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Performance Analysis of FBMC/O-QAM System using Peak to Average Power Ratio

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Abstract: ***Filter Bank Multicarrier with Offset Quadrature Amplitude Modulation (FBMC/O-QAM) is an alternate transmission method where a dedicated filter is applied on each subcarrier, that reduces the OOB (Out Of Band) emission and results in high spectral efficiency. FBMC/O-QAM system has many advantages, but being a MCM (Multicarrier Modulation) technique, it suffers from a major problem of high PAPR (Peak to Average Power Ratio). High PAPR reduces the power efficiency of the system and it needs to be addressed. In this research study, some PAPR reduction methods such as companding and clipping are studied and implemented on FBMC/O-QAM system, and it is found that clipping technique provides better result among the considered schemes.***

Keywords: FBMC, FBMC/O-QAM, OFDM, PAPR, Companding, Clipping.

I. INTRODUCTION

OFDM (Orthogonal Frequency Division Multiplexing) is the most widely used MCM scheme in wireless networks. It uses CP (Cyclic Prefix) to minimize the ISI (Inter Symbol Interference), which reduces the spectral efficiency of the system. As low spectral efficiency is one of the major problems being faced today, OFDM will not be a suitable choice for future wireless networks [1-3].

In FBMC/O-QAM system a filter is applied on each subcarrier which significantly reduces the OOB (Out Of Band) emission. Because of low OOB emission, FBMC/O-QAM system does not require CP, hence provides high spectral efficiency. It also resolves other problems of OFDM system such as frequency sensitivity, high side lobes etc. [4-5]. FBMC/O-QAM is a MCM scheme and has high PAPR. Usually a HPA (High Power Amplifier) is used at the transmitter of the communication system. When a signal with high PAPR passes through the HPA, it gets distorted and because of this, power efficiency of the system gets reduced. Therefore, PAPR is a big issue and it needs to be resolved. To overcome this issue, many research works have been proposed to reduce PAPR. In [6], PPTS (Pretreated Partial Transmit Sequence) scheme is proposed. Iterative clipping method is used in [7]. In [8], SLM (selective mapping) technique is being proposed, DSLM (Dispersive Selective Mapping) is presented in [9]. In this research study, some PAPR reduction methods such as companding and clipping are studied and implemented on FBMC/O-QAM system, and it is found that clipping technique provides better result among the considered schemes.

II. SYSTEM MODELLING

In fig. 1, block diagram of FBMC/O-QAM system is shown. In FBMC/O-QAM system, the offset QAM modulation is used where the orthogonality condition is relaxed and applied only on the real (or imaginary) part of the complex data symbols. In O-QAM modulation, the in-phase and the quadrature-phase components of data symbols are shifted by half symbol duration (T/2). IFFT is applied on the symbols and filtering of each subcarrier is done efficiently by the poly-phase network (PPN).

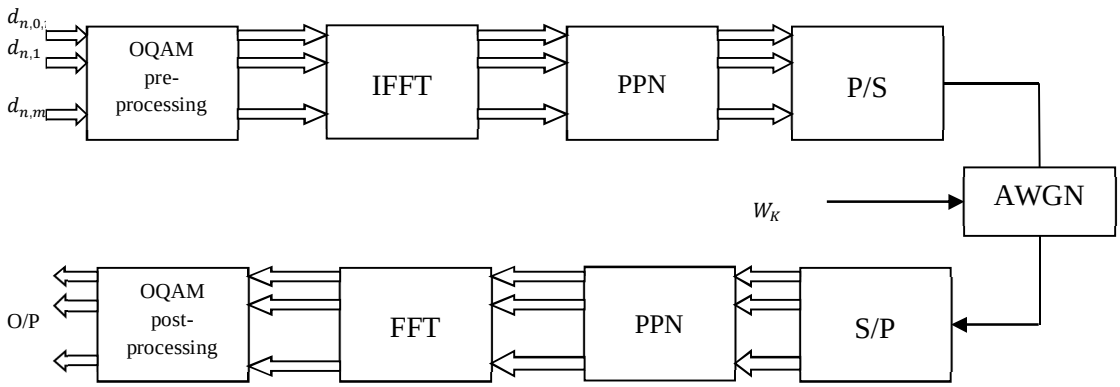


Fig. 1: Block diagram of FBMC/O-QAM system.

