Australian Journal of Basic and Applied Sciences, 9(12) Special 2015, Pages: 48-57

ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

Reducing the Power Envelope Fluctuation of OFDM Systems Using a Simplified Amplitude Clipping Approach

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ARTICLE INFO

Article history:
Received 22 February 2015
Accepted 20 March 2015
Available online 25 April 2015

Keywords:
BER; OFDM; PAPR; PTS; SAC; SLM.

ABSTRACT

A new and crucial modulation technique that is being developed, under the communication systems domain, is Orthogonal Frequency Division Multiplexing (OFDM). The signals from OFDM can not only fight multipath propagation and fading channels but also advocate huge rates of data. Nevertheless, OFDM too has its disadvantage as it is a multicarrier system and can face issues because of the demanded summation of sinusoids during the combination of the in-phase subcarriers, which in turn tends to produce high power peaks. The performance of the BER can be degraded by the big fluctuations in the power envelope called peak to average power ratio (PAPR), which causes in-band and out-band distortion. There are a plethora of methods to solve the problem posed by the PAPR that includes SLM – Selected Mapping, PTS-Partial Transmit Sequence and clipping of amplitude. The former two methods are very complex, whereas amplitude clipping is seen as a much simpler alternative for implementing real-time. This paper aims to provide an alteration to the technique of amplitude clipping, by presenting a fresh method named SAC - Simplified Amplitude Clipping. In the SAC method, extra bit of information is sent, in order to ensure that all of the clipped data is retrieved by the receiver. Furthermore, the SAC method is not complex and results from the simulations advocate the point that this technique is more adept than the original one. The size of the mean squared error vector stays the same when compared to the conventional unclipped signal, whereas the PAPR reduced by approximately 1.0dB. On the other hand, the ordinary clipping method makes a much larger magnitude of mean squared error vector.

ToCite ThisArticle: Dheyauldeen Najm Abdulameer and R. Badlishah Ahmad., Reducing the Power Envelope Fluctuation of OFDM Systems Using a Simplified Amplitude Clipping Approach. ***Aust. J. Basic & Appl. Sci.**, 9(12): 48-57, 2015*

INTRODUCTION

Communications systems with single carriers can be seen as a simple system. Despite their simplicity, they do have drawbacks such as low bit rate and the need for complex equalizers to help fight the multipath channels. Although it is widely believed that multicarrier systems are more complicated than single-carriers, this is incorrect as the latest technological developments makes it easy to implement such systems – the OFDM system is a prime example that will be assessed further in this paper. IFFT/FFT – Inverse/Fast Fourier Transform chips aid to easily implement the OFDM system. Furthermore, the OFDM signals are of high data rates, and hence are superior to that of single carrier signals. Another advantage of the OFDM is that it has the capability to go through multiple channels to the receiver without the help of equalisers that single-carriers would need. As mentioned earlier, the signals from OFDM are able to give high data rates, because they separate the available channels into *N* number of orthogonal subcarriers.

One disadvantage of the OFDM system however is that they make bigger power envelope fluctuations when compared to the ordinary power of output. However, there are many ways in existing literature that helps face this issue (Tao Jiang, and Yiyan Wu, 2008). One is the SLM method (Montadar Abas Taher, *et al*., 2015) in which the signal is imitated *U* number of times, and the phase rotation vector is used to multiply each copy by element. The phase rotation vector receives the extra information, whereas the copy holding the most PAPR is directed towards the receiver. This is performed by the use of IDFT- the Inverse Discrete Fourier Transform. In practicality, the IFFT or the FFT processes would be preferred for implementation over the conventional IDFT/DFT method due to its lower computational complexities. A second study advocated the cost of

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the BER to help lower complexity (Chin-Liang Wang, and Sheng-Ju Ku, 2009). Yet another approach suggests the use of the PTS method to decrease the PAPR (Müller, S.H. and J.B. Huber, 1997). Although this technique reaps similar performance to that of the SLM, it is much more complicated when compared to the latter. Some researchers have shown to have decreased the complexity of this technique (Yajun Wang, Wen Chen, Chintha Tellambura, 2010; Necmi Taspinar, Adem Kalinli and Mahmut Tildirim, 2011; Ho-Lung Hung, 2011), however in each case the BER is an opportunity cost.

