EFFICIENT SIMULATION OF NPR FOR THE OPTIMUM DESIGN OF SATELLITE TRANSPONDERS SSPAs

J. Lajoinie*,E. Ngoya*, D. Barataud*, J.M. Nebus*, J. Sombrin** and B. Rivierre***

** IRCOM - University of Limoges 123, av. A. Thomas - 87060 LIMOGES (France)
** CNES 18, av. E. Belin - 31055 TOULOUSE (France)
*** ALCATEL-ESPACE 26, av. J.F. Champollion - BP 1187 - 31037 TOULOUSE (France)

Abstract— **It is now well known that the prediction of intermodulation distorsions at the system level using the AM-AM and AM-PM characteristics of power amplifiers may be of very poor accuracy if amplifiers exhibit nonlinear low frequency dispersion effects (memory effects). This paper presents a new cost effective method for computing the NPR of power amplifiers at the circuit level, hence providing a more accurate prediction and the possibility to include the NPR as a direct optimisation objective in the design of amplifiers. The method is particularly well suited to the design of high efficiency solid state power amplifiers.**

I. Introduction

When building the link budget of global satellite systems, the knowledge of the noise power ratio (NPR) of power amplifiers is of prime importance. In multi-carrier amplification, the NPR gives a better indication of the amount of intermodulation distortion than the usual two-tone third order intercept point (IP3) does [1] [2]. While designing transponder, simulation of the power amplifier (PA) NPR is performed only at the system level using AM-AM and AM-PM characteristics of the PA. Unfortunately, the NPR computed from the (AM-AM, AM-PM) characteristics is not very accurate. In fact, (AM-AM, AM-PM) characteristics do not account for possible amplifier impedance mismatch and biasing circuit memory effects. Memory effects are particularly sensitive in power amplifiers including predistortion linearizers [3]. The system level design strategy based on the use of (AM-AM, AM-PM) characteristics is globally satisfactory for systems employing TWT amplifiers but not for those using SSPAs. An optimal design of a SSPA needs to include the NPR as an optimisation objective, as well as output power and power added efficiency [4]. Hence the NPR of the PA has to be simulated at the circuit level. Thanks to the new simulation algorithm, the Envelope transient method [5], it is now possible to efficiently perform nonlinear amplifier analysis with the test signal required for NPR computation. For illustration, the power spectrum of the test signal used for the NPR simulation is sketched in Fig.1.

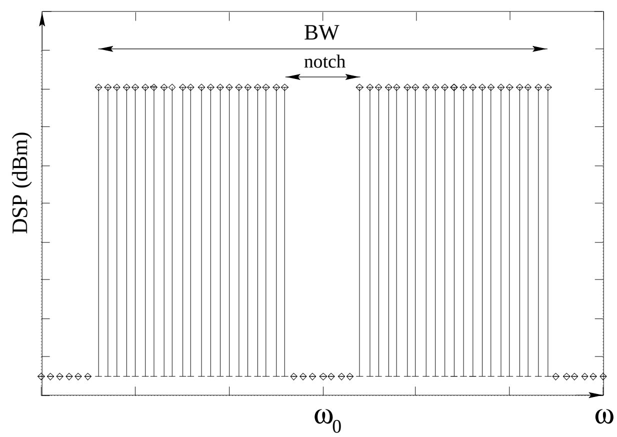

Fig. 1. Power spectrum of the test signal

This is a coarse representation of a band-pass gaussian white noise, with a notch usually impressed around the center carrier frequency. Practically the spectrum is made of a large number of equi-amplitude carriers having independent random phases with a uniform distribution. When this signal is fed into the PA, intermodulation products fill up the notch so that the ratio of the average output power within the notch to the average output power outside the notch defines the NPR. When simulating this test signal directly derived from practical measurement setups, we face two problems :

- The ratio of the notch bandwidth to the total signal bandwidth must remain small in order to have a minimum perturbation of the original signal.
- It is necessary to consider a fairly large number of carriers within the notch, about 100, in order to minimise the variance of the notch average power.

