Digital Pre-distortion Technology For Optimization Design Of VDB Transmitter

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Abstract:Due to the nonlinear distortion of the power amplifier, the problems of in-band distortion and Adjacent Channel Interference will occur in VDB transmitter .To address the problem ,this paper introduces a digital pre-distortion method based on memoryless polynomial model ,which can solve the coefficients of digital pre-distorter with indirect learning structure. The results show that the digital pre-distortion method can effectively improve the third-order intermodulation distortion, the adjacent channel power ratio (ACPR) and the error vector amplitude (EVM) of VDB transmitter, and it can also improve the performance and efficiency of the communication system.

Key words:VDB transmitter ;memoryless polynomial ;digital pre-distortion

1. Introduction

Ground Based Augmentation System(GBAS) is used to provide precise approach and landing guidance to the airspace of aircraft . The VHF Data Broadcast radio is an important part of the GBAS system. It modulates the differential enhancement information generated by the ground satellite navigation reference receiver and transmits the data with power amplifier.

The performance of the power amplifier is an important factor affecting the efficiency and communication quality of VDB transmitter. When the power amplifier is in the area of the nonlinear, it will lead to the distortion and out-of-band spectrum expansion of VDB transmitter, resulting the interference of the adjacent channel[1]. In order to overcome the nonlinear distortion of VDB transmitter, the linear optimization is carried out with digital pre-distortion.

2. Pre-distortion Structure

2.1 Basic Principles Of Digital Pre-distortion

Digital pre-distortion technology does non-linear processing , so that the amplitude and phase characteristics of the baseband signal are distorted in the opposite direction ,and the overall linear relationship between the input and output signals is realized[2]. The basic principle of digital pre-distortion is shown in Figure 1 below:

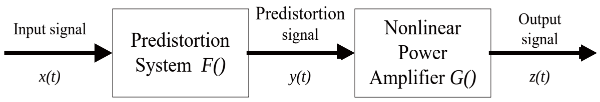

Fig.1The principle diagram of pre-distortion system

The principle of digital pre-distortion processing can be expressed as follows:

$$z(t) = G(F(x(t))) = L(x(t)) = Amp * x(t) \quad (1)$$

The symbol Amp is the linear magnification of the signal.

The objective of digital pre-distortion technology is to find the digital pre-distortion transmission function G (x), so that the input signal can satisfy the linear amplification transmission after the combination of digital pre-distortion and nonlinear power amplifier[3]。

2.2 Memoryless Polynomial Model

The common methods of digital pre-distortion include lookup table (LUT) method and polynomial model method. Polynomial model method has a faster convergence speed and self-adaptability, which is widely used in digital pre-distortion design.

The polynomial model method includes memoryless power amplifier model and memory power amplifier model. The signal of VDB transmitter belongs to narrow band signal and the memory effect is no obvious, so we select the memoryless power amplifier model.

The memoryless power amplifier model means that the output signal is only related to the current input signal and has nothing to do with the historical input[4].Generally, AM/AM and PM/PM distortion curves can be used to describe the characteristic of the amplitude and phase in memoryless power amplifier models. The model can be expressed as follows:

$$z(n)=\sum_{k=1}^{K}a_k x(n)^k \qquad (2)$$
$$=a_1x(n)+a_2x(n)^2+\cdots+a_Kx(n)^K$$

where x(n) and z(n) represent the input and output signals of the power amplifier at the n moment, ak is the factor of each power, K is the highest order of the polynomial[5]。

The modulation distortion caused by even order in memoryless polynomial model will fall outside the frequency band and be filtered by band-pass filter. In this paper, we mainly focus on the odd order intermodulation distortion which is difficult to filter out in the intermodulation distortion component. Therefore, the power amplifier model only considers the odd terms, and the polynomial model can be changed into:

$$z(n)=\sum_{k=1}^{K}a_k x(n)^{2k-1}$$
$$=a_1x(n)+a_2x(n)^3+\cdots+a_Kx(n)^{2K-1} \qquad (3)$$

