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FPGA Implementation of SLM Technique for OFDM Communication Systems

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Abstract

Objectives: To investigate Orthogonal Frequency Division Multiplexing (OFDM) and perform peak-to-average power ratio reduction using Selective Mapping (SLM) method. **Methods/Statistical Analysis**: Mathematical modeling and Matlab simulation of SLM technique for PAPR reduction of the OFDM signal. Verify the result obtained with FPGA implementation using Xilinx Spartan 3 Protoboard XC 3S 400 board and performance comparison with Matlab and FPGA implementation. **Findings:** PAPR obtained with the FPGA implementation of SLM technique for the case of 4 QAM OFDM signal with 1024 number of subcarriers is 9.8 dB whereas it is 8.9 dB with Matlab simulations. The value obtained with FPGA implementation and Matlab simulation are 2.8 and 3.7 dB less from the original OFDM signal respectively. **Application/Improvements:** It is widely used in a modern multicarrier high data rate communication system as it requires fewer resources with fast computational capability at the cost of a marginal reduction in the transmission data rate.

Keywords:FPGA, OFDM, PAPR, QAM, SLM

1. Introduction

Nonlinearity effect is one of the most undesirable phenomena in the modern communication systems which appear in the form of harmonic distortion, gain compression, intermodulation distortion, phase distortion, adjacent channel interference, etc. Modern communication systems use multicarrier OFDM which has high data rate transmission capability in addition to robustness to channel impairments. One of its major disadvantages is having high Peak-to-Average Power Ratio (PAPR)[1]. To improve the quality of inband signal and reduce leakage of energy in the adjacent channel its PAPR has to be reduced to a permissible value. There are many efficient PAPR reduction techniques available in the literature such as clipping technique, coding technique, probabilistic (scrambling) technique, and Single Carrier Frequency Division Multiple Access (SCFDMA) technique, etc. and each has got its own merits and limitations. None of them are useful for universal application and the careful decision has to be made for use of an individual technique for the particular application[2].

In the present research work first, mathematical modeling and Matlab simulations have been carried out on the multicarrier OFDM communication systems. Its PAPR have been calculated using 4 QAM baseband modulated signal with different number of subcarriers[3]. Second, in order to reduce its PAPR, selective mapping method (SLM), have been investigated[4]. Selective mapping method is an efficient PAPR reduction technique which has been analyzed using mathematical modeling and Matlab simulations and the results obtained have been further verified with the FPGA implementation using Xilinx Spartan 3 Protoboard XC 3S 400 development board[5].

2. Orthogonal Frequency Division Multiplexing

The block diagram of the OFDM transceiver system is shown in Figure 1. The baseband modulated signal in the

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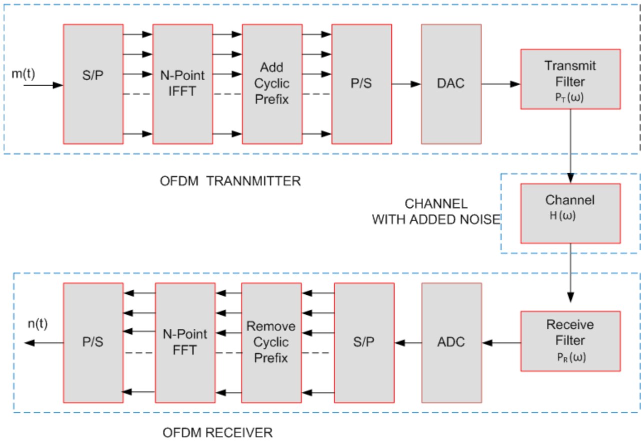

Figure 1. OFDM transceiver block diagram.

form of QPSK, QAM, etc. is fed to the serial to parallel converter[6]. N-number of parallel signals are generated from the serial to parallel converter which is termed as subcarrier and are multiplied with complex signal $e^{j2\pi nk/N}$ and added together. This operation is known as inverse discrete Fourier transform (IDFT) and its equivalent algorithm to be used with digital computer with higher speed and low computational complexity is Inverse Fast Fourier Transform (IFFT), is used for OFDM modulation. It is to be noted that with IDFT/IFFT operation now the complex signal is converted into time domain. In order to prevent the Intercarrier Interference (ICI), Intersymbol Interference (ISI), Interblock Interference (IBI), and to maintain orthogonality among the adjacent subcarriers cyclic prefix is added with each block of data after the IFFT operation.

