VHDL Implementation of Circularly Shifted PTS Technique for PAPR Reduction in OFDM

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***Abstract*—This paper presents an efficient VHDL implementation of circularly shifted partial transmit sequence (CS-PTS) scheme for peak-to-average power ratio (PAPR) reduction in orthogonal frequency division multiplexing (OFDM) signals. It eliminates the search for optimum phase factors from a given set, which manifests improved PAPR at reduced computational complexity as compared to conventional PTS (C-PTS). The amplitude of the signal is reduced by rotating each of the partially transmitted sequence anti-clockwise by a pre-determined degree and the peak power is reduced by circularly shifting the quadrature component of the partially transmitted sequence after phase rotation. A brief description of C-PTS and CS-PTS is also presented and VHDL implementation of Circularly Shifted PTS is designed. The peak-to-average power ratio performance of the proposed method has been investigated.**

Keywords—OFDM, PTS,PAPR, Circular shift, VHDL.

I. INTRODUCTION

The 4G wireless technology has adopted OFDM transmission supporting high data rate communications [1]. OFDM is a multicarrier technique which converts frequency selective channel to several flat fading channels eliminating ISI. International standards like European Digital Video Broadcasting (DVB), Wireless LAN (IEEE 802.11 a/g), Wireless MAN (IEEE 802.16e) have adopted the OFDM method [1].

OFDM employed in transmission systems exhibits very high peak-to-average power ratio. The high PAPR drives the power amplifier to operate in non-linear region which causes inter-modulation distortions and out-of-band radiations. So, it is highly essential to reduce PAPR. For the same, various techniques have been employed such as coding, companding, amplitude clipping and filtering, active constellation extension (ACE), tone reservation (TR), tone injection (TI), selected mapping (SLM), partial transmit sequence (PTS) [1, 2]. Among these, PTS is considered to be a suitable scheme for PAPR reduction whereas; its computational complexity is very high.

In C-PTS [2], the sub-block partitioning and phase factor combining operations are carried out, to obtain an optimum transmit sequence. In [3] the author has proposed a low-complexity PAPR reduction scheme, which at the transmitter side a single IFFT block is used without any sub-block partitioning or phase factors. Another PAPR reduction scheme has been proposed [4] in which the phase sequences are cyclically shifted, with a low complexity but same PAPR reduction as in C-PTS. In [5] Yang et al. proposed a low complexity PTS, which involves cyclic shifting of time domain sequences and combining them which leads to reduced computational complexity. In this paper, the use of phase factors is removed, which is originally employed in C-PTS, by introducing the method of rotating each time domain sub-block symbol by a pre-determined degree and circular shifting of partially transmitted quadrature phase components. This technique lowers the computational complexity in addition to reduction in peak to average power ratio as compared to C-PTS. Furthermore, paper also discusses, the VHDL implementation of circularly shifted partial transmit sequence technique. This is achieved where parallel processing of symbols are carried out instead of serial processing. In addition, the multiplicative complexity is reduced by shift and add algorithm. VHDL implementation of PAPR calculation is also performed which provides the PAPR of the respective symbol transmitted.

This paper is organized as further: In Section II, a brief review of PAPR and C-PTS is discussed. The modification carried out in C-PTS, leads to CS-PTS is revealed in Section III. Results of simulation performed are presented in Section IV to show reduction in PAPR and comparison with C-PTS. Finally, in Section V, CS-PTS is implemented in Xilinx ISE 14.2 using very high speed integrated circuit hardware description language (VHDL). Section VI presents the concluding remarks.

II. PAPR IN OFDM AND ITS IMPLEMENTATION USING C-PTS

In an OFDM system, the serial data stream to be transmitted is divided into parallel data stream constituting series of frames. All bits/symbols in a frame is modulated by N subcarriers, X=[$X(0), X(1),\cdots, X(N\text{-}1)]^{T}$, which are orthogonal. This is achieved by considering, $\Delta f = \frac{1}{NT}$ where T denotes the duration of OFDM symbol, Δf is the subcarrier spacing and N is number of subcarriers. After modulation, the frequency domain symbol is converted to time domain symbol with an N-point IFFT operation. The transmitted symbol is given by,

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) \exp\,(j2\pi t \Delta f k), \quad 0 \le t \le NT \qquad (1)$$

where NT is the data block period.

The average power of the transmitted signal can be written as,

$$P_{av} = E\{|x(t)|^2\}, \tag{2}$$

where, $E\{\cdot\}$ is the expectation.

