Compensation for Nonlinear RF Power Amplifier using a Variable Step-Size LMS algorithm

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Abstract

An adaptive predistorter is proposed to compensate for the nonlinear distortion of a high power amplifier (HPA) in 16 QAM system. It turned out that the proposed predistorter using a variable step-size least mean square (VSSLMS) algorithm is stable and can reduce the Total Distortion (TD) to 0.1dB at the HPA output backoff=0.0 dB.

1. Introduction

When an M-ary Quadrature Amplitude Modulation (QAM) is employed to increase data rate in satellite or microwave communication system. The system performance is limited by the nonlinearity of High Power Amplifier (HPA) caused by nonlinear AM/AM and AM/PM effect due to the multi-level envelope of 16 QAM waveform[1][2][3]. The nonlinearity of the HPA causes Adjacent Channel Interference (ACI) and Bit Error Rate (BER) degradation. However, it can be reduced by backing-off the output signal power level, resulting in the reduction of the effective signal power, which ends up reducing data rate. It keeps the error rate from increasing.

Several data predistortion method compensating for the nonlinearity of the HPA are proposed[9]-[12]. These methods based on the Volterra series model, neural network model, Hammerstein model, and Look-Up-Table (LUT) with random access memory(RAM). The data predistorter based on the Volterra series model are not practical for real-time implementation due to high computational complexity for large filter coefficients. The data predistorter based on the neural netwok model and Hammerstein model perform better with relatively fewer coefficients than that of Volterra model but the convergence speed is low. Then it cannot effectively perform in the case that it is not sufficient data samples. The data predistorter based on the LUT with RAM requires a massive amount of RAM to store a sufficiently accurate mapping and the convergence speed is low. Also it is necessary to check the stability of the previous mentioneddata predistorter because they are recursive systems.

We proposed an adaptive predistorter that consisting of pre-adaptive predistorter and post-predistor based on polynomial approximation method. In order to guarantee stable operations regardless of the environmental change, we used VSSLMS algorithm satisfying the stability condition [8]. The performance of the proposed adaptive predistorter is compared with an Amplitude&Phase predistorter [5].

2. Transmission System Model

The baseband-equivalent block diagram of the transmission system is shown in Fig.2. We assume 16 QAM as modulation format. The block labeled pulse shaping represents a square-root raised cosine filter with rolloff factor α. The spectrally shaped signal at the output of the pulse shaping filter is fed to the cascade of the adaptive PD, the PD and the HPA. The HPA is modeled as a nonlinear memoryless system with $M(r)$, $\Phi(r)$ denoting its AM/AM and AM/PM responses, respectively. We assumed the nonlinearity of the HPA is represented as following normalized AM/AM and AM/PM [4]

$$M(r) = \frac{2r}{1+r^2} \quad (1)$$

$$\Phi(r) = \frac{\pi}{3}\frac{r^2}{1+r^2} \quad (2)$$

3. Proposed predistorter structure

A polynomial predistorter which consists of an amplitude predistorter and an phase predistorter is proposed in[5]. A(r)andΘ(r) roughly compensate for AM/AM and AM/PM effect in HPA, respectively. A(r)and Θ (r) are modified to suitable for a 16-QAM system.

$$A(r) = 0.097r^2 + 0.78 \quad (3)$$

$$\Theta(r) = 0.48r^2 - 0.075 \quad (4)$$

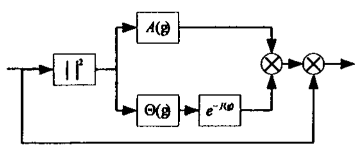

Fig. 1. Polynomial predistorter

The adaptive predistorter is based on VSSLMS [6][7]. The output of the adaptive predistorter and error are

$$y(n) = \sum_{i=0}^{N-1} \omega^*(n)x(n-i) \quad (5)$$

$$e(n) = x(n-d) - z(n) \quad (6)$$

The delay term is caused by system delays of the adaptive predistorter, the polynomial predisorter and the HPA. The VSSLMS algorithm in this case works on the basis of the update equation.