The time domain signal is now converted into the serial form using serial to parallel converter. DAC is used to convert these signals into the analog form before the passband modulation is performed. In the passband modulation, the signal is up-converted to the desired RF frequency for upward transmission. In the present work, the RF operating frequency has been taken as 2 GHz. This passband signal is now transmitted through the channel after passing through the transmit filter. In the channel, the signal is mixed with additive white Gaussian noise. In the receiver, the reverse process takes place as discussed in the transmitter. After passing through low pass filter the signal is down-converted in the passband demodulator before being converted back in the digital form with the help of Analog-to-Digital Converter (ADC) for digital processing. Serial to parallel converter is used for converting the serial data into parallel form. Before using DFT/FFT block to demodulate the OFDM signal cyclic prefix is removed and once again converted back into the serial form using parallel to serial converter. Finally, the baseband signal is demapped and the constellation diagram is obtained.

In the OFDM system a given larger frequency band is subdivided into N-number of smaller bands which are known as subcarriers. The adjacent subcarriers are overlapping to each other in the frequency domain and do not create interference as they maintain orthogonally among them. They are in the form of sinc pulses and have zero crossings at the multiples of the time period and as per the Nyquist criteria, they are ISI free. Because of overlapping nature of adjacent carriers, it preserves bandwidth and is considered to be spectrally efficient[7].

The time domain signals are generated by multiplying the subcarriers with N number of complex signal $e^{j2\pi nk/N}$ and adding together. The process of multiplication and addition of subcarriers is known as IDFT/IFFT operation.

$$x_n = \frac{1}{N}\sum_{k=o}^{N-1} X_k \, e^{\frac{j2\pi nk}{N}} \tag{1}$$

where, N is the symbol period, X_k is the data symbol for the k-th subcarrier and the entire process of equation (1) is equivalent to the N-point IDFT/IFFT operation. Care has to be taken to maintain orthogonality among the subcarriers. Two signals, $s_1(t)$and $s_2(t)$ are said to be orthogonal to each other if condition depicted in equation (2) is satisfied[8].

$$\frac{1}{T}\int_0^T s_1(t)s_2(t)dt = 0 \tag{2}$$

The subcarriers are in the form of sinc-shaped pulses whose zero crossings are located at the multiples of time periods which helps in reduction of inter carrier interference and inter symbol interference[9].

3. Peak to Average Power Ratio

Peak to average power ratio is the measure of the fluctuations in the envelope of OFDM multicarrier signals. For the given sample $\{x_n\}$ the average power is represented by equation (3).

$$P_{av} = \frac{1}{F_s}\sum_{n=0}^{F_s-1} x_m^{\ 2} \tag{3}$$

where as, equation (4) is the representation of the peak power for the OFDM signal.

$$P_{peak} = \max_{m}\{x_m{}^2\} \tag{4}$$

PAPR is defined as the ratio of peak power to average power of the complex passband discrete time signal[10]. Sometimes, PAPR is also expressed in terms of Crest Factor (CF) and given by square root of PAPR. If the number of subcarriers is large, Gaussian distribution can be used to represent the approximation of the baseband OFDM signal[11]. Cumulative Distribution Function (CDF) is used to find out the probability that the received signal z_{max} has an amplitude less than the threshold value z. In order to find out the PAPR of the OFDM signal Complementary Cumulative Distribution Function (CCDF) is used to find out the probability that the PAPR exceeds a particular value z, as given in (5).

$$\tilde{F}z_{max}(z) = P(z_{max} > z) = 1 - P(z_{max} \leq z)$$
$$= 1 - Fz_{max}(z) = 1 - \left(1 - e^{-z^2}\right)^N \tag{5}$$

Figure 2 gives the Matlab simulated value of PAPR for 4 QAM OFDM signal. At 10^{-3} CCDF, with 64, 128, 256, 512 and 1024 subcarriers the corresponding PAPR values are 11.5, 11.7, 12.0, 12.2, and 12.6 dB respectively.

