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Comparison of MATLAB and FPGA Implementation of PAPR Reduction Technique Using Polar Clipping

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ABSTRACT:

The spectral efficient modulation techniques introduced in 3G and 4G suffer from a high Peak-to-Average Power Ratio. High PAPR results in in-band and out-band distortion. Various PAPR reduction techniques are available in literature. But due to its less hardware complexity, polar clipping is widely used. This paper presents the FPGA and MATLAB implementation of polar clipping technique.

KEYWORDS: Crest Factor, FPGA, Peak to Average Power Ratio, Polar Clipping, Clipping Threshold

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1. INTRODUCTION

3G wireless networks are progressing out nearly all over the world. Interest in streaming media and other high-speed wireless data applications are rising. To make sure wireless networks can meet future users demand, operators and manufacturers plan for the fourth generation (4G) mobile communication systems. These systems which are estimated to have a wider bandwidth with bit rates of up to 100 Mbps able to hold interactive multimedia services, global mobility, teleconferencing and wireless. The spectral efficient modulation techniques such as Wideband-Code Division Multiple Access system (W-CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) used in 3G and 4G suffer from a high Peak-to Average Power Ratio (PAPR). It means that there is a large variation between the average signal power and the maximum signal power. The PAPR is stated as 1,2.

$$PAPR = \frac{\max(x^2(t))}{\text{mean}(x^2(t))} \quad (1.1)$$

Where $x(t)$ is the amplitude of the signal.

PAPR is directly related to Crest Factor (CF) ,2

$$CF = \sqrt{PAPR} \quad (1.2)$$

To spread the signal through the antenna, it is first converted to analog time domain by means of a D/A converter and then amplified with an RF power amplifier. High PAPR causes nonlinear distortion because of the nonlinear component in the transmitter i.e. Power Amplifier (PA). Characteristic curve of power amplifier has been shown in Fig 1.

It shows two operating regions, namely linear and the saturation regions. When the amplifier operates in the linear region, signals are linearly amplified. However, when it operates in the saturation region, signals are not amplified anymore; they are compressed at the maximum output power of the amplifier.

In order to bound the Adjacent Channel Leakage Ratio (ACLR), which is defined as the ratio between the transmitted power (power inside the BW) to the power measured in the adjacent channel (power outside the BW) and in order not to distort the data, it is desirable for the PA to operate in its linear region. The better result can be achieved for an Input Back-Off (IBO) = 0 dB. An IBO= 0 dB means that the amplifier is running at the upper limit of the linear region. The problem appears when the peaks of the signal are too large and do not fit in the linear region. In this case they are treated by the saturation region and so they are non-linearly modified, causing Inter Modulation Distortion (IMD) among subcarriers and out-of-band radiation.

