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GCD Matrix based PAPR Reduction Technique for OFDM System

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Abstract

Orthogonal Frequency Division Multiplexing (OFDM) is an efficient method of data transmission for high speed communication systems. One of the challenging issues for OFDM system is its high Peak-to-Average Power Ratio (PAPR) which causes inefficient use of the High Power Amplifier (HPA) and could limit transmission efficiency. In this paper we analyze the effects of PAPR on HPA and its reduction technique based on GCD matrix In Selected Mapping (SLM) method. Simulation results shows that the new phase sequence based SLM method has good performance in PAPR reduction.

Keywords: *Orthogonal Frequency Division Multiplexing (OFDM), Peak-to-Average Power Ratio (PAPR), Selected Mapping (SLM), High Power Amplifier (HPA).Greatest Common Division (GCD) matrix*

1. Introduction

OFDM is a Multi Carrier Modulation (MCM) technique, offers a considerable high spectral efficiency, multipath delay spread tolerance, immunity to the frequency selective fading channels, power efficiency and immune to inter symbol interference [1]. These days the OFDM technique is considered as a strong candidate for the Fourth Generation (4G) of mobile communication systems.

However, though OFDM has many advantages, still some challenging issues remains unsolved in the design of the system. One of the major problems is high Peak-to-Average Power Ratio (PAPR) of transmitted OFDM signal. These multi carrier systems have a problem that PAPR increases with the increase of the number of sub carriers, which makes the signal peaks moves into the non linear region of the RF power amplifier which causes signal distortion [2]. Therefore, the OFDM receiver's detection efficiency is very sensitive to the non linear devices used in its signal processing loop, such as Digital-to- Analog converter (DAC) and high power amplifier, which may severely impair system performance due to induced spectral regrowth and detection efficiency degradation [3]. The high peaks of OFDM signal can be reduced in three ways. The fist kind is distribution technique, such as clipping, companding and so on. This kind of technique is simple and intuitionistic, but it's inevitable to cause some performance degradation. The second kind is coding technique. In particular, the use of Golay complementary sequence. In an efficient method to reduce the PAPR for a small number of subcarriers, but it has a drawback that it decreasing the transmission rate significantly for a large number of subcarriers. The third kind is probabilistic technique including selective mapping (SLM) and the partial transmit sequence (PTS)[4].In this paper, firstly, we investigate the effect of PAPR on HPA based on characteristics of the OFDM

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signal. The new phase sequence based SLM technique has proposed to reduce the PAPR, so that the HPA operates in linear region.

2. OFDM System Model and PAPR Problem

In this section, we review the basic OFDM transmitter and PAPR definition. The model considered for the implementation of OFDM transmitter basically consist of the following block.

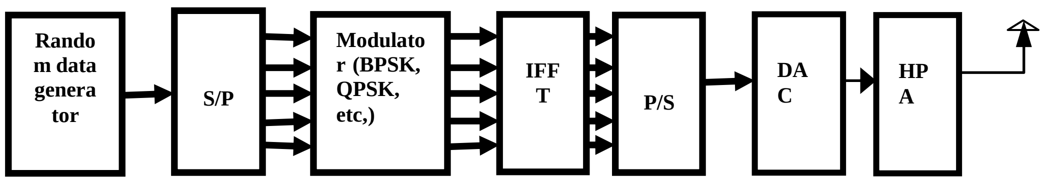

Figure 1. Block Diagram of OFDM Transmitter

OFDM is a special form of multi carrier modulation (MCM) and the OFDM time domain waveforms are chosen such that mutual orthogonality is ensured even though sub-carrier spectra may over-lap. With respect to OFDM, it can be stated that orthogonality is an implication of a definite and fixed relationship between all carriers in the collection. It means that each carrier is positioned such that it occurs at the zero energy frequency point of all other carriers. The sine function, illustrated in Figure 2 exhibits this property and it is used as a carrier in the OFDM system.

