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PAPR Reduction Based on Proposed Rotating Phase Shift Technique in MC-CDMA Using FPGA

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Abstract

FPGA implementation used of Rotating phase shift (RPS) for peak-to-average power ratio (PAPR) reduction in Multi Carrier Code Division Multiple Access (MC-CDMA) signals. Because, MC-CDMA is still suffering from PAPR which is a major drawback in most of the multi carrier communication systems. In addition, the implementation of the system in an FPGA becomes more flexible and scalable. 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 and SLM. The amplitude of the signal is reduced by rotating each of the partially transmitted sequence anti-clockwise by a π/2 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 PTS, SLM is compared with the RPS, which best reduces PAPR from PTS and SLM. It is also presented that VHDL code of the RPS is designed by Xilinx ISE 14.1 implements of FPGA. The peak-to-average power ratio performance of the proposed method has been investigated.

Keywords

MC-CDMA, PAPR, RPS and FPGA

1. Introduction

The 4G wireless technology has approved MC-CDMA transmission supporting high data rate communications [1]. In the MC-CDMA, orthogonal codes are used to spread symbols of users and combine them in the frequency domain; this results in a comparatively low symbol rate and non-selective fading in each subcarrier [2]. But, the

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MC-CDMA systems are facing problems cast by PAPR due to the nature of the multicarrier OFDM and CDMA [3]. The high PAPR drives the power amplifier to operate in the nonlinear area that causes distortions between inter-modulation and out-of-range radiation. Therefore, it is highly essential to reduce PAPR. In addition, several techniques have been proposed like clipping and filtering, coding, active constellation extension, Tone Injection (TI), Tone Reservation (TR), partial transmit sequence (PTS), and selected mapping (SLM) [4]. Among all these approaches, SLM is considered to be appropriate to reduce the PAPR, whereas its computational complexity is very high [5] [6].

In [7], the authors have proposed a lower complexity PAPR reduction scheme, which at the transmitter side a single IFFT block is used without any sub-block partitioning or phase factors. FPGA implementation of DS-CDMA transmitter has been proposed in [8], which research complicated two phases—simulation and synthesis of the Verilog codes. The Xilinx Synthesis Technology (XST) of Xilinx ISE 12.3 tool was used for synthesis of the transmitter and simulates a design's reaction to different stimuli. In [9], the authors suggested a low complexity PTS, which includes cyclic shifting of time domain sequences and combining them which leads to reduced computational complexity. In addition, Low Complexity VLSI Architecture for DS-CDMA Communication System uses FPGA [10]. In [11], the error control code makes each sequence more random and reduces the probability of in phase addition of sub-carriers by interleaved. Thus, it is an improved SLM method with n-tuple PAPR control bits followed by an interleaved and an error control code. The PAPR reduction in the MC-CDMA system increases the probability of PAPR reduction.

In this present paper, the use of phase factors is eliminated, which is originally employed in SLM and PTS, by introducing the method of rotating each time domain sub-block symbol by a predetermined degree and circular shifting of partially transmitted quadrature phase components. Moreover, the Very High Speed Integrated Circuits Hardware Description Language (VHDL) implementation of Rotating Phase shifted technique is achieved where parallel processing of symbols is carried out instead of serial processing. Furthermore, 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: Section 2 discussed a brief review of PAPR in MC-CDMA system. It proposed method Rotating Phase Shift display in Section 3. In Section 4, RPS-PAPR is implemented in Xilinx ISE 14.1 using VHDL. Finally, results of simulation performed are provided in Section 5. Section 6 presents the concluding remarks.

2. The PAPR of an MC-CDMA Signal

The MC-CDMA is a multi-carrier transmission, which has a high data rate and greater flexibility for voice, data, and video and internet services for future wireless systems. This is multiplied by the first of the original data load, with the spreading code and then the chips of spread data are modulated onto orthogonal subcarriers [12]. **Figure 1** shows the MC-CDMA signal generation in transmitting side of a complex data symbol an assigned to user h. In the transmitter of data symbol a^h is first multiplied with the user specific spread code by = $\left[b_1^h, b_2^h, \cdots, b_{M-1}^h\right]^{\mathrm{T}}$ of spread factor M. The spread code c^h obtained after spreading can be given in vector scheme as:

$$c^h = a^h b^h = \left[C_1^h, C_2^h, \cdots, C_{M-1}^h\right]^{\mathrm{T}} \tag{1}$$

The c^h is converted to parallel C_m^h, where $m = 0,1,\cdots,M-1$, and modulated onto M subcarriers followed by IDFT of size $N = 1 \times M$ to obtain a multi-carrier spread spectrum signal. A time domain baseband transmission signal $x^h(t)$, after IDFT, for one MC-CDMA symbol, $0 \le t \le T_s$, has:

$$x^h(t) = \sum_{m=1}^{M} \sum_{h=1}^{H} a^h b_m^h \mathrm{e}^{j2\pi(m-1)t/T_s} \tag{2}$$

where T_s is the MC-CDMA symbol period and H the total number of users.

