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Riemann Sequence based SLM with nonlinear effects of HPA

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Abstract: *Orthogonal frequency division multiplexing (OFDM) has been considered as a promising technique to achieve high data rate transmission in mobile environment. However, it is very sensitive to nonlinear effects due to high peak to average power ratio (PAPR). In this paper firstly the nonlinear effect of high power amplifier in the form of inband & outband distortion caused by high PAPR is analyzed and then Riemann sequence and normalized Riemann sequence based SLM is applied to reduce the effect of high PAPR. All the simulation results are obtained in presence of Rapp's SSPA model.*

Keywords: *Peak to average power ratio (PAPR), high power amplifier (HPA), Riemann sequence, and orthogonal frequency division multiplexing (OFDM)*

I. Introduction

Orthogonal frequency division multiplexing (OFDM) is a very attractive technique for high bit rate transmission due to its various advantages such as high spectral efficiency, robustness to channel fading, immunity to impulse interference and capability of handling very strong multi-path fading and frequency selective fading without having to provide powerful channel equalization [1].Despite the advantages, OFDM suffers from high peak-to-average power ratio (PAPR) which is the major obstacle. With high PAPR, nonlinearities increase in the system by high signal peaks, causing inter-modulation among subcarriers and due to that undesired out-of-band radiation occurs. If RF power amplifiers are operated without large power back-offs, it is impossible to keep the out-of-band power below specified limits and leads to inefficient amplification and expensive transmitters. So, it is highly desirable to reduce the PAPR [2].To deal with this problem several PAPR reduction techniques have been proposed in literature such as clipping and filtering [3], block coding [4], constellation shaping, Tone Reservation (TR) and Tone Injection (TI), nonlinear companding transforms [5], multiple signal representation techniques such as Partial Transmit Sequence (PTS)[6]and selective mapping(SLM) [7]. Every technique is having its advantages and drawbacks. Among them, multiple signal representation is one of the most promising techniques because it is simple to implement, no distortion in the transmitted signal, high bandwidth efficiency, high power efficiency and significant improvement of the statistics of the PAPR [8]. However, the conventional SLM (C-SLM) and PTS scheme suffer from higher computational complexity due to a bank of IFFT operations required to produce candidate signals, which may hinder its practical application in the systems. To overcome the inherent high computational complexity, several SLM and PTS schemes have been proposed to improve the PAPR reduction performance and reduce the computational complexity but these schemes still have substantial requirement on the computational complexity.

It is well known that every radio system employs the high power amplifier (HPA) in the transmitter to obtain sufficient transmission power and to achieve the maximum output power efficiency; it is usually operated at or near the saturation region. The nonlinear characteristic of the HPA is very sensitive to the variation in signal amplitudes and this variation becomes wide with high PAPR.For power efficient operation of the non-linear HPA with lower back off values it is necessary to reduce PAPR of OFDM system [5]. In [9], the Riemann matrix based phase sequence has been claimed to achieve the best PAPR reduction capability in SLM-OFDM system. In this work initially, the nonlinear effect of HPA is shown in the form of inband and out of band distortion and then the performance of a modified Riemann sequence based SLM with Rapp's SSPA model is analyzed with different no. of subcarriers.

II. Ofdm Signal Representation And Papr

1.1 OFDM system and PAPR definition

In an OFDM system with N subcarriers, the discrete-time transmitted signal is represented as:

$$x_k = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j\frac{2\pi nk}{N}}, k = 1, 2, ...N - 1 \quad (1)$$

Where $j = \sqrt{-1}$, X_n are the input symbols modulated by QPSK such that $X_n \in \{1, j, -1, -j\}$

The PAPR of the transmitted signal in (1) is defined as the ratio of the maximum to the average power can be expressed as [10]:

$$PAPR = 10\log_{10}\frac{\max_k |x_k|^2}{E\left[|x_k|^2\right]}\ (dB) \qquad (2)$$

where E [.] denotes expectation operation.