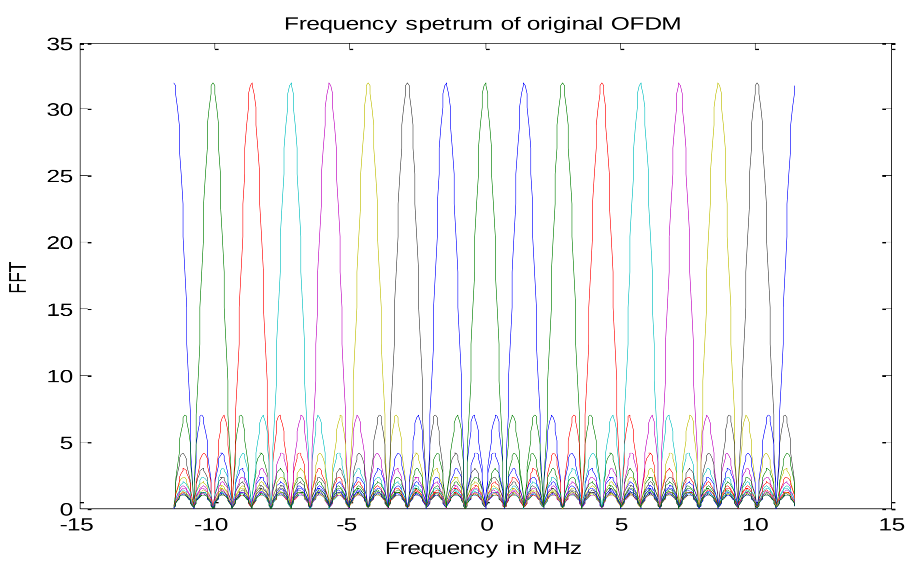

Figure 2. OFDM Spectrum for Orthogonal Carriers

In an OFDM based system, the signal contains a set of N base band subcarriers, $\{f_n, n = 0,1,2,....N-1\}$, which are modulated by the signal samples from a block of N symbols, $\{X_n, n = 0,1,......,N-1\}$.these subcarriers are chosen to be orthogonal ,that is

$f_n = n\Delta f$,where $\Delta f = \frac{1}{T}$,and T is the OFDM symbol period. The OFDM signal is expressed as

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi f_n t} \quad (1)$$

The PAPR of OFDM is defined as the ratio between the maximum instantaneous power and the average power [4]:

$$PAPR[x(t)] = \frac{P_{peak}}{P_{average}} = \frac{\max|x(t)|^2}{E\left[|x(t)|^2\right]} \quad (2)$$

Where $E[\bullet]$ is the expectation operator, *i.e.*, average power. However, in practice most system deals with the discrete-time signals, the amplitude of samples of $x(t)$ is deals with many of the PAPR reduction techniques. Since symbol spaced sampling of $x(t)$ some times misses some of the signal peaks and results in optimistic result for the PAPR, signal samples are obtained by over sampling $x(t)$ by a factor of L to approximate the true PAPR better, where L-is an integer larger than 2. The L-time over sampled signal can be given by

$$x_n = \frac{1}{\sqrt{N}} \sum_{K=0}^{N-1} X_k e^{j2\pi nk/LN}, n = 0,1,2,....LN-1. \quad (3)$$

From the above equation, the L-time over sampled samples can be obtained by performing LN point IFFT on the data block X with (L-1)N zero padding. For the discrete time signals $|x_n|$,the PAPR can be expressed as:

$$PAPR[x_n] = \frac{\max_{0 \le n \le LN-1} \left[|x_n|^2\right]}{E\left[|x_n|^2\right]} \quad (4)$$

