Research on PA Digital Predistortion Simulation Based on an Improved Model

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Abstract. Based on the study of the traditional power amplifier predistortion model, this paper proposes a new model. In order to verify the ability of the new model to compensate for the nonlinear distortion of the power amplifier, this paper designs a predistortion joint verification system based on ADS and MATALB, tested with a three-carrier LTE signal. Simulation results show that the ACPR (Adjacent Channel Power Ratio) of the PA output signal compensated by predistorter is improved 17.230dB compared with the PA (Power Amplifier) original output signal.

1. Introduction
Mobile communication system uses a non-constant envelope modulation. Such as 16-QAM, OFDM, etc. Compared with a mobile communication system using a constant envelope modulation method, spectrum utilization can be more effectively improved. However, when a non-constant envelope signal passes through the power amplifier [1]-[3], since the inherent nonlinearity of the power amplifier causes intermediation distortion and spectrum expansion, the result will be a decline in the quality of the system transmission, therefore, we must compensate the power amplifier nonlinearity accordingly.

In modern wireless communication systems with non-constant envelope digital modulation, in order to get higher power output efficiency, we need the power amplifier to work near the saturation point, which is the most serious nonlinear problem [4]. Therefore, the power efficiency and linearity of power amplifiers in modern wireless communication systems become a major contradiction, and linearization technology will play a very important role in solving this contradiction. Among the many linearization technologies, the power amplifier digital predistortion technology has become the most popular linearization technology due to its stability, wideband communication, and high precision.

2. Power amplifier predistortion model
Since the power amplifier and the predistorter are both nonlinear systems, and there are complementary characteristics between the two. Therefore, we can study the modeling effect of the amplifier and transplant the high-performance power amplifier model into the construction of the predistorter model. Establishing an accurate model is of great significance for the simulation of amplifier systems, especially the design and simulation of predistortion amplifier systems [5].
2.1. Memoryless polynomial model
When the bandwidth of the input signal of the power amplifier is relatively small, the influence of the memory effect of the power amplifier can be ignored. Therefore, we can use the memoryless polynomial model for power amplifier modeling [6]. The mathematical expression of memoryless polynomial model is as follows

\[ y(n) = b_1 x(n) + b_2 x(n)^2 + b_3 x(n)^3 + \cdots = \sum_{p=1}^{P} b_{km} |x(n)|^{p-1} x(n) \] (1)

Where \( x(n) \) is input signal of the power amplifier system, \( y(n) \) is output signal of the power amplifier system, \( b_{km} \) is complex coefficient of the model and \( m=0 \), \( p \) is the highest nonlinear order of the model.

2.2. Memory power amplifier behaviour model
When the power amplifier input signal bandwidth is relatively large, the influence of the power amplifier memory effect cannot be ignored. The effect of the memory effect of the amplifier must be considered. The traditional descriptions of memory power amplifier models are as follows [7].

2.2.1. Volterra series model. Volterra series are generally used to represent nonlinear systems and are referred to as "memory Taylor series." The truncated discrete model is defined as

\[ y(n) = \sum_{l=0}^{L} h_l(n-l)x(n-l) + \sum_{l_1=0}^{L} \sum_{l_2=0}^{L} h_{l_1,l_2}(n-l_1,l_2)x(n-l_1)x(n-l_2) + \cdots \] (2)

Where \( n \) is discrete time, \( h_l(n-l) \) is kernel function with \( k \) order, related to the \( k \)-order nonlinearity of the power amplifier, \( L \) represents the maximum memory depth of the nonlinear system. The biggest disadvantage of this model is that with the increase of the nonlinearity of the power amplifier and the increase of the series parameters, it will lead to a large computational complexity, which makes the power amplifier predistortion model more complicated and leads to the digital predistorter parameters. The identification is more difficult.

2.2.2. Memory polynomial model. The memory polynomial model is essentially a simplification of the Volterra series model. The memory polynomial model is defined as

\[ y(n) = \sum_{l=0}^{L} \left[ h_l(n-l)x(n-l) + h_2(l,l)x(n-l)\left|x(n-l)\right|^2 \right] + \cdots \] (3)

Let \( h_k(l_1,l_\cdots,l) = a_{kl} \), formula (3) can be written as
\[ y(n) = \sum_{q=1}^{Q} \sum_{l=0}^{L} a_{qm}^l x(n-l) |x(n-l)|^{q-1} \] (4)

Where Q represents the highest nonlinear order of the memory polynomial model, and L represents the maximum memory depth of the model. Compared with Volterra series model, the computational complexity of the memory polynomial model is reduced, however, the calculation accuracy of this model is not high [8].

