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STUDY AND CONSTRUCTION ON MEMORYLESS NONLINEAR MODEL OF DOHERTY AMPLIFIER

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Abstract- OFDM technology has become the core technology of DTMB system. The high Doherty power amplifier can effectively improve the peak-average power ratio of OFDM system, but with poor linear performance. This paper starts with improving linear performance of Doherty power amplifier, analyzes the nonlinear model of power amplifier, presents a construction method of nonlinear performance model of Doherty power amplifier, gets the corresponding nonlinear performance curve, and then presents a design of pre-distorter which can improve system linear performance. The nonlinear performance curve is used to do the simulation. The result shows that the system linear performance is improved greatly.

Index terms: Doherty power amplifier, nonlinear, nonlinear model, pre-distortion, linearization

I. INTRODUCTION

OFDM technology which has high signal spectrum efficiency and strong resistance to inter-symbol interference (ISI) has become the core technology of DTMB system. As OFDM signals are composed of multiple independent modulated subcarrier signals, synthesized signals may produce high peak to average power ratio (PAPR) [1]. When signals go through a nonlinear amplifier with high power, the power amplifier nonlinearity will cause serious distortion of the signals and destroy the orthogonality between subcarriers, and results in inter-carrier crosstalk (ICI) [2]. So, power amplifier with high efficiency has become the focus of OFDM system. Although Doherty power amplifier [3] is with high efficiency, its linear performance is unsatisfactory. It need adopt appropriate linearization techniques to improve the linearity of Doherty power amplifier [4]. Among the various linearization techniques, pre-distortion technology is a good choice [5]. In order to build the pre-distorter successfully, we must provide appropriate nonlinear model of power amplifier firstly. Therefore, the nonlinear model of power amplifier plays a very important role in the entire pre-distortion design system.

II. ANALYSIS OF MEMORYLESS NONLINEAR MODEL OF POWER AMPLIFIER

Currently, nonlinear power amplifier model is divided into two kinds: memory and memoryless. The signal bandwidth of DTMB system is 8MHz, which is smaller than the power amplifier device's. At this moment, the memory of power amplifier is negligible, but the memoryless is mainly reflected [6].

Power amplifier is in the final stage of transmitter of communication system. The signal is amplified by the power amplifier and transmitted to the wireless channel for transmission. The power amplifier is a key component of the entire communication system. The advantages and disadvantages of its characteristic will directly relate to whether the receiver can demodulate the signal correctly or not, and then affect the performance of the communication system. The transmission characteristic of an ideal power amplifier should be linear, which includes two aspects: first, the output amplitude of power amplifier should be scalar multiples of its input amplitude, which means the gain should be a constant; second, signal through the power amplifier still retains the same frequency component as the signal before entering the power amplifier. However, in practical applications, power amplifier is not ideal. As an active device, the signal will still generate nonlinear distortion.

Nonlinear interaction of the signal in power amplifier mainly reflects in two aspects: the AM / AM nonlinear characteristic and AM / PM nonlinear characteristic. AM / AM characteristic shows that the corresponding relationship between input signal amplitude and the output signal amplitude of power amplifier, and the AM/PM characteristic shows the corresponding relation between input signal amplitude of the power amplifier and the additional output signal phase which is generated because of the action of the power amplifier.

Suppose the equivalent baseband form of the input signal of power amplifier is:

$$V_{in}(t) = r(t)e^{j\theta(t)} \tag{2.1}$$

In Formula (2.1), $r(t)$ means the input signal amplitude of power amplifier. $\theta(t)$ means the input signal phase of power amplifier. In addition, suppose the AM/AM and AM/PM nonlinear characteristic of power amplifier are $A(\cdot)$ and $\Phi(\cdot)$ respectively, then the signal through the power amplifier is

$$V_{out}(t) = A(r(t))e^{j(\theta(t)+\Phi(r(t)))} \tag{2.2}$$

Thus, we can get the general form of memoryless nonlinear model of power amplifier, which is shown in Figure 2.1.