These two conditions cause long simulation times and besides, the notch technique does not provide the intermodulation noise distribution over the whole signal bandwidth. An alternative technique avoiding the use of a notch has been recently proposed by Chen [6]. This technique which makes use of the concept of the equivalent gain of a noisy system provides the distribution of the intermodulation power in the whole bandwith and has proved to be less time consuming. However this is only applicable to memoryless nonlinearities, which is not the common case for SSPAs. In this paper, we present the extension of the above technique to handle nonlinearities presenting memory effects. In the next section the new technique is briefly presented and applied to compute the NPR of a MESFET amplifier. The MESFET amplifier is simulated with a complete circuit level nonlinear model using Envelope Transient Method. We will conclude by comparing the measured NPR with those obtained from the proposed circuit level simulation and from the classical system level simulation using (AM-AM, AM-PM) characteristics.

II. Extraction of intermodulation noise by cross correlation

Let us consider $x(t) = \Re(\hat{x}(t)e^{j\omega t})$ and $y(t) = \Re(\hat{y}(t)e^{j\omega t})$ as the input and output of a noisy communication system exhibiting memory effects. As an extension of the equivalent gain principle adopted in [6], the complex envelope $\hat{y}(t)$ of the output signal may be expressed as

$$\hat{y}(t) = h_x(t) * \hat{x}(t) + \hat{n}(t) \qquad (1)$$

where * denotes the convolution operation and $\hat{n}(t)$ the complex envelope of the noise generated by the system. As regards NPR simulation the noise generated by the system corresponds to intermodulation products arising from the nonlinearities.

Following the principle of the equivalent gain, the complex impulse response $h_x(t)$ depends on the waveform or the statistical properties and power of the input signal.

In our case the input signal $\hat{x}$ is a random gaussian process.

Writing the cross correlation function of $\hat{n}(t)$ and $\hat{x}(t)$

$$R_{\hat{x}\hat{n}}(\tau) = E[\hat{n}^*(t)\hat{x}(t+\tau)] \qquad (2)$$

and taking its Fourier transform, we have :

$$S_{\hat{n}\hat{x}}(f) = S_{\hat{y}\hat{x}}(f) - H_x^*(f)S_{\hat{x}\hat{x}}(f), \ \ |f| < \frac{BW}{2} \qquad (3)$$

where $S_{ab}(f) = \mathcal{F}(E(a^*(t)b(t+\tau))$ represents the cross spectral density of processes a and b while BW is the input signal bandwidth.

In a large number of band-pass applications the transfer function $H_x(f)$ is a smooth function which can be reasonably expressed in terms of a low order polynomial serie expansion.

$$H_x(f) = \sum_{i=0}^{P} a_i f^i \qquad (4)$$

Note that if P=0 in (4), this corresponds to memoryless solution proposed by Chen [6]. Now given the polynomial order P and assuming the orthogonality of intermodulation noise and input signal, we have to find the coefficient a_i $(i = 0 \cdots P)$ so that the energy (5) is minimum.

$$\int_{-\frac{BW}{2}}^{+\frac{BW}{2}} |S_{\hat{n}\hat{x}}(f)|^2 df = \int_{-\infty}^{+\infty} |R_{\hat{x}\hat{n}}(\tau)|^2 d\tau \qquad (5)$$

The spectral density of the test signal for NPR analysis being constant and discrete the problem reduces to minimize the cross correlation power

$$\frac{1}{N}\sum_{k=1}^{N}|S_{\hat{n}\hat{x}}(f_k)|^2 = \frac{1}{N}\sum_{k=1}^{N}|S_{\hat{y}\hat{x}}(f_k) - H_x^*(f_k)S_{\hat{x}\hat{x}}(f_k)|^2 \quad (6)$$

which leads to minimize

$$P_{\hat{n}\hat{x}}(a_0 \ldots a_P) = \sum_{k=1}^{N}|H[f_k] - \frac{Y[f_k]}{X[f_k]}|^2 \quad (7)$$

where X_k and Y_k are discrete carriers of the input signal describing the gaussian band limited noise and N is the number of independent carriers.

The solution is obtained by a least square analysis. The optimal value of polynomial order P is obtained when the computed NPR which is equal to (8) becomes constant with increasing P.

$$\frac{\sum_{k=1}^{N}|H[f_k] * X[f_k]|^2}{\sum_{k=1}^{N}|Y[f_k] - H[f_k * X[f_k]|^2} \quad (8)$$

Once the transfer function is determined we can extract the noise from (1). This method has been implemented and applied to compute the NPR of a MESFET amplifier.

