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Out of Band Leakage Performance of Generalized Frequency Division Multiplexing

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Abstract
In this work the out of band (OOB) leakage performance of Generalized frequency division multiplexing (GFDM) with clipping and filtering technique is shown and also the effect of clipping and filtering on the bit error rate (BER) performance of GFDM signal is observed. All simulation results are performed with high power amplifier.The BER performance of the proposed scheme is compared with orthogonal frequency division multiplexing (OFDM) which is a popular modulation scheme for 4th Generation wireless communication systems.Simulation results show that out of band leakage in GFDM signal is reduced up to a large extent after applying the clipping and filtering method as compared to the OFDM signal maintaining almost equal BER performance.

Keywords: *OOB, GFDM, OFDM, SSPA*

INTRODUCTION

Generalized frequency division multiplexing is an upcoming modulation waveform for future wireless communication systems. Many advantages such as flexibility, applicability to MIMO systems, low out of band(OOB) radiation, easy channel equalization and higher spectral efficiency compared to orthogonal frequency division multiplexing(OFDM) make it a popular modulation waveform for fifth generation wireless communication systems[1-2].

In GFDM, the data symbols are transmitted in frequency-time block manner and pulse shaping is performed on every subcarrier. The advantage of pulse shaping is to control the out of band radiation and Peak-to-Average Power Ratio (PAPR) [3], it causes self induced interference which needs to be compensated using interference cancellation techniques at receiver end [4].On the other hand such type of transmission of data symbols in GFDM reduces the requirement of large number of subcarriers, so PAPR in GFDM signal is less compared to OFDM. By adding cyclic prefix to the entire block instead of each time slot makes GFDM more spectrally efficient compared to OFDM system.The properties mentioned above makes GFDM an attractive choice for deployment in 5G communication systems.

Unlike the other multicarrier communication systems such as OFDM, GFDM also suffers from high peak to average power ratio [5] and the problem becomes severe when the high peak GFDM signal passes through the high power amplifier.The high PAPR GFDM signal introduces additional interference into the system in the form of in-band and out of band leakage after passing through the high power amplifier (HPA).This additional interference occurs due to nonlinear behavior of HPA,which reduces the efficiency of the system and demands more battery life.

Many PAPR reduction techniques are discussed in literature for OFDM system such as coding, partial transmit sequence, clipping and filtering, Tone reservation, Tone injection, companding, precoding etc.[5, 6]. Among all these techniques, clipping is simple in operation and easy to implement but it increases inband and out of band radiation in the signal,hence filtering is applied after clipping. The clipping and filtering is used in a iterative manner which is quite complex process for OFDM but it is less complex in case of GFDM as it requires lesser number of iterations to achieve the performance comparable to OFDM due to its pulse shaping property which reduces the out of band radiation.

The work presented in this paper gives the performance of Clipped and filtered Generalized Frequency Division Multiplexing (GFDM) for out of band radiation and Bit error rate with high power amplifier. Results obtained from simulation show that after applying clipping and filtering technique to the GFDM system, out of band radiation is reduced up to a large extent.

PROPOSED SCHEME

The baseband GFDM signal when passed through HPA, nonlinear distortions occur in the form of out of band emission (OOB) due to nonlinear behavior of HPA and these distortions become severe with high PAPR signal. To avoid these distortions, clipping and filtering technique is applied to the baseband GFDM signal before passing through the power amplifier.

The detailed process of proposed GFDM signal transmission is depicted in Figure 1.The QAM mapped data is converted from serial to parallel and then passed through GFDM modulator.Further, GFDM modulated signal is clipped and filtered and converted back from parallel to serial and finally cyclic prefix is added to the whole data block of the signal.Now after digital to analog conversion, the GFDM signal is passed through high power amplifier.

