Spectrum Characteristic Analysis of FBMC, UFMC, and W-OFDM System Under The Nonlinear HPA Environments

Changyoung An[1], Kyunglok Kung[2], Byeongjae Kim[3], and Heung-Gyoon Ryu[4]
[1,2,3,4] Department of Electronics and Engineering, Chungbuk National University
Cheongju, Chungbuk, 361-763, Korea
E-mail: [1]acy890217@naver.com, [2]kkr427@hanmail.net, [3]bj5236@nate.com, and [4]ecomm@cbu.ac.kr

Abstract: In order to satisfy requirements of 5G mobile communication, researches on new waveform based on multi-carrier are being carried out. In this paper, we describe OFDM, UFMC, FBMC, and W-OFDM. And then, we evaluate and analyze spectrum characteristics of these system under the nonlinear HPA environment. As simulation results, FBMC has the lowest OOB power under the linear HPA condition. But, OOB power levels of UFMC, FBMC, and W-OFDM are similar under the nonlinear HPA environment. In real implementation, HPA has nonlinear characteristic. Therefore, W-OFDM technique is more advantageous because W-OFDM system has low-complexity and requires simple processing.

1. Introduction

5G mobile communication requires higher key performance indicators (KPIs) than 4th generation (4G) mobile communication [1-2]. To realize 5G mobile communication, much research is being carried out actively [3-4]. Especially, in physical layer, multi-carrier based universal filtered multi-carrier (UFMC), filter bank based multi-carrier (FBMC), and W (Weighted overlap and add)-OFDM are well known as new waveforms for spectral efficiency improvement [5]. These systems target at 5G mobile communications. These systems have low OOB power level. The lower out-of-band (OOB) power, the higher spectral efficiency. But, in real world, because of HPA nonlinearity, Advantages of these systems are degraded. That is, OOB power of these systems increases.

In this paper, in order to analyze OOB characteristics degradation of these systems, firstly, we design these systems. Next, we simulate these systems under the nonlinear HPA environment. By using simulation, we evaluate and analyze spectrum characteristics of these systems.

2. System model

2. 1 OFDM

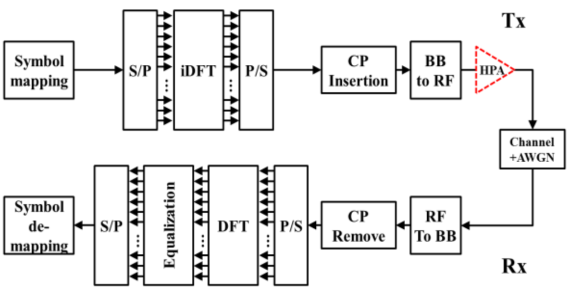


Fig. 1. Block diagram of OFDM system.
OFDM system uses orthogonal multi-carrier [5].

2. 2 UFMC

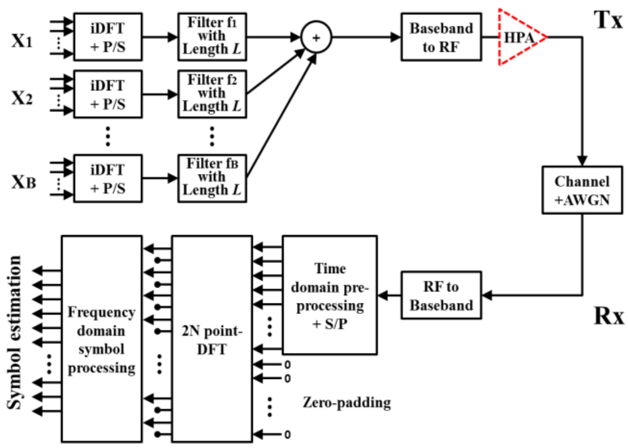
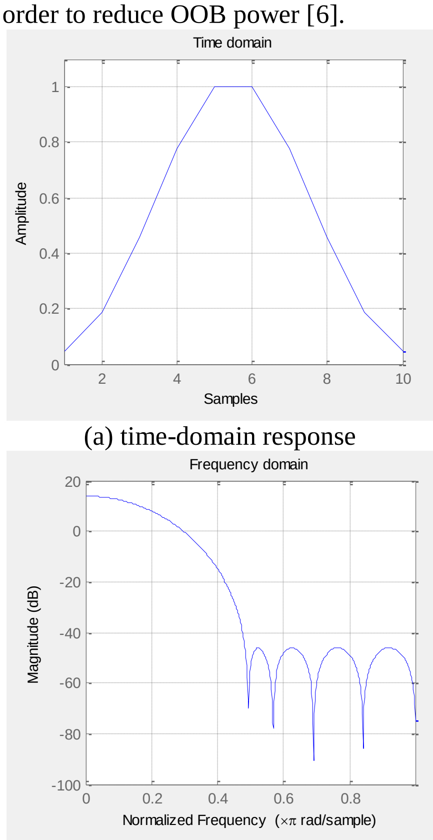


Fig. 2. Block diagram of UFMC system.

