission scheme, the bandwidth of the spectrum was subdivided into many carriers. Each carrier was then modulated with data and multiplex orthogonally. Since the carrier was orthogonal to each other, the carrier spectrum was a null at the central frequency of another carrier. Hence, there was no interference between carrier and they can space close together. The advantage of using OFDM scheme were high spectral efficiency, multipath fading and co-channel interference resistance [1, 3].

Despite the advantages, there were some drawback in OFDM scheme. First drawback was OFDM signal has high PAPR which cause signal distortion [1]. PAPR was the ratio of maximum power of an OFDM sample within the transmit symbol to the average power of the OFDM sample within the transmit symbol. An example of high PAPR was N times the average power occurs when N signal which all has the same phase were added together. The high PAPR was sensitive to nonlinear amplifier and can cause signal distortion. The signal distortion was due to amplifier operate in nonlinear region due high PAPR. The signal distortion further causes intermodulation and out of band radiation problem [4].

To overcome high PAPR problem, two categories of PAPR reduction technique has been introduced. The first category was signal distortion technique and the second category was data scrambling technique [2]. The examples of signal distortion technique were clipping and filtering (CF), peak cancelation, peak windowing, and companding. The disadvantage of this technique was BER degradation. On the other hand, data scrambling technique examples were Selective Mapping (SLM), and Partial Transmit Sequence (PTS). Unlike signal distortion technique, data scrambling technique does not cause BER degradation, instead system complexity increases as iteration number and subcarriers require for the system increase [2]. In [2, 5], both the signal distortion technique and data scrambling technique were combined to reduce PAPR.

1.2 Problem Statement

The PAPR was the ratio of sample peak power in time domain to the sample average power in time domain. In other words, PAPR can be reduce if the peak power decrease or average power increase. In exponential companding, the PAPR was reduced by compress sample peak power [13]. In Mu law companding, the PAPR was reduced by increase the average power of the sample [10]. While in SLM, the PAPR was reduced by the means of phase rotation which reduce peak power of the sample [11]. In [5], a combination scheme of SLM and Mu law was introduced and result shown that combination scheme has better PAPR performance than single scheme alone. However, Exponential scheme was not use in [5]. In this project, a combination scheme of SLM-Exp was proposed. Since Exponential has better PAPR performance than Mu law [12], SLM-Exp has better PAPR performance than combination scheme of SLM-Mu, or SLM, Mu law, or Exponential scheme.

To evaluate the PAPR performance of the SLM-Exp scheme, PAPR value of SLM-Exp scheme at 1×10^{-3} of CCDF plot was compare with other PAPR reduction scheme. Several research questions were made to investigate the performance of SLM-Exp scheme. The first question was improvement in PAPR performance of SLM-Exp scheme when compare to SLM-Mu scheme, and Exponential scheme as number of subcarrier of the system varied from 64, 128, 256, to 512. The second question was improvement in PAPR performance of SLM-Exp scheme when compare to SLM-Mu scheme as number of phase sequence increase from 8, 16 to 32.

1.3 Objectives

There are two objectives for this project.

1) To develop a PAPR reduction scheme based on combination of Selective Mapping and exponential companding.
2) To analyze the SLM-Exp scheme performance by comparing PAPR value at 1×10^{-3} of CCDF plot of SLM-Exp scheme with SLM-Mu, and Exponential scheme under various parameter.

1.4 Project Scope

In this project, a PAPR reduction scheme was developed using the combination of Selective Mapping (SLM) and exponential companding. The schemes were simulate using MATLAB 2016A and only concern transmitter part before the high-power amplifier. Thus, only PAPR performance was evaluated and Bit Error Rate (BER) will not be included. The PAPR performance of the schemes was analyze using MATLAB 2016A by plotting Continuous Complementary Distribution Function (CCDF) of PAPR of various PAPR reduction scheme with different parameters such as modulation scheme, number of subcarrier, and number of phases in SLM. The PAPR reduction scheme that involve in CCDF plot were SLM-Exp, SLM-Mu, SLM, Mu, and Exponential scheme. The types of modulation schemes were QPSK, 16 QAM, and 64 QAM while for number of subcarrier, the parameters were 64, 128, 256 and 512. For number of phase sequence, the parameters were 8, 16 and 32.

1.5 Chapter Organization

This final year project report was organized as follow. Chapter 2 of this report describe the literature review about PAPR, companding, Selective Mapping, and related past work regarding combination scheme. Chapter 3 describe the methodology on development of MATLAB code for simulation of PAPR reduction schemes of SLM-Exp, SLM-Mu, SLM, Mu, and Exponential scheme in MATLAB. This chapter also describe the methodology on development of MATLAB code for simulation of performance evaluation of the SLM-Exp scheme in MATLAB. Chapter 4 of this report interpret and discuss the result obtain from chapter 3. Chapter 5 describe the conclusion of this report.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction to Literature Review

Chapter 2 of this report review about the PAPR and CCDF of PAPR, SLM, companding, follow by review on the research that has been done on and combination of SLM and companding scheme.

