PAPR Reduction of FBMC-OQAM using A-law and Mu-law Companding

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***Abstract*— Filter bank multicarrier scheme is an efficient multicarrier scheme and candidate waveform for 5G. Similar to OFDM and other multicarrier schemes, FBMC also has high Peak-to-Average Power Ratio (PAPR) which leads us to the use of high power amplifiers with high dynamic range. Companding techniques are used to reduce PAPR at the expense of bit error rate (BER) performance degradation. In this paper, a novel usage of A-law and Mu-law companding techniques for PAPR reduction of FBMC-OQAM scheme are proposed. The paper also investigates the tradeoff between PAPR reduction and Bit error rate performance of FBMC-OQAM using A-law and Mu-law companding techniques. Simulation results have shown a significant decrease in PAPR but BER of the system has increased. Both the companding techniques have shown similar results but Mu-law companding has given a slightly better performance than A-law companding in PAPR reduction but BER of A-law companding is better than Mu-law companding.**

Keywords— High Power Amplifier (HPA), Filter Bank Multicarrier (FBMC), Bit Error Rate (BER), Peak to Average Power Ratio (PAPR)

I. INTRODUCTION

With the increased demand for higher data rates, the future wireless communication systems need to be designed according to these specifications. Multicarrier schemes are the best choice to increase the bit rate as the whole frequency selective channel is distributed into multiple sub-bands each with less frequency selective fading [1]. Simple equalization can be achieved at the receiver by increasing the number of subbands and then each subband can be considered to have flat-fading only.

The popular multicarrier scheme is Orthogonal Frequency Division Multiplexing (OFDM) [2], which is used Digital Audio Broadcast (DAB), Digital Video Broadcast (DVB) etc. OFDM is spectrally efficient scheme which allows ISI Reduction through cyclic prefix (CP). This CP, at the same time, reduces the spectral efficiency depending upon its length. This drawback is successfully overcome by a new multicarrier scheme known as filter bank multicarrier (FBMC). In FBMC system, the system can have a good stopband attenuation because of subchannel filters due to which frequency leakage between the subchannels can be reduced and the order of prototype filter can be large. Equalization can be simplified at the receiver due to Sub channel filters, without the need of CP [3].

As OFDM suffers from high peak to average power ratio (PAPR) due to non-linearity of practical HPAs which are used to amplify the transmitted signal, FBMC also has the same drawback, so to achieve high data rate PAPR reduction is the main requirement. High PAPR leads to the use high dynamic range amplifiers and ADC/DACs [1]. High PAPR is the main problem in all multicarrier systems as it distorts the signal which leads to poor Bit Error Rate (BER) performance.

Many PAPR reduction techniques have been used for OFDM such as partial transmit sequence (PTS) [4], coding schemes, selective mapping (SLM) [4], phase optimization, tone injection (TI), companding [5], tone reservation (TR), clipping and filtering, and active constellation extension (ACE). Clipping and filtering is the simplest technique to implement [5]. In this technique peak exceeding the threshold value are clipped and then filtered to maintain low peak value. PTS and SLM are probabilistic techniques in which signal subcarriers are weighted with phase factors and then signal with low PAPR are transmitted [6][12]. Both of these techniques require side information along with the signal to be transmitted thus reducing the spectral efficiency. Companding techniques are widely used for PAPR reduction because of its low complexity and flexibility [7].

In this paper, we investigate PAPR and BER performance of FBMC-OQAM (Offset Quadrature Amplitude Modulation) and then apply A-law and Mu-law companding techniques for PAPR reduction. It is worth-mentioning here that the authors of [1] have also presented the PAPR reduction analysis by using the same techniques but a detailed comparison by varying the number of subcarriers and the values of compression parameters is missing. In our paper, a detailed PAPR reduction and BER analysis for various number of subcarriers (16, 32, 64, and 128) and different values of compression parameters for both the companding techniques is presented and discussed. It is shown that the selection of compression parameter introduces a trade-off between PAPR reduction and BER performance.

