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# Design, Simulation and Hardware Testing of MIMO 8 x 8 OFDM System to Reduce PAPR with SLM technique using FPGA

Bharati. R .Gondhalekar, Dr. B.K. Mishra, Rajesh Bansode

**Abstract**—Speed, range, Channel Capacity,and reliability enhancement is achieved using a combination of MIMO-OFDM system. Despite of OFDM's various advantages a major obstacle in using this signal is that it exhibits a very high Peak to Average Power Ratio (PAPR) which tends to reduce the power efficiency of radio frequency amplifiers and increase in design complexity.PAPR can be reduced by using SLM technique.Comparison of PAPR reduction with and without SLM technique is executed.With SLM PAPR of 10dB and without SLM PAPR of 15dB is observed and hence a substantial reduction of 5 dB is achieved.The VHDL code is written and simulated in XILINX 14.7 and tested using VIRTEX 5 XC5VLX50T..

**Index Terms**— Field Programmable Gate Array (FPGA), Multiple Input Multiple Outputs (MIMO), Orthogonal Frequency-Division Multiplexing (OFDM), Peak To Average Power Ratio (PAPR), Quality of Service (QoS), Selective level Mapping (SLM) ,Space Time Block Code (STBC).

## 1 INTRODUCTION

One of the major challenges facing modern communications is to satisfy the ever increasing demand of high speed reliable communications with the constraints of extremely limited frequency spectrum and limited power. Wireless communications systems like cellular mobile communications, internet and multimedia services require very high capacity to full fill the demand of high data rates. This necessitates the need for communication systems with increased throughput and capacity. Multiple input multiple outputs and orthogonal frequency division multiplexing (MIMO-OFDM) is one way to meet this need. OFDM offers high spectral efficiency and resilience to multipath channel effects [1]. MIMO makes use of multiple antennas to increase throughput without increasing transmitter power or bandwidth. The MIMO operations are based on STBC (Space Time Block Code) and SM (Spatial Multiplexing) techniques. The STBC method helps in enhancing Quality of Service (QoS) of the system whereas SM method leads to result in higher capacity in the system.

## 2 SYSTEM ARCHITECHTURE

### 2.1 OFDM

Orthogonal frequency-division multiplexing (OFDM) is a multicarrier modulation scheme in which the incoming data stream is split into N parallel streams of reduced data rate with each of them transmitted on separate subcarriers which is depicted in Figure 1.1.


- *Bharati R Gondhalekar is currently pursuing masters degree program in electronics and telecommunication engineering in Mumbai University, India, PH-+91-9423365470. E-mail: bharatirgav@gmail.com*
- *Dr. B.K Mishra is currently Principal of Thakur College of Engineering and Technology in Mumbai University, India. E-mail: drbk.mishra@thakureducation.org*
- *Mr. Rajesh Bansode is currently Assistant Professor of Thakur College of Engineering and Technology in Mumbai University, India, PH-+91-9820271046. E-mail: rajesh.bansode@thakureducation.org*


OFDM is successfully applied to a wide variety of wireless communication due to its high data rate transmission capability with high bandwidth efficiency [2] and robust to multipath delay.

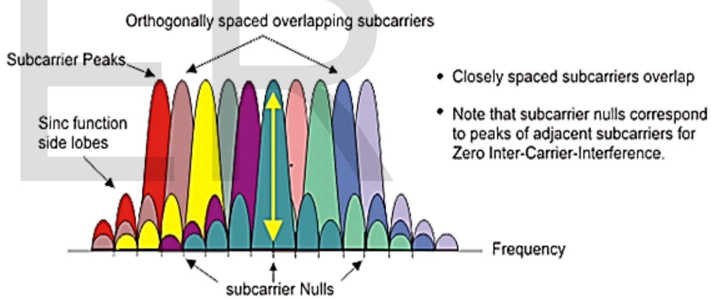


Fig. 1 OFDM Spectrums

The mathematical representation of the orthogonal continuous time signal is written as

$$\int_0^T \cos(2\pi nft)\cos(2\pi mft)\,dt = 0\ (n \neq m) \quad (1)$$

### 2.2 MIMO

There are three basic link performance parameters that completely describe the quality and usefulness of any wireless link: speed, range, and reliability. The use of multiple waveforms transmission in parallel constitutes a new type of radio communication, communication using multidimensional signals which is the way to improve all three basic link performance parameters using multiple antenna system [3].