Formerly, the PAPR [13] of MC-CDMA signals $x(t)$ is defined as the ratio between the maximum instantaneous power and average output power

$$\mathrm{PAPR} = \frac{P_{\mathrm{peack}}}{P_{\mathrm{average}}} = \frac{\max_{0 \le n \le m-1}\left(|x|^2\right)}{E\left\{|x^2|\right\}} \tag{3}$$

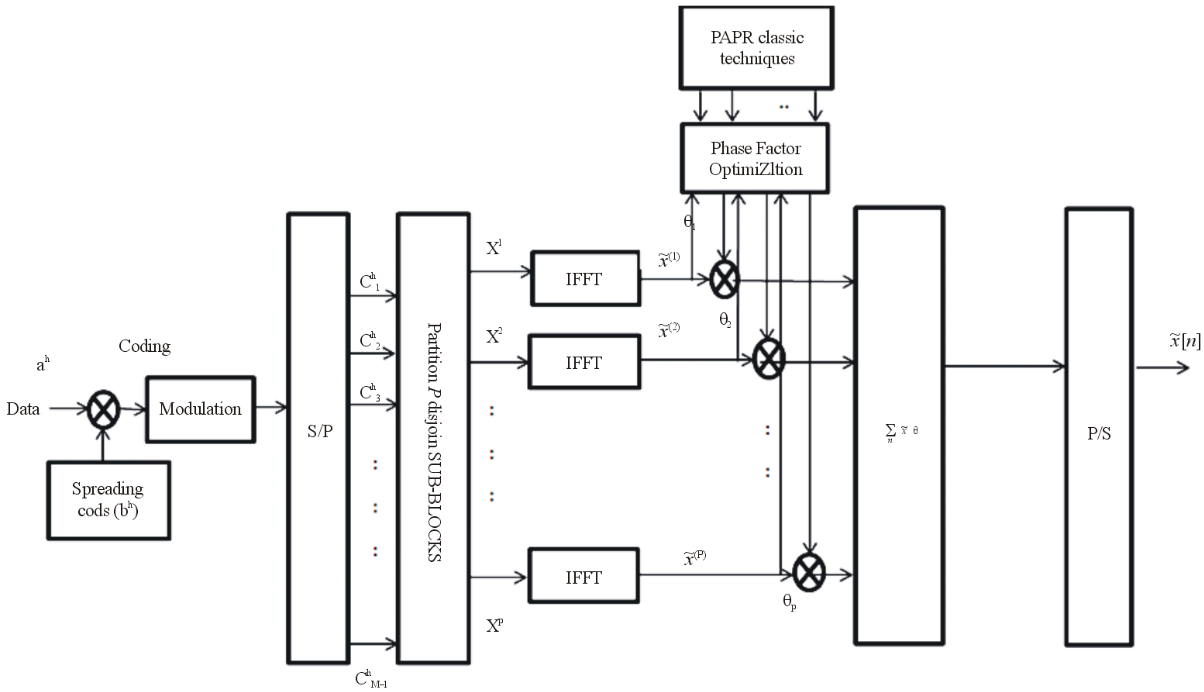


Figure 1. Block diagram of MC-CDMA, transmitted side.

P_{average} can be calculated as:

$$P_{\text{average}} = \frac{1}{T_s}\int_0^{T_s} \left|x(t)\right|^2 \mathrm{d}t = \frac{1}{N}\sum_{n=0}^{N-1} E\left\{\left|\sum_{h=1}^{H} x^h(n)\right|^2\right\} \tag{4}$$

where N is the number of sub-carriers and $E\{.\}$ denotes expectation. Also, PAPR in the discrete time domain can be expressed as:

$$\text{PAPR}_{\max} = 10\log_{10}(N)(\text{dB}) \tag{5}$$

As one of the characteristics of the PAPR, which bears stochastic characteristics in MC-CDMA systems, often can be expressed in terms of Complementary Cumulative Distribution Function (CCDF). Which is described as the probability of the PAPR exceeding a certain level w [14] [15], that can calculate as:

$$\text{CCDF}(\text{PAPR}) = prob\{\text{PAPR} > w\} = 1-\left(1-\mathrm{e}^{-w}\right)^N \tag{6}$$

where, N total number of sub-carrier and w is the level of exceed.

3. Proposed Method

RPS takes away the use of phase factors and reduces PAPR. After multiple data by spreading code, then modulation, the data symbols are partitioned into sub-blocks which generate the frequency domain symbols [16]. These frequency domain symbols are converted to time domain symbols by N-point IFFT operation on each sub-block. Figure 2 shows the block diagram of the transmitter system of proposed RPS-PAPR. Now, instead of combining phase factor and the rotation phase of the work in phase and beating by rotating phase is employed, to suppress the amplitude of a signal. Phase rotation adjusts the amplitude of the samples, but the power of the samples has not changed. Moreover, the quadrature components of the output samples of symbols after rotation stage and turned carousel by the equation of shift where the transformation of each quadrature component p times. In a joint operation of the phase rotation and circular shift results in reducing PAPR.

