

# Peak-to-average power ratio reduction scheme in impulse postfix OFDM system

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**Abstract**—A recently introduced impulse postfix OFDM (IP-OFDM) system achieves the enhanced bit error rate (BER) performance compared to that of conventional OFDM systems, but there is an important peak-to-average power ratio (PAPR) issue of using impulse postfix (IP) that needs to be resolved. This paper proposes a combined IP-OFDM scheme with the selected mapping technique and the optimum power boosting factor (PBF) determination method to resolve the PAPR issue while achieving the enhanced BER performance. In this paper, the effectiveness of proposed scheme is analyzed in terms of the BER performance as well as the input back-off (IBO) to high power amplifier. The analytic results show that the proposed scheme provides the remarkable BER performance enhancement with relatively low IBO (or PBF) rather than with high IBO (or PBF).

**Index Terms**—Impulse Postfix OFDM (IP-OFDM), Peak-to-Average Power Ratio (PAPR), SLM, Power boosting factor.

## I. INTRODUCTION

A novel channel estimation technique for OFDM systems, which is called as impulse postfix OFDM (IP-OFDM), has recently been introduced [1], [2]. The IP-OFDM system exploits the IP, which consists of a high power impulse sample and several zero samples at the end of a zero padded-OFDM symbol block, to estimate channel impulse responses in time-domain. As shown in [1], [2], the IP-OFDM system achieves the enhanced bit error rate (BER) performance compared to that of conventional OFDM systems. However, there is an important peak-to-average power ratio (PAPR) issue, which can degrade the BER performance of IP-OFDM systems due to the nonlinear distortion of the IP. For this reason, an optimum power boosting factor (PBF) determination method for IP was proposed to avoid nonlinear distortion of IP [3]. The PBF of IP should be decided using the CCDF and the IBO, which are determined by HPA characteristics. It is also shown that boosting the IP without considering these factors may degrade the BER performance significantly.

In this paper, we propose a combined IP-OFDM scheme with a selected mapping (SLM) technique and the optimum PBF determination method to resolve the PAPR issue, while achieving the enhanced BER performance. In the scheme, the signal with minimum PAPR is selected from the generated multiple signals with different PAPRs and then, the optimum PBF of IP is determined to enhance the BER performance of the system. According to the analytic results, the proposed

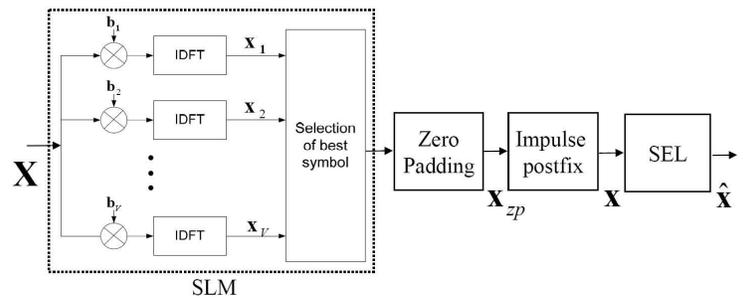


Fig. 1. Simplified block diagram for the proposed scheme

scheme provides the remarkable BER performance enhancement with relatively low input back-off (IBO) rather than with high IBO.

## II. SYSTEM DESCRIPTION

The time-domain representation of OFDM symbol with  $N$  subcarriers can be represented as follows:

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X[k] e^{j2\pi f_k t}, \quad 0 \leq t \leq T_s, \quad (1)$$

where  $T_s$  is the duration of the OFDM symbol and  $f_k = \frac{k}{T_s}$ .

