International Journal of Electrical and Computer Engineering (IJECE)
Vol. 12, No. 3, June 2022, pp. 2220~2227
ISSN: 2088-8708, DOI: 10.11591/ijece.v12i3.pp2220-2227

Hybrid clipping and companding techniques based peak to average power ratio reduction in orthogonal frequency division multiplexing based differential chaos shift keying system

Sajjad Razzaq Abdulridha, Fadhil S. Hasan
Department of Electrical Engineering, Mustansiriyah University, Baghdad, Iraq

Article Info

Article history:

Received May 17, 2021
Revised Dec 27, 2021
Accepted Jan 6, 2022

Keywords:

Differential chaos shift keying
Orthogonal frequency division multiplexing
Palm clipping
Peak power to average power ratio

ABSTRACT

In this paper, a hybrid approach using clipping and companding techniques is introduced to reduce the peak to average power ratio (PAPR) of orthogonal frequency division multiplexing based differential chaos shift keying (OFDM-DCSK), which is the major drawback of the OFDM-DCSK. The hybrid function is processed at the end of the transmitter before transmitting the signal. However, there is no need for an inverse function at the receiver, which decreases the system complexity. Several techniques have been proposed in the literature for decreasing the PAPR value. Clipping and companding are active methods in terms of reducing the PAPR. Finally, the PAPR reduction and bit error rate (BER) performances are evaluated. The simulation results show that this technique gives better performance as compared with the clipping and companding techniques.

Corresponding Author:

Sajjad Razzaq Abdulridha
Department of Electrical Engineering, Mustansiriyah University
Palastine Street, Iraq, Baghdad
Email: sejjad_alqassab@yahoo.com

1. INTRODUCTION

In the past two decades, chaotic based communication has been studied and estimated due to their good properties such as non-periodicity, great correlation property, and noise-like performance [1]–[5]. Moreover, the chaotic signals are easy to generate, deterministic, secure, and wideband. From all the chaotic modulation sketches, the non-coherent modulation sketches have attracted researchers since the complicated synchronization circuit was removed. One of the most practical sketches is the non-coherent differential chaos shift keying (DCSK). Several chaos-based modulations are proposed. High efficiency DCSK (HE-DCSK) [6] was proposed to enhance the spectral efficiency. Furthermore, a radio frequency (RF) delay line is required at the receiver, which is not a simple operation to integrate into communication technology. To overcome the issue of RF delay line, a code shifted DCSK (CS-DCSK) was proposed in [7], [8]. Some researchers used the multicarrier techniques that are attached to enhance the performance of DCSK systems [9], [10]. Orthogonal frequency division multiplexing (OFDM) is a specific state of multicarrier which presents numerous advantages like high data rate, robustness to multipath fading channel, robust against narrow-band co-channel interference, and high efficiency. To enhance bit error rate (BER) and energy efficiency of the DCSK system, multicarrier based differential chaos shift keying (MC DCSK) is presented [11]. In other words, MC DCSK systems benefit from both the non-coherency of DCSK and the multicarrier systems advantages. In [12]–[14] show a variety of approaches for modifying the multicarrier with DCSk system. advantage of the OFDM-DCSK system is that there is no radio frequency (RF) delay required. On the other hand, the main drawback of OFDM-DCSK is the high peak to average power ratio (PAPR) of the transmitted signal. A high PAPR causes signal distortion as it makes the signal peaks attenuate into the nonlinear region of the amplifier and, accordingly, the performance will be degraded and in-band distortion and out-of-band radiation will occur. Therefore, the OFDM transmitters need expensive linear high power amplifier (HPA) with a wide dynamic range [15]. Clipping [16], companding [17], selective mapping (SLM) [18], partial transmit sequence (PTS) [19], and hybrid techniques [20], [21] are proposed to overcome the problem of high PAPR in OFDM system. In this paper, palm clipping, companding, and hybrid approach techniques are utilized to reduce the PAPR in the OFDM-DCSK system and compared with carrier interferometry spreading codes technique [22] and merit factor SLM technique [23]. The rest of the paper is arranged as follows: The proposed OFDM-DCSK system model is presented in section 2. Section 3 presents the PAPR reduction techniques including the palm clipping, the μ-Law companding, and hybrid approach techniques. Performance evaluation and descriptions of the tried techniques are presented in section 4. Finally, the conclusion is summarized in section 5.