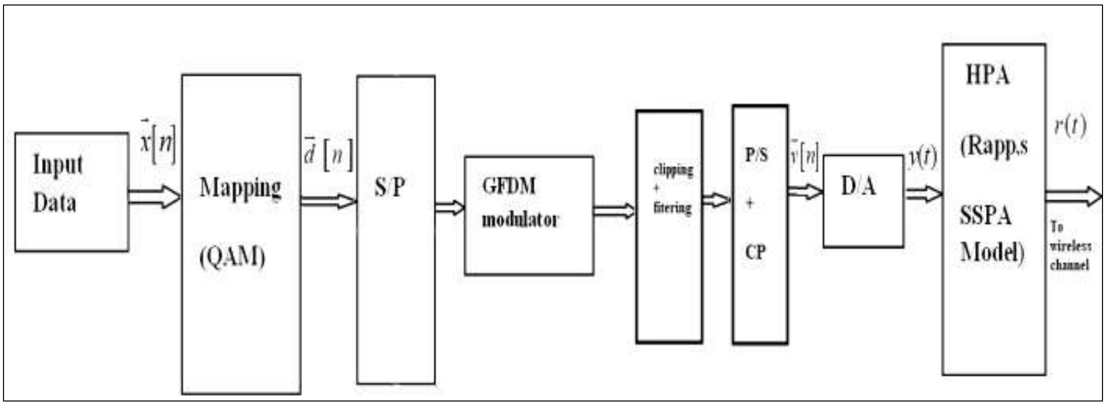

Figure 1:*Clipped and Filtered GFDM with high Power Amplifier.*

Clipping and Filtering

In the proposed work, clipping and filtering method is applied for peak to average power ratio (PAPR) reduction of GFDM signal.Clipping is very simple technique for PAPR reduction which is deliberately performed to limit the peaks in the signal to be transmitted in the nonlinear channel. The clipped signal can be written as in [7, 8]:

$$f\left(x[n]\right)=\begin{cases} x[n] & \text{if } \left|x[n]\right| \le \mathrm{V}_{\max} \\ V_{\max} e^{j\psi(x[n])} & \text{if } \left|x[n]\right| \ge \mathrm{V}_{\max} \end{cases} \quad (1)$$

Where, $x[n]$ is the original signal and $\psi\left(x[n]\right)$ is phase of the signal. The clipping ratio is defined in dB by

$$CR = 10\log_{10}\left(\xi\right) \quad (2)$$

$$\text{If } \xi = \frac{V_{\max}^2}{P_0}$$

The operation of clipping causes nonlinear degradation in the signal also BER performance of the clipped signal is degraded due to out of band emissions. In the proposed work filtering technique is applied with clipping to improve out of band emission.

HighPower Amplifier Model

The most commonly used baseband power amplifier models are Saleh model for travelling wave tube amplifier (TWTA), Ghorbani model for field-effect transistor (FET) amplifier, Rapp model for envelope characteristic of solid state power amplifier (SSPA).The output signal of nonlinear HPA is expressed as:

$$f(t) = r(t)e^{j\varphi(t)} \quad (3)$$

Where $R[.]$ and $\varphi[.]$ is AM/AM and AM/PM characteristics of high power amplifier.In the proposed work the performance of GFDM system is evaluated in presence of Rapp's SSPA Model.For SSPA,the AM/AM and AM/PM conversion characteristics are expressed as:

$$R_{out} = \frac{R_{in}}{\left[1+\left(R_{in}/R_0\right)^{2p}\right]^{1/2p}} \quad (4)$$

$$\varphi[R_{in}] = 0 \quad (5)$$

Where, R_{in} and R_{out} are input and output amplitudes of high power amplifier respectively. R_0 Is the saturated amplitude parameter which can found to be $R_0 = R_{sat}/\sqrt{2}$ and p is the smoothness parameter which controls the transition from linear region to saturation. The range of parameter p may be between 2 to 3.In the proposed work parameter p is set to two.

Out of Band Radiation in GFDM

Power spectral density (PSD) of a signal is an important performance metric to measure the impact of out of band leakage (OOB) which appears in the signal due to nonlinear nature of power amplifier.In general the OOB radiation of a signal is the ratio between amount of energy in out of band and in band frequency range and is represented as:

$$OOB = \frac{|B_I|}{|B_O|} \cdot \frac{\int_{f \in B_O} S_a(f)\,df}{\int_{f \in B_I} S_a(f)\,df} \tag{6}$$

Where, B_I and B_O are in band and out of band set of frequencies.
The Autocorrelation function is required to calculate the PSD of GFDM signal and which can be derived from the transmitted GFDM signal $x(t)$ is represented as:

$$R_{xx}(t,\tau) = E\left[x(t)x^*(t-\tau)\right] \tag{7}$$

The output of GFDM per frame is represented as:

$$x[n] = \sqrt{\beta}\sum_{k=0}^{K-1}\sum_{m=0}^{M-1} d_{k,m}\, g[n-mN]_{MN}\, e^{j2\pi\frac{\left(k-\frac{K-1}{2}\right)n}{N}} \quad \text{For } 0 \le n \le MN-1 \tag{8}$$

Where, β is the power scaling factor. If v no. of frame index of GFDM modulator is used then after concatenating GFDM blocks, the GFDM signal can be represented as:

$$x_v[n] = \sqrt{\beta}\sum_{v=-\infty}^{\infty}\sum_{k=0}^{K-1}\sum_{m=0}^{M-1} d_{k,m,v}\, g_m[n-vmN]_{MN}\, e^{j2\pi\frac{\left(k-\frac{K-1}{2}\right)n}{N}} \quad -\infty \le n \le \infty \tag{9}$$