3. Effects of PAPR on HPA

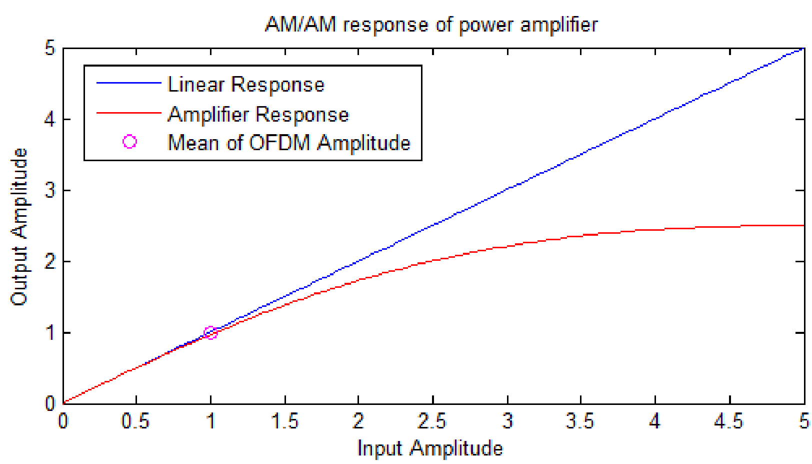

Figure 3. Response of Power Amplifier

Most radio frequency communication systems have a high power amplifier in the transmitter to obtain sufficient transmit power. This high PAPR forces the HPA to have a large back-off in order to ensure linear amplification of the signal, which significantly reduces the efficiency of the amplifier [2]. On the other hand, if an amplifier work with non linear characteristics, it will cause undesired distortion of OFDM signal and degrades the BER performance of the system. The response of power amplifier is shown in Figure 3, it reflects that the power amplifier doesn't maintain linear response.

It is well known that original OFDM signals have a very sharp, rectangular-like power spectrum as shown in Figure 4. This good property will be affected by the High Peaks in the OFDM signals, so that HPA goes into nonlinear region, results spectral distortion.

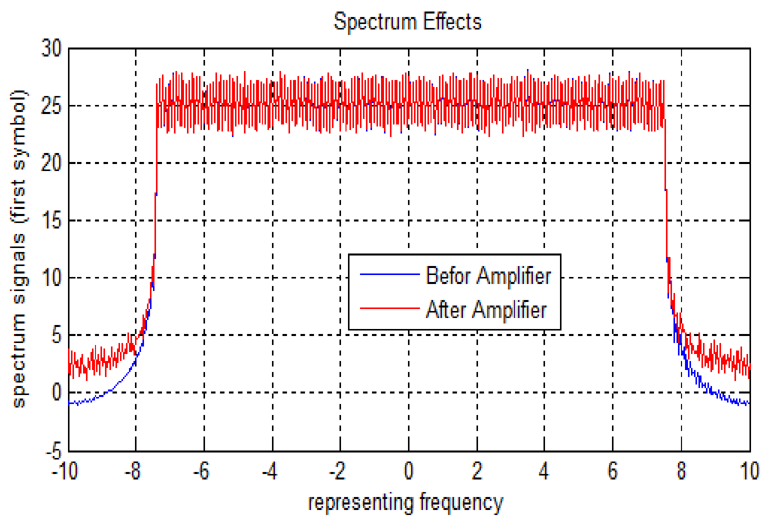

Figure 4. Spectrum of Original OFDM and after HPA

Large PAPR also demands the DAC with enough dynamic range to accommodate the large peaks of the OFDM signals. Therefore, the best solution is to reduce the PAPR before OFDM signals are transmitted into nonlinear HPA and DAC.

4. SLM Based New Phase Sequence Technique

4.1. Review of SLM Technique

Selected Mapping (SLM) technique is the most promising reduction technique to reduce Peak to Average Power Ratio (PAPR) of Orthogonal Frequency Division Multiplexing (OFDM) system. The basic idea of this technique is based on the phase rotation [5]. The lowest PAPR signal will be selected for transmission from a number of different data blocks (independent phase sequences) that have the same information at the transmitter. Figure5 shows a block diagram of SLM scheme [7-9].

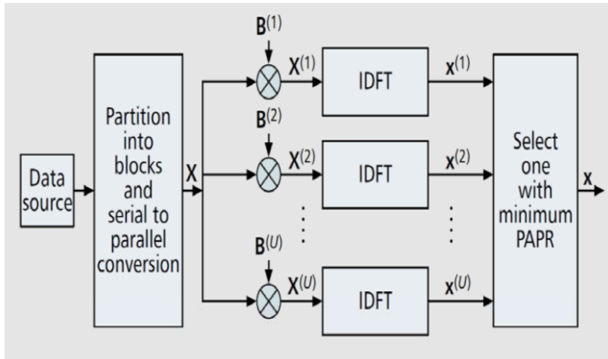

Figure 5. Block Diagram of SLM Technique

At first, input data is portioned into a data block X of length N. then the OFDM data block is multiplied element by element with phase sequence $B^{(u)} = \left[b_{u,0}, b_{u,1}, \ldots\ldots\ldots, b_{u,N-1}\right]^T, u = 1,2, \ldots\ldots\ldots, U$,to make the U phase rotated OFDM data blocks $X^{(u)} = \left[X_{u,0}, X_{u,1}, \ldots\ldots, X_{u,N-1}\right]^T$ where $X_{u,n} = X_n \bullet b_{u,n}, n = 0,1, \ldots\ldots, N-1$. All U phase rotated OFDM data blocks represents the same information as the unmodified OFDM data block provided that the phase sequence is known. To include unmodified OFDM data block in the set of the phase rotated OFDM data blocks, we may set the first phase sequence $B^{(1)}$ as all one vector of length N. after applying SLM technique to X,(1) becomes

$$x^{(u)}(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \bullet b_{u,n} \bullet e^{j2\pi f_n t} \tag{5}$$