2.2 PAPR

Peak to Average Power Ratio (PAPR) was one of the main drawback of OFDM system. PAPR was the ratio of maximum power of a sample to the average power of the sample in time domain. Its formula was given in equation 2.1 [4].

$$PAPR = \frac{\max|x(t)|^2}{E[|x(t)|^2]} \tag{2.1}$$

A large PAPR can occur when subcarrier of OFDM signal add up coherently. For example, N signal which has the same phase, when added together produce peak power which was N times the average power of the signal. The high PAPR cause signal distortion as the amplifier force to work in nonlinear region [4]. One of the method to evaluate PAPR was by Complementary Cumulative Distributive Function. The CCDF is a plot of probability of maximum PAPR exceed the threshold value T. Its formula was given in equation 2.2 [6].

$$CCDF(T) = P(Max\ PAPR > T) \tag{2.2}$$

To construct a CCDF plot, 1000 samples of PAPR were require to compute so that probability can be calculate from the samples.

2.3 Selective Mapping (SLM)

In Selective Mapping, a data source was used to produce several alternatives transmit sequence, then sequence with lowest PAPR was transmitted. The original input data in frequency domain with N size, for example D { D_0 , D_1 , D_2 , … , D_{N-1} } was multiplied with a set of independent phase sequence with M as number of phase sequence, for example P { P_0 , P_1 , P_2 , … , P_{M-1} }. The first phase sequence has zero phase to keep the original signal as one of the alternate sequence. After input data was multiplied with each phase in the phase sequence, it produces M number of alternative data sequence. Each alternative data sequence was shifted by phases in phase sequence. Then, IFFT was applied to transform each alternative data sequence in frequency domain to time domain. The PAPR among these alternative data sequence in time domain was calculated and sequence with lowest PAPR was selected to transmit [6, 7]. In SLM scheme, PAPR reduction was achieved by phase rotation of input data in frequency domain which reduce the chance of data with same phase [11]. In [6, 7], PAPR reduction performance decrease as the number of subcarrier increase. In [6], the PAPR reduction performance improve as number of phase sequence increase.

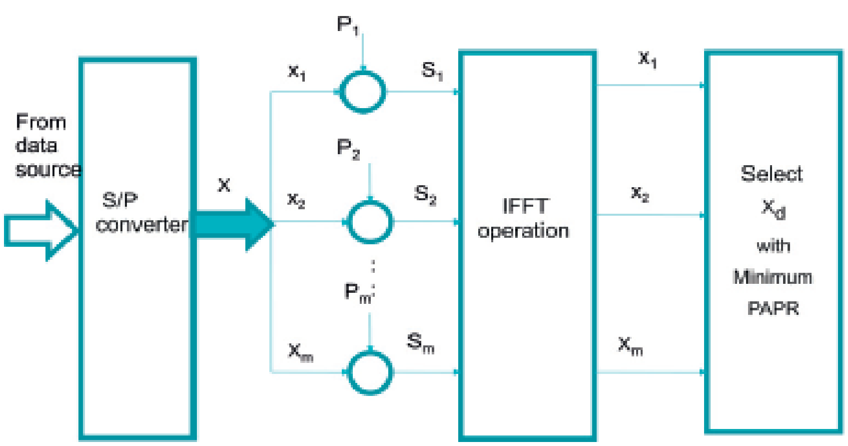

Figure 2.1: Block diagram of SLM [6]

2.3.1 Comment On SLM

Despite the ability to reduce PAPR, there were several problems with SLM. First was the side information about the phase that need to transmit in order to recover the original signal. Second, the PAPR reduction increase as the number of phase sequence increase. When the number of phase sequence M increase, more IFFT require to be done. This means that increase in PAPR reduction can lead to increase in computational complexity [6, 7].

2.4 Non-Linear Companding

In companding, OFDM signal to be transmitted was compressed and received signal was expand. Another feature of companding was it improve quantization resolution of small signal while lower the quantization resolution of large signal. Despite the advantage of PAPR reduction, Bit Error Rate (BER) of the signal was increase [8, 9]. In this section 3 types of non-linear companding was discussed.

2.4.1 Mu Law

The formula for Mu law was shown in equation 2.3 [9]. The x_{max} was maximum amplitude of the input, μ was the Mu law constant where standard value was 255, $sgn(x)$ was the sign function of the input x.

$$Output(x) = x_{max} \frac{\log\left(1+\frac{\mu|x|}{x_{max}}\right)}{\log(1+\mu)} sgn(x) \;\; ; 0 \leq |x| < x_{max} \qquad (2.3)$$

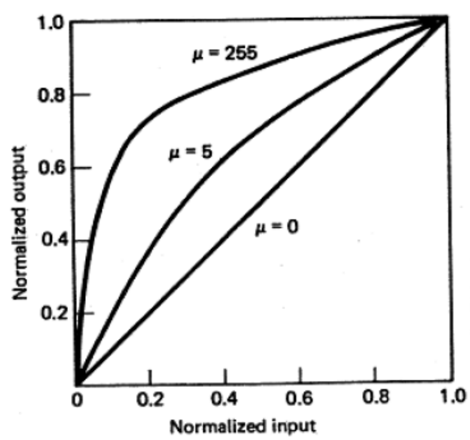

Figure 2.2: Characteristic of Mu law compressor [10]