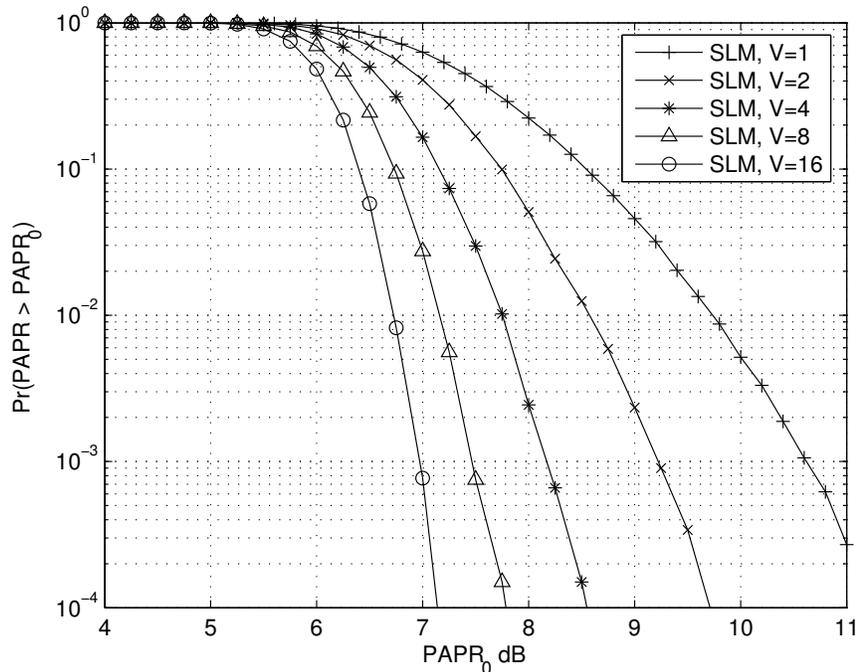
The IP-OFDM proposed in [1] is a modified OFDM system, which adds an impulse sample and several zero samples at the end of a zero padded-OFDM symbol [4] for time-domain channel estimation. If we assume the length of the guard interval is  $L$ , we can represent the time-domain IP-OFDM symbol vector  $\mathbf{u}$  as follows:

$$\mathbf{u} = [u(0), u(1), \dots, u(N + 2L)]^T = [\mathbf{x}, \mathbf{g}, \mathbf{p}]^T, \quad (2)$$

where  $\mathbf{x}$  is the  $1 \times N$  OFDM data vector,  $\mathbf{g}$  is the  $1 \times L$  zero vector,  $\mathbf{p}$  is the  $1 \times (L + 1)$  IP for channel estimation, and  $T$  represents transpose operation. The IP,  $\mathbf{p}$ , is composed of an impulse sample,  $s$ , and  $L$  zeros, and can be expressed as follows:

$$\mathbf{p} = [s, \mathbf{0}_{(1 \times L)}], \quad (3)$$

where  $\mathbf{0}_{(1 \times L)}$  is the  $(1 \times L)$  zero vector.


 Fig. 2. PAPR performance of SLM with various  $V$ .

### III. PROPOSED SCHEME

#### A. System Framework

The simplified block diagram for a transmitter part of the proposed scheme is shown in Fig. 1. A SLM block and a soft envelope limiter (SEL) are employed to obtain the signal with the reduced PAPR and to represent the nonlinearity of high power amplifier (HPA), respectively. In the figure,  $\mathbf{X}$ , the input symbol of SLM, represents a QPSK/QAM modulated baseband signal and  $\mathbf{b}_i$ ,  $i = 1, 2, \dots, V$ , represents  $V$  different phase sequences to be multiplied with  $\mathbf{X}$ . Each phase sequence consists of  $N$  phases, which are selected from  $\{\pm 1\}$  for simplicity. Note that the length of both  $\mathbf{X}$  and  $\mathbf{b}_i$  are same with the number of subcarriers  $N$ . If a signal block  $\mathbf{X}$  is multiplied with  $V$  different phase sequences and the inverse discrete Fourier transform (IDFT) is applied to each block, then  $V$  different OFDM signal blocks are generated from one original signal block. Since the PAPR of OFDM signal is very sensitive to phase variation, the  $V$  different signal blocks have different PAPRs. Therefore, we can select the signal with minimum PAPR from the generated multiple signals with different PAPRs [5]. After that, zero samples and IP are added to constitute IP-OFDM signal [1].

Generally, the PAPR in the digital domain is not necessarily the same as the PAPR in the analog domain, where nonlinear distortion due to high PAPR occurs. However, it is shown that the PAPR in the analog domain can be closely approximated by oversampling the signal in the digital domain [6]. Usually, an oversampling factor  $D = 4$  is sufficient to approximate the PAPR in the analog domain. Therefore, we can express the

PAPR of the OFDM signal as follows:

$$PAPR = \frac{\max_{0 \leq n \leq DN-1} |x(n)|^2}{E(|x(n)|^2)}, \quad (4)$$

where  $E(\cdot)$  denotes the expectation operator.