The multiple input multiple outputs (MIMO); a multi antenna system describes the scheme to achieve the above mentioned parameters without using additional frequency spectrum. The combination of multi antenna system with multicarrier system gives an excellent performance [4]. One of the earliest MIMO to wireless communications applications is brought in mid-1980 with the breakthrough developments by Jack Winters

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and Jack Saltz of Bell Laboratories. In comparison with Single-input-single-output (SISO) system MIMO provides enhanced system performance under the same transmission conditions. MIMO system greatly increases the channel capacity, which in proportional to the number of transmitter and receiver arrays[5].The channel capacity for SISO system is given as

$C = \log_2 (1 + \rho |h^2|)$ b/s/Hz (2)

where h is the normalized complex gain of a fixed wireless channel and ρ is the SNR at any receiver antenna.

The capacity for a MIMO system with N Transmitter and M Receiver antennas is given by

$$C = \log_2 \left[\det\left(I_M + \frac{\rho}{N} HH^*\right)\right] \text{b/s/Hz} \quad (3)$$

Where (*) means transpose-conjugate and H is the M x N channel matrix.

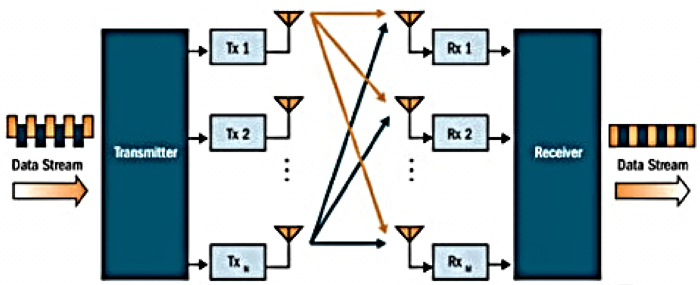


Fig. 2 N x M antenna structure

## 2.3 PEAK TO AVERAGE POWER RATIO

An OFDM signal consists of a number of independently modulated subcarriers, which can give a large peak –to-average power ratio when added up coherently. When N signals are added with same phase, they produce a peak power that is N times the average power [6]. It is defined as a ratio of peak power to average power. This tends to reduce the power efficiency of Radio frequency amplifiers and increase in design complexity of analog to digital and digital to analog converters. Fluctuations in signal peaks are depicted in Figure 1.3

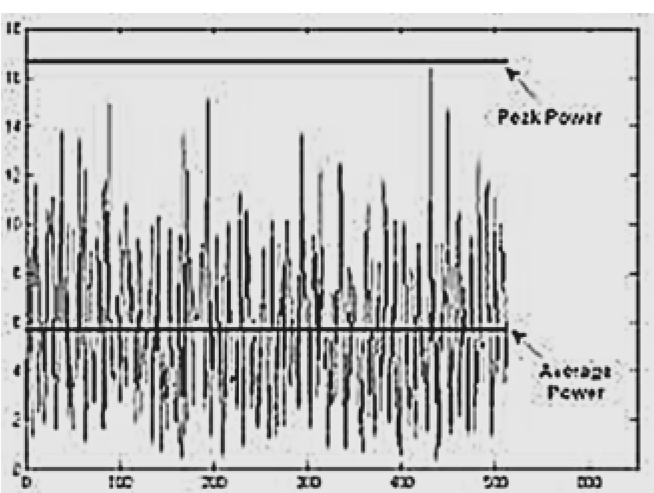


Fig.3 Signal with high and average peaks

A major problem with OFDM signals which is often cited as its major drawback is its large envelope fluctuations, which is usually measured by parameter called PAPR. In general, the PAPR of OFDM signals x (t) is defined as the ratio between the maximum instantaneous power and its average power

$$PAPR_{dB} = 10log_{10} \frac{max[|x(n)|^2]}{E[|x_n|^2]} \quad (4)$$

$$= 10\log_{10}\left\{\frac{P_{peak}}{P_{avg}}\right\} \quad (5)$$

### 2.4 SLM

Selective level Mapping (SLM) was first proposed in 1996 to reduce PAPR in OFDM systems. The system block diagram of SLM is shown below. At first, the input information is divided into OFDM data block X, which consists of N symbols, by the serial-to parallel (S/P) conversion and then data block X is multiplied carrier wise with each one of the U different phase sequences B(u), resulting in a set of U different OFDM data. In the SLM algorithm, the data source, denoted as X, is multiplied by the U different sets of phase factors/masks, element-wise to produce U different copies of X,