2. OFDM-DCSK SYSTEM MODEL

Figures 1 and 2 describe the block diagram of the OFDM-DCSK system at transmitter and receiver sides, respectively. When the switch at position (1), the μ-Law companding technique is used, and when the switch at position (2), the palm clipping technique or the hybrid approach technique is used to reduce the PAPR in the OFDM-DCSK system. In the first, the chaotic sequence is generated using second-order chebychev polynomial (CPF), which is given $x_{k+1} = 1 - 2x_k^2$ so that the *k*-th reference sequence is defined as X_k=$[X_{k,0}, X_{k,1}, \dots \dots \dots \dots, X_{k,\beta-1}]$ where β is the spreading factor. The mean value for the generated sequence is zero and the mean square value is unity, E[X_k]=0 and E[X_k^2]=1. The *k*-th data sequence, b_k =$[b_{k,1}, b_{k,2}, \dots \dots \dots \dots, b_{k,M}] \in \{-1,1\}$, is generated from the parallel mapped stream bits using a parallel to serial converter, where *M* is the length of a data sequence. The parallel data sequence is multiplied by a chaotic reference sequence. Taking inverse fast Fourier transform (IFFT) for each *p*-th vector, β number of IFFT transform is required to complete one symbol, the *k*-th transmitted OFDM-DCSK signal can be expressed as (1):

$$s_k(n,p) = \frac{1}{\sqrt{N}}\left(\sum_{m=1}^{M} b_{k,m} X_{k,p} * e^{\left(\frac{j2\pi mn}{N}\right)} + X_{k,p}\right), n = 0, 1, \dots, N-1, p = 0,1,..,\beta - 1 \quad (1)$$

where *N* is the FFT size, *N*=*M*+1. We assume here, the cyclic prefix is not considered. Before the signal is transmitted over a multipath Rayleigh fading channel, it is processed by either the PC function or the companding function or the hybrid approach function to reduce the PAPR. The *k*-th received signal is expressed as (2) [11], [24]:

$$r_k(n,p) = \sum_{l=1}^{L} \gamma_l \tilde{s}_k(n - \tau_l, p) + w_k(n,p), n = 0, 1, \dots, N-1, \ p = 0,1,..,\beta - 1 \quad (2)$$

where γ_l and τ_l are the Rayleigh channel coefficient and the corresponding time delay for the *l*-th path, respectively. *L* is the number of paths and w_k is the *k*-th additive white Gaussian noise (AWGN) with zero mean and variance of $N_0/2$. The Rayleigh pdf of γ_l is written as (3) [22]:

$$f_\gamma(v) = \frac{v}{\sigma^2} e^{-\frac{v^2}{2\sigma^2}}, \ v > 0 \quad (3)$$

where σ is the standard deviation of the distribution that is greater than zero. At the receiver, non-coherent detection is used, there is no channel estimation required as in the OFDM system and no RF delay required as in the DCSK system. The received signal, r_k either passes through the decompanding function and then converted to parallel sequence when the companding technique is used (the switch at position 1) or directly passes through the serial to parallel converter if the clipping technique or hybrid approach is used (the switch at position 2). The *k*-th parallel sequence, $\tilde{r}_{j,k}$, *j*=0,.., *M*, is passed through FFT transform to obtain the OFDM-DCSK demodulated signal at the *k*-th frame and *p*-th vector as (4):

$$\tilde{R}_k(m,p) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} \tilde{r}_k(n,p) * e^{\left(\frac{-j2\pi mn}{N}\right)}, m = 0,1,..,N-1, p = 0,1,..,\beta - 1 \quad (4)$$

The first subcarrier (zero frequency) contains the received reference chaotic sequence, $\tilde{R}_k(0,p)$ and the remaining subcarrier contains the *M* received information chaotic sequences, $\tilde{R}_k(m,p), m = 1,..,M$. *M* correlators are produced from these sequences by multiplying the reference chaotic sequence by the *m*-th information sequence and summing over β period. Then the output of the m-th correlator is given by (5):

$$Q_{k,m} = \sum_{p=0}^{\beta-1} \tilde{R}_k(0,p) * \tilde{R}_k(m,p) \;\; m = 1,..,M \tag{5}$$

for the k-th frame, the m-th recovered symbol is obtained by applying a decision threshold to the output correlator $Q_{k,m}$ and then the parallel symbol is converted to serial using a parallel to serial converter. Finally, the recovered stream bits are obtained using the Demapping function by mapping +1 to 1 and -1 to 0.