Figure 2.2 show the characteristic of Mu law compressor as the μ parameter varies. μ was the parameter for controlling amount of compression. From Figure 2.2, high value of μ have higher compression. When μ was 0, there was no compression of input value. The standard value of μ was 255 and was a constant. [10]

2.4.2 A Law

The characteristic of the compressor for A law was piecewise with linear segment for low level input and logarithmic segment for high level input. The formula for A law was shown in equation 2.4 [10]. The A was A law constant where 87.6 was the standard value, x_{max} was the maximum amplitude of input x, $sgn(x)$ was the sign function of the input.

$$output(x) = \frac{A|x|}{1+\log A} sgn(x) \qquad ; 0 \leq |x| \leq \frac{x_{max}}{A}$$

$$output(x) = \frac{x_{max}\left(1+\log\left(\frac{A|x|}{x_{max}}\right)\right)}{1+\log A} sgn(x) \quad ; \frac{x_{max}}{A} < |x| \leq x_{max} \tag{2.4}$$

Figure 2.3 show the characteristic of A law compressor as A parameter varies. When A was 1, there was no compression of input value. The standard value of A parameter was 87.6 [10].

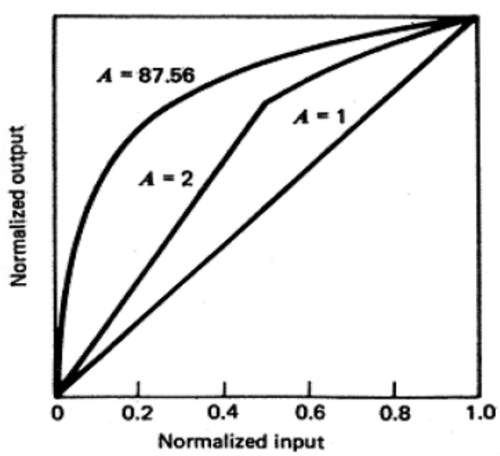

Figure 2.3: Characteristic of A law compressor [10]

2.4.3 Exponential Companding

The characteristic of exponential companding were peak signal compression and small signal expansion while maintain average power. This create uniform distribution of the signal without increase the average power of the signal like Mu law and A law [12, 13]. The formula for exponential companding was shown in equation 2.5 [14].

$$output(x) = sgn(x)\sqrt[d]{\alpha\left[1 - exp\left(-\frac{x^2}{\sigma^2}\right)\right]}$$

$$\alpha = \left[\frac{E[|s_n|^2]}{E\left[\sqrt[d]{\left[1 - \exp\left(-\frac{|s_n|^2}{\sigma^2}\right)\right]^2}\right]}\right]^{\frac{d}{2}} \qquad (2.5)$$

In equation 2.5, $sgn(x)$ was the sign function of input, α was constant that determine average output power of signal, s_n was the input signal, x was original signal, σ^2 was the variance of the signal, d was degree of specific companded scheme and its optimum value was 2 [13, 14]. From Figure 2.4, as d increase, compression of input signal also increases.

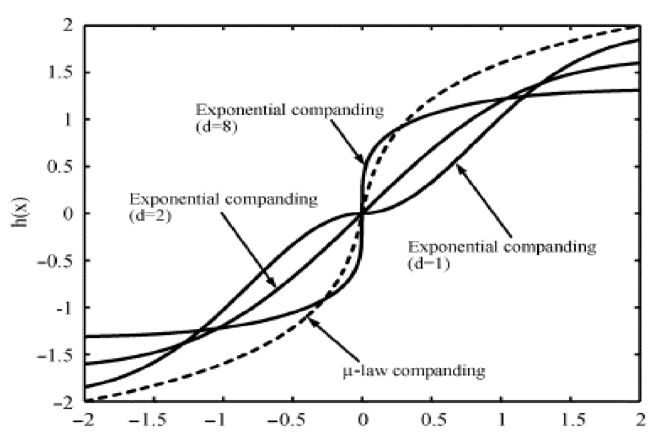

Figure 2.4: Characteristic of exponential companding [14]

2.4.4 Comment on Companding

In this project, exponential companding was used as it has a better compression curve than Mu law and A law. On the other hand, exponential companding does not increase the average power of the signal as Mu law and A law does. Unlike SLM that consist of 3 steps, which was phase rotate, IFFT operation, selection of minimum PAPR, within a scheme, exponential companding scheme, was apply at the time domain of the signal. Lastly, in [12], the CCDF of PAPR comparison show that exponential companding has better PAPR performance than Mu law as show in Figure 2.5.