In the continuous form the circularly shifted GFDM signal is represented as:

$$x(t) = \sqrt{\beta}\sum_{v=-\infty}^{\infty}\sum_{k=0}^{K-1}\sum_{m=0}^{M-1} d_{k,m,v}\, g_m[t-vT_B]_{MN}\, e^{j2\pi\frac{\left(k-\frac{K-1}{2}\right)t}{T_s}} \quad -\infty \le t \le \infty \tag{10}$$

Here, T_B and T_s are block duration and symbol duration respectively. Now from Equation (7),autocorrelation function of GFDM can be calculated as:

$$R_{xx}(t,\tau) = p_d\sum_{v=-\infty}^{\infty}\sum_{k=0}^{K-1}\sum_{m=0}^{M-1} g_m(t-vT_B)\, g^*_m[t-\tau-vT_B]_{MN}\, e^{j2\pi\frac{\left(k-\frac{K-1}{2}\right)\tau}{T_s}} \tag{11}$$

If p_d is the average power of data symbols $x_{k,m,v}$ which are identically distributed random variables having autocorrelation function p_d .By taking the fourier transform of eq.(11) PSD of GFDM signal can be obtained which is denoted as:

$$S_{xx}(f) = \int_{-\infty}^{\infty} R_{xx}(\tau)\, e^{-j2\pi f\tau}\, d\tau \tag{12}$$

For the out of band(OB) and inband (IB) frequency ranges, out of band radiation for the GFDM signal can be calculated as:

$$OOB = \frac{\int_{f \in OB} S_{xx}(f)\,df}{\int_{f \in IB} S_{xx}(f)\,df} \qquad (13)$$

RESULTS AND DISCUSSION

The performance of the proposed method is evaluated for GFDM system with 16-QAM modulation.Here; zero forcing detection method is applied to recover the GFDM signal. All the simulation results are obtained using MATLAB tool in the presence of Rapp's SSPA model of HPA with smoothness parameter p =2.Simulation parameters are depicted in table1.

Table1: *Simulation Parameters.*

Parameters	GFDM
No. of Frequency slots K (subcarriers)	128
No. of time slots M	4
Modulation technique	16QAM
Oversampling factor L	4
Root raised cosine filter Roll off factor	0.3
HPA model	SSPA
Clipping ratio CR	1.2

Figure 2(a) and 2(b) show the out of band leakage in terms of power spectral density (PSD) of baseband and pass band GFDM signal respectively.Probability density function (PDFs) and power spectra of clipped GFDM signal and clipped and filtered GFDM signal with HPA is depicted in Figure 3(a) and 3(b) respectively. Comparing the simulation results of Figure2(b), 3(a) and 3(b), it can be concluded that after applying clipping scheme,out-of-band leakage increases slightly in GFDM signal but decreases up to a large extent after applying filtering.

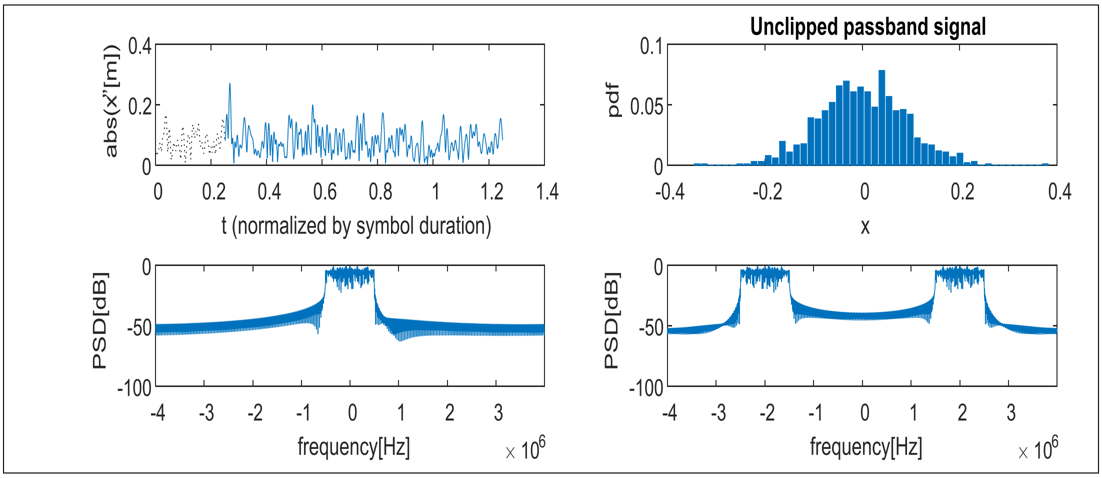

Figure 2:*(a) Pdf and Power Spectra of BasebandGFDM Signal.(b) Pdf and Power Spectra of Passband GFDM Signal.*