Some trade-offs such as lower bit rates must be made in order to simplify the PAPR reduction strategy. This reduction can be achieved through block coding (Werner Henkel and Björn Wagner, 2000). This technique requires the ZCZ - Zero Cross-correlation Zone to be wide enough to decrease the PAPR to an accepted rate. However, this technique sends redundant bits, hence producing a loss in the rate of data bits. The reader may see (Daoud, O., O. Alani, 2008; Young-Jin Kim, *et al.*, 2009; Ying Li, 2010) for more knowledge. Other methods to enhance the PAPR values include the TR – Tone Reservation (Saeed Gazor and Ruhallah AliHemmati, 2011; Haibo, Li, *et al.*, 2011; Jung-Chieh Chen, *et al.*, 2011) and TI- Tone Injections (Jung-Chieh Chen, and Chao-Kai Wen, 2010). In order to find the optimal tones to decrease the PAPR, it needs more power and complex optimization techniques. Another technique that helps solves this problem is known as interleaving (Jayalath, A.D.S .and C. Tellambura, 2000; Prasad, V.G.S. and K.V.S. Hari, 2004). Interleaving is a method which sends the extra information, and is closely based on similar rationale as that of the SLM method. The ACE - Active Constellation Extension (Brian Scott Krongold and Douglas L. Jones, 2003; Cai, Li, *et al.*, 2011) is also another technique to help reduce the PAPR, through the alteration of the constellation map. However, in the ACE method, it is crucial to note that only the outer points can be moved, because if the distance between the inner constellation points are decreased, the BER will be compromised. Such movement causes an increase in transmission power that is seen as a disadvantage, no matter which optimization method was used to find the most suitable points to shift.

The techniques discussed above are all based on frequency-domain. There is also some time-domain techniques which can prove effective, namely that companding transform method (Xianbin Wang, T., *et al.*, 1999; Jeng, S.-S. and J.-M Chen, 2011 Athinarayanan Vallavaraj, *et al.*, 2010). This is a simple method that degrades the BER, but ensures stable computational complexity and also largely reduces the PAPR by raising the average power levels. The APF – All Pass Filter (Eonpyo Hong, and Dongsoo Har, 2010; Eonpyo Hong, and Dongsoo Har, 2011) is another technique under the time-domain. This method is also similar to that of SLM, however instead if phase rotation vectors, it uses all-pass filters. This method allows to modify the filter settings to decrease the PAPR by sending it to the receiver as side information.

Of all the time-domain methods, the amplitude clipping is the most simple. The foundation of this method lies in the clipping of high peaks after the performance of the Inverse Discrete Fourier Transform. To do this, a soft envelope limiter is needed in the baseband prior to the transmissions (Mestdagh, D.J.G., *et al.*, 2014; O'Neill, R. and L.B. Lopes, 1995; Xiaodong Li, and Leonard J. Cimini, Jr., 1998; Dov Wulich, Nati Dinur, and Alex Glinowiecki, 2000). Since the operation of the clip is nonlinear, discontinuities in the samples can be expected. Theory side, the bandwidth at this stage would be infinite; therefore a low pass filter would be suggested in order to keep the out of band emissions under the accepted level. However, there will be a re-growth in the amplitude of the in-band, which must be decreased using other techniques (Hideki Ochiai and Hideki Imai, 2002; Hosein Nikopour and S. Hamidreza Jamali, 2004) to reduce the BER to a lower level. This essay aims to provide an alteration to the clipping method, one that would enhance, rather than decrease the level of BER by utilising some side information. The analysis of the envelope is an important topic for the circuit-designer engineers, but it is out of the scope of this work at the moment, the reader can refer to (Junji Kawata, *et al.*, 2012; Timo Rautio, *et al.*, 2009). Whatever remains of this paper is sorted out as takes after: Section 3 portrays the OFDM framework and characterizes the PAPR; Section 4 introduces the basic amplitude clipping technique and the recommended changes; the outcomes and discussions are given in Section 5; the conclusions are displayed in Section 6.