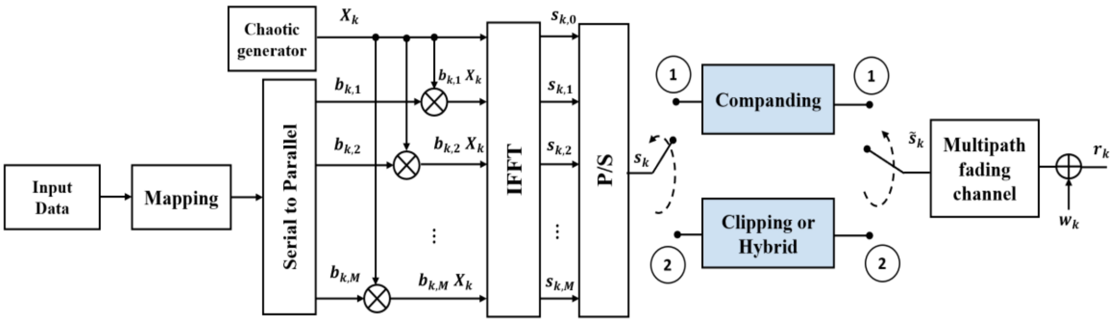

Figure 1. OFDM-DCSK transmitter scheme

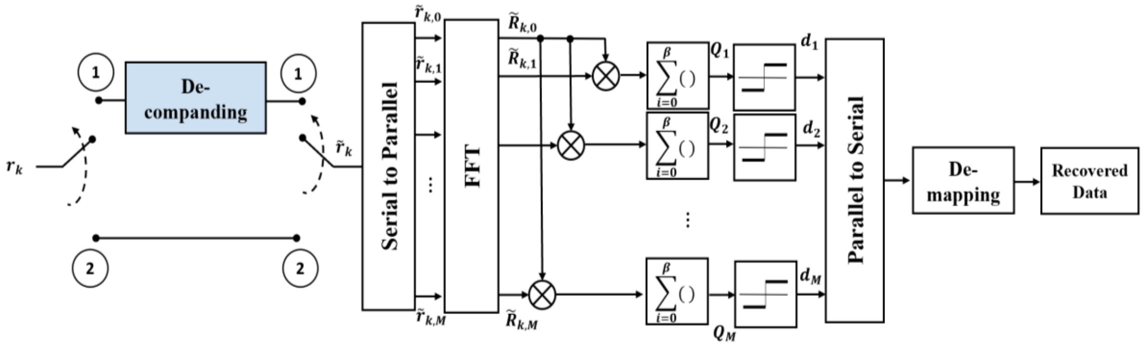

Figure 2. OFDM-DCSK receiver scheme

3. CLIPPING AND COMPANDING TECHNIQUES

3.1. Palm clipping (PC) technique

At the end of the transmitter, the PC block is added before transmitting the signal. The function of the palm clipping is described in (6) [25]:

$$\tilde{s}_k(n,p) = \begin{cases} s_k(n,p) & , \; |s_k(n,p)| \le A \\ P_B^A\,(|s_k(n,p)|) * e^{j\phi(s_k(n,p))}, & |s_k(n,p)| > A \end{cases} \tag{6}$$

where A is the threshold value and is defined to be $(\alpha * \sqrt{P_{mean}})$ and α is considered to be clipping factor, $\phi(s_k(n,p))$ is the phase of the input signal $s_k(n,p)$, and the function $P_B^A(|s_k(n,p)|)$ for a given absolute signal, $|s_k(n,p)|$, is expressed by (7):

$$P_B^A(|s_k(n,p)|) = \frac{A}{\cosh(\frac{|s_k(n,p)|-A}{B})} \tag{7}$$

where B is the smoothness factor of the PC function. In this paper, we will use clipping ratio (CR) to find out the effect of the clipping method. There is a relation between the clipping threshold A, and the average power of the OFDM-DCSK signal as described in (8).

$$CR = 20\ log_{10}\left(\frac{A}{\sqrt{P_{mean}}}\right)[dB] \tag{8}$$

3.2. Nonlinear companding technique

Nonlinear companding is a distinct case of clipping structure used to improve PAPR reduction with less degradation in the BER performance. The companding techniques magnify the slight signals while squeezing the great signals to raise the resistance of slight signals from noise and interference. The most PAPR reduction techniques used in the OFDM system are the companding techniques due to less difficulty and great BER performance. At the end of the transmitter, the companding process is performed to attenuate the high amplitudes and magnify the low peaks. The decompanding process is performed at the receiver to detect the original signal. Furthermore, by taking suitable companding parameters, the mean sending power can be preserved unchanged after companding. The μ-Law technique is used in this paper to reduce the PAPR of the OFDM-DCSK system. At the end of the transmitter, the companding function applied is given by (9) [26].

