Impact of the Solid State Power Amplifier on the BER Performance of the SC-FDMA System

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Abstract: - This paper presents an investigation of the impact of the solid state power amplifier SSPA on the performance of localized SC-FDMA and interleaved SC-FDMA system. SSPA is used for amplification of the SC-FDMA signal. The input back off IBO is simulated for pederstain A (Ped A) and vehicular A (Veh A) channel with MMSE equalizer. SSPA is used with IBO=1,3,6 dB and P=2 values. Simulation results show that the IBO of the SSPA has a significant effect on the bit error performance BER of the SC-FDMA system. Finally, the SSPA should be designed carefully for the SC-FDMA system in order to provide a good performance.
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Key-Words: - SC-FDMA, BER, SSPA, IBO, MMSE

1 Introduction

SC-FDMA system has been adopted by the third generation partnership project (3GPP) for uplink transmission in the technology standardized for long term evolution (LTE) of cellular system[1]. SC-FDMA is a combination of single carrier modulation, orthogonal frequency multiplexing and frequency domain equalization (FDE) [2]. It also provides the multipath resistance and flexible sub-carrier frequency allocation offered by OFDMA. SC-FDMA commonly exploits one of three subcarrier mapping schemes: Distributed FDMA (DFDMA), Localized FDMA (LFDMA) or Interleaved FDMA (IFDMA). Each subcarriers mapping technique has its own strengths and weaknesses. For example, the LFDMA system is more robust to multiple access interference, but it has a higher PAPR. More importantly, the IFDMA system is more sensitive to the timing and frequency errors, but it has a lower PAPR [3]. Localized SC-FDMA has been selected since it performs best in the presence of multiple access interference.

However, multicarrier transmission systems show a great sensitivity to the nonlinear distortion effects caused by the use of high power amplifiers (HPA) [4] or clipping devices [5] at the transmitter. Hence, a proper design should take into account performance evaluation in the presence of nonlinear distortion.

The nonlinear distortion at the transmitter causes some interference both inside and outside the signal bandwidth. The in-band component determines a degradation of the system bit-error rate (BER), whereas the out-of-band component affects adjacent frequency bands. In many applications, out-of-band emissions might become intolerable even when BER degradation is still acceptable [6].

The problem of BER performance in SC-FDMA system without HPA has been studied in several works [7][8][9]. However, the impact of HPA on the performance of SC-FDMA has been made in [3]. In this work we study the impact of the SSPA on the performance of localized SC-FDMA and interleaved SC-FDMA system. The objective of this work is to investigate the impact of IBO on the performance of SC-FDMA system for Ped A and Veh A channel with MMSE equalizer.

The paper is organized as follows: Section II presents SC-FDMA system model; in section III we describe the SSPA model. Simulation results are provided in section IV. Section V concludes the paper.

2 Localized SC-FDMA Uplink System

In SC-FDMA system, the input block data after S/P converter is a complex vector of length M, that can be written as $s = [s_0, s_1, s_2, \ldots, s_M]^T$. A DFT precoded is applied to this vector that gives

$$S_n = DFT\{s\} = \frac{1}{M}\sum_{l=0}^{M-1} s_l \, . \, e^{-j2\pi\frac{n}{M}l} \tag{1}$$

$n = 0,1,2, \ldots, M-1$

The resulting signal is then mapped to N orthogonal subcarriers so, we get:

$$\tilde{S}_k = [\tilde{S}_0, \tilde{S}_1, \tilde{S}_2, \ldots, \tilde{S}_{N-1}]^T \tag{2}$$

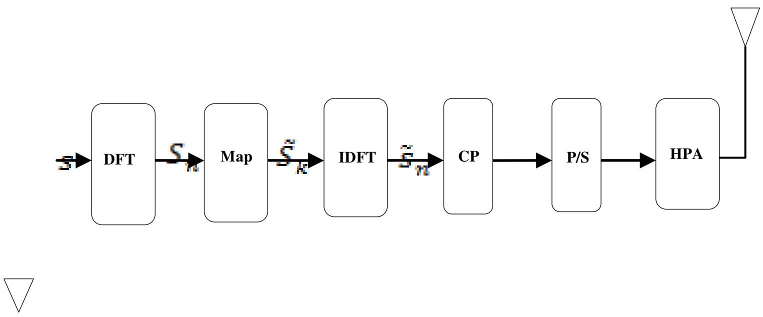
.