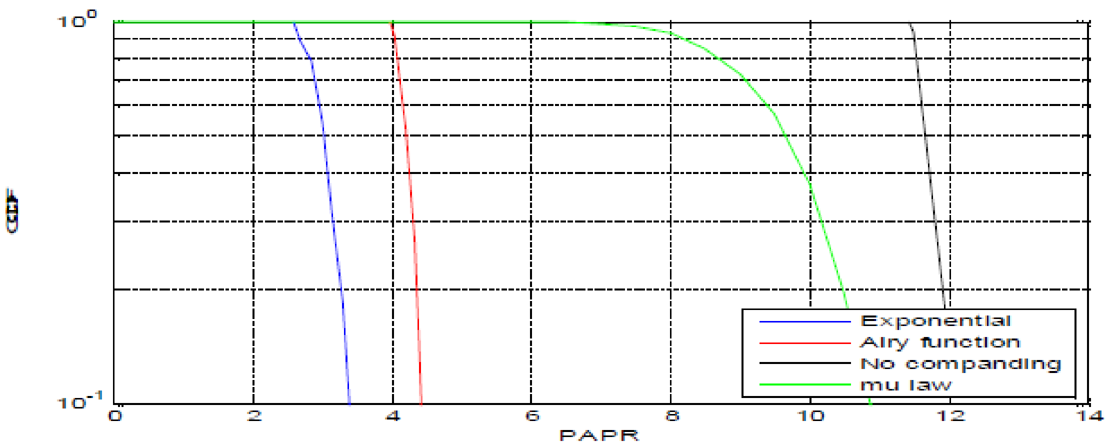

Figure 2.5: CCDF of PAPR in [12]

2.5 Related Work on Combination scheme

In [2], a combination scheme of Selective Mapping (SLM) and A Law was implemented. The parameter involve in this scheme were 16 QAM modulation, 128 subcarriers, and 10000 symbols. In [2], additional convolution coding was applied before QAM modulation. The convolution coding was a type of error correction codes that improve the Bit Error Rate (BER) performance of the system. The block diagram of the combination scheme was shown at Figure 2.6 where it was cascade of Selective Mapping (SLM) and A law technique. CCDF of PAPR result of this paper show that the combination scheme was better than Selective Mapping (SLM) scheme and A law scheme alone. Figure 2.7 show the result of PAPR performance of the combine scheme [2].

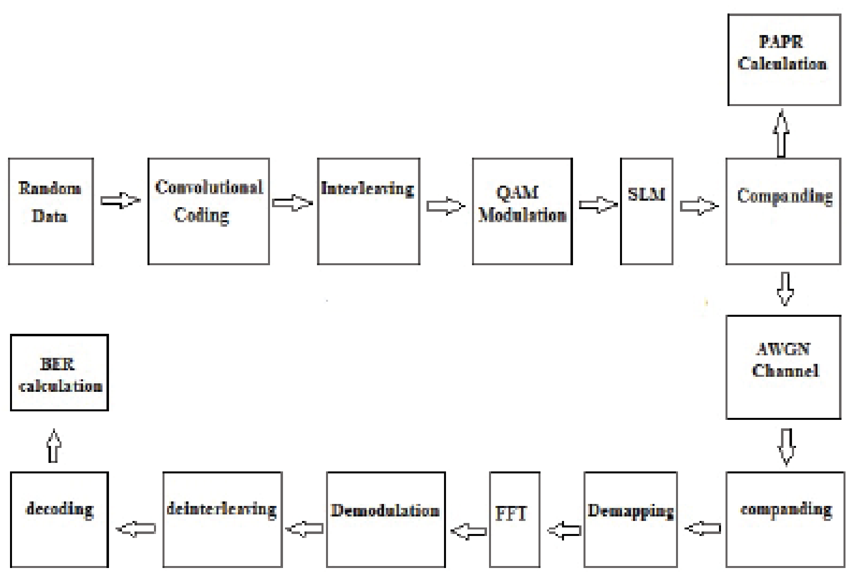

Figure 2.6: Block diagram of COFDM scheme [2]

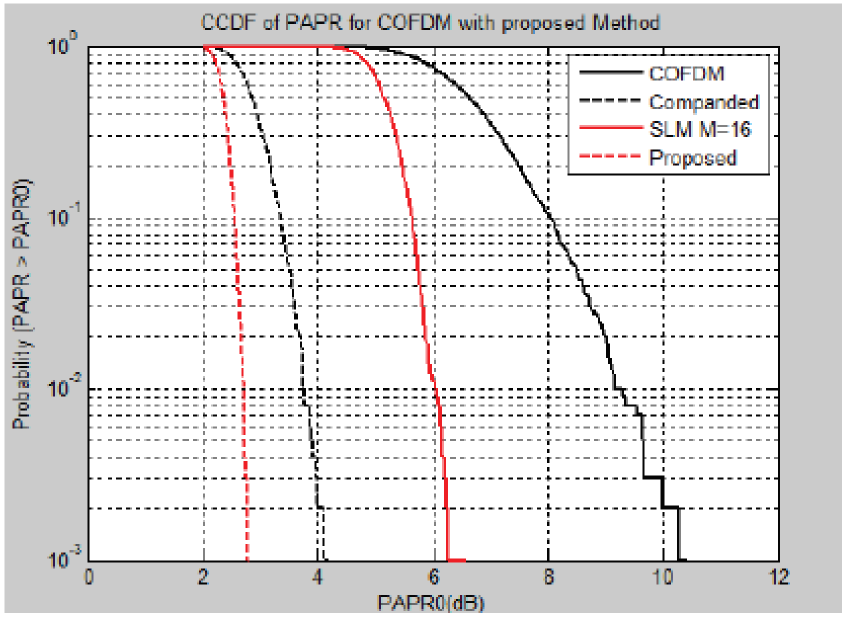

Figure 2.7: CCDF plot of COFDM scheme [2]