2. OFDM Signal and Definition of PAPR:

The OFDM symbol for a discrete time, over samples, baseband, N-orthogonal subcarrier can be mathematically represented as follows:

$$x(k) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X(n) e^{j2\pi \frac{kn}{N}} \quad (1)$$

In the equation above, time is represented by k and frequency by n which have a range between 0 to $N-1$. $X(n)$ signifies the symbols that are selected from M-QAM or M-PSK mapping constellations at random. The final expression shows a small IDFT that makes N orthogonal sinusoidal outputs. It is advised that after the guard interval insertion, these outputs must be carried at a RF – Radio Frequency level. This signal can be produced by the use of inexpensive circuitry, for instance the one made by Oliveira (Luis Bica Oliveira, *et al.*, 2012). However, some of these sinusoids may be in-phase, which in turn extends to constructive summations. Hence, the average power can now be compared to the peak power. This comparison is known as the PAPR and can be represented by the mathematical equation:

$$\zeta = \frac{\|x\|_\infty}{P_{avg}} \qquad (2)$$

Here, P_{avg} represents the average powerand $\|x\|_\infty = max(|x_1|, \ldots, |x_n|)$.$x(k)$ is the output samples are iid – Independently Identically Distributed samples. Since the value of $N \geq 64$, it shows a Gaussian distribution with a mean of zero and variance σ^2 according to the CLT - Central Limit Theorem (Tao Jiang, *et al*., 2008). Hence, the CCDF - Complementary Cumulative Distribution Function of the PAPR can be coined as

$$CCDF(\zeta) = \Pr(\zeta > \gamma) \qquad (3)$$

In which γ stands for the clipping level. The factor for oversampling must at least be 4 (Tao Jiang, *et al*., 2008). As discussed previously, there are numerous methods used to reduce the value of the PAPR. In the rest of this paper, the conventional amplitude clipping technique will be represented by CAC whereas the proposed method would be denoted by SAC.

3. Conventional Amplitude Clipping Technique:

One of the many different techniques used to decrease the PAPR level is amplitude clipping. Although the CAC can reduce the PAPR, it does so at the cost of degrading the BER (Hangjun Chen, and Alexander M. Haimovich, 2003; Guangliang Ren, Hui Zhang, and Yilin Chang, 2003). There is much literature that aims at enhancing the performance of the BER of CAC [37-42]. Many of these theories suggested coding methods (Guosen Yue, and Xiaodong Wang, 2006; Ui-Kun Kwon *et al*., 2007), however, as discusses earlier, they tended to reduce bit rates. Other researchers used iterative clipping and filtering through the IDFT method, however it resulted in an increase in computational complexity (Luqin Wang and Chintha Tellambura, 2008; Fei Peng, and William E. Ryan, 2008; Kitaek Bae *et al*, 2010; Wang, Y.-C. and Z.-Q. Luo, 2011). For more information about filters, the reader may refer to (Rohini Deshpande, B. Kumar and S.B. Jain, 2012; Vlastimir, D. Pavlović, 2011). This paper will not repeat existing literature, theperformance of the CAC technique has been analyzed in the literature (Hideki Ochiai and Hideki Imai, 2002; Hosein Nikopour and S. Hamidreza Jamali, 2004; Fei Peng, and William E. Ryan, 2008; Lgal Kotzer and Simon Litsyn, 2011; Luciano Leonel Mendes and Renato Baldini Filho, 2011). Parameters that can be utilised to evaluate the performance of the OFDM system includes the BER, and the EVM – Error Vector Magnitude (Lgal Kotzer and Simon Litsyn, 2011). The value of EVM is crucial, particularly when it involves techniques of clipping. The input signal $x(k)$ can be represented as

$$x(k) = r_k\, e^{j\theta_k} \qquad (4)$$

$f(r_k)$ is the soft envelope function which helps to make the output of $\tilde{r}_k$. Hence the sample of the output $\tilde{x}(k) = \tilde{r}_k\, e^{j\theta_k}$ is

$$\tilde{r}_k = f(r_k) = \begin{cases} r_k & for\, r_k \leq A \\ A & for\, r_k > A \end{cases} \qquad (5)$$