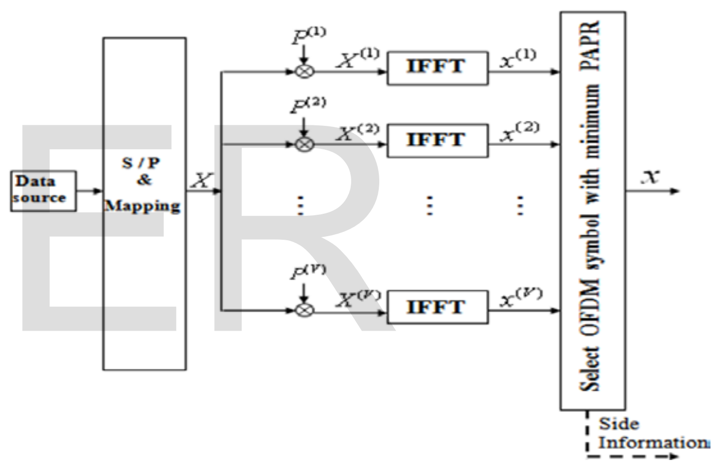


Fig. 4 SLM Block diagram

$X_u = B_u X$ u= 1, 2, ..., U (6)

Where, U is the design parameter in SLM. In general, more reduction in PAPR is likely to achieve when U increases.

In addition, Bu is defined as:

$B_u = [B_{u,1} \; B_{u,2} \; B_{u,3} \ldots B_{u,(N-1)}]$ (7)

Then all U alternative data blocks (one of the alternative subcarrier sequences can be the unchanged original one) are transformed into time domain to get transmit OFDM symbol

Where N represents the number of subcarriers in IFFT and $B_{u,k}$ is given by:

$B_{u,k} = e^{j\phi u,k}$ k = 0, 1, 2, ...,N – 1 (8)

After multiplying X with the phase factors, each $X_u$ is processed by IFFTs and its PAPR is then computed and compared with the others. The resulting signal that yields the lowest PAPR is subsequently chosen for transmission [7]. In addition, the $B_{opt}$ which implies the optimal Bu that produces the lowest PAPR has to be transmitted to receiver as side information. The receiver will then use $B_{opt}$ to recover the data source, X.

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The basic idea of SLM technique is to generate several OFDM symbols as candidates and then select the one with the lowest PAPR for actual transmission. This technique is a variation of selective mapping (SLM), in which a set of independent sequences are generated by some means from the original signal, and then the sequence with the lowest PAPR is transmitted.

## 3 Design and Methodology

Since OFDM is carried out in the digital domain, there are several methods to implement them. ASICs (Application Specific Integrated Circuit), Microprocessor or Micro Controller and FPGA (field-programmable gate arrays) are some of the methods. The main problem using ASICs is inflexibility of design process involved and the longer time to market period for the designed chip. Microprocessor or Micro Controllers uses the most power usage and memory space, and would be the slowest in term of time to produce the output compared to other hardware. FPGA [8] is the best choice for OFDM implementation since it gives flexibility to the program design besides the low cost hardware component compared to others.MATLAB Simulink 2013, Xilinx ISE 14.7 Model sim 6.3 is the basic requirement.

The algorithm of each block using MATLAB Simulink is implemented by use of constructing block diagrams in Simulink. VHDL code is imported into Simulink via the Xilinx System Generator block set, which gives flexibility to design flow. Simulink and Xilinx System Generator create bit-true. The Xilinx Integrated Software environment (ISE) is used as the synthesizer in the design flow diagram. ModelSim is used to verify the hardware simulation of the blocks by using test vectors generated by System Generator or HDL test benches [9][10]. Finally synthesis and performance results of the blocks are reported using ISE, and bit streams are generated to program the FPGA board.