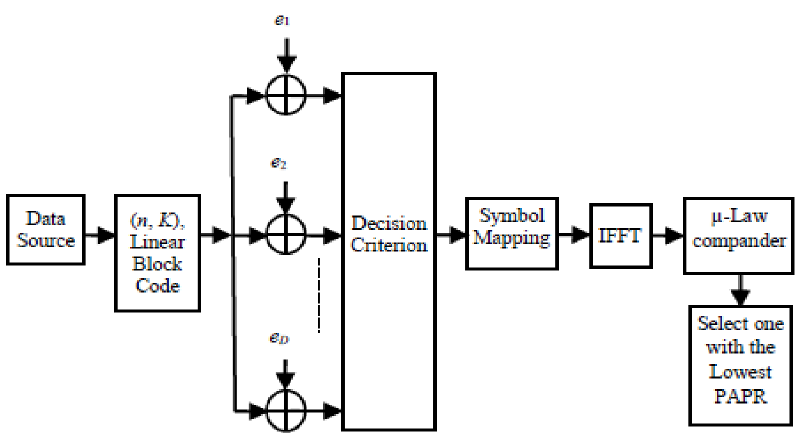

Figure 2.8: Block diagram of combination scheme [5]

In [5], a combination scheme of modified Selective Mapping (MSLM) and Mu law was proposed. Modified SLM (MSLM) reduce the number of IFFT require to perform which in turn reduce computational complexity [7]. In [5], coding technique was applied before the MSLM to further improve BER performance. The parameter involve in this scheme were QPSK, DOPSK and 8QAM modulation, 64 subcarriers, and 900 symbols. The block diagram of the combination scheme was shown in Figure 2.8 where it was cascade of Modified Selective Mapping (MSLM) and Mu law technique. Although combination of SLM and Mu law was not shown directly in this paper, the combination of SLM and Mu law scheme was build and compare to the combination of MSLM and Mu law scheme for its PAPR performance. The result of this paper show that the combination scheme was better than Modified Selective Mapping (MSLM) and Mu law alone. Figure 2.9 show the result of CCDF of PAPR performance for the combination scheme [5].

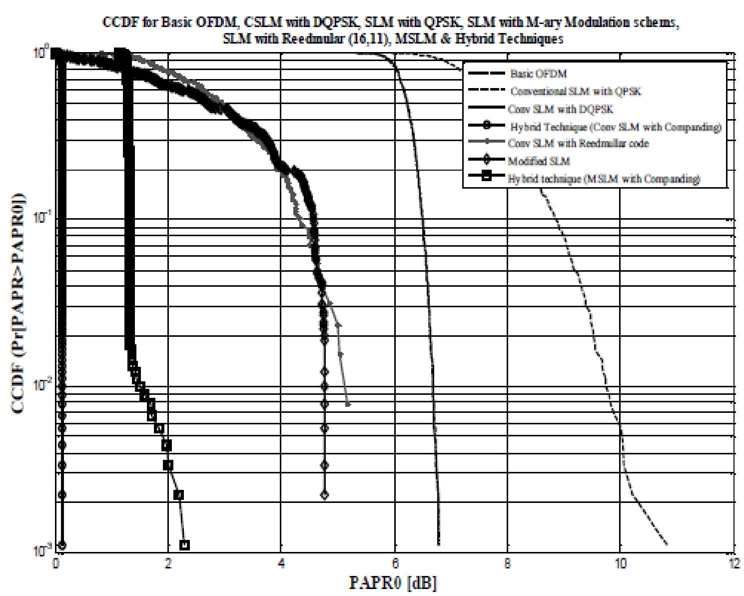

Figure 2.9: CCDF plot of combination scheme [5]

2.4.1 Comment on Related Work of Combination Scheme

In [2, 5], only scheme that cascading SLM first follow by A law and Mu law was done, but the combination of SLM and exponential companding has not been done. Furthermore, the subcarriers used in [5] was 64 only, the scheme with 128 subcarriers or higher or with different modulation scheme like 16 QAM and 64QAM has not been done.

2.5 Summary of Literature Review

In summary, the idea of PAPR, SLM scheme, and companding scheme has been explained in literature review. The related works of combination of SLM and companding scheme have been discuss and the result of the journal show that combination scheme has better PAPR performance than SLM scheme and companding scheme alone. However, the PAPR performance for combination of SLM and exponential companding has not been done. On the other hand, exponential companding have better PAPR performance than Mu law as shown in [12]. In addition, the scheme with different parameter like subcarrier, number of phase and different modulation scheme should be done.