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III. MATHMATICAL MODELLING

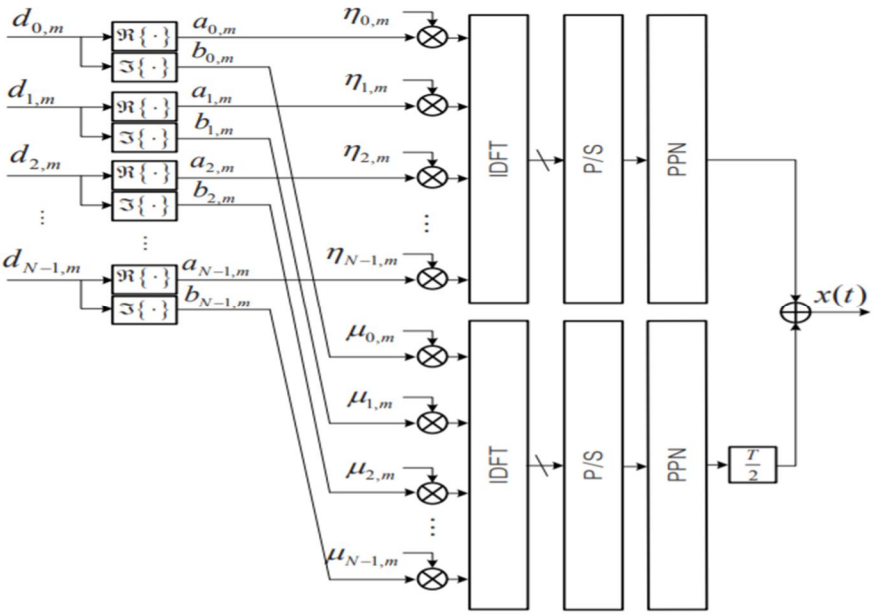


Fig. 2**:** Implementation of FBMC/O-QAM system

Fig. 2, shows the implementation of FBMC/O-QAM system. If the total subcarriers are denoted by N, then m^{th} data on n^{th} subcarrier is represented as

$$d_{n,m} = a_{n,m} + j\, b_{n,m} \tag{1}$$

Where, $a_{n,m}$ and $b_{n,m}$ are the real and imaginary part of the complex symbols respectively. Now real and imaginary parts of the symbol get phase shifted, and the phase shift coefficients are given by $\eta_{n,m}$ and $\mu_{n,m}$ respectively.

For FBMC

$$\eta_{n,m} = \begin{cases} 1 (or -1) if\ n = even \\ j (or -j) if\ n = odd \end{cases} \tag{2}$$

$$\mu_{n,m} = \begin{cases} j (or -j) if\ n = even \\ 1 (or -1) if\ n = odd \end{cases} \tag{3}$$

In general,

$$\eta_{n,m} = j^{n+2m}\ or\ (-1)^m j^n \tag{4}$$

$$\mu_{n,m} = j^{n+2m+1}\ or\ (-1)^m j^{n+1} \tag{5}$$

Now, the composite signal can be given as

$$x(t) = \sum_{n=0}^{N-1} \left\{ \sum_{m=0}^{M-1} (-1)^m j^n a_{n,m} h(t - mT) \right\} e^{jn\frac{2\pi}{T}t}$$

$$+ \sum_{n=0}^{N-1} \left\{ \sum_{m=0}^{M-1} (-1)^m j^{n+1} b_{n,m}\, h(t - mT - \frac{T}{2}) \right\} e^{jn\frac{2\pi}{T}(t-\frac{T}{2})}$$

$$= \sum_{n=0}^{N-1} \sum_{m=o}^{M-1} (-1)^m \begin{Bmatrix} a_{n,m} h(t - mT) e^{jn\frac{2\pi}{T}\left(t+\frac{T}{4}\right)} \\ + j b_{n,m}\, h(t - mT - \frac{T}{2}) e^{jn\frac{2\pi}{T}(t+\frac{T}{4}-\frac{T}{2})} \end{Bmatrix} \tag{6}$$

Where, $h(t)$ is the impulse response of prototype filter. In this work, PHYDYAS filter is being used as the prototype filter.

