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Hardware Implementation of PAPR Reduction with Clipping and Filtering Technique for Mobile Applications

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***Abstract*-Orthogonal frequency division multiplexing (OFDM) is preferred for mobile communications applications due to its increased data transmission capability. At one hand, it has advantages of being robust to multipath fading and possessing high data rate transmission capability, on the other hand it suffers from high peak to average power ratio (PAPR). In this paper FPGA implementation of clipping and filtering method have been implemented on Xilinx Spartan 3 Protoboard XC 3S 400 board for 4 QAM OFDM signals. The results obtained have been compared with National Instrument's (NI) AWR visual system simulator and Matlab software simulations. FPGA implementation of pre-filtering and post clipping technique results with 2.2 dB PAPR, whereas, PAPR values obtained in the case of pre-clipping and post filtering method, are 10.6, 10.7 and 10.9 dB with NI's AWR simulation, Matlab simulation and FPGA implementation respectively. When compared with original OFDM signal having 12.5 dB PAPR, FPGA implementation of pre-filtering and post-clipping reduces PAPR by 10.3 dB, whereas for the case of pre-clipping and post-filtering technique the reductions in PAPR are 1.6, 1.8 and 1.9 dB with FPGA implementation, Matlab and NI's AWR software simulations respectively.**

Keyword-FPGA, OFDM, PAPR, BER, Clipping and filtering

I. INTRODUCTION

In the modern mobile communication systems, one of the major concerns is the nonlinearity of RF amplifiers. The nonlinear power amplifiers degrades quality of the transmitted signal, causing increase in the bit error rate (BER), increase in adjacent channel interference, causing harmonic and phase distortions, gain compression, intermodulation distortions etc. Different techniques are available to analyse linear circuits [1]. But OFDM is required to be used in modern mobile communications systems in order to reduce the power consumption requirement, enhance battery life, reduce weight and size of battery and increased data transmission capability. Apart from that it has additional advantage of high spectrum efficiency and immunity to multi-path fading. OFDM systems are widely used for other applications like, digital high definition tele vision (HDTV) broadcasting, digital subscriber line (DSL), digital video broadcasting (DVB), and digital audio broadcasting (DAB), etc. But one of the major disadvantage of OFDM system is that it exhibits high peak to average power ratio (PAPR). The effect of power amplifier nonlinearity is further gets increased with use of orthogonal frequency division multiplexing (OFDM) owing to its high PAPR.

The problem of power amplifier linearity can be reduced at three different levels. First in the transmitter itself by introducing power amplifier linearity techniques. One of the simplest method is to operate power amplifiers in power back - off mode. It is one of the simplest technique to reduce the effect of nonlinearity in power amplifiers. But it results in lower efficiency, oversized amplifier and unsuitable for most of the practical applications [2-3]. This also causes not only to in-band signal distortion but also to out-of-band spectral re-growth, which are strictly regulated as a service provider cannot pollute the band of its competitor [4].

In order to improve linearity along with efficiency there are different power amplifier linearization techniques, such as feedback, feed forward and pre-distortion. Feedback technique is simple to implement but results in lowest efficiency. Feedforward technique is used for wide bandwidths applications in multicarrier systems where feedback technique is impractical. It gives improvements in distortion from 20 to 40 dB with 10-15% lower efficiency. This technique also costs more due to use of couplers, delay lines, error power amplifier, etc. The digital predistortion technique does not use these RF components and improves linearity with approximately 1dB degradation in efficiency[5]. In modern communication systems digital predistortion technique is mostly used owing to many advantages associated with it when compared with other available techniques.Second method of reducing power amplifier linearity is to reduce the effect of PAPR of OFDM systems in the transmitter itself by incorporating different PAPR reduction techniques[6-8]. There are different PAPR reduction techniques such as, clipping and filtering, selective mapping method, partial transmit sequence, DFT spread technique, etc. [9]. Among them the clipping and filtering is the simplest method to reduce the value of PAPR [10]. In the pre-clipping and post filtering method, PAPR can be reduced by clipping the peak amplitude of the transmitted signal and passing it through a low pass filter. On the other PAPR can also be reduced by first passing the signal through a filter and then clipping the amplitude of signal in the pre-filtering and post-clipping method. The pre-filtering and post-clipping method results in the lowest PAPR value but with worst BER performance when compared with pre-clipping and post-filtering method[10].

The third method of reducing effect of linearity is by applying pulse shaping with Nyquist filtering (windowing) technique at the receiver of the mobile communication systems. Out-of-band radiation can be maintained within a certain level by using different windowing techniques such as raised cosine, parametric linear combination pulses, parametric construction of Nyquist-I pulses, improved Nyquist filter with piece-wise linear characteristic, improved Nyquist pulses, etc. [11].

II. Peak to Average Power Ratio of OFDM Signal

PAPR is used to find out fluctuations in the envelope of the OFDM signal [6]. For example, for a given sample {xm} the average power and peak power is given by equation (1) and (2) respectively.

$$P_{av} = \frac{1}{F_s}\sum_{n=0}^{F_s-1} {x_m}^2 \quad (1)$$

$$P_{peak} = \max_m\{{x_m}^2\} \quad (2)$$

PAPR is defined as the ratio of peak power to average power of the signal as given by equation (3).

$$PAPR = \frac{P_{peak}}{P_{av}} \quad (3)$$

The probability that the PAPR exceeds a particular value is given by complementary cumulative distribution function (CCDF, as given in equation (4).

$$\tilde{F}z_{max}(z) = 1 - \left(1 - e^{-z^2}\right)^N \quad (4)$$

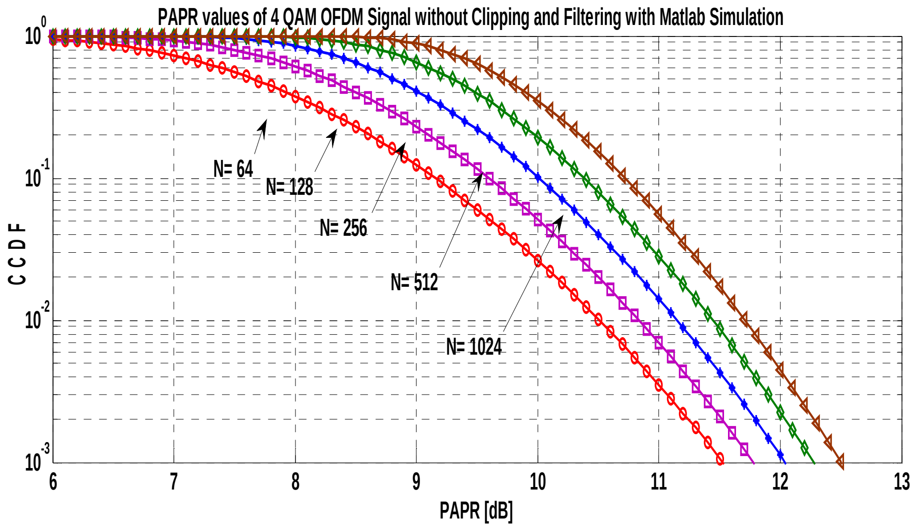

Fig. 1. PAPR of 4 QAM signal without clipping & filtering

The value of PAPR for 4 QAM OFDM signal is plotted in figure 1 for different number of subcarriers, N. For N = 64, 128, 256, 512 and 1024, PAPR values at 10^{-3} of CCDF are 11.5, 11.7, 12.0, 12.2, and 12.5 dB respectively. PAPR increases with increase in number of subcarriers as observed from the figure.