PAPR is calculated for U phase rotated OFDM data blocks. Among the phase rotated OFDM data blocks one with the lowest PAPR is selected and transmitted.

4.2 Proposed GCD Matrix Technique

Generation of phase sequence, which is one of the important aspects of SLM technique, is very random in existing phase sequence sets. Selecting of proper phase sequences to achieve good PAPR reduction is very important in SLM. Phase sequence set is chosen randomly from $[\pm i, \pm j]$ by Bauml **[6]**, who first described SLM technique. The PAPR reduction technique proposed in this paper is based on the technique proposed in [10]. In the proposed method, row of GCD matrix (B) are used as phase rotation vectors. Suppose D= $D = \{d_1, d_2, \ldots\ldots d_m\}$ is set of distinct positive integers containing GCD matrix (B). Assume the matrix $A = (a_{ij})$ is defined as follows:

$$a_{ij} = e_{ij}\left(\lambda_j\right)^{\frac{1}{2}} \tag{6}$$

Where $e_{ij} = \begin{cases} 1 & \text{if } d_j \text{ divides } x_i \\ 0 & \text{Other wise} \end{cases}$

And $\lambda_i = \phi\left(d_j\right)$

Hence A is the $n \times m$ and A^T is $m \times n$.
Fortheremore

$$(AA^T)_{ij} = \sum_{k=1}^{m} a_{ik} a_{ij} \; . \tag{7}$$

$$= \sum_{dk/xi,dk/xj} \sqrt{\phi(d_k)} \sqrt{\phi(d_k)} \tag{8}$$

$$= \sum_{dk/(xi,xj)} \phi(d_k) = (x_i, x_j) = B_{ij} \tag{9}$$

Thus $[B] = AA^T$

If the GCD matrix (B)is of size $N \times N$,the entries in the normalized GCD matrix(B)will be B=gcd/N. MAT lab syntax for GCD matrix is gcd=gallery('gcdmat',N).

The algorithm can be described in following steps [7]:

1. The sequence of data bits are mapped constellation points M-QAM (or) BPSK to produce sequence symbols X_0, X_1 ,..............
2. These symbol sequences are divided into a data block X of length N. Nis the number of sub-carriers.
3. The OFDM data block is multiplied element by element with phase sequence $B^{(u)} = [b_{u,0}, b_{u,1}, ..., b_{u,N-1}]^T$ where each row of the normalized GCD matrix B is taken as $B^{(u)}, u = 1,2,......,U$.
4. A set of U phase rotated OFDM data blocks $X^{(u)} = [X_0 b_{u,0}, X_1 b_{u,1}, ..., X_{N-1,} b_{u,N-1}], u = 1,2,......,U$.
5. Transform $X^{(u)}$ into time domain to get $x^{(u)} = IDFT[X^{(u)}]$.
6. Among the phase rotated OFDM data block one with the lowest PAPR is selected and transmitted.

5. Results and Discussion

In this work, computer simulation in implemented to evaluate PAPR reduction performance of the proposed approach. In our simulation, we assume an OFDM system with N=256 subcarriers together with 16-QAM modulation scheme. Figure (a) and (b) show the results of PAPR.