*A*stands for the maximum amplitude allowed, which is linked with the mean power through the clipping ratio denoted by ε and defined as

$$\varepsilon = \frac{A}{\sqrt{P_{avg}}} \qquad (6)$$

It is a known fact that such operations involving clipping, can cause OOB – Out of Band radiations, hence a band-pass-filter (BPF) (Hideki Ochiai and Hideki Imai, 2002) must be made use of to help eliminate as much OOB as possible. However, this paper is more concentrated towards the function of clipping itself, than over other operations, for instance the BPF to eliminate the complexity. The aim is to retain the clipped portions without the aid of a filter, and this will be elaborated upon in the upcoming sections.

4. Simplified Amplitude Clipping Technique:

The CAC method, as mentioned earlier, fails to provide the receiver with data of the clipped samples and also amplitudes. This deficiency of information causes the BER to increase. The SAC method can be used to overpower this dilemma. In equation 5, both the amount of clipped samples and the original amount of amplitudes is unknown. Hence, accurate results cannot be expected from the receiver without the aid of costly components. This paper suggests a novel method to help find the number of clipped samples, the location of each of them and also the original amplitude of each sample, which is clipped, by transmitting it in the form of side information, in such a way that ensures that the receiver can only retrieve the signals of the original sample.

One may argue that the data in the side information in too large, and hence the method is invalid. However, not all of the data will be transmitted. There will be a function at both the transmitter and the receiver, which will ensure that clipped portions will not be sent as side information. Hence, we can say that the side information is a vector or equal length to that provided by the SLM technique. Nevertheless, whatever function of clipping may be used, for instance diving by an integer greater than zero (B) at the transmitter and then multiply the same at the receiver side. In this paper, the utilized function is as follows,

$$\hat{r}_k = \begin{cases} r_k & for\, r_k \le A \\ (r_k)^{1.5} & for\, r_k > A \end{cases} \quad (7)$$

The amount of clipped amplitude is,

$$\alpha_k = r_k - (r_k)^{1.5} \quad (8)$$

In equation 8, if the value of r_k is bigger than A, then the new magnitude will follow the value in equation 7.

The output power of the CAC technique can be represented as (Hideki Ochiai and Hideki Imai, 2002)

$$P_{out} = \left(1 - e^{-\varepsilon^2}\right) P_{avg} \quad (9)$$

Wherein ε, the clipping ratio is as defined as in equation 6. The SAC output power is limited upwardly using equation 9.

$$\lim_{\varepsilon \to 0} \frac{|\hat{r}|}{\sqrt{P_{out}}} \le \lim_{\varepsilon \to 0} \frac{\max(r_k)}{\sqrt{P_{out}}} = \lim_{\varepsilon \to 0} \frac{\max(r_k)}{\sqrt{\left(1 - e^{-\varepsilon^2}\right) P_{avg}}} \quad (10)$$

since,

$$\max(r_k) = \varepsilon \sqrt{P_{avg}} \quad (11)$$

then,

$$\lim_{\varepsilon \to 0} \frac{|\hat{r}|}{\sqrt{P_{out}}} \le \lim_{\varepsilon \to 0} \frac{\varepsilon \sqrt{P_{avg}}}{\sqrt{\left(1 - e^{-\varepsilon^2}\right) P_{avg}}} = \lim_{\varepsilon \to 0} \frac{\varepsilon}{\sqrt{\left(1 - e^{-\varepsilon^2}\right)}} = 1 \quad (12)$$

In which, the output power of both the CAC and the SAC remains alike.