2.3. Improved behavioural model
In many published articles, modeling only considers the use of models containing only odd-order nonlinear terms to represent nonlinear power amplifier systems. This modeling method can reduce the computational complexity of the model, but it cannot improve the accuracy of the model. In order to improve the accuracy of the power amplifier model while reducing the complexity of modeling, a new model is proposed, which adds even-order nonlinear terms. In order to overcome the computational complexity of the proposed model, an effective model order reduction method, dynamic deviation reduction method, is adopted to simplify the Volterra baseband model. The mathematical formula of the improved behavioral model is as follows

\[
y = \sum_{p=1}^{P} \sum_{m=0}^{M} b_{pm} x(n-m) |x(n-m)|^{p-1} \\
+ \sum_{p=1}^{P} \left\{ \sum_{r=1}^{\left(\frac{p+1}{2}\right)} \sum_{d=1}^{\left(\frac{p-1}{2}\right)} x^{(p+1)/2-\gamma} (n) (x^{(p-1)/2-\delta} (n))^* \right\} \\
\sum_{m_0=0}^{M} \cdots \sum_{m_d=0}^{M} \alpha_{p,r+d} (0, \cdots, 0, m_1, \cdots, m_{r+d}) \\
\prod_{j=1}^{r} x(n-m_j) \prod_{\ell=1}^{d} x(n-m_{\ell}) \right\} \] (5)

Where P is the order of the model, M is the maximum memory depth of the model. The choice of parameters r and d depends on the characteristics of the power amplifier and the need for model accuracy.

3. Co-simulation verification
To verify the compensation effect of the predistorter built by the improved model on the nonlinearity of the power amplifier, a joint predistortion verification system based on ADS and MATLAB is built. The main modules of the verification system include:

Test signal generation module, the test signal generated by the system is a 4G system three-carrier LTE signal with a bandwidth of 60 MHz, and the signal sampling frequency is 245.76 MHz. The power amplifier circuit of the verification system is a class AB power amplifier built on a transistor of the type MRF6S21140H. The applicable frequency range for this transistor is: 2110MHz to 2170MHz.
Figure 1 shows three-carrier LTE signal generation module with a bandwidth of 60 MHz.
Figure 2 shows the composition of joint predistortion verification system. After the simulation using the joint verification platform, the power input spectrum of the original input and output signals of the power amplifier is obtained in the data display window of the ADS2008, as shown in Figure 3.

![Figure 2. Three-Carrier LTE Joint Predistortion verification system.](image)

Figure 3. Power amplifier input and output signal power spectral density. (a) Power amplifier raw input signal power spectrum, (b) Power amplifier raw output signal power spectrum.

Figure 3 shows that the PA output signal without predistorter compensation compensates for the spectral interference of adjacent channels. Therefore, the nonlinear PA must be compensated.
Next, using the improved model predistorter proposed in this paper, the class AB amplifier consisting of MRF6S21140H transistor is nonlinearly compensated. The model has a predistorter with a maximum nonlinear order of 7 and a maximum memory depth of 2, \( r = 1, d = 1 \). The spectrum of the output signal of the power amplifier compensated by the predistorter is as shown in Figure 4. Figure 4 shows that the spectral interference of the nonlinear power amplifier to adjacent channels is well suppressed by the improved predistorter compensation. In order to compare the predistorter compensation ability proposed in this paper, the power spectrum of the power amplifier output signal after compensation by the memoryless polynomial model predistorter and the ordinary memory polynomial model predistorter is given below. As shown in Figure 5 and Figure 6.
4. Conclusion
After compensating with the predistorter constructed by the improved model, the nonlinear amplifier's spectral interference to adjacent channels is well suppressed. This proves that the improved model can better approximate the characteristics of the actual power amplifier, and can also better compensate the nonlinear characteristics of the power amplifier.

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