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IV. PROTOTYPE FILTER

In FBMC/O-QAM, a dedicated filter is applied on each subcarrier known as prototype filter. In this work, PHYDYAS filter is being used as the prototype filter [10]. The design of this filter is based on frequency sampling.

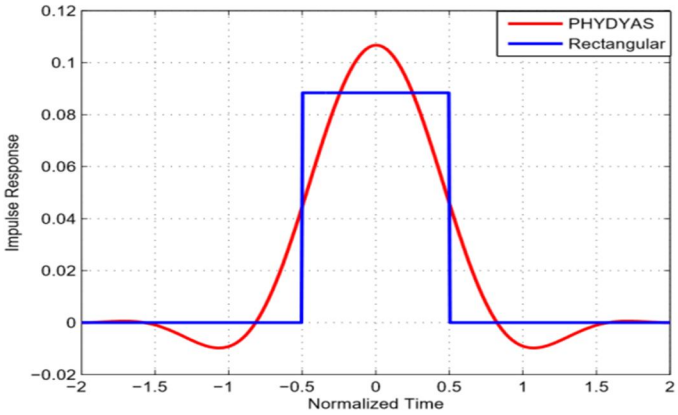


Fig. 3: Comparison of PHYDYAS and rectangular filter.

$$H(0) = 1$$

$$H\left(\frac{1}{L}\right) = 0.971960$$

$$H\left(\frac{2}{L}\right) = \frac{1}{\sqrt{2}}$$

$$H\left(\frac{3}{L}\right) = \sqrt{1 - H^2\left(\frac{1}{L}\right)} = 0.235147$$

$$H\left(\frac{4}{L}\right) = 0 \; ; 4 \le k \le L - 1$$

Then,

$$h(n) = 1 + 2\sum_{k=1}^{K-1}(-1)^k H\left(\frac{k}{L}\right)\cos\left(\frac{2\pi kn}{L}\right), 0 \le n \le L - 1 \quad (7)$$

V. PAPR ANALYSIS

PAPR is the ratio of peak power of the signal to the average power of the signal.

$$PAPR = \frac{max_{(m-1)T<t<mT}|x(t)|^2}{P_a}, m = 0,1 \ldots\ldots M - 1 \quad (8)$$

PAPR is a random variable and a better way to characterized it, is by CCDF (Complementary Cumulative Distribution Function). CCDF gives the probability that the PAPR exceeds some threshold value X.

$$CCDF = P_r\{PAPR > X\}$$

VI. μ-LAW COMPANDING

Companding stands for compressing-expanding mechanism. In this, the stronger signals are compressed and the weaker signals are expanded. Companding action improves the average power of the signal and reduces the peak power of the signal hence PAPR reduces.

In [11], authors showed that out of μ-law companding, A-law companding, erf companding, log companding and tanh companding techniques, μ-law companding performs the best. The μ-law companding function is given by

$$x_\mu(t) = \frac{ln(1+\mu|x(t)|)}{ln(1+\mu)} sgn(x(t)) \quad (9)$$

Where, μ is the compression parameter.

