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ACPR PREDICTION OF A CDMA POWER AMPLIFIER

ABBAS POURZAKI[1], **HOSSEIN MIRZAEE**[1]
and ELAHEH MIRZAEE[2]

[1]Department of Electrical and Electronic Engineering
Khorasan Research Institute for Food Science & Technology
Mashhad
Iran
e-mail: pourzaki@krifst.ir

[2]Department of Electrical Engineering
Engineering Faculty
Ferdowsi University of Mashhad
Mashhad
Iran

Abstract

This paper investigates the use of the two-tone signal intended to approximate digitally modulated excitation in ACPR measurements. We subject a nonlinear device to both types of excitation and their ACPR is explored for replacing validity of CDMA signal with two-tone excitation. It has been shown that to reach similar ACPR, the output power spectral density of former must be multiplied by a factor, then it is possible that exploited as the power density of two-tone signal. This factor is satisfied both theoretically and by simulation. The difference was less than 2% in forward link system.

Keywords and phrases: nonlinear system-CDMA, signal-two-tone, signal-ACPR-power amplifier.

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1. Introduction

The power amplifier's nonlinearity broadens the input signal's bandwidth. This is known as spectral regrowth and causes interference with adjacent channels. The availability of accurate methods for the estimation of spectral regrowth is of particular interest to those involved in the design of cellular communication systems [2, 5]. Stringent regulatory emission requirements directly affect the design of microwave power amplifiers. One group of theoretical research has used white or colored Gaussian noise stimuli as substitutes for real-world telecommunication signals [1]. Some authors have tried to substitute random CDMA excitation by multitone signals as these enable the use of powerful tools of CDMA signal analysis [6-8]. Another more practical set of activities has concentrated on the use of a certain class of periodic signals to present the nonlinear effects produced by known stochastic or deterministic excitations [9]. However, the response to uncorrelated multitones was calculated at each frequency during the mixing computations, thus giving the correct output spectra without attempting to separate correlated and uncorrelated IMs (intermodulations). In [3, 4], it is developed and disclosed a methodology for analyzing and measuring the correlated and uncorrelated co-channel band distortion produced by a multitone representation of a CDMA signal.

This paper presents a contribution by discussing the problem of designing signal standards capable of approximating desired random stimulus. Starting from a formal and general model description of a nonlinear dynamic system, it begins by defining a metric of signal similarity, given the responses that two different excitations can be possibly produced in an arbitrary nonlinearity. *This paper presents an analytical expression that relates ACPR of a CDMA system output to two-tone output spectrum. With this expression, one can predict the ACPR of CDMA output spectrum by only two-tone excitation.* Since the measurement of the amplified CDMA output spectrum requires the spreading input signal that is generated from the baseband and modern part, it is much easier to measure the IM products of a two-tone test than the amplified CDMA output spectrum. To show the effects of AM–PM distortion on the CDMA output spectrum, a nonlinear power amplifier is modelled by a complex envelope transfer function not only by AM–AM distortion.

Two-tone is preferred by contrast to multitone for its convenient to construction, set-up, and experiment. In previous paper [10], we extracted the independent factor by neglecting 3rd and higher order nonlinearity effects in the main band. But in this paper, 3rd order nonlinearity is considered. So, by using the new factor ACPR estimation of CDMA signal passing through a nonlinear power amplifier is more precise than past analysis by using multitone signals. In that paper, a virtual signal named "deterministic signal" was introduced that in this paper is replaced by real practical world signal (i.e., two-tone signal).

2. CDMA Signal in Nonlinear System

The general transmit system can be simplified as Figure 1, where a nonlinear power amplifier is sandwiched between bandpass filters (BPFs) [9]. Input signal can be written as:

$$x(t) \equiv x_o(t)\cos(\omega_c t + \theta(t)) = \mathrm{Re}\left[x_o(t)e^{j\theta(t)}e^{j\omega_c t}\right], \tag{1}$$

where ω_c is angular frequency and $\theta(t)$ is phase of the carrier, and $x_o(t)$ denotes the equivalent of $x(t)$ in baseband. Due to the nonlinearities of the power amplifier, the input signal experiences AM–AM and AM–PM distortions, and the output signal can be represented as:

$$\begin{aligned} y(t) &= \mathrm{Re}\left[y_o(t)e^{j\theta(t)}e^{j\omega_c t}\right] = \mathrm{Re}\left[F(x_o(t))e^{j\theta(t)}e^{j\omega_c t}\right] \\ &= |F(x_o(t))|\cos(\omega_c t + \theta(t) + \angle F(x_o(t))), \end{aligned} \tag{2}$$

where $y_o(t)$ denotes $y(t)$ baseband equivalent and $F(x_o(t))$ is the envelope transfer function of the power amplifier. In Equation (2), $|F(x_o(t))|$ represents AM–AM distortion and $\angle F(x_o(t))$ represents AM–PM distortion.