$$\tilde{s}_k(n,p) = sgn\ (s_k(n,p))\ \frac{\ln(1+\mu\ |s_k(n,p)|)}{\ln(1+\mu)} \tag{9}$$

The companding level was adjusted by μ ratio, which is the normalization constant. At the receiver, the decompanding function is applied to the received signal $r_k(n,p)$ and it is given by (10):

$$\tilde{r}_k(n,p) = sgn\ (r_k(n,p))\left(\frac{1}{\mu}\right)((1+\mu)^{|r_k(n,p)|} - 1) \tag{10}$$

3.3. Hybrid approach

It was discovered that the clipping curve is the same as the companding curve, where the amplitude of the large signals is restricted to a predefined threshold. When the clipping method is used, the amplitude of the small signals is not changed, while it may be compressed or expanded when the companding technique is used. A hybrid technique is a combination of both companding and clipping techniques in which the amplitude of the large signals is compressed, while the amplitude of small signals is not changed. The hybrid function is given by (11) [27]:

$$\tilde{s}_k(n,p) = \begin{cases} \dfrac{A\ e^{j\phi(s_k(n,p))}}{(1+\left(\frac{A}{|s_k(n,p)|}\right)^{s})^{\frac{1}{s}}} & , |s_k(n,p)| > 0 \\ 0 & , |s_k(n,p)| = 0 \end{cases} \tag{11}$$

where A is the threshold value and is defined to be $(\alpha * \sqrt{P_{mean}})$, α is the clipping factor, and s is defined to be the shaping factor.

4. SIMULATION RESULTS AND DISCUSSION

Simulations were taken in this section to evaluate the performance of the hybrid technique by comparing it with PC and μ-Law techniques. We built the MATLAB model of the system over two path Rayleigh fading channel, L=2, are used with delays, τ_l=0 and $\tau_2 = 2T_c$ and average power gain, $E[a_1^2] = \frac{2}{3}$ and $E[a_2^2] = \frac{1}{3}$, the number of subcarriers N is set to 256 and 512, the spreading factor β is 75 and 125, the clipping ratios (CR) in dB for PC and Hybrid techniques are 1, 2, 3, 4, 5, 6, and 7, we set the smoothing factor B that was used for clipping technique to 200 and set the μ value to 25 while setting the shaping factor (s) to 60.

Firstly, the PAPR reduction performance comparison of the tried techniques was studied, while setting the SNR value is 10 dB. In the second, the BER is evaluated with the same condition, but for variant SNR values. Figures 3 and 4 describe the gain of the tried techniques in terms of PAPR at CCDF=10^{-3} and 10^{-2} for N is equal to 256 and 512 respectively. It was noticed that the $PAPR_{EF}$ values of the tried techniques are approximately similar. Figures 5 and 6 show the simulated BER performance for OFDM-DCSK system with the all tried techniques for number of subcarriers are equal to 256 and 512 respectively, it is obvious from this figure that the Hybrid technique presents the best performance at a BER=10^{-5}, the loss of the signal to noise ratio is 1.455 dB when the number of subcarriers is equal to 256 and -0.345 when the number of subcarriers is 512.