#### B. Analysis of CCDF

It is known that the CCDF (Complementary Cumulative Distribution Function) of the SLM-OFDM signal can be represented as follows [7]:

$$CCDF = P(PAPR \geq PAPR_0) \approx (1 - (1 - e^{-PAPR_0 \alpha N})^V), \quad (5)$$

where  $\alpha$  is an adjustment factor for the close approximation of the CCDF of OFDM signal,  $N$  and  $V$  are the numbers of subcarriers and different phase sets, respectively. As we can see from (5), if the number of subcarriers,  $N$ , is increased, the PAPR of OFDM signals is increased. On the other hand, if the number of phase set,  $V$ , is increased, the PAPR of OFDM signals is reduced as shown in Fig. 2

Fig. 3 shows the CCDF simulation results of the signal of proposed scheme, when the randomly generated four different phase sets  $V = 4$  and various PBFs,  $p = 0, 2, 5, 6, 7, 8$  dB, are assumed. In the simulations, we use QPSK modulation with  $N = 64$  subcarriers and  $D = 4$  oversampling factor. As shown in the figure, the PAPR of the signal of the proposed scheme is remarkably reduced compared to that of the original signal and a HPA that is linear up to around  $8 \sim 9$  dB is good enough if allowable nonlinear distortion probability is  $10^{-4}$ .

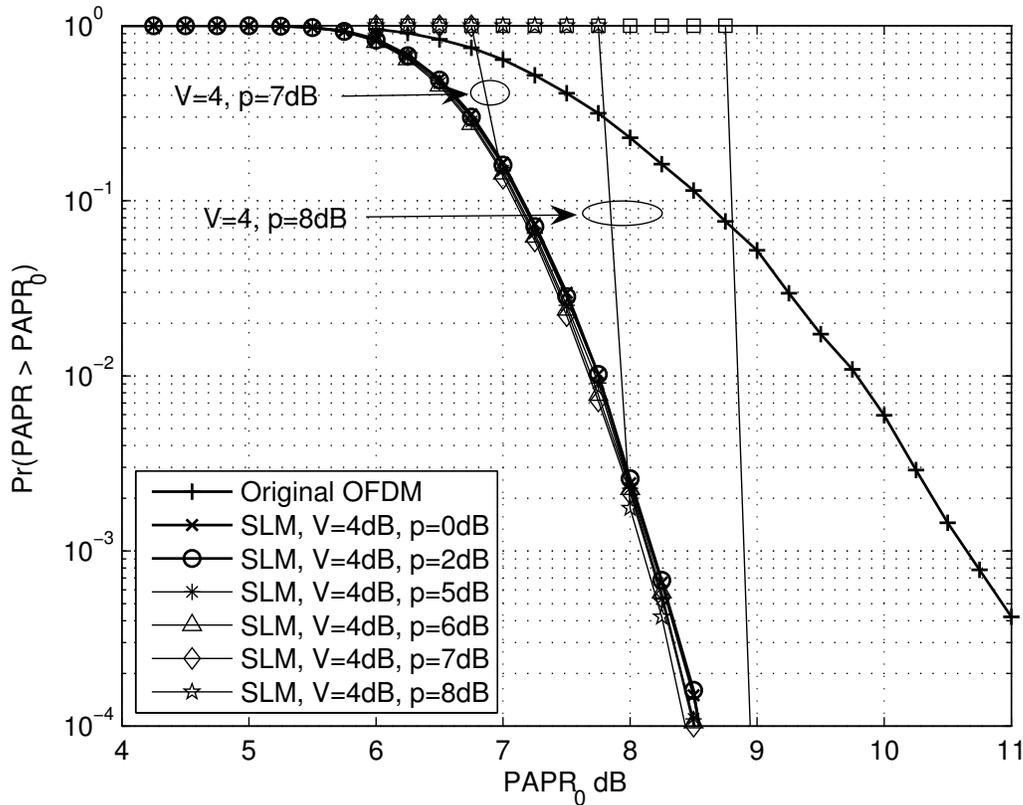


Fig. 3. CCDF of the signal of proposed scheme, when  $p=0, 2, 5, 6, 7, 8$  dB.