UFMC system uses sub-band filtering technique. UFMC filters each sub-band that consists of orthogonal multi-carrier in order to reduce OOB power [6].



(a) time-domain response

(b) frequency-domain response

Fig. 3. Time-domain response and frequency-domain response of Dolph-Chebyshev filter for UFMC.

2. 3 FBMC

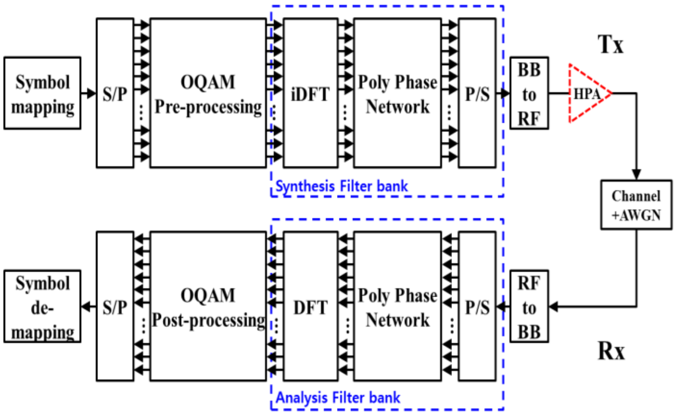
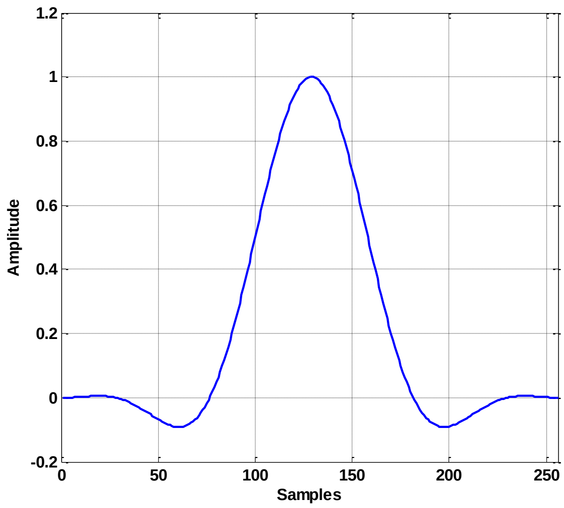
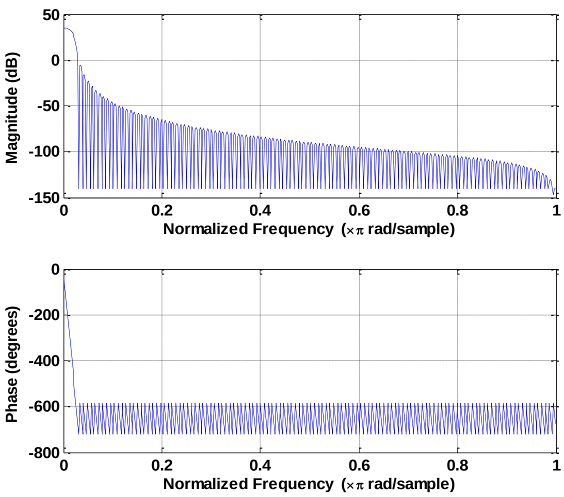


Fig. 4. Block diagram of FBMC system.

FBMC system is based on multi-carrier, like OFDM system. FBMC system filters each sub-carrier in order to reduce OOB power of spectrum [7].



(a) time-domain response



(b) frequency-domain response

Fig. 5. Time-domain response and frequency-domain response of Phydyas prototype filter for FBMC.

2. 4 W-OFDM

W-OFDM uses weighted overlap and addition method for windowing time-domain signal. Windowing technique can reduce OOB power of OFDM system.

3. HPA nonlinearity

In this paper, we have used Saleh model in order to apply HPA nonlinearity. AM-AM and AM-PM characteristic for Saleh model are as follows [8].

