The Impact of Long Term Memory Effects in Wireless QPSK Modulated Signals

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Abstract— **This paper studies the impact of Power Amplifiers, PA, long term memory effects in QPSK modulated signals. To quantify the memory effects an expansion of the nonlinear distortion behavior of the PA is obtained. Both the co-channel and adjacent distortion are calculated. It is then showed that the co-channel and adjacent channel distortion are significantly affected by the long term memory effects, which implies a rise in the EVM figures. The theoretical results are further compared with CAD/CAE simulations and measurements.**

Index Terms— **Power Amplifiers, Nonlinear systems, Long term memory.**

I. INTRODUCTION

LONG term memory effects, MEs, have being an important problem in recent wireless communication systems.

The impact of this type of phenomena is responsible for the failure of linearizing techniques, and the degradation in EVM values usual obtained with memoryless systems; which reduce de accuracy in the overall system performance prediction.

The recent increase of most of these problems is due to the fact that the newly communication systems have an increase in bandwidth, for achieving higher values of data rate with similar values of occupied spectrum bandwidth.

Nevertheless these systems are highly sensitive to nonlinear distortion noise, what is normally measured using the Signal to Noise and Distortion Ratio, SNDR [1].

In the past several authors have addressed the problem of nonlinear distortion in highly complex systems, as a CDMA IS-95 wireless mobile scenario [2, 3], in those previous works several important information have been given to the RF design engineers. First it was found in [2] that the statistics of a QPSK signal is not equivalent to the statistics of narrow band Gaussian noise, Fig.1, which was the usual type of excitation signal used for identifying and extracting behavioral models with nonlinear distortion capabilities.

Secondly these works were mainly developed for memoryless systems, and not for systems presenting what we have called long term memory effects, which means that they have not addressed the main problems arising from the rising of the RF bandwidth.

In those cases the value of EVM degradation with SNDR was also addressed, but as we said before exclusively for memoryless systems [1].

Some interesting properties were obtained from those papers [2-3], one of those is that the in-band distortion of a QPSK signal in a memoryless system, is reduced when compared with the NBGN behavior, Fig. 2.

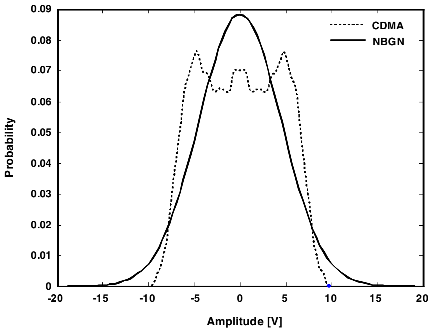
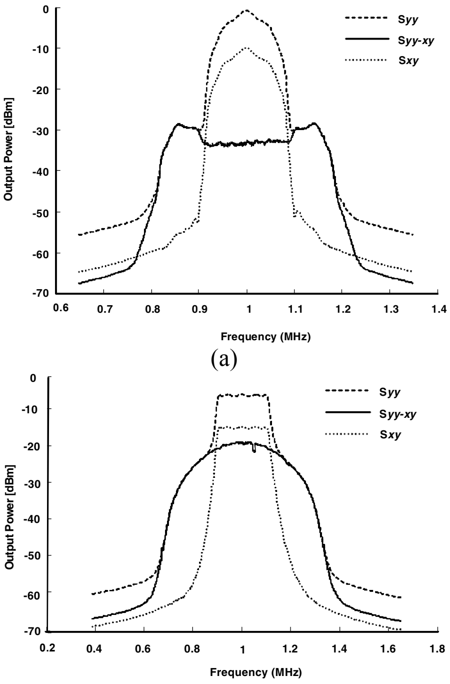


Fig. 1 – Probability Density Function, *pdf*, of a CDMA and NBGN.

Moreover the bell shape of the out-of-band distortion usually seen in NBGN is altered, and can even tend to a plateau, Fig. 2.



(a)

(b)

Fig. 2 – CDMA (a) and NBGN (b) passing through a memoryless nonlinear device.

Nevertheless all the analysis was made for memoryless systems [2-3], or to nonlinear systems presenting short term memory effects [3].

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In this paper we will address the impact of long term memory effects in QPSK based signals, and present some results that in certain specific cases state that the distortion obtained with a memoryless system is optimistic relatively to the QPSK nonlinear distortion.

Thus we will start first with a simple explanation of the model used to obtain these results, then we will pass to an analysis of simulated outcome of a nonlinear system with memory, and finally some experimental measurements will also be given when the nonlinearity, in this case a PA, is excited by a IS95 CDMA reverse link signal.

