A Block Coded Amplitude Clipping and Filtering for Peak-to-Average Power Ratio in Orthogonal Frequency Division Multiplexing System

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Abstract- One of the major setbacks of Orthogonal Frequency Multiplexing (OFDM) is its peak-to-average power ratio (PAPR). In this paper, an investigation of block coded amplitude clipping and filtering method to reduce further the PAPR in OFDM system is presented. The BER performance of this method is also analyzed. It is shown through simulation that the block coded amplitude clipping and filtering method improves the PAPR and BER performance as compared to a block coding technique.

Keywords
OFDM, PAPR, block coding, clipping and filtering.

I. INTRODUCTION

The increasing demand for high bit rate and reliable wireless system has led to many new emerging modulation techniques. One of the best techniques is Orthogonal Frequency Division Multiplexing (OFDM) which meets such demand requirements with reasonable complexity. Recently, OFDM systems are being implemented for fixed and mobile transmission such as DVB, DAB, and ADSL. The primary reason OFDM is preferred in most high bandwidth efficiency transmission systems are because of it's robustness in multipath fading hence effectively resists intersymbol Interference (ISI) which limits the maximum bit rate of the wireless transmission system.

Despite the advantages of OFDM system, one of the major disadvantages is that the OFDM signal exhibits a very high PAPR. This is due to the summation of the subcarriers, which can be added constructively or destructively. This creates the potential for a large variation between the average signal power and the maximum signal power in OFDM system. Therefore, RF power amplifiers should be operated in a very large linear region or large back-offs that leads to expensive transmitter and receiver system. Otherwise, the signal peaks might get into non-linear region of the power amplifier causing signal distortion. This signal distortion introduces intermodulation among the subcarriers and out of band radiation [1].

Due to the factors mentioned, it is highly desirable to reduce the PAPR. Many researchers have focused on methods for controlling this problem and a number of elegant solutions have emerged such as coding, clipping and phase rotation signaling.

This paper focuses on block coding and clipping techniques. The basic idea of the block coding scheme is, in general, to avoid the use of codeword which yields a high PAPR while increasing the transmission bandwidth due the redundancy bits being introduced. However, no good coding solution are known which can maintain a reasonable coding rate for arbitrary number of subcarriers [2, 3]. On the other hand, clipping technique is a nonlinear process. The effects of clipping are in-band distortion and out-of-band distortion. In-band distortion or the degradation in the wanted signal strength occurs since clipping modifies the signal artificially. Nyquist rate clipping causes severe in-band distortion as the entire signal and clipping noise fall back into the wanted signal's bandwidth. However, clipping an oversampled signal causes lesser effect to the signal within the original band as oversampling reduces the effect of clipping noise in the wanted signal by spreading them in a wider bandwidth. Performing clipping on an oversampled version of the digital signals also shows a lesser peak regrowth. Theoretically, any discontinuities in an analogue signal will lead to an infinite bandwidth, which causes aliasing with adjacent symbols. Performing frequency domain filtering can reduce these out-of-band radiations. This filtering results in a lesser peak regrowth and also completely eliminates the out of band radiation thus allowing the original unclipped signal to be retrieved [4, 5, 6].

In literature, block codes and amplitude clipping and filtering have been considered separately in reducing PAPR. The objective of this paper is to investigate the performance of block coded amplitude clipping and filtering in reducing PAPR and BER in an OFDM system. This paper is organized as follows: section II discusses about PAPR in OFDM system. Section III explains the block coded amplitude clipping and filtering method. Section IV discusses the simulation results and lastly, section V is the conclusion and future work recommendations.

II. PAPR IN OFDM SYSTEM

The complex envelope expression of the nth OFDM signal at the transmitter can be written as:

$$s_n(t)=\sum_{n=0}^{N-1} c_n e^{j2\pi n f_0 t} \qquad 0 \le t \le T_s \qquad (1)$$

Where c_n is the complex-valued data symbol of the nth OFDM symbol and T_s is the OFDM symbol period. The PAPR of OFDM signals can be written as:

$$\mathrm{PAPR} = \frac{\max\left|s_n(t)\right|^2}{P_{av}} \qquad (2)$$

Here P_{av} is the average power of OFDM signal. In earlier investigations into OFDM modulation, it was shown that for N subcarriers the worst case of PAPR can be as large as N times the average power of the signal and the theoretical PAPR is obtained by :

$$\mathrm{PAPR} = 10 \log_{10} N \,(\mathrm{dB}) \qquad (3)$$

Different messages produce different peak values in the OFDM signal $s_n(t)$ in the OFDM system. If only the subset of messages that produce acceptable Peak Envelope Power (PEP) are permitted codeword in the scheme, then the overall PEP can be held within specified limits. From this statement, the occurrence of PEP can be avoided hence reducing the PAPR by employing linear block coding.