Note that the actual PBF,  $p$ , needs not to be reduced because the maximum allowable amplitude is given with the HPA in real systems, when the PAPR of OFDM signals is reduced.

To represent the nonlinearity of HPA, the SEL, which is equivalent to Rapp's SSPA model with an infinity smoothness factor [8], is employed. With the input signal  $x(n)$ , the output signal  $\hat{x}(n)$  of the SEL can be represented as follows [6]:

$$\hat{x}(n) = \begin{cases} x(n), & |x(n)| \leq A_{max} \\ A_{max} e^{j\phi(n)}, & |x(n)| > A_{max} \end{cases} \quad (6)$$

where  $A_{max}$  is the maximum allowable amplitude without distortion and  $\phi(n)$  is the phase of the input signal.

In [3], it is shown that the PBF of IP should be carefully determined with two criteria, the CCDF of signal and the value of IBO defined as follows [9]:

$$IBO(dB) = 10 \log_{10} \left( \frac{A_0^2}{P_{in}} \right), \quad (7)$$

where  $A_0$  is the maximum allowable input amplitude and  $P_{in}$  is the average input power of the OFDM signal before going through the HPA. In the SEL,  $A_{max}$  is equivalent to  $A_0$ , which is the maximum allowable amplitude in the HPA, and is fixed regardless of the PAPR of the input signals. As shown in [3], therefore, the optimum PBF of IP can be determined as the same value of IBO, where the amplitude of the impulse

sample is the same with  $A_{max}(=A_0)$ . That is, even though the PAPR of OFDM signals is reduced by the SLM technique, the optimum PBF is same with IBO, as is without the SLM technique.

#### IV. NUMERICAL RESULTS

Fig. 4 shows the BER performance of the proposed scheme over the frequency selective Rayleigh fading channel with 8-taps exponential power delay profile, where the parameters are set as  $N=64$  subcarriers,  $L = 16$  guard interval, 16QAM, four different values of  $IBO=2, 3, 4, 5$ dB with the optimum PBF,  $p(=IBO)$ , and  $V=1$ (w/o SLM), 4, 8. We assume perfect SLM side information at the receiver. As shown in the figure, we can enhance the BER performance of IP-OFDM by increasing  $V$  in the SLM technique at the low IBO. Note that the BER performance is remarkably enhanced by increasing  $V$  1 to 8 at  $IBO=2, 3$ . However, the effect of SLM is significantly reduced at the high  $IBO=4, 5$ .

This is because the effect of OFDM PAPR reduction for HPA is reduced as increasing IBO. Note that the power efficiency of HPA, which is another system constraint, is degraded as increasing the IBO to the HPA.