On the other hand, the support sets of X_p's are disjoint. The sub-vector $x_p = \left[x_{p,0}\ x_{p,1} \cdots x_{p,N-1}\right]^{\mathrm{T}}$ is created using apply IFFT to each symbol sub-vector X_p, also known as a sub-block. Each sub-vector x_p is

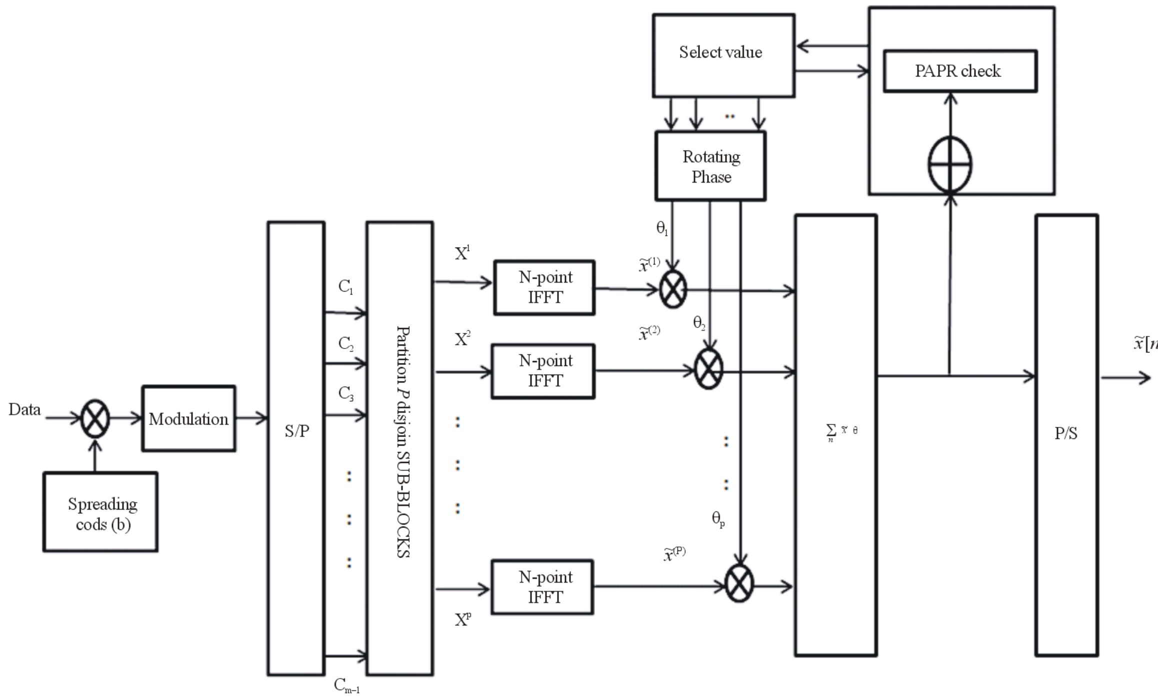


Figure 2. Bloc diagram of the MC-CDMA with RPS PAPR reduction technique.

then multiplied by a valid phase shift $\theta=[\theta_1,\theta_2,\cdots,\theta_{P+1}]$ chosen from a given symbols ξ, that is generally $\xi=\{\pm 1\}$ or $\xi=\{\pm 1,\pm j\}$, where ξ the rotating facto. Also can be shifted the phase on the circumference of a circle to any value such as $\pi/4$ that is shown in **Figure 3**. Similarly, this results in a rotating MC-CDMA signal vector $x^w=\left[x_0^w\ x_1^w \cdots x_{N-1}^w\right]^T$ given as

$$x^w=\sum_{p=1}^{P} r_p^w x_p \tag{7}$$

where,

$$r^w=\left[r_1^w \quad r_2^w \quad \cdots \quad r_p^w\right], 1\le w\le W, \text{ and } W=\left|\xi\right|^{p+1} \tag{8}$$

The PAPR of x^w is computed for rotating vectors and compared, which has the minimum PAPR is selected for transmission. The index $\tilde{w}$ of the corresponding rotating vector $r^{\tilde{w}}$ is selected according to

$$\tilde{w}=\arg\min_{1\le w\le W} \max_{0\le n\le N-1}\left|\sum_{p=1}^{P} r_p^w x_{p,n}\right| \tag{9}$$

The receiver must know the index information to recover the original input vector. The PAPR reduction performance and the computational complexity of the RPS structure depend on the method of sub-block separating. Furthermore, a search is a strategy that works well on optimization problems with the minimize PAPR show in Algorithm. 1 the search algorithm For algorithm, let X be the MC-CDMA signal and θ be a set of valid phase shifts [17].

