NPR & Co-channel Distortion Ratio: A Happy Marriage?

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Abstract **This paper investigates the disagreement that exists between Noise Power Ratio (NPR) measurements and a recently published statement that those measurements always underestimate the real nonlinear in-band distortions. This disagreement is only a matter of definition of what one considers to be a distortion. The properties of the input signal are the criterion for using the classical NPR method or the alternative. A general measurement technique (using a nonlinear vectorial network analyzer) is presented that is valid in both cases. Next, measurement are performed to validate the theory.**

I. INTRODUCTION

In modern telecommunication protocols, the frequency band is divided into small separate channels. It is hence important to characterize the in- and out-band distortions caused by the nonlinearity of active circuits.

Classically, the Noise Power Ratio (NPR) is used as a figure of merit for in-band distortions. It is defined as the ratio between the in-band distortion power spectral density and the useful signal power spectral density when an in-band noise spectrum slice is removed. Automated commercial equipment is available to measure this NPR [1].

Recently published papers [3], [4] objected against the validity of the NPR for being a good measure for the in-band distortions, and they proposed an alternative measurement setup to measure co-channel distortion ratio.

As a matter of fact, there is no discrepancy between both approaches. The difference depends only on the definition of what one considers to be "distortion".

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II. A CLOSER LOOK AT BOTH APPROACHES

The classical NPR measurement aims to measure the in-band distortion, by removing a slice in the input spectrum. In the output spectrum, frequency components will be created within the notch, due to nonlinearities in the DUT. These components are supposed to be a good measure for the overall distortion in the whole frequency band of interest. Arbitrary waveform generators (AWG) can also be used to perform the NPR measurements with different types of input signals (e.g. OFDM, CDMA) [2].

The co-channel distortion power ratio (CCPR) measurement is capable of subtracting the response of the underlying linear system of the output of the DUT, hence revealing the "true" nonlinear part of the output spectrum. The paper describing this technique [4] states that the presence of the notch in the input signal (for the classical NPR technique) produces an underestimation up to 7dB of the in-band distortion.

III. PROPOSED MEASUREMENT METHOD

A measurement method is proposed that is capable of yielding both earlier defined quantities, but that does neither need a notch in the spectrum, nor ad hoc hardware setups.

The DUT is excited by multicarrier signals with noise-like properties (e.g. OFDM, CDMA), generated by an AWG. The incident and reflected wave spectra at both ports of the amplifier are measured with the Nonlinear Vectorial Network Analyzer (NNMS-HP85120A-K60) [7].

An absolute calibration is needed to correct for systematic errors, since nonlinear system characterization requires the knowledge of the absolute waves at the ports of the DUT. Hence, the relative calibration, as used for S-parameter measurements, has to be extended with a power meter calibration, which sets the absolute power level of the waves; and a phase reference calibration, which gives the phase relations between the waves on an harmonic frequency grid relative to a single time origin [7].

When a system is excited by a random multisine, the nonparametric frequency response function (FRF or S_{21})

can be split into systematic contributions and stochastic contributions [5]. The gain FRF $G(j\omega_k)$ can be written as:

$$G(j\omega_k) = G_0(j\omega_k) + G_B(j\omega_k) + G_S(j\omega_k) \quad (1)$$

Where:

- $G_0(j\omega_k)$ is the gain of the underlying linear system (if it exists)
- $G_B(j\omega_k)$ represents the bias or systematic nonlinear contribution to the FRF. This value is independent of the random phase of the multisine, it depends only on its power.
- $G_S(j\omega_k)$ is the stochastic nonlinear contribution to the FRF. This value is a function of the random phase and the power of the multisine and it has noise-like properties.

Note that if the power of the input signal is constant, $G_0(j\omega_k)$ and $G_B(j\omega_k)$ cannot be measured separately, only the sum of both $G_0(j\omega_k) + G_B(j\omega_k)$ can be determined. This represents the gain of the amplifier in compression.

