Peak to Average Power Ratio (PAPR) Reduction in OFDM System

N. N. Nik Abd Malik, N. Ngajikin, S. M. Idrus and N. D. Abdul Latif

Faculty of Electrical Engineering, Universiti Teknologi Malaysia
81310 UTM Skudai, Johor, MALAYSIA
noordini@fke.utm.my, nhafizah@fke.utm.my, sevia@fke.utm.my

Abstract – Orthogonal Frequency Division Multiplexing (OFDM) is a special form of multi-carrier modulation which is robust against the multipath effect, Intersymbol Interference (ISI) and high spectral efficiency. However, Peak to Average Power Ratio (PAPR) is a major drawback in the system since this leads to the distortion problem in the linear devices such as the power amplifier (PA). Thus, the PAs require a backoff which is approximately equal to the PAPR for distortionless transmission. This decreases the efficiency for amplifiers. Hence, reducing the PAPR is the main focus of this paper. One of the available PAPR solutions is clipping. In the technique, the efficiency does not depend on the number of carriers. This paper investigates the effectiveness of the clipping technique by focusing on the performance of PAPR value with different values of clipping ratios (CRs) and the relationship between PAPR value and Bit Error Rate (BER).

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), Power to Average Power Ratio (PAPR), Bit Error Rate (BER), Clipping Ratio (CR)

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a special form of multi-carrier modulation which can transmits multiple signals simultaneously over a single transmission path. Each signal travels within its own unique frequency range (carrier), which is modulated by the data. It has been chosen due to its robustness against the multipath effect, intersymbol interferences (ISI), and high spectral efficiency.

This OFDM is a type of Multi Carrier Modulation (MCM) whereby a channel is partitioned into a set of independent subcarriers [1]. The concept is based on spreading the data to be transmitted over a large number of carriers, each being modulate at low rate. The carriers are made orthogonal to each other by appropriately choosing the frequency spacing between them, such as letting the carrier spacing be equal to the reciprocal of the useful symbol period.

The orthogonality enables each subcarriers to be extracted from the set with no interference from the other subcarriers. The subcarriers can be placed as close as possible to each others. It provides the efficient usage of bandwidth. Therefore the OFDM provide higher data rate for the same bandwidth [2]. Figure 1 indicates the OFDM Spectrum.

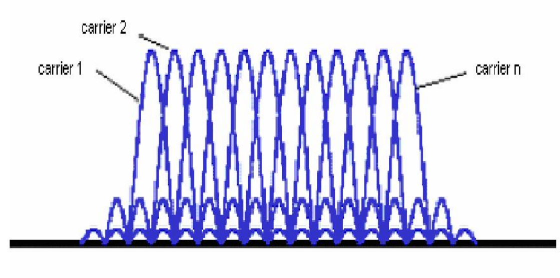

Figure 1: OFDM Spectrum.

Peak to Average Power Ratio is one of a major drawback to the OFDM system [3]. A large PAPR value is coherently due to the summation of a large number of subcarriers. As the number of subcarriers increases, the maximum possible peak power becomes higher than the average power. The large value of PAPR requires a wide linear region of the amplifier in order to avoid signal waveform distortion. However, the amplifier has only certain range of linear region and beyond that will be the saturation region. The saturation region is where the output power does not increase even though the input power is substantially increased. Therefore, high PAPR causes saturation in the PA, leading to intermodulation products among the subcarriers, causing interference inside the signal band and disturbing out of band energy. The nonlinear effects on the transmitted OFDM symbols are spectral spreading, intermodulation, and changing the signal constellation. In other words, the nonlinear distortion causes both in-band and out-of-band interference to signals Besides, a high Peak Average Power Ratio (PAPR) is undesirable because it requires a large dynamic range of the D/A and A/D converters. Figure 2 shows the PAPR in OFDM transmitted signal. The amplitude X_k exhibits a large peak of PAPR.

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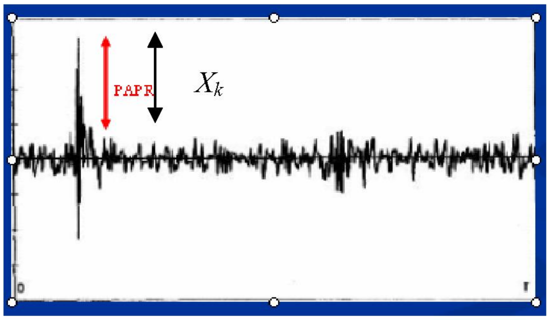

Figure 2: PAPR in OFDM Transmitted Signal.