Algorithm 1: GVS Search

- **Let:** $\theta=\{\theta_1,\theta_2,\cdots,\theta_P\}$ be phase at partition limit.
- **Require:** $X>0, P>0, k>0, \varphi>0;$
- **Inialize:** $x_{op}(t)=X[0]; \theta=\varphi_M, R_m=0.$
- **For** $p=1:P$ do
- $X_p[n]=\begin{cases} X[n], n=r_{p-1}+1,\cdots,r_p \\ 0, \quad \text{otherwise}\end{cases}$

- **For** m=1:M do

$$R_{m+1} = R_m + \frac{(r_p+1)(r_{p-1})}{2}$$

$$X_p^m[n] = X_p[n]e^{\left(j\left(\theta_p + \frac{R_m}{R_{m+1}-R_m}\right)\varphi_m\right)};$$

- **IF** $n < r_p$ **then**

$$x_0^m(t) = ifft\left(X_p^m\right)$$

- **Else** empty R_{m+1}, *otherwise n*

- **End**

$$m_{op} = \arg\min_{m=1:M}\left(\text{Max}_{0\le t\le\tau}\left(\left|x_{op}(t) + x^m(t)\right|\right)\right);$$

$$x_{op}(t) = x_{op}(t) + x^{m_{op}}(t);$$

$$\theta_P = \theta_{P-1} + \varphi_{m_{op}};$$

❖ **End**

❖ **Return** $x_{op}(t), \theta, R_m$

In addition, to define the effect of each factor is compared to the performance of the RPS algorithm by selecting one of the factors are constant and change the rest of the factors in order to measure the effectiveness of that factor in the reduction of PAPR and then change with all cases the same method and each parameter triple (N_R, Z_θ, R_{ph}). As a zero phase shift is always one of the valid phase shifts, the relationship of these factors can be defined as:

$$\left(1 - \frac{\xi^{2N_R}}{N_R}\right) Z_\theta = R_{ph} \tag{10}$$

where N_R is the number of valid phase shifts, ξ the rotating factor R_{ph} the rotate a range of possible phase shifts, M number of partition phase and $Z_\varnothing$ the step size of the phase shifts. Phase delay values for RPS algorithm are in $(R_{ph}, 0)$. This can be illustrated calculating the previous equation, taking into account all or most of the possible cases, according to the following shown in **Table 1**. Besides, **Table 2** turns of the other cases with phase shift e.g. $-\pi/4$.

4. VHDL Implement Based on the RPS-PAPR Reduction

Implement the RPS-MC transmitter system and its peak to average power ratio calculation in VHDL. The archi-

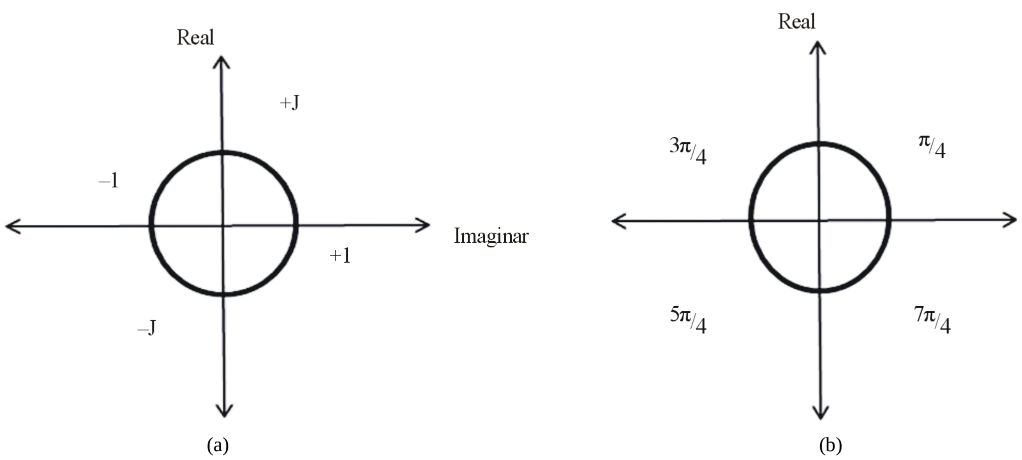


Figure 3. (a) Rotate magnitude constant ξ; (b) Phase shift by $\pi/4$.

Table 1. Phase lags (R_{ph}) at $\xi = \pm j$.

N_R	Z_θ			
	π/2	π	3π/2	2π
1	π	2π	π	2π
2	π/4	π/2	3π/4	π
3	2π/3	4π/3	2π	π/3
4	3π/8	3π/4	9π/8	3π/2

Table 2. phase lags (R_{ph}) with phase shift $-\pi/4$.

N_R	$Z_\varnothing$			
	π/4	3π/4	5π/4	7π/4
1	π/2	3π/2	π/4	3π/2
2	π/8	3π/8	5π/8	7π/8
3	π/3	π	5π/3	π/3
4	3π/16	9π/16	15π/16	21π/16

tecture proposed in this paper was coded in VHDL and then simulated and synthesized in Xilinx ISE 14.1. The computational complexity which arises due to IFFT operation is reduced by its VHDL implementation [18]. Where, the MC-CDMA signal partition according rotation factor R_{ps} the rotate a range of possible phase shifts shown in **Table 3**, for parallel processing of the time domain symbols, a multiplexer is incorporated where the select inputs are selected by a select maximum value. In addition, the PAPR calculation of this MC-CDMA symbol is calculated and the symbol with minimum peak-to average power ratio is transmitted. The same can be evaluated in VHDL as per the block diagram shown in **Figure 4**. At this point, the operations are performed individually on Rotating Phases Shift components. The inputs are taken in integer representation upon which squaring, adding and division operations are performed. **Figure 5** shows the overall for RPS-PAPR calculation of an MC symbol after implementing in FPGA that shows the input IFFT for 64-bits, real and imaginary, then the output after PAPR reduction with enable control in order to build RTL circuits. Moreover, **Figure 5** shows the PAPR architecture in the ISE 14.1 RTL circuit for more details.

