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# CLIPPING TECHNIQUES FOR PAPR REDUCTION IN FBMC/OQAM SYSTEM OVER DOUBLY-SELECTIVE CHANNELS

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**Abstract:** One of the major disadvantages of Filter Bank Multicarrier (FBMC) is high Peak-to-Average Power Ratio (PAPR) of transmitted signal. As a result, nonlinear power amplifier (PA) properties, considerable out-of-band and the in-band distortion types take place in the case where the signals of high peak exceed the PA saturation level. In the present study, a new method of the PAPR reduction is presented and applied to reduce PAPR in FBMC/OQAM system. Different clipping methods have been proposed and studied that are Amplitude Clipping (AC), Palm Clipping (PC), Deep Clipping (DC), and smooth Clipping (SC) for the reduction of PAPR. To evaluate and analyze the performance of PAPR reduction methods, PAPR and Bit Error Rate (BER) measures are used and programmed using MATLAB program. The simulation results show that the clipping methods are strong substitute methods which may be assumed as a method of PAPR reduction for the FBMC-based communication systems and AC appears to be the best method.

**Keywords**: *FBMC/OQAM, MMSE equalizer, peak-to-average power ratio, clipping techniques, doubly selective fading channel.*

## 1. Introduction

The future system of the wireless communication will possibly have greater values of the bit rate. For increasing system bit rate, the multi-carrier (MC) system has been viewed as optimal option where the entire selective communication channel of wide-band frequency has been split to a number of the sub-bands, every one of those sub-bands has lower frequency selective fading. In the case where the number of the sub-bands has been increased, every sub-band may be considered approximately to be having flat-fading only that leads to the simple methods of the equalization at receiver. Orthogonal Frequency Division Multiplexing (OFDM) is one of those ideas that had been created for a very long time [1]. It have a few benefits, such as the high spectrum efficiency, the reduction of the ISI with the use of the cyclic prefix (CP), and so on. In the same time OFDM also has some disadvantages.

A fundamental drawback of the OFDM is weak spectral properties. The next solution is the FBMC modulation, which considered a strong contenders for the 5-G [2]. It presents numerous benefits in comparison with the CP-OFDM according to the capacity, user mobility and spectrum utilization [3],[4],[5]

Offset Quadrature Amplitude Modulation (OQA M) (FBMC/OQAM) has lower out-of-band emission in comparison with the OFDM. The concept of the FBMC systems has been

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obtained from trans-multiplexer idea [6], [7]. More sufficient sub-channel filter spectral shaping may be utilized to simplify equalizations at receiver with no utilization of the cyclic prefix. FBMC/OQAM system utilizes the OQAM [8], [9],[10].Which comes at a cost of sacrificing complex condition of orthogonality and substituting it with less strict real condition of orthogonality, which require special care. In some practical cases, the interference caused by channel may be ignored in comparison with noise, for this reason clipping method suggested in FBMC, gives good efficiency in the BER case. In some of the cases, especially in the high Signal-to-Noise Ratio (SNR) control system interference is found. For this reason developed reduction approaches will be required. The majority of the articles that deal with the clipping are studied.

In [11], A Minimum Mean Squared Error (MMSE) approach of equalization has been suggested for the time-invariant channel, which requires several of the parallel blocks of the Fast Fourier Transform (FFT). The approach of equalization has been operated after a traditional function of the FFT. In [12], an enhanced joint optimization method has been proposed, in combination with linear and non-linear approaches, which are referred to as the enhanced bilayer partial transmission sequence and iterative clipping and filtering (IBPTS-ICF) approach. MFTN is mainly dependent upon the time-frequency packing of the original Nyquist multi-carrier systems of transmission, like the OFDM or FBMC. It make this through the reduction of the interval of time between the neighboring symbols and packing spacing of frequency between the neighboring sub-carriers [13]. Every one of these papers considers the contribution of the interference of the neighboring sub-carriers only in the statistical senses. From conceptual viewpoint, there aren't any differences between the interference that comes from the adjacent time-symbols and the interference that comes from the neighboring subcarriers.

