Efficient Simulation of Spectral Regrowth Using Nonlinear Transformation of Signal Statistics

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The availability of accurate methods for the estimation of spectral regrowth is of particular interest to those involved in the design of cellular and personal communications systems where nonlinear devices, especially in the power amplifiers, generate co-channel and adjacent channel interference due to sideband regrowth. Stringent regulatory emission requirements directly affect the design of microwave power amplifiers. In particular, design choices that limit adjacent channel interference affect the efficiency and power output of RF active components by forcing them to operate in regimes that are closer to being linear. Thus RF power amplifier design depends on trade-offs between three main performance indicators: output power, efficiency, and sideband regrowth. Hence the importance of developing schemes to accurately predict ACPR of a RF amplifier in a timely manner. ACPR is more difficult to predict than one-tone or two-tone responses, since it depends not only on the intrinsic nonlinear behavior of the amplifier but also on the encoding method and modulation format being used.

Interference produced in the adjacent channel is characterized by the Adjacent Channel Power Ratio (ACPR), which is the power in the main channel divided by the power in the lower plus upper adjacent channels. Analog cellular radio uses frequency or phase modulation, and ACPR is adequately characterized by intermodulation distortion of discrete tones. Typically, third order intermodulation product (IP3) generation, in a two-tone test, is adequate to describe spectral regrowth. Thus distortion in analog radio is accurately modeled using discrete tone steady-state simulation. Digital radio, however, uses complex modulation, and adjacent channel distortion has little relationship to intermodulation in a two-tone test. A modulated input signal applied to RF electronics in digital radio is a sophisticated waveform resulting from coding, filtering and quadrature generation. It cannot be represented by a small number of discrete tones (or frequencies), and neither can the waveform be represented in a simple analytic form. The only way the input stream can conveniently and accurately be represented is by its statistics, and transforming these using an appropriate behavioral model provides accurate and efficient modeling of ACPR and of gain compression.

The purpose of this paper is to develop techniques for the prediction of at the output of a nonlinear amplifier, represented as a behavioral model, from the statistics of the input modulated RF signal. The major contributions of this paper are:

1. Characterization of a digitally modulated signal by its autocorrelation functions, and using this with a behavioral nonlinear model to obtain the output statistics of the

digitally modulated signal. From this, Adjacent Channel Power Ratio (ACPR) is obtained.

2. Use of readily available AM-AM and AM-PM measurements (experimentally obtained or derived from simulation) to derive a complex envelope behavioral model.

AM-AM and AM-PM data is derived from measurements of complex gain versus input power for a one- tone signal. These are relatively straightforward and widely available to the RF designer. AM-AM and AM-PM effects are easily extracted from single tone, complex gain measurements swept over input power using a network analyzer or vector voltmeter. It can also be developed from discrete tone steady state (i.e., harmonic balance or shooting method) simulations. The method is limited to cases in which AM-AM and AM-PM characteristics provide a satisfactory representation of the device, leaving out biasing circuit memory effects and the effect of amplifier impedance mismatch

This section presents a method for predicting spectral regrowth based on the nonlinear transformation of the amplitude statistics of the input signal. A scheme that is simple to calculate, and therefore more readily available to the practicing engineer seeking to estimate the nonlinear transfer response, is developed. The proposed formulation seeks to provide design insight into how the nonlinearity affects the output spectrum, by developing a modular approach that considers the successive transformation of the input statistics through the modulation scheme and the nonlinearity itself. The output power spectrum is estimated from an analytical expression for the output autocorrelation function that describes the transformation of a complex gaussian signal when passed through a bandpass nonlinearity.

The development proceeds with two filtered data inputs to a quadrature modulator, treated as two identically distributed independent gaussian random variables. Baseband filters are commonly specified by wireless standards to band limit the modulated signal to increase the number of usable channels for a fixed amount of spectrum. It is interesting to note that filtering the data usually increases amplitude variation, which in turn increases power amplifier linearity requirements. The output of the modulator is the quadrature sum the filtered inputs forming a complex gaussian random variable, which is then applied to a nonlinear device, characterized by a complex power series model. The output signal is derived in terms of the complex gaussian random variable and the power series coefficients. The output autocorrelation function is obtained by computing the expected value of the output signal resulting in a sum of individual moments of products of the complex gaussian random variable. A moment theorem for complex gaussian random variables is used to calculate the output moments yielding a simple expression for the output autocorrelation function. The resulting power spectrum is obtained from the fourier transform on the output autocorrelation function resulting in a simple expression for the output power spectrum from which ACPR is readily calculated.