III. Measurements and simulated results

A MESFET amplifier has been, simulated with a complete circuit level non linear model (2) using Envelope Transient Method.

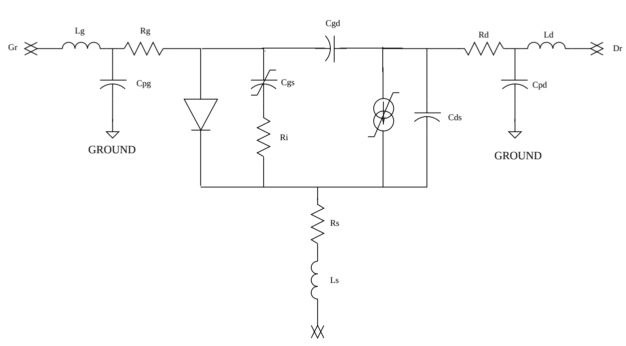

Fig. 2. Nonlinear FET model

Fig. 3 shows the comparison of the NPR computed with our new method, the classical notch method and the equivalent gain method [6].

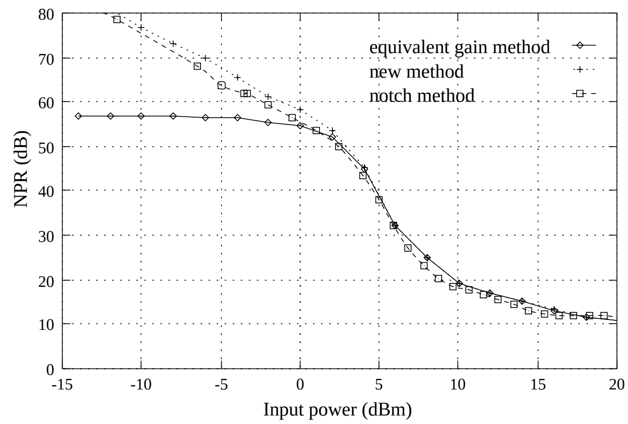

Fig. 3. NPR of the MESFET amplifier versus input power

We can see that the NPR computed with our new method tracks closely that computed with the classical notch method, while the NPR obtained from the equivalent gain method becomes constant for small input powers. This is partly due to the effect of phase delay is being considered as intermodulation in the equivalent gain method.

The computation cost of the new method is five times less than the notch method.

Fig. 4 shows the spectral densities of the output useful signal and intermodulation noise for a 26 dBm input signal, corresponding to a 14 dB NPR.

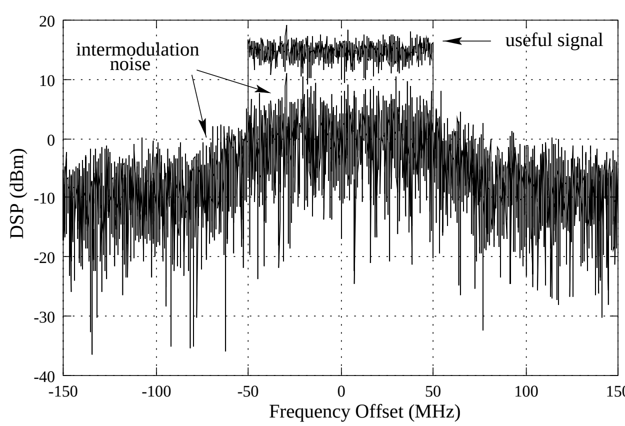

Fig. 4. Intermodulation and output signal power distribution (NPR=14 dB, Pin=26 dBm)

The test signal is composed of 1000 carriers within a 16 MHZ bandwidth.

Fig. 5 shows the comparison of measured and simulated NPR.

The simulation has been performed using the complete circuit level model and also using the AM/AM and AM/PM characteristics.

We see that simulations using the circuit level model are in good agreement with measurements while the NPR obtained from AM/AM and AM/PM characteristics is too much optimistic by about 2 dB. This discrepancy is due to the presence of nonlinear memory effects which are not accounted for by (AM/AM, AM/PM) characteristics.

