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A Pre-distortion Method for 64APSK

Zijian Li[1, a], Jinshu Chen[1, b]

[1]Department of Electronic Engineering Tsinghua University Beijing, China

[a]zj-li16@mails.tsinghua.edu.cn ,[b]chenjs@mails.tsinghua.edu.cn

Abstract. This paper investigated the nonlinear distortion of high-order modulated signals generated at high power amplifiers (HPA) in remote sensing satellite communications. An improved pre-distortion structure is proposed for the problems existing in traditional methods, and an adaptive adjustment algorithm for pre-distorter is given. The simulation result shows that the proposed method can effectively suppress the distortion and reduce the bit error rate of the signal, which provides guarantee for subsequent decoding.

Keywords: 64APSK, nonlinear distortion, digital pre-distortion, adaptive algorithm.

1. Introduction

As the data transmission rate of remote sensing satellites continues to increase, in order to make full use of limited spectrum resources and achieve higher frequency band utilization, high-order modulation methods are proposed, such as M-Quadrature Amplitude Modulation(M-QAM), M-Amplitude Phase Shift Keying(M-APSK). In 2012, Consultative Committee for Space Data Systems (CCSDS) and in 2014 the Digital Video Broadcasting (DVB)-S2X standard proposed higher-order modulation methods, including 64APSK and even higher-order modulation modes[1][2].

Due to its non-constant envelope characteristics, the high-order modulation has large fluctuations in signal envelope and high peak-to-average-power-radio(PAPR). So the influence of the nonlinear channel on it is greater than that on the constant envelope modulation, and this will also lead to more severe distortion, which will affect the communication quality and cause loss of decoding.

Nonlinear effects mainly come from high power amplifiers (HPA). In order to make full use of the power efficiency of the amplifier, it is generally expected to work near the saturation region, but this will produce more serious nonlinear distortion. At present, in order to solve the nonlinear characteristics of HPA, most methods used are linearization techniques at the transmission, such as feedforward method[3][4], negative feedback method[5][6], pre-distortion method and so on. Among them, the pre-distortion technology is one of the most promising linearization techniques due to its relatively simple and practical advantages.

The principle of pre-distortion technology is very clear. Letting the signal go through a pre-distortion module that is opposite to the nonlinear characteristic before entering the HPA. So that the resulting joint output signal is the standard signal that we want. The pre-distortion technology includes analog RF pre-distortion and baseband digital pre-distortion. Baseband digital pre-distortion has received more research and attention by using digital signal processing techniques to avoid complex RF signal processing. In addition, during the use of HPA, the nonlinear characteristics will change due to environmental changes such as temperature and time, etc. To avoid frequent adjustments to the pre-distortion module, we usually use an adaptive learning algorithm to make tracking adjustments to accommodate slow changes in the channel.

As the increasing order of modulation methods, the traditional look-up-table based pre-distortion method[7] is no longer applicable due to the increase of entries, and the direct use of two quadrature IQ signals can not correct the distortion well under the polynomial model. This paper proposes an improved pre-distortion structure that separates the input quadrature IQ signals into amplitude-phase signals for pre-distortion calculation. The new structure can match the Saleh model better and restore the distorted signal.

The simulation verified the pre-distortion effect of 64APSK.The results show that the method can effectively reduce the nonlinear distortion of HPA.

2. System Model

2.1 Whole Frame.

The system block diagram of the signal is as follows:

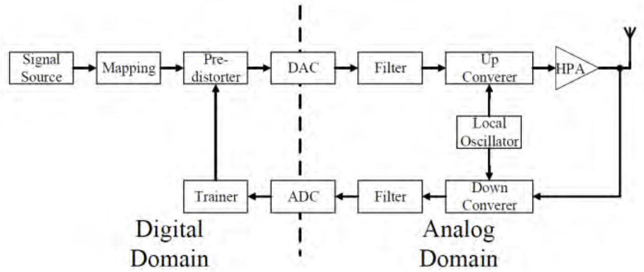

Fig. 1 System model

Where the pre-distorter is a copy of the trainer. The signal is sent from the signal source, then after constellation mapping and pre-distortion the signal entered the analog domain. As for the return signal, through the continuous adjustment of the trainer, the parameters of the pre-distorter were finally obtained. For the specific signal, compared with the structure directly using the IQ signals, a signal conversion module is added before the pre-distortion. It converts the quadrature IQ signals into amplitude-phase signals and then enter the pre-distortion module for calculation.