5. Simulation Results

Simulations were performed to compare the performance of PAPR reduction in MC-CDMA system SLM, PTS and RPS at phases 3π/2 and 3π/8, with N = 64 subcarriers. The CCDF plots of the PAPR of the MC-CDMA signals in **Figure 6** are shown for four users. Number of partitions for proposed technique RPS and classic PTS is four while predetermined codes for SLM method take 32 and 64. The performances for proposed at both shift registers is best an author's technique as shown in **Figure 7**. The PAPR reduction performance is measured using simulation parameters for MC-CDMA as in **Table 4**

RPS-PAPR calculation of the MC-CDMA system is calculated and the symbol with minimum peak-to average power ratio is transmitted. **Table 5** represents the resources utilization summary of the RPS. In addition, **Figure 8** shows the test-bench waveform for PAPR calculation of an MC-CDMA symbol. It can be observed that for each transmitted symbol a PAPR is calculated. Moreover, the test-bench waveform of the transmit side as shown in **Figure 9**.

6. Conclusion

RPS technique is achieved, which verifies the best PAPR reduction as compared to traditional SLM and PTS techniques. Additionally, the application is parallel processing and pipeline of symbols by implementation in

Table 3. Control registers values.

R_{ph}	R_{ps} With shift $\pi/4$	Register Value
$\pi/2$	$\pi/4$	01
π	$3\pi/4$	10
$3\pi/2$	$5\pi/4$	11
2π	$7\pi/4$	00

Table 4. MC-CDMA simulation parameters.

Parameters	Value
Number of transmitting bits	2000
No. Subcarriers N	64
No. of Users H	4
Modulation	32-QAM
IFFT&FFT size	128
Additive noises	20dB
Spading code type	Gold code
No. Partitions P	4
Predetermined codes C_m	16, 32

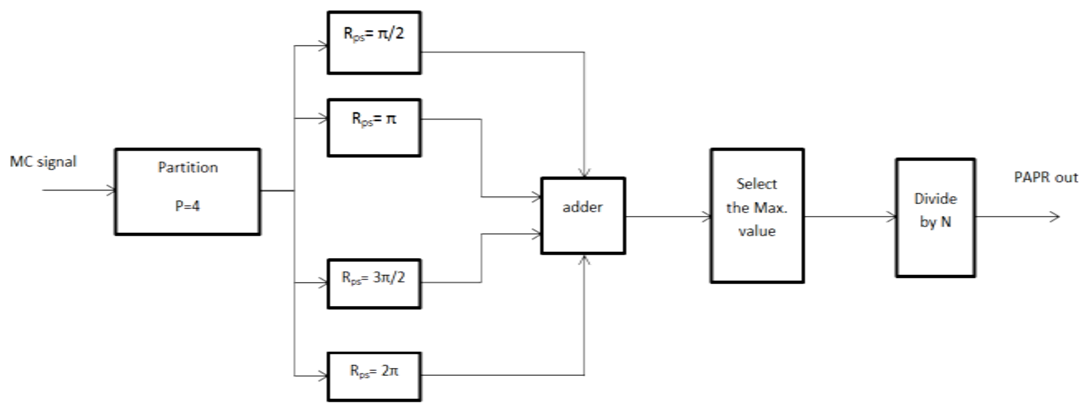
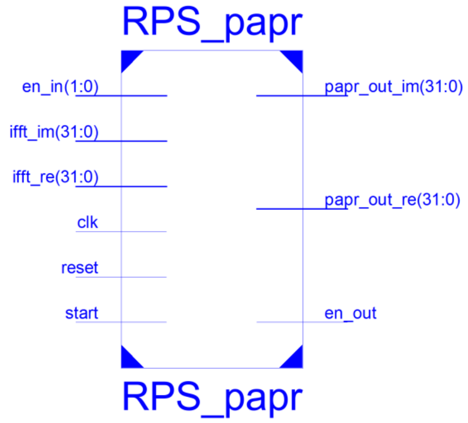
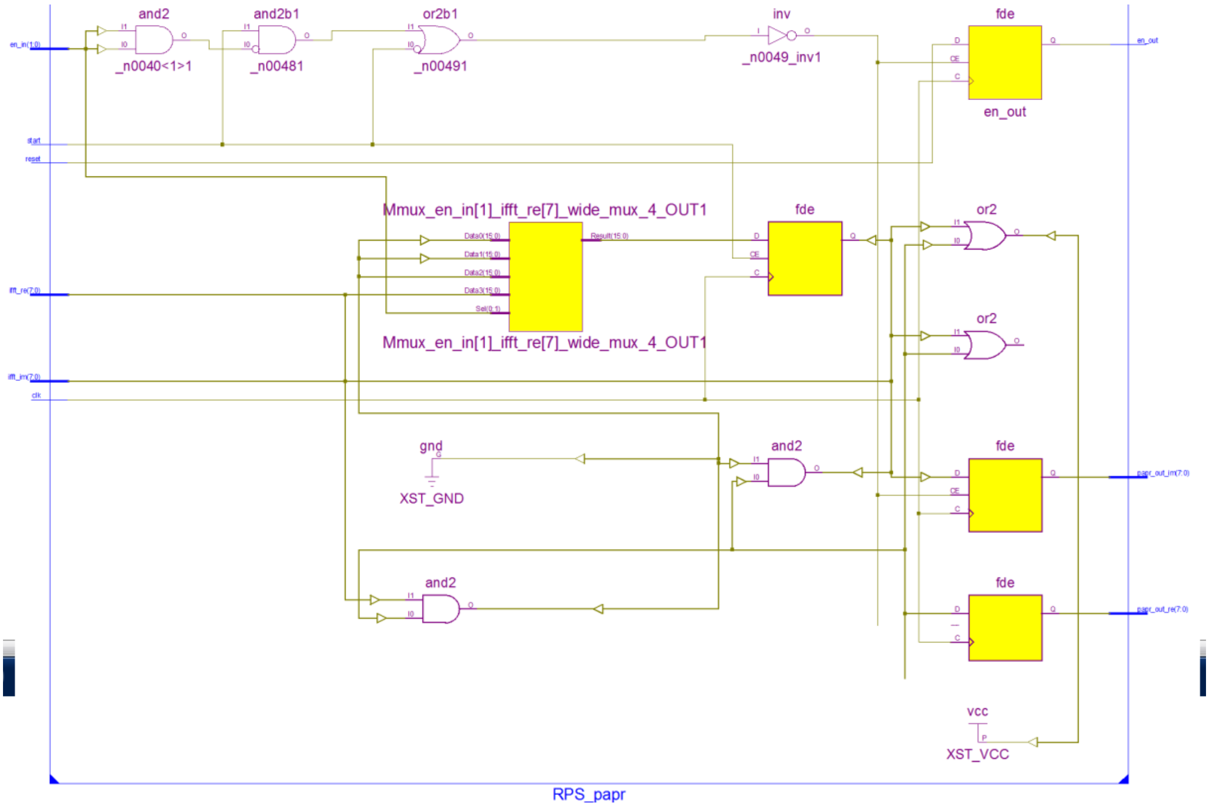