$$P_{out-SISAC} = \left(1 - e^{-\varepsilon^2}\right) P_{avg} \quad (13)$$

$\alpha_k$from equation 8 is a predefined parameter, and hence does not need to be transmitted as side information. Hence, it can be seen that the side information only comprises of the clipped samples. It can be transferred to the receiver as described: Taking the values of the clipped samples to be $[0, 3, 5, \text{and } 7]^T$for an eight subcarrier OFDM symbol; then the side information will consists of a vector of binary data, in which the value 1, will be designated to portray clipped samples. Hence, using this example, the side information vector would be [1, 0, 0, 1, 0, 1, 0, 1] or 95_h (in which hexadecimalis denoted by *h*). It is now possible for the receiver to distinguish the clipped samples, since the reduction function is defined at the receiver, the receiver has the ability to retrieve the original amplitudes without complexity at either the transmitters' or the receivers' end. The performance of the SAC technique, we can use the EVM method to evaluate the performance of the BER, which will be defined as (Lgal Kotzer and Simon Litsyn, 2011; Satoshi Yamazaki and David K. Asano, 2010)

$$EVM_i = \sqrt{\frac{E\left\{|r - \hat{r}|^2\right\}}{N\,E\left\{|\hat{r}|^2\right\}}} \quad (14)$$

In which$E\{\cdot\}$ represents the expectation operation and *i* the index of the OFDM symbol. Another more quantitative method is the LT-EVM – Long Term EVM (Wang, Y.-C. and Z.-Q. Luo, 2011). LT-EVM can be defined by representing the *rms* – root mean squared

$$LT - EVM = \sqrt{\frac{1}{R} \sum_{i=1}^{R} EVM_i^2} \quad (15)$$

where *R*stands for the total number of OFDM symbols. Hence, it can be said that if the value of LT-EVM is little, then the distortion caused is also small, therefore the performance of the BER is strong. On the contrary$\hat{r}_k$will be sentto a SSPA - solid state power amplifier. Many existing methods use inexpensive and small scales CMOS implementation for the OFDM application (Ryu Heung-Gyoon, Jin Byoung-Ii, and Kim In-Bae, 2002; Sen, S., R. Senguttuvan and A. Chatterjee, 2011; Berland, C., *et al*., 2006; Park Dong-Hyun and Song Hyoung-Kyu, 2007; Bo Ai, *et al*., 2005). For the purpose of simplicity and simulation, the SSPA can be defined as (Ryu Heung-Gyoon, Jin Byoung-Ii, and Kim In-Bae, 2002)

$$g[\hat{r}_k] = \frac{v_\lambda \hat{r}_k}{\left[1 + \left[\frac{v_\lambda \hat{r}_k}{A_o}\right]^{2p_\lambda}\right]^{1/2p_\lambda}} \quad (16)$$

where $v_\lambda$stands for the small signal amplification, $p_\lambda$for the model parameter, and A_o for the output amplitude at the saturation region ($A_o \ge 0$). In the simulation, $p_\lambda = 2$, and $v_\lambda = 1$.

RESULTS AND DISCUSSIONS

This sections will present the PAPRs, BERs and EVMs of the CAC and the SAC with the AWGN and with absence of the AWGN. Around 50,000 OFDM symbols will be simulated, with a clipping ratio chosen randomly such as $\varepsilon = 0.28$, where the OFDM size will be 256 subcarriers, modulated by 16-QAM (16-quadrature amplitude modulation), as shown in Table 1. As a comparison, the $\varepsilon = 0.28$ and another $\varepsilon = 0.7$ will be used for the CAC, for comparison purposes only, with the SAC are all shown in Figure 1.

Figure 1 shows that at a probability of 10-4, the PAPR was reduced by almost 1 dB with an LT-EVM $\sim$ 0, when $\varepsilon = 0.28$ for the SAC, while the CAC method produced more reduction in the PAPR, which was 9.3 dB at the same clipping ratio. However, the LT-EVM of the CAC was 0.4146 which it stands for more BER as shown in Figure 2 and 3. That is, the second clipping ratio, ε = 0.7, was simulated for the CAC, for a comparison purpose only, the PAPR of the CAC was not reduced which is shown in Figure 1. For more explanation, the LT-EVM was equal for both the original signal and the SAC, this means that the signals are both retrieved completely, but the expense is the power. However, the power required is due to the constellation points were changed.