1.2 OFDM with Conventional SLM

In SLM, each of the phase sequences to generate alternative input sequences multiplies the input data [7]. Each of these alternative input data sequences is made the IFFT operation, and then the one with the lowest PAPR is selected for transmission. Each data block is multiplied by U different phase factors, each of length M,

$$H_u = \left[h_{u,0}h_{u,1},\ldots,h_{u,M-1}\right]^T \ (u = 0,1,\ldots U-1)$$

resulting in U different data blocks. Thus the u^{th} phase sequence after multiplication is

$$X^u = \left[X_0h_{u,0}, X_1h_{u,1},\ldots,X_{M-1}h_{u,M-1}\right]^T \ (u = 0,1,\ldots U-1)\cdot$$

therefore, OFDM signals becomes as

$$x^u(t) = \frac{1}{\sqrt{M}}\sum_{m=0}^{M-1} X_m h_{u,m} e^{j2\pi f_m t} \qquad (3)$$

where $0 \le t \le MT$, $u = 1,2,\ldots U-1$

Among the data blocks X^u , only one with the lowest PAPR is selected for transmission and the corresponding selected phase factors $h_{u,m}$ also should be transmitted to receiver as side information. As U increases, PAPR reduction becomes large while the computational complexity becomes too high, mainly due to U IFFTs. It should be noted that there is a saturation effect, that is, the additional PAPR reduction gain decreases as U increases.

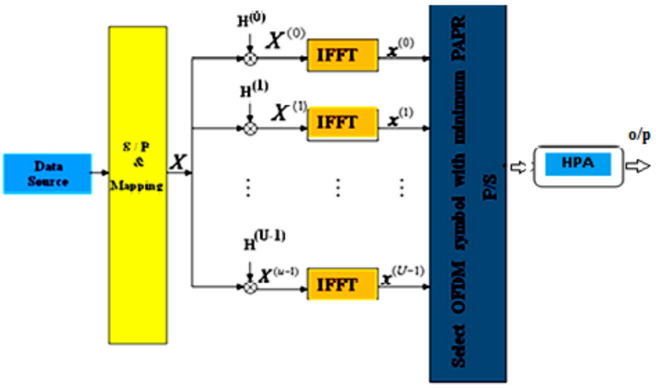


Fig.1 Block diagram of conventional SLM with HPA

1.3 Riemann sequence

The Riemann matrix (B) of size NN is obtained by removing the first row and first column of Matrix A of size $(N+1)(N+1)$ [9]

$$A(i,j) = \begin{cases} i-1 & \text{if i divides j} \\ -1 & \text{otherwise} \end{cases} \qquad (4)$$

Using Equation (4), Riemann Matrix (B) of order four can be written as:

$$B = \begin{bmatrix} -1 & -1 & -1 & -1 \\ -1 & 2 & -1 & -1 \\ -1 & -1 & 3 & -1 \\ -1 & -1 & -1 & 4 \end{bmatrix} \qquad (5)$$

The elements of p^{th} row in Riemann matrix (B) are either p or -1 for $1 \le p \le N$. If any row, except the 1st row is used for PAPR reduction in SLM-OFDM system of matrix B as phase sequence, it results not only in phase change but also amplitude change of the modulated data symbols. So, average energy of the OFDM signal after multiplication with phase sequence increases and PAPR is improved [9].

III. Nonlinear Distortion Caused By Hpa In Presence Of Ofdm Signal

When OFDM signal is passed through the HPA, the high peak to average power ratio (PAPR) of OFDM signal results into nonlinear distortions that is caused by the HPA nonlinearity. The resulting nonlinear distortion can be categorized into two types: in band distortion and out of band distortion. In-band distortion produces a degradation of the system bit error rate, whereas the out-of-band component affects adjacent frequency bands. The in-band distortion due to non-linear amplification at the transmitter results intersymbol interference (ISI), when the signal is filtered with the matched filter at the receiver. The increased ISI further increases the bit error rate (BER) and the performance of the system degrades [5].

1.1 Characterization of nonlinear distortion model

A distortion is typically characterized in the form of its amplitude-to-amplitude (AM/AM) and amplitude-to-phase (AM/PM) modulation curves, which reflect, respectively, the amplifier gain and phase progression as a function of the input power. Fig.2 shows a typical AM/AM response for HPA, with the associated input and output back-off regions (IBO and OBO) respectively.