III.Reduction of Peak to Average Power Ratio with Clipping and Filtering technique

In this paper, we have investigated clipping and filtering method of PAPR reduction. It is simplest from application point of view. PAPR reduction of 4 QAM OFDM signal with 1024 number of subcarriers have been carried out for two cases, first pre-clipping and post-filtering and second pre-filtering and post-clipping[12]. Pre-filtering and post-clipping method gives the lowest PAPR but with increase in the value of bit error rate (BER). Whereas, the PAPR value obtained through pre-clipping and post-filtering are higher than the first method but its BER performance is better. The results obtained with hardware implementations have been compared with mathematical modeling and Matlab simulations and also with National Instrument's AWR visual system simulator commercial software. The value of bit error rate (BER) has also been evaluated and plotted.PAPR can be reduced by clipping the peak amplitude of the transmitted signal and passing it through a low pass filter to obtain response in time domain [13]. PAPR can be also reduced by clipping and frequency domain filtering as shown in figure 2. Performance of PAPR reduction schemes can be evaluated in the following three aspects: (a) In-band ripple and out-of-band radiation that can be observed via the power spectral density (b) distribution of the crest factor (CF) or PAPR, which is given by the corresponding CCDF and (c) coded and un-coded BER performance [14].

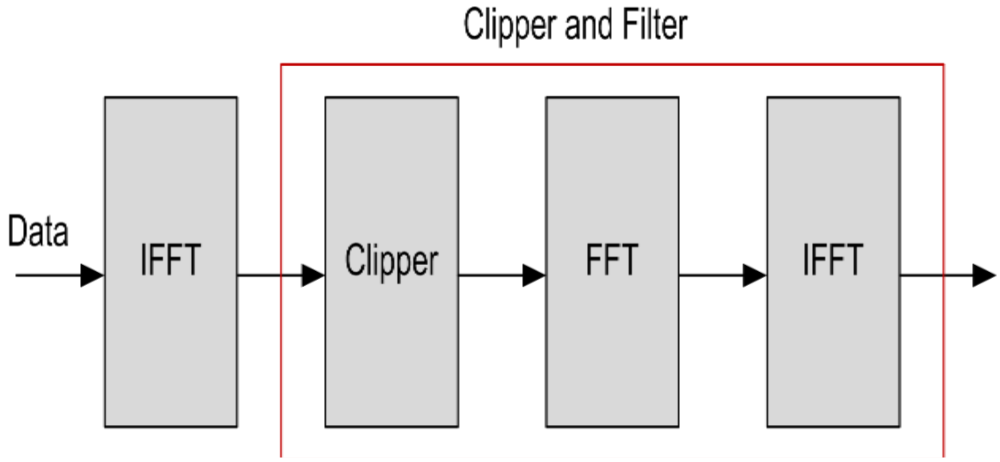

Fig. 2. Clipping and Filtering in frequency domain

In case of over sampled signal band pass filter is required to reduce the out of band radiation. But for the band limited signal clipped at Nyquist sampling rate all the distortions lies within the band, hence a low pass filter is sufficient. However, the low pass filter used after clipping operation moderately enlarges the PAPR. To reduce peak regrowth caused by filtering recursive/ iterative clipping and filtering techniques are also used. Clipping and filtering with over sampled signal is shown in figure 3. For a single iteration two FFT/IFFT plus one extra IFFT operations are required to convert the clipped symbol in time domain. In the case of W number of iterations 2W+1 FFT/IFFT operations are required, which causes increased computational complexity.

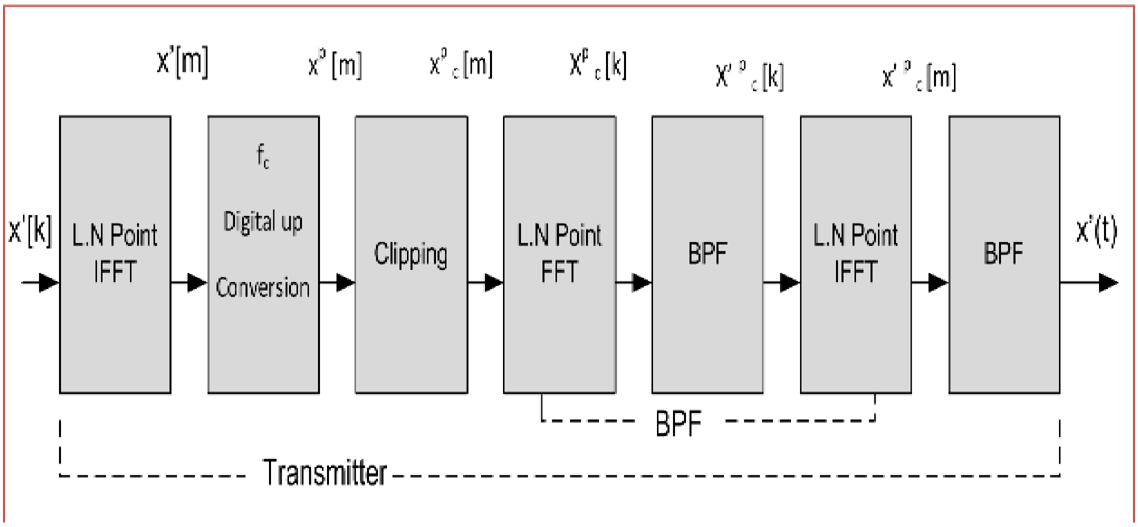

Fig. 3. Clipping and filtering with over sampling factor

The L-times oversampled discrete-time signal x' [m] is generated from the IFFT operation. Then it is modulated with carrier frequency, f_c to yield a passband signal$x^p\ [m]$, where $x_c^P[m]$ denote the clipped version of signal $x^p\ [m]$ and is expressed as given in equation (5).

$$x_c^P[m] = \begin{cases} -A & x^p\ [m] \leq\ -A \\ x^p\ [m] & \left|x^p\ [m]\right| <\ A \\ A & x^p\ [m] \geq\ A \end{cases} \quad (5)$$

PAPR obtained also depends upon clipping ratio (CR) which is defined as the clipping level normalized by the RMS value σ of OFDM signal given as in equation (6).

$$CR = \frac{A}{\sigma} \quad (6)$$

A. *FPGA Implementation of Clipping and Filtering Technique*

Clipping and filtering method has been implemented on FPGA and tested on hardware co-simulation using Xilinx Spartan 3 Protoboard XC 3S 400 development board. Two different cases have been considered, in the first case pre-clipping and post-filtering whereas in the second case pre-filtering and post-clipping [15].

1) *FPGA Implementation of Pre-Clipping and Post-Filtering Technique:*The block diagram of Pre-clipping and post filtering in time domain is shown in figure 4, which is mainly used for practical applications because of being simple and effective in PAPR reduction with better BER performance.

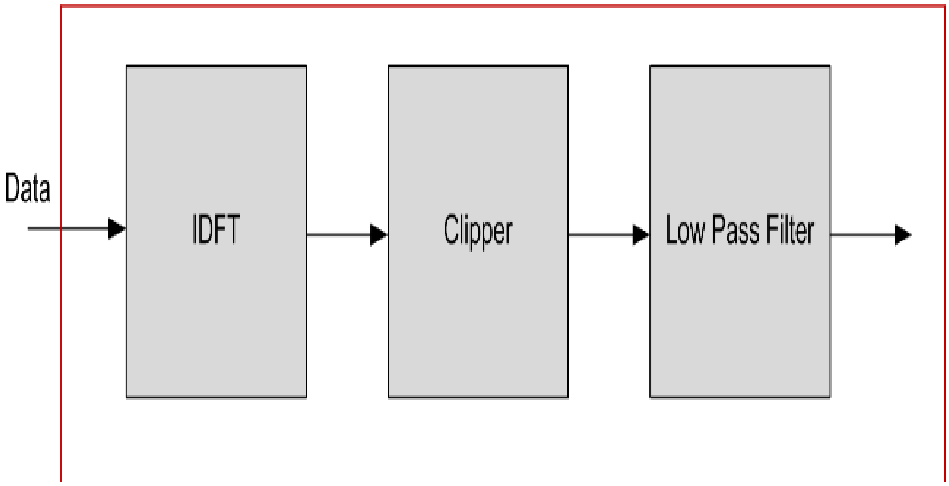

Fig. 4. Pre-Clipping and Post-Filtering in time domain

Figure 5 shows the system generator block diagram of pre-clipping and post filtering. Its major blocks are binary number generator, 4 QAM mapper, serial to parallel convertor, IFFT operator, clipper and filter. The clipping is done with clipping ratio of 0.8, 1.0, 1.2, 1.4 and 1.6. The filter used is an equiripple low pass FIR type.