To determine the contributions of the FRF, we present the following method:

$G_0(j\omega_k)$ can be determined with a classical FRF (or S_{21}) measurement (calculate b_2/a_1), but the amplitude of the multisine has to be kept as low as possible. In this case, only the underlying linear system will be measured. Because small signals are used, a good signal-to-noise ratio is mandatory. Minimizing the crest factor of the multisine will yield the best signal-to-noise ratio for a given spectral content [6].

$G_0(j\omega_k) + G_B(j\omega_k)$ has to be determined for a certain input power and can be measured by averaging the FRF (b_2/a_1) over a large number of phase realizations of the input signal. This will indeed eliminate the stochastic nonlinear contributions, since they behave as noise. $|G_0(j\omega_k) + G_B(j\omega_k)|^2$ is then the power gain of the amplifier for that specified input power.

$G_S(j\omega_k)$ is a stochastic quantity that has noise-like properties. The stochastic nonlinear contributions reveal themselves as an extra noise source superimposed on the output of the amplifier in compression. It can be determined by calculating its power, i.e. the variance of the noise source over different phase realizations of the multisine.

$$\begin{aligned} \sigma_{Y_S}^2 &= \text{Distortion Power} \\ Y_S &= b_2 - \overline{(b_2/a_1)} \cdot a_1 \end{aligned} \quad (2)$$

IV. The happy marriage

Both the NPR measurer (person A) and the CCPR measurer (person B) want to quantify the in-band distortions, but they both have a different idea about what these distortions are.

Person A (NPR) measures the generated frequency components in the notch. These are the stochastic nonlinear contributions Y_S at the output of the DUT. Person A also considers the compressed gain of the amplifier $|G_0(j\omega_k) + G_B(j\omega_k)|^2$ to be constant, which is indeed the case if the power of the input signal does not vary too much. Hence, Person A evaluates the bit error rate (BER) or signal-to-noise ratio (SNR) by comparing both quantities, and he is right (for this type of input signal).

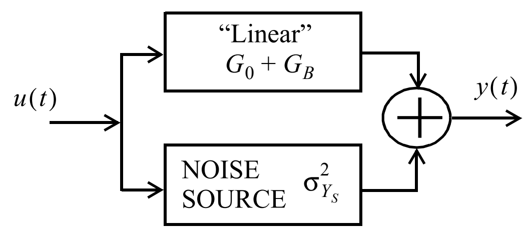

Fig. 1 : Amplifier model according to NPR

Person B (CCPR) knows that the DUT should be linear (with power gain $|G_0(j\omega_k)|^2$), and tags everything that differs from the linear output to be distortions, which she quantifies as $\overline{|(G_0 + G_B + G_S)U - (G_0 \cdot U)|^2}$. Where U represents the input spectrum of the amplifier. If the power of the input signal varies strongly in a stochastic way, $G_B(j\omega_k)$ has also a stochastic behavior. Hence, Person B evaluates the BER or SNR by comparing both quantities, and she is also right (for that type of input signal).

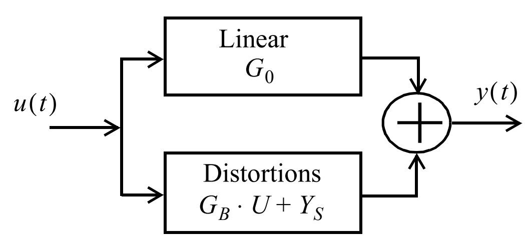

Fig. 2 : Amplifier model according to CCPR

V. Practical Measurements

The measurements used for modeling are performed on a power amplifier of type MAR6 (Mini-Circuits). The power amplifier has a supply voltage of 12V and is terminated in a $50\,\Omega$ load impedance.