4. Selective Mapping Method

SLM is an efficient technique for PAPR reduction. The 4 QAM baseband signal is converted into N number of parallel subcarriers after passing through the serial to parallel converter[12]. Then each subcarrier is multiplied with a complex signal having different phase vector and then its IFFT is taken. The PAPR is calculated for each phase vector and the one having lowest PAPR is selected for transmission from the N available PAPR. In this way, a large number of data vectors are generated. The information about the phase vector which was responsible for producing minimum PAPR has to be transmitted to the receiver as side information for detection of the signal. This additional information is an overhead and marginally reduces the data transmission rate of the multicarrier OFDM communication system[13].

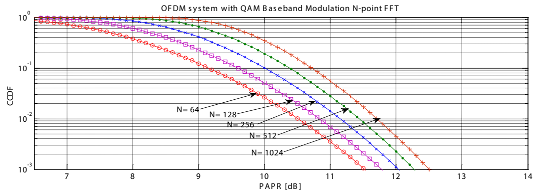

Figure 2. PAPR of 4 QAM OFDMsignal.

The block diagram of SLM technique is depicted in Figure 3. In this, the N number of subcarriers are multiplied with N different phase vectors as shown in equation (6).

$$Q^v = [Q_0^v,\ Q_1^v,\ \dots\dots Q_{N-1}^v]^T \tag{6}$$

Here, $Q_r^v = e^{j\theta_r^v}$ and $\theta_r^v \in [0, 2\pi]$ for r = 0, 1, ……., N-1 and v = 1, 2,……N-1 and equation (7) shows the modified data block produced from this process.

$$M^v = \left[M^v[0], M^v[1], \dots\dots..M^v[N-1]\right]^T \tag{7}$$

As mentioned from the N data vectors, $W_{min} = W_v^N$ which has the lowest PAPR is selected for transmission and represented by equation (8).

$$W = \underset{[v=1,2,\dots V]}{\arg\min}\left(\max_{n=0,1,\dots N-1} |\ W^v[n]\ |\right) \tag{8}$$

Information about the phase vector which has produced minimum PAPR is selected and transmitted to the receiver as side information. SLM technique requires N number of IFFT operation and $\log_2 V$ bits of side information for each block of the data set[14].

4.1 PAPR of SLM Technique with Matlab Simulation

In order to calculate PAPR with SLM technique mathematical modeling and Matlab simulations have been performed for 4 QAM signal with 1024 subcarriers. Figure 4 shows its PAPR with different number of phase vectors, V. At 10^{-2} value of CCDF the observed PAPR are 8.2, 8.4, 8.9, 9.7 and 10.6 dB with phase vectors, V = 16, 8,

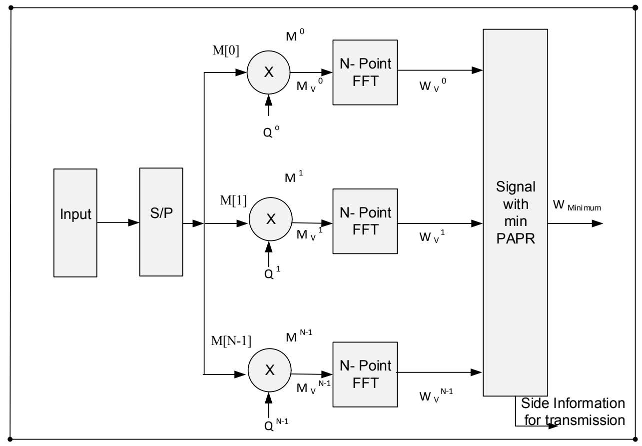

Figure 3. Block diagram of selected mapping method.

4, 2 and 1 respectively. Once again it is important to be noted that the PAPR is a function of phase vector and decreases with increase in the number of phase vector[15].

PAPR for different number of subcarriers with different phase vectors are depicted in Table 1 and it shows that the PAPR increases when the number of sub-carriers are increased.

4.2 PAPR of SLM Technique with FPGA Implementation

Figure 5 shows the block diagram of a system generator using SLM technique for PAPR reduction. The digital data is fed to the mapper which in turn generates 4 QAM signal[16]. This is converted into parallel form with the help of serial to parallel converter then after multiplying with phase vectors IFFT is performed for each subcarrier.