III. BLOCK CODED AMPLITUDE CLIPPING AND FILTERING

The application of the block codes in OFDM system is straightforward. In this paper, we present a code rate r=1/2 block coding scheme which achieves the minimum PAPR for an OFDM system which employs 4-QAM modulation. The codeword with high PAPR is avoided in the vocabulary library of codeword. Two types of block coding are investigated: look-up table and matrix generator.

modulation is performed on the 8-bit vector **x** which converts into complex symbol.

Oversampling by a factor of K=2 is performed by inserting N(K-1) zeroes in the middle of the mapped complex vector. An oversized IFFT is selected to convert the discrete frequency domain signal to a discrete time domain signal. The output of the IFFT is the summation of all the subcarriers. Since the subcarriers are independent of each other, they tend to add up constructively and destructively. This forms a high peak to average power ratio. The high peak of the signal is clipped by the amplitude clipper. The transfer function of the clipping nonlinearity under consideration can be expressed mathematically as,

$$y(t) = \begin{cases} -G, & \text{for } s(t) \le -G \\ s(t), & \text{for } |s(t)| < G \\ G, & \text{for } s(t) \ge G \end{cases} \qquad (4)$$

where y(t) is the clipped OFDM signal and G is the clipping level [4].

Out-of-band radiation which occurs due to clipping an oversampled signal is filtered by frequency domain filtering [6, 8]. This filter consists of a forward FFT and an Inverse FFT. The clipped signal will be passed to the forward FFT that will convert the discrete time domain signal to discrete frequency domain signal. The zeroes that are added when performing the oversampling are the out-of-band components. Thus these out-of-band components must be removed and finally the filtered signal is passed back to the Inverse FFT for transmission. The plus point of this filter is that it does not introduce any intersymbol interference (ISI) since it operates on symbol-by-symbol basis and no filtering is performed across the symbol boundaries.

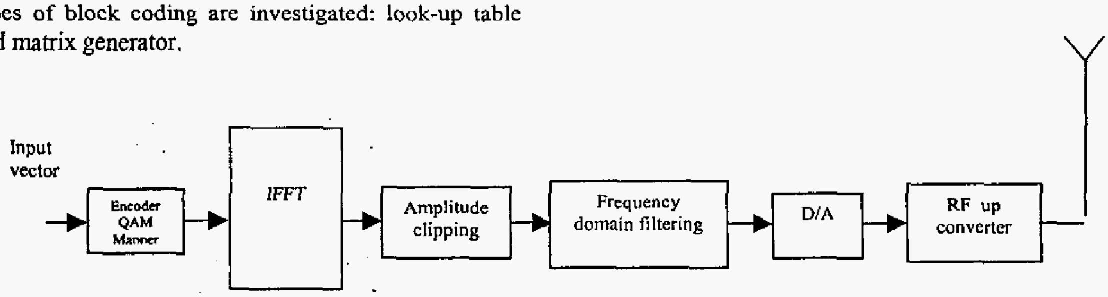

Fig. 1. Block diagram of the OFDM transmitter with block coded clipping and filtering scheme

Fig. 1 shows the block diagram of an OFDM transmitter with the block coded amplitude clipping and filtering scheme. A block of 4-bits data $\mathbf{u} = (u_0, u_1, u_2, u_3) \in \{0, 1\}^4$ is encoded by a look-up table to yield the encoded output $\mathbf{x} = (x_0, \ldots, x_7) \in \{0, 1\}^8$. 4-QAM

IV. SIMULATION RESULTS

Table 1 shows the PAPR values for different number of subcarriers using different block coding techniques. From the table, it shows that the look-up table technique gives a better PAPR reduction performance compared to the generator matrix generation. For N=64, the PAPR is reduced by 16%. However, increasing the code rate at the expense of spectral efficiency can further reduce this reduction.