At receiver, the original signal is obtained by

$$x(t) = \frac{1}{\mu}\left[(1+\mu)^{|x_\mu(t)|} - 1\right] sgn\left(x_\mu(t)\right) \quad (10)$$

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VII. CLIPPING

In this technique, high peaks of the signal are clipped off, which reduces the peak power of the signal hence PAPR gets reduced. If the threshold value of clipping is A, then,

$$\bar{x}(t) = \begin{cases} x(t) if\ |x(t)| \leq A \\ A \quad if\ |x(t)| > A \end{cases} \tag{11}$$

Then the PAPR of clipped signal,

$$PAPR = \frac{max_{(m-1)T<t<mT}|\bar{x}(t)|^2}{P_a}, m = 0,1 \ldots . . M-1 \tag{12}$$

VIII. RESULTS

Parameters that have been used in the simulation of this work are listed in the table 1.

Table 1: List of useful parameters

Parameter	Value
Number of subcarriers	64
Number of FBMC symbols per frame	48
Oversampling factor for IDFT	4
Clipping Level	0.65×peak value
SNR (dB)	1 to 15
No of frames for PAPR check	1000

In fig. 4, it is clear from the magnitude spectrum of OFDM and FBMC/O-QAM that FBMC/O-QAM has lower side lobes hence better frequency localization. In fig. 5, magnitude response of FBMC/O-QAM for different value of K is shown, where, K is the oversampling factor. It is clear that side lobes decreases for higher values of k. In fig. 6, high amplitude peaks can be observed, which causes high value of PAPR, whereas in fig. 7 clipped samples are shown.

In fig. 8, PAPR performance in terms of CCDF is shown for various techniques. FBMC/O-QAM suffers the most from PAPR, FBMC/O-QAM with μ-law performs better than the FBMC/O-QAM, and clipped FBMC/O-QAM performs the best among the considered schemes. Quantitative results are shown in table 2.

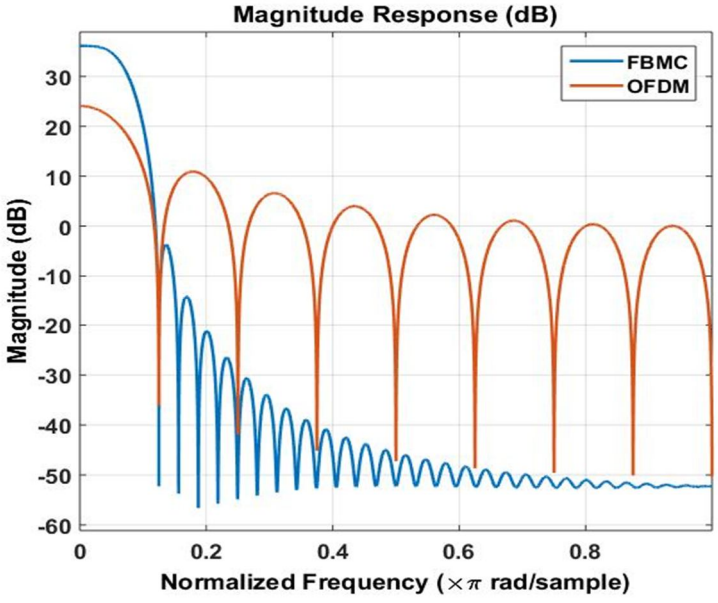


Fig. 4: Magnitude response of FBMC and OFDM.

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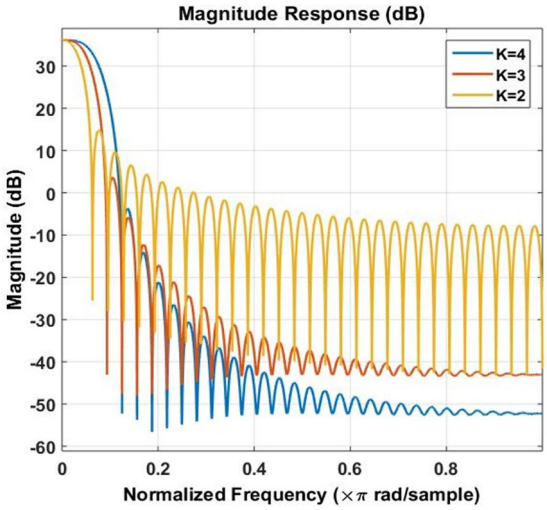


Fig. 5**:** Magnitude response of FBMC and OFDM for different K.