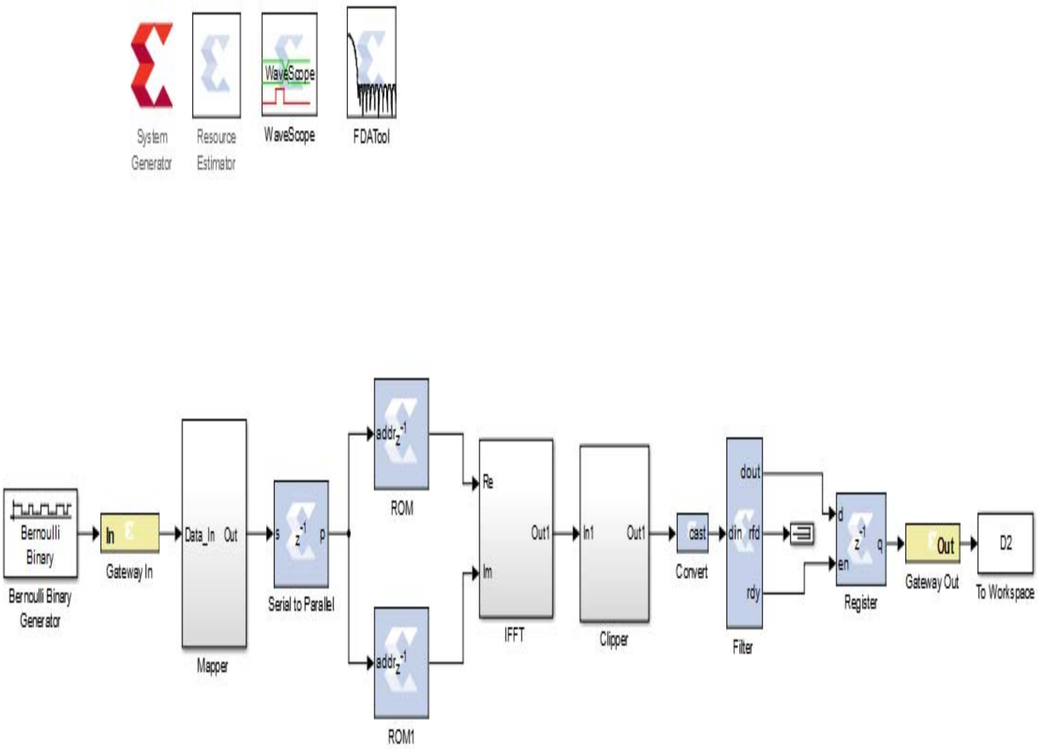

Fig. 5. Block diagram of Pre- Clipping and Post Filtering

Figure 6 depicts the values of PAPR for pre- clipping and post filtering with FPGA implementation of 4 QAM baseband OFDM signal with 1024 number of subcarriers. For clipping ratio of 0.8, 1.0, 1.2, 1.4 and 1.6 corresponding PAPR values are 10.9, 11.2, 11.5, 11.8 and 12.1 dB respectively.

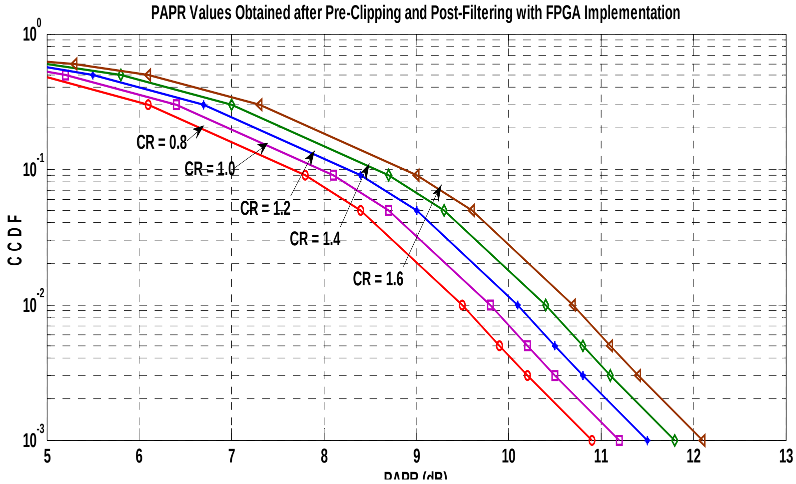

Fig. 6. PAPR values obtained after Pre- Clipping and Post Filtering with FPGA implementation

Wave Scope diagramafter running the system generator of pre-clipping and post-filtering operation is depicted in figure 7.

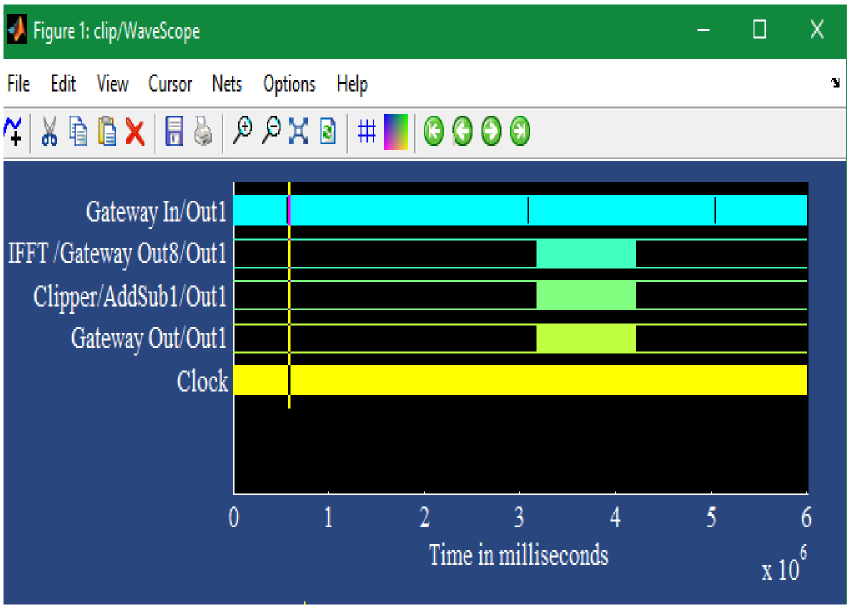

Fig. 7. WaveScope for Pre- Clipping and Post Filtering

2) FPGA Implementation of Pre-filtering and post-Clipping Technique: Figure 8 shows the block diagram of Pre-filtering and post-Clipping Method in time domain.