$$\overline{w}(n+1) = \overline{w}(n) - \mu(n)\nabla_{\overline{w}}^{C}|e(n)|^2 \quad (7)$$

where $\nabla_{\overline{w}}^{C}$ denotes complex gradient operator with respect to the variable vector $\overline{w}$. Replacing $|e(n)|^2$ by $e^*(n)e(n)$ following a derivation is

$$\nabla_{w_i^*}^{C}|e(n)|^2 = -2e^*(n)x(n-i) \quad (8)$$

for $i = 0,1,\ldots,N-1$

where the asterisk denotes complex conjugation. Substitution (8) and insertion in (7), we obtain

$$\overline{w}(n+1) = \overline{w}(n) + 2\mu(n)e^*(n)\overline{x}(n) \quad (9)$$

And the following formula for the step-size update is used

$$\mu(n) = \begin{cases} \mu_{\min} + \beta M(e^2(i)), & \text{If } \mu(n) \ge \mu_{\min} \\ \mu_{\max} & \text{,If } \mu(n) \ge \mu_{\max} \end{cases} \quad (10)$$

$$M(e^2(i)) = \gamma M(e^2(i-1)) + (1-\gamma)e^2(i) \quad (11)$$

where $\beta \in [0,1]$ is the error reflection factor and $\gamma \in [0,1]$ is the forgetting factor.

The step size is controlled by average error signal power. For instance, the step-size increases until it approaches maximum step size when average error signal power increases and the step size decreases until it approaches minimum step size when error power decreases.

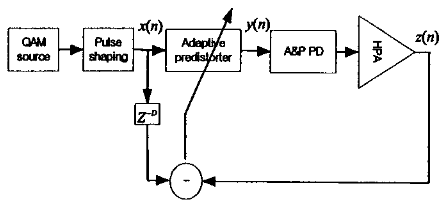

Fig. 2. The proposed predistorter

4. Simulation Result

Simulations were carried out using the Signal Processing Workshop (SPW). The parameters of the proposed predistorter are set to N=0, β=0.98, γ=0.99, $\mu_{min}=5\times10^{-4}$ for efficient operation and $\mu_{max}=0.8$ to satisfy stability condition [8]. We can know that the order of the adaptive predistorter in the proposed predistorter can be reduced to 0 when a polynomial preistorter and the variable step-size are used.

From Fig3 to Fig5, one can know that the 16 QAM system with the proposed predistorter can be used at output backoff=0.0 by reducing the nonlinearity of the HPA. Fig4 shows that the adaptive predistorter without a polynomial predistoter can not compensate the nonlinearity of the HPA in circled areas although the order of the adaptive predistorter is increased N=8.

A typical performance measure for representing the influence of nonlinear effect in HPA is total degradation (TD). The TD in decibels is defined as follows [5].

$$TD = \left(\frac{E_b}{N_o}\right)_{HPA} - \left(\frac{E_b}{N_o}\right)_{AWGN} \quad (12)$$

where $(Eb/No)_{HPA}$ represents the required Eb/No to obtain BER=10^{-4} in 16-QAM system when the HPA is used, and $(Eb/No)_{AWGN}$ is the required Eb/No to obtain the same BER on the AWGN channel with HPA. Fig6 TD in decibels is shown for different values of output backoff, which provide the optimum HPA backoff.

