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Peak to Average Power Ratio (PAPR) Reduction in OFDM

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Abstract: ***Wireless technologies have gradually become more and more involved into people's daily life. Among multicarrier transmission techniques, Orthogonal Frequency Division Multiplexing (OFDM) is the most popular one that uses parallel data streams. Compared with single carrier modulation, OFDM has many advantages as immunity to impulse interference, high spectral density, resilient to RF interference, robustness to channel fading, resistance to multipath, much lower computational complexity. In this paper, we will give an overview to OFDM technique, identify the PAPR problem and a technique for reducing PAPR (peak to average power ratio) in OFDM by changing the phase of some of the subcarriers.***
Keywords: PAPR, OFDM, FDMA

I. INTRODUCTION

The Internet revolution has created the need for wireless technologies that can deliver data at high speeds in a spectrally efficient manner. However, supporting such high data rates with sufficient robustness to radio channel impairments requires careful selection of modulation techniques. The most suitable choice appears to be OFDM (Orthogonal Frequency Division Multiplexing). Orthogonal Frequency Division Multiplexing (OFDM) is an alternative wireless modulation technology to CDMA. OFDM has the potential to surpass the capacity of CDMA systems and provide the wireless access method for 4G systems. OFDM is a modulation scheme that allows digital data to be efficiently and reliably transmitted over a radio channel, even in multipath environments. The name 'OFDM' is derived from the fact that the digital data is sent using many carriers, each of a different frequency (Frequency Division Multiplexing) and these carriers are orthogonal to each other, hence Orthogonal Frequency Division Multiplexing.

A. Fundamental Concept

OFDM owes its origin to Frequency Division Multiplexing (FDM). In FDM, each of the several low rate user signals is modulated with a separate carrier and transmitted in parallel. Thus the separation of the users is in the frequency domain. In-order to be able to easily demodulate each user signal; the carriers are spaced sufficiently apart from each other. Moreover, guard band has to be provided between two adjacent carriers so that realizable filters can be designed (Lathi,1983) Hence the spectral efficiency is very low. The above idea can be easily extended to provide communication service for a user with high rate data stream. The data stream can be split into N low rate data streams, modulated using N sub-carriers and transmitted over the channel. Let's compare this parallel transmission scheme with a single high rate data transmission. The results of the comparison are tabulated in Table 1.1.It is of interest to note that before equalizers were developed, the parallel transmission method was the means of achieving high data rates over a dispersive channel, in spite of its high cost and relative bandwidth inefficiency.

Table 1: Comparison of Parallel and Serial Transmission Schemes

Transmission method	Parallel	Serial
Symbol time	Ts	Ts/N
Rate	1/Ts	N/Ts
Total BW required	2*N/Ts + N*0.1/Ts (Assume Guard band = 0.1/Ts)	2*N/Ts
Susceptibility to ISI	Less	More

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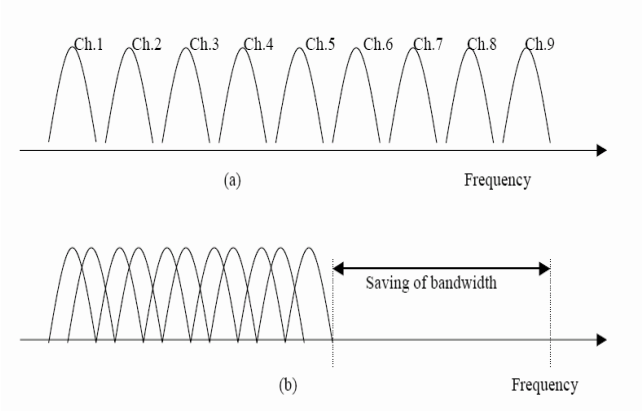

Figure 1 Concept of OFDM signal
(a) Conventional Multi-carrier Technique
(b) Orthogonal Multi-carrier Modulation Technique

Figure 1 illustrates the difference between the conventional non-overlapping Multicarrier technique and the overlapping Multi-carrier modulation technique. As can be seen from the figure 1 by using the overlapping Multi-carrier modulation technique, we save almost 50% of band width.