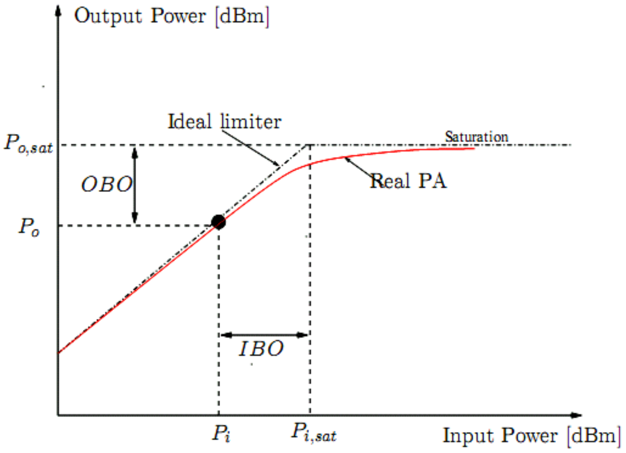


Fig.2 A typical power amplifier response for IBO and OBO.

At low input power levels, the output is a linearly scaled version of the input. However, as the power increases, the amplifier gain starts decreasing and eventually the PA is driven into saturation. The operating point where the gain of the amplifier deviates from the linear small-signal gain by 1 dB is called the 1-dB compression point. Additionally, varying input power levels also affect the phase of the output signal. Both these characteristics are a key stepping-stone in understanding symbol recovery errors that occur on the receiver end because of PA non-linearity.To avoid such undesirable nonlinear effects, a waveform with high peak power must be transmitted in the linear region of the HPA by decreasing the average power of the input signal. This is called input back off (IBO) and results in a proportional output back off (OBO), but high back-off reduces the power efficiency of the HPA and may limit the battery life for mobile applications.
The input back-off and output back-off are defined in [5] as

$$IBO = 10\log_{10}\frac{P_{i,sat}}{P_i} \qquad (6)$$

and

$$OBO = 10\log_{10}\frac{P_{o,sat}}{P_o} \qquad (7)$$

1.2 HPA model

The most common and practical model for amplifiers is the SSPA [12]. The AM/AM and AM/PM transfer characteristics can be modelled as

$$F[r] = \frac{ur}{\left[1+\left(\frac{ur}{A}\right)^{2p}\right]^{\frac{1}{2p}}} \qquad (8)$$

$$\psi[r] = 0 \qquad (9)$$

Where r is the magnitude of an OFDM signal, A is the limiting (saturating) output amplitude or clipping level of HPA, u is the small signal gain and the parameter p controls the smoothness of the transition from the linear region into the saturation region. When $p \rightarrow \infty$, the SSPA acts as a soft limiter.

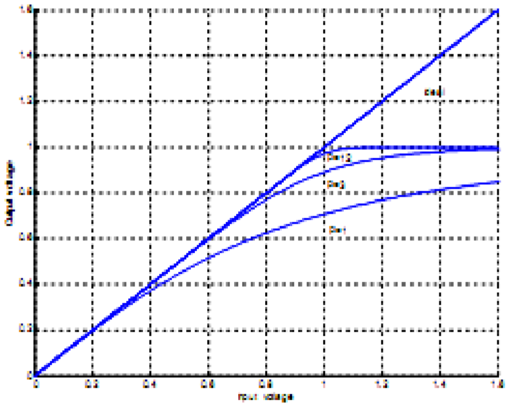
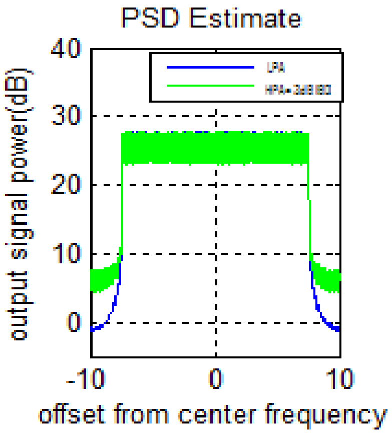