In the present research, different clipping approaches have been presented for the reduction of PAPR in the systems of the FBMC. AC approach has been inspired with the Amplitude date shape leaves on massive stems. Their form provides them with the capability of resisting the interferences from other leaves and twisting which may be a result of the wind. By the analogy the Palm Clipping doesn't trim a signal after being reduced with threshold, which is a thing which results in the simplification of its identification. Its analysis of efficiency based on BER and PAPR. The suggested approach may result in the effective enhancement of PAPR reduction efficiency with optimal BER for a specific $\alpha$ value. Clipping has been defined as the most fundamental approach which has been utilized for the reduction of the value of PAPR. The fundamental concept is truncating the FBMC signal peak below a level of the threshold.

## 2. FBMC-OQAM PAPR Reduction Model

Figure1 shows the FBMC/OQAM PAPR reduction system model based on clipping methods. The detail explain of the proposed transmitter and receiver are depicted below.

### 2.1. The Proposed Transmitter Model

Let define the symbol of the transmitted data at sub-carrier location $l$ and time-position k as $x_{l,k}\in\mathbb{R}$ which represents the output of PAM mapping. The FBMC.OQAM signal that is transmitted in time domain that consists of K time-symbols and L sub-carriers may then be represented as [11]:

$$S(t) = \sum_{k=1}^{K}\sum_{l=1}^{L} g_{l,k}(t)x_{l,k} \quad (1)$$

Where $g_{l,k}(t)$ is the shifted versions of the time and frequency of prototype filter p(t) that may be defined by [11]

$$g_{l,k}(t) = P(t-kT)e^{j2\pi lF(t-kT)}e^{j\frac{\pi}{2}(l+k)} \qquad (2)$$

where T & F respectively represent time and frequency spacing. The multi-carrier system has been fundamentally identified by prototype filter in addition to the frequency spacing (F) and time spacing (T). Prototype in the FBMC filter has been modeled to be complicated orthogonal for a (TF = 2) time-frequency spacing. Decreasing time and frequency spacings with a factor of 2 (for every one of them) for the purpose of getting the maximal data rate. Leading to (TF = 0.50). Which results in causing interference that has been shifted to entirely imaginary domain by phase shifting$e^{j\frac{\pi}{2}(l+k)}$. Which is why, as a result of that imaginary interference only the real-valued symbols may be transmitted. Continuous-time representation in equation (1) results in understanding the FBMC concept. A sufficient production of this signal is possible in cases of the discrete-time domains. In addition to a discrete-time representation results in the simplification of analytical researches. Therefore, sampled signal S ∈ $\mathbb{C}^{N\times 1}$ has been considered, where N is the dimension of transmitted signal, of the equation (1), which can be expressed by:

$$S = GX \qquad (3)$$

and

$$\text{G} = [g_{1,1} \quad g_{2,1} \quad g_{L,1} \quad g_{1,2} \quad g_{L,K}] \qquad (4)$$

$$X = [x_{1,1} \quad x_{2,1} \quad x_{L,1} \quad x_{1,2} \quad x_{L,K}]^T \qquad (5)$$

The transmitted matrix G ∈ $\mathbb{C}^{N\times LK}$ is build-up with the vector $g_{l,K}$∈ $\mathbb{C}^{N\times 1}$, which represents pulses of the sampled basis in equation (2). The vector of the data symbols X ∈ $\mathbb{R}^{LK\times 1}$. However, stacks all data symbols that are transmitted in large vector. It should be noted that in equation (3) has been produced with IFFT instead of a multiplication of the matrix [14].

2.2.1. *Clipping Methods*

In the present subsection, some approaches have been explained, which have been utilized for the reduction of the PAPR value Amplitude clipping and palm clipping methods. The main concept is trimming the peak of the signal of the FBMC above a certain value of the threshold that will be represented as A in the present paper. The signal $S(t)$ may be updated with the polar representation using the following equation below:

$$\tilde{S}(t) = f(|S(t)|) * e^{j\boldsymbol{\phi}(S(t))} \qquad (6)$$

Where $\tilde{S}(t)$ is the output of clipping function. $f$ is the clipping function depends on the type of clipping techniques. |S(t)| & $\phi(s(t))$ represent amplitude and phase of a signal S(t), respectively. Every one of the methods has been identified with its function of clipping. Below the characteristic function of every one of the clipping methods has been explained.

