The Applicability of Noise Power Ratio (NPR) in Real Communication Signals

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Abstract - **A study of Noise Power Ratio (NPR) of real communication signals is performed. The analysis of NPR is done using the orthogonalization of the behavioral model which allows the separation of the correlated and uncorrelated components of the nonlinear output. It is shown that NPR measurements using NBGN overestimate in-band distortion of real communication signals. Simulated NPR of a reverse link IS-95 signal is compared to that of Narrow Band Gaussian Noise (NBGN) and verified by measurements.**

I. Introduction

System performance is usually defined in terms of the effective signal-to-noise ratio (SNR). SNR is the ratio of the signal power to the effective noise and in-band nonlinear distortion powers. In-band distortion, however, cannot be easily measured since it shares the same bandwidth with the signal and hence it needs a special setup to separate the effective distortion from the useful part of the signal [1], [3]. An alternative method to measure in-band distortion is to use the noise loading techniques. In noise loading the system is excited by a NBGN signal after passing it through a notch filter. Noise power ratio (NPR) is then defined as the ratio of the output power of a nonlinear system with the notch present and measured within the notch bandwidth to the output power without the notch in the same notch bandwidth, see Fig. 1 [4], [5], [6]. Therefore NPR represent the ratio of the total output power to the uncorrelated in-band distortion power.

The main issue with NPR is that it is defined in terms of a Gaussian signal which is generally not applicable to many practical communication signals. In this paper we explore NPR analysis of practical communication signals and compare results using NBGN signals. NPR analysis is compared against the uncorrelated in-band distortion power which represents the effective in-band distortion noise obtained using the orthogonalization of the nonlinear model [1]. The ratio of desired output signal power to the uncorrelated co-channel distortion power is used to calculate NPR of a reverse link IS-95 CDMA signal. The findings of this paper are two-fold: First we show that NPR of an IS-95 CDMA signal overestimate uncorrelated in-band distortion by about 5 dB, and second, we show that using NBGN signals to estimate also over estimates in-band distortion of the real signals. The predicted NPR and in-band distortion of IS-95 signals are verified against measurements and compared to estimates using the NBGN.

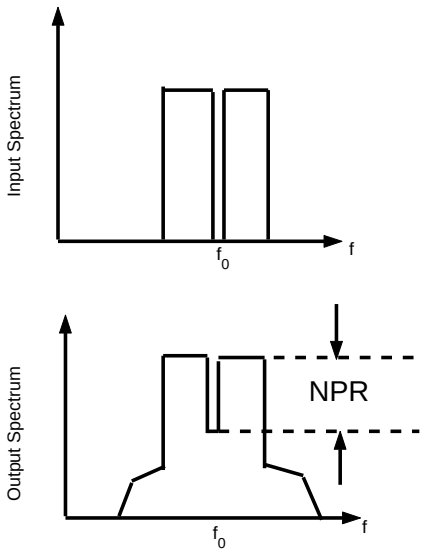

Fig. 1. Definition of NPR.

II. NPR Analysis of CDMA signals

In order to derive an expression for NPR we need to derive the output PSD for the input signal after applying the notch filter. The signal at the output of the notch

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filter is expressed as:

$$\hat{w}(t) = h(t) * w(t)$$

where $w(t)$ is the complex envelope of the input waveform, $\hat{w}(t)$ represents the output of the notch filter and $h(t)$ is the low pass equivalent of the notch filter having a notch at frequency f_0. Let us first consider a memoryless model which is characterized by the envelope (power series) model, then the output of the nonlinearity is expressed as

$$\hat{y}(t) = \sum_{n=1}^{N} b_n \hat{w}(t)|\hat{w}(t)|^{n-1}$$

and the coefficients b_n can be obtained by polynomial fitting of the measured AM-AM and AM-PM coefficients. NPR can now be defined according to [4] as

$$\mathrm{NPR}(f_0) = \frac{S_{yy}(f_0)}{S_{\hat{y}\hat{y}}(f_0)} \tag{1}$$

where $S_{\hat{y}\hat{y}}(f_0)$ is the output power spectral density (PSD) with the notch and $S_{yy}(f_0)$ is the output PSD without the notch. If the system is linear and noise free then NPR approaches infinity. The derivation of NPR in terms of NBGN signal was presented in [4], [5] where a closed form for NPR was reached. The problem now is to derive NPR for a general CDMA signal and to find its relation to the effective uncorrelated in-band distortion.