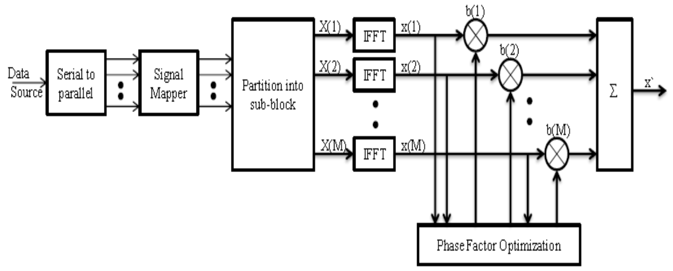

Fig. 1. PAPR reduction by conventional partial transmit sequence technique (C-PTS).

and, the peak power of the transmitted signal is,

$$P_{peak} = max_{0\le n\le NT}|x(t)|^2 \tag{3}$$

From (2) and (3), the PAPR of the transmitted OFDM symbol can be defined by,

$$PAPR = \frac{\mathrm{P_{peak}}}{\mathrm{P_{av}}} = \frac{\max_{0\le n\le NT}|x(t)|^2}{E\{|x(t)|^2\}} \tag{4}$$

PAPR is generally represented by a complementary cumulative distribution function (CCDF) where x-axis denotes the preset threshold and y-axis denotes the probability that the PAPR exceeds this threshold.

The CCDF is defined by,

$$P(PAPR > PAPR_{th}) = 1-(1-e^{-PAPR_{th}})^N \tag{5}$$

where, $PAPR_{th}$ is the threshold PAPR.

A. *Conventional PTS Algorithm (C-PTS)*

The data symbols after modulation are partitioned into M disjoint sub-blocks, $X_m = [X_{m,0}, X_{m,1}, \dots, X_{N-1}]$, m=1,2,., M where M is the number of sub-blocks. An N-point IFFT is employed on each sub-block which can be written as,

$$x_m = IFFT\ \{X_m\} \tag{6}$$

These time domain sequences x_m are the partial transmit sequences, each of which are then multiplied by the phase factors b_m =[b_1,b_2, …, b_M]. These phase factors are chosen from $\{\pm 1\}$ and $\{\pm 1, \pm j\}$ for W= {2, 4}, where W is the set of allowed phase factors. The phase factors can also be generated from,

$$b_m = e^{j\varphi_m} \tag{7}$$

where, φ_m is the phase and m = 1,2,… M.
The candidate signals are generated by combining the partial transmit sequence after phase factor multiplication, which is defined by,

$$\tilde{x} = \sum_{m=1}^{M} b_m \ \ x_m \tag{8}$$

Finally, the optimum candidate signal with lowest PAPR is selected from W^{M-1} candidate signals and is transmitted [2, 6]. This guarantees reduction in PAPR. The PAPR reduction by conventional PTS technique is shown in Fig. 1.

III. Circularly Shifted Partial Transmit Sequence (CS-PTS)

CS-PTS eliminates the use of phase factors and reduces peak to average power ratio. After modulation, the data symbols are partitioned into sub-blocks which generate the frequency domain symbols. These frequency domain symbols are converted to time domain symbols by N-point IFFT operation on each sub-block. Fig. 2 depicts the block diagram of the transmitter system of modified PTS. Here, instead of phase factor combining, the phase rotation of in-phase and quadrature phase components is employed, to suppress the amplitude of the signal. Phase rotation adjusts the amplitude of the samples but the power of the samples remains unchanged. Each sub-block performs phase rotation for Q times. Further, the quadrature components of output samples from the symbols after phase rotation are circularly shifted by a shift matrix, where each quadrature component is shifted P times. The combined operation of phase rotation and circular shifting results in PAPR reduction. The shift matrix is generated in a random fashion which is denoted as,

$$L_q^p = \begin{pmatrix} L_1^1 & \cdots & L_q^1 \\ \vdots & \ddots & \vdots \\ L_1^p & \cdots & L_q^p \end{pmatrix}_{P\times Q} \tag{9}$$

where p = 1,2,… P , q = 1,2,… Q.

Meanwhile, the in-phase components are kept intact. The in-phase and shifted quadrature phase components are recombined together in a mis-aligned manner to form the candidate signals. The signal with lowest PAPR is selected among the candidate signals.

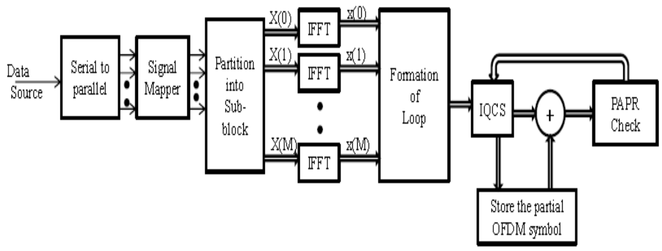

Fig. 2. PAPR reduction by modified partial transmit sequence technique (CS-PTS).

A. *Steps to obtain CS-PTS*

The modified PTS can be obtained in following steps:

1) Partitioning of the input data sequence X into M subblocks.