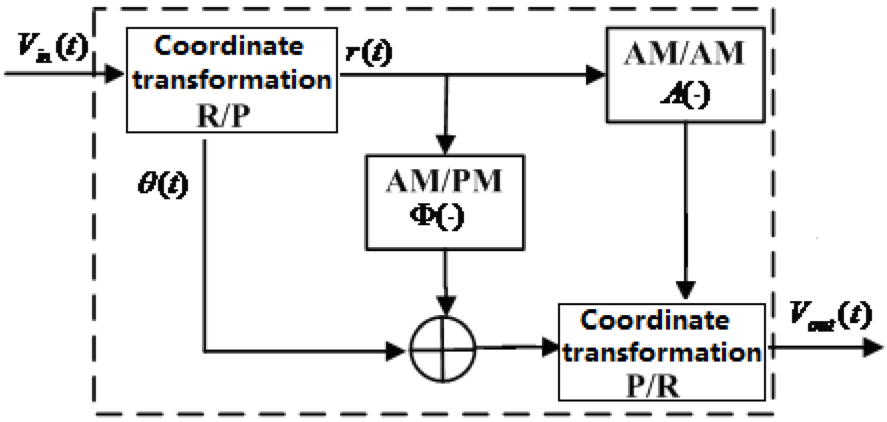

Figure 2.1: General Form of Memoryless Nonlinear Model of Power Amplifier

In Figure1, in determining a memoryless nonlinear model of power amplifier, the key is to know the AM / AM characteristic and AM / PM characteristics. With these two characteristics of power amplifier and general form, when the input signal of power amplifier is known, the corresponding output signal can be got.

Currently, memoryless nonlinear power amplifier models which are more commonly used are Model Rapp [7] and Model Saleh [8].

Model Rapp is designed to describe the nonlinear characteristic of solid state power amplifier (Solid-State Power Amplifier, SSPA). When the input power of SSPA is below its saturation point, it can be approximately considered that it does not produce nonlinear distortion. In addition, since the AM / PM characteristic of SSPA is ideal, the phase distortion can be neglected. Its AM / AM characteristic is as follows:

$$A[r(n)] = \frac{r(n)}{(1+(r(n))^{2S})^{\frac{1}{2S}}} \tag{2.3}$$

In Formula (2.3), $r(n)$ is the input signal amplitude of power amplifier. S is the smooth factor. It shows the AM / AM characteristic curve of Model Rapp when the smooth factor S takes different values in Figure 2.2.

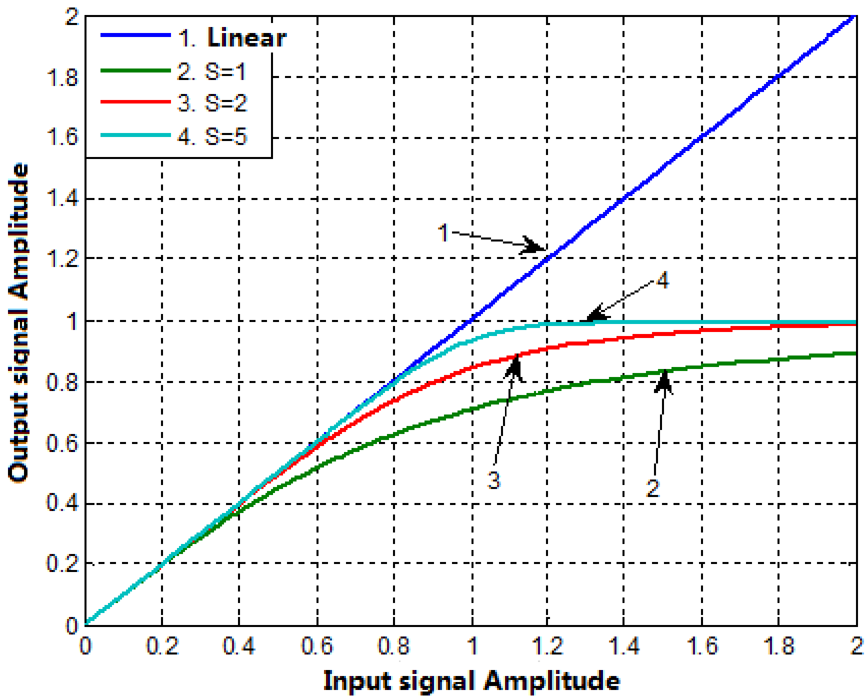

Figure2.2: AM / AM Characteristic Curve of Model Rapp Changing with Smooth Factor S