II. THEORETICAL BACKGROUND

Long term memory effects arise from low frequency behaviour of PA. Several scientific works have been done on this scenario, and the theme is nowadays commonly studied [4-6].

In a PA, the most important contribution for the memory effects is the bias networks [4], which impose a very low frequency response to the output/input of a nonlinear circuit.

This phenomenon is thus nothing more than a feedback mechanism that imposes nonlinear distortion inside the band of interest, by somehow up-convert the low frequency behaviour of the PA to the in-band RF frequency. A deep study of this type of scheme can be found in [4] and [7].

Some authors have tried to represent these memory effects using some special behavioural models [8], which somehow represent the mechanism that were already described.

Recently we have also proved that the model presented in [8] presents quite good results when applied to a PA presenting memory effects coming from the bias networks [9]. The proposed model is presented in Fig. 3.

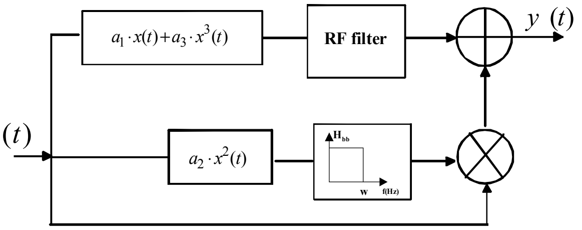

Fig. 3 – Behavioral model presenting long term memory effects capability.

This model tells us that the output signal is given by:

$$y(t) = a_1 \cdot x(t) + a_2 \cdot x(t) \cdot \left[\int_{-\infty}^{+\infty} x^2(t-\tau) \cdot h_{bb}(\tau)\ d\tau \right] + a_3 \cdot x^3(t) \tag{1}$$

Where $x(t)$ is the RF digitally modulated signal

Which when compared with a memoryless nonlinearity includes the second term that is responsible for the up-conversion of the low frequency behaviour of the PA[1].

Since the QPSK excitation is a statistical signal, no information can be obtained from the "voltage" waveforms, thus more robust analysis of this system should be done.

A similar approach followed by Bendat [10] will be used. In that case the different values of autocorrelation functions should be obtained both for the input, output and cross-values.

Thus the output autocorrelation will be obtained as:

$$R_{yy}(\tau) = E\left[y(t)y^*(t+\tau)\right] \tag{2}$$

Where $R_{yy}(\tau)$ is the output autocorrelation and $E[\cdot]$ is the mean value.

It should be noticed that:

$$\begin{aligned} R_{yy}(\tau) &= E\left[y(t)y^*(t+\tau)\right] \\ &= E\left\{\left[y_1(t) + y_{dist}(t)\right]\left[y_1(t+\tau) + y_{dist}(t+\tau)\right]^*\right\} \\ &= E\left\{\left[y_1(t)\right]\left[y_1(t+\tau)\right]^*\right\} + E\left\{\left[y_1(t)\right]\left[y_{dist}(t+\tau)\right]^*\right\} + \\ &\quad E\left\{\left[y_{dist}(t)\right]\left[y_1(t+\tau)\right]^*\right\} + E\left\{\left[y_{dist}(t)\right]\left[y_{dist}(t+\tau)\right]^*\right\} \end{aligned} \tag{3}$$

From (3) we can see that the first term is the linear response, the second and third terms are the correlated part of the output signal with the input, normally the more important term relating to the gain compression and expansion, and the forth term is the nonlinear distortion correlation, usually called in [2-3] spectral regrowth, but unfortunately also has some correlated components with the linear part of the output.

Since we are searching for the uncorrelated part exclusively we can also divide the output in:

$$\begin{aligned} R_{yy}(\tau) &= E\left[y(t)y^*(t+\tau)\right] \\ &= E\left\{\left[y_c(t) + y_u(t)\right]\left[y_c(t+\tau) + y_u(t+\tau)\right]^*\right\} \\ &= E\left\{\left[y_c(t)\right]\left[y_c(t+\tau)\right]^*\right\} + E\left\{\left[y_c(t)\right]\left[y_u(t+\tau)\right]^*\right\} + \\ &\quad E\left\{\left[y_u(t)\right]\left[y_c(t+\tau)\right]^*\right\} + E\left\{\left[y_u(t)\right]\left[y_u(t+\tau)\right]^*\right\} \\ &= E\left\{\left[y_c(t)\right]\left[y_c(t+\tau)\right]^*\right\} + E\left\{\left[y_u(t)\right]\left[y_u(t+\tau)\right]^*\right\} \end{aligned} \tag{4}$$