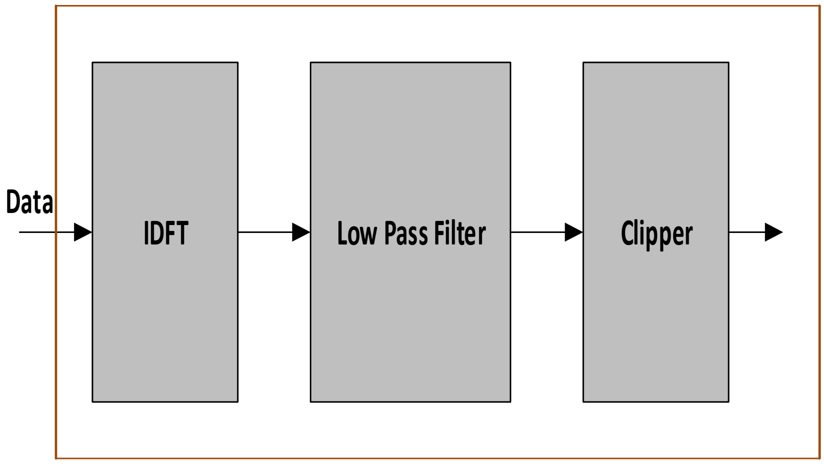

Fig. 8. Pre- Filtering and Post- Clipping in time domain

Its FPGA implementation on Xilinx Spartan 3 Protoboard XC 3S 400 board is shown in figure 9 for 4 QAM OFDM signals with 1024 number of subcarriers with different clipping ratio.

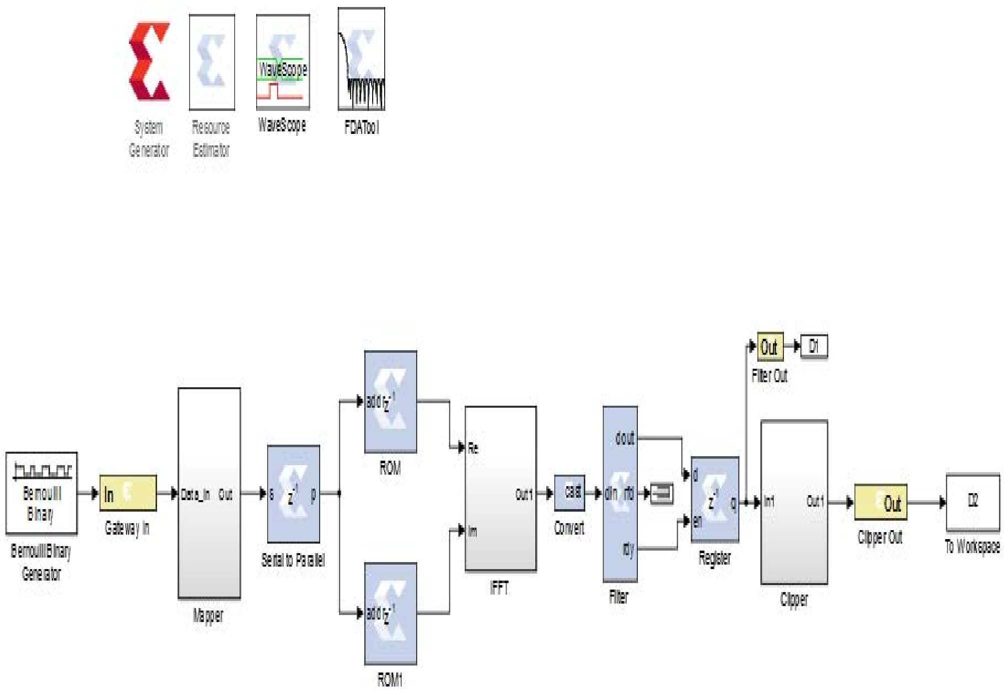

Fig. 9. Block diagram of Pre- Filtering and Post Clipping process

The PAPR values obtained are 2.2, 2.9, 3.6, 4.3 and 5.0 dB with 0.8, 1.0, 1.2, 1.4 and 1.6 clipping ratio respectively as shown in figure 10.

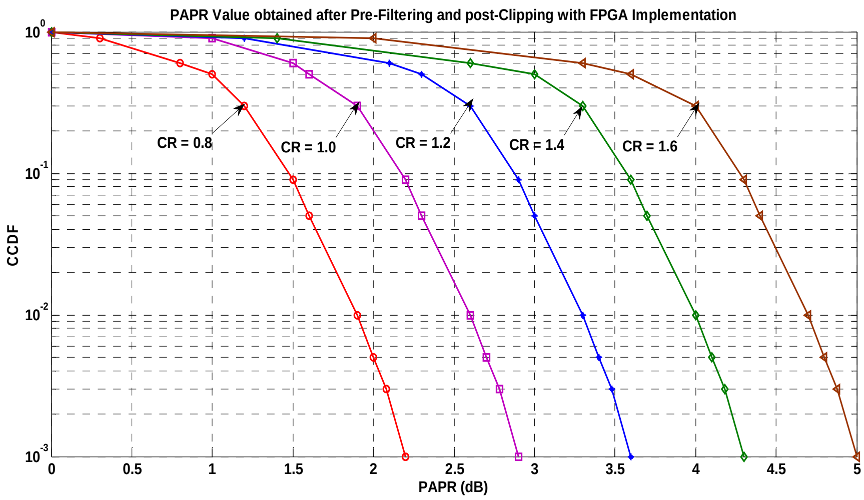

Fig. 10. PAPR values obtained after Pre- Filtering and Post Clipping process with FPGA implementation

The wave scope of pre-filtering and post-clipping technique is depicted in figure 11 which has been obtained after running the system generator of block diagram shown in figure 9.

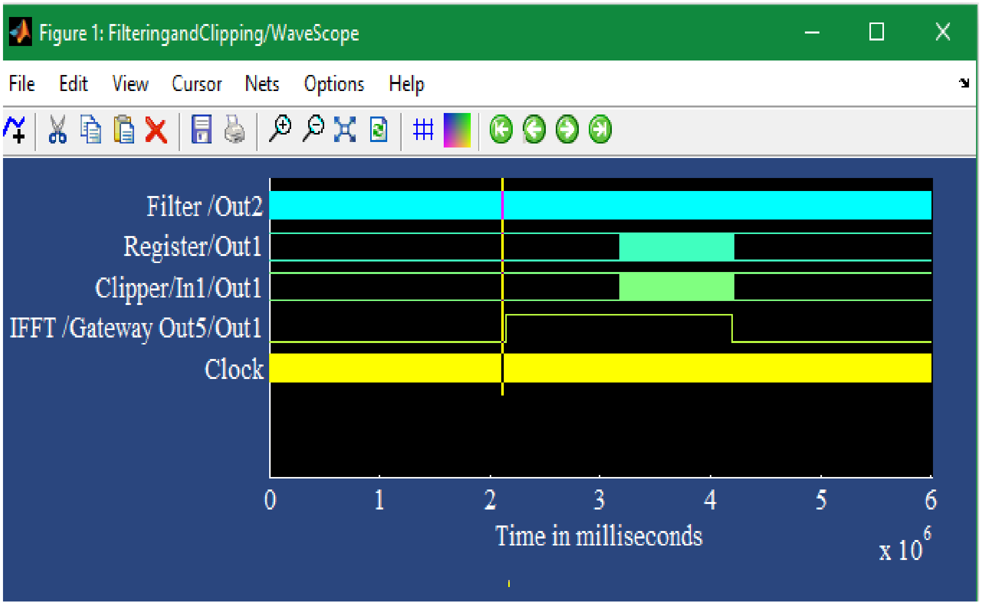

Fig. 11. Wave Scope of Pre- Filtering and Post Clipping

The block diagram of mapper for generating 4 QAM signal is shown in figure 12.