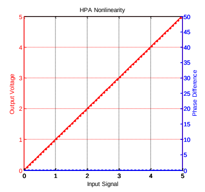
$$G[A(t)] = \frac{\alpha_A A(t)}{1+\beta_A A(t)^2} \quad (1)$$

$$\Phi[A(t)] = \frac{\alpha_\Phi A(t)}{1+\beta_\Phi A(t)^2} \quad (2)$$

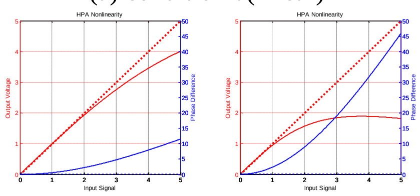
Equation (1) shows AM-AM characteristic. Equation (2) shows AM-PM characteristic. *A(t)* is amplitude of input signal. α_A , β_A , α_Φ , and β_Φ are coefficients for adjusting HPA nonlinearity strength.

Table 1. Nonlinear HPA conditions for simulation.

Condition	AM-AM	AM-PM
0 (linear)	$\alpha_A = 1$	$\alpha_\Phi = 0$
	$\beta_A = 0$	$\beta_\Phi = 0.01$
1	$\alpha_A = 1$	$\alpha_\Phi = 0.01$
	$\beta_A = 0.01$	$\beta_\Phi = 0.01$
2	$\alpha_A = 1$	$\alpha_\Phi = 0.07$
	$\beta_A = 0.04$	$\beta_\Phi = 0.01$



(a) condition 0(linear)



(b) condition 1 (c) condition 2

Fig. 6. Nonlinear HPA conditions for the simulation.

In the fig. 4, red line and blue line mean AM-AM and AM-PM characteristic respectively. Condition 0 shows linear HPA characteristic. Condition 1 shows weak HPA nonlinearity. Condition 4 shows the strongest HPA nonlinearity.

4. Simulation results and Analysis

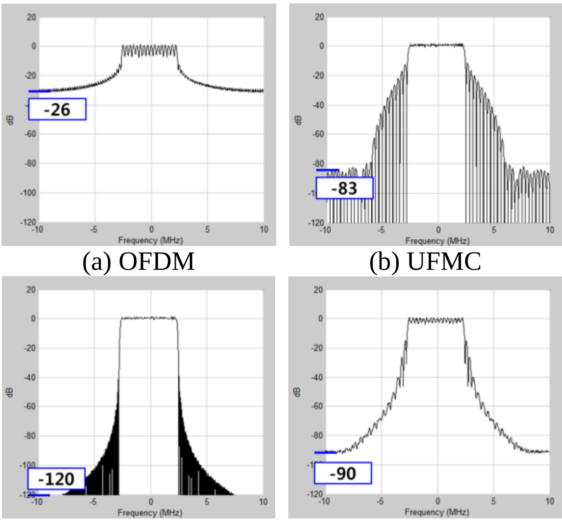
Table 2. Simulation parameters.

Parameters	Values
Modulation	QAM
# of total subcarriers (total system)	64
# of used subcarriers	16, 32
Filter for FBMC	Phydyas prototype H0 = 1 H1 = 0.97196 H2 = 0.7071 H3 = 0.235147
Filter for UFMC	Chebyshev Attenuation = 60dB Length = 10
# of sub-band in UFMC	64/8
Extension length in W-OFDM	16*2

In order to analyze spectrum characteristics, we have used Simulink simulation tool.

Table 3. OOB power comparison.

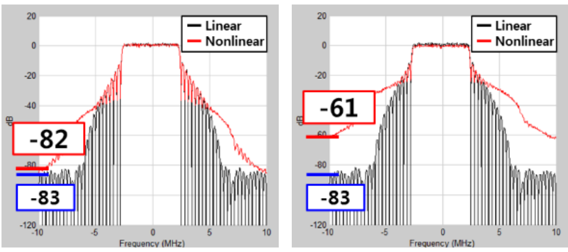
Condition	OFDM	UFMC	FBMC	W-OFDM
Linear	-26 dB	-83 dB	-120 dB	-90 dB
condition 1	-26 dB	-82 dB	-85 dB	-85 dB
condition 2	-26 dB	-61 dB	-62 dB	-63 dB



(a) OFDM (b) UFMC

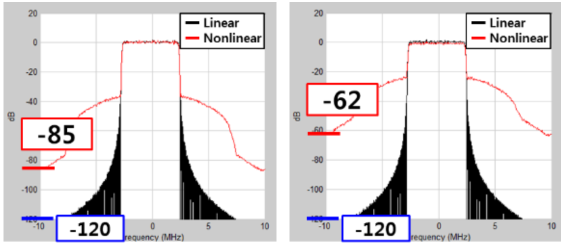
(c) FBMC (d) W-OFDM

Fig. 7. Spectrum characteristic of OFDM, UFMC, FBMC, W-OFDM under the linear HPA condition (condition 0).