In practice, it is necessary to involve the high power of polynomial calculation. In order to simplify the calculation, the polynomial model is used as follows:

$$z(n)=\sum_{k=1}^{K}a_k x(n)\left|x(n)\right|^{k-1} \qquad (4)$$

2.3 Indirect Learning Structures

Generally, there are two kinds of ways to obtain the parameters of digital pre-distortion model: direct learning structure and indirect learning structure. The direct learning structure needs to predict the parameters model of the power amplifier, while the indirect learning structure only needs a set of the input signals, output signals and the ideal linear magnification of the power amplifier[6].This paper adopts the indirect learning structure to estimate the parameters.

The implementation block diagram of the digital pre-distortion with indirect learning structure is shown in figure 2, where x(n) is the input signal, y(n) is the digital pre-distortion signal, z(n) is the signal of the power amplifier, G is the ideal linear magnification of the power amplifier, v(n) is the estimated coefficient of the digital pre-distortion, and e(n) is the error between the actual value of the digital pre-distortion and the estimated value. The estimated parameter values is modified adaptively according to e(n)[7]. When the error e(n) is zero, the linear amplification of the power amplifier is realized.

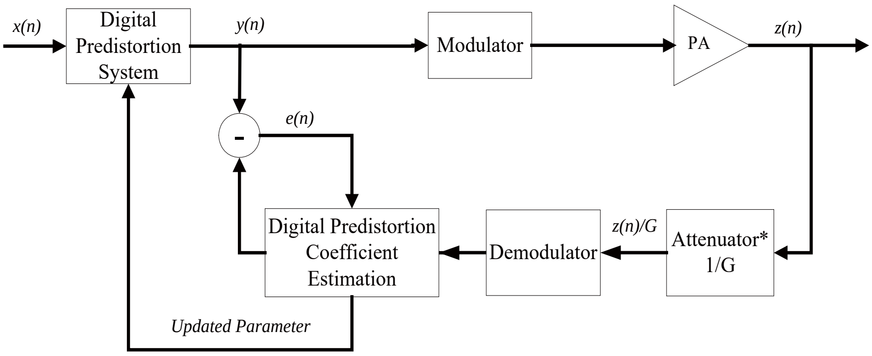

Fig.2 The indirect learning structure of digital pre-distortion

The objective of the pre-distorter is to obtain the estimated coefficient of the digital pre-distortion. According to equation (4),We can first define:

$$z(n)=\sum_{k=1}^{K}a_k\phi_k(x(n)) \quad (5)$$

Then equation (4) can be changed to:

$$\phi_k(x)=|x|^{k-1}x \quad (6)$$

Define N*1 order vector of the input signal:

$$x=[x(1),x(2),\cdots,x(N)]^T \quad (7)$$

N*1 order vector of the output signal:

$$z=[z(1),z(2),\cdots,z(N)]^T \quad (8)$$

K*1 order vector of the parameter:

$$a=[a_1,a_2,\cdots,a_K]^T \quad (9)$$

Re-defined

$$\phi_k(x)=[\phi_k(x(1)),\cdots,\phi_k(x(N))]^T \quad (10)$$

$$\Phi=[\phi_1(x),\phi_2(x),\cdots,\phi_k(x)] \quad (11)$$

The equation (6) can be expressed as:

$$z=\Phi\cdot a \quad (12)$$

According to the least square method[8](LMS)

The parameter vector can be obtained as follows:

$$\hat{a}=(\Phi^H\Phi)^{-1}\Phi^H z \quad (13)$$

The calculation involves the transpose and inverse of matrix, which is complicated and suitable for calculation in the DSP processor.