*A. Amplitude Clipping*

The time domain of the result of Amplitude Clipping (AC) function, $\tilde{S}_{AC}(t)$, can be characterized by the equation below:

$$\tilde{S}_{AC}(t) = \begin{cases} S(t) & if\ |S(t)| \le A \\ Ae^{j\boldsymbol{\phi}(S(t))} & if\ |S(t)| > A \end{cases} \qquad (7)$$

A represents the level of the threshold which is associated with both the positive factor $\alpha$ and the FBMC signal average power, $P_{avg}= E\{|S(t)|^2\}$, and it can be expressed as:

$$A = \alpha\sqrt{P_{avg}} \quad (8)$$

The signal output amplitude is linear in the case where the value is lower than clipping value A. And it equals value A in the case where reasoning is higher than A [17].

*B. Palm Clipping*

The suggested clipping function based upon cosine hyperbolic for the clipping of signal $S(t)$ has been represented as [17]

$$\tilde{S}_{PC}(t) = \begin{cases} S(t) & if\ |S(t)| \leq A \\ P_\beta^A\ (|S(t)|) * e^{j\phi(S(t))} & if\ |S(t)| > A \end{cases} \quad (9)$$

Where $P_\beta^A$ is the Palm function that has been characterized as [17]

$$P_\beta^A(|S(t)|) = A(\cosh\frac{|S(t)|-A}{\beta})^{-1} \quad (10)$$

where $\beta$ represents the curve smoothness factor. The fundamental concept of the suggested function $P_\beta^A$ is the attenuation of signal after a value of the threshold. The function $P_\beta^A$ has the tends to the value of the saturation A when $\beta$ tends to infinity, (the same as in Amplitude Clipping).

*C. Deep Clipping (DC)*

The output of deep clipping function is defined as [18]

$$\tilde{S}_{DC}(t) = \begin{cases} S(t) & if\ \ |S(t)| \leq A \\ \left(A - d(|S(t)|)\right) * e^{j\phi(S(t))} & if\ A < |S(t)| \leq \frac{1+d}{d}A \\ 0 & if\ \ |S(t)| > \frac{1+d}{d}A \end{cases} \quad (11)$$

Where d represents the clipping depth factor.`

*D. Smooth Clipping (SC)*

The output of smoothing clipping is expressed as [19]

$$\tilde{S}_{SC}(t) = \begin{cases} S(t) - \frac{1}{b}(S(t))^3 & if \quad |S(t)| \leq \frac{3}{2}A \\ A & if \quad |S(t)| > \frac{3}{2}A \end{cases} \quad (12)$$

Where b=$\frac{27}{4}A^2$.

*2.1.2 PAPR Analysis*

The PAPR of time domain FBMC/OQAM signal, S(t), has been characterized as a maximum power ratio to average power of signal and can be expressed as [9],[17]:

$$PAPR = \frac{Max(|S(t)|^2)}{E\{|S(t)|^2\}} \quad (13)$$

where the value $E\{.\}$represents the mean value and Max (.) is the maximum value of a signal.

The efficiency of the PAPR has been represented with the use of a CCDF that represents a likelihood that the PAPR is exceeding a value of threshold. The following formula is act the CCDF [9],[17]

$$CCDF(PAPR_0) = \Pr[PAPR \geq PAPR_0] \quad (14)$$

Where $PAPR_0$ is a threshold value.

Let define ΔPAPR as the gain factor in terms of PAPR reduction defined as

$$\Delta PAPR = PAPR - PAPR_C \quad [dB] \quad (15)$$

Where PAPR is the PAPR without clipping and $PAPR_C$ is the PAPR after clipping at certain CCDF level [21]. Also, the loss in SNR due to clipping technique can be calculate as:

$$SNR_{LOSS} = SNR_C - SNR \quad (16)$$

Where SNR is the SNR without clipping and $SNR_C$ is the SNR after clipping at certain BER value.