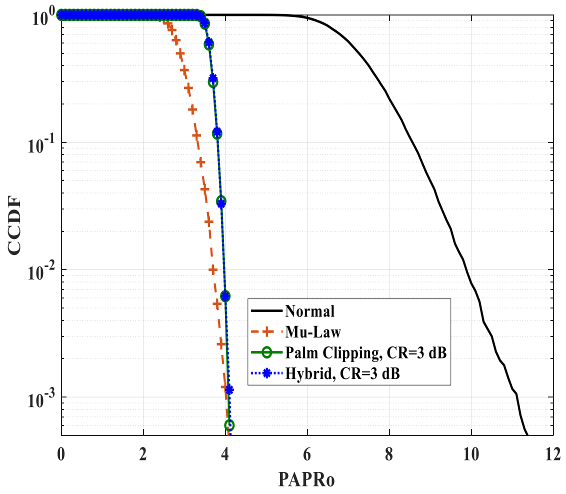

Figure 3. The CCDF of OFDM-DCSK system for the tried techniques, N=256 and β=125

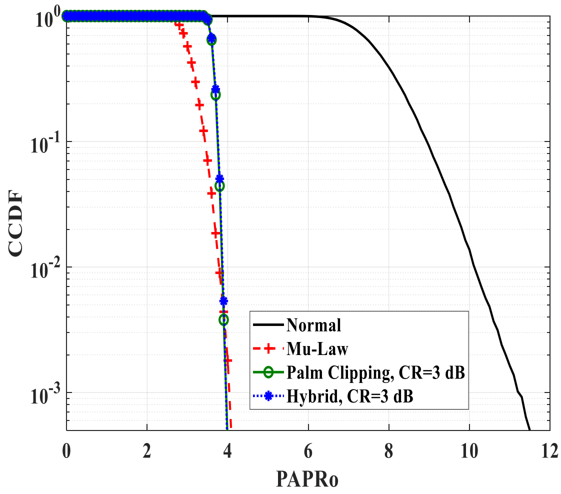

Figure 4. The CCDF of OFDM-DCSK system for the tried techniques, N=512 and β=125

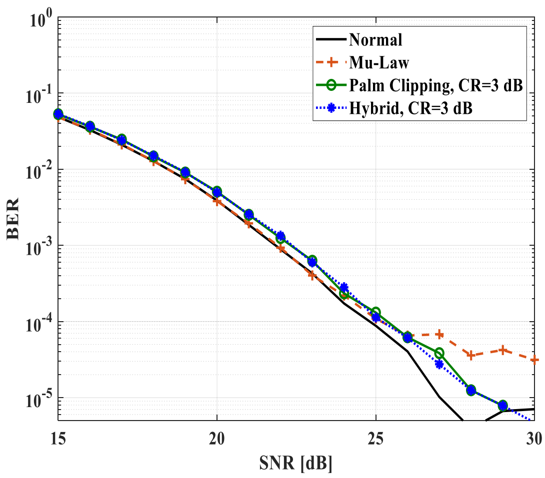

Figure 5. BER performance comparison of OFDM-DCSK for the tried techniques, N=256 and β=125

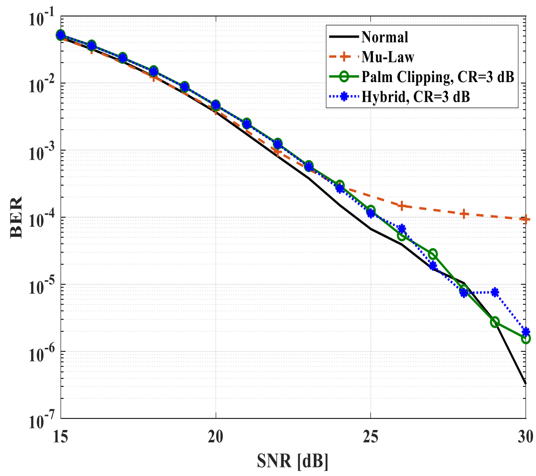

Figure 6. BER performance comparison of OFDM-DCSK for the tried techniques, N=512 and β=125

Figure 7 depicts the function characteristics of the palm clipping technique. When the value of B is increased, the output value tends to reach the saturation value. In the hybrid technique, the value of s controls the shaping factor. The output value tends to the saturation value when the value of s is increased, as shown in Figure 8.

Finally, the results of the performance evaluation are listed for all the techniques that were used in our work in Tables 1 to 4 for N=256 and 512, respectively. The included results are obtained for different number of N with changing the spreading factor (β). The Tables present the comparison between the techniques in terms of $PAPR_{EF}$ and SNR_{loss}.

$$SNR_{loss} = SNR_{new} - SNR_{original} \tag{12}$$

$$PAPR_{EF} = PAPR_{original} - PAPR_{new} \tag{13}$$

According to the results presented in the tables, we got better PAPR reduction values when the number of subcarriers is increased. It is obvious that the hybrid technique gives 7.24 dB $PAPR_{EF}$ when the number of subcarriers is equal to 512, the spreading factor is equal to 125 at CCDF=10^{-3} while the SNR_{loss} value is -0.345 dB.

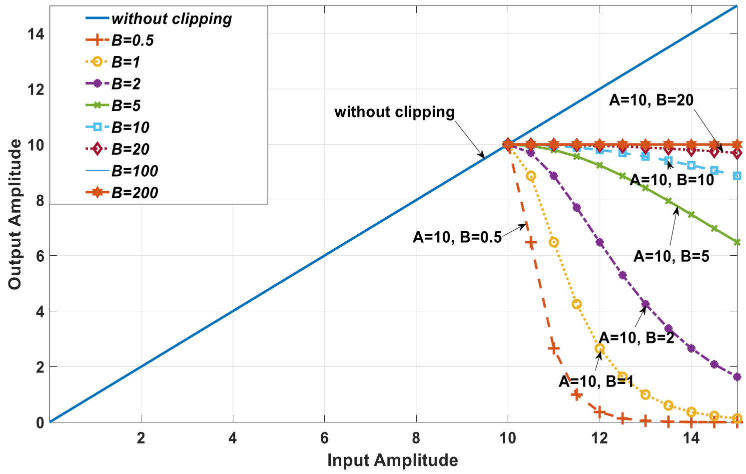

Figure 7. Function characteristics of the PC technique for *A*=10 and different values of B