2) IFFT operation on each subblock which is denoted by,

$$x_m = [x_1, x_2, \dots, x_M]^{\mathrm{T}} \tag{10}$$

3) Phase Rotation of time domain partially transmitted sequences.

$x_p^q(m)$, being a complex variable, can be represented as,

$$x_p^q(m) = u_p^q(m) + j v_p^q(m), \tag{11}$$

m = 1,2,… M, p=1,2,…,P, q=1,2,…,Q

where, $u_p^q(m)$ and $v_p^q(m)$ are in-phase and quadrature phase components.

The phase rotation of in-phase and quadrature phase components can be written as,

$$x_p^q(m)=(u_{p-1}^q(m)+jv_{p-1}^q(m))\ (\cos\theta\ +\ j\sin\theta), \qquad (12)$$

where, θ is taken as $\frac{\pi}{4}$ for which $\cos\theta = \sin\theta$

So, (12) can be modified as,

$$r_{p-1}^q(m)=\frac{1}{\sqrt{2}}\,(u_{p-1}^q(m) - v_{p-1}^q(m)), \qquad (13)$$

$$s_{p-1}^q(m)= \frac{1}{\sqrt{2}}\,(u_{p-1}^q(m) + v_{p-1}^q(m)), \qquad (14)$$

$$m = 1,2,\ldots,M,\ p=1,2,\ldots,P,\ q=1,2,\ldots,Q$$

where, $r_{p-1}^q(m)$ and $s_{p-1}^q(m)$ are in-phase and quadrature components after phase rotation.

Therefore, (13) and (14) shows that instead of phase rotation, the addition and subtraction of in-phase and quadrature phase components with a constant multiplication can be performed. This operation reduces complexity by eliminating the need of complex multiplication.

4) Circular shifting of output samples, $s_{p-1}^q(m)$, where $r_{p-1}^q(m)$ is kept intact.

$$S_p^q(m)= s_{p-1}^q(m)\ ((\text{n} - L_q^p))_{\text{N}}, \qquad (15)$$

$$m = 1,2,\ldots, M\ ,\ p = 1,2,\ldots,P\ ,\ q = 1,2,\ldots,Q.$$

5) Re-combination of in-phase component, r_{p-1}^q (m) and quadrature component, $S_p^q(m)$ gives the $P \times Q$ candidate signals.

$$\widetilde{x_m}= r_{p-1}^q(m) + \text{j}\ S_p^q(m), \qquad (16)$$

6) Select the candidate signals with minimum PAPR from each sub-block and add them.

7) The selected signal is the signal with minimum PAPR.

IV. Simulation Results

Simulations was performed to compare the performance of PAPR reduction in OFDM symbols among OFDM without PTS, with PTS and modified PTS with N=64 subcarriers.

For conventional PTS, M=4 and W=4 was considered whereas in modified PTS M=4, P=8 and Q=8 iterations are assumed. Fig.3. represents the CCDF of PAPR for OFDM system without PTS, with PTS and modified PTS. The CCDF of PAPR was generated using 10000 random samples. It is observed that the modified PTS has better PAPR performance than C-PTS with less computational complexity.

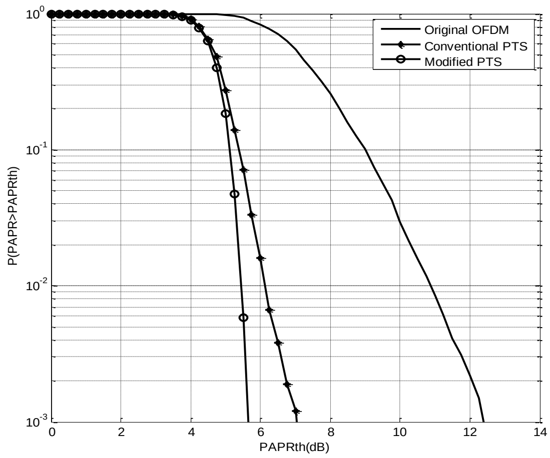

Fig. 3. CCDF of PAPR with N=64, M=4 and P=8, Q=8 for OFDM without PTS, with conventional PTS and with modified PTS.

V. Implementation Using VHDL

With the advent of new and efficient technologies [7 - 11], it has been simpler to implement the PTS-OFDM transmitter system and its peak to average power ratio calculation in VHDL. The architecture proposed in this paper was coded in VHDL and then simulated and synthesized in Xilinx ISE 14.2 device, XC5VLX110T, with a speed of -1, and the package used is FF1136.VHDL implementation provides parallel processing of data symbols instead of serial processing. The resource utilization for this design can also be known by VHDL implementation.