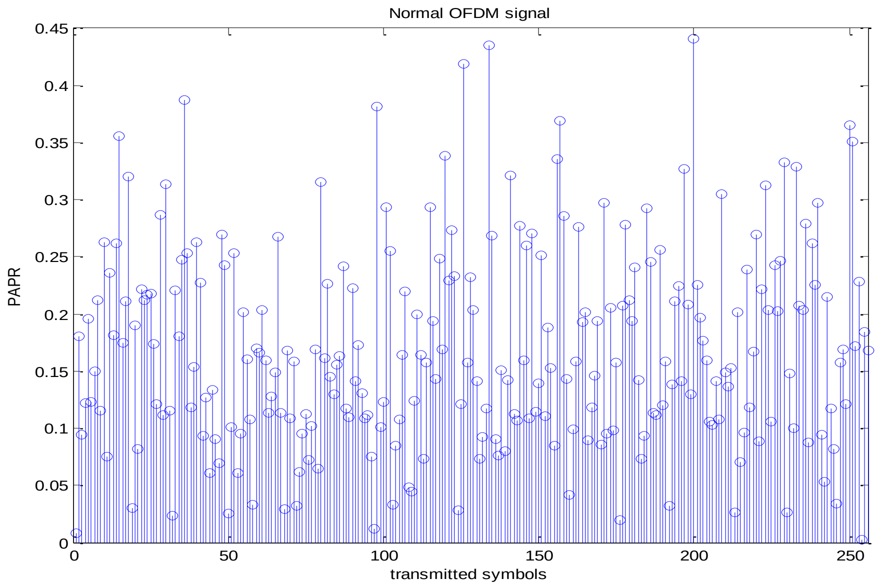

Figure 6(a). Normal OFDM Signal

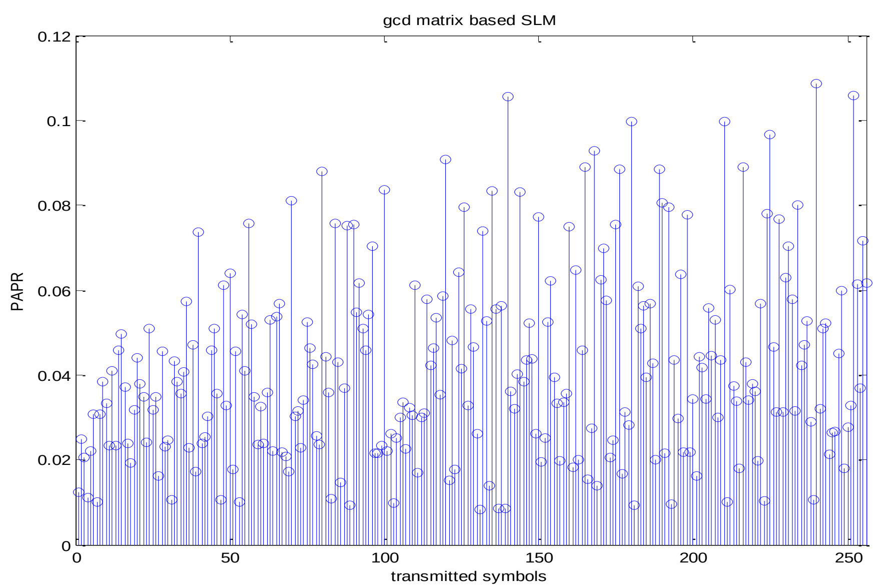

Figure 6 (b). PAPR of the GCD Matrix Based SLM

The PAPR of normal OFDM system is shown in Figure 1(a) and PAPR of GCD matrix based SLM system proposed in this paper is shown in Figure 1(b).in Figure 1(1) the peak value is 0.45, in Figure 1(b) the peak value is lower than the 0.12. So from Figure (a) and (b) we can conclude that the proposed technique has good performance in reducing the PAPR of OFDM system. We made a performance comparisons Table between Riemann matrix and GCD matrix based SLM system. From the Table we observed that GCD matrix based SLM gives better results than conventional one.

Table 1. Comparison of PAPR on Riemann and GCD Matrix based SLM

Sub carriers(N)	Riemann matrix (PAPR in dB)	GCD matrix (PAPR in dB)
64	16.0764	13.2982
128	15.9564	15.4377
256	19.2541	18.0038
512	20.0568	18.4076

6. Conclusion

OFDM is very attractive technique for wireless communications due to its spectral efficiency and channel robustness .one of the serious drawbacks of in OFDM system is that the composite signal can exhibits a very high PAPR when the input sequences are highly correlated. In this paper, we described the effects of PAPR on HPA, as well as a new phase sequence based SLM technique is proposed. The proposed method is suitable for OFDM applications that are sensitive to spectral efficiency and noise, since it allows reduction in PAPR value with no-out of band radiation. For 16-QAM OFDM system with N=256 data sub carriers, 1.2503dB reduction in PAPR value is achieved compare with the conventional OFDM system.

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