The N-point IDFT of this signal converts it to a time domain complex sequence and can be expressed as

$$\tilde{s}_n = IFDT\{\tilde{S}_k\} = \frac{1}{N}\sum_{k=0}^{N-1} \tilde{S}_k \, . \, e^{j2\pi\frac{n}{N}k} \tag{3}$$

$0 \leq n \leq N-1$

Finally, a cyclic prefix (CP) of length L_{cp} is added to the output signal and then the HPA is applied. L_{cp} must be greater than the maximum excess delay of the channel to accommodate for the inter-block interference.



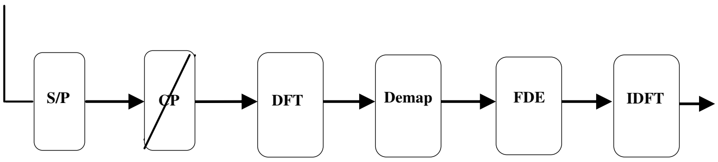


Fig 1. Block diagram of the SC-FDMA.

At the reception, the CP is removed from the received signal, and N-points DFT is applied to the signal in order to transform into the frequency domain, after that, the subcarrier demapping and the frequency domain equalization FDE processes are applied. Finally, the resulting signal is transformed back into the time domain via an N-points IDFT and the demodulation process is performed.

3 Solid State Power Amplifier (SSPA)

The high power amplifier (HPA) is one of the high cost components of the user terminal. The relationship between the HPA cost and its maximum power rating is an important technology issue. The HPA used in radio transmitters have nonlinear characteristics causes some interference both inside and outside the signal bandwidth.

Nonlinear HPAs can be described by two kinds of models, memory-less models with frequency-flat responses and memory models with frequency-selective responses [10]. Memory-less HPA models, such as TWTA model [11], the SSPA model [12], the SEL model [13], and the polynomial model [14]. On the other hand, HPAs may be characterized by more realistic memory models, such as the Volterra, Wiener, Hammerstein, Wiener Hammerstein, and memory polynomial models [10].

A HPA model can be described by its input/output or transfer function characteristics. The AM/AM and AM/PM characteristics indicate the relationship between, respectively, the modulus and the phase variation of the output signal as functions of the modulus of the input one. The AM/AM and AM/PM characteristics cause distortions on the constellation scheme and spectral regrowth, degrading then the system performance.

Modulated symbol stream has a complex envelop $i(t) = x(t) + jy(t)$ that can be written for both modulation schemes as

$$i(t) = \rho(t)e^{j\varphi(t)} \tag{4}$$

Where

$\rho(t) = \sqrt{|x(t)|^2 + |y(t)|^2}$ is the signal input modulus,

$\phi(t) = arctan(\frac{y(t)}{x(t)})$ is the signal input phase.

The amplified signal $u(t)$ can be written as

$$u(t) = F_a(\rho)\, e^{jF_p(\rho)}\, e^{j\phi}$$

$$= S(\rho)e^{j\phi} \tag{5}$$

Where

$F_a(\rho)$ is the AM/AM characteristic of the HPA,

$F_p(\rho)$ is the AM/PM characteristic of the HPA,

$S(\rho) = F_a(\rho)\, e^{jF_p(\rho)}$ is the complex envelop of the amplified signal $u(t)$.

In our study, we will use one memory-less HPA model that is usually used in the literature; solid state power amplifier (SSPA). This model, also known as the Rapp model, was presented in [12] and presents only AM/AM conversion. It can be expressed as

$$F_a(\rho) = \frac{\rho}{\left(1 + \left(\frac{\rho}{A_{sat}}\right)^{2v}\right)^{\frac{1}{2v}}} \tag{6}$$

$$F_a(\rho) = 0 \tag{7}$$

Where

A_{sat} is the HPA input saturation level,

v is a smoothness factor.