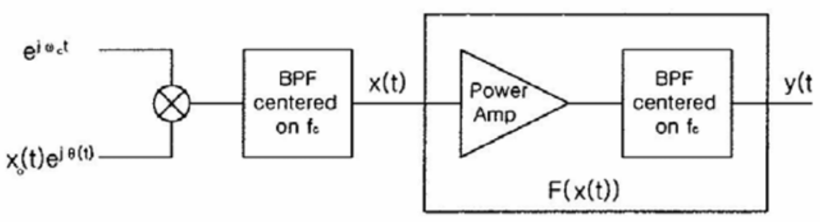

Figure 1. Block diagram of a general transmit system.

In a narrowband memoryless system (as the power amplifier of this paper), the function $F(x_o(t))$ can be presented by the limited odd order Taylor series:

$$y_o(t) = F(x_o(t)) = \sum_{k=1}^{n} f_{2k-1} x_o^{2k-1}(t). \tag{3}$$

Lets $x(t)$ be a CDMA signal, so its power spectral function (PSF) can be supposed rectangular with this density:

$$PSD_{xo}(f) = \begin{cases} P_{i(CDMA)} / 2B & |f| \le B, \\ 0 & |f| > B, \end{cases} \tag{4}$$

where B is the bandwidth of the PSF and input power is $P_{i(CDMA)}$. Using analysis results of Pourzaki et al. [9], output ACPR can be written as:

$$ACPR_{CDMA} = \frac{\sum_{k=1}^{n}\left[a_{2k-1}\frac{1}{(2k-1)!}\left(\frac{P_{i(CDMA)}}{2}\right)^{2k-1}\left\{\sum_{r=0}^{k-2}(-1)^r C_r^{2k-1}\left((2k-2r-4)^{2k-1}-(2k-2r-2)^{2k-1}\right)\right\}\right]}{2\sum_{k=1}^{n}\left[a_{2k-1}\frac{1}{(2k-1)!}\left(\frac{P_{i(CDMA)}}{2}\right)^{2k-1}\left\{\sum_{r=0}^{k-1}(-1)^r C_r^{2k-1}\left((2k-2r-2)^{2k-1}\right)\right\}\right]}, \tag{5}$$

where:

$$a_{2k-1} = \frac{1}{(2k-1)!}\left|\sum_{j=0}^{n-k}\frac{(2j+2k-1)!}{2^j.j!} f_{2j+2k-1} P_0^j\right|^2 \text{ and } C_r^{2k-1} = \frac{(2k-1)!}{r!\,(2k-1-r)!}.$$

In weak nonlinear systems, ACPR can be simplified to:

$$ACPR_{CDMA} \cong \frac{f_3^2 P_{i(CDMA)}^2}{f_1^2 + 6 f_1 f_3 P_{i(CDMA)} + 11 f_3^2 P_{i(CDMA)}^2}. \tag{6}$$

And more, if $f_1 >> f_3$:

$$ACPR_{CDMA} \cong \frac{f_3^2}{f_1^2} P_{i(CDMA)}^2. \tag{7}$$

3. Nonlinear System Response to Two-Tone Signal

In nonlinear systems, input signal can be considered as a two-tone:

$$x(t) = a(\cos \omega_1 t + \cos \omega_2 t), \tag{8}$$

x and y_o relation is as the Equation (3). Considering only three order nonlinearities tend to:

$$\begin{aligned} y(t) &= \sum_{k=1}^{2} f_{2k-1} x^k(t) = f_1 x(t) + f_3 x^3(t) \\ &= f_1(a(\cos \omega_1 t + \cos \omega_2 t)) + f_3(a(\cos \omega_1 t + \cos \omega_2 t))^3 \\ &= \left(f_1 a + 2.25 f_3 a^3\right)\cos \omega_1 t + \left(f_1 a + 2.25 f_3 a^3\right)\cos \omega_2 t \\ &\quad + 0.75 f_3 a^3(\cos(2\omega_1 - \omega_2)t + \cos(2\omega_2 - \omega_1)t) \\ &\quad + 0.25 f_3 a^3(\cos(2\omega_1 + \omega_2)t + \cos(2\omega_2 + \omega_1)t + \cos 3\omega_1 t + \cos 3\omega_2 t). \end{aligned} \tag{9}$$