CHAPTER 3

METHODOLOGY

3.1 Introduction of Methodology

In chapter 3, the method to develop combination scheme of SLM and exponential companding was discussed. The scheme was simulate using MATLAB 2016A software. After the combination SLM and exponential companding scheme was developed, the method to analyze the PAPR performance of combination scheme was develop which plot the CCDF of PAPR. Section 3.2 discuss the overall project implementation flow, section 3.3 discuss the requirement for the project, section 3.4 discuss the method to implement SLM and exponential companding and combine it into single scheme in MATLAB and method to plot CCDF of PAPR in MATLAB. Section 3.5 discuss the method to evaluate the PAPR performance of combined scheme. Section 3.6 summarize the methodology.

3.2 Project Implementation Flow

In this project, a combination of SLM and exponential companding scheme was required to develop and CCDF of PAPR was required to analyze the PAPR performance of the combined scheme. In order to compute the CCDF of PAPR, K instant of PAPR was required. Each instant of PAPR can be obtain by simulate the combined scheme with random data. Then from the K instant of PAPR, probability of PAPR greater than threshold (CCDF) was computed and analyzed. Thus, combine scheme of SLM and exponential companding was required to develop first in order to compute CCDF. After the combined scheme was developed, it was implemented inside CCDF block for PAPR performance analysis.

In project implementation flow, the program flow of CCDF was discussed as it includes the combined scheme of SLM and exponential companding and CCDF plot was the result that require to show at the end of the project. The CCDF plot of combined scheme was then compare with CCDF plot of other PAPR reduction scheme and with different parameter.

In OFDM system, each instant of data in time domain consist of N data which orthogonally multiplex in frequency domain. The orthogonality of the N data in frequency domain can be achieve by applying IFFT on the N data [3]. This convert N data in frequency domain orthogonally to OFDM signal in time domain. In this way, the orthogonality of the OFDM signal can be ensure. At first, to create K symbol of data with N subcarriers, a matrix of N subcarrier by K symbol of random data was generated. This mean that each column of the matrix represents one instant of data and a total of K instant. K instant of data was needed because CCDF require K instant of PAPR value to compute the probability plot. Then the data matrix was QAM modulated. After that, the data was pass through a series of PAPR reduction scheme. The data was first pass through SLM, sequence with minimum PAPR was selected from the alternate data sequence of SLM [6, 7]. Then exponential companding was applied at that sequence with minimum PAPR. The PAPR value was recorded and next symbol from the data matrix was repeated for the simulation of combination scheme for PAPR. After K instant of PAPR was compute, CCDF of PAPR was computed and CCDF of PAPR was plotted.

3.2.1 Flow Chart of Project Implementation Flow

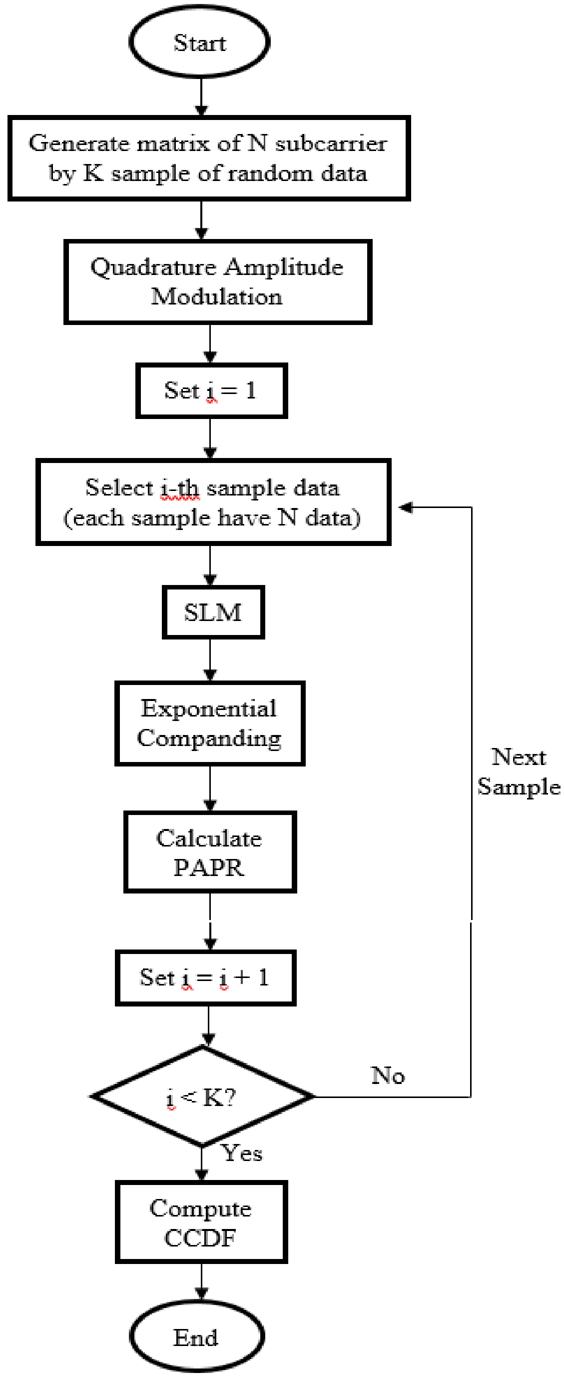

Figure 3.1: Flow chart of project implementation flow

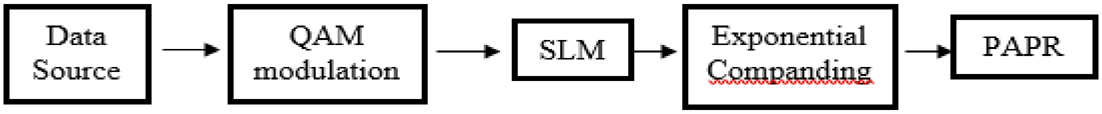

Figure 3.2: Block diagram of combined scheme

3.3 Project Requirement

This project requires MATLAB R2016a software with Communication System Toolbox in order to simulate the combine scheme.