3 System Simulation and Verification

Matlab is used to verify the linear optimization effect of digital pre-distortion. The main parameters of the VDB signal[9] are shown in table 1:

3.1 Power Amplifier Model

Table 1 The main parameters of the VDB signal

Parameter	Value
Frequency/(MHz)	108-117.975
Power/(W)	<= 80
Modulation	D8PSK
Bandwidth/(KHz)	25
Code Rate/(KHz)	10.5
Filter	Raised Cosine Firer
Roll-Off factor	0.6

Saleh model[10] is a typical narrow-band power amplifier model, which can well characterize the AM/AM and PM/PM characteristics of power amplifier. Its expressions are as follows:

$$G_{\theta}(r)=\frac{a_{\theta}r}{1+\beta_{\theta}r^{2}} \quad (14)$$

$$G_{R}(r)=\frac{a_{R}}{1+\beta_{R}r^{2}} \quad (15)$$

The parameters selected in this paper are as follows :

$\beta_{\theta}=2.135, \beta_{R}=1.13, \alpha_{\theta}=\beta_{R}=1$

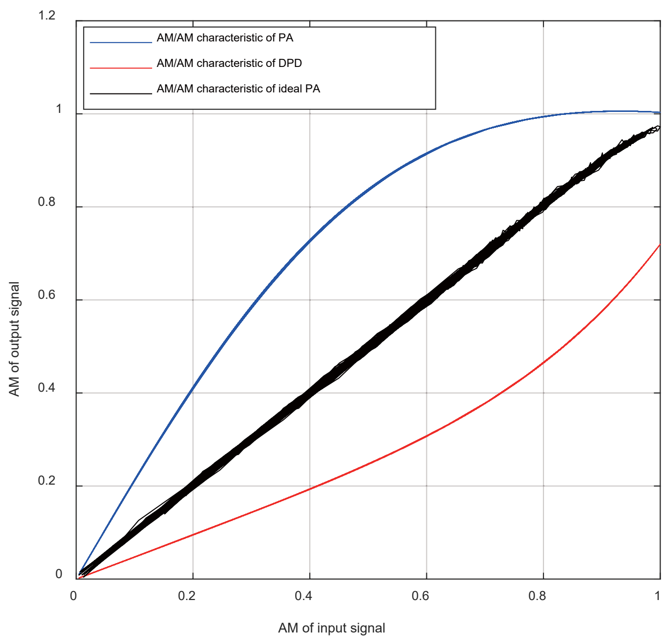

Fig.3 AM /AM Characteristic curve

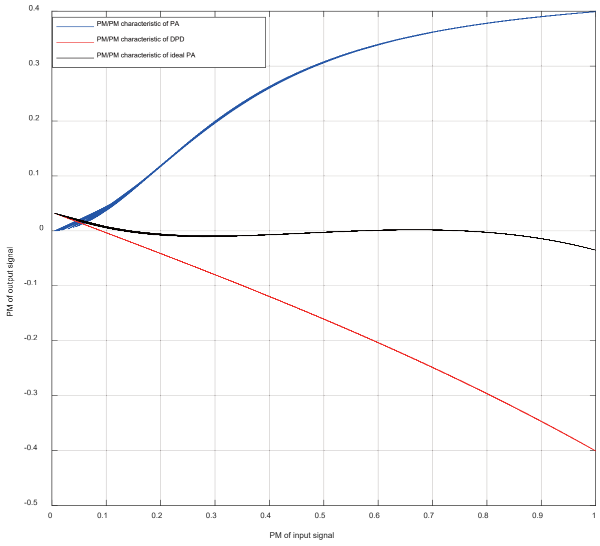

Fig.4 PM/PM Characteristic curve

Figures 3 and 4 respectively show the AM /AM and PM/PM characteristic curves of the VDB signal after power amplifier and the digital pre-distortion. It can be seen that the output curve after the combination of digital pre-distortion and power amplifier is nearly linear, which effectively improves the performance of the power amplifier.