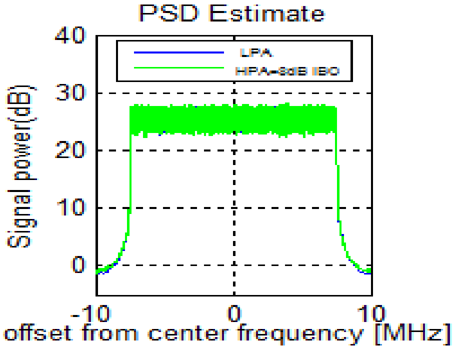
Fig.3 AM/AM properties of a Solid State Amplifier SSPA) for different values of p and an ideal amplifier

IV. Simulation Results

In this section, the effect of nonlinearity of SSPA in presence of OFDM signal is shown and to reduce this effect, Riemann based SLM is used as PAPR reduction technique. In addition, the PAPR reduction performance of conventional SLM scheme and the Riemann based SLM with SSPA for different no. of subcarriers is compared using MATLAB simulation. To show the PAPR performance of the proposed system, the data is generated randomly and then modulated by QPSK .In order to generate the complementary cumulative distribution function CCDF [5] of the PAPR, 10000 random OFDM frames have been generated. The sampling rate for an accurate PAPR is considered here four times. The Rapp's coefficient p is taken as three. Fig.4 (a) & 4(b) shows the estimated power spectral density of the distorted OFDM signal by a nonlinear SSPA for input back off values 3dB & 8dB respectively. From the results, it is clear that distortions due to HPA will decrease the out of band noise with larger backoff values. The effect of inband distortion due to non-linear amplification is depicted in fig.5 (a) & 5(b) in the form of constellation diagram for backoff values 3 dB & 8 dB respectively. Results show that with larger input backoff value, the inband distortion reduces.

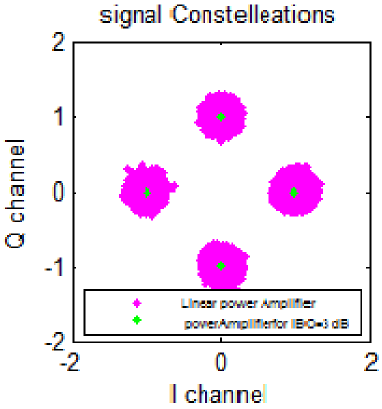


4(a)

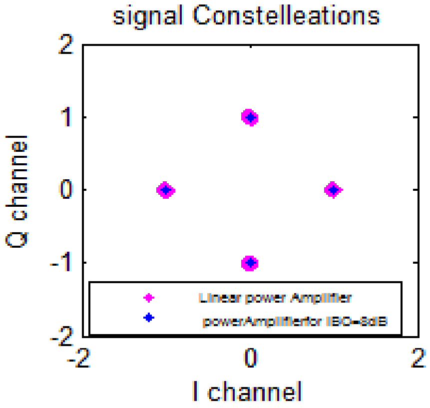


4(b)

Fig.4 Comparison for PSD of OFDM signal at the output of SSPA at IBO=3dB&8dB



5 (a)



5 (b)

Fig.5 Constellation distortions of SSPA with QPSK modulated data for input backoff IBO=3dB&8dB with p=3

Fig.6 shows the PAPR reduction using Conventional Selective Mapping with Riemann sequence and normalized Riemann sequence for no. of subcarriers N=128. The QPSK modulated data is mapped to a 128 point IFFT for modulation, a root raised cosine filter is used for pulse shaping and a SSPA is used as the amplifier model with smoothness parameter p =3 and input backoff 3dB. Results show that 1.8dB PAPR is reduced using normalized Riemann based SLM as compare to conventional SLM. Similarly fig.7 shows the performance of Riemann sequence based SLM for QAM modulated data for N=256 with same parameters as above. Here also 2.2dB PAPR reduction is achieved using Riemann based SLM as compare to conventional SLM.