Table 1. PAPR(dB) for different number of subcarriers

No. Subcarrier	Theory	Look-up Table (8,4)	Generator Matrix (8,4)
4	6.02	0	7.225
8	9.03	7.66	9.422
16	12.04	10.66	12.18
32	15.05	12.6	12.91
64	18.06	13.03	15.52
128	21.07	15.06	17.54

Fig. 2 shows the PAPR CDF graph for a 64 subcarriers OFDM simulation model. From the graph, the look-up table limits the PAPR value to only 13 dB while the generator matrix technique limits the PAPR value to 16 dB compared to the non-coded OFDM system which gives a PAPR as high as 18 dB for 64 subcarriers system. Further investigation in this paper employs block coding using look-up table.

By employing block coded amplitude clipping and filtering, a better PAPR reduction can be achieved. Table 2 shows the PAPR obtained when employing this technique for different number of subcarriers. A reduction is obtained for 16 and 32 number of subcarriers while the PAPR is the same for higher value of subcarriers. However, this can be improved if appropriate clipping ratio is used.

Table 2. PAPR(dB) of block coded amplitude clipping and filtering

No. Subcarrier	Block Coded	Block Coded Amplitude Clipping and Filtering
16	10.66	10.1
32	12.6	12.33
64	13.03	13.03
128	15.06	15.06

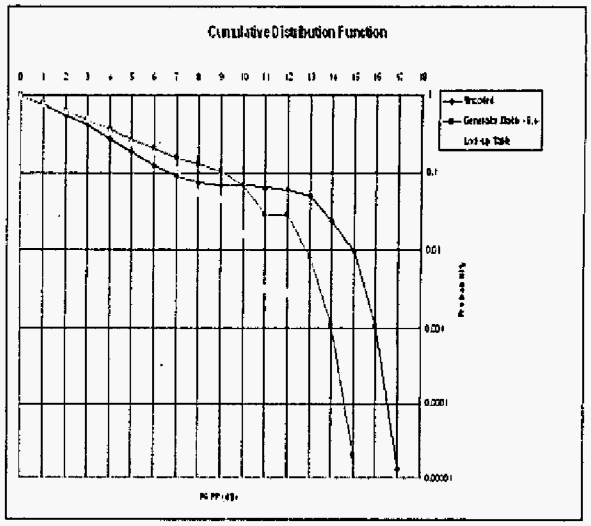

Fig. 2. PAPR cumulative distribution function for 64 subcarriers

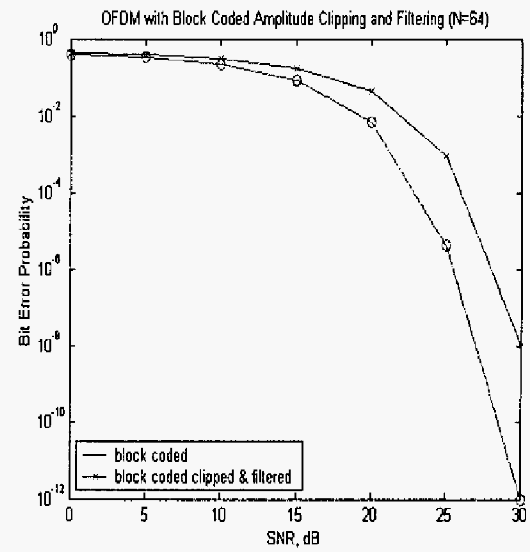

Fig. 3. Performance of block coded amplitude clipping and filtering in AWGN channel with N=64

It is shown clearly in Fig. 3 that the BER improves with block coded amplitude clipping and filtering technique in AWGN channel. For example, at a bit error probability of 10^{-4}, the system using the block coded amplitude clipping and filtering outperforms the system using the block coded by about 3.5 dB.

V. CONCLUSION

In this paper, block coded clipping and filtering OFDM system was studied through simulation work. A look-up table block coding and oversampling clipping and filtering technique was employed in this study. It was shown that this technique is capable in resulting a reduction in PAPR and BER performance. This technique avoids optimization algorithm that is required in phase rotation method. For better performance of PAPR reduction and BER degradation, forward error correction mechanism should be included in the OFDM system. Other performance measurement such as intercarrier interference (ICI) is being carried out in order to know the effectiveness of this technique in OFDM system.

VI. REFERENCES

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