Combining (1), (3) and (4) and using [10] we found that the correlated part of the output could be given by:

$$\begin{aligned} R_{ycyc}(\tau) &= \left|G_{correlated}\right|^2 E\left\{\left[x(t)\right]\left[x(t+\tau)\right]^*\right\} \\ &= \left|G_l + G_{distc}\right|^2 E\left\{\left[x(t)\right]\left[x(t+\tau)\right]^*\right\} \end{aligned} \tag{5}$$

With G_l the linear gain and G_{distc} the correlated gain between the outputs distorted correlated signal and the input signal, which can be further given by:

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[1] In this case we will use the same assumptions that we have used before in [9], were the in-band response is flat all over the bandwidth.

$$G_{distc} = \frac{E\{[y_{dist}(t)][x(t+\tau)]^*\}}{E\{[x(t)][x(t+\tau)]^*\}} \tag{6}$$

The uncorrelated part is thus:

$$R_{yuyu}(\tau) = E\{[y_{dist}(t)][y_{dist}(t+\tau)]^*\} - |G_{distc}|^2 E\{[x(t)][x(t+\tau)]^*\} \tag{7}$$

This is exactly what we are searching when measuring the in-band uncorrelated distortion, and thus the SNDR and ACPR figures of merit.

III. CAD/CAE RESULTS

The first analysis made to the long term memory impact was related to the small signal evaluation of the co-channel and adjacent channel distortion.

First a communication system based on QPSK modulation was implemented in Matlab Simulink.

This signal was further passed through the nonlinear model presented in Fig. 3, and the developed expressions were applied to the input and output expressions. The output uncorrelated nonlinear distortion results are presented in Fig. 4, for base band low pass filters, LPF, with 1/10 of signal bandwidth, ½ signal bandwidth and two times the signal bandwidth.

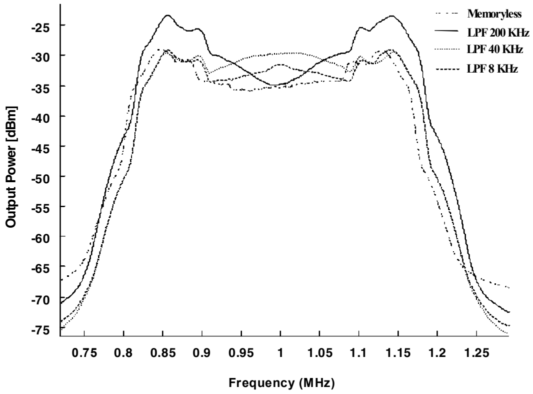

Fig. 4 – QPSK Output uncorrelated distortion PSD when passed through a nonlinearity presenting memory.

In Fig.4 we see that the filters with a high value of long term tails, impose a rise in the co-channel uncorrelated response, and thus a decrease in SNDR, this result is perfectly in accordance with the results presented in [9] for a multi-sine signal.

The only case similar to the memoryless one is the case where the filter is completely opened, and thus allows the up-conversion of all the 2nd order term to the in-band distortion, as been a new third order memoryless term.

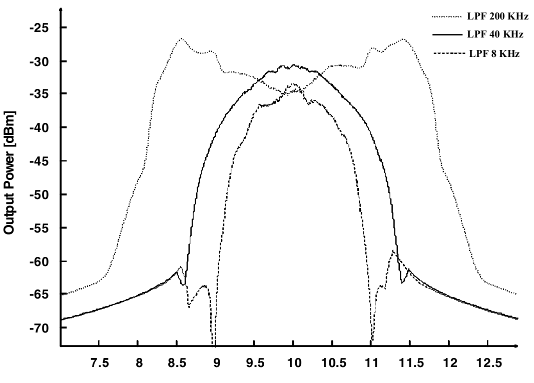

Fig. 5 – QPSK Output uncorrelated distortion of the 2nd harmonic branch PSD when passed through a nonlinearity presenting memory.

In Fig. 5 we have also plotted the uncorrelated distortion coming out from the second order path, there it is clear that the small bandwidth filter imposes a rises only at the in-band distortion, degrading like that the in-band SNDR. While the large bandwidth filter as a similar behavior as the pure third order memoryless distortion, and thus only contributes to the overall rise of the distortion, mainly at the band edges.

IV. EXPERIMENTAL RESULTS

In order to see the experimental impact of the memory effects in a QPSK like modulated signal; we have picked up an IS-95 CDMA reverse channel as the excitation signal, and apply it to a PA presenting memory, mainly at the large signal behavior. A VSA was used to obtain the results for this scenario.

In this case it was proved that the results gathered in [11] for real complex Gaussian signals, could also be confirmed here for a CDMA OQPSK signal as shown in Fig. 6.