The amplifier is excited by a random multisine consisting of 64 tones, each 5kHz spaced, and with a center frequency of 900MHz. However, spectral components 1 till 4 and 22, 24, 26, 28 symmetrical to the carrier of 900MHz were omitted (see Fig. 3) to illustrate that the location of the notch doesn't matter when determining the NPR.

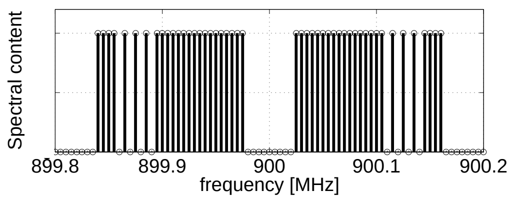

Fig. 3 : Power spectrum of the amplifier's input signal.

This RF signal is generated with a SMIQ06B Vector Signal Generator (Rohde & Schwarz), driven by 2 AWGs at its I and Q ports. The power of the tones is swept from –47 dBm to –27 dBm in steps of 1dB. 20 different realizations of the random multisine were created.

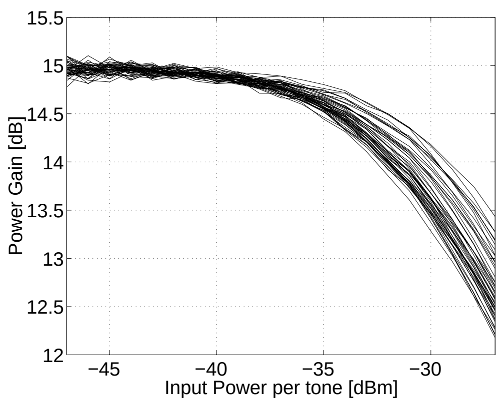

Fig. 4 : Gain vs. input power for each tone

In Fig. 4, the gain of the RF amplifier vs. the input power per tone is plotted. This illustrates that the amplifier goes into compression when the input power increases.

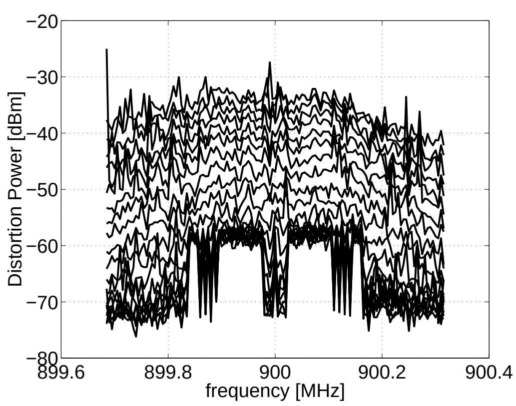

Fig. 5 : Distortion power vs. frequency

Fig. 5 shows the distortion power spectra (calculated with equation (2)), plotted for each input power. As expected, the distortion increases with the power of the input signal, but for low input powers, the excitation band becomes visible (compare Fig. 5 with Fig. 3), indicating that it is distorted by a noise source that is very localized in frequency, such as the noise on the carrier. This carrier noise will be present on every spectral component of the multisine. Small errors on $\overline{b_2/a_1}$ also yield the presence of a very small part of the input signal U in the calculated distortion power $\sigma^2_{Y_S}$ (see equation (2)).

Fig. 6 shows the same distortion power as Fig. 5, but as a function of the signal input power. Here one sees the spectral regrowth increasing with the input power, and the presence of the noise source (that is constant as a function of the input power) in the excitation band.

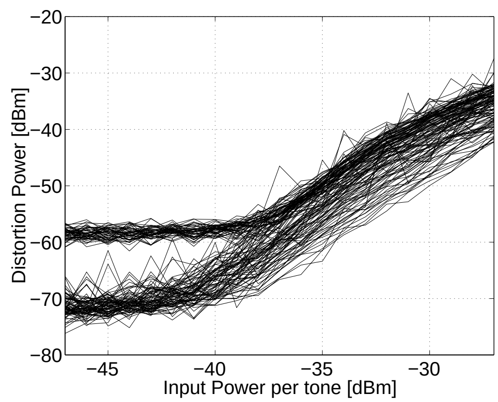

Fig. 6 : Distortion power vs. input power

When performing a classical NPR measurement, one would look at the power of b_2 in the notch, and claim that this is the distortion power. Hence, in the next figure, the power in the notches (which were not only at the center of the excitation band, but also spread across this band, see Fig. 3), and outside the excitation band is plotted.