Figure 2 represents the simulation of the absence of the AWGN for both signals, CAC and SAC. Thus, it is shown that the CAC signal was lost at the receiver almost completely, while the SAC shown in Figure 2 was completely recovered, with the help of some bits of side information, without the need for block coding (Werner Henkel and Björn Wagner, 2000; Guosen Yue, and Xiaodong Wang, 2006), where the block coding may requires redundant data more than the side information of the SAC. In fact, even if the block coding was used with CAC, it is likely that most of the signal will be lost, unlike the SAC approach, where all the data have been recovered without using another approaches, like the block coding. Moreover, it is mentioned that the filtering (Hangjun Chen, and Alexander M. Haimovich, 2003; Ui-Kun Kwon *et al.*, 2007) will not be needed with SAC algorithm, still the suggested method, SAC, outperforms the CAC algorithm.

For more comparing the error bits, the EVM plot for 100-OFDM symbols is shown in Figure 4. It is shown in Figure 4 that the logarithmic plot for the SAC and CAC schemes have different behaviours. Where the SAC curve did not appears which it has one meaning; no-error was detected in the recovered signal, while the CAC shows that the error is really happen, for both clipping ratios. This phenomenon was confirmed in the BER-performance curves (see Figures 2 and 3).

Table I: parameters setting for the conducted simulation.

N	Mapping order	Clipping ratio ε	# OFDM symbols
256	16-QAM	0.28 & 0.7	50,000

On the other hand, the power spectral density (PSD) confirms our claim with respect to the SAC-scheme. In other words, the SSPA has been used in our simulation, where the PSD was plotted at two points, before and after the SSPA, as shown in Figures 5 and 6. Obviously, best performance, for both clipping algorithms (CAC and SAC), the clipping ratio of 0.7 is the best, but this clipping ratio did not reduce the PAPR, while for ε = 0.28, the PAPR was reduced but the BER is the expense, where for the CAC method, the BER-performance was degraded, while the SAC has better BER-performance. This reflects the behaviours of the PSD, as shown in Figures 5 and 6. It is shown that the OOB radiation was enhanced for the suggested approach without using extra components, such as the block coding or filtering after the clipping operation.

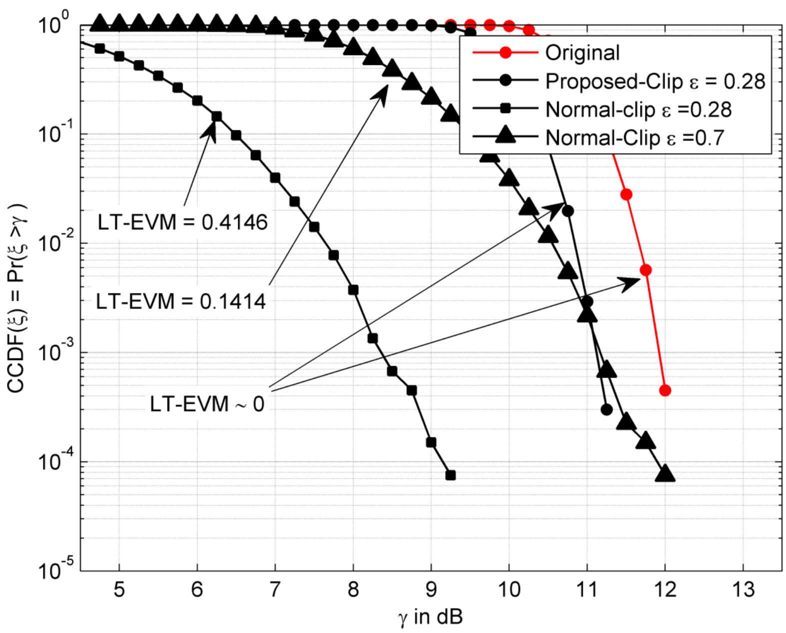

Fig. 1: PAPR simulation results for the CAC and SI-SAC methods with different clipping ratios.