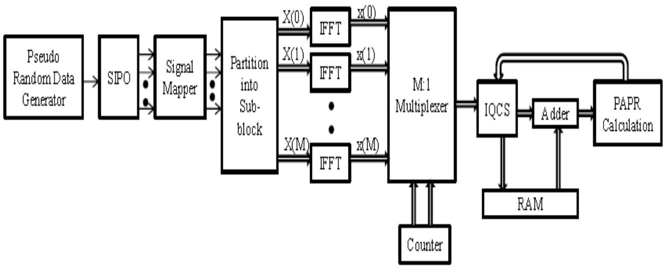

Fig. 4. VHDL implementation of the modified partial transmit sequence technique (CS-PTS).

A. The Transmitter System Block Diagram for implementation in VHDL

Fig.4. illustrates the VHDL implementation of modified partial transmit sequence technique. Pseudo-random data generator provides random serial data which is converted to parallel with the help of serial-in-parallel-out register. These data symbols are then modulated and partitioned into subblocks. Each subblock is employed with an N-point IFFT operation. An IFFT operation is carried out by $\frac{\text{N}}{2}\log_2 N$ number of butterfly processing elements. The twiddle factor multiplications involved in a butterfly is eliminated by the use of shift and add algorithm [8]. Here, radix-2 multi-path delay commutator (R2MDC) pipelined architecture processing element is employed for IFFT operation. Moreover, the

computational complexity which arises due to IFFT operation is reduced by its VHDL implementation.

For parallel processing of the time domain symbols, a multiplexer is incorporated where the select inputs are selected by a counter. The count of a counter depends on the number of select inputs. As shown before, that instead of phase rotation, the addition, subtraction and constant multiplication operations can be performed on the in-phase and quadrature phase components. Now, the quadrature phase components are circularly shifted by a random variable and then the in-phase and quadrature phase components are re-combined to form the partial OFDM symbol. The partial OFDM symbol is stored in a random access memory which is then added when the counter reads the last count. PAPR calculation of this OFDM symbol is calculated and the symbol with minimum peak-to-average power ratio is transmitted. Table I represents the resouces utilization summary of the modified partial transmit sequence.

TABLE I. RESOURCES UTILIZATION SUMMARY

Logic Utilization	***Resources Used***	***Performance (%)***
Number of Slices	2517	3
Number of fully used LUT-FF pairs	256	9
Number of bonded IOBs	148	23
Number of DSP48 slices	16	25

B. Peak-to-Average Power Ratio Calculation in VHDL

Peak-to-average power ratio is calculated by the expression given in (4). The same can be evaluated in VHDL as per the block diagram shown in Fig. 5. Here, the operations are performed individually on in-phase and quadrature components. The inputs are taken in integer representation upon which squaring, adding and division operations are performed. For an example, an OFDM signal with N=8 subcarriers is considered to verify the results. Fig. 6. depicts the test-bench waveform for PAPR calculation of an OFDM symbol. It can be viewed that for each transmitted symbol a PAPR is calculated.

VI. CONCLUSION

In this paper, the phase rotation and circular shifting of partial transmit sequences is carried out which provides better peak-to-average power ratio as compared to conventional PTS. Moreover, the parallel and pipe-line processing of symbols is applied by implementation in VHDL. This implementation in VHDL lowers the complexity by eliminating the complex multiplications. Matlab simulations done for N=64 subcarriers with 10000 samples of OFDM symbols to plot the CCDF, which shows that the modified PTS gives better PAPR reduction as compared to C-PTS. The same concept is implemented in VHDL in addition to its PAPR calculation. PAPR calculation in VHDL can also be simulated for subcarriers greater than 8 using the same process as is done for N=8. In comparison to C-PTS, this scheme eliminates phase factor combination with a better PAPR reduction.

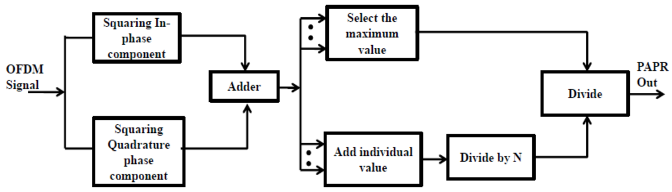

Fig. 5. Block Diagram for PAPR calculation inVHDL.

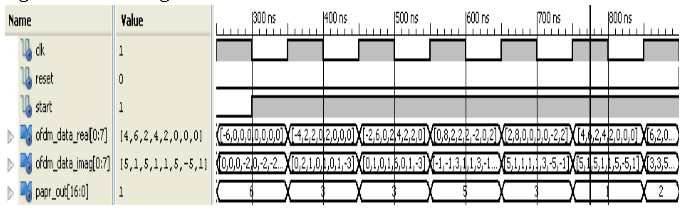

Fig. 6. Test-bench waveform for PAPR calculation.

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