PAPR Evaluation in Multi-Mode SDR Transceivers

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***Abstract*— This paper presents a study of the impact of peak-to-average power ratio in multi-mode Software Defined Radio transceivers. The nonlinear distortion degradation will also be studied both at the SDR transmitter and receiver. Moreover the use of crest factor reduction schemes based on clipping is presented, by showing that clipping followed by filtering should be used carefully in order not to degrade the overall performance.**

I. INTRODUCTION

Multi-Mode transceivers based on software defined radio solutions, SDR [1], increases significantly the complexity of the receiving and transmitting stages. If we consider that the input receiving system and the output transmitter should deal simultaneously with all the multi-standards to transmit and receive, we rapidly moves towards a very complex and demanding problem related to the degradation of the Signal to Noise and Distortion Ratio, SNDR.

Moreover, recently wideband wireless Orthogonal Frequency-Division Multiplexing (OFDM) communication systems have gained in popularity because of OFDM's spectral efficiency and capability to transmit high data rates over broadband radio channels.

Due to its robustness, OFDM has been adopted by a variety of standards which include DVB, WiFi, WiMax and other high quality communication systems.

The conjugation of both multi-norm systems and OFDM based schemes impose high values of peak-to-average power ratio (PAPR), which limits the amount of power that can be received or transmitted without distortion [2].

This PAPR problem immediately degrades the quality of the transmitted and received signal, either by the fact that we should use high values of input power back off in power amplifiers, and thus degrade completely its efficiency, or by the fact that the PAPR impose a degradation of the SNDR in receiver ADC's, accordingly to (1), or if we allow the clipping of the signals peaks, then immediately the nonlinear distortion raises.

$$SNR = 6.02N + 1.76 - \alpha + 10\log_{10}\left[2 * OSR\right] \quad (1)$$

where N is the number of bits, α the PAPR and OSR the over-sample ratio.

One possible solution to this problem is to use crest factor minimization techniques, but in that case a care should be taken in order not to degrade either the nonlinear distortion, neither the error vector magnitude of the symbols.

This paper is organized as follows, first the analysis of the PAPR in multi-norm multi-mode signals will be presented, and then the degradation of receiving and transmitting systems is presented in single and multi-mode operation. Finally the compromise between crest factor minimization using clipping, Symbol Error Rate (SER) and PAPR is presented when used in multi-mode transceivers.

II. PAPR OF MULTI-STANDARD SIGNALS

SDR evolution will impose the use of multi-mode transceivers. If we look back to Mitola's work [1], the SDR is composed by a simple antenna and an ADC for receiving and a DAC with a power amplifier for transmitting.

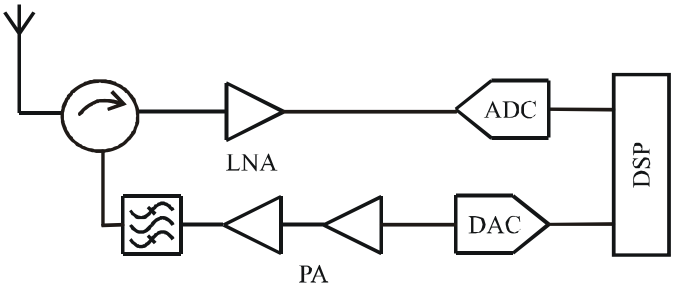


Fig.1 – Software-Defined Radio Concept.

Since no filter is considered at the entrance of the receiver, and since we expect to filter the seek signal in the digital domain, which will also be important for cognitive radios, the signals to be captured exists simultaneously at the input, imposing high values of PAPR.

The same approach is also been considered for transmitters were several channels should be transmitted at once, traversing simultaneously the same DAC and PA.

In order to evaluate the complexity that we will be dealing with, we have generated (using an R&S generator) several combinations of usually used wireless standards, as WiFi and WiMax (since they both work at near 2.4/2.5 GHz) and GSM1800 and UMTS. Table 1, present the characteristics of the generated signals.