2.2 HPA Model.

In satellite communications, most of the power amplifiers used are traveling wave tube amplifiers(TWTA). There are many ways to establish the model, such as the polynomial model. Some people have proposed their own models, Sunde proposes a soft limiter to represent its amplitude characteristics and uses polynomials to represent phase characteristics. The current simulation of TWTA usually uses the model proposed by Saleh[8].

If the input HPA signal is expressed as：

$$x(t) = r(t)\exp[j\varphi(t)] \tag{1}$$

The output signal is：

$$y(t)= A[r(t)]\exp\{j\varphi(t) + \Phi[r(t)]\} \tag{2}$$

Where $A[r(t)]$ and $\Phi[r(t)]$ represent the AM-AM distortion and AM-PM distortion of the signal respectively.

$$A[r(t)] = \alpha_a r / (1 + \beta_a r^2) \tag{3}$$

$$\Phi[r(t)] = \alpha_\phi r^2 / (1 + \beta_\phi r^2) \tag{4}$$

2.3 Pre-distorter Model.

For the pre-distorter, as an inverse model of the HPA, we can use the polynomial model as its structure. We get amplitude and phase signals r , θ from the IQ signals, as the input of the pre-distorter. According to the Saleh model of HPA, for its inverse model, the output amplitude is only related to the input amplitude, and the output phase is related to the input amplitude and phase. Therefore, under the polynomial model, the output of the pre-distorter can be modeled as:

$$r_{out}(t) = \sum_{i=0}^{K} w_{r,i} r_{in}^{i}(t)$$

$$\theta_{out}(t) = \theta_{in} + \sum_{i=0}^{K} w_{\phi,i} r_{in}^{i}(t)$$

Where K is the order of the model and w is the coefficient of the pre-distorter, which can be identified by an adaptive learning algorithm.

3. Adaptive Learning Algorithm

The adaptive learning algorithm is a method of continuously adjusting the parameters of an adaptive filter to adapt to the signals in an unknown environment by the given signals. A commonly used and effective algorithm is the Least Mean Square (LMS) algorithm.

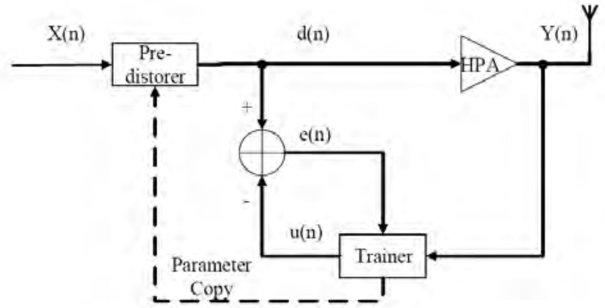

Fig. 2 Adaptive learning structure

In Fig. 2, according to the model structure described above, the input signal of the pre-distorter $x(n)$ is the amplitude and phase signals after transforming the IQ signals. In the polynomial model, the vector is expressed as:

$$Xr(n) = [1, r(n), r(n)2, \ldots, r(n)K]T \quad (5)$$

$$X\theta(n) = [1, \theta(n), r(n), \ldots, r(n)K\text{-}1]T \quad (6)$$

The coefficient of the polynomial is:

$$Ar(n) = [ar,0(n), ar,1(n), ar,2(n), \ldots, ar,K(n)]T \quad (7)$$

$$A\theta(n) = [a\theta,0(n), a\theta,1(n), a\theta,2(n), \ldots, a\theta,K(n)]T \quad (8)$$

Since the principle is the same, the coefficient identification of the amplitude is taken as an example.

After the pre-distortion module, the output of the pre-distorter is:

$$d(n) = A^T(n)X \quad n \quad (9)$$

It is both the input signal of the HPA and the reference signal of the adaptive algorithm. $d(n)$ goes through HPA to be the signal affected by the distortion. Then we acquire the signal $y(n)$ by a coupler and attenuate it to cancel the effect of the amplification. Multiplied by the trainer coefficient

$$W(n) = [w_0(n), w_1(n), \ldots, w_K(n)]^T \quad (10)$$

We get

$$u(n) = W^T(n)Y \quad n \quad (11)$$

Compared with the reference signal $d(n)$, the error is:

$$e(n) = d(n) - u(n) = d(n) - W^TY \quad (12)$$

The goal of LMS is to make $J(n)$ minimum

$$J(n) = |e(n)|^2 \quad (13)$$

We find the gradient vector and make it 0, so we can get the minimum value of the objective function at this time.

$$g(n) = \partial J(n) / \partial W(n) = -2e(n)Y(n) \quad (14)$$

By adjusting to the negative gradient direction, the minimum value of the objective function can be obtained, so the iteration formula is

$$W(n+1) = W(n) - \mu g(n) = W(n) + 2\mu e(n)Y(n) \quad (15)$$

Where μ is the iteration step.