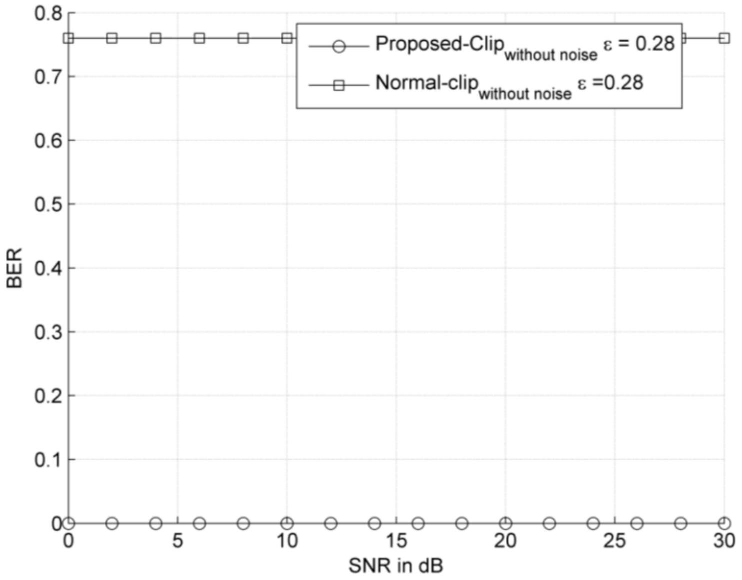

Fig. 2: BER comparison between the CAC and SI-SAC approaches.

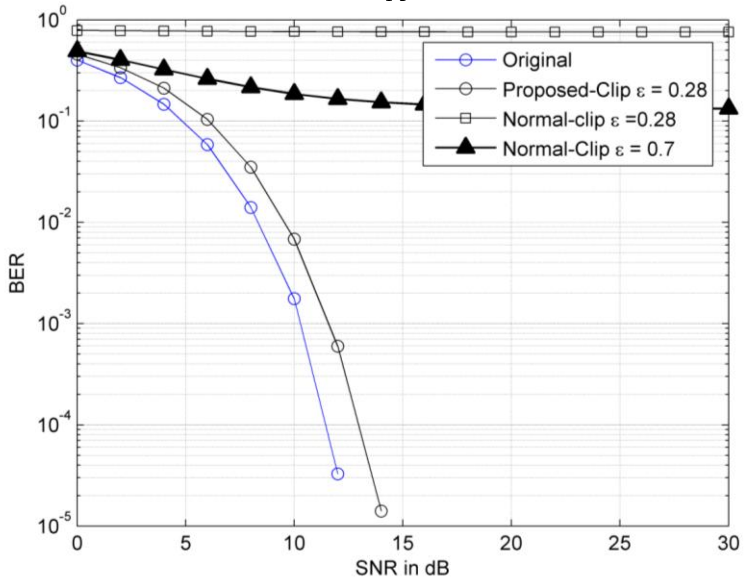

Fig. 3: Comparison of BER simulation results for all cases.