B.Peak Average Power Ratio (PAPR)

When the phase of different subcarriers add up to form large peaks, an important complication comes in OFDM systems. This problem is called Peak Average Power Ratio (PAPR) and it is defined for each OFDM signal on a time interval [n, n+Ts] by the following formula:

For continuos signals

$$\chi_n = \frac{\max_{t\in[n,n+T_s]} |x(t)|^2}{\int_n^{n+t_s} |x^2(t)| dt}$$

For sampled signals

$$\chi_n = \frac{\max_k |x_n[k]|^2}{E\{|x_n[k]|^2\}}$$

In OFDM systems PAPR can have very high values for certain input sets of sample $(X_n[k])$ and overload non-linear characteristics of systems, causing inter-modulations among different carriers and undesired out-of-band radiation. Another main drawback of PAPR can be seen as quantization noise domination towards the performance of system (Huber,1996). This domination can be excited by avoiding the clipping effect of the maximum level of the Digital to Analog Converter (DAC) that is set too high. Various techniques are proposed to reduce PAPR in OFDM signals, but that reduction is not obvious because PAPR and SNR are closely linked.

II. LITERATURE SURVEY

Naga VishnuKanth I, member IEEE; [1] reviewed the idea of multicarrier modulation for data transmission. In the paper, he discussed about the one of the main issues of Orthogonal Frequency Division Multiplexing (OFDM), high Peak-to-Average Power Ratio (PAPR) of the transmitted signal which adversely affects the complexity of power amplifiers. Selected Mapping (SLM) technique is one of the promising PAPR reduction techniques for OFDM. In this paper, rows of normalized Riemann matrix are selected as phase sequence vectors for SLM technique.

Burton R.Saltzberg, et. al., [2] has compared the single carrier and multicarrier digital modulation techniques and it was found that each scheme has its own pros and cones. At one hand, single carrier system provides good sensitivity to narrowband noise, latency ,complexity of algorithm, and lower cost and power consumption of the system while multi tones is sensitive to impulse noise and

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requires less power consumption per unit time with high adaptability of bit rate and was seen that multicarrier is linear reversible transformation of single carrier signal.

Denis J.G.Mestdagh, et. al., [3] proposed that the probability of reducing clipping in DMT based transceiver without using any kind of pre-coding. The method proposed improved the system performance in terms of SNR up to 8dB.

Stefan H.Miller ,et. al., [4] proposed a peak power reduction scheme called PTS for OFDM based on the coordination of approximately phase rotated signal parts to minimize peak power of multiplex signal that provided improved statistical characteristics of transmit signal introducing little additional redundancy.

S.H.Miller ,et. al., [5] studied and compared the two existing techniques-PTM and SLM and found that SLM reduces PAR by 6 dB with a high system complexity and thus outperforms PTS in terms of PAR reduction Vs redundancy.

III. TECHNIQUE USED

A. OFDM Simulation Model

OFDM signals are typically generated digitally due to the difficulty in creating large banks of phase lock oscillators and receivers in the analog domain. Figure 4.1 shows the block diagram of a typical OFDM transceiver. The transmitter section converts digital data to be transmitted, into mapping of subcarrier amplitude and phase. It then transforms this spectral representation of the data into the time domain using an Inverse Discrete Fourier Transform (IDFT). The Inverse Fast Fourier Transform (IFFT) performs the same operations as an IDFT, except that it is much more computationally efficient, and so used in all practical systems. In order to transmit the OFDM signal the calculated time domain signal is then mixed up to the required frequency.

The receiver performs the reverse operation of the transmitter, mixing the RF signal to base band for processing, then using a Fast Fourier Transform (FFT) to analyze the signal **in** the frequency domain (Wang,2005). The amplitude and phase of the subcarriers is then picked out and converted back to digital data. The IFFT and the FFT are complementary function and the most appropriate term depends on whether the signal is being received or generated. In cases where the signal is independent of this distinction then the term FFT and IFFT is used interchangeably.