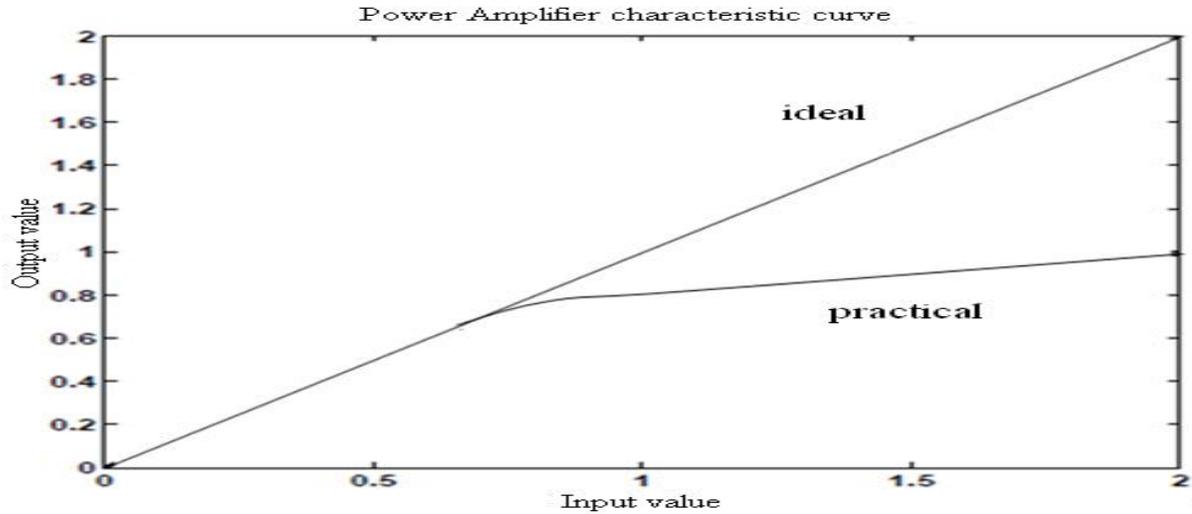


Fig 1. Non-linear amplifier characteristic curve

To minimize these peaks, PA of the transmitter wants a very large dynamic range. Increasing the linear region of a PA is very exclusive and it is ineffective in this case. Also, the larger the PA's dynamic range is, the more battery it consumes and since most of the systems are power limited, an PA with a large linear region would use most of the battery of the system, which is another reason why increasing the dynamic range of the PA is not a good solution. A high PAPR causes saturation in power amplifiers, leading to IMD products among the sub carriers and disturbing out of band energy. Therefore, it is desirable to reduce the PAPR by means of PAPR reduction schemes -3.

1.1. PAPR Reduction Using Polar Clipping

Among all other techniques clipping has been identified as the most efficient and simplest technique. Clipping too large peaks is a simple solution to the PAPR problem. Clipping reduces large peaks but also introduces distortion in the signal. But due to low probability of occurrence of too large peaks this nonlinear distortion is generally small. The maximum peak power allowed is determined by the system specifications. A maximum peak amplitude A is chosen so that the signal does not exceed the limits of this region, symbols that exceed this maximum amplitude, will be clipped. The clipping function is performed in digital time domain, before the D/A conversion as shown in Figure 2 and the process is described by the following expression:

$$x_k^c = \begin{cases} x_k & |x_k| \leq A \\ Ae^{j\phi_k} & |x_k| > A \end{cases}, 0 \leq k \leq N - 1 \quad (3)$$

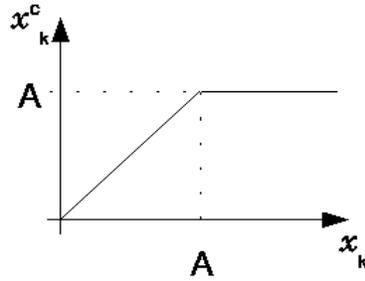


Fig 2. Clipping function

Where x_k^c is the clipped signal, x_k is the transmitted signal, A is the clipping amplitude and $f(x_k)$ is the phase of the transmitted signal x_k . The graphical expression of this function is shown in Fig 3.

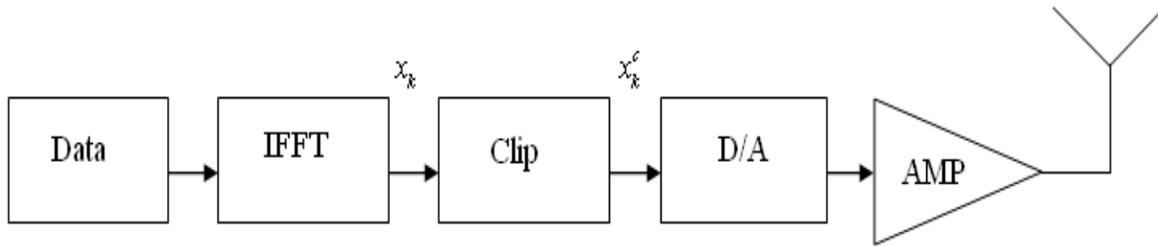


Fig 3. Clipping in the transmitter

The Clipping Ratio (CR) is defined as

$$CR = \frac{A}{\sigma} \tag{4}$$

And the Clip Ratio in dB is given by

$$CR_{[dB]} = 20 \log \frac{A}{\sigma} \tag{5}$$

Where σ is the root mean squared value of the unclipped OFDM signal and its mathematical expression is

$$\sigma^2 = \frac{1}{N} \sum_{k=1}^N x_k^2 \tag{6}$$

The simplest way to remove the peaks is by clipping the signal such that the peak amplitude becomes limited to some predefined maximum level. By defining the highest accepted peak value as the Clipping Threshold, any peak above this value can be clipped appropriately. Clipping Threshold is defined as

$$CT = \sqrt{10^{0.1 * clip_ratio} * avg_power} \tag{7}$$

Clipping is a non-linear process so it introduces in-band distortion, also called clipping noise, out-of-band radiation and inter-carrier interference shown in Fig 4, which degrade the system performance and the spectral efficiency⁴.

In-band distortion: This distortion occupies the same bandwidth as the desired signal. It can be seen as additive noise and it reduces BER performance of a communication system.