With the increasing value of S In Figure 2.2, the linearity of power amplifier becomes better. Under normal circumstances, the values of S are restricted to [2,3].

Model Saleh is mainly used to describe the nonlinear characteristics of traveling wave tube amplifier (Traveling-Wave Tube Amplifier, TWTA). TWTA, which is widely used in satellite communication systems, is a vacuum tube device with great power and wide frequency band. The AM / AM characteristic and the AM / PM characteristic are expressed as follows:

$$A(r(n)) = \frac{\alpha_r r(n)}{1+\beta_r r(n)^2} \tag{2.4}$$

$$\Phi(r(n)) = \frac{\alpha_\theta r(n)^2}{1+\beta_\theta r(n)^2} \tag{2.5}$$

In above formulas, $r(n)$ is the input signal amplitude of power amplifier. α_r, β_r, α_θ, β_θ are adjustable parameters. These four parameters can be adjusted appropriately to get the appropriate power amplifier model. Model Saleh has simple structure and fits the measured data well. It is widely used in simulation experiments. The power amplifier model used in the simulation of this topic is Model Saleh. In this model, the typical values of the four parameters in a group are $\alpha_r = 2.1587$, $\beta_r = 1.1517$, $\alpha_\theta = 4.0330$, $\beta_\theta = 9.1040$. Accordingly, AM / AM and AM / PM characteristic curves of Model Saleh are depicted in Figure 2.3.