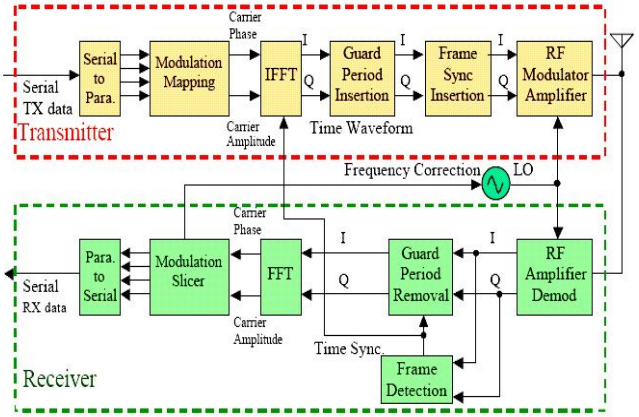

Figure 4.1 Block Diagram showing a basic OFDM Transceiver

The coding algorithm for generating complementary sequences is now given by the following steps:

1) Make a kernel, that is, one complementary pair from which all other complementary sequences can be derived. For lengths equal to a power of two, kernels can easily be formed by using Golay's rule for length expansion. Starting with the length 2 sequence *A*1 *B*1, where *A*1 = 1 and *B*1 = 1, longer length codes can be formed by making *AnBn* with *An* = *An* – 1*Bn* – 1 and *Bn* = *An* – 1 –*Bn* – 1. In this way, codes of length 2*n* + 1 are formed from the codes of length 2*n*. For example, the following codes of up to length 16 can be obtained:

a) length 2: *A*1 *B*1 = 1 1;

b) length 4: *A*2 *B*2 = 1 1 1 –1;

c) length 8: *A*3 *B*3 = 1 1 1 –1 1 1 –1 1;

d) length 16: *A*4 *B*4 = 1 1 1 –1 1 1 –1 1 1 1 1 –1 –1 –1 1 –1;

2) Determine the number of orthogonal subsets. For length *N* codes, formed by the length expansion method described above, there are log2*N* orthogonal subsets, all of which can be given an arbitrary phase offset. The orthogonal subsets within a code are

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formed by all single elements, pairs, quads, and so forth, which are of even order. Thus, a length 16 ode has four orthogonal subsets, consisting of all even elements, pairs, quads, and one octet. All of these can be given a different phase without changing the complementary characteristics of the code. Further, it is also possible to apply an arbitrary phase shift to the entire code. Hence, a complementary code set based on the kernel of (6.13) can be written as:

$$C = \begin{Bmatrix} e^{j(\varphi_1+\varphi_2+\varphi_3+\varphi_4)}, e^{j(\varphi_1+\varphi_3+\varphi_4)}, e^{j(\varphi_1+\varphi_2+\varphi_4)}, -e^{j(\varphi_1+\varphi_4)}, \\ e^{j(\varphi_1+\varphi_2+\varphi_3)}, e^{j(\varphi_1+\varphi_3)}, -e^{j(\varphi_1+\varphi_2)}, e^{j\varphi_1} \end{Bmatrix}$$

Notice that this code is actually implemented in a 20-Mbps OFDM modem for the Magic WAND project [12]. It is also used in the 11-Mbps IEEE 802.11 WLAN standard [17]. The latter is not an OFDM system, but here the benefit of using complementary sequences is their good aperiodic autocorrelation properties, which make it easier to build a receiver with sufficient robustness to multipath.

An alternative code description is to write the code phases as

$$\begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \\ \theta_6 \\ \theta_7 \\ \theta_8 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ \varphi_4 \\ \pi \end{bmatrix}$$

The output code is given by $\exp(j \cdot 2\pi\theta i / M)$, where θi is the coded phase and M is the size of the phase constellation. For BPSK (M = 2), the code set is equal to the Walsh-Hadamard codes, which is offset by the kernel, defined by the fourth column.