Out-of-band distortion: The inter-modulation products produce undesired frequency components at frequencies that are not occupied by signal of interest. This can cause high out-of-band radiation, which can interfere with other signals and can render a system unable to comply with spectral regulations.

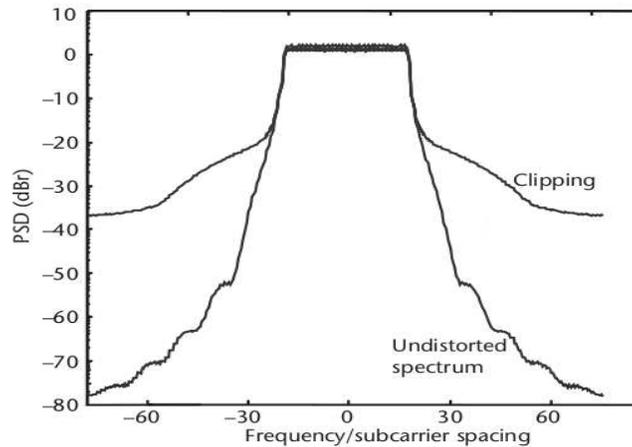


Fig 4. . Out-of-band radiation due to clipping⁵

In a complex waveform, either Cartesian or polar clipping can be used. In polar clipping, the magnitude of the signal is clipped while preserving the phase. From the literature it has been concluded that polar clipping gives better performance in terms of overall signal distortion i.e. lower EVM, which is define as the ratio of the RMS value of the error signal to the RMS value of the reference signal. Polar clipping quantizes the magnitude of the resultant complex signal. Filtering after clipping can reduce out-of-band radiation but may also origin some peak re-growth. To reduce overall peak re-growth, a repeated clipping and filtering operation can be used. Noise shaping is a method that limits the spectral content of the clipping noise during filtering. The noise-shaping method reduces the PAPR of a signal by subtracting a spectrally shaped clipping error, where the clipping noise is the difference between the

clipped signal and the original signal. The noise shaping filter can be defined to reduce unnecessary out-of-band energy^{6,7}.

2. MATLAB IMPLEMENTATION OF PAPR REDUCTION TECHNIQUE.

2.1. Implementation of Crest Factor Reduction

The System Generator block diagram of the CFR design has been shown in Fig 5. It describes the implementation details of each module such as clipping error, noise shaping filter and subtract. For the CFR design implementation, the clipping ratio is assumed to be 7.7 dB to meet the desired target of PAPR reduction of 1.5 dB at an EVM of 2%. So if the clip ratio is 7.7 dB and average power is 0.0524.

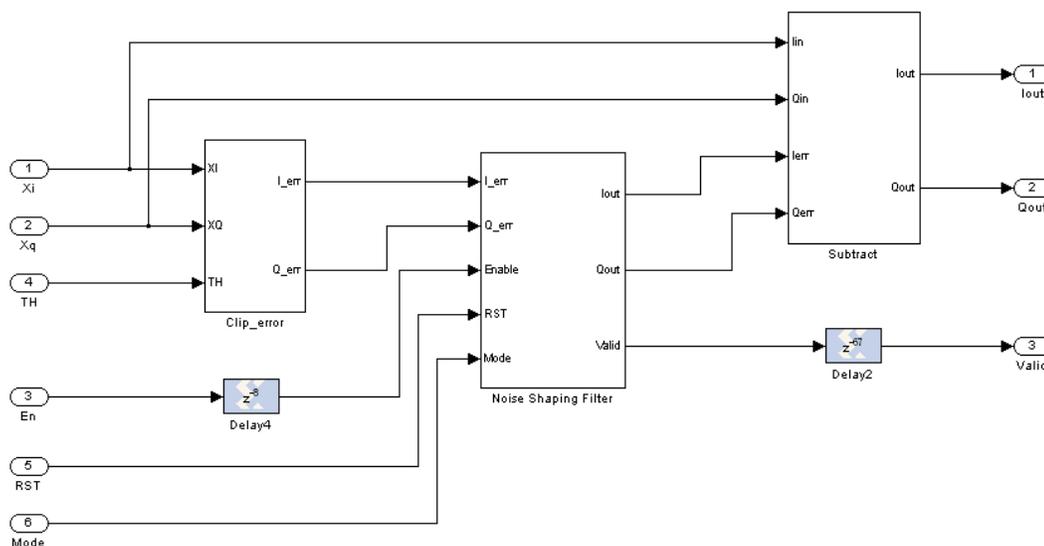


Fig 5. System Generator Block Diagram of CFR

$$CT = \sqrt{10^{0.1 * clip_ratio} * avg_power} \tag{8}$$

Then according to the given formula, the clipping threshold can be calculated as 0.555dB which has been used in this polar clip design.