In order to find the relationship between NPR and the effective in-band distortion we define NPR in terms of the correlated and uncorrelated components of the output [1]. As a result the output is expressed as the sum of uncorrelated components where the cross correlation between any two components of the output is zero. Therefore, the output spectrum can be expressed as

$$S_{yy}(f) = S_{y_c y_c}(f) + S_{y_d y_d}(f) \tag{2}$$

where $S_{y_d y_d}(f_0)$ represent the power spectral density (PSD) of the correlated component and $S_{y_d y_d}(f_0)$ represents the PSD of the uncorrelated distortion component. Note that this analysis does not require an assumption that the input signal is Gaussian. NPR can now be defined in terms of the above analysis as [4]

$$\begin{aligned} \mathrm{NPR}(f_0) &= \frac{S_{yy}(f_0)}{S_{\hat{y}\hat{y}}(f_0)} \\ &= \frac{S_{yy}(f_0)}{S_{\hat{y}_c\hat{y}_c}(f_0) + S_{\hat{y}_d\hat{y}_d}(f_0)} \end{aligned}$$

where $S_{\hat{y}\hat{y}}(f_0)$ is the output PSD with the notch and $S_{yy}(f_0)$ is the output PSD without the notch. Assuming that the notch is very narrow then $S_{\hat{y}_c\hat{y}_c}(f_0) = |H(f_0)|^2 S_{y_c y_c}(f_0) = 0$ and hence,

$$\mathrm{NPR}(f_0) = \frac{S_{yy}(f_0)}{S_{\hat{y}_d\hat{y}_d}(f_0)} \tag{3}$$

Note that, in general, $S_{\hat{y}_d\hat{y}_d}(f_0) \neq S_{y_d y_d}(f_0)$ and hence, NPR does not always represent the effective uncorrelated in-band distortion characterized by $S_{y_d y_d}(f_0)$. However, the equality holds for the case of NBGN. NPR of NBGN is therefore equivalent to the uncorrelated in-band distortion within the notch bandwidth which can be measured using feed-forward cancelation as shown in [1]. Hence, NPR can directly be related the effective SNR in a similar way to the effective in-band distortion.

III. Simulations And Measurements

The evaluation of NPR using the above analysis was verified by simulations and measurements of the output spectrum of both IS-95 reverse-link signal and NBGN signal. Signals were generated in MATLAB and then applied to the nonlinear model after passing them through a notch filter (10 KHz bandwidth). The input power of the signal was swept and the effective NPR was calculated. The signals were then dumped in a vector signal generator and measurements of the output spectrum and the effective in-band distortion at the output of a nonlinear amplifier were performed using a vector signal analyzer.

Figs. 2(a) (b) show the output spectrum of IS-95 reverse-link signal and a NBGN signal after passing them through a notch filter and then through the nonlinear amplifier. Figs. 3(a), (b) and show the NPR and the effective in-band distortion of the two signals versus output power compared to the effective uncorrelated in-band distortion. It is clear that NPR represent a good estimate of in-band distortion in the case of NBGN while it overestimates in-band distortion in the case of a CDMA signal. The figure also show measured values of NPR and measured in-band distortion using feed-forward cancelation.

IV. Conclusion

We have developed an analysis to estimate the effective NPR of real communication signals. It has been shown that NPR test overestimates the effective in-band distortion of CDMA signals. We have also shown that NPR measured using NBGN overestimates NPR of a CDMA reverse link signal.