0: 1 1 1 –1 1 1 –1 1
1: 1 1 1 1 1 –1 –1 1
2: 1 1 1 –1 1 –1 1 1

3) Finally, a transformation can be applied that unfortunately cannot be described by simple multiplications or phase rotations. Instead, it can be described as an interleaving operation on the underlying shorter length codes used to make a longer length code [14]. For a length 8 sequence, for instance, two new length 8 codes can be generated by interleaving the first and second halves of the original code. Interleaving the code three times reproduces the original code. In general, a code with a length of 2n can be interleaved n – 1 times before reproducing itself. The following shows three different codes produced by interleaving out of one length 8 code:

For a length 16 code, it turns out that except for four different codes that can be produced by interleaving the first and second halves of the code, more codes can be made by simultaneously interleaving the quarters of the code, giving a total of 3 · 4 = 12 different codes. The described coding rules can now be used to determine the size of complementary code sets. For an N-length code with M possible phases, the kernel can be multiplied by 1 + log2N modified Walsh-Hadamard rows with$M$different phases. This gives a size of$M$1+log$N$. The amount of bits per code word can be expressed as (1 + log2 N)log2M. For instance, a length 8 code with four possible phases gives eight bits per code word. The above numbers have not yet taken into account the interleaving rule, which adds another log2([(log2N)!]/2) bits to the total number of bits per symbol (for N > 4 with N being a power of 2). Notice that the interleaving rule does not necessarily produce an integer number of bits per encoded symbol code set.

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IV. RESULTS

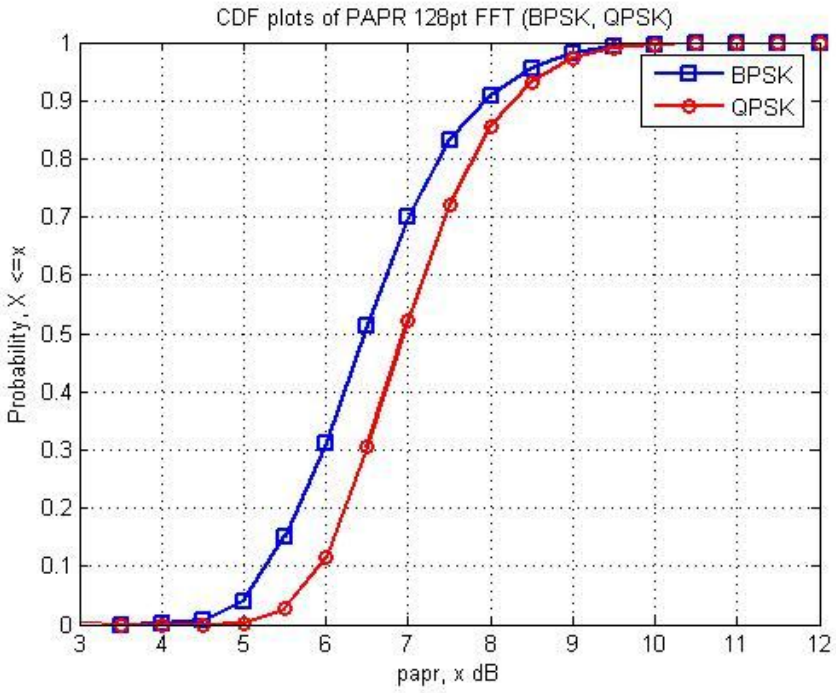
The various techniques for reducing the of PAPR such as no. of techniques as clipping, Coding, selected mapping (SLM), partial transmit sequence (PTS), etc .has been studied.

Here work performed is reducing PAPR (peak to average power ratio) in OFDM by changing the phase of some of the subcarriers through Matlab Simulation. In 40MHz mode where a 128pt FFT is used, PAPR of HT-LTF (High Throughput Long Training Field) can be reduced by multiplying the upper 20MHz subcarriers by j.

A. No rotation is 5.6317dB and

B. With 90 degree rotation is 3.4066dB.

So, around 2.2dB reduction in PAPR is achieved.