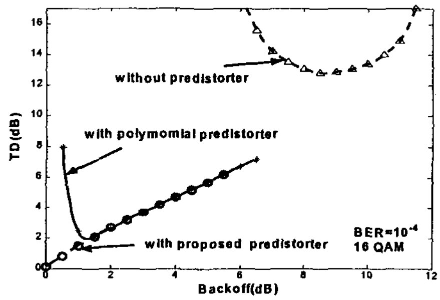

Fig. 6. Total Distortion

We notice that the 16 QAM system with proposed predistorter achieves a gain of 8.5 dB over the HPA without predistortion and 1.2 dB over than the previous polynomial predistorter. From Fig 6, one can also know that the TD of the proposed predistorter is as low as 0.1 dB at the HPA output backoff=0.0dB

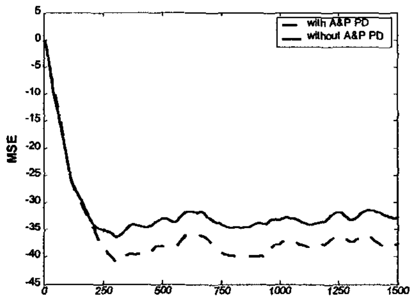

Fig. 7. Learning curve

Fig 7 shows the learning curve of the proposed predistorter and here the MSE represents the distance between $x(n)$ and $z(n)$. The errors are averaged over 20 independent trials. We can see that approximately 300 samples are required to reach the MSE = -32dB when only adaptive predistorter is used, however, MSE reaches approximately -38dB when the proposed predistorter is used although almost same convergence speed.

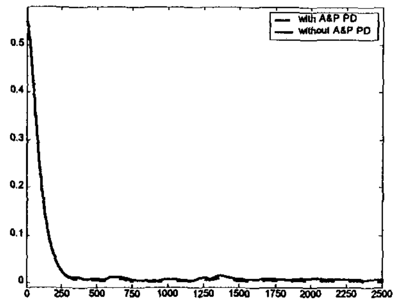

Fig. 8. The step-size variation

The step size of each predisotorter is designed by reflecting error signal power. Its step size is more precisely controlled than that of the adaptive predistorter when adaptive predistorter is combined with a polynomial predistorter in Fig8.

Type	OBR
HPA	-17.6 dBr
Polynomial Predistorter	-21.3 dBr
Proposed Predistorter	-23.1 dBr

Table 1 Transmitted Out of Band Radiation

We observed that the presence of the proposed predistorter provides beneficial also with respect to ACI. When the proposed predistorter is employed, spectral spreading due to nonlinearity of the HPA is reduced smaller than that of the polynomial predistorter. A typical measure of the above spectrum spreading is represented by the fraction of transmitted power that exceeds the bandwidth $(1+\alpha)/2T$ established by the signal pulse shaping. The OBR was evaluated at the HPA output backoff=0.0dB in table1.

5. Conclusion

We proposed an efficient adaptive predistorter that combines a polynomial predistorter and a zero order adaptive predistorter using VSSLMS algorithm in 16

QAM system with HPA. From simulation results, it is confirmed that the proposed predistorter is stable and can be used at the HPA output backoff=0.0dB. The OBR of the proposed predistorter is lower than that of the polynomial predistorter as much as approximately 1.8 dB. Thus the proposed predistorter can be used at an OFDM system highly sensitive at the nonlinearity of the HPA.

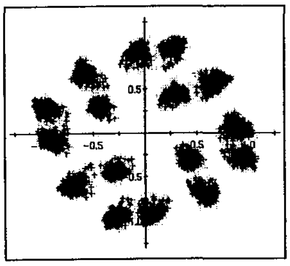

Fig. 3. Signal constellation with HPA (BO=0.0dB)

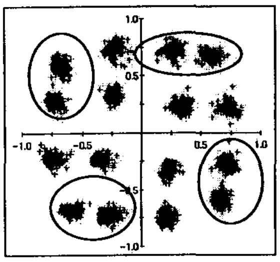

Fig. 4. Signal constellation with the adaptive predistorter (BO=0.0dB)

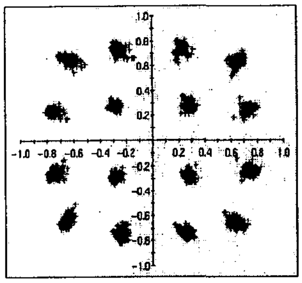

Fig. 5. Signal constellation with the proposed predistorter (BO=0.0dB)

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