### 2.2 The Proposed Receiver Model

The time-variant multi-path propagation channel has been modelled by a time variant matrix of convolution H $\in \mathbb{C}^{N\times N}$. The received symbols Y$\in$ $\mathbb{C}^{LK\times 1}$ have been obtained through the matched filtering 'this for the AWGN' which multiplies the received samples by $G^{\mathcal{H}}$, where $\mathcal{H}$is the Hermitian operator. The overall transmission system can be expressed by:

$$Y = G^{\mathcal{H}}\mathrm{H}\tilde{\mathrm{S}} + G^{\mathcal{H}}W \tag{17}$$

Where $\tilde{\mathrm{S}}$ is the output of clipping function and W ~ CN $(0, P_n\, I_n)$ representing the white Gauss noise with $P_n$, which denotes noise power in time domain. Define the transmitted matrix D $\in \mathbb{C}^{LK\times LK}$ as:

$$D = G^{\mathcal{H}}\ \mathrm{H}\ \mathrm{G} \tag{18}$$

In some practical case, the off-diagonal elements of D as shown in equations (6&7), are fixed to F = 15kHz. For the FBMC, K = 30 time-symbols has been considered to lead to same time of transmission for the two methods, (KT=1 *ms*). The order of the Pulse-Amplitude Modulation (PAM) modulation has been fixed at 16, equal to a 256-QAM (i.e. Quadrature Amplitude Modulation) signal + constellation. For those parameters of the channel, 1-tap equalizers might be insufficient. We require more development equalization methods. To very small, the noise is dominated by them. The 1-tap Zero Forcing (ZF) equalizer, $y_{l,k}\ h_{l,k}$, with $h_{l,k}$ represents the diagonal D element, is adequate for the achievement of a near optimum likelihood of the symbol detection. For the white Gauss noise, a 1-tap ZF equalizer is corresponding to symbol detection of a maximal likelihood. Which is explaining the reason behind the 1-tap equalizers being very beneficial in the practice. In the highly double-selective channels and in the case of operating in high value of the Signal to Noise Ratio, 1-tap equalizers will not be potentially efficient. For more sufficient illustration of that fact, considering a 1-tap equalizer in the cases of the Vehicular-A channel model (200km/h for a 60GHz carrier frequency). So, we assume an F = 15kHz sub-carrier spacing [15]. In the present research, the channel model (Vehicular-A, Jakes Doppler spectrum) has been considered. The sub-carriers number has been fixed as L = 24 and sub-carrier spacing has been

avoid this problem [16] the full block MMSE equalization of $Y$ is suggested. Then, the symbol estimation that is the output of MMSE equalizer can be calculated by:

$$\tilde{X} = \begin{bmatrix}\Re\{D\}\\ \Im\{D\}\end{bmatrix}^T \left(\begin{bmatrix}\Re\{D\}\\ \Im\{D\}\end{bmatrix}^T \begin{bmatrix}\Re\{D\}\\ \Im\{D\}\end{bmatrix} + \Gamma\right)^{-1} \begin{bmatrix}\Re\{Y\}\\ \Im\{Y\}\end{bmatrix} \tag{19}$$

$$\text{And } \Gamma = \frac{P_n}{2}\begin{bmatrix}\Re\{G^H G\} & -\Im\{G^H G\}\\ \Im\{G^H G\} & \Re\{G^H G\}\end{bmatrix} \tag{20}$$