Figure 4. Block Diagram for PAPR calculation in VHDL.



(a)



(b)

Figure 5. Top level view (a) with all inputs & outputsof the RPS-PAPR and (b) details for RTL circuits.

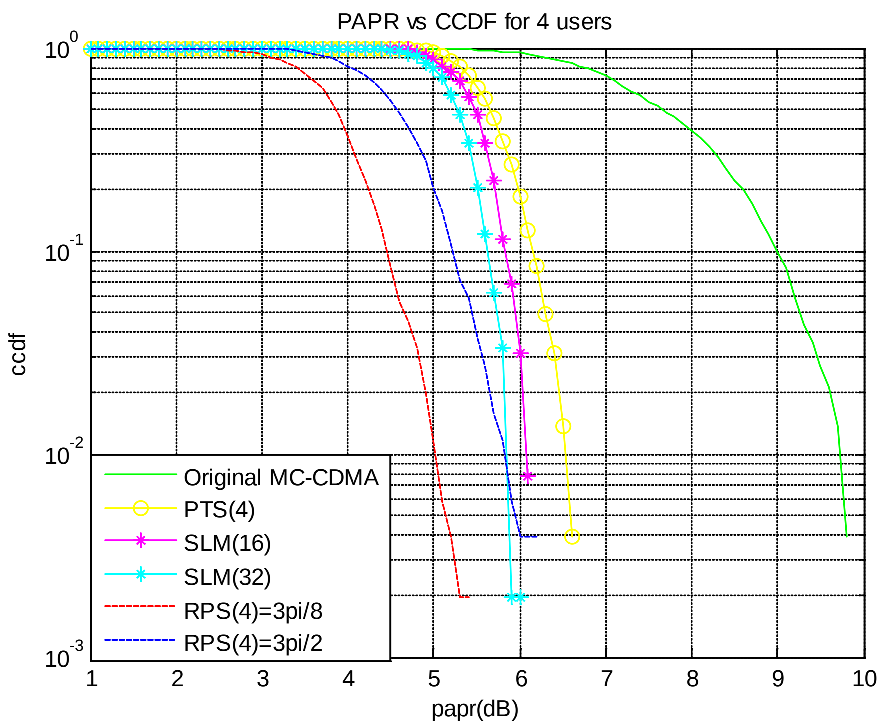


Figure 6. A CCDF of the PAPR of 4 users MC-CDMA signals compares an SLM C_m = 16, C_m = 32 and PTS and RPS, P = 4, 32-QAM.