The PAPR is defined as follows:

$$PAPR = 10\log\frac{\{(X_k)^2\}_{\max}}{E\{(X_k)^2\}}\ \text{(dB)} \qquad (1.0)$$

The $\{(X_k)^2\}_{\max}$ represents the peak amplitude of the signal while $E\{(X_k)^2\}$ is the average value of the signal.

BER is increased when the PAPR value is high. Therefore, it is desirable to reduce the PAPR value in the OFDM system. Several alternative solutions have been proposed to reduce the crest factor (CF) of the signal input to the amplifier [4]-[9]. One of these approaches, and the simplest, is to deliberately clip the OFDM signal before amplification.

2. OFDM Communication Model

OFDM model is divided into three main parts; which are transmitter block, channel block and receiver block. Figure 3 shows the OFDM block diagram for the simulation.

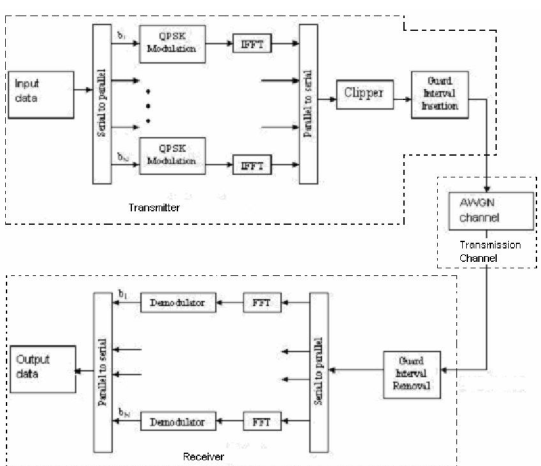

Figure 3: OFDM Block Diagram.

In this simulation, random serial data of 0 and 1 were generated. These serial data vector were then converted into the parallel data vector in order to enable parallel transmission with N subchannels. Each channel used a Quadrature Phase Shift Keying (QPSK) modulation scheme. After the mapping process, these parallel data at the frequency axis was fed into the Inverse Fast Fourier Transform (IFFT) circuit. In this circuit, the parallel data were converted into serial data (time axis). The IFFT circuit generates the complex OFDM modulation.

The complex baseband OFDM samples were denoted in the next equation below, where the X_k value is the complex QPSK symbol with $0 \le k \le N-1$ [10].

$$x_n = \sum_{k=0}^{N-1} X_k e^{(j2\Pi nk/N)},\ 0 \le n \le N-1 \qquad (2.0)$$

The OFDM signals were clipped before it was fed into guard interval. The guard interval was inserted to eliminate ISI caused by multipath effect fading. After that, the filtered signal was transmitted into the channel. The transmitted signal passed through the radio channel (equivalent lowpass system) and was transmitted to the receiver.

During propagation through transmitter channel, the OFDM signal was contaminated with Addition White Gaussian Noise (AWGN). Then, the guard interval was removed from received signal. After that, these data was fed into the FFT circuit. In the circuit, the serial data were converted back into parallel data. The converted data in each channel was unnormalized and was sent to the demodulation function. After that, the parallel data was converted into the serial data [11]. All the parameters and specification used in this simulation are shown in Table 1.

Table 1: Simulation Parameter of OFDM System.

Number of data	1.2 Mbits
Number of subcarriers	100 000 subcarriers
Number of subchannels	12 subchannels
Modulation	QPSK
Bit Rate	500 kbits/s
Guard Interval	25 000 points
Noise channel	AWGN
Signal to noise ratio (SNR)	Between 1(0dB) until 10 000(40dB)

3. PAPR Reduction

Figure 4 shows OFDM signal with SNR value of 4.77 dB. 100 kbits data was modulated at each subchannel. In this figure, the PAPR and the average value of the signal had been performed and analyzed. From the analysis, it was observed that as the number of subcarriers increased, the maximum possible peak power became greater than the average power. Therefore, the PAPR value is increased if more data was transmitted. Figure 5 represents the clipped OFDM signal with $CR = 2dB$. After the clipping process, it can be noted that the peak of the signal is limited to a certain value.