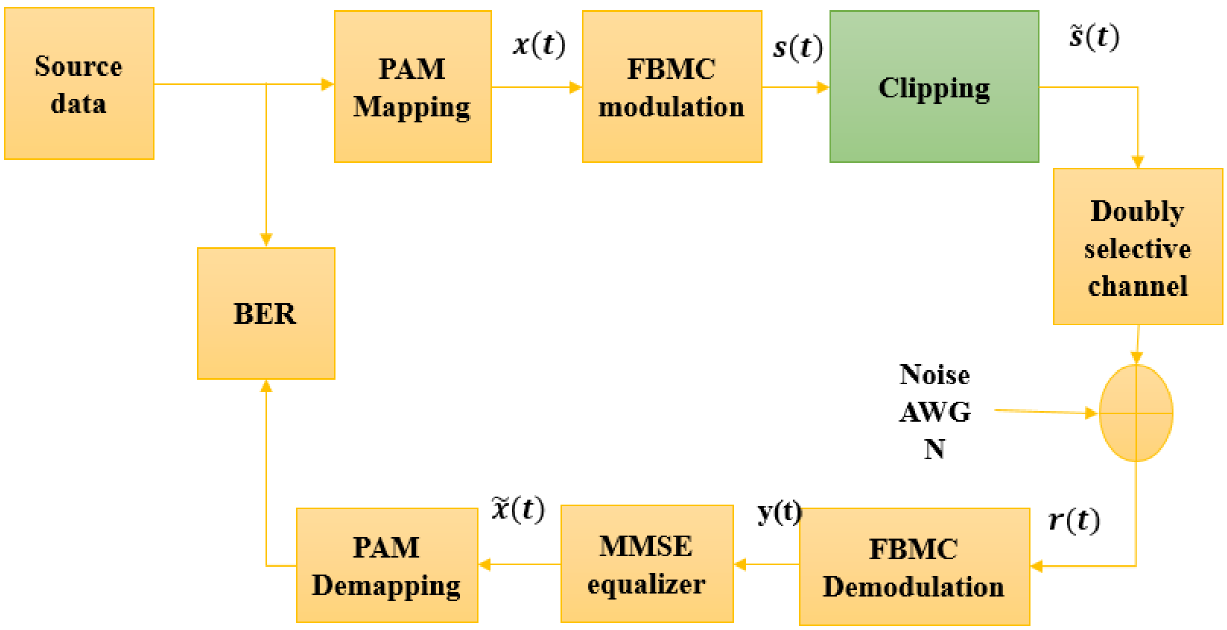


**Figure 1.** FBMC/OQAM PAPR reduction model based on clipping methods.

## 3 Simulation Results

In order to assess the efficiency of the suggested Clipping method, FBMC has been considered, which is illustrated in Fig. (1) and parameters have been set as provided in the Table1. Due to the fact that it has been referred to as PAPR issue turns worse for higher-order QAM, 64QAM has been considered as schemes of modulation. The number of subcarriers $N$ has been fixed at 24, and the number of FBMC symbols generated was 30. The efficiency of the suggested approach has been characterized by CCDF 64QAM has curves of PAPR and BER degradations. The 2 principal parameters have been considered as well, which are $\alpha$ and parameter of smoothness β.

**Table1.** Parameters of Simulation.

| Parameters | Values |
|---|---|
| Number subcarriers | 24 |
| Type of Modulation | 64 QAM |
| Number FBMC symbols | 30 |
| Channel model | Doubly-selective fading channels (Vehicular-A) + AWGN |
| Prototype Filter | Hermite |
| Carrier Frequency (GHz) | 60 |
| Overlapping factor | 8 |
| Velocity (Km/h) | 200 |

Figures (2-5) show the CCDF of FBMC for AC, PC, DC, and SC, respectively. Figures (6-9) show the BER performance of FBMC for AC, PC, DC, and SC, respectively. Table 2 shows the performance comparison between different types of clipping at $\alpha$ = 2.5 and 2.7. According to the simulation results, increasing $\alpha$ cause to reduce the PAPR reduction factor and the BER flows in the direction of original BER without clipping. Among all types of clipping techniques, AC gives the best results since it reduced the PAPR with little effect the BER performance.