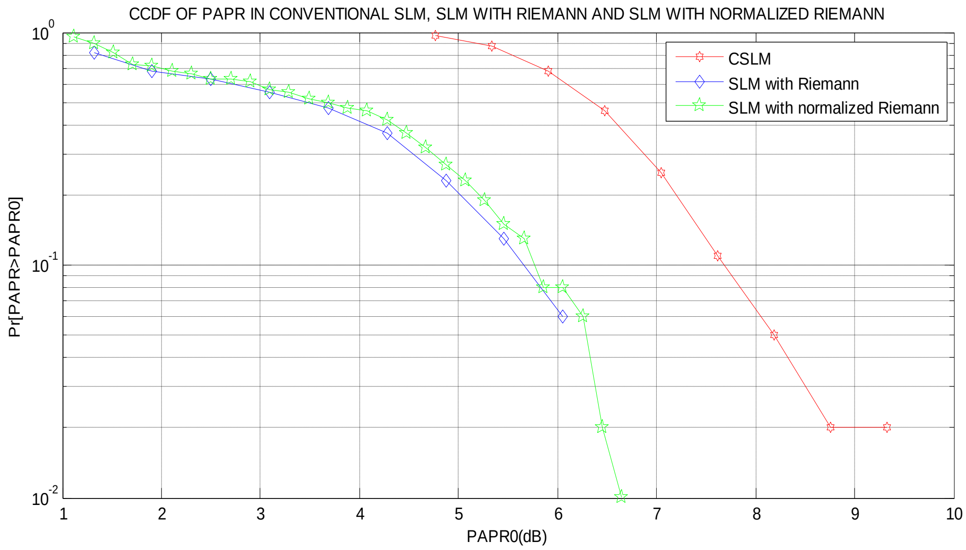


Fig.6 PAPR performance of OFDM system using Riemann based SLM, QPSK with Rapp's SSPA Model, N=128

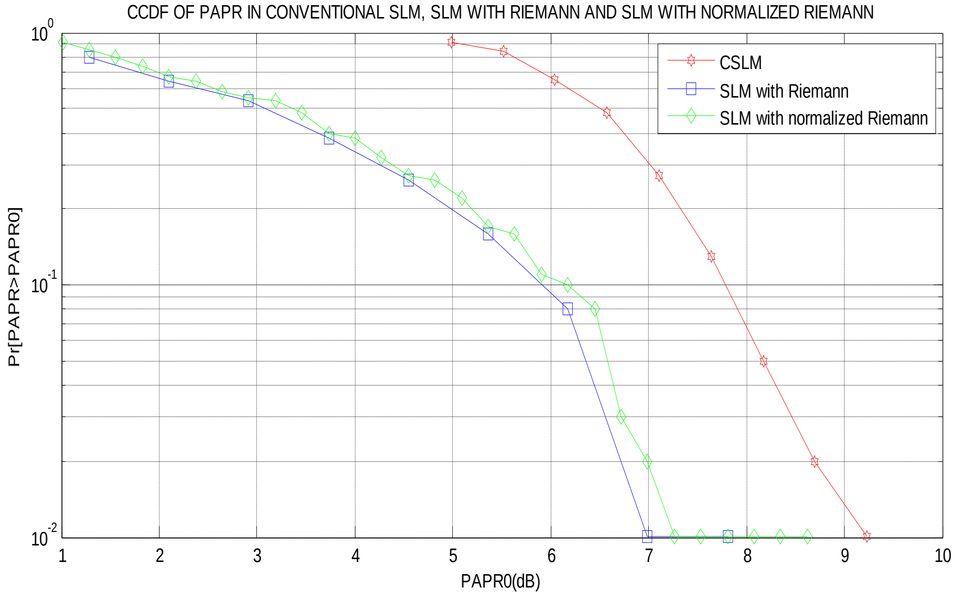


Fig.7 PAPR performance of OFDM system using Riemann based SLM, 256QAM with Rapp's SSPA Model, N=256

V. Conclusion

From the results shown here, we can conclude that to minimize the nonlinear effects, it is desirable to operate HPA in the linear region i.e.with huge back off but in this case, linear amplifier has poor efficiency. It is therefore important to aim at a power efficient operation of the nonlinear HPA with lower back-off values. Hence, reducing the PAPR of the transmitted signal is a better solution to prevent the occurrence of such interference. This paper initially analyzes the nonlinear effect of high power amplifier in the form of inband & outband distortion caused by high PAPR and then Riemann sequence and normalized Riemann sequence based SLM with HPA is applied to reduce the effect of high PAPR. Simulation results show that the Riemann based SLM outperforms than conventional SLM scheme and normalized Riemann based SLM also gives almost similar results.

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