4. Simulation

Perform Matlab simulation on the process described above to verify the validity of the structure and algorithm. We assume that the impact of other modules as an ideal Gaussian channel and that nonlinearity is only generated by the HPA. We select 64APSK as modulation mode. The parameters of HPA use the classical measurements simulations by Kaye, George and Eric[9]: $\alpha_a = 2.16$, $\beta_a = 1.15$, $\alpha_\phi = 4.00$, $\beta_\phi = 9.10$. Pre-distorter uses the sixth-order polynomial model. In addition, to facilitate simulation, the amplifier and the coupled signal attenuation factor are normalized.

The simulation constellation is as follows:

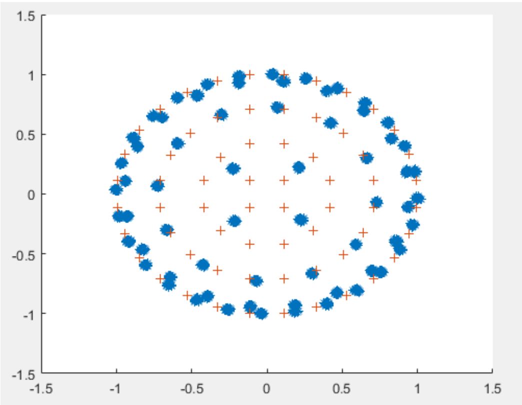

Fig. 3 Un pre-distorted constellation

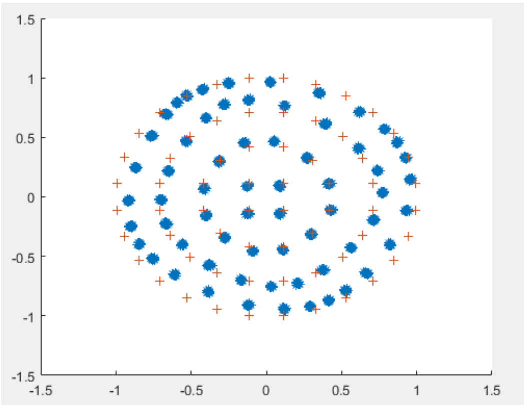

Fig. 4 IQ pre-distorted constellation

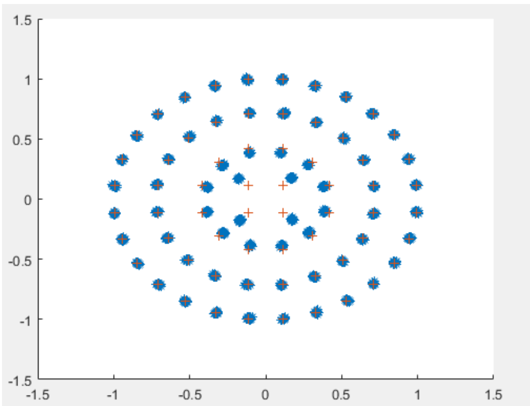

Fig. 5 New pre-distorted constellation

From the constellation diagram, it can be seen that without the pre-distorter, the transmitted signal will have amplitude distortion and phase rotation. By using the pre-distortion of the IQ signals, the distorted constellation is restored to some extent. However, this degree of reduction is not enough in the case of high requirements in high-order modulation, and will still have a large impact on subsequent decoding. As for the new method, it can be seen from the joint output signal that the constellation is transmitted as expected.

The effect can be evaluated by Error Vector Magnitude (EVM):

$$EVM = \sqrt{\frac{\frac{1}{N}\sum_{k=1}^{N}|d(k)-y(k)|^2}{\frac{1}{N}\sum_{k=1}^{N}|d(k)|^2}}$$

Where $d(k)$ is the ideal signal and $y(k)$ is the actual signal.

By calculation, the un-distorted EVM is 54.3%, the IQ pre-distortion is 33.6%, and the new method is 3.8%. It can be seen that the new method can restore the distortion signal better.

5. Conclusion

Due to the demand for data transmission rates of remote sensing satellites, the modulation order is increasing. For high-order modulation, the problem of nonlinear distortion is getting worse, but the signal quality requirements are higher, so the problem of signal linearization needs to be solved. The digital pre-distortion method is mostly used for signal linearization, but the traditional look-up-table based method is no longer applicable, and the polynomial model of the IQ signals can not fit the distortion model well. So a method of converting the IQ signals into the amplitude-phase signals before the IQ signals enter the pre-distortion is proposed. The simulation shows that the new method can effectively reduce the distortion caused by the nonlinear HPA of the 64APSK, ensure that subsequent decoding can proceed smoothly.

Acknowledgments

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