After that, this clipped signal is transmitted into the channel that had been contaminated with the AWGN.

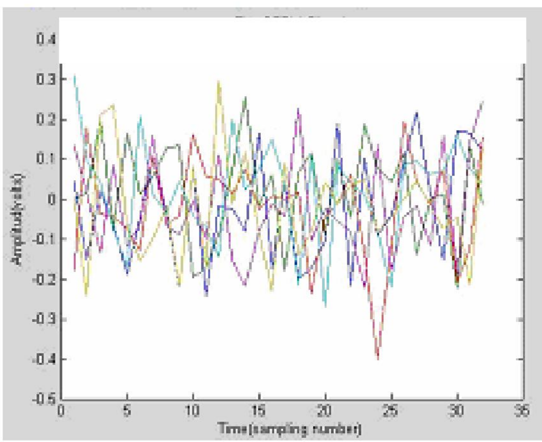

Figure 4: OFDM Signal.

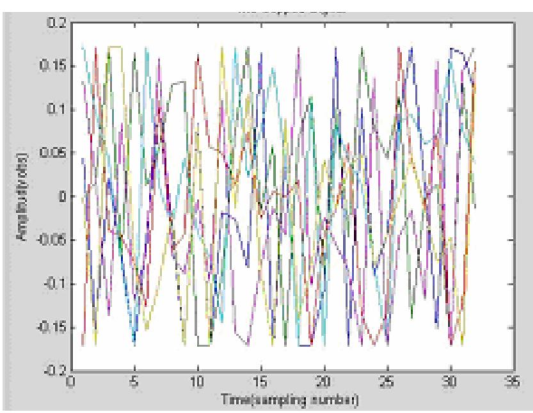

Figure 5: Clipped OFDM Signal.

3.1 PAPR and BER Performance

Figure 6 shows the PAPR level with different SNR values. The SNR range is between $0\,dB$ and $40\,dB$. From Figure 6, it can be inferred that the PAPR value is constant throughout the SNR. Therefore, PAPR performance cannot be changed by altering the SNR value (E_b/N_0).

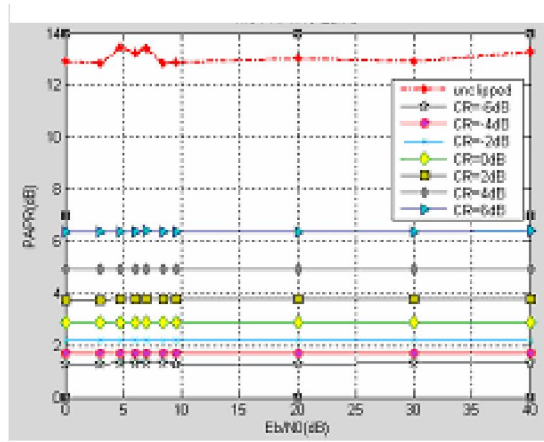

Figure 6: PAPR versus E_b/N_0 (SNR).

Figure 7 describes the relationship between the BER and the E_b/N_0 (SNR). The SNR is evaluated between $0\,dB$ and $40\,dB$. Figure 7 illustrated that if SNR value is increased, BER decreased. Additionally, the BER performances may also vary with different CR level although the SNR value is constant. The BER value is also increased with the reducing of CR level. This simulation report had been investigated for a signal with SNR range from 0dB to 40dB and CR level of -6dB to 6dB. From the inspection, the CR level of $2\,dB$ and above with SNR value exceeds $20\,dB$ gave the finest performance.

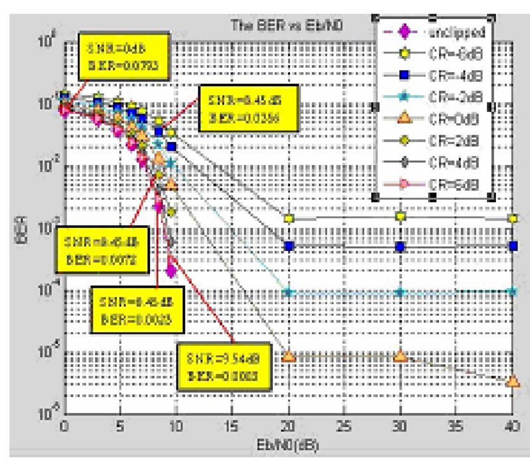

Figure 7: BER versus E_b/N_0 (SNR).