V. CONCLUSIONS

Recently the OFDM technique is being considered as a strong candidate for the fourth generation (4G) of mobile communication systems. Compared with single carrier modulation, OFDM has many advantages as immunity to impulse interference, high spectral density, resilient to RF interference, robustness to channel fading, resistance to multipath, much lower computational complexity.

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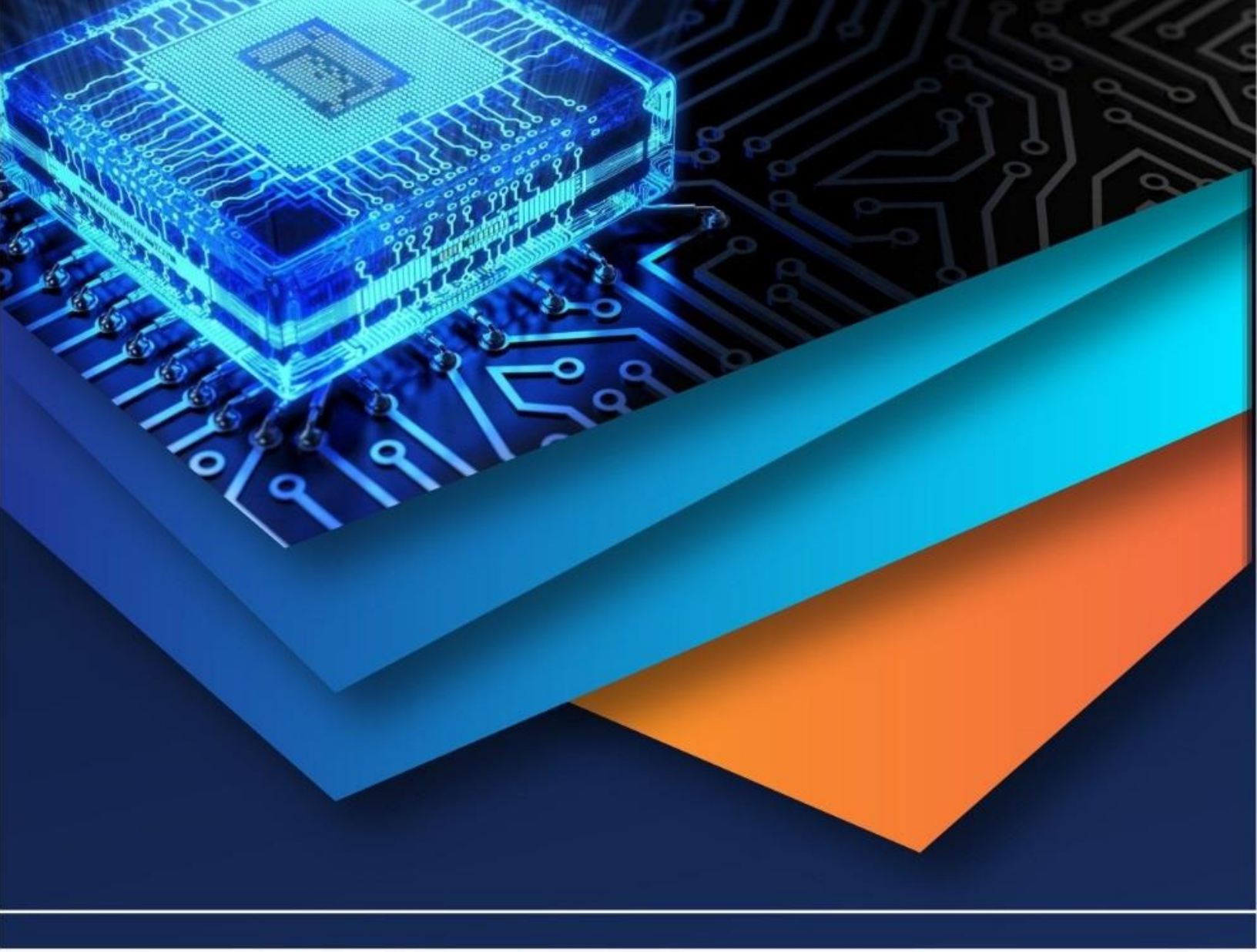

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