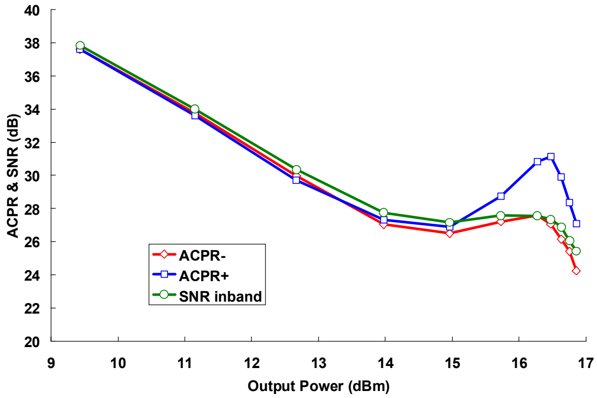

Fig. 6 – IS-95 excitation passed through a PA nonlinearity presenting memory.

From the figures it is possible to see a high value of asymmetry, and thus of memory effects in the ACPR values, and by a comparison with the Gaussian behavior, we see that that it states the viability of the large signal IMD sweet spot use for this respect. An interesting observation that can also be obtained in this graph is that the SNDR also presents a large signal sweet spot, despite it follows the worst behavior of the

ACPR values. Therefore the uncorrelated inband distortion is impacted very similarly as the ACPR, but since the inband distortion is integrated over the signal bandwidth the overall degradation is dominated by the increase in distortion caused by the memory effect. It should also be noted that the memory effect is actually reducing the distortion and improving the SNDR compared to the pure memoryless case. This illustrated by comparing the ACPR and SNDR predicted by a memoryless model of the amplifier AM-AM AM-PM response to the measured values as shown in Fig. 7 where the memoryless case indicates a consistent increase in inband and out of band distortion compared to the measurements. We have also plotted the output spectrum in Fig. 8, where a clear impact is visible at the large signal sweet spot both at the co-channel and adjacent channel distortion.

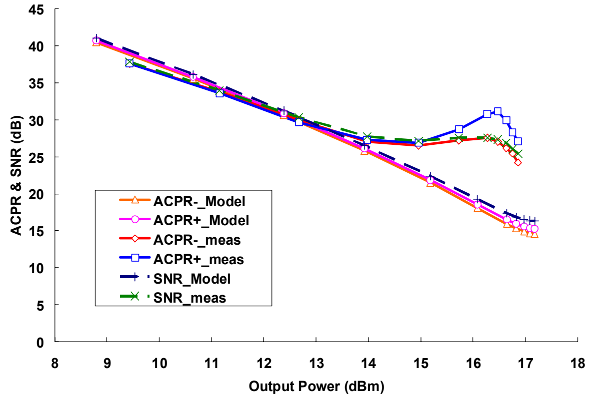

Fig. 7 – Comparison of ACPR and SNDR measured and predicted by a memoryless model of the amplifier.

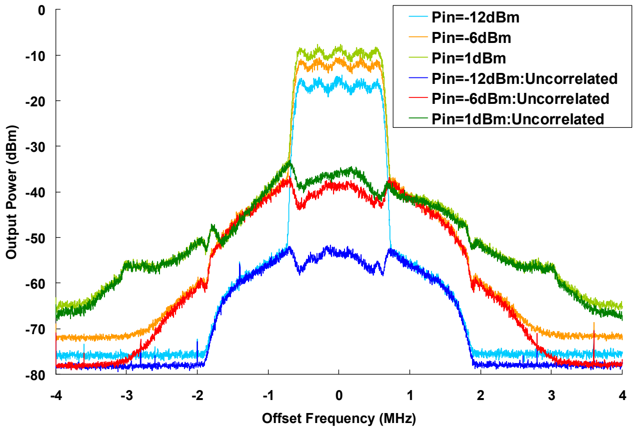

Fig. 8 – Output spectrum of the IS-95 excitation passed through a PA nonlinearity presenting memory.

From that figure is also interesting to note that the co-channel distortion is completely different at small signal where no impact of memory effects is visible both at the co-channel and adjacent channel, and at large signal, where a clear impact of memory effects is visible at the adjacent channel asymmetry.

V. CONCLUSIONS

We observe that the memory effects have a strong impact in the wireless systems. This effect appears in the co-channel as in the adjacent channel components. It can compromise the system performance as we saw trough the SNDR improvement/degradation.

The experimental results states that a large signal SNDR sweet spot is also visible on IS-95 Systems, even in PA's presenting memory effects, which is important for RF design engineers.

ACKNOWLEDGMENT

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