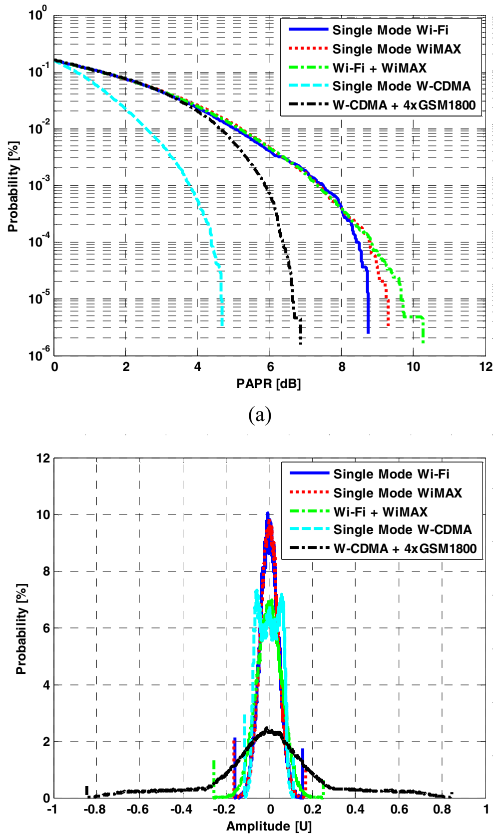
In Fig. 2 we present the measured complementary cumulative distribution function (CCDF) and the probability density function (PDF) of these signals, when they are considered alone or in multi-mode configuration.

TABLE I
CHARACTERISTICS OF THE GENERATED SIGNALS

Signal Type	Carrier Frequency	Bandwidth	Multiplexing	Modulation
IEEE 802.11g	2.45 GHz	22 MHz	OFDM	64 - QAM
IEEE 802.16e	2.502 GHz	12 MHz	OFDM	64 - QAM
WCDMA	1.9 GHz	5 MHz	--	$\pi/4$ - QPSK
GSM1800	1.81 GHz	200 kHz	--	GMSK

As can be seen from Fig. 2 the PAPR of the multi-mode signals is always much higher than the single mode configuration.

This fact imposes that a great care should be taken when dealing with nonlinear components.



(b)

Fig. 2 - Measured signal statistics for different signal configurations, (a) CCDF and (b) PDF.

III. Impact on SDR Receivers

In order to evaluate the impact of those multi-standard signals in the receiver of a SDR, the simple configuration of a low noise amplifier, LNA, followed by and analogue-to-digital converter, ADC was simulated.

Fig. 1 presents the receiver configuration. For modelling the LNA and the ADC a memoryless model as was presented in [3] was used.

In this case we assume that the SDR will be receiving several signals simultaneously, one Wi-Fi (@2.4 GHz) combined with WiMax (@2.5 GHz) and four GSM1800 (@1.8 GHz) channels combined with one WCDMA (@1.9 GHz) channel, as was previously presented these signals presents very high values of PAPR when combined. Fig. 4 presents the obtained results.

In the graph, the adjacent channel and the output power are represented for the single mode signal and the multi-mode configuration, in both cases the adjacent channel are measured for each useful signal.

As can be seen in the multi-mode configuration the ACPR starts to increase and present a higher value of nonlinear distortion, several dB’s before the single mode configuration, this start of nonlinear distortion is equivalent to the PAPR difference between both signals. The small signal distortion is attributed to input noise that already appears at the input signal as in [3].

The maximum output power is degraded due to the fact that both signals are already clipping. If clipping is to be avoided then the SNR of the overall receiving signals will be degraded.

IV. Impact on SDR Transmitters

In this scenario the underneath idea was to simulate a multi-standard power amplifier, represented by a Wiener-Hammerstein behavioural model [4], Fig. 3.

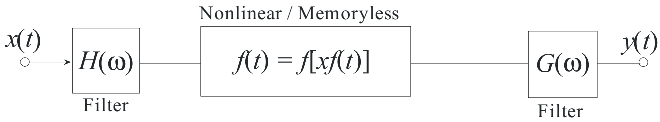


Fig. 3 – Power Amplifier Behavioral Model.