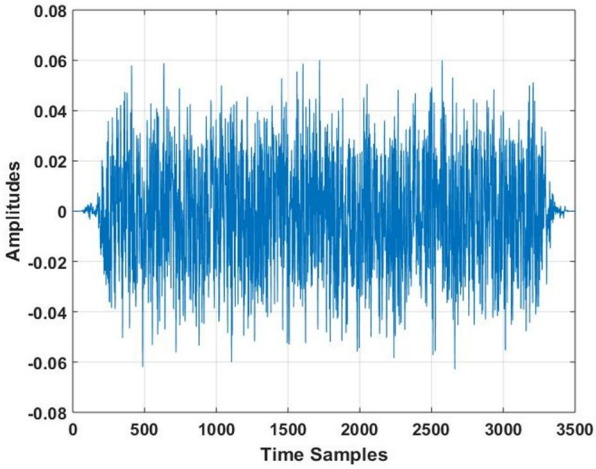


Fig. 6**:** Variation in peak amplitude.

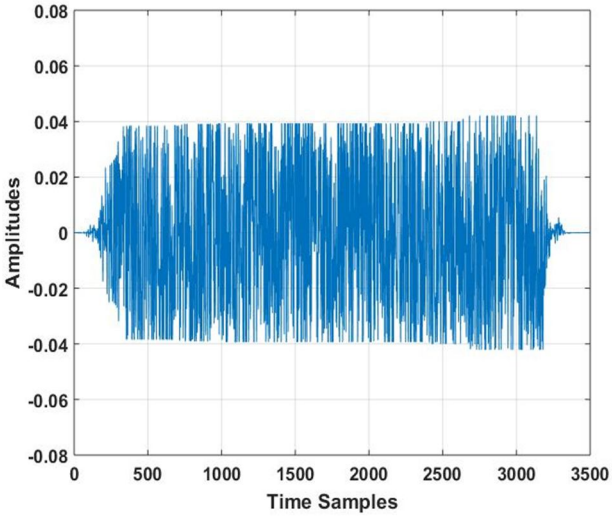


Fig. 7: Variation in peak amplitude along-with clipping

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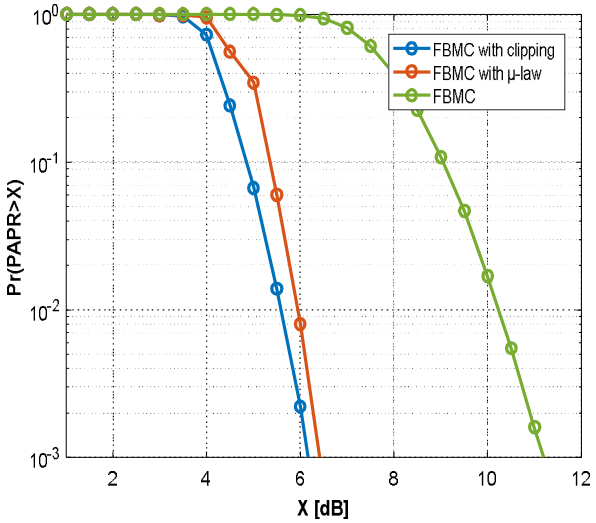


Fig. 8: CCDF vs. PAPR (dB)

Table 2: PAPR for different methods.

Techniques	PAPR(dB) (@ CCDF = 10^{-3})
FBMC	11.2
FBMC + μ Law	6.67
FBMC + clipping	6.1