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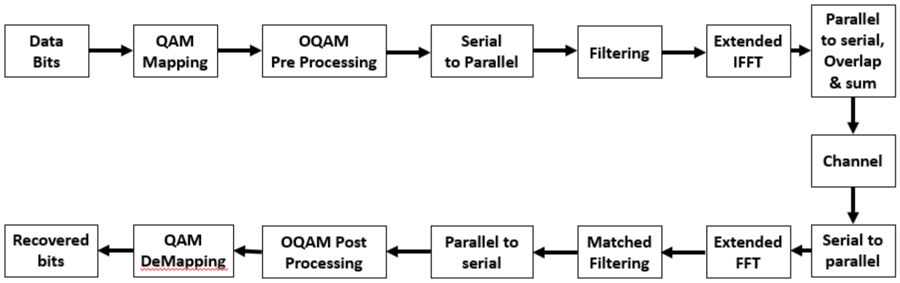

Fig. 1. **FBMC-OQAM System**

II. FBMC-OQAM SYSTEM

FBMC is a 5G candidate waveform along with Universal Filter Multicarrier (UFMC) system [8] and Generalized Frequency Division Multiplexing (GFDM) system [9]. FBMC is a multicarrier waveform in which each subcarrier is filtered through a filter. Compared to OFDM where orthogonality between all the carriers must be ensured, orthogonality with neighbouring subcarriers is only required in FBMC leading to less channel interference for which offset quadrature amplitude modulation (OQAM) is used [3]. OFDM utilizes a frequency bandwidth with multiple subcarriers, while FBMC splits the channel into multiple subchannels. There is no need for cyclic prefix as OQAM modulation and filtering leads to the maximum bit rate.

FBMC-OQAM system is shown in figure 1. The difference between the OFDM and FBMC is the OQAM processing and filtering. OQAM processing is required to achieve the orthogonality between subcarriers because there is overlap between neighbouring subchannels in FBMC. In OQAM processing, real and imaginary part are not transmitted simultaneously as they both are delayed by half of the symbol duration. The term 'offset' in OQAM, indicates the time shift of the sub-carrier spacing between the imaginary part and the real part of a symbol [3]. OQAM also increases the symbol rate by 2.

Filter banks are used in FBMC to filter each subcarrier. At the transmitter, Synthesis filter bank is used while at the receiver analysis filter bank is used. Prototype filter is designed keeping in view the Nyquist Criterion. In FBMC transmission, the filter is separated into two parts, one part of that filter is used at the transmitter and the other part is used at the receiver. The symmetry condition is fulfilled by taking the squares of the frequency coefficients. The frequency coefficients of the filter for K=2, 3 and 4 are given in Table1 [3].

Frequency response can be obtained from the following equation:

$$H(f) = \sum_{k=-(K-1)}^{K-1} H_k \frac{\sin(\pi\left(f - \frac{k}{NK}\right)NK)}{NK\sin(\pi\left(f - \frac{k}{NK}\right))}$$

Table 1. Frequency Domain Filter Coefficients

K	H_0	H_1	H_2	H_3	σ^2 (dB)
2	1	$\sqrt{2}/2$	-	-	-35
3	1	0.911438	0.411438	-	-44
4	1	0.971960	$\sqrt{2}/2$	0.235147	-65

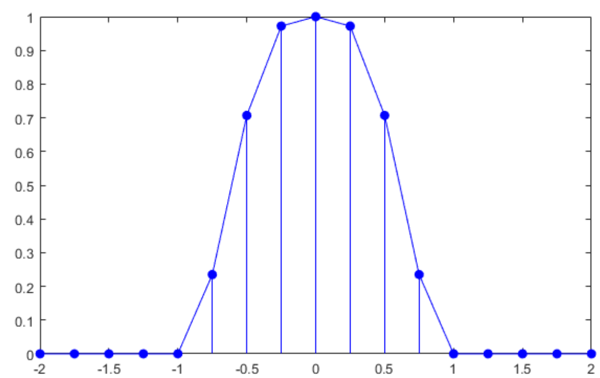

Fig. 2. Frequency Response of the FBMC-OQAM prototype filter

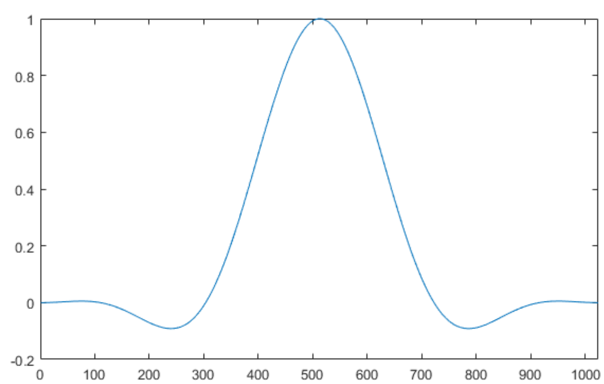

Fig. 3. Impulse Response of the FBMC-OQAM prototype filter

Where N is the number of subchannels. Figure 2 shows the frequency response of the filter for K = 4 and N = 256.