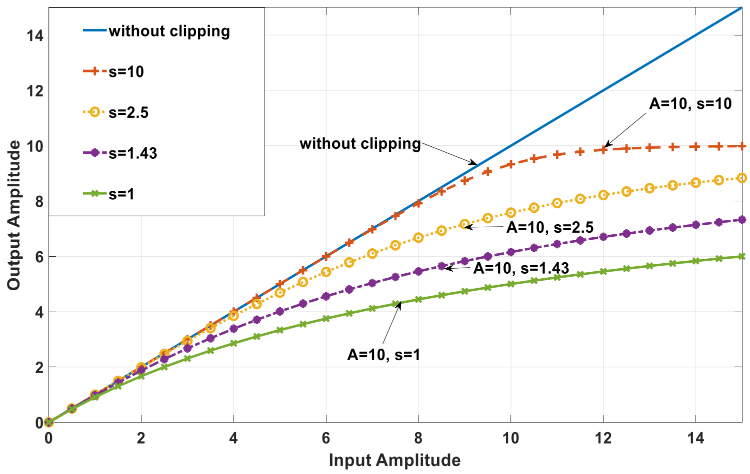

Figure 8. Function characteristics of the hybrid technique for *A*=10 and different values of s

Table 1. Comparative study of the suggested PAPR reduction techniques for BER at *N*=256

Methods	SNR_{loss} (dB) at BER=10^{-3}		SNR_{loss} (dB) at BER=10^{-4}		SNR_{loss} (dB) at BER=10^{-5}
	β=75	β=125	β=75	β=125	β=125
Palm Clipping	0.63	0.485	0.46	0.55	1.455
μ-Law	0.23	0.06		0.36	
Hybrid	0.37	0.515	0.285	0.4	1.455

Table 2. Comparative study of the suggested PAPR reduction techniques for BER at *N*=512

Methods	SNR_{loss} (dB) at BER=10^{-3}		SNR_{loss} (dB) at BER=10^{-4}		SNR_{loss} (dB) at BER=10^{-5}
	β=75	β=125	β=75	β=125	β=125
Palm Clipping	0.49	0.58	0.11	0.76	-0.185
μ-Law	0.17	0.2		4.7	
Hybrid	0.39	0.54	0.11	0.74	-0.345

Table 3. Comparative study of the suggested PAPR reduction techniques for $PAPR_{EF}$ at N=256

Methods	$PAPR_{EF}$ (dB) at CCDF=10^{-2}		$PAPR_{EF}$ (dB) at CCDF=10^{-2}	
	β=75	β=125	β=75	β=125
Palm Clipping	5.94	5.8775	7	7.02
μ-Law	6.32	6.15	7.2	7.08
Hybrid	5.93	5.8785	6.95	7

Table 4. Comparative study of the suggested PAPR reduction techniques for $PAPR_{EF}$ at N=512

Methods	$PAPR_{EF}$ (dB) at CCDF=10^{-2}		$PAPR_{EF}$ (dB) at CCDF=10^{-3}	
	β=75	β=125	β=75	β=125
Palm Clipping	6.35	6.26	7.2	7.24
μ-Law	6.55	6.34	7.275	7.16
Hybrid	5.35	6.24	7.2	7.24

5. CONCLUSION

In this paper, palm clipping, μ-Law companding, and hybrid techniques were performed to overcome the issue of high PAPR which affects the efficiency of the power Amplifier. PAPR reduction was done by involving clipping or companding or hybrid blocks to the OFDM-DCSK system before transmitting the signal over the multipath Rayleigh fading channel. The inverse function was used at the receiver in the case of companding techniques. The simulation results obtained by running the MATLAB program show that the PAPR reduction value has improved as a result of BER. Hybrid technique gives the best results from the other tried techniques in terms of PAPR reduction and BER performance.

REFERENCES

[1] Y. Fang, G. Han, P. Chen, F. C. M. Lau, G. Chen, and L. Wang, "A survey on DCSK-based communication systems and their application to UWB scenarios," *IEEE Communications Surveys and Tutorials*, vol. 18, no. 3, pp. 1804–1837, 2016, doi: 10.1109/COMST.2016.2547458.