The block diagram of 4 QAM mapper and IFFT is depicted in Figure 6. The real and imaginary parts of the complex signal are separated and finally fed to the wave scope.

In the SLM technique the particular input data M[1] is multiplied with phase vectors, say Q^0 , Q^1, Q^2 and Q^3. The IFFT blocks diagram is shown in Figure 7.

For the given input data different PAPR is obtained with each phase vector and among different PAPR obtained the minimum value is selected for transmission. Also, the phase vector responsible for producing lowest PAPR is transmitted as side information to the receiver[17].

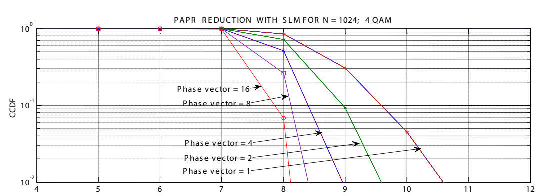

Figure 4. PAPR of 4 QAM signal with SLM technique.

The hardware cosimulation shown in Figure 8 has been carried out using Xilinx Spartan 3 Protoboard XC 3S 400 development board. Figure 9 shows its corresponding

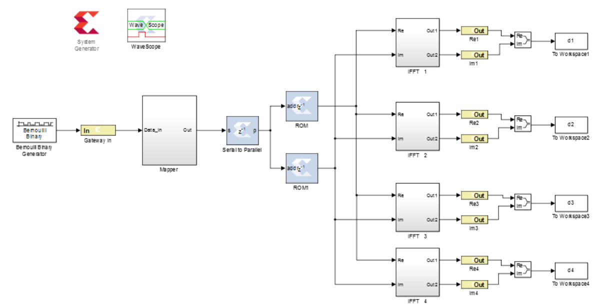

Figure 5. System generator block diagram for PAPR reduction using SLM technique.

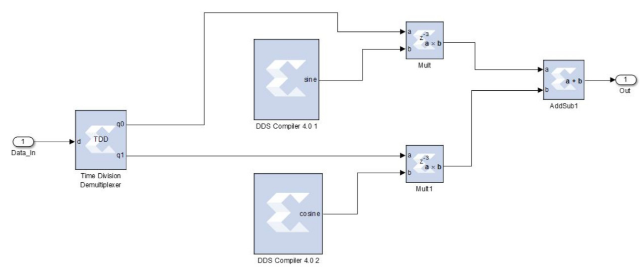

Figure 6. Mapper for generating 4 QAM baseband signal.

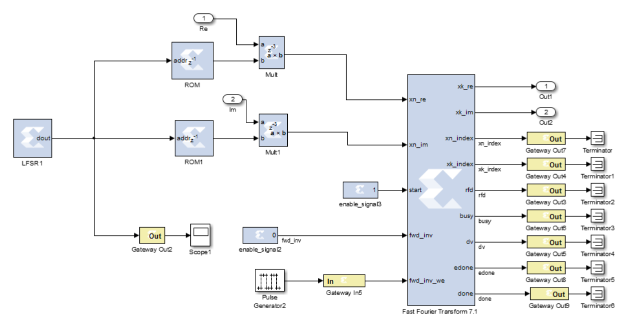

Figure 7. Block diagram of IFFT.

Table 1. PAPR of selective mapping method with Matlab

No of carriers (N) / Phase vector (V)	V= 16 (dB)	V = 8 (dB)	V = 4 (dB)	V = 2 (dB)	V = 1 (dB)
64	5.8	6.3	7.5	8.1	9.3
128	6.4	7.0	8.1	8.4	9.7
256	7.1	7.5	8.5	8.9	10.1
512	7.6	8.1	8.8	9.2	10.3
1024	8.2	8.5	8.9	9.6	10.6

system generator status at the time of hardware cosimulation. Figure 10 depicts the system generator OFDM SLM panel.