In order to reduce the effects of nonlinearities, the HPA is operated at a given input back-off (IBO) from a given level. In the literature there are two definitions for the IBO. In the first definition, the IBO is computed from the 1dB compression point [15]. However, in the second one [16], the authors defined the IBO form the input saturation level. In this paper, we will use the second definition, in which the IBO is expressed as follows:

$$IBO = 10\log_{10}\left(\frac{A_{sat}^2}{\sigma^2}\right) \tag{8}$$

Where σ^2 is the variance of the input signal.

4 Simulation & Results

In this part, we present numerical results illustrating the impact of the SSPA amplifier on the performance BER of the SC-FDMA system over Ped A and Veh A channels. The BER is computing by averaging on 10^{-4} randomly generated SC-FDMA symbols. Simulation parameters are given in Table 1.

Table 1. Simulation Parameters.

Parameters	Values
Channel bandwidth	5Mhz
Cyclic prefix	20
User subcarriers	128
System subcarriers	512
Spreading	DFT
Modulation schemes	4-QAM
Smoothness parameter	2
Channel estimation	Perfect
Frequency division equalization	MMSE

Fig. 2 shows the BER performance of the localized SC-FDMA system used on a Ped A channel with MMSE equalizer. SSPA is used for amplification of the SC-FDMA signal. SSPA is used with IBO=1,3,6 dB and P=2 values. The BER performance without HPA is about 15dB at BER=10^{-4}, and this value is 21 dB lower than the SSPA with IBO=1 dB. In case of IBO=3 dB and IBO=6 dB, SNR values are 27 and 27.7 respectively at BER=10^{-4}. It is clear that as IBO decrease from 6dB to 1dB, the BER performance degrades significantly. IBO is very important for the system's BER performance. IBO affect the operating point of the SSPA.

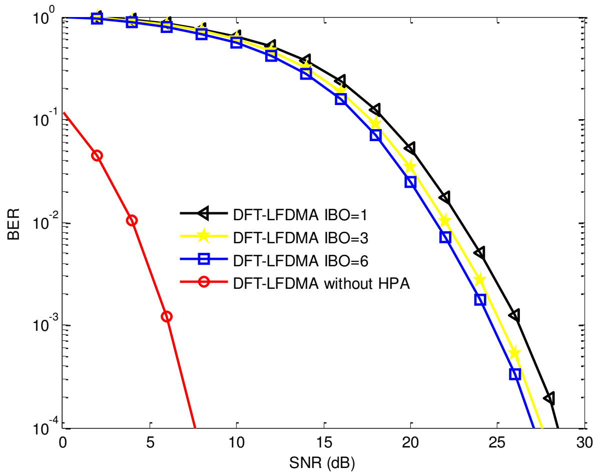


Fig. 2. BER performance of localized SC-FDMA system when a SSPA with P=2 and IBO=1,3,6 dB is used on a Ped A channel.

Fig. 3 shows the BER performance of the localized SC-FDMA system used on a Veh A channel with MMSE equalizer. SSPA is used with IBO=1,3,6 dB and P=2 values. The BER performance without HPA is about 15dB at BER=10^{-4}, and this value is 22.2 dB lower than the SSPA with IBO=1 dB. In case of IBO=3 dB and IBO=6 dB, SNR values are 33.2 and 33 respectively at BER=10^{-4}. It is clear that as IBO decrease from 6dB to 1dB, the BER performance degrades significantly.

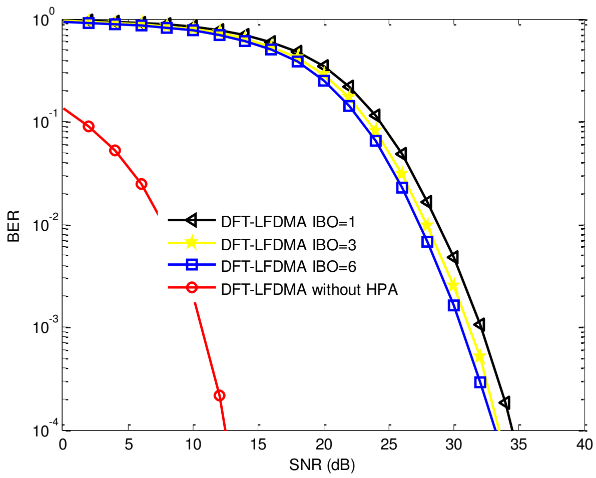


Fig. 3. BER performance of localized SC-FDMA system when a SSPA with P=2 and IBO=1,3,6dB is used on a Veh A channel.