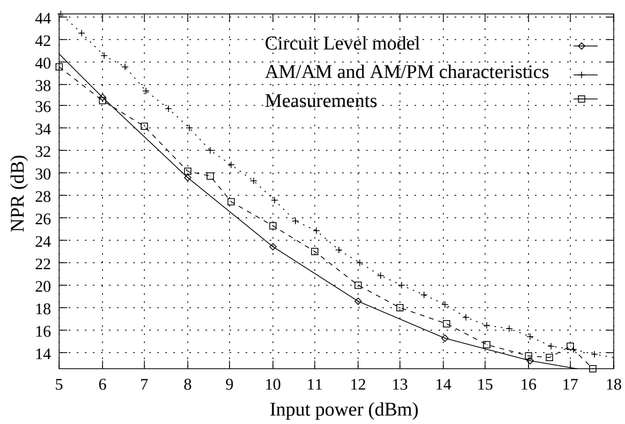

Fig. 5. Comparison of measured and simulated NPR versus input power

Finally, Fig. 6 shows the plot of NPR as a function of the power added efficiency, using circuit level analysis and also (AM/AM, AM/PM) characteristics. The two curves are again separated by more than 2 dB.

IV. Conclusion

We have presented a new method for simulating Noise Power Ratio of nonlinear systems exhibiting memory effects. This method has demonstrated to be as accurate as the classical notch method and less time consuming.

We have shown that using system level (AM/AM, AM/PM) characteristics can cause large errors on the NPR prediction of SSPA, because of memory effects. The moderated computation cost of the proposed method makes possible the simulation of NPR at circuit level with much more accuracy. It is therefore possible to optimise the amplifier topology and matching circuits in order to find the best compromise between NPR and other factors such as the power added efficiency and output power.

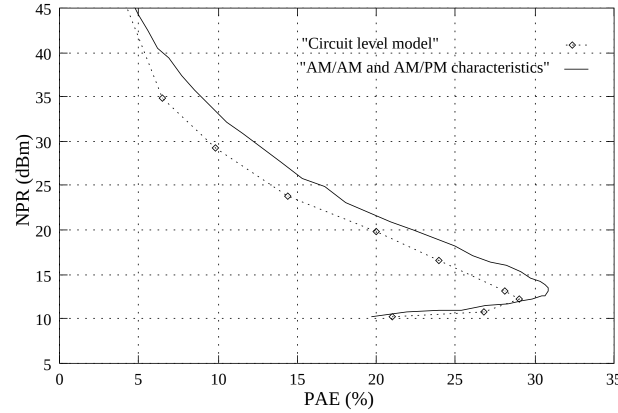

Fig. 6. NPR versus power added efficiency : comparison of circuit level model with AM/AM and AM/PM characteristics.

References

[1] R.J. Westcott, ”Investigation of multiple f.m./f.d.m. carriers through a satelitte t.w.t. operating near saturation”, Proc. IEE, Vol. 114, No. 6, pp. 726-740, June 1967.

[2] A. Platzker and S. Bouthillette, ”Variable output high efficiency, low distorsion S-band power amplifiers and their performances under single tone and noise power excitations.”, IEEE MTTS Digest, pp. 441-444, 1995.

[3] W. Bosch and G. Gatti, ”Measurement and simulation of memory effects in predistortion linearizers”, IEEE Trans. Microwave Theory and Techn., vol. 37, no. 12, pp.1885-1890, Dec. 1989.

[4] J. Sombrin, ”Critere de comparaison, d’optimisation et d’utilisation optimale des amplificateurs de puissance non-lineaires” , CNES report, Ref. CNES DT-96-16-CT/AE/TTL/HY, May 1989.

[5] E. Ngoya and R. Larchevèque, ”Envelope transient analysis: a new method for the transient and steady state analysis of microwave communication circuits and systems”, IEEE MTT’s Digest, 1996.

[6] S.W. Chen, W. Panton and R. Gilmore, ”Effects of nonlinear distortion on CDMA communication systems”, IEEE Trans. MTT, Vol. 44, No. 12, pp. 2743-2750, Dec. 1996.