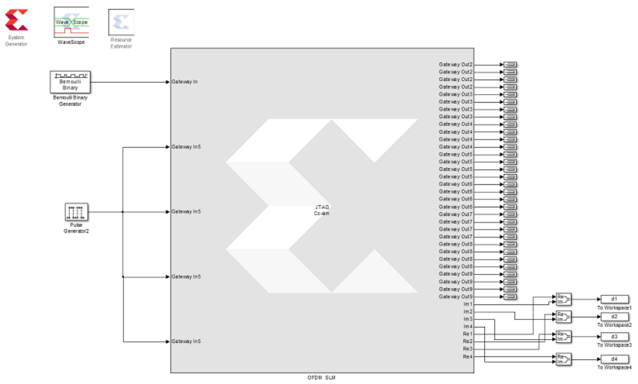

Figure 8. Hardware cosimulator block diagram.

Figure 9. Hardware Cosimulation on Xilinx Spartan 3 Protoboard XC 3S 400board.

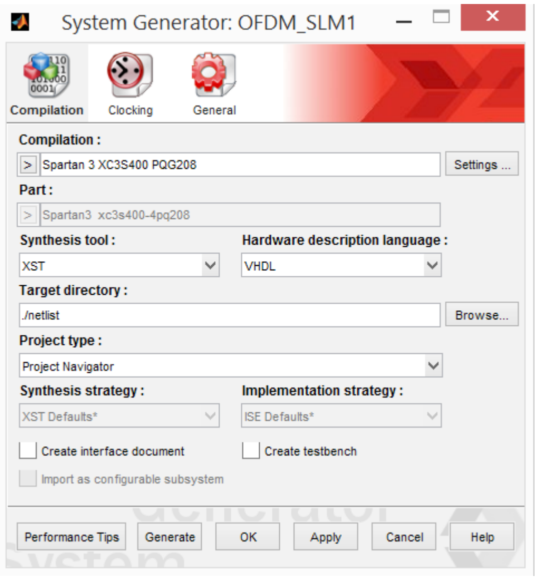

Figure 10. System generator OFDM SLM.

For 4 QAM OFDM signal Table 2 gives the PAPR values obtained through hardware implementation with 64, 128, 256, 512 and 1024 subcarriers and four different phase vectors: Q^0, Q^1, Q^2 and Q^3.

The minimum PAPR obtained through FPGA implementation with 64, 128, 256, 512 and 1024 subcarriers are 7.8, 8.4, 8.9, 9.2 and 9.8 dB respectively. Whereas the corresponding PAPR obtained with Matlab simulations are 7.5, 8.1, 8.5, 8.8 and 8.9 dB. On the other hand, the corresponding PAPR for original unclipped OFDM signals are 11.5, 11.7, 12.0, 12.2 and 12.6 dB respectively.

4.3 Comparative Value of PAPR of SLM with Different Techniques

Figure 11 shows the comparative value of PAPR with Matlab simulation, FPGA implementation and original unclipped OFDM signal. It can be observed from the table that 3.7 dB reduction in PAPR has been achieved with Matlab simulations whereas it is 2.8 dB with FPGA

Table 2. Value of PAPR of SLM with Matlab simulation and FPGA implementation

Phase vector / No of carriers	N=64 (dB)	N=128 (dB)	N=256 (dB)	N=512 (dB)	N=1024 (dB)
Q^0	11.3	11.5	8.9	9.7	10.8
Q^1	9.4	10.9	11.6	11.2	12.1
Q^2	7.8	10.9	9.6	10.9	9.8
Q^3	9.1	8.4	11.0	9.2	11.5
Minimum PAPR with FPGA implementation	7.8	8.4	8.9	9.2	9.8
PAPR with Matlab simulation	7.5	8.1	8.5	8.8	8.9
PAPR without SLM(original OFDM signal)	11.5	11.7	12.0	12.2	12.6

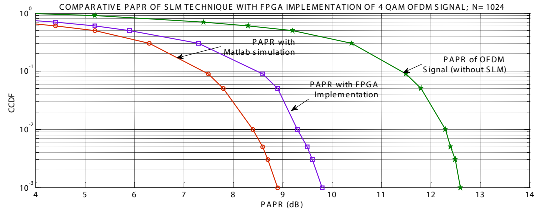

Figure 11. Comparative PAPR performance.

implementation. A similar trend as observed in Matlab simulations have been obtained for the PAPR reduction with FPGA implementation.