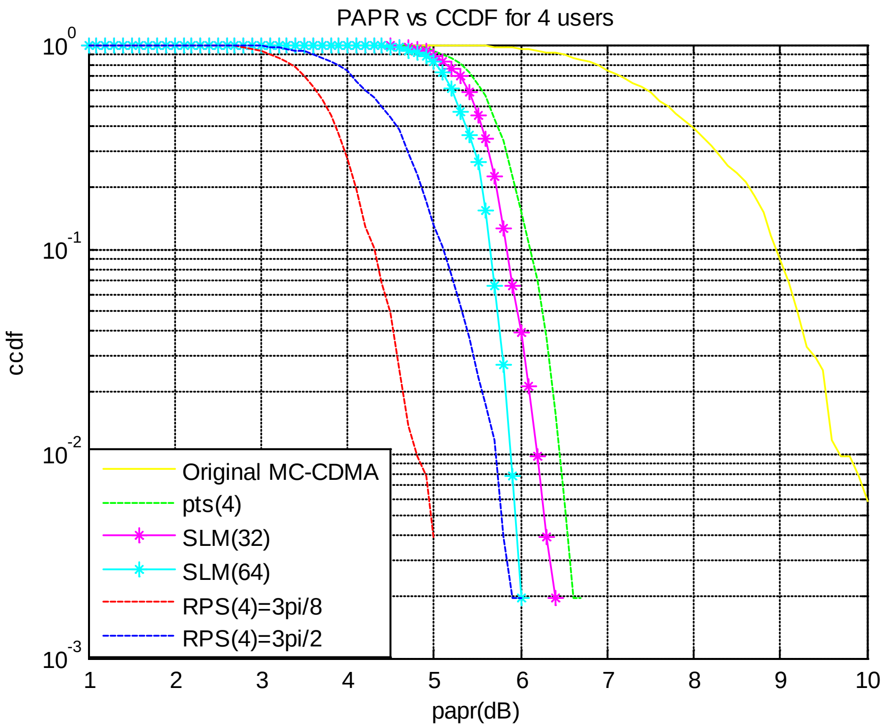
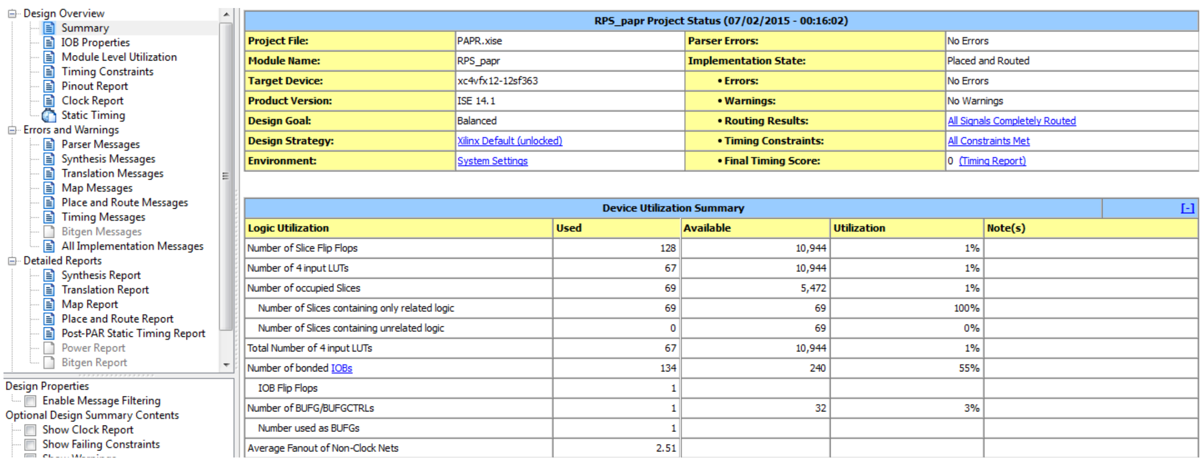


Figure 7. A CCDF of the PAPR for 4 users of MC-DMA signals compares an SLM C_m = 16, C_m = 32 and PTS P = 4, and RPS R_{ph} = 3π/2, R_{ph} = 16π/21.

Table 5. Resources utilization summary.



RPS_papr Project Status (07/02/2015 - 00:16:02)			
Project File:	PAPR.xise	**Parser Errors:**	No Errors
Module Name:	RPS_papr	**Implementation State:**	Placed and Routed
Target Device:	xc4vfx12-12sf363	**• Errors:**	No Errors
Product Version:	ISE 14.1	**• Warnings:**	No Warnings
Design Goal:	Balanced	**• Routing Results:**	All Signals Completely Routed
Design Strategy:	Xilinx Default (unlocked)	**• Timing Constraints:**	All Constraints Met
Environment:	System Settings	**• Final Timing Score:**	0 (Timing Report)

Device Utilization Summary				[-]
Logic Utilization	**Used**	**Available**	**Utilization**	**Note(s)**
Number of Slice Flip Flops	128	10,944	1%	
Number of 4 input LUTs	67	10,944	1%	
Number of occupied Slices	69	5,472	1%	
Number of Slices containing only related logic	69	69	100%	
Number of Slices containing unrelated logic	0	69	0%	
Total Number of 4 input LUTs	67	10,944	1%	
Number of bonded IOBs	134	240	55%	
IOB Flip Flops	1			
Number of BUFG/BUFGCTRLs	1	32	3%	
Number used as BUFGs	1			
Average Fanout of Non-Clock Nets	2.51			