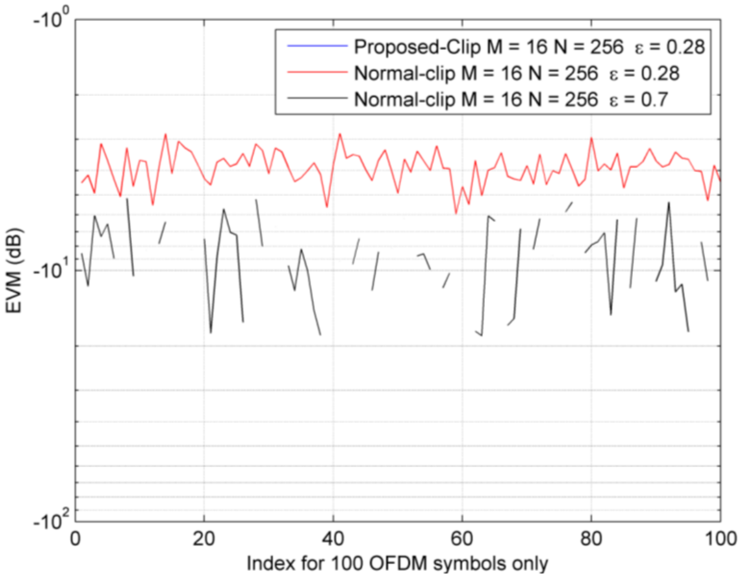

Fig. 4: EVMs of MAC (SI-SAC) and CAC for both ε values

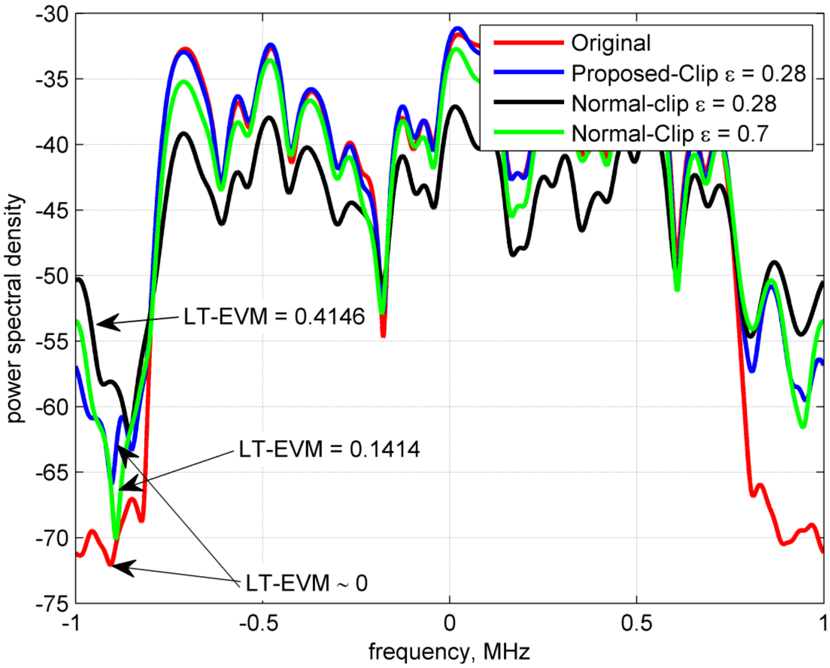

Fig. 5: PSDs of all cases before the SSPA.

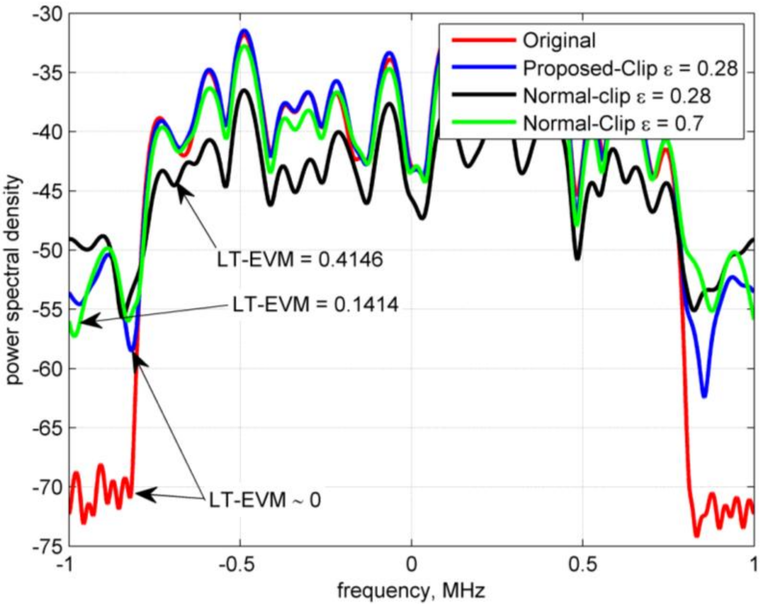

Fig. 6: PSDs of the simulated cases after the SSPA.

Conclusions:

This paper suggested a new method named simplified amplitude clipping –SAC that aims to alter the CAC method, wherein the samples of clipped indices were transmitted to the receiver in the form of side information, in order to let complete retrieval of all the information at the receiver end. The function of clipping is present at both the transmitter and also the receiver. The use of these procedures not only met the reduced PAPR levels as by that of the CAC method, but also helped enhance the performance of the BER. However, the only expense in using this technique is the amount of power being transmitted. Furthermore, this technique is not limited to a particular modulation map; hence it may be used with the aid of other constellation mapping families.

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