Simulink Model

The Fig 6 represents the MIMO OFDM model. A signal is provided as input by connecting the Gateway_ In to the workspace with the support of a manual switch. The Gateway_ In block is required to convert input which is of Simulink type to Xilinx type. The signal is then connected to the parallel to serial convertor and it is later applied to the Subsystem. The transmitter module and the receiver module are depicted in Figure 5.1. The Gateways are used to convert Xilinx type to Simulink type output or vice versa. At the end a scope is connected where the first plot is for output of the model whereas the second plot is just the input signal applied to the model. The use of this is to verify whether the same signal is reproduced at the receiver side. Displays, scopes are connected to get the readings and observe the signals at different points to get more clear idea of functioning of the entire system.

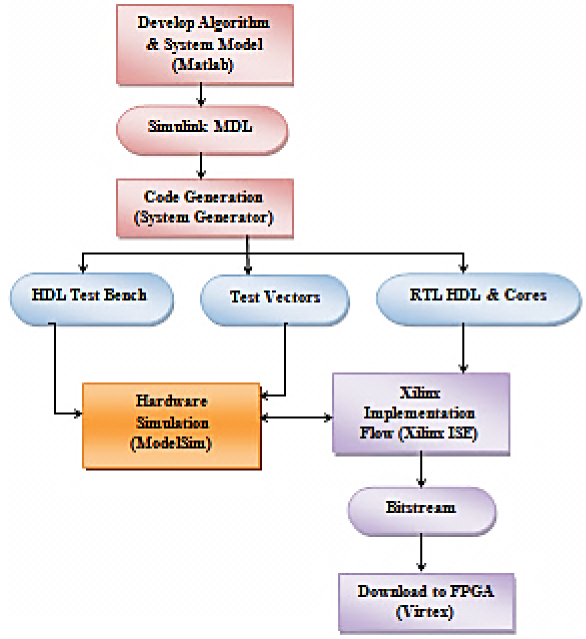


Fig. 5 Methodology and flow diagram

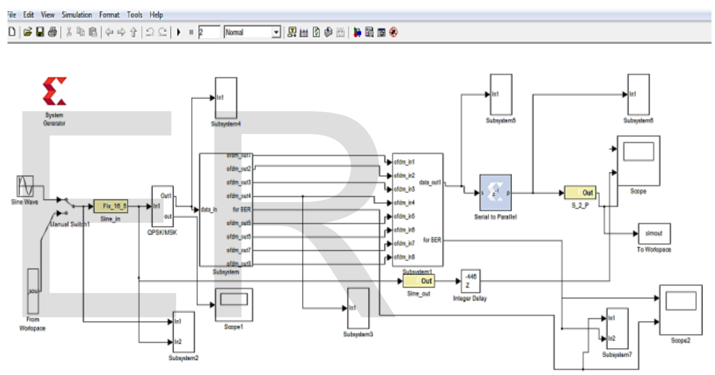

Fig. 6 Top Level Design of the model

## 4 Results and Discussion

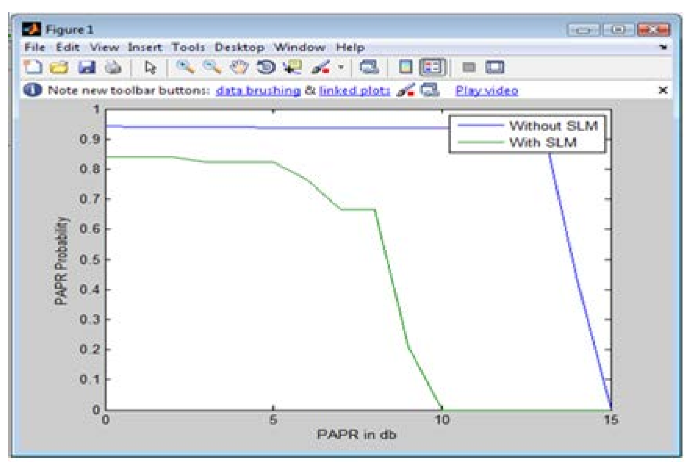


Fig.7 PAPR reduction with & without SLM

When signals are transmitted and received in a model without

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SLM we observe a constant value and sudden drop at the end whereas in case of a system with SLM there is constant value for some time and gradually decrease at the end. For without SLM system the PAPR probability remains constant till 14 dB and deceases abruptly. For SLM system, the PAPR probability is constant up to 9dB and decreases abruptly later on. A difference of PAPR reduction levels in two techniques is achieved.