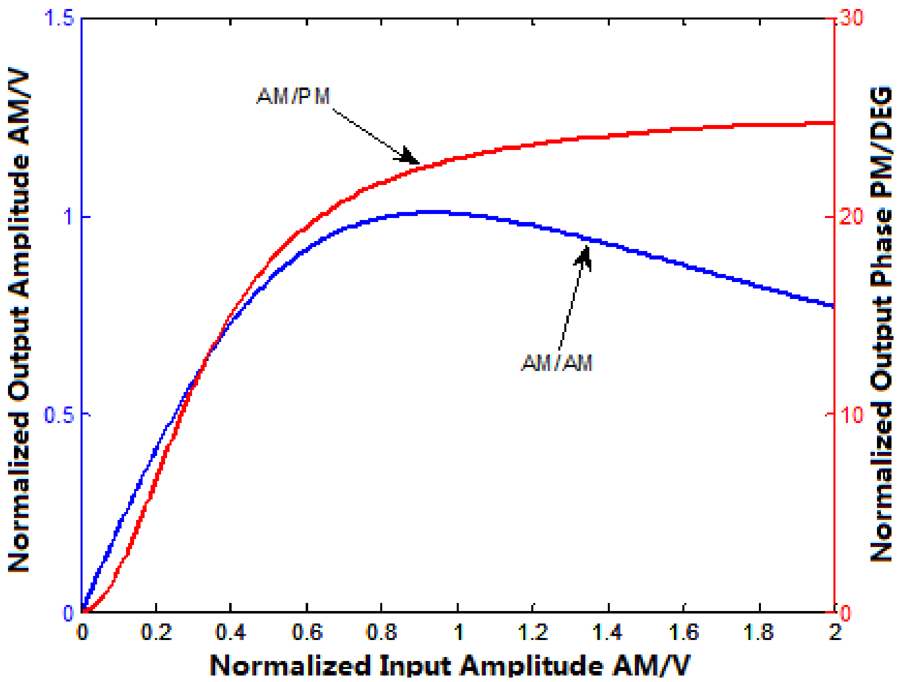

Figure2.3: AM / AM and AM / PM Characteristic Curves of Model Saleh

III. MEASURING AND FITTING OF NONLINEAR CHARACTERISTIC CURVE OF POWER AMPLIFIER

The performance of pre-distorter's design, to a large extent, depends on the results of getting the nonlinear performance of power amplifier. Thus, only by obtaining the nonlinear characteristic of Doherty power amplifier can the pre-distorter in front of Doherty power amplifier play its good role and improve the linearity of the whole system [9]. Therefore, obtaining accurate nonlinear performance of Doherty power amplifier becomes critical [10].

a. Measuring instruments and equipments.

Power amplifier characteristics include AM / AM characteristic curve and AM / PM characteristic curve. Because of the use of the SSPA solid state amplifier, the foregoing analyses show that SSPA phase distortion can be ignored, and only the AM / AM characteristic curve of power amplifier needs to be measured. Measuring instruments and equipments required are summarized as follows:

Table 3.1: Measuring Instruments and Equipments

SN	Description	standard	application
1	**Doherty power amplifier module**	1	**characteristic curve for measured**
2	**digital signal generator**	1	**generate signal of the tested power amplifier**
3	**signal analyzer**	1	**test the output signal of power amplifier**
4	**radiator**	1	**cool Power amplifier at work**
5	**attenuator**	50dBm adjustable 1	**Attenuate output signal of power amplifier in order to receive**

b. Measuring method

During operation, the pre-distorter designed uses the pointer based on the instantaneous power value or the instantaneous amplitude value of each input signal to search for the corresponding pre-distortion coefficient in the lookup table. Then we multiply its input signals with corresponding pre-distortion coefficients to complete the pre-distortion process. Therefore, the method to measure the characteristic curve of Doherty power amplifier is based on instantaneous power [11]. The measurement block diagram is shown in Figure 3.1.

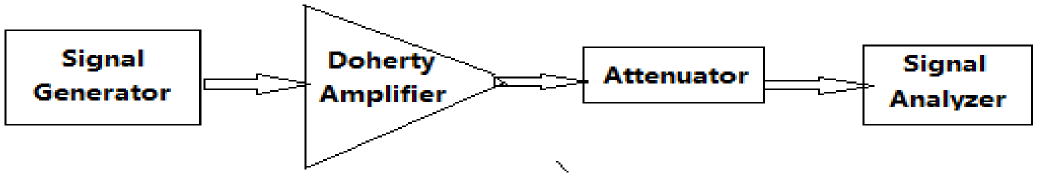

Figure3.1: AM / AM Characteristic Measurement Block Diagram of Power Amplifier

In the figure, we can measure AM / AM characteristic of power amplifier. Firstly, the signal generator generates rectangular square wave which is similar to pulse. Secondly, it is sent to the tested power amplifier. Thirdly, the output signal of power amplifier is attenuated by the attenuator and then passed into the signal analyzer. Finally, we can read out the corresponding output power value. Thus, we get a set of input / output values of power amplifier [12]. According to the measured data, AM / AM characteristic curve is drawn and shown in Figure5.