This power amplifier configuration considers the same approach as before, that is, we have a single mode and a multi-mode operation. Fig. 5 presents the obtained results.

For the Wi-Fi plus WiMax configuration, the small signal of the power amplifier is predictable as it rises at 3dB/dB in the adjacent channel power. In the multi-mode configuration the distortion rises compared with the single mode operation for both communication standards and due to that, for large signal operation, both starts to compress sooner by a difference similar to the PAPR relationship between the two modes. Another obvious observation is that the maximum output power will be reduced in the case of multi-mode communications as was previously seen for the receiving stage. In the multi-mode mobile standards, GSM plus WCDMA, the impact of the overall PAPR degradation in the final distortion of the WCDMA is astonishing, since for small-signal we already have a 20dB rise compared with the single mode, and the compression is also considerable, in this case the output power for the WCDMA solution compresses for less 10dB of output power.

So it is clear that the PAPR of the multi-mode configuration should be reduced as much as we can, before applying these signals to either the receiver or the transmitter stage.

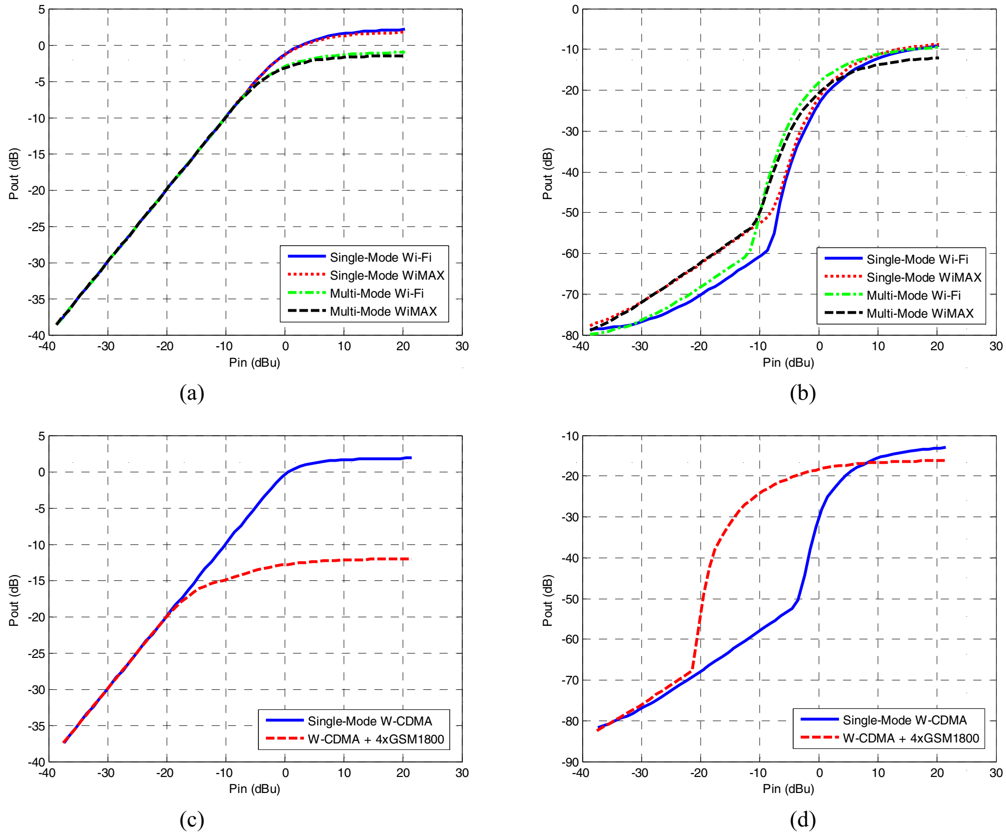


Fig. 4 - Simulated results for Output Power and ACPR for the receiver Wi-Fi / WiMax signals (a)-(b) and WCDMA / GSM1800 signals (c)-(d)