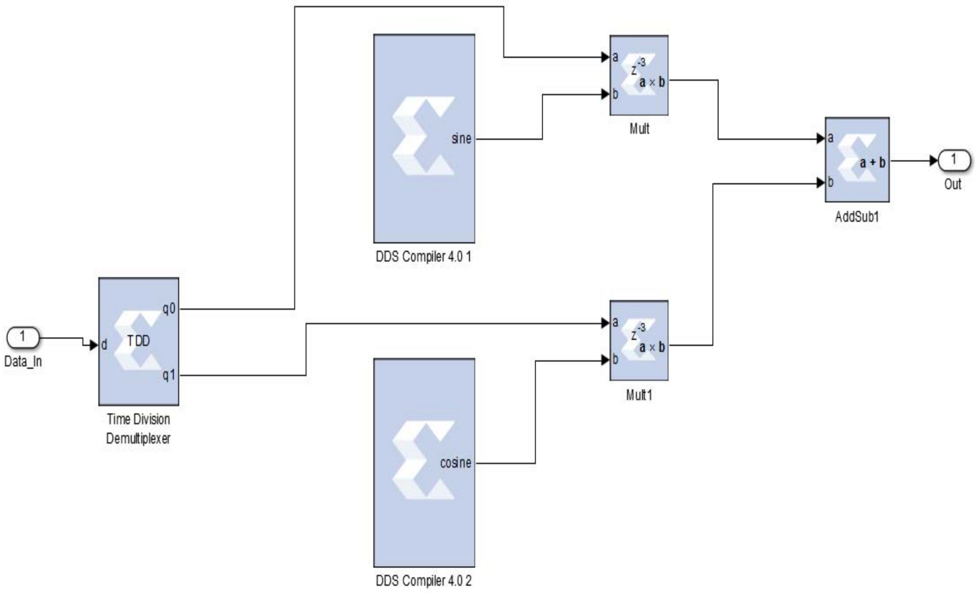

Fig. 12. Block digram of 4 QAM Mapper

To generate the baseband OFDM signal inverse discrete Fourier transform (IDFT) operation is required to be done at the transmitter after serial to parallel conversation of 4 QAM signal. Inverse fast Fourier transform (IFFT) is the algorithm used for implementation of IDFT on digital computer. The block diagram of IFFT is given in figure 13.

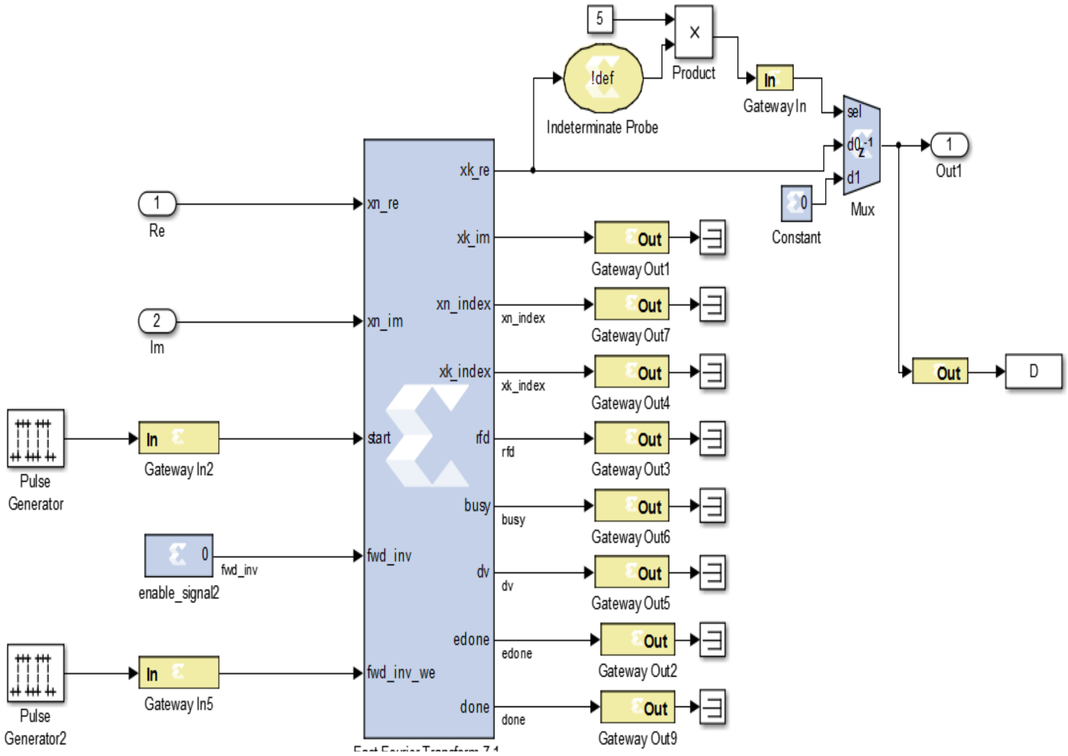

Fig. 13. Block diagram of IFFT

The block diagram for clipping the amplitude of the signal is shown in figure 14. The clipping operation has been performed with clipping ratio of 0.8, 1.0, 1.2, 1.4 and 1.6 as defined by equation (6).

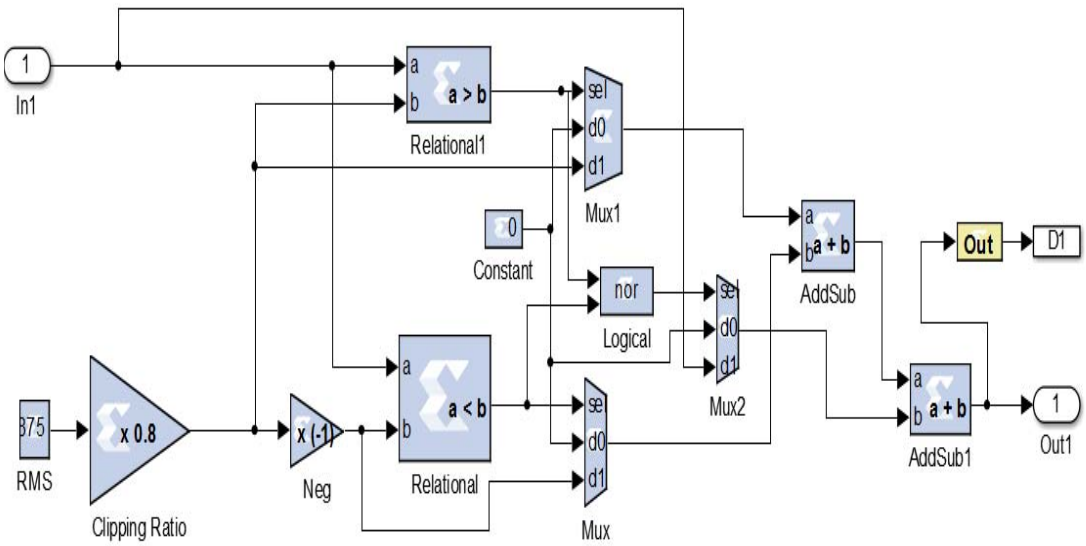

Fig. 14. Block diagram of Clipper Circuit

Figure 15shows the block diagram of hardware cosimulaion used for hardware cosimulation with Xilinx Spartan 3 Protoboard XC 3S 400 development board.

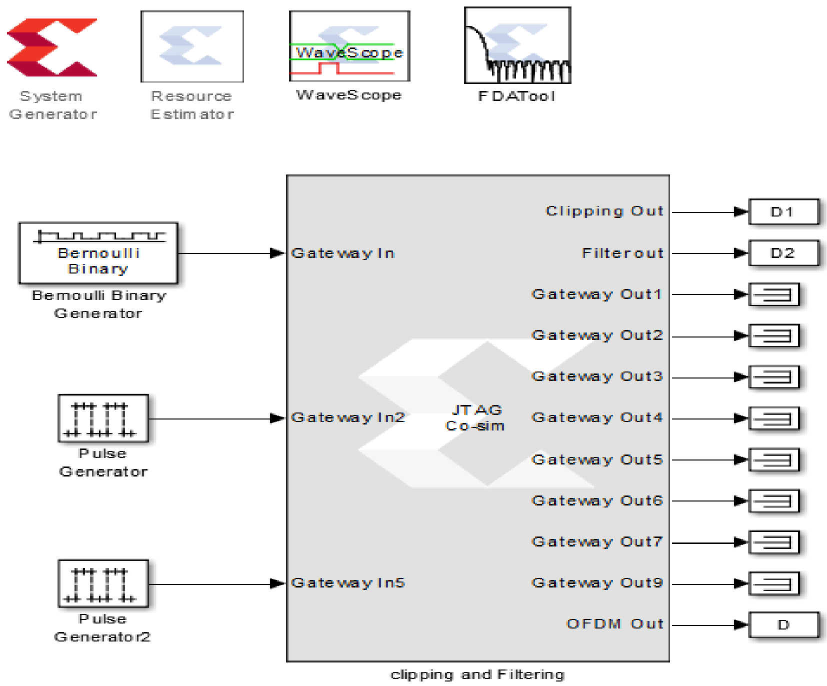

Fig. 15. Block diagram of Hardware Cosimulation

The filter used is a 57 order low pass FIR equiripple direct form-II structure with 2 GHz passband and 5 GHz stopband cut frequencies and passband gain of -1 dB, stopband gain of -50 dB and of 20 density factor. Filter response is shown in figure 16.