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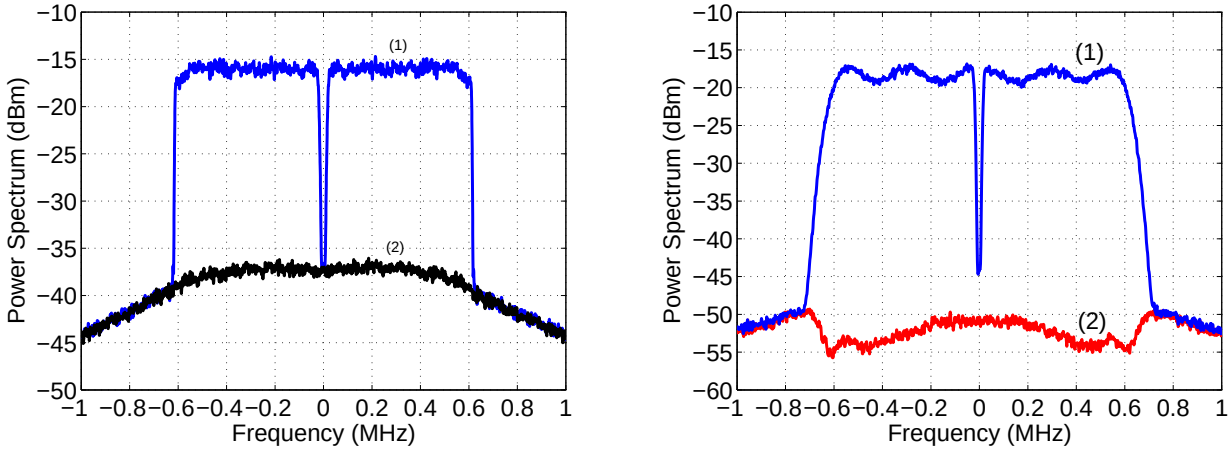

Fig. 2. Simulated output spectrum of (a) NBGN signal and (b) IS-95 reverse-link signal; (1) total output spectrum and (2) uncorrelated distortion spectrum.

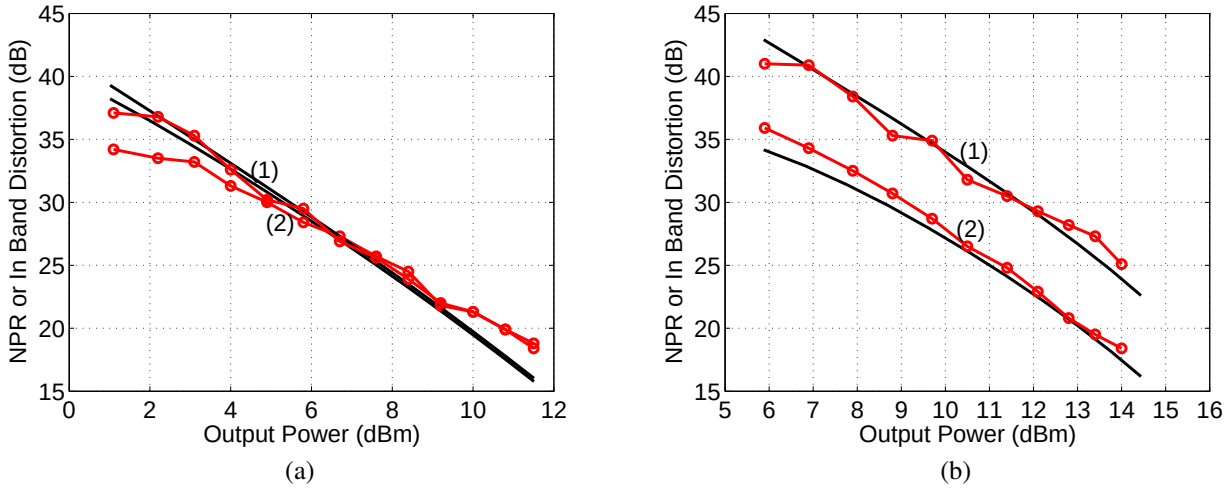

Fig. 3. Distortion vs. output power: (a) NBGN and (b) IS-95 reverse-link signal; Solid: simulated and ○: measured; (1) NPR and (2) In-band distortion.

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