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PAPR Reduction with Palindromic Codes Using Biasing Vector Technique in OFDM

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Abstract: *The main drawback of the OFDM system is high Peak to Average Power Ratio (PAPR), which calls for high power amplifiers in the system. This problem can be mitigated by using Block codes that are Non Transparent. We investigated the potential of the Palindromic codes in reducing the PAPR with the proposed biasing method. Using exhaustive search, a bias vector of n bits is chosen and added to all possible codewords (using modulo-2 addition) such that the maximum PAPR of all these codewords is minimized. For making the number of carriers to be a power of two for efficient IFFT/FFT, Redundant Bits are to be added to the biased code word even though there is a slight degradation in PAPR performance.*

Keywords: *Peak to Average Power Ratio (PAPR), Orthogonal Frequency Division Multiplexing (OFDM), Biasing Vector (BV), Redundant Bit (RB), Inverse Fast Fourier Transform (IFFT).*

1. INTRODUCTION

The IFFT can be used to efficiently to perform the modulation on to orthogonal carriers as given in equation 1 [1-4]

$$x(t) = \sum_{i=0}^{N-1} X_i e^{-2\pi f_i t} \qquad 0 \le t \le NT \tag{1}$$

Where X_i is the amplitude of the spectrum for the q^{th} frequency, i is index of the frequencies over the N frequencies and f_i is the frequency of the i^{th} carrier.

As OFDM signal consists of N independent orthogonal carriers, the peak power is N times the average power when the sub carriers are in phase, which in turn increases PAPR as described below [5-10].

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

For normalized input power, $E[|x(t)|^2] = 1$

$$\text{PAPR} = \max|x(t)|^2$$

$$\text{PAPR}_{\text{dB}} = 10 \log_{10} (\max|x(t)|^2) \tag{3}$$

When OFDM signal is passed through a non linear device, such as power amplifier, the signal suffers significant spectral spreading and in-band distortion [11]. It is desired to reduce PAPR because the power amplifiers at the transmitter have a linear behavior up to a certain range and beyond this range, distortion occurs. Hence, the problem of PAPR reduction has received widespread attention in recent years.

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If the peak transmission power is physically limited or limited by regulatory rules, the system must be designed with reduced average transmitter power which in turn reduces the effective range of the system. Additionally, costs rise as more equipment may be needed to cover the same transmission range [12].

The PAPR is controlled by selecting code words which are having a relatively low PAPR to transmit the source information [12, 13-14]. Thus, it avoids transmitting the code words which generates high PAPR and can be achieved by using Linear Block Codes as channel coding [15, 7, 16-17].

1.1. (7, 3) Palindromic Block Codes

For the message bits m_0 m_1 m_2 m_{k-1}, the *i*th code bit in the Palindromic code word of length *n* bits is described as [18]

$$c_i = \begin{cases} m_i & for\ i = 0,1,2,...,k-1 \\ m_0 \oplus m_1 ... m_{k-1} & for\ i = k \\ m_{2k-1} & for\ i = k+1, k+2,...,n-1 \end{cases} \tag{4}$$

Hence code word C of (7, 3) palindromic code, can be rewritten as:

$$C = [c_0\ c_1\ c_2\ c_3\ c_4\ c_5\ c_6]$$

$$= [m_0\ m_1\ m_2\ m_0 \oplus m_1 \oplus m_2\ m_2\ m_1\ m_0]$$

2. PAPR REDUCTION TECHNIQUE WITH (7, 3) PALINDROMIC CODE IN OFDM

Figure 1a, shows the strategy for reduction of PAPR for the proposed (7, 3) Palindromic code. The PAPR at various stages in the encoder is described below.

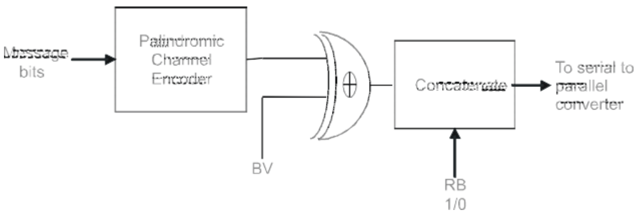

Figure 1: Encoder for Reducing PAPR

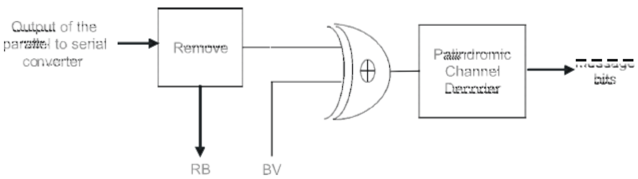

Figure 1a: Decoder for the Proposed PAPR Reduction Technique

Channel Encoding (Stage1)

The PAPR for all code vectors are computed using the equation 3. A brief mathematical procedure for computing PAPR from the code word is described below for the code word 0 0 1 1 1 0 0, with BPSK modulation.

$$x(t) = -e^{j\omega t} - e^{j2\omega t} + e^{j3\omega t} + e^{j4\omega t} + e^{j5\omega t} - e^{j6\omega t} - e^{j7\omega t}$$

$$|x(t)|^2 = x(t).x^*(t)$$

$$= (-e^{j\omega t} - e^{j2\omega t} + e^{j3\omega t} + e^{j4\omega t} + e^{j5\omega t} - e^{j6\omega t} - e^{j7\omega t})$$
$$(-e^{-j\omega t} - e^{-j2\omega t} + e^{-j3\omega t} + e^{-j4\omega t} + e^{-j5\omega t} - e^{-j6\omega t} - e^{-j7\omega t})$$

$$= 7 + 4\cos\omega t - 6\cos 2\omega t - 8\cos 3\omega t - 2\cos 4\omega t + 4\cos 5\omega t - 2\cos 6\omega t$$

The PAPR distribution for the signal $x(t)^2$ as a function of ωt is presented in Figure 2.