The impulse response of the prototype filter is calculated by taking IFFT of frequency response of the filter which is given as

$$h(t) = 1 + 2\sum_{k=1}^{K-1} H_k \cos(2\pi \frac{kt}{KT})$$

The impulse response of the prototype filter is shown in Figure 3, for filter length L = 1024. The transmitted FBMC signal after taking IFFT can be denoted as

$$s(m) = \sum_{i=0}^{M-1} d_i(m) e^{j2\pi\frac{in}{M}}, \quad 0 \le n \le M-1$$

where M is the number of subcarriers.

The data bits obtained after FFT at the receiver can be denoted as

$$d_i(m) = \frac{1}{M}\sum_{n=0}^{M-1} s(m)\, e^{-j2\pi\frac{in}{M}}, \quad 0 \le i \le M-1$$

PAPR gives the information about how much large is the peak value from the average value. PAPR for the transmitted signal s_n can be defined as [10]

$$PAPR(s[n]) = \frac{max_{0\le n<M} |s[n]|^2}{E[|s[n]|^2]}$$

where s_n is the transmitted signal and N is the number of sub carriers. $E[|s[n]|^2]$ is the mean or average value of the signal.

For FBMC-OQAM signals, the cumulative distribution function (CDF) of the PAPR, can be written as [11]:

$$CDF(\gamma) = \Pr(PAPR(s[n]) \le \gamma) = (1 - e^{-\gamma})^M$$

Therefore, the complementary cumulative distribution function (CCDF) of PAPR is given by [11]:

$$CCDF(\gamma) = \Pr(PAPR(s[n]) > \gamma) = 1 - (1 - e^{-\gamma})^M$$

Figure 4 shows the CCDF of FBMC for different subcarriers. It can be seen that with increasing number of subcarriers the PAPR increases. PAPR of FBMC with 16 subcarriers is 16.8 dB while PAPR of FBMC with 128 subcarriers has increased to 17.9 dB.

III. COMPANDING TECHNIQUES FOR PAPR REDUCTION

A. Mu-law Companding

Mu-law companding for the given input x is stated as:

$$F(x) = sgn(x)\frac{\ln(1+\mu|x|)}{\ln(1+\mu)}$$

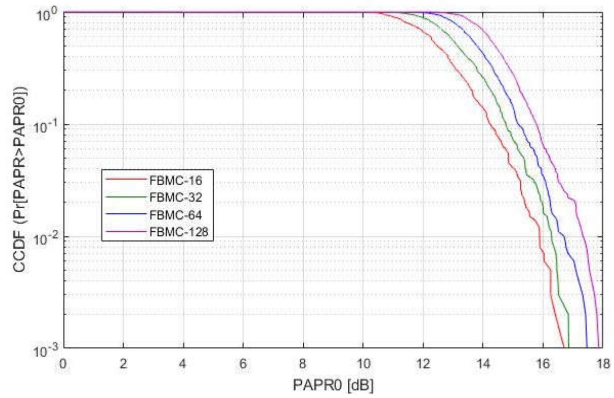

Fig. 4. CCDF of FBMC for different subcarriers

the value used here is μ = 25 and μ = 255.This technique does has greater effect on small amplitudes but dynamic range is increased of the transmitted signal [1].