[2] G. Kaddoum, H. V. Tran, L. Kong, and M. Atallah, "Design of simultaneous wireless information and power transfer scheme for short reference DCSK communication systems," *IEEE Transactions on Communications*, vol. 65, no. 1, pp. 431–443, 2017, doi: 10.1109/TCOMM.2016.2619707.

[3] M. Mobini and M. R. Zahabi, "An approach to security in VANET's using chaos-based cryptography," in *15th International Conference on Traffic and Transportation Engineering*, 2016, pp. 1–10.

[4] H. Yang, W. K. S. Tang, G. Chen, and G. P. Jiang, "System design and performance analysis of orthogonal multi-level differential chaos shift keying modulation scheme," *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 63, no. 1, pp. 146–156, Jan. 2016, doi: 10.1109/TCSI.2015.2510622.

[5] A. Litvinenko and A. Aboltins, "Chaos based linear precoding for OFDM," in *Proceedings - 2015 Advances in Wireless and Optical Communications, RTUWO 2015*, Nov. 2015, pp. 13–17, doi: 10.1109/RTUWO.2015.7365709.

[6] H. Yang and G.-P. Jiang, "High-efficiency differential-chaos-shift-keying scheme for chaos-based noncoherent communication," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 59, no. 5, pp. 312–316, May 2012, doi: 10.1109/TCSII.2012.2190859.

[7] W. K. Xu, L. Wang, and G. Kolumbán, "A novel differential chaos shift keying modulation scheme," *International Journal of Bifurcation and Chaos*, vol. 21, no. 3, pp. 799–814, Mar. 2011, doi: 10.1142/S0218127411028829.

[8] G. Kaddoum and F. Gagnon, "Design of a high-data-rate differential chaos-shift keying system," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 59, no. 7, pp. 448–452, Jul. 2012, doi: 10.1109/TCSII.2012.2198982.

[9] S. Wang, J. Zhu, and J. Zhou, "OFDM-based chaotic spread spectrum communications with high bandwidth efficiency," in *International Conference on Control Engineering and Communication Technology*, Dec. 2012, pp. 940–943, doi: 10.1109/ICCECT.2012.139.

[10] N. X. Quyen, L. Van Cong, N. H. Long, and V. Van Yem, "An OFDM-based chaotic DSSS communication system with M-PSK modulation," in *2014 IEEE 5th International Conference on Communications and Electronics, IEEE ICCE 2014*, Jul. 2014, pp. 106–111, doi: 10.1109/CCE.2014.6916688.

[11] G. Kaddoum, F. D. Richardson, and F. Gagnon, "Design and analysis of a multi-carrier differential chaos shift keying communication system," *IEEE Transactions on Communications*, vol. 61, no. 8, pp. 3281–3291, Aug. 2013, doi: 10.1109/TCOMM.2013.071013.130225.

[12] S. Li, Y. Zhao, and Z. Wu, "Design and analysis of an OFDM-based differential chaos shift keying communication system," *Journal of Communications*, vol. 10, no. 3, pp. 199–205, 2015, doi: 10.12720/jcm.10.3.199-205.

[13] F. S. Hasan, "Design and analysis of an OFDM-based short reference quadrature chaos shift keying communication system," *Wireless Personal Communications*, vol. 96, no. 2, pp. 2205–2222, Sep. 2017, doi: 10.1007/s11277-017-4293-1.

[14] H. F. Fahad and F. S. Hassan, "Design and performance analysis of orthogonal multi-level code-shifted differential chaos shift keying communication system," *Journal of Engineering and Sustainable Development*, vol. 24, no. 06, pp. 42–56, Nov. 2020, doi: 10.31272/jeasd.24.6.4.

[15] B. M. Lee, Y. Kim, and R. J. P. de Figueiredo, "Performance analysis of the clipping scheme with SLM technique for PAPR reduction of OFDM signals in fading channels," *Wireless Personal Communications*, vol. 63, no. 2, pp. 331–344, Mar. 2012, doi: 10.1007/s11277-010-0136-z.

[16] Shang-Kang Deng and Mao-Chao Lin, "OFDM PAPR reduction using clipping with distortion control," in *IEEE International Conference on Communications, 2005. ICC 2005. 2005*, 2005, vol. 4, pp. 2563–2567, doi: 10.1109/ICC.2005.1494812.