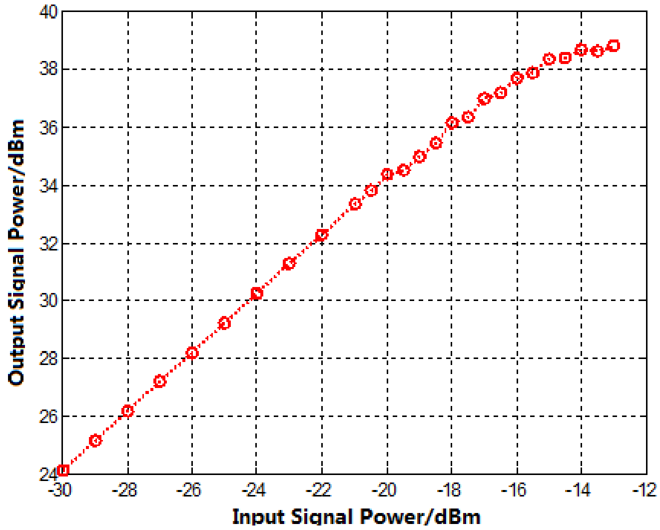

Figure3.2: AM / AM Characteristic Curve of Power Amplifier

In Figure3.2, when the input power of the power amplifier is small, the characteristic of power amplifier is linear. As the input power is increasing, it also highlights the nonlinearity of the power amplifier.

c. Matlab fitting of characteristic curve

In Figure5, the characteristic curve of power amplifier which is drawn according to the measured data is not that smooth, but it is similar to a quadratic curve. Therefore, in order to ensure that the fitted polynomial is close to actual characteristic curve of power amplifier as much as possible, the piecewise fitting method is adopted. It means that we must divide the measured input / output data of power amplifier into multiple groups and take a number of data points from each group to fit a quadratic curve $y = ax^2 + bx + c$. When the values of a、b、c in the polynomial are known we can determine the quadratic curve. If we divide the measured characteristic curve of power amplifier into eight segments to fit, we can determine the corresponding eight sets of data a、b、c [13].

In order to find the corresponding signal pre-distortion coefficients, the index pointer of lookup table may be the power value or amplitude value of the input signal. When the amplitude is small, the table entries are sparsely distributed. While the amplitude is large, the distribution is denser, which will result in undesirable pre-distortion of small signal. So lookup table pre-distortion technique based on the amplitude value index is adopted. Before fitting the characteristic curve of power amplifier, we need to transform power value into amplitude value firstly [14].

$$P(dBm) = 10\lg\frac{P(mW)}{1mW} \tag{3.1}$$

$$U = \sqrt{PR} \tag{3.2}$$

According to Formula (3.1), we convert power value in unit of dBm into power value in unit of mW, convert mW into W, and based on Formula (3.2), we convert the power value into amplitude value. After converting the measured power data into amplitude data, the results are obtained by piecewise fitting with Matlab as shown in Figure 3.3.