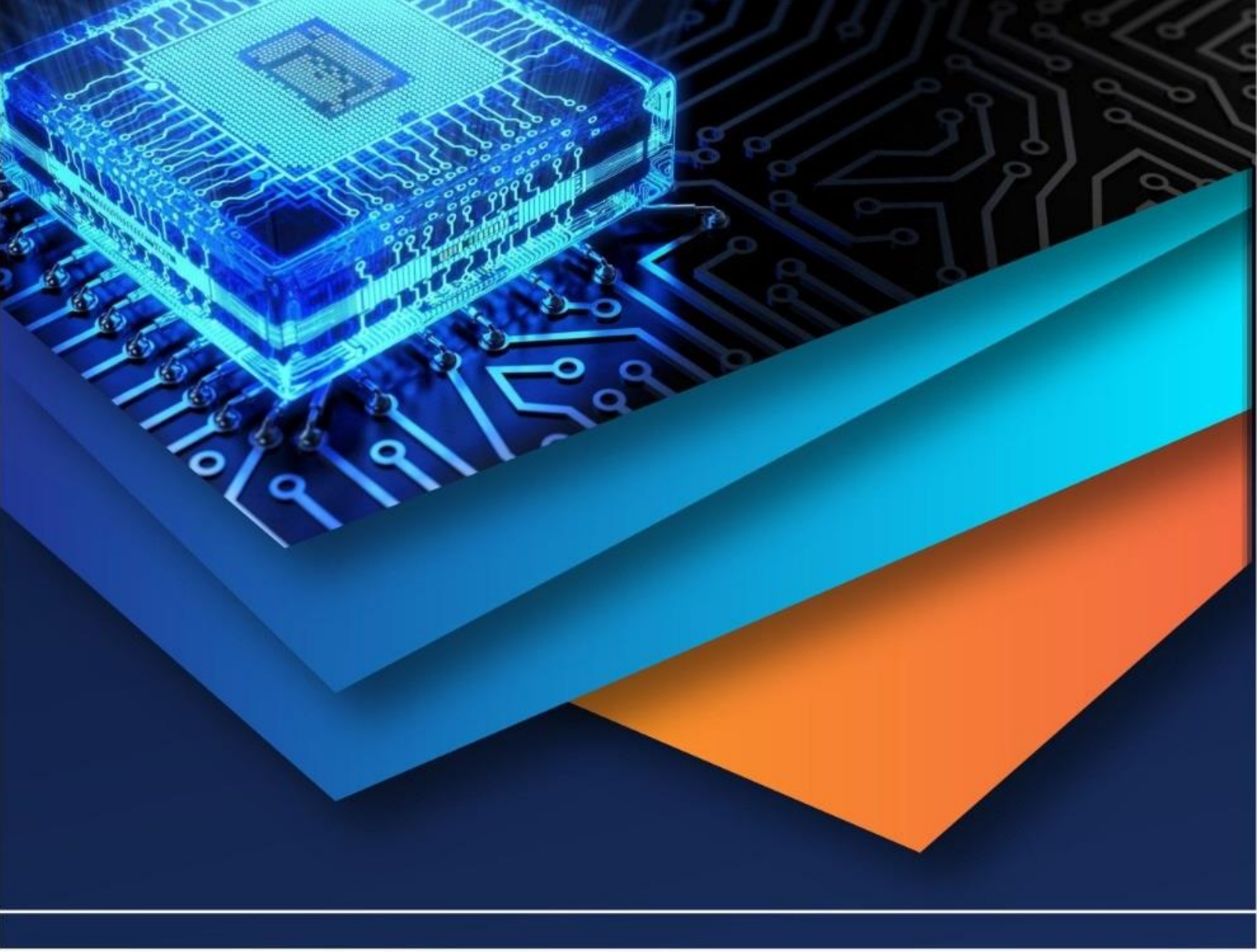
IX. CONCLUSION

In this research study, different PAPR reduction techniques for FBMC/O-QAM were studied and implemented. It was found that FBMC/O-QAM suffers the most from PAPR, FBMC/O-QAM with μ-law companding performs better than the FBMC/O-QAM, and clipped FBMC/O-QAM performs the best among the considered schemes. Furthermore, in FBMC/O-QAM system PAPR at different clipping levels can be evaluated and selection of the appropriate clipping level can be made according to the requirements. Also, other PAPR reduction techniques can be studied and implemented for the FBMC/O-QAM system.

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