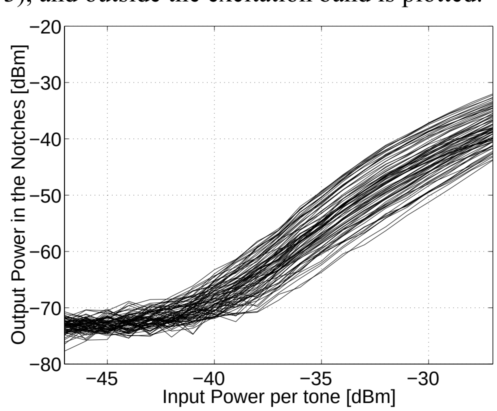

Fig. 7 : Distortion power according to the NPR method

Note that this figure corresponds to the lower bifurcation of Fig. 6. This implies two things:

- •The proposed measurement method is in good agreement with the classical NPR measurement.
- •For classical NPR measurements, the location or coherence of the notch is of no importance.

For the CCPR measurement, the gain of the underlying linear system is determined first as described in section III. This gain turned out to be 15dB. After subtraction of the linear part of the output from the actual amplifier output, one obtains the following figure:

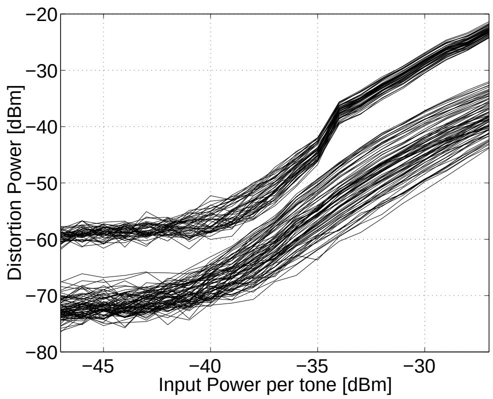

Fig. 8 : Distortion power according to the CCPR method

This plot consists of two distinguishable traces.

The lower trace shows the spectral regrowth and the distortion power in the notches. This trace agrees with the proposed method (Fig. 6) and the results of the NPR method (Fig. 7). This is quite obvious, because in the notches an outside the excitation band, there was no input signal (a_1=0). In that case NPR, CCPR and the proposed method are identical.

The upper trace gives the distortion power at the excitation lines. For high input powers, this is much (8dB) larger than the classical NPR method or the constant input power hypothesis predicts, due to the systematic nonlinear contribution $G_B(j\omega_k)$ which is tagged this time as a distortion. At low input powers, the presence of the constant noise source at the excitation lines is again detected.

VI. Conclusion

In this paper, the nonlinear distortions of a narrowband amplifier have been qualified an quantified. It was shown that both NPR (notch) measurements and CCPR measurements quantify the nonlinear distortions of an amplifier, but for a different type of input signal. If the input signal amplitude remains quite constant, the NPR method gives a valid figure of merit for in-band distortions. If the input signal amplitude varies much, the CCPR method presented in [4] is valid.

In most practical cases however, such as modulated input signals, the input power of the amplifier will not vary very much and hence the classical NPR measurement method (with notch) will quantify the in-band nonlinear distortions of the amplifier.

A measurement method using an AWG has been proposed that is capable of measuring the NPR and the contributions to the FRF, without need for a notch in the power spectrum, or special hardware setup.

The measurements performed validate the proposed theory.

VII. References

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