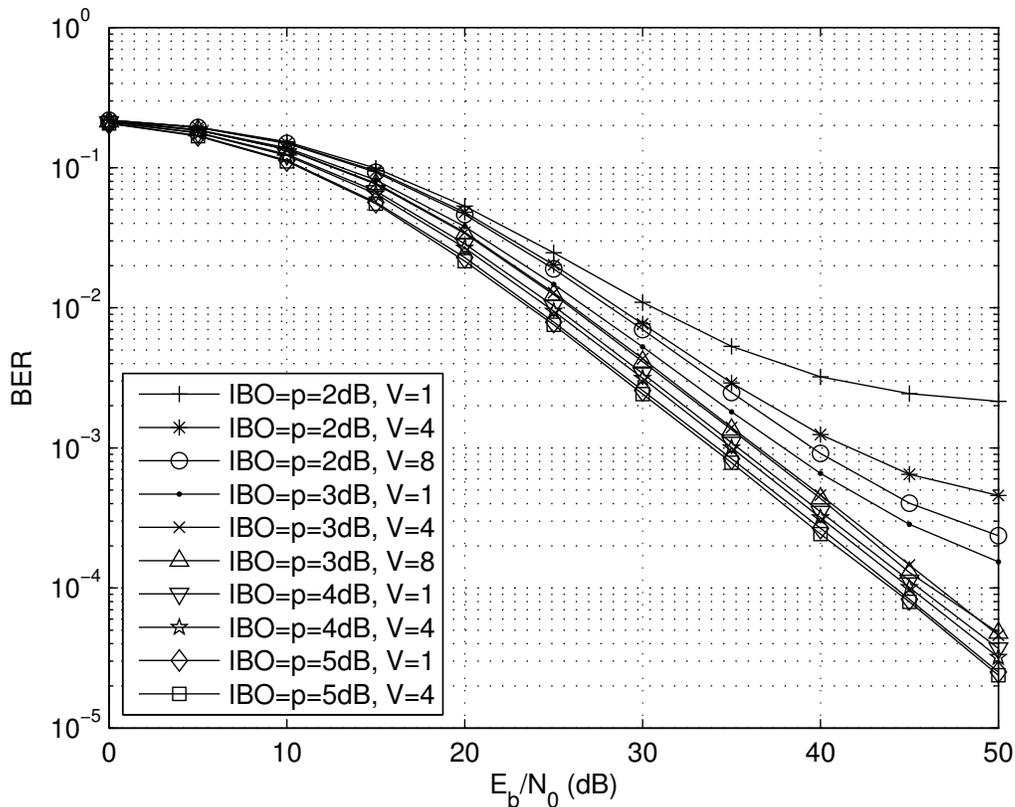


Fig. 4. BER performance of the proposed scheme.

V. CONCLUSION

A combined IP-OFDM scheme with the SLM technique and the optimum PBF determination method is proposed to resolve the PAPR issue, while achieving the enhanced BER performance. The analytic results show that the proposed scheme can provides the remarkable BER performance enhancement with relatively low IBO. On the other hand, the BER performance can be enhanced by increasing the IBO at the cost of degradation of the power efficiency of HPA. As a future work, a practical IP-OFDM system with a nonlinear HPA will be considered and the impact of nonlinear HPA on the determination of the PBF of IP as well as the BER performance will be analyzed.

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REFERENCES

[1] N. Chang and J. Kang, "Impulse Symbol Based Channel Estimation in OFDM Systems," *IEEE Internation Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 1-5, Sep. 2006.

[2] N. Chang, N.Y. Kim, J. Kang, Y. Kim, and H. Lee, "Statistic-Based magnitude determination of impulse sample in impulse postfix OFDM Systems," *IEICE Transactions on Communications*, vol.E90-B, no.12, Dec. 2007.

[3] B. Lee and Y. Kim, "Practical determination of impulse sample power boosting factor in impulse postfix OFDM systems," *IEEE Communications Letters*, pp. 187-189, Mar. 2009.

[4] B. Muquet, Z. Wang, G.B. Giannakis, M. de Courville, P. Duhamel, "Cyclic prefixing or zero padding for wireless multicarrier transmissions?," *IEEE Transactions on Communications*, vol. 50, Issue 12, pp. 2136-2148, Dec. 2002.

[5] R.W. Bauml, R.F.H. Fischer, and J.B. Huber, "Reducing the peak-to-average power ratio of multicarrier modulation by selected mapping," *Electronics Letters*, vol.32, pp. 2056-2057, Oct. 1996.

[6] L. Wang and C. Tellambura, "A Simplified Clipping and Filtering Technique for PAR Reduction in OFDM Systems," *IEEE Signal Processing Letters*, vol.12, no.6, Jun. 2005.

[7] H. Ochiai and H. Imai, "Performance of the deliberate clipping with adaptive symbol selection for strictly band-limited OFDM systems," *IEEE Journal on Selected Areas in Communications*, vol.18, pp.2270-2277, Nov. 2000.

[8] C. Rapp, "Effect of HPA-nonlinearity on 4-DPSK/OFDM-signal for a digital sound broadcasting system," *Proc. the Second European Conference on Satellite Communications*, Liege, Belgium, pp.179-184, Oct. 1991.

[9] B. Lee and R.J.P. de Figueiredo, "Adaptive Pre-Distorters for Linearization of High Power Amplifiers in OFDM Wireless Communications," *Circuits, Systems and Signal Processing*, Birkhauser Boston, vol.25, pp. 59-80, 2006.