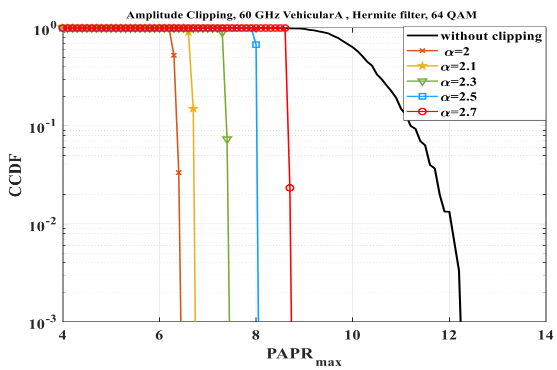


**Figure 2.** CCDF of FBMC AC with 64-QAM for various α value

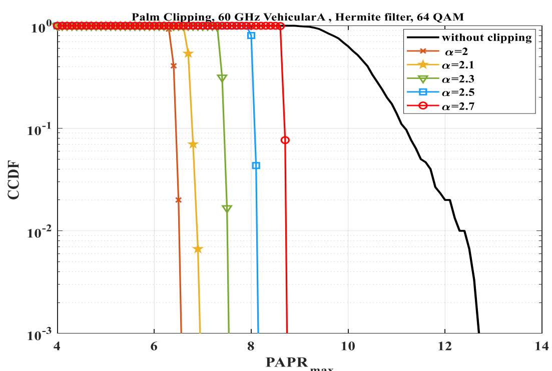


**Figure 3.** CCDF of FBMC PC with 64-QAM for a variety of the values of α.

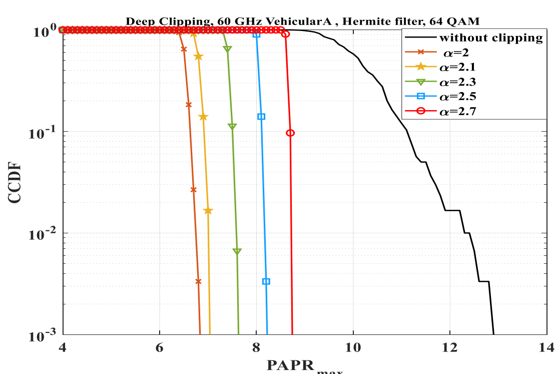


**Figure 4.** CCDF of FBMC DC with 64-QAM for a variety of the values of α.

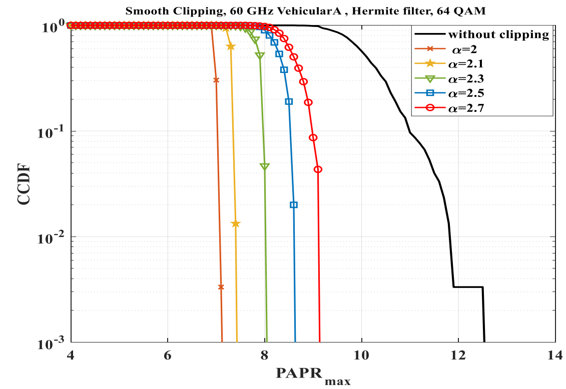


**Figure 5.** CCDF of the FBMC SC with 64QAM for a variety of the values of $\alpha$.

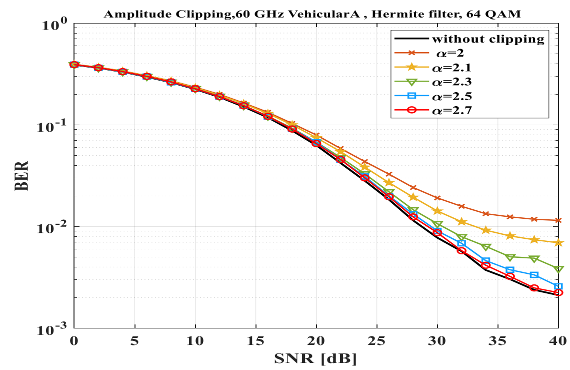


**Figure 6.** BER performance of AC of FBMC with 64-QAM for various values of $\alpha$

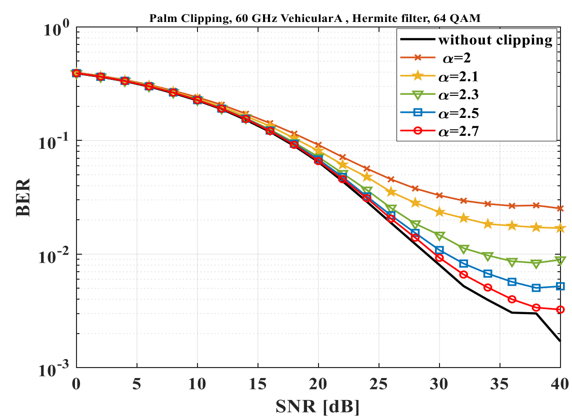


**Figure 7.** BER efficiency of the FBMC PC with 64-QAM for various values of $\alpha$.

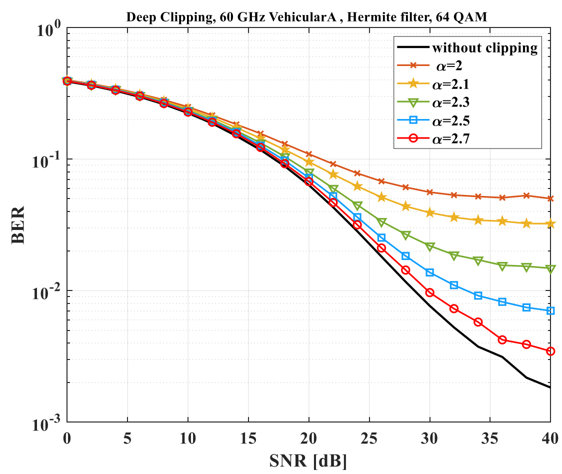


**Figure 8.** BER efficiency of the FBMC DC with 64-QAM for various values of $\alpha$.

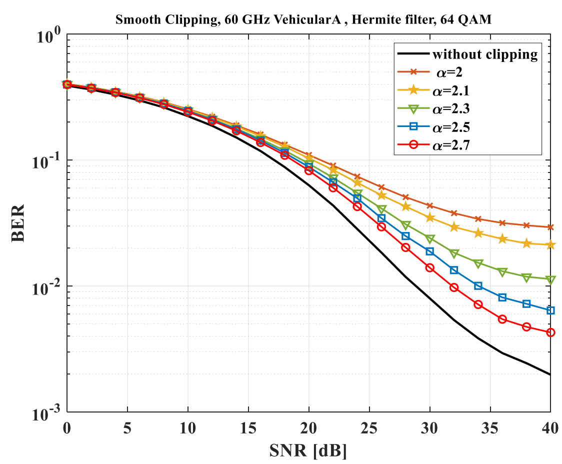


**Figure 9.** BER efficiency of FBMC SC with 64-QAM for a variety of the values of $\alpha$.

**Table 2.** comparison results between clipping techniques at α=2.5 and α=2.7

| Method | $\alpha$ = 2.5 | | $\alpha$ = 2.7 | |
|---|---|---|---|---|
| | ΔPAPR [dB] | $SNR_{LOSS}$ [dB] | ΔPAPR [dB] | $SNR_{LOSS}$ [dB] |
| AC | 4.3 | 4.1 | 3.5 | 0.5 |
| PC | 0.6 | 5 | 3.6 | 1.2 |
| DC | 4.2 | 3.9 | 3.7 | 2 |
| SC | 1.3 | 6 | 3.3 | 4 |

## 4. Conclusions

In the present research, various methods of clipping have been compared, based on the reduction of PAPR in FBMC/OQAM system over the doubly selective fading channel. The efficiency of the suggested method of the clipping has been assessed based on the BER and PAPR for different clipping factor value $\alpha$ and 64 