Co-channel and Adjacent Channel Distortion in Microwave Amplifiers Presenting Memory

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Abstract— This paper studies both for the co-channel and adjacent channel distortion in Power Amplifiers, PA, presenting long term memory effects. It is proved that the minimization of the adjacent channel distortion, is not equivalent to the minimization of the co-channel distortion in a PA, presenting long term memory effects.

Index Terms— Power amplifiers, Nonlinear systems, Long term memory.

I. INTRODUCTION

MEMORYLESS linearizers have been used for many years, due to their easy design and tuning characteristics. This is mainly due to the fact that the devices usually linearized, present low values of long term memory effects, MEs. Nevertheless the increasing demand for solid state devices associated with a rise of the operating bandwidth in the new wireless systems, make the assumption of memoryless DUT questionable.

Even though, the behavioral modeling capabilities for DUT’s presenting memory are in its infancy, and most of the system design engineers try to use memoryless linearizers to compensate the impact of nonlinear distortion [1].

Since a static linearizer cannot cancel perfectly a dynamic response, we can foresee a bound in the linearization that is achieved with a Best Memoryless Linearizer (BML). The BML concept was already presented in [2] for a two tone excitation.

Furthermore, recently the authors have published a paper [3] were the multi-sine response of a nonlinearity presenting memory when excited with a two tone and multi-sine signal excitations.

In [2-4] we have presented a mapping between the IMD outcomes of a third order nonlinearity presenting memory when excited with a two tone and multi-sine signal excitations.

This relationship is in agreement with the model proposed in [5], where it is stated that the output can be decomposed as the sum of a cubic polynomial direct path response, with an up-converted baseband component.

With such a model in mind, the baseband component is demodulated from the RF signal in a second-order nonlinearity and then pressed with memory in a low-pass filter that mimics the baseband response of the nonlinear system [5, 6].

The in-band intermodulation distortion output for a two-tone signal can be given by [3]:

\[ H_1(\omega_1,\omega_2,\omega_3) = H_{L}(2\omega_1-\omega_2)+H_{L}(\omega_1,\omega_2) \]  

(1)

where, \( H_{L}(2\omega_1-\omega_2) \) is the third order nonlinear transfer function arising directly from the third order static conversion, and \( H_{L}(\omega_1,\omega_2) \) are the second order nonlinear transfer functions responsible for the baseband and second harmonic signal components, that will then be remixed to fall onto the system’s first zone output.

We have also considered that if the multi-sine excitation is narrow-band, i.e., if the system’s bandwidth is greater than the signal’s bandwidth, then \( H_3(2\omega_1-\omega_2) \) would be approximately constant and equal to \( K_3 \). The mixing product arising from \( H_{L}(\omega_1,\omega_2) \), where \( \omega_1 + \omega_2 \) is at the 2nd harmonic, could also be considered constant, \( K_3 \), since the relative bandwidth change with the tone spacing is very small.

Thus, for the case presented above the nonlinear Kernel transforms into:

\[ H_3(\omega_1,\omega_2,\omega_3) = K - 2F_2(\omega_1,\omega_2) \]  

(2)

The computation of the system nonlinear transfer functions is achieved by using Higher Order Statistics, HOS, considering a two-tone as the input test signal [7]. Thus for any combination of input tones, the output will be:

Then, some simulations and measurements are presented in order to validate the proposed hypothesis. Finally, the conclusions of this work are given.
This states that the third order distortion has a constant part, that is common to the overall spectral regrowth values, and a part that changes with tone spacing.

In [4] we have presented the generalization of this concept for the adjacent channel and co-channel distortion. So, considering Fig. 1, the adjacent channel distortion power could be given by:

\[
P(\omega_k) = \sum_{a \in \{\pm 1\}} \sum_{k \in \{\pm 1\}} [K + F(a \omega) + F(i \omega)]_{\text{multi}} A^k
\]

(4)

And the co-channel nonlinear uncorrelated distortion can be given by:

\[
P(\omega_a) = A^a \sum_{k \in \{\pm 1\}} \begin{cases} \sum_{i \in \{\pm 1\}} [K + F(a \omega + i \omega)]_{\text{multi}} & \text{if } a > 0 \\ \sum_{i \in \{\pm 1\}} [K + F(a \omega + i \omega)]_{\text{multi}} & \text{if } a < 0 \end{cases}
\]

(5)

where

\[
\text{vertex} = \left\lfloor \frac{b}{2} \right\rfloor - 1
\]

(6)

\(\text{floor}(x)\) is a function that rounds the elements of \(x\) to the nearest integers towards minus infinity.

In [4] we also showed that this sum leads to the conclusion that in the co-channel distortion, the low frequency range of the base band response has a strong impact in the overall distortion, while in the adjacent-channel the middle of the base band frequency response presents a higher impact.