Fig. 4 shows the BER performance of the interleaved SC-FDMA system used on a Ped A channel with MMSE equalizer. SSPA is used with IBO=1,3,6 dB and P=2 values. The BER performance without HPA is about 9.7dB at BER=10^{-4}, and this value was 16.7 dB lower than the SSPA with IBO=1 dB. In case of IBO=3 dB and IBO=6 dB, SNR values are 25.7 and 25 respectively at BER=10^{-4}. It is clear that as IBO decrease from 6dB to 1dB, the BER performance degrades significantly.

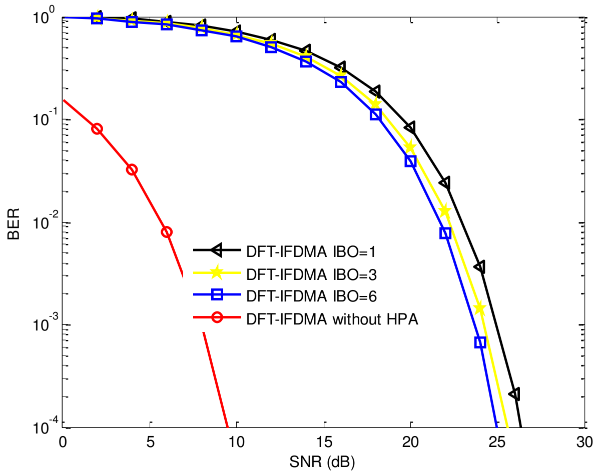


Fig. 4. BER performance of interleaved SC-FDMA system when a SSPA with P=2 and IBO=9 dB is used on a Ped A channel.

Fig. 5 shows the BER performance of the interleaved SC-FDMA system used on a Veh A channel with MMSE equalizer. SSPA is used with IBO=1,3,6 dB and P=2 values. The BER performance without HPA is about 9.7dB at BER=10^{-4}, and this value is 20 dB lower than the SSPA with IBO=1 dB. In case of IBO=3 dB and IBO=6 dB, SNR values are 34.2 and 33.6 respectively at BER=10^{-4}. It is clear that as IBO decrease from 6dB to 1dB, the BER performance degrades significantly.

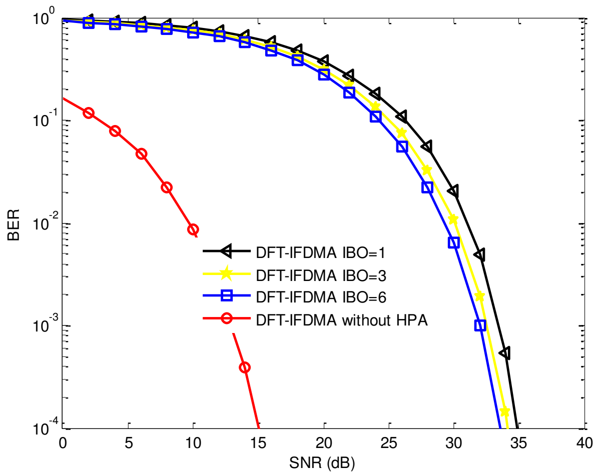


Fig. 5. BER performance of interleaved SC-FDMA system when a SSPA with P=2 and IBO=9 dB is used on a Veh A channe.l

5 Conclusion

In this paper, the impact of the SSPA on the BER performance of the localized SC-FDMA and interleaved SC-FDMA system over Ped A and Veh A channel with MMSE equalizer is investigated. From the obtained simulation results, it is clear that IBO has a significant effect on the BER performance. When IBO decrease, the BER performance degrades significantly. IBO is very important for the system's BER performance, it affect the operating point of the SSPA. Finally, the SSPA should be designed carefully for the SC-FDMA system in order to provide a good performance.

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