[17] S.-S. Jeng and J.-M. Chen, "Efficient PAPR reduction in OFDM systems based on a companding technique with trapezium distribution," *IEEE Transactions on Broadcasting*, vol. 57, no. 2, pp. 291–298, Jun. 2011, doi: 10.1109/TBC.2011.2112237.

[18] D. W. Lim, J. S. No, C. W. Lim, and H. Chung, "A new SLM OFDM scheme with low complexity for PAPR reduction," *IEEE Signal Processing Letters*, vol. 12, no. 2, pp. 93–96, Feb. 2005, doi: 10.1109/LSP.2004.840915.

[19] L. Yang, R. S. Chen, Y. M. Siu, and K. K. Soo, "PAPR reduction of an OFDM signal by use of PTS with low computational complexity," *IEEE Transactions on Broadcasting*, vol. 52, no. 1, pp. 83–86, Mar. 2006, doi: 10.1109/TBC.2005.856727.

[20] D. Kumutha and N. Amutha Prabha, "Hybrid STBC-PTS with enhanced artificial bee colony algorithm for PAPR reduction in MIMO-OFDM system," *Journal of Ambient Intelligence and Humanized Computing*, pp. 1–17, Oct. 2017, doi: 10.1007/s12652-017-0595-0.

[21] B. Li, W. Xu, H. Zhang, C. Zhao, and L. Hanzo, "PAPR reduction for hybrid ACO-OFDM aided IM/DD optical wireless

vehicular communications," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 10, pp. 9561–9566, Oct. 2017, doi: 10.1109/TVT.2017.2698265.
[22] Z. Liu, L. Zhang, and Z. Chen, "Low PAPR OFDM-based DCSK design with carrier interferometry spreading codes," *IEEE Communications Letters*, vol. 22, no. 8, pp. 1588–1591, Aug. 2018, doi: 10.1109/LCOMM.2018.2842196.
[23] M. Mobini and M. R. Zahabi, "A low complexity PAPR reduction architecture for OFDM-DSCK communication system," *Wireless Personal Communications*, vol. 107, no. 4, pp. 1759–1776, Aug. 2019, doi: 10.1007/s11277-019-06355-5.
[24] F. S. Hasan and A. A. Valenzuela, "Design and analysis of an OFDM-based orthogonal chaotic vector shift keying communication system," *IEEE Access*, vol. 6, pp. 46322–46333, 2018, doi: 10.1109/ACCESS.2018.2862862.
[25] B. Bakkas, R. Benkhouya, I. Chana, and H. Ben-Azza, "Palm date leaf clipping: a new method to reduce PAPR in OFDM systems," *Information*, vol. 11, no. 4, Apr. 2020, doi: 10.3390/info11040190.
[26] N. Varghese, J. Chunkath, and V. S. Sheeba, "Peak-to-average power ratio reduction in FBMC-OQAM system," in *2014 Fourth International Conference on Advances in Computing and Communications*, Aug. 2014, pp. 286–290, doi: 10.1109/ICACC.2014.74.
[27] B. Tang, K. Qin, and H. Mei, "A hybrid approach to reduce the PAPR of OFDM signals using clipping and companding," *IEEE Access*, vol. 8, pp. 18984–18994, 2020, doi: 10.1109/ACCESS.2020.2968560.

BIOGRAPHIES OF AUTHORS

Sajjad Razzaq Abdulridha was born in Baghdad, Iraq in 1987. He received the Engineer degree in electrical Engineering in 2009 from from the Mustansiriyah University, Iraq. His recent research is to reduce the peak to average power ratio (PAPR) of orthogonal frequency division multiplexing based different chaotic shift keying (OFDM-DCSK) system using distortion and distortion-less techniques. He can be contacted at email: sejjad.alqassab@uomustansiriyah.edu.iq.

Fadhil S. Hasan was born in Baghdad, Iraq in 1978. He received his B.Sc. degree in Electrical Engineering in 2000 and his M.Sc. degree in Electronics and Communication Engineering in 2003, both from the Mustansiriyah University, Iraq. He received Ph.D. degree in 2013 in Electronics and Communication Engineering from the Basrah University, Iraq. In 2005, he joined the faculty of Engineering at the Mustansiriyah University in Baghdad. His recent research activities are wireless communication systems, multicarrier system, wavelet based OFDM, MIMO system, speech signal processing, image signal processing, cryptography and computer security, chaotic modulation, field-programmable gate array (FPGA) and Xilinx system generator based communication system. Now he has been an Assist. Prof. at the Mustansiriyah University, Iraq. He can be contacted at email: fadel˙sahib@uomustansiriyah.edu.iq