5. Results and Discussions

The PAPR of original OFDM signal with 1024 subcarriers of 4 QAM signal is 12.6 dB. The corresponding PAPR with FPGA implementation and Matlab simulation are 9.8 and 8.9 dB respectively. It can be observed that 3.7 dB reduction in PAPR has been achieved with Matlab simulations whereas it is only 2.8 dB with FPGA implementation.

6. Conclusion

The multicarrier OFDM system provides high data rate transmission capability but suffers from the high value of peak-to-average power ratio which causes power amplifier to operate in the nonlinear region. Different techniques are used to reduce PAPR value and the present work investigates the FPGA implementation of SLM techniques for PAPR reduction for 4 QAM signal with different number of subcarriers.The result obtained has been validated with mathematical modeling and Matlab simulations. At 10^{-3} of CCDF with 1024 subcarriers the PAPR obtained through FPGA implementation is 9.8 dB which is 0.9 dB higher than the Matlab simulated value but 2.8 dB less than the original OFDM signal.This technique is widely used in a modern multicarrier high data rate communication system as it requires fewer resources with fast computational capability.

7. References

1. Park DH, Song HK. A new PAPR reduction technique of OFDM system with nonlinear high power amplifier. IEEE Transactions on Consumer Electronics. 2007; 53(2):327–32.
2. Shaiq PM, Saurabh, Krishan G. Hybrid technique for BER and paper analysis of OFDM systems. Indian Journal of Science and Technology. 2016 Apr; 9(15):1–5.
3. Gayathri S, Sabitha R. Multi-level queue based resource allocation in downlink of OFDMA wireless cellular networks. Indian Journal of Science and Technology. 2016 Mar; 9(10):1–6.
4. Kannan T, Krishnakumar T, Karthikeyan M, Selvakumar K. A STUDY on QOS improvement using MIMO-OFDM technique. Indian Journal of Science and Technology. 2016 Sep; 9(35):1–4.
5. Han SH, Lee JH. An overview of peak-to-average power ratio reduction techniques for multicarrier transmission. IEEE Wireless Communications. 2006;12(2):56–65.
6. Proakis JG. Digital Communications. McGraw-Hill, New York, USA; 2000.
7. Nee RV, Prasad R. OFDM for wireless multimedia communications. Artech House Publishers: Norwood, MA, USA; 2000.
8. Prasad R. OFDM for wireless communications systems. Artech House Publishers, Norwood: MA, USA; 2004.
9. Hara S, Prasad R. Multicarrier techniques for 4G mobile communications. Artech House Publishers: Norwood, MA, USA; 2003.
10. Cho YS, Kim J, Yang WY, Kang CG. MIMO- OFDM wireless communications with Matlab. IEEE Press, John Wiley and Sons (Asia) Pvt. Ltd; 2010.
11. Aanchal J, Lavish K. Performance assessment of OFDM utilizing FFT/DWT over Rician channel effected by CFO. Indian Journal of Science and Technology. 2016 Mar, 9(12):1–7.
12. Bguml RW, Fischer RFH, Huber JB. Reducing the peak-to-average power ratio of multicarrier modulation by selected mapping. Electronics Letters.1996;32(22):2056–7.
13. Wang C.L, Ku SJ, Yang CJ. A low-complexity PAPR estimation scheme for OFDM signals and its application to SLM-based PAPR reduction. IEEE Journal of Selected Topics in Signal Processing. 2010; 4(3):637–45.
14. Goff S, Le Y, Khoo BK, Tsimenidis CC, Sharif BS. A novel selected mapping technique for PAPR reduction in OFDM systems. IEEE Transactions on Communications. 2008; 56(11):1775–9.
15. Bansode RS, Mishra BK, Temrikar A. Design, simulation andperformance evaluation of OFDM system to reduce PAPR using SLM and LCM with FPGA. Global Journal of Researches in Engineering Electrical and Electronics Engineering. 201313(15).
16. Kamdar B, Shah D, Sorathia S. Hardware implementation of PAPR reduction scheme for OFDM system. IEEE Conference ICCICT, Mumbai; 2012. 1–3.
17. Mohammady S, Sidek RM, Varahram P, Hamidon MN, Salaiman N. FPGA implementation of the proposed DSI-SLM scheme for PAPR reduction in OFDM systems. IEEE 17th Asia Pacific Conference on Communications (APCC-2011), Malaysia; 2011. 484–7.