QAM. Through the implementation of this approach, a gain has been achieved based on a PAPR value in the range from 4dB to 6dB, with sufficient results in the terms of the BER. The results have been highly interesting and have generated areas for the future studies, including the definition of the optimal result for the evaluations for the purpose of giving the optimal efficiency for the degradation in the BER and PAPR. The suggested approach has been compared to the latest approaches based on the BER and PAPR this comparative research has confirmed that AC approach has been capable of achieving a sufficient reduction in term of the PAPR with a sufficient efficiency of the BER for some $\alpha$ value. Besides that, AC approach isn't complicated and requires no side information for the reduction of PAPR values.

## 5. Comparison with Other Methods

The PAPR reduction of the proposed method are compared to the other methods presented in [21][22][23].

According to the results presented in Table 3 we observe that the Clipping method is this proposed method was compared with recent methods in terms of PAPR and SNR loss. This comparative study confirms that the Clipping method can achieve a good reduction in terms of PAPR with a good BER performance.

**Table 3.** Comparison with other Methods

| Method | ΔPAPR[dB] | $SNR_{LOSS}$[dB] |
|---|---|---|
| hybrid(CR=2) | 4.1 | 0.7 |
| Pruned DFT-s , LCP=0 | 4.8 | - |
| hybrid(CR=3) | 3.3 | <0.2 |
| S-PTS | 3 | - |

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**Conflict of interest**

The authors declare no conflict of interest in publication of this research.

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