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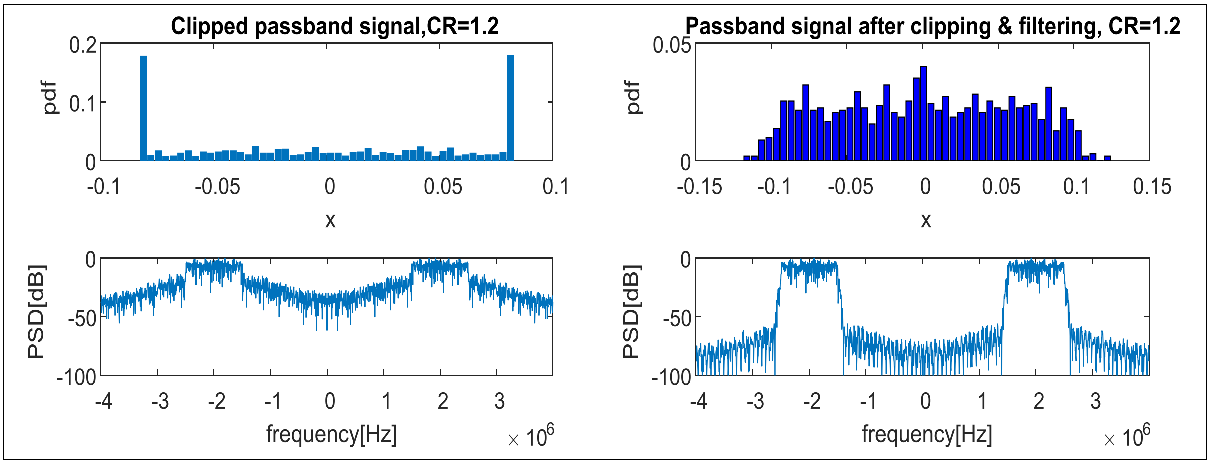

Figure 3:*(a) Pdf and Power Spectrum of Clipped GFDM Signal.(b) Pdf and Power Spectrum of Clipped &Filtered (C+F)GFDM Signal.*

The comparative BER performance curves for conventional OFDM and GFDM (with and without clipping and filtering) are depicted in Figure 4.From the results it can be concluded that conventional OFDM and GFDM systems have similar BER performance but BER deviates largely when clipping and filtering is applied toOFDM and GFDM system.

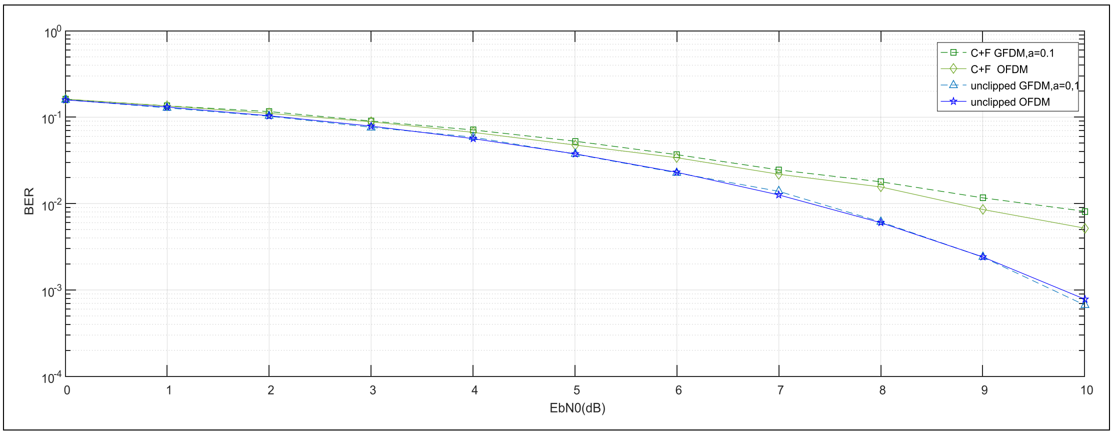

Figure 4: *BER Performance Comparison of Conventional OFDM and Conventional GFDM with Clipped andFiltered OFDM and GFDM for roll off Factor a=0.3 and Clipping Ratio CR=1.2.*

CONCLUSION

The work proposed here shows that OOB leakage of GFDM system is reduced up to a large extent with clipping and filtering technique at the cost of small BER deviation which can be further reduced by using successive interference cancellation method.

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