2.2) Simulation and Results

The performance of the proposed CFR technique has been evaluated for four different bandwidths like 3.5 MHz, 5 MHz, 7 MHz and 10 MHz. The performance of the proposed technique has

been evaluated on the basis input spectrum and output spectrum, clipping noise, Peak-to-Average Power Ratio reduction and Error Vector Magnitude.

2.3) Clipping Noise Spectrum for Different Bandwidths

The clipping noise spectrum for the bandwidth of 3.5 MHz, 5 MHz, 7 MHz and 10 MHz has been shown in Fig 6, Fig 7, Fig 8 and Fig 9 respectively.

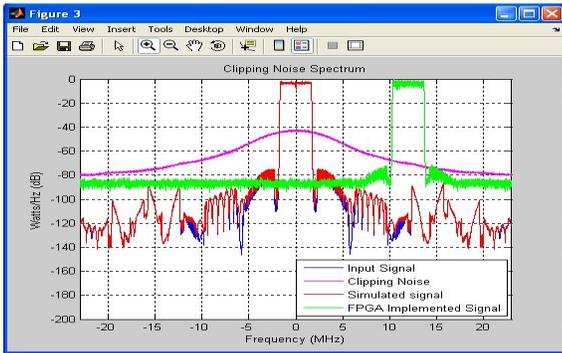


Fig 6.Signal and Noise Spectrum for 3.5 MHz

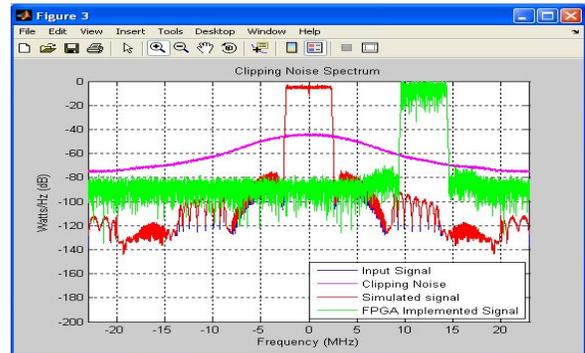


Fig 7.Signal and Noise Spectrum for 5 MHz

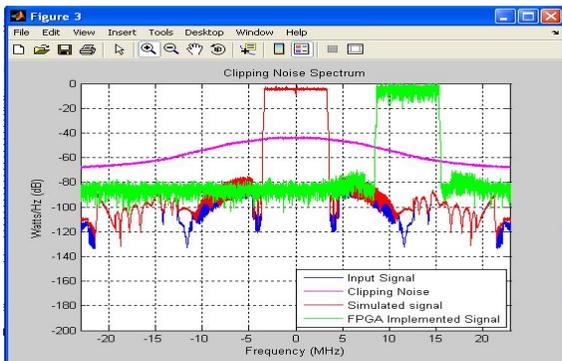


Fig 8.Signal and Noise Spectrum for 7 MHz

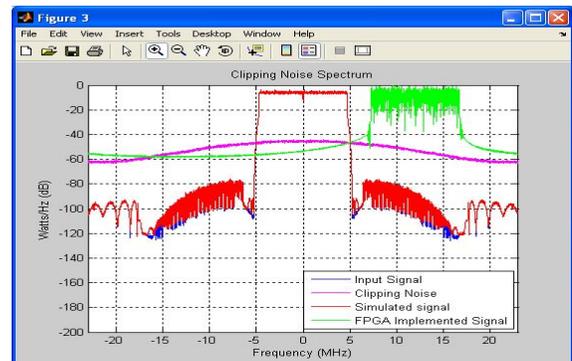


Fig 9.Signal and Noise Spectrum for 10 MHz

The input signal is firstly clipped using the polar clipping technique and then clipping noise is generated by the subtracting the clipped signal from the original signal. The clipping noise is then filtered by the noise shaping filter in order to maintain the spectral mask requirements. The clipping noise is shaped and then subtracted from the input signal to create a PAPR reduced signal. The shaped signal obtained by simulation in MATLAB implementation has been shown in above results. It shows

that clipping noise is very high, the noise shaping filter confines the clipping-noise spectrum to the same spectrum occupied by the unclipped input signal.

3. FPGA IMPLEMENTATION OF PAPR REDUCTION TECHNIQUE

Fig.10 and Fig.11 shows a top level and internal structure Register Transfer Level schematic diagrams of proposed Crest Factor Reduction technique. In this design, RTL is a level of abstraction used in describing the operation of a synchronous digital circuit.