Table 1: Comparison of PAPR with and without SLM

| PAPR (dB) | PAPR Probability without SLM | PAPR Probability with SLM |
|---|---|---|
| 1 | 0.942 | 0.842 |
| 3 | 0.94 | 0.84 |
| 5 | 0.94 | 0.822 |
| 7 | 0.937 | 0.765 |
| 9 | 0.937 | 0.665 |
| 11 | 0.937 | 0 |
| 13 | 0.933 | 0 |
| 15 | 0.427 | 0 |

It is observed that a PAPR reduction with and without SLM techniques achieves a substantial difference of 5dB.

Scope output
The output of the scope can be seen in the Figure 8 where the first waveform is the signal which has been received at the output of model i.e. received signal and the second waveform is the actual signal which was been fed as input to the model.

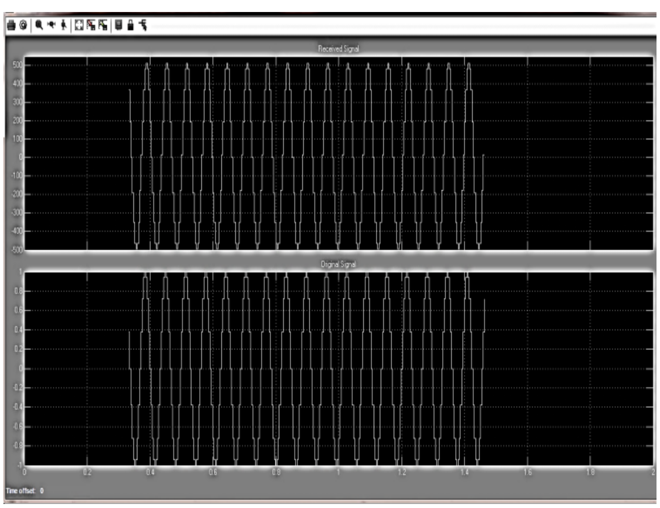

Fig. 8 Received and original signals

RTL Schematic
In digital circuit design, register-transfer level (RTL) is a design abstraction which models a synchronous digital circuit in terms of the flow of digital signals (data) between hardware registers and the logical operations performed on those signals.

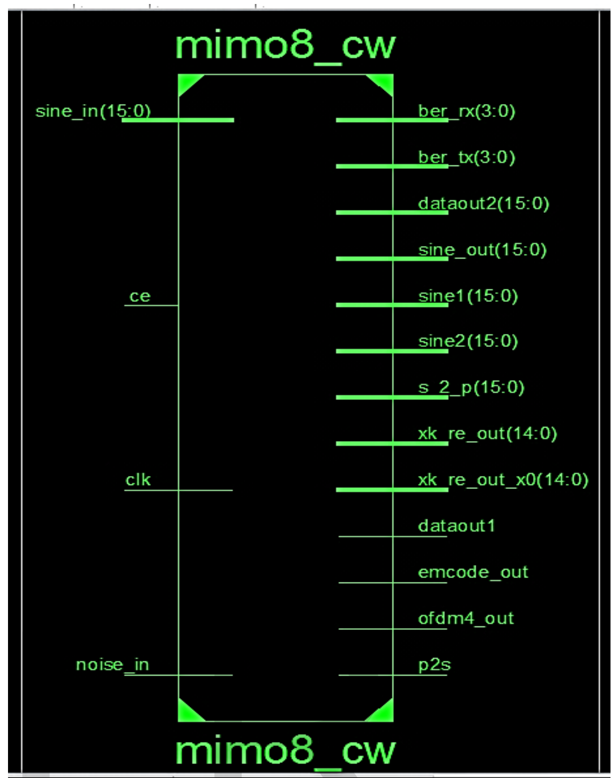


Fig 9: RTL Schematic

Final output obtained from the hardware implementation of the MIMO 8 x 8 OFDM model is the techbench.Figure 10 depicts the testbench generated for sinusoidal signal as the input.

Fig 10: Test Bench generated for sine wave input

## 5 Conclusion

MIMO OFDM system is the answer to our ever increasing data rate needs. By implementing a MIMO OFDM baseband transceiver on an FPGA, high-speed data transmission for a wireless communication system with reasonable prices of hardware implementation is fulfilled. PAPR reducing SLM technique has achieved a 5dB reduction in comparison to the model using non SLM technique.Using XILINX 14.7 software for simulation and then it is tested on VIRTEX 5 XC5VLX50T. The results obtained are stable and reliable.

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