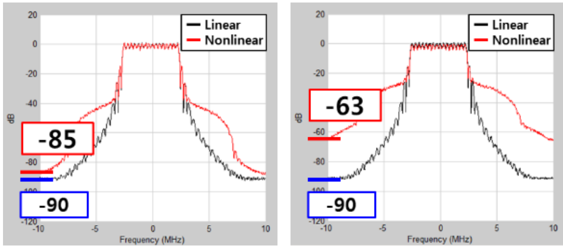
(a) condition 1 (b) condition 2

Fig. 8. Spectrum characteristic of UFMC according to the nonlinear HPA conditions.



(a) condition 1 (b) condition 2

Fig. 9. Spectrum characteristic of FBMC according to the nonlinear HPA conditions.



(a) condition 1 (b) condition 2

Fig. 10. Spectrum characteristic of W-OFDM according to the nonlinear HPA conditions.

Fig. 7, fig. 8, fig. 9, and fig. 10 show spectrum characteristics of each system under the linear or nonlinear HPA conditions.

Table 3. Comparison of OOB power characteristic.

Table 3 represents OOB power comparison of each system under the nonlinear HPA environments. OFDM system has the highest OOB power on every condition. FBMC system just has the lowest OOB power on the linear condition. In nonlinear HPA condition, OOB power of UFMC, FBMC, and W-OFDM system is similar to each other.

5. Conclusions

In this paper, we have evaluated OOB power of UFMC, FBMC, and W-OFDM system. We also have considered Nonlinear HPA condition. As simulation results, FBMC has the lowest OOB power under the linear HPA condition. But, OOB power levels of UFMC, FBMC, and W-OFDM are similar under the nonlinear HPA environment. In real implementation, HPA has nonlinear characteristic. Therefore, W-OFDM technique is more advantageous because W-OFDM system has low-complexity and requires simple processing. W-OFDM also has flexibility between transmission time interval (TTI) of time-domain and OOB power of frequency-domain.

Acknowledgment

This work was supported by Institute for Information & communications Technology Promotion (IITP) grant funded by the Korea government (MSIP) (No. R0101-16-244, Development of 5G Mobile Communication Technologies for Hyper-connected Smart Services).

References

[1] Dahlman, E.; Mildh, G.; Parkvall, S.; Peisa, J.; Sachs, J.; Selén, Y.; Sköld, J., "5G wireless access: requirements and realization," *Communications Magazine, IEEE*, vol. 52, no. 12, pp. 42-47, December 2014.

[2] Shanzhi Chen; Jian Zhao, "The requirements, challenges, and technologies for 5G of terrestrial mobile telecommunication," *Communications Magazine, IEEE*, vol. 52, no. 5, pp. 36-43, May 2014.

[3] P. Banelli et al., "Modulation Formats and Waveforms for the Physical Layer of 5G Wireless Networks: Who Will be the Heir of OFDM?", *in arXiv:1407.5947*, July 2014.

[4] G. Wunder et al., "5GNOW: non-orthogonal, asynchronous waveforms for future mobile applications", *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 97-105, Feb. 2014.

[5] F. Schaich, and T. Wild, "Waveform contenders for 5G — OFDM vs. FBMC vs. UFMC", *Communications, Control and Signal Processing (ISCCSP), 2014 6th International Symposium on*, pp. 457-460, 21-23 May 2014.

[6] V. Vakilian, T. Wild, F. Schaich, S. ten Brink, and J. F. Frigon,, "Universal-filtered multi-carrier technique for wireless systems beyond LTE", *in Globecom Workshops (GC Wkshps), 2013 IEEE*, pp. 223-228, 9-13 Dec. 2013.

[7] B. Farhang-Boroujeny, "OFDM versus filter bank multicarrier," *in Signal Processing Magazine, IEEE*, vol. 28, no. 3, pp. 92-112, May 2011.

[8] P. Drotar, J. Gazda, D. Kocur, and P. Galajda, "MC-CDMA performance analysis for different spreading codes at HPA Saleh model," *18th Int. Conf. Radioelektronika, pp*. 1-4, Prague, Apr. 2008.