3.4 Process Modelling

In process modelling, the process in the flow chart of project implementation flow was explained and the method to implement the process in MATLAB was shown. The parameter of the combination scheme was 128 subcarriers and 1000 symbol with 16 QAM modulation and 16 number of phase.

3.4.1 Generate Random Data

The parameter in this project was 128 subcarriers and 1000 symbol with 16 QAM and 16 number of phase. Thus, a matrix of 64 by 1000 random data with minimum value of 0 and maximum value of 15 was require to generate. In MATLAB, this can be done by using randi function. Figure 3.3 show the implementation of randi function in MATLAB.

```
data1 = randi([mini,maxi],x,y);
```

Figure 3.3: randi function implementation

The mini and maxi set the minimum and maximum value of random integer, the x and y set the size of the output matrix x by y.

To create a 128 by 1000 matrix with element of random integer between 0 to 15, the randi function was implement as shown in Figure 3.4.

```
data1 = randi([0,15],128,1000);
```

Figure 3.4: randi function for 128 by 1000 matrix

data1 was now a 128 by 1000 matrix with element of random integer between 0 to 15.

3.4.2 Quadrature Amplitude Modulation

After random data was generate, the data was proceeded to quadrature amplitude modulation. Quadrature amplitude modulation in MATLAB can be done by using qammod function. Figure 3.5 show the implementation of qammod function in MATLAB.

```
MODdata1 = qammod(input,Modulation);
```

Figure 3.5: qammod function implication

The input of qammod specify the input data while Modulation specify the type of modulation.

```
MODdata1 = qammod(data1,16);
```

Figure 3.6: qammod function in MATLAB

To apply 16 QAM modulation to input data, qammod function was implement as Figure 3.6. MODdata1 now contain 128 by 1000 matrix of data that has been modulate by 16 QAM.

3.4.3 Combination Scheme

Before develop the combination scheme, some constant data was generated. The constant data are the phase sequence that use in the SLM scheme. Figure 3.7 show the MATLAB code for creating the 16 alternate phase sequence.

```
4    p = [1 -1 1i -1i];
5    ary_phase = [ones(128,1) randsrc(128,15,p)];
```

Figure 3.7: MATLAB code for generate 16 phase angles

In SLM, to rotate the phase of complex signal, the data was multiplied with complex exponential of the desire phase [7]. The line 4 set the possible phase value, and line 5 of the code generate 128 by 16 matrix of random distributed phase. The 128 was due to 128 subcarriers and 15 was due to 16 phase sequences was used in this scheme with first column keep original OFDM signal. The role of the ary_phase matrix was explained in SLM part.

After constant data was generated, the combination scheme of the code was developed. Figure 3.8 show the MATLAB code for the combination scheme.

```
Comb_PAPR_list = zeros(1,1000);
Normal_PAPR_list = zeros(1,1000);
for i = 1:1000
    Current_data = MODdata1(1:128,i);
    datamul = repmat(Current_data,1,16);
    ary_output = datamul.*ary_phase;
    t_ary_output = ifft(ary_output,128);
    mag_sqr = abs(t_ary_output).^2;

    ary_PAPR = zeros(1,16);
    for m = 1:16
        PAPR = 10*log((max(mag_sqr(1:128,m)))/(mean(mag_sqr(1:128,m))));
        ary_PAPR(1,m) = PAPR;
    end

    [min_ary_PAPR,pos_ary_PAPR] = min(ary_PAPR);

    Exp_input_data = t_ary_output(1:128,pos_ary_PAPR);
    Exp_output_data = expcompand(Exp_input_data,2);
    mag_sqr2 = abs(Exp_output_data).^2;
    PAPR = 10*log((max(mag_sqr2))/(mean(mag_sqr2)));
    Comb_PAPR_list(1,i) = PAPR;

    t_data = ifft(Current_data,128);
    Normal_mag_sqr = abs(t_data).^2;
    Normal_PAPR = 10*log((max(Normal_mag_sqr))/(mean(Normal_mag_sqr)));
    Normal_PAPR_list(1,i) = Normal_PAPR;

end
```