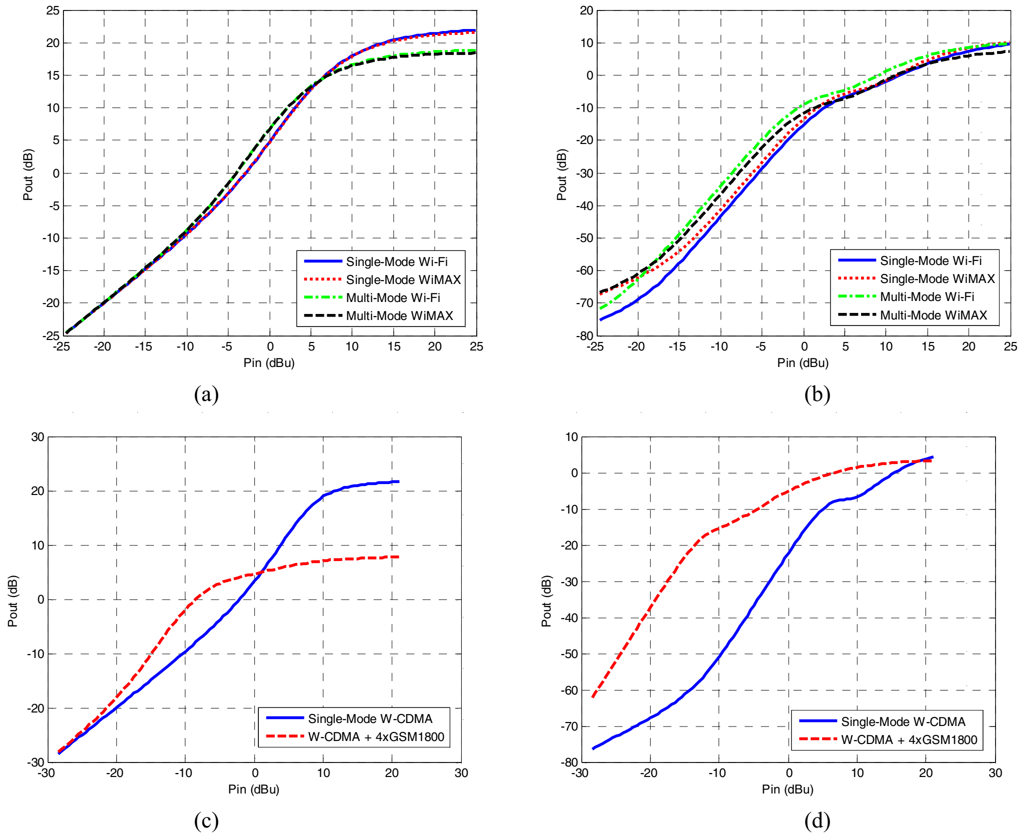
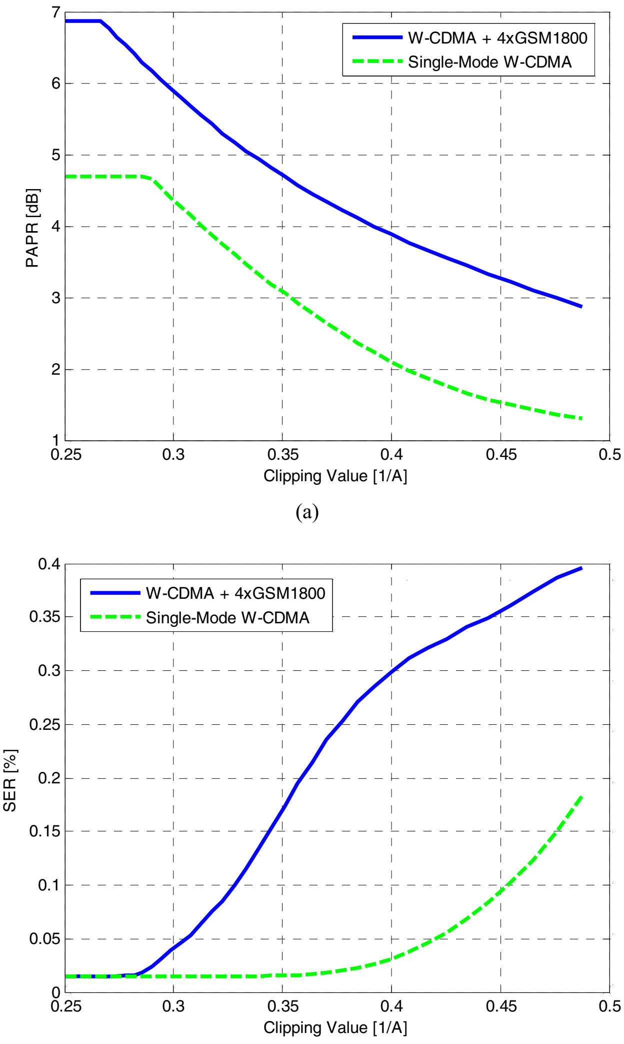