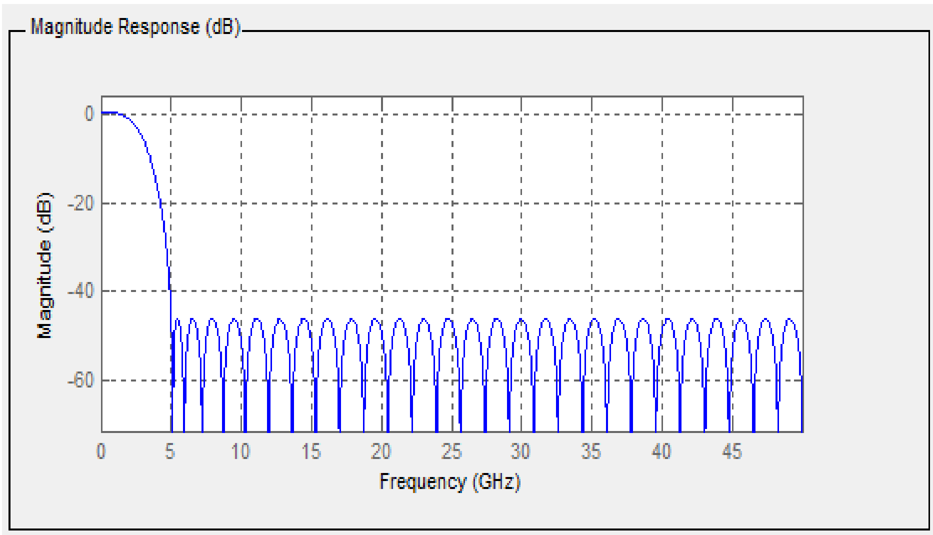

Fig. 16. Low Pass Filter Response

Figure 17 shows the system generator clip with HDL netlist compilation on Xilinx Spartan 3 XC3S400-4PQ 208 development board.

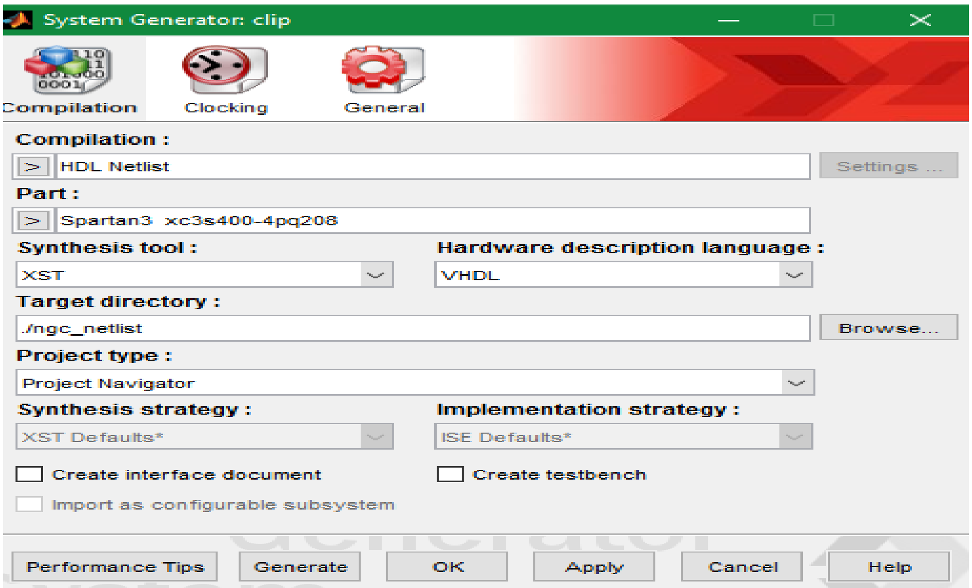

Fig. 17. System Generator for Pre- Clipping and Post Filtering

Xilinx Spartan 3 Protoboard XC 3S 400 development board is shown in figure 18.

Fig. 18. Xilinx Spartan 3 Protoboard XC 3S 400 development board

Similarly the FPGA implementation through hardware cosimulaion is shown in figure 19.

Fig. 19. Hardware Co-simulation on Xilinx Spartan 3 Protoboard XC 3S 400 board

B. *Matlab Simulaion of Pre-Clipping and Post-Filtering method*

Mathematical modeling and Matlab simulation have been carried for pre-clipping and post-filtering circuit as depicted in figure 4. Both PAPR and BER performance have been obtained as explained below.

1) *PAPR value of Pre-Clipping and Post-Filtering Method with Matlab Simulaion:* Figure 20 gives values of PAPR with Matlab simulation for 4 QAM baseband OFDM signal with 1024 number of subcarriers. The PAPR values obtained are 10.7, 11.0, 11.2, 11.4 and 11.7 dB with 0.8, 1.0, 1.2, 1.4 and 1.6 clipping ratio respectively.

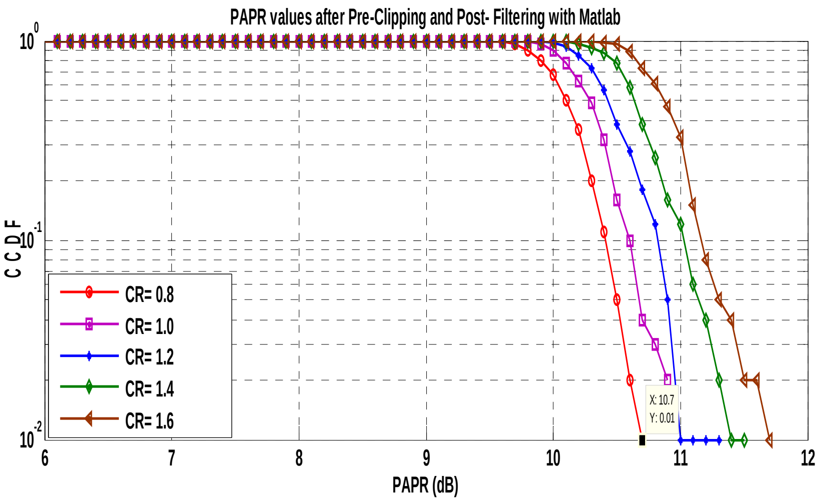

Fig. 20. PAPR of pre-clipped and post-filtered signal with Matlab simulation

2) *BER Performance of Pre-Clipping and Post-Filtering Method with Matlab Simulation:*The bit error rate (BER) is defined as the percentage of bits that have errors relative to the total number of bits received. BER is dependent upon ratio of signal to noise (E_b/N_o) power. There are many other factors on which BER performance depends. The important among them are interference level, transmitted power, modulation format and bandwidth of the system. In order to decrease BER, interference level and bandwidth of the system are to be reduced and the order of modulation and the level of the transmitted power are to be increased.