Now, third order intermodulation (IM_3) can be calculated:

$$IM_3 = \frac{\left(0.75 f_3 a^3\right)^2}{2\left(f_1 a + 2.25 f_3 a^3\right)^2} = \frac{9}{32} \frac{f_3^2 a^4}{\left(f_1 + 0.75 f_3 a^2\right)^2}. \tag{10}$$

If input power is sufficiently low:

$$IM_3 = \frac{9}{32}\frac{f_3^2 P_{i(2tone)}^2}{\left(f_1 + 0.75 f_3 P_{i(2tone)}\right)^2} \cong \frac{9}{32}\frac{f_3^2}{f_1^2} P_{i(2tone)}^2. \tag{11}$$

As we can see from (7) and (11), for equal (low) input power, a simple relation exists between $\mathrm{ACPR}_{(\mathrm{CDMA})}$ and IM_3 (with supposing $P_{i(CDMA)} = P_{i(2tone)}$):

$$ACPR_{(CDMA)} = (32/9) IM_3 = 3.55 IM_3. \tag{12}$$

In practice, it is sufficient to measure or simulate two-tone excitation for obtaining IM_3. Using Equation (12), $\mathrm{ACPR}_{(\mathrm{CDMA})}$ can be estimated.

Now, considering a correction factor for $P_{i(2tone)}$ for its capability to tend to the ACPR of CDMA signal ACPR, i.e.,

$$P_{i(2tone)} = c P_{i(CDMA)}, \tag{13}$$

where c is correction factor that tend to:

$$IM_3 = ACPR_{(CDMA)}. \tag{14}$$

So, from Equations (6) and (10),

$$c = \frac{4\sqrt{2}}{3} \cong 1.89. \tag{15}$$

And if we want to be more precise, Equations (5) and (9) will become:

$$c = \frac{24 f_1 f_3 P_{i(CDMA)} + \sqrt{288 f_1^4 + 1728 f_1^3 f_3 P_{i(CDMA)} + 3168 f_1^2 f_3^2 P_{i(CDMA)}^2}}{9\left(f_1^2 + 6 f_1 f_3 P_{i(CDMA)} + 9 f_3^2 P_{i(CDMA)}^2\right)}. \tag{16}$$

So, if input power of two-tone analysis is multiplied by this factor, obtained IM_3 will be equal to ACPR of the system with excitation of CDMA signal. IM_3 can be obtained by measurement or simulation.

4. Results

In this paper, the nonlinear system is a power amplifier that is designed for 1.9GHz with 2MHz bandwidth. The circuit of this power amplifier is depicted in Figure 2.