3.2 Critical Performance Analysis

The effect of pre-distortion was evaluated by comparing the Adjacent Channel Power Ratio(ACPR) before and after digital pre-distortion. The simulation results are shown below:

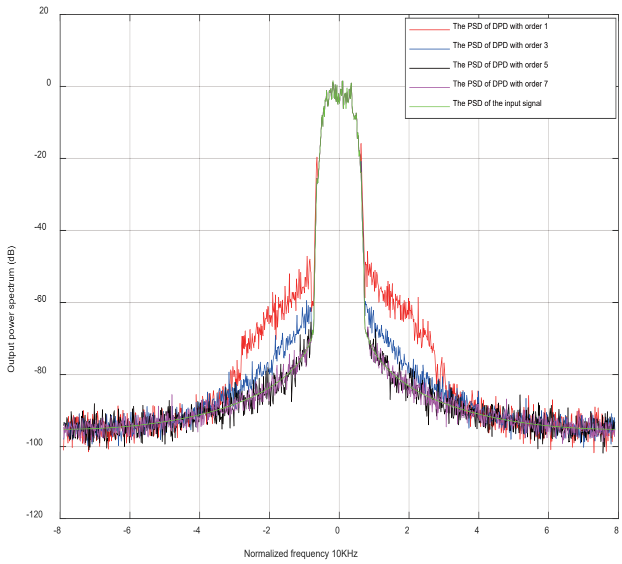

Fig.5 The comparison of the PSD with different order polynomials

Figure 5 shows that when the order is from K=1 to 3, the ACPR increases about 16 dB. When the order is from K=3 to 5, the ACPR increases about 10 dB, and when the order is from K=5 to 7, the ACPR increases about 3 dB. If the order K is above 7, the power spectral density after pre-distortion is almost as the same as the input signal. It can be seen from the diagram that the order 3 and 5 are the major components of nonlinear distortion and the composition above order 7 is obviously reduced. Therefore, in order to reduce the amount of calculation, the order of K=5 is adopted in engineering applications.

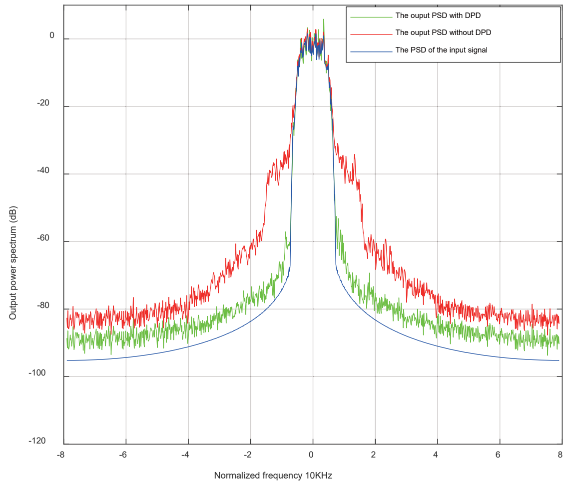

Fig.6 The comparison of PSD

Fig. 6 shows the comparison diagram of the power spectral density of original baseband signal, the power spectral density without and with digital pre-distortion (order K=5). As can be seen from the figure, the ACPR of the signal without digital pre-distortion is -35dB, while the ACPR of the signal with digital pre-distortion is -50dB, and the improvement degree reaches 15dB. It can be seen from the simulation results that the spectrum expansion is effectively suppressed with digital pre-distortion correction, the power spectrum density is very close to the original signal, and the final signal of the power amplifier has a good linearity.