Figures 21 shows the BER performance of unclipped, clipped and clipped and filtered signal with mathematical modelling and Matlab simulations. The BER value of unclipped signal at 10 dB of signal power is $7X10^{-4}$. It can be observed from figure that BER performance is a function of clipping ratio (CR). For the clipped signal it is observed from the figure that at 10 dB of signal power and with CR value of 0.8, 1.0, 1.2, 1.4 and 1.6 the BER values are $41X10^{-3}$, $27X10^{-3}$, $19X10^{-3}$, $10X10^{-3}$ and $7X10^{-3}$ respectively. It can be observed that as the value of clipping ratio decreases BER performance becomes worse. This increase in BER value is due to distortions caused during the process of clipping [15]. When the clipped signal is passed through filter circuit its BER value improves.

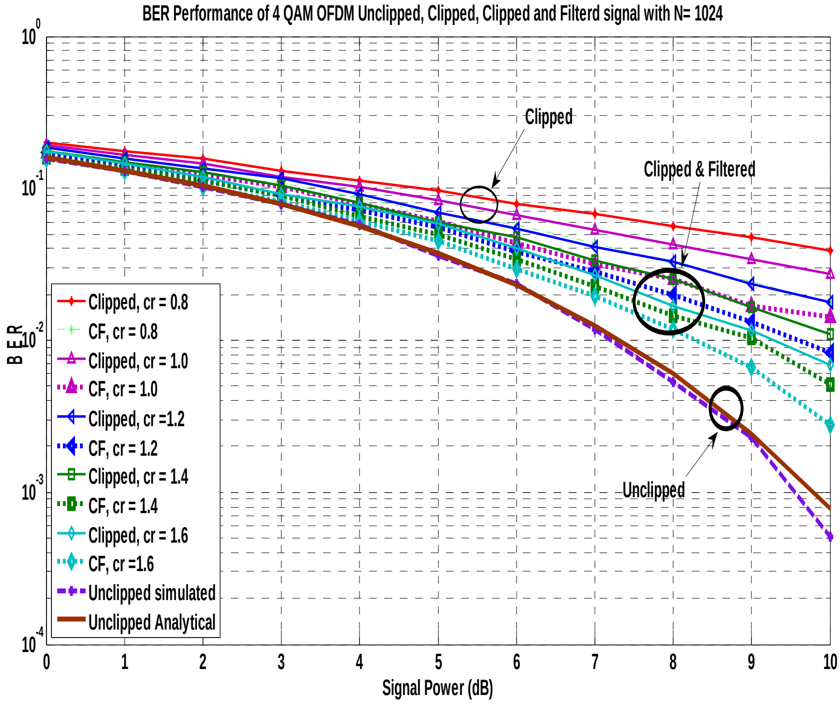

Fig. 21. BER of clipped and filtered signal with Matlab

At 10 dB of signal power and at CR value of 0.8, 1.0, 1.2, 1.4 and 1.6 the BER values of clipped and filtered signal are $19X10^{-3}$, $13X10^{-3}$, $7X10^{-3}$, $5X10^{-3}$and $3X10^{-3}$respectively. The improvement in BER in clipped and filtered signal is approximately $14X10^{-3}$ at CR value of 1.0 than that of only clipped signal.

C. *Pre-Clipping and Post-Filtering with National Instument'S AWR Visual System Simulator*

The PAPR value and BER performance of pre-clipped and post-filtered 4 QAM OFDM signal with 1024 number of subcarriers have also been obtained through student evaluation license of National Instrument's AWR visual system simulator radio frequency (RF)/ wireless communication system design software version 12. NI'S AWR design environment is a portfolio of software products used to design, develop and realize microwave/RF components, circuits and systems including monolithic microwave integrated circuits, RF printed circuit boards, microwave modules, RF integrated circuits, communication systems, radar systems and antennas [16].

1) PAPR value with NI'S AWR Visual System Simulator Software: The pre-clipping and post filtering operation has also been simulated using student evaluation license of National Instrument's AWR visual system simulator commercial software. Figure 22 depicts its simulation diagram.

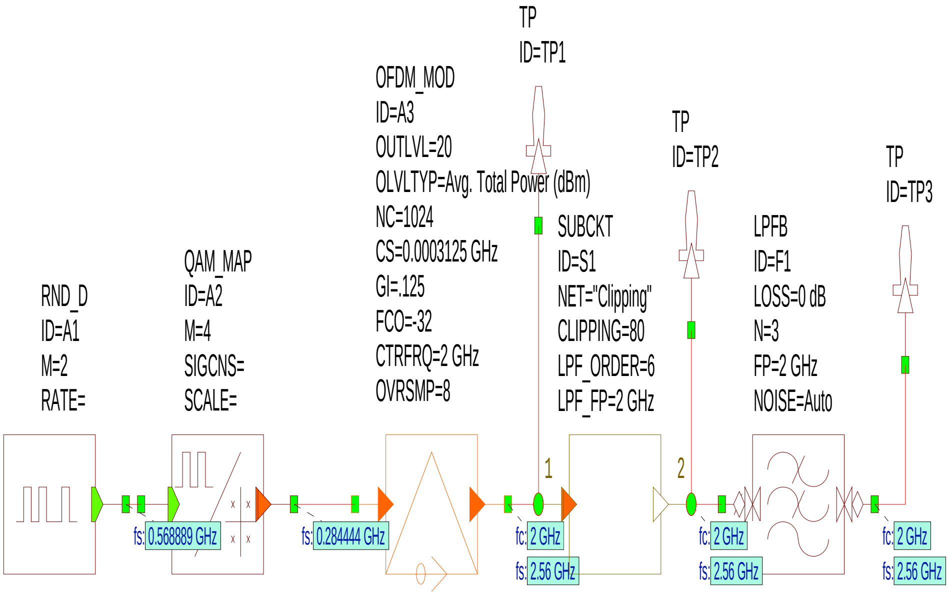

Fig. 22. Simulation diagram of PAPR using NI's AWR visual system simulator

As observed from figure 23 that at CCDF of 10^{-5} the PAPR value obtained are 4.2 and 10.6 for clipped and pre-clipped post-filtered signals respectively.

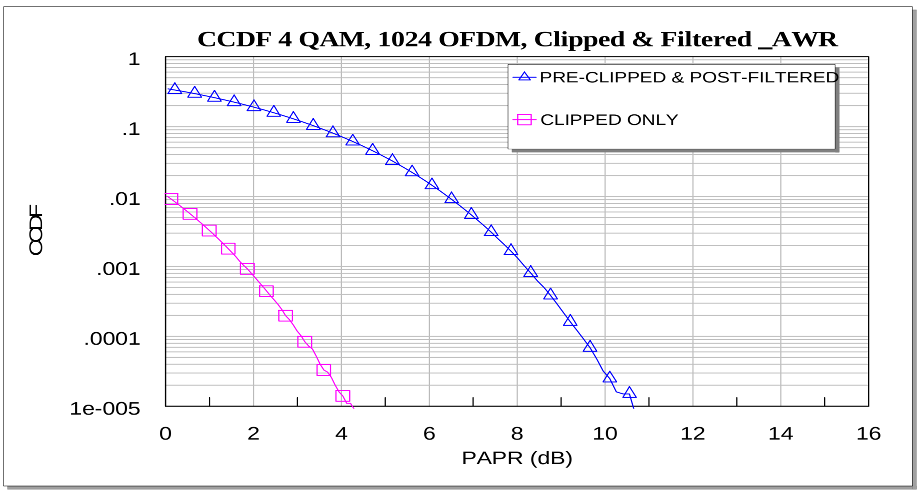

Fig. 23. Simulation Result of PAPR using NI's AWR visual system simulator

2) BER Performance with NI'S AWR Visual System Simulator Software: Figure 24 shows the simulation block diagram of bit error rate (BER) circuit using visual system simulator of National Instrument's AWR software for 4 QAM OFDM signal with 1024 number of subcarriers.