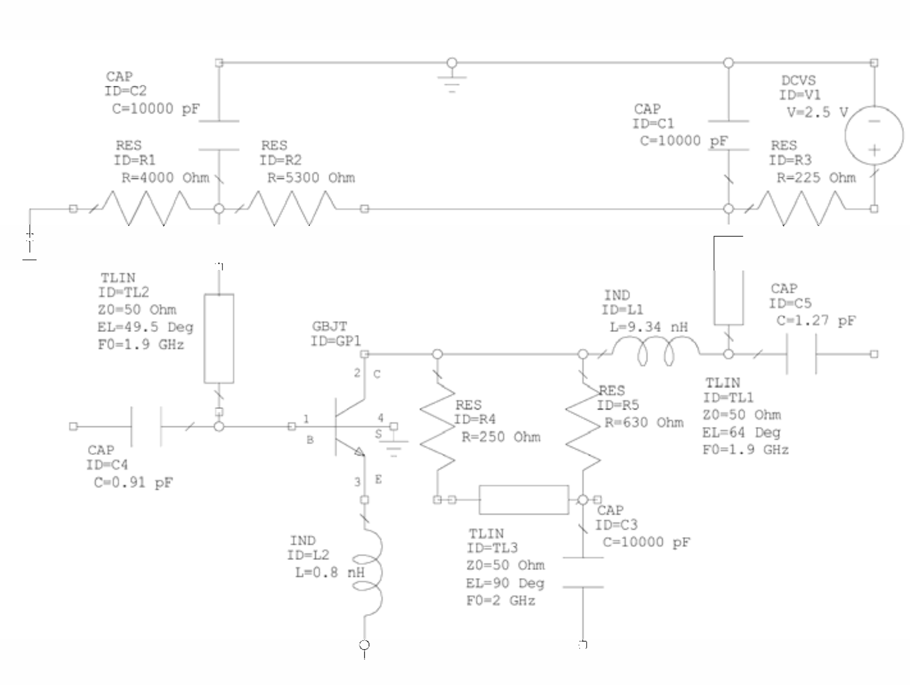

Figure 2. Power amplifier circuit designed for 1.9GHz.

We simulate this circuit by Microwave-office software. Using simulation comparisons are made in MATLAB software. ACPR curves versus input powers are shown in Figure 3 (using Equation (16)). This figure shows that the result of ACPR calculation at standard levels is satisfactory, because in ACPR = –55dB standard, error of estimation is negligible. In higher power levels, that higher nonlinearity than three is appeared; the difference between curves can be obviously observed.

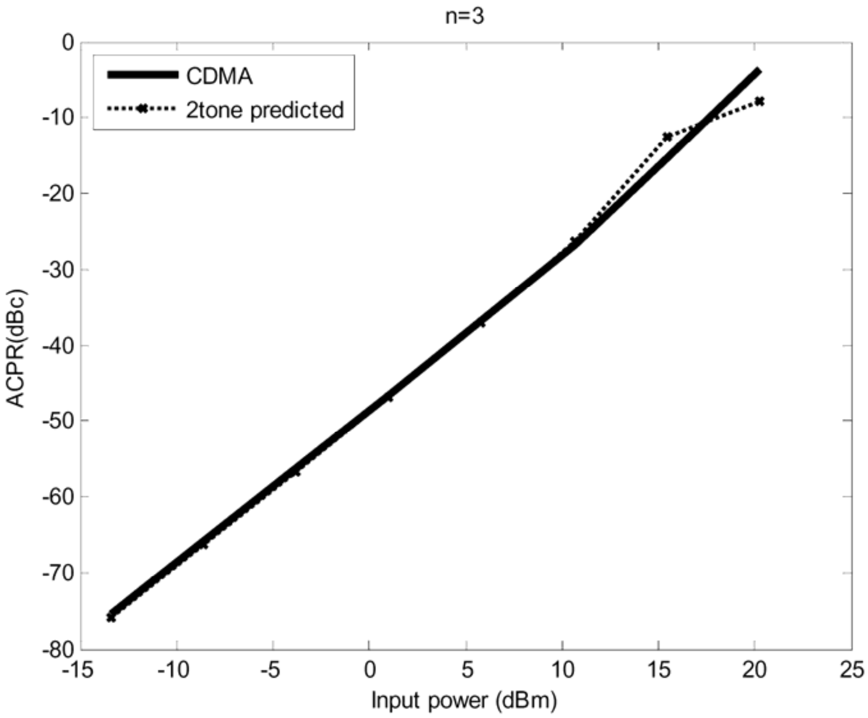

Figure 3. Comparison of ACPR of CDMA signal and IM_3 (by two-tone excitation).

5. Conclusion

In this paper, we analyzed and surveyed the effects of nonlinear systems on pseudo noise (CDMA) and deterministic signals (two-tone signals). Two new subjects were discussed: (i) ACPR analysis of CDMA and two-tone responses, and (ii) describing how to substitute pseudo noise with the two-tone signal.

In this paper, ACPR is analytically extracted for two kinds of signals and the results are compared. It seemed that up to high level input power, the difference between ACPR of the two kinds of signals is constant and as a result, we could define two-tone input power in terms of CDMA input power. Therefore, ACPR of CDMA can be calculated from ACPR of the two-tone signal with acceptable error. Theoretically and using simulation acceptable result in ACPR of both signal kinds can be shown.

The other more important result is that, in practice, it is not necessary to have a CDMA excitation for predicting CDMA ACPR. It is enough to use Equation (16) and calculate deterministic signal (two-tone). If the system is not strongly nonlinear, the resulting ACPR will be moderately equal to ACPR of CDMA signal and more precise than results of [10]. Therefore, authors of this paper believe that it could help RF system designers to predict the distortion effects of an RF power amplifier, and it is thought to be useful for nonlinear behavioral modelling.

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