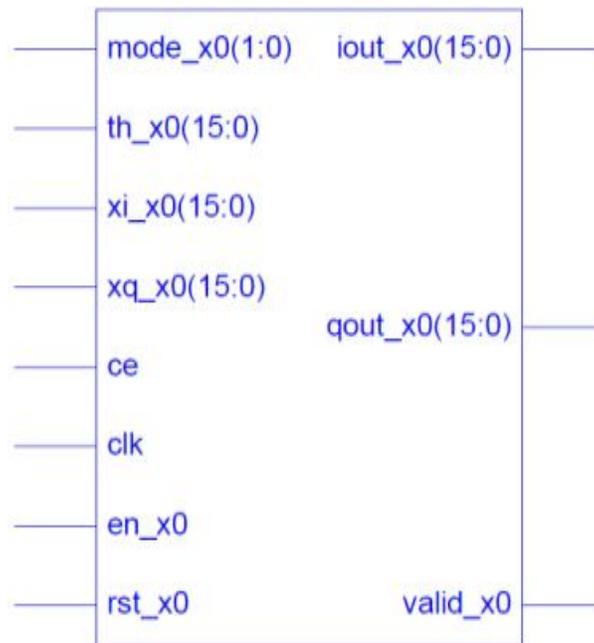


Fig 10 Top level RTL Schematic diagram of CFR Module

In RTL design, a circuit's behavior is defined in terms of the transfer of data between hardware registers, and the logical operations performed on those signals. Register transfer level concept is used in Hardware Description Languages (HDLs) like Verilog and VHDL to create high-level representations of a circuit, from which lower-level representations and ultimately actual wiring can be derived.

Using an EDA tool for synthesis, VHDL code of the circuit can usually be directly translated to an equivalent hardware implementation file for an FPGA. The synthesis tool also performs logic optimization. Fig 4.5 and Fig 4.6 show the top level and internal structure of RTL Schematic diagrams for noise shaping filter respectively.

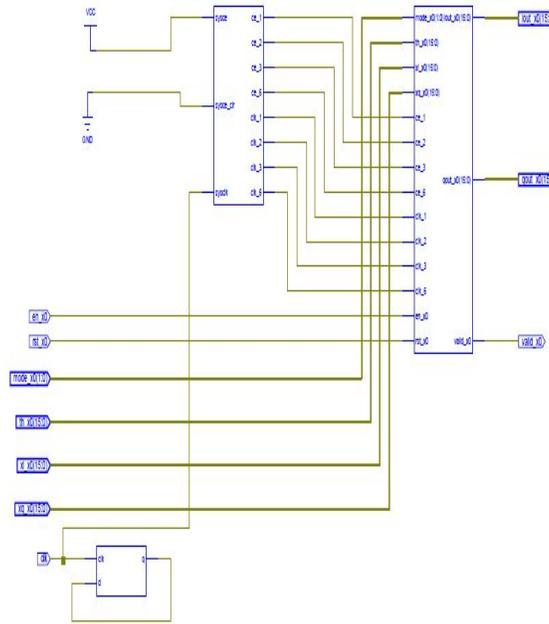


Fig.11.Internal Structure of RTL Schematic diagram of CFR Module

3.1 Resource Utilization

Table 1 shows the resources used in this model which just takes a small part in Xilinx Virtex-4 Kit for CFR.

Table1.Device Utilization Summary of Xilinx FPGA for Polar Clipping

Device Utilization Summary (Estimated Values)			
Logic Utilization	Used	Available	Utilization
Number of Slices	938	6144	15%
Number of Slice Flip Flops	1384	12288	11%
Number of 4 input LUTs	1275	12288	10%
Number of bonded IOBs	86	240	35%
Number of GCLKs	1	32	3%

4. CONCLUSION

From the above results it has been concluded that the clipping noise is least for 10 MHz bandwidth as compared to all other bandwidths. It shows that the CFR input and output are almost

identical to each other and the distortion is almost negligible. Thus the comparison shows that the proposed PAPR reduction technique gives better performance for 10 MHz bandwidth.

The implementation of the proposed clipping technique is done using Virtex-4 FPGA; it shows an efficient utilization of internal resources. The resource utilization for polar clipping and noise-shaping filter shows that almost every item is below 40%. The FPGA implementation has been done for 10 MHz bandwidth. The comparison shows that FPGA implemented model has almost same performance as given by the simulated model.

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