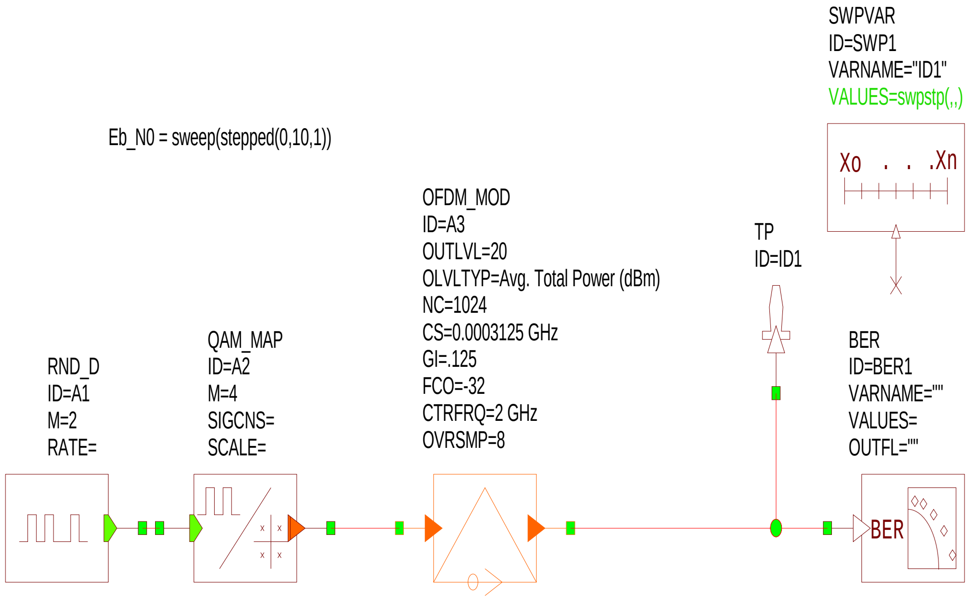

Fig. 24. Simulation diagram of PAPR using NI's AWR visual system simulator

Similarly, figure 25 shows the bit error rate simulation result of the setup of OFDM system shown in figure 24. It can be deduced from figure 25 that the observed value of simulated BER is higher than the reference (unclipped) value. The clipped signal has low PAPR but it is getting distorted from the original unclipped signal and results in higher BER. A trade-off has to be maintained between the required BER and PAPR level, because the reduction in PAPR causes distortion in the output and increase in the BER value.

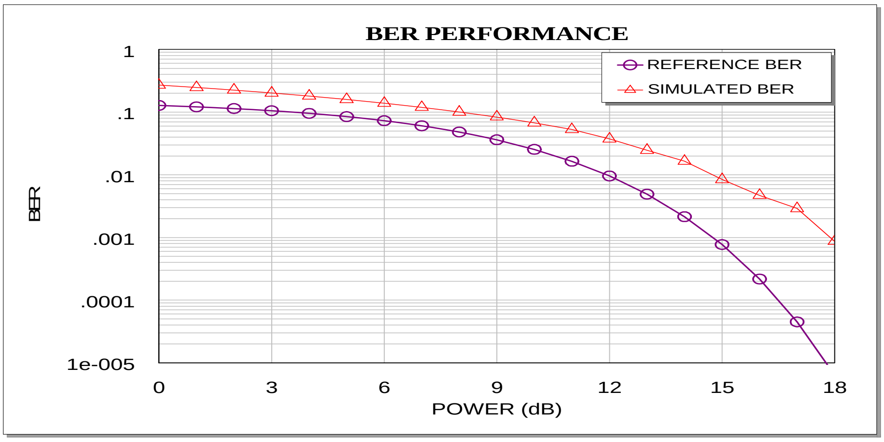

Fig. 25. Simulation result of BER using NI's AWR visual system simulator

IV. Results and Analysis

Figure 26 depicts the comparative values of PAPR obtained through simulation with Matlab, NI's AWR and FPGA implementations.

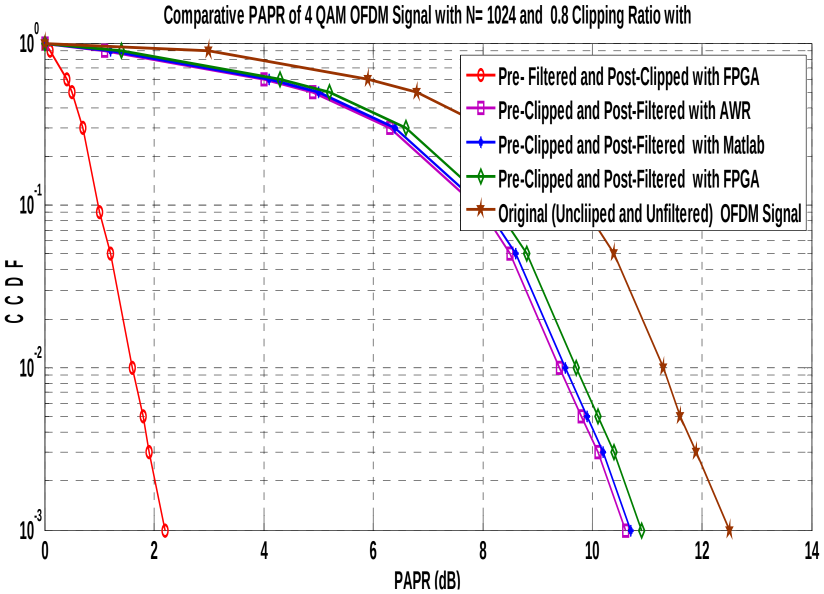

Fig. 26. Comparative value of PAPR with different methods

PAPR with FPGA implementation of pre- filtering and post clipping is 2.2 dB, whereas the corresponding value of pre- clipping and post filtering is 10.9 dB. The simulated value with NI's AWR visual system simulator of pre- clipping and post filtering method is 10.6 dB. On the other hand its value obtaiend with Matlab simulation is 10.7 dB. It is to be noted that the PAPR of original OFDM signal without clipping and filtering operation is 12.5 dB. When compared with original OFDM signal PAPR with FPGA implementation of pre-filtering and post clipping reduces PAPR by 10.3 dB, where asit is only 1.6 dB reduction withFPGA implementation of pre- clipping and post filtering. On the other hand these reductions are 1.9 and 1.8 dB with AWR and Matlab software simulations. Pre-clipping and post-filtering method is mostly used for all practical purposes than pre-filtering and post- clipping technique owing to its better BER performance. As observerved in figures 21 and 25 the BER performance degrades after clipping but improves after filtering operation.

V. Conclusion

OFDM is one of the most desirable modulation technique for high data rate mobile communication system. At one hand, it has advantages of being robust to multipath fading and possessing high data rate transmission capability, on the other hand it suffers from high PAPR. In this paper FPGA implementation of clipping and filtering method have been carried on Xilinx Spartan 3 Protoboard XC 3S 400 board for 4 QAM OFDM signals with 1024 number of subcarriers with different clipping ratio. The result obtained has been compared with NI's AWR visual system simulator and Matlab software simulations. FPGA implementaion of pre-filtering and post clipping technique results with 2.2 dB PAPR value but having worst BER performance. Whereas, PAPR values obtained in the case of pre-clipping and post filtering method, are 10.6, 10.7 and 10.9 dB with NI's AWR, Matlab and FPGA implementations respectively with better BER results. Reductions in PAPR for the case of pre- clipping and post-filtering technique are 1.6, 1.8 and 1.9 dB with FPGA implementation, Matlab and NI's AWR software simulations respectively having better BER performance. Whereas the reduction in PAPR with FPGA implementation is 10.3 dB for pre- filtering and post-clipping method but worst BER performance.

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