The de-companding formula is given as:

$$F^{-1}(x) = sgn(x)\frac{1}{\mu}((1+\mu)^x - 1)$$

B. A-law Companding

A-law companding for the given input x is stated as:

$$F(x) = sgn(x)\begin{cases} \frac{A|x|}{1+\log(A)}, & |x| < \frac{1}{A} \\ \frac{1+\log(A|x|)}{1+\log(A)}, & \frac{1}{A} \le |x| \le 1 \end{cases}$$

where A is the compression parameter and value used is A =13 and A =87.6. This value must be chosen in such a way that it gives a good PAPR reduction and better BER performance.
The de-companding formula is given as

$$F^{-1}(x) = \begin{cases} \frac{|x|(1+\ln(A))}{A}, & |x| < \frac{1}{1+\ln(A)} \\ \frac{\exp(|x|(1+\ln(A)) - 1)}{A}, & \frac{1}{1+\ln(A)} \le |x| < 1 \end{cases}$$

IV. SIMULATION RESULTS

In this section, we present results through Matlab simulations. The PAPR performance of FBMC with and without reduction techniques is investigated along with BER performance. Random data is generated and is OQAM processed while keeping the number of subcarriers fixed at N=128. The oversampling factor used is K=4 and additive white Gaussian noise (AWGN) channel is used.

Table 2. PAPR Analysis OF FBMC OQAM

		PAPR in dB at CCDF = 10^{-3}
FBMC without Reduction		17.87
μ-Law Companding	$\mu = 25$	10.55
	$\mu = 255$	7.38
A-Law Companding	$A = 13$	10.88
	$A = 87.6$	7.7

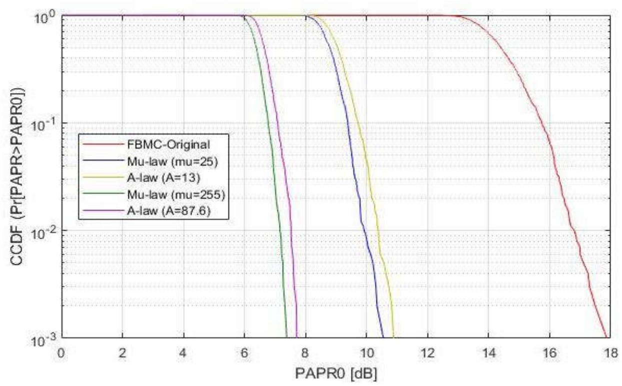

Fig. 5. CCDF of original FBMC-OQAM and companded signals

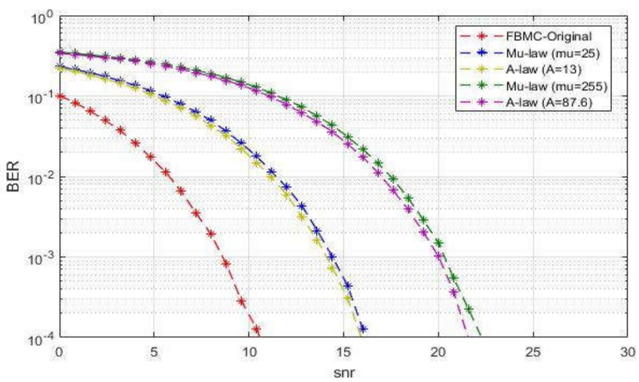

Fig. 6. BER performance of original FBMC-OQAM signal and companded signal over AWGN channel

Figure 5 shows the CCDF of the original FBMC signal and companded signals. There is a significant decrease in PAPR in both Mu-law and A-law companded signals. At CCDF=10^{-3}dB there is a difference of 0.33 dB when $\mu = 25$ and $A = 13$. When $\mu = 255$ and $A = 87.6$ At CCDF=10^{-3}dB there is a difference of 0.32 dB. From the figure 5 it can be seen that Mu-law is giving slightly better result compared to A-law.

Figure 6 shows the BER of original FBMC signal and companded signals. There is a very high increase in BER of companded signals. A- law companding is giving slightly better BER than Mu-law companding.

It can also be seen in figure5 and figure 6 that by increasing the values of μ and A a better PAPR reduction can be achieved but BER of the system is also increased.

V. CONCLUSION

In this paper, a novel usage of the Mu-law and A-law companding techniques for the reduction of PAPR in FBMC-OQAM scheme is proposed. Companding techniques are good for PAPR reduction but the overall system performance is also affected. It is evident from the simulation results that there is a significant decrease in PAPR when companding is applied but at the cost of high BER. More the reduction in PAPR, more the BER of the system increases.

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