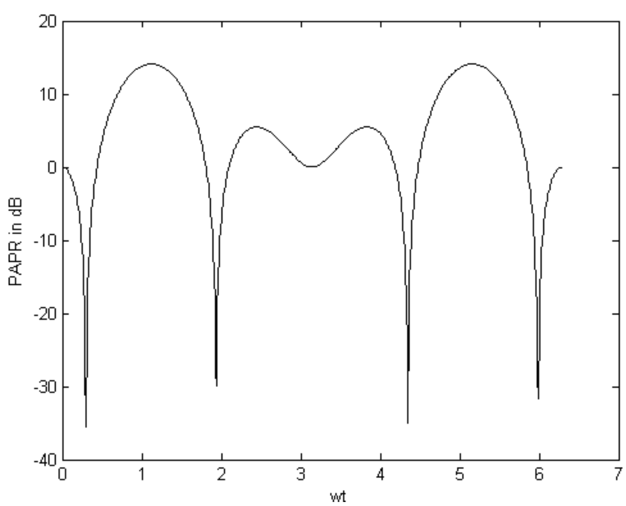

Figure 3: PAPR Distribution for the Code Word 0011100

$\max|x(t)|^2$ occurs at

$$\frac{d}{d\omega t}|x(t)|^2 = 0$$

or

$$-4\sin\omega t + 12\sin 2\omega t + 24\sin 3\omega t + 8\sin 4\omega t - 20\sin 5\omega t - 12\sin 6\omega t = 0$$

Or

$$\omega t = 1.12$$

Substitute for wt in equation 5, we obtain

$$\max|x(t)|^2 = 25.64$$

Form equation 3, PAPR is given by
PAPR = 14.09 dB.

Identification of Biasing Vector (Stage 2)

The Biasing Vector (BV) of the same length as the encoded message is added at this stage to evaluate the effect on PAPR. Any one of 2^7 probable BVs' is selected and PAPR is computed for all eight codes and maximum PAPR is also identified from the computed values of PAPR. Similarly for all other BVs', maximum PAPR has been calculated. The BV which has given the lowest of the maximum PAPRs is considered as the favorable BV.

Identification of Biasing Vector and Redundant Bit combination (Stage 3)

For efficient FFT/IFFT implementation it is necessary that the number of carriers to be in power of two. For this purpose, one Redundant Bit (RB) is added to the biased code words for (7, 3) Palindromic code. RB is chosen such that the PAPR is under control. The favorable BV and RB combination that can provide minimum PAPR is also identified and now (7, 3) Palindromic code transforms to (8, 3) code.

The summary results of the PAPR performance during different processes in the encoder are presented in Table 1.

Table 1
Maximum PAPR at Different Stages for Palindromic Code

Process	*PAPR in dB*
Channel Encoding (stage 1)	16.90
With BV (stage 2)	11.22
With BV and RB (stage 3)	13.22

It is evident from the Table 1, PAPR improvement of 5.6dB is achieved with BV. With RB usage PAPR performance is 2dB less than that of stage 2. However, the improvement in the performance of PAPR is better by 3.68 dB compared to the stage 1.

At the receiver, RB is discarded from the transformed code and use the same BV as the transmitted BV to detect coded message as shown in Figure 1b.

3. PAPR WITH (6, 3) HAMMING CODE

For three message bits, the Hamming code requires three parity bits for single bit correction and hence the code becomes (6, 3) code. In order to minimize PAPR using BV and make the IFFT/FFT more efficient using RB, an eight bit code is generated. So the RB must have 2 bits.

The summary results of the PAPR performance during different processes in the encoder are presented in Table 2.

Table 2
Maximum PAPR at Different Stages for Hamming Code

Process	*PAPR in dB*
Hamming Encoding (Stage 1)	15.56
With BV (Stage 2)	12.08
With BV and RB (Stage 3)	15.56

A 3.48 dB PAPR improvement is achieved, when (6, 3) Single bit Error Correcting Hamming codes with BV addition. With two redundant bits, PAPR reduces to the original values of PAPR. No apparent benefit is seen with RB inclusion in the process for improving the PAPR performance in the (6, 3) Hamming code.

4. CONCLUSIONS

In case of Palindromic code, the PAPR is reduced when BV is transposed on the encoded bits by an amount of 5.68 dB, whereas in Hamming code by 3.48 dB only.

When RB is also considered for the code, PAPR increases by 2 dB only where as in Hamming code, it does not show any reduction in PAPR. Even though there is a slight degradation in PAPR performance in Palindromic code after RB is considered, it is insignificant vis-à-vis Hamming code because there is absolutely no improvement seen in the latter case.

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