3.2 PAPR versus BER

Figure 8 describes the relationship between BER and the PAPR with different CR level. It can be observed that high CR level of 6dB can yield a good BER performance with only 0.039. However, the drawback that had been encountered here is the increase of PAPR value when CR equals to 6dB. The PAPR value of CR equals to 6dB is 6.3824dB while the PAPR value of CR equals to -6dB is only 1.3077dB. Although there is an increment in PAPR value which depends on the increment of CR, but still the PAPR value of unclipped signal is much more higher than the PAPR of CR=6dB.

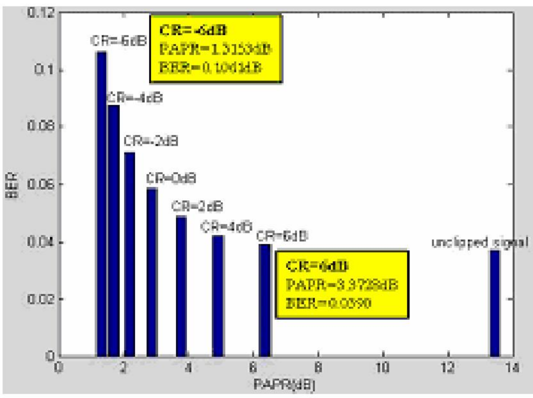

Figure 8: BER versus PAPR (SNR=4.77dB).

This trend also demonstrated and proved in other OFDM clipped signal with different SNR value. Figures 9 and 10 show OFDM clipped and unclipped signal at SNR equals to 9.54dB and 20dB, respectively. It can be concluded from the three situations (signal with SNR=4.77dB, 9.54dB and 20dB) that the increment of CR has increased the PAPR value but still below the PAPR value of unclipped OFDM signal. The decrement of CR also had increased BER.

4. Summary

Based on the simulation, it is concluded that the PAPR that occurs in OFDM signal can be reduced by using clipping technique which clip the signal before it is being transmitted. The range of CR level from -6dB to 6dB had been analyzed and discussed in this paper with variety of SNR value (0dB to 40dB). From the simulation, it is demonstrated that different CR level have provided different PAPR value. The optimum BER performance of OFDM signal can be improved by increasing the CR level and the SNR value. The

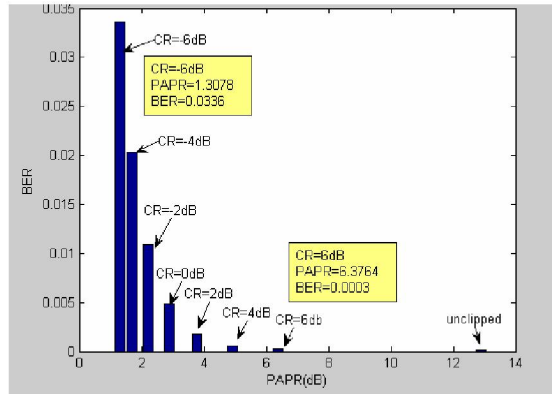

Figure 9: BER versus PAPR (SNR=9.54dB).

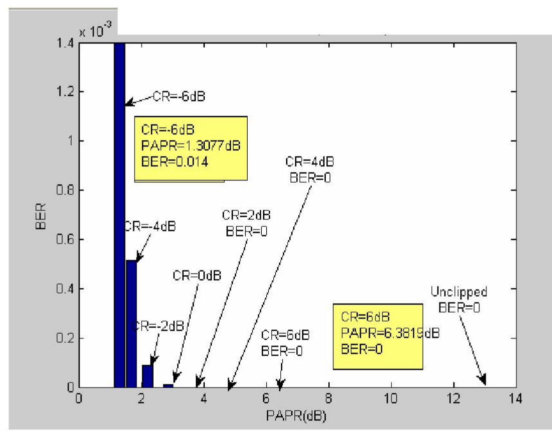

Figure 10: BER versus PAPR (SNR=20 dB).

slightly small drawback that exists by increasing the CR level is the minor growth in PAPR value. However this PAPR value is greatly and significantly much lower than the unclipped OFDM signal. This paper had proved and verified that clipping technique is a promising technique to reduce PAPR in the OFDM signal. The OFDM signal with the reduction of PAPR value will boost up the OFDM popularity in the wireless telecommunications system network.

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