Figure 3.8: MATLAB code of combination scheme

At line 7 to line 8, 2 1 by 1000 matrixes of zeros were preassign to serve as memory location for each instant of PAPR of combination scheme and normal OFDM scheme. From line 9 to line 35, the for loop was to simulate the combination scheme 1000 times with the random data generated. This was to create 1000 sample of PAPR for CCDF computation. At line 10, 'Current_data' was set with the data from column i of MODdata1 matrix according to the number of times of simulation. At line 11 a matrix of 128 by 16 was create as 'Current_data' which was 128 by 1 matrix replicate 16 times. The 'Current_data' was dot multiply with 'ary_phase' to produce 16 alternate data sequences. At line 13, the 16 alternate sequence was IFFT to transform data from frequency domain to time domain for PAPR calculation. Line 14 to line 22 was the code to find the position of minimum PAPR sequence from the 16 alternate data sequence. After the sequence with minimum PAPR was located (line 24), the sequence is exponential companded at line 25. Figure 3.9 show the exponential companding function.

```
function y = expcompand(x,d)

magnitudesquare = abs(x).^2;
meanofmag = mean(magnitudesquare);
varian = var(abs(x));
inputsize = length(x);

explowerpart = zeros(1,inputsize);
for i = 1:inputsize
    lowerinnerinnerpart = -1*(magnitudesquare(i,1)/varian);
    lowerinnerpart = (1 - exp(lowerinnerinnerpart))^2;
    explowerpart(1,i) = nthroot(lowerinnerpart,d);
end

meanlowerpart = mean(explowerpart);
constantalpha = (meanofmag/meanlowerpart)^(d/2);

y = zeros(inputsize,1);
for j = 1:inputsize
    xsqu = abs(x(j,1))^2;
    innerpart = 1 - exp(-1*(xsqu/varian));
y(j,1) = sign(x(j,1))*nthroot((constantalpha*innerpart),d);
end

end
```

Figure 3.9: MATLAB code for exponential companding function

The exponential companding function in Figure 3.9 was the code implementation of equation 2.5 in chapter 2 section 2.3.3. The x of exponential companding function was input data and d was the degree of exponential companding. The exponential companding function return the exponential companded signal at y. Line 25 of Figure 17 call the exponential companding function to compress the signal. Line 26 to 28 was the code that calculate and store PAPR value. Line 30 to line 33 compute the PAPR for normal OFDM signal.

3.4.4 Compute CCDF

After 1000 sample of PAPR was compute, the value of PAPR from 'Comb_PAPR_list' and 'Normal_PAPR_list' was used to calculate probability of PAPR greater than certain threshold which was the CCDF [6]. Figure 3.10 show the code block for calculate the CCDF of PAPR.

```
37 -        Size_CCDF_plot = length(0:0.01:round(max(Normal_PAPR_list),2));
38 -        Comb_CCDF_plot = zeros(1,Size_CCDF_plot);
39 -        Normal_CCDF_plot = zeros(1,Size_CCDF_plot);
40 -        q = 0;
41
42 -        for Count = 1:Size_CCDF_plot
43 -        Comb_CCDF_plot(1,Count) = length(find(Comb_PAPR_list > q))/length(Comb_PAPR_list);
44 -        Normal_CCDF_plot(1,Count) = length(find(Normal_PAPR_list > q))/length(Normal_PAPR_list);
45 -        q = q + 0.01;
46 -        end
47
48 -        xplot = 0:0.01:round(max(Normal_PAPR_list),2);
49 -        semilogy(xplot,Comb_CCDF_plot,'-o',xplot,Normal_CCDF_plot,'-+');
50 -        title(strcat('CCDF PLOT(',int2str(16),' QAM)'));
51 -        ylabel('CCDF');
52 -        xlabel('PAPR(dB)');
53 -        legend('Comb Scheme Plot','Normal Scheme Plot');
```

Figure 3.10: MATLAB code for compute CCDF

In line 37 of the code, the total step requires to reach maximum PAPR was compute from the 'Normal_PAPR_list' as original OFDM have the highest PAPR. Line 38 and line 39 was to set the memory location for probability of each PAPR threshold or CCDF by pre-allocate zeros in matrix. The 'Comb_CCDF_plot' and 'Normal_CCDF_plot' was the memory location for CCDF of combined scheme and normal OFDM. Line 42 to line 46 was the for loop that compute CCDF according to threshold of PAPR. Line 43 and line 44 of the code compute CCDF of combined scheme and normal OFDM scheme respectively and save its result to 'Comb_CCDF_plot' and 'Normal_CCDF_plot' respectively. Line 48 to 53 of the code plot the CCDF of PAPR in semi log graph and set the parameter and name of the plot.

3.5 Performance Evaluation

PAPR performance of SLM-Exp scheme can be shown in CCDF plot of PAPR. However, in order to evaluate the PAPR performance of the SLM-Exp scheme, PAPR performance of others scheme like SLM-Mu, Exponential, Mu law, and SLM should be compare alongside PAPR performance of SLM-Exp to show the different as well as improvement in PAPR performance of the scheme. On the other hand, PAPR performance of the system when parameter varied should also be investigated in order to find out the optimum parameter for the scheme. This means that CCDF plot of PAPR should include not only SLM-Exp, but also other scheme that stated above. The MATLAB code should also be convenient for variation of parameters. In order to achieve these, two modifications have been made to MATLAB code in section 3.4. Section 3.5.1 discuss the variation of parameter and its modification in order to facilitate the variation of parameter. Section 3.5.2 discuss the comparison among PAPR reduction scheme and its modification. The modified code for performance evaluation can be refer in appendix section.