III. BML FOR MULTI-SINE EXCITATION

The BML was defined in [2] as the static device that gives the maximum integrated energy reduction in the adjacent-channel for a two tone excitation. Despite the BML was presented based on a theoretical reasoning it was only considered the one-dimensional case. When a multi-sine excitation is used, this definition is no longer valid since different states of the system are now excited and contribute to the output. So, if we are dealing with an \(n\)-th-order system the complete kernel should be accounted in the BML computation. This led us to the next formula for the third order case.

\[
C(\Omega_1, \Omega_2) = \min_{-W < \Omega_1, \Omega_2 < W} \int_{-W}^{W} \int_{-W}^{W} \left[ C - (H_3(\Omega_1, \Omega_2)) \right] d\Omega_1 d\Omega_2
\]

(7)

This states that the optimum value of \(C\), should minimize the output spectral regrowth energy in all its bandwidth. Thus the minimum of this function is in fact the optimum value of the linearizer.

\[
\frac{\partial C}{\partial C} \int_{-W}^{W} \int_{-W}^{W} \left[ C - (H_3(\Omega_1, \Omega_2)) \right]^2 d\Omega_1 d\Omega_2 = 0
\]

(8)

If we look carefully to expression (8) we see that this BML definition is nothing more than the normalized integrated response of the third order kernel of the system. So if the system is memoryless, then each third order contribution should contribute with a similar value for \(H_3\), and thus the value of \(C\) should be equal for each intermodulation product. The value of \(C\) can thus be obtained by a close inspection of the \(H_3\) function, by using for instance the evaluation of the HOS of the output signal for a multi-sine excitation.

![Fig. 2 – BML Concept.](image)
Mixing components

\[ \omega_4^+ \omega_4^- \omega_3 \]

Co-channel un-correlated distortion

Table 1 – 4 tone third order mixing products.

Looking back to the tables, we see for instance that the base band impedance at frequency \( 3\Delta \), is of no importance for the co-channel distortion, and even the term \( 2\Delta \) is mildly referred at the co-channel, while they appear several times at the adjacent channel distortion.

If the value of \( C \) is chosen as the one that minimizes the constant part of the non-linear distortion, thus the variable one, referring to the base band frequency separations, will be quite different in the outside and inside bandwidths.

On the other side, if we chose \( C \) that will compensate some of the residues due to memory effects, then again the residues affecting the co-channel are different from the ones affecting the adjacent channel, and thus the BML for the adjacent channel could not signify the same for the co-channel.

**IV. SIMULATED RESULTS**

In order to prove this theoretical hypothesis, we conduct two different tests. First we consider a memoryless nonlinearity, and try to find out the optimum value \( C \), that minimizes the distortion in the adjacent channel.

From Fig.3 we can see that the BML linearizer is perfectly applicable both inside and outside of the band with equal values of linearization (30dB of linearization).

We use then the same PA, but now with a certain value of memory pressed by the base band impedance.

From Fig. 4 it is possible to see that despite the good linearization values at the adjacent channel (25 dB), the co-channel linearization ratio is much lower (10dB).

This states by simulation that to linearize the adjacent channel is not equivalent as linearizing the co-channel band.

Fig. 3 – Simulated memoryless case, before (.) and after the BML application (o).

Fig. 4 – Simulated memoryless case, before (.) and after the (o) BML application.
V. MEASURED RESULTS

In order to prove further our hypothesis we built a PA, based on the ATF 55143 P-HEMT from Agilent, and biased it with two different bias networks, one that presses memory due to its baseband characteristics, and another one that leads to a memoryless behavior.

Next figure presents the case of the memoryless solution.

![Fig. 5 – Experimental results for the memoryless case, before (.) and after (o) the BML linearization.](image)

Fig. 5 – Experimental results for the memoryless case, before (.) and after (o) the BML linearization.

From Fig. 5 we can see that the BML linearized output presents very good results both at co-channel and adjacent channel, with only the residual part of the distortion remaining.

Then the bias network with memory was used and the obtained results are presented on Fig. 6.

As can be seen in Fig. 6, in the presence of memory, the BML, could be considered reasonably applicable to the adjacent channel. In the upper band, a 10dB cancellation level is visible, but the co-channel distortion cancellation is completely degraded. In this case the co-channel distortion even rises, compared to the un-linearized DUT.

VI. CONCLUSIONS

In this paper we showed that the linearization of a PA presenting memory is not so effective as the memoryless counterpart. Furthermore, the direct extrapolation of the adjacent channel linearization level could not be extrapolated to the co-channel band. The Best Memoryless Linearizer (BML) concept is presented for a generic multi-sine excitation.

Fig. 6 – Experimental results for the case presenting memory, before (.) and after (o) the BML application.

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