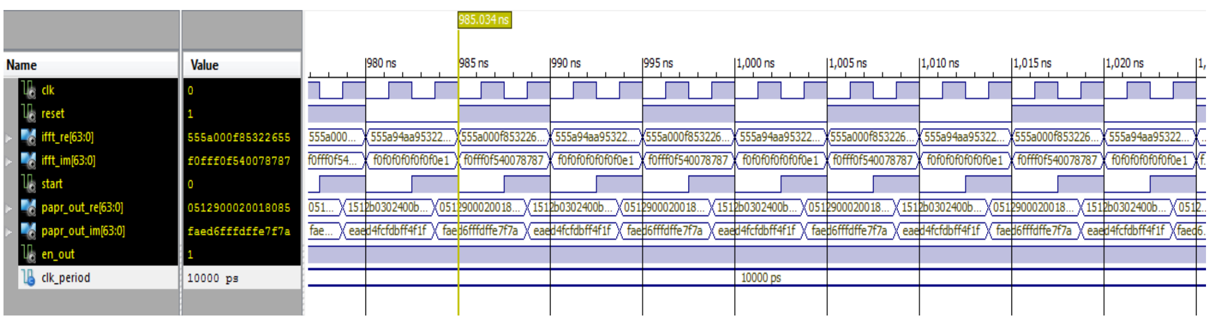


Figure 8. PAPR calculation test-bench waveform.

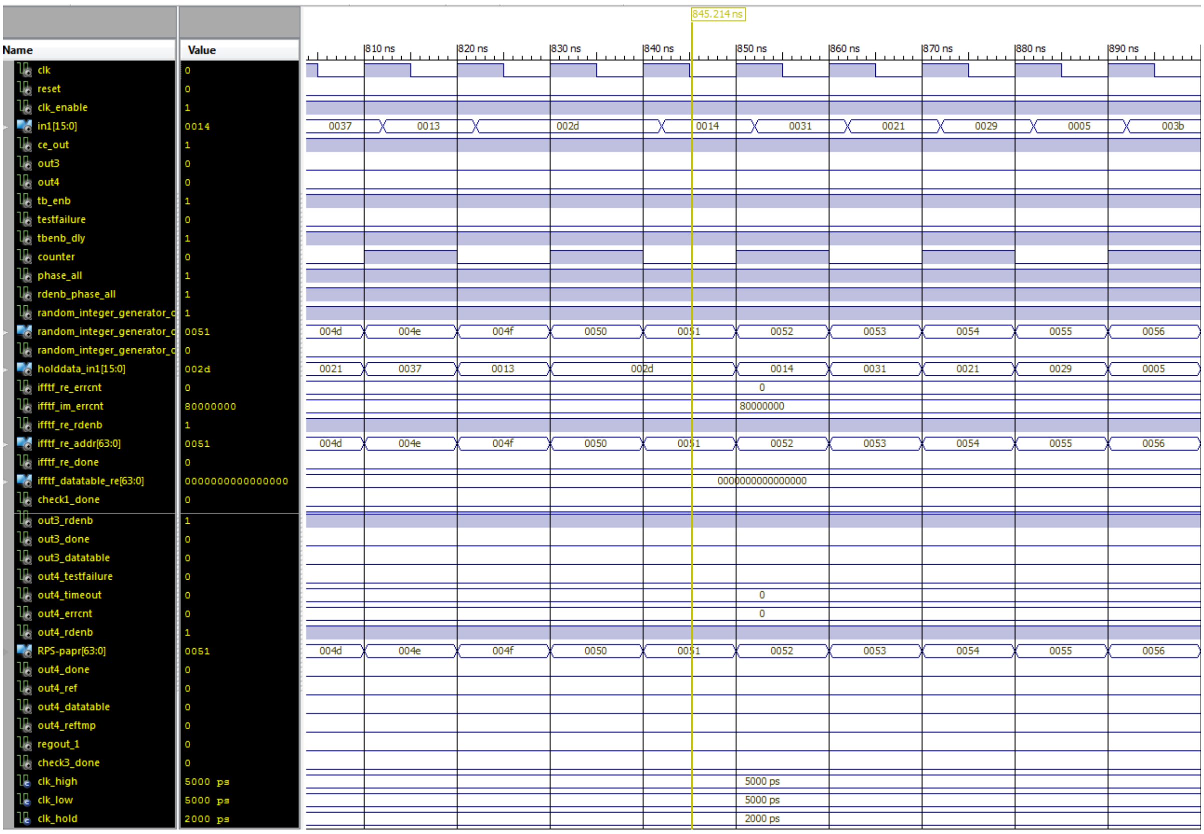


Figure 9. Transmitting side in MC-CDMA System test-bench waveform.

VHDL, which reduces the complexity by eliminating the difficult multiplication. Matlab simulations are done for 1000 samples of the MC-CDMA system with N = 64 subcarriers to plot the CCDF, which shows that RPS is the best method compared with the ways in various cases. The same idea is implemented in VHDL to calculate PAPR, and it can also be a simulation of subcarriers equal to 16 and 32 using the same process. This system eliminates the phase combined factor with lower PAPR better.

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