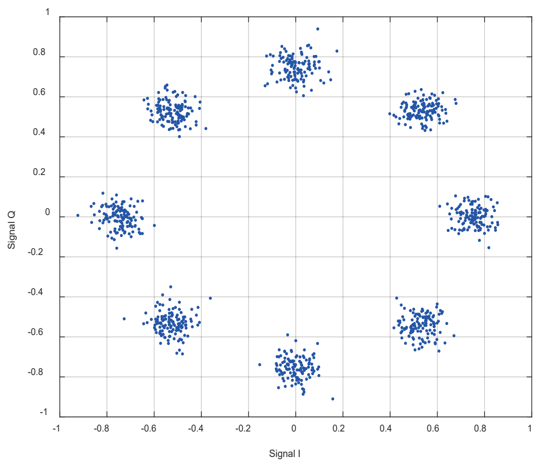

Fig.7 The constellation from the power amplifier without digital predistorter

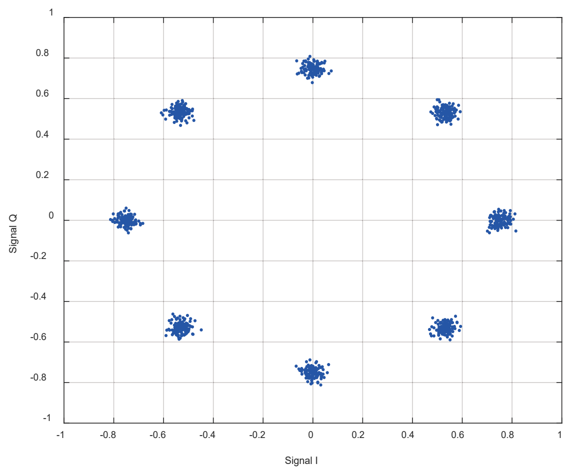

Fig.8 The constellation from the power amplifier with digital pre-distorter

Figure 7 shows the constellation of the VDB signal without digital pre-distortion, and figure 8 shows the constellation with digital pre-distortion. From figure 7, it can be seen that the distortion and divergence of the constellation caused by the nonlinearity of the power amplifier, and EVM is 5.6%, while the constellation with digital pre-distortion processing is more condensed and EVM increases to 2.8%. At the same time ,the amplitude and phase of the VDB signal are corrected.

The simulation results show that the digital pre-distortion method with memoryless polynomial model can effectively improve the linearity of power amplifier ,ACPR and EVM can also be significantly improved.

4 Terminology

In this paper, by using the digital pre-distortion method with memoryless polynomial model, the nonlinear distortion of power amplifier are solved effectively ,and the efficiency of VDB transmitter are improved. At present, the scheme has been applied in the project, meeting all the indicators and achieving good results.

References

1. Wu Lianhui ,Xia Weijie R esearch on Nonlinear Characteristics and Predistortion of Power Amplifier[J]. Computer simulation ,2014,10(15) 250-255.
2. Youjiang Liu ,Gang Liu ,Peter M.Asbeck .High-order modulation transmission through frequency quadrupler using digital predistortion[J]. IEEE Transactions On Microwave Theory And Techniques,2016,64(6) 1896-1910.
3. Zhu, A., Draxler, P.J.,Yan, J.J., Brazil, T.J.,Kimball, D.F.,&Asbeck, P.M .Open-loop digital predistorter for RF power amplifiers using dynamic deviation reduction-based Vol-terra series[J]. IEEE Transactions on Microwave Theory andTechniques,2008,56(7) 1524–1534.
4. Muhonen, K.J.,Kavehrad, M .,& Krishnamoorthy, R.Look-up table techniques for adaptive digital predistortion A development and comparison[J]. IEEE Transactions on Vehicular Technology, 2000, 49(9) 1995–2002.
5.Zhang Sen.Study on Digital Predistortion Modeling of Power Amplifiers[D]. Wuhan Wuhan university of technology,2015.
6. ZHANG Shen ,LI Yang.Research on Memory Adaptive Pre-distortion for Power Amplifier in OFDM Systems[J]. Audio Engineering ,2013,5(2) 171-174.
7. Cao Yao.Design of Digital Preimstortion Using Orthogonal Polynomials [D]. Jiangsu Southeast University,2015.
8. Zhu Q,Lu H.Pilot based channel estimation in IEEE 8 02.16 Journal of China Universities of Posts and Telecommunications,2005, 12(1): 41-46.
9. RTCA ,Inc .GNSS-Base Precision Approach Local Area Augmentation System (LAAS) Signal-in-Space Interface Control Document (ICD): RTCA DO-246D [S]. USA,2008.
10. A.M.Saleh, Frequency-independent and frequency-dependent non linear models of TWT amplifiers[J]. IEEE Trans.Commun ,vol.29,1981 1715–1720.