Fig. 5 - Simulated results for Output Power and ACPR for the transmitter Wi-Fi / WiMax signals (a)-(b) and WCDMA / GSM1800 signals (c)-(d)



(a)

(b)

Fig. 7 - Simulated results for the reduction of PAPR by clipping plus filtering the input signal, (a) PAPR and (b) SER.

V. Reduction of PAPR by Clipping plus Filtering

In this section we will evaluate the impact of a typical technique for PAPR reduction in multi-mode transceivers, referred as clipping followed by filtering [5], Fig.6.

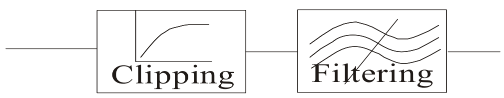


Fig. 6 – Clipping plus filtering PAPR reduction technique.

In this case the clipping function [5] is implemented by:

$$y = \begin{cases} x, & |x| \le A \\ A \cdot e^{j\phi(x)}, & |x| \ge A \end{cases} \qquad (2)$$

We will be studying two different cases, the single-mode WCDMA operation, and the multi-mode operation when in presence of four GSM1800 signals.

The PAPR reduction and Symbol Error Rate (SER) will be evaluated for both situations when the clipping coefficient, *A*, is changed from a small to a large value, Fig. 7.

As can be seen from the presented results, despite the reduction of PAPR achieved, a great increase in SER is visible which increases significantly in the case of the multi-mode configuration.

VI. Conclusions

In this paper we have evaluated the situation when a multi-mode SDR transceiver is used with simultaneous presence of Wi-Fi and WiMax or WCDMA and GSM1800 signals.

The results showed that the PAPR rises significantly, and in the case of the mobile standards degrade completely and turns the multi-mode SDR transceiver an unfeasible solution.

We have also showed that the PAPR reduction techniques based on clipping plus filtering can be a solution for resolving most of these problems, but a great care should be taken since the PAPR reduction even without ACPR change normally implies that SER increases continuously with the PAPR clipping factor, degrading the overall system, and opening a need for future research on how to reduce PAPR in multi-mode transceivers.

References

[1] J. Mitola, “The Software Radio Architecture”, *IEEE Communications Magazine*, vol. 33, nº 5, pp. 26-38, May 1995.

[2] T. May and H. Rohling, “Reducing the peak-to-average power ratio in OFDM radio transmission systems”, in *Proceedings of VTC*, 48th IEEE, vol. 3, pp. 2474–2478, 1998.

[3] P. M. Cruz, N. B. Carvalho and K. A. Remley, “Evaluation of Nonlinear Distortion in ADCs Using Multisines”, in *IEEE MTT-S Int. Microwave Symp. Dig.,* pp. *tbd.*, Atlanta, GA, 2008.

[4] J. C. Pedro and N. B. Carvalho, “Designing multisine excitations for nonlinear model testing”, *IEEE Trans. Microwave Theory and Techn.*, vol. 53, no. 1, Jan. 2005, pp. 45-54.

[5] Seung Hee Han and Jae Hong Lee, “An overview of peak-to-average power ratio reduction techniques for multicarrier transmission”, *Wireless Communications, IEEE*, vol. 12, Issue 2, pp. 56–65, April 2005.