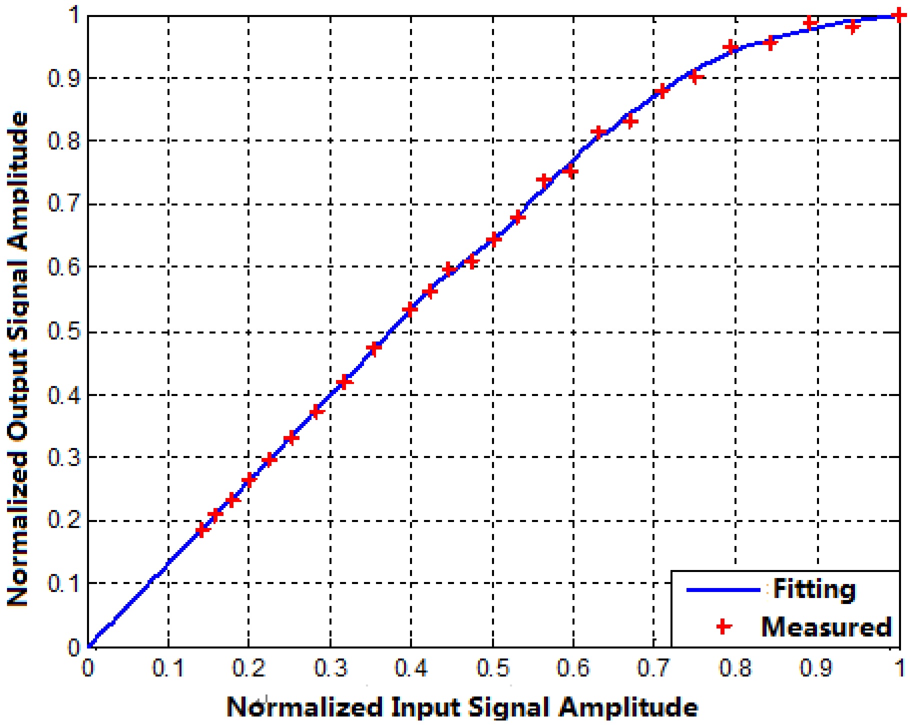

Figure3.3: Characteristic Curve Fitting of Power Amplifier

In Figure 3.3, the AM/AM characteristic curve of power amplifier painted after piecewise fitting is relatively close to the test data points, which is relatively smooth. Therefore, the use of piecewise fitting is more reasonable[15].

IV. SOFTWARE DESIGN AND IMPLEMENTATION OF SEMI-AUTOMATIC PRE-DISTORTER

After testing and fitting AM / AM characteristic curve of Doherty power amplifier, the next step is how to obtain its anti-characteristic curve, calculate the corresponding pre-distortion coefficients, and write them in the lookup table LUT under the premise of knowing the characteristic curve.

a. Principle introduction

In semi-automatic pre-distorter, the pre-distortion coefficient is stored in the lookup table, which is defined as the ratio of the output signal to the corresponding input signal. Each input signal of Semi-automatic pre-distortion finds the corresponding pre-distortion coefficient in the lookup table according to the signal amplitude value, and then multiplies the pre-distortion coefficient to the signal, and the pre-distortion operation is completed. The specific calculation of pre-distortion coefficient is shown in Figure4.1.

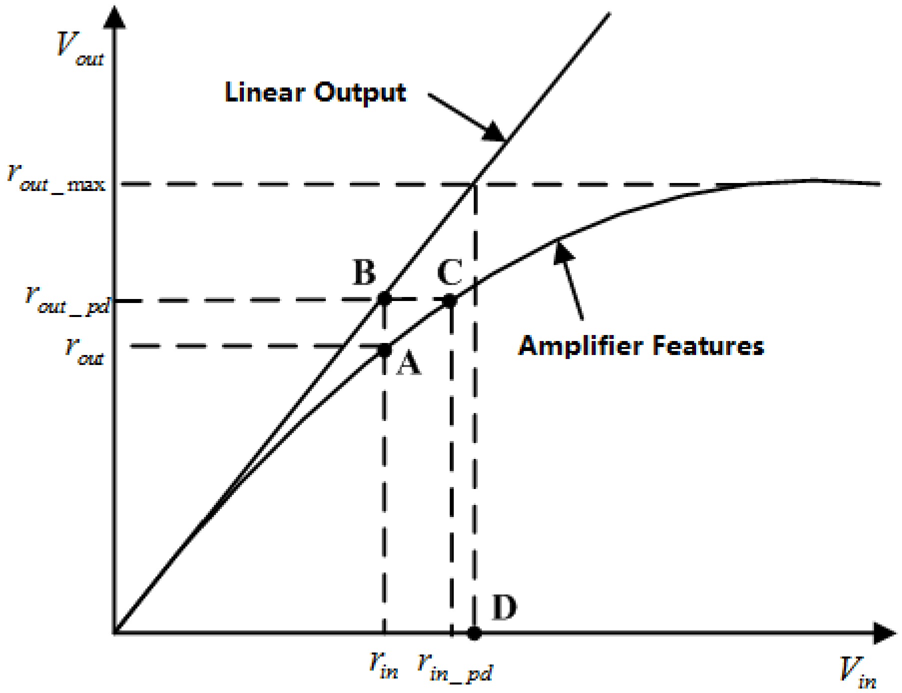

Figure4.1: Schematic Diagram of Semi-automatic Pre-distorter

The principle of semi-automatic pre-distorter is shown in Figure 4.1. It depicts two curves. One is the characteristic curve of power amplifier; the other is the linear characteristic curve of ideal power amplifier. Let the input signal of the power amplifier is r_{in} , r_{out} is its output signal after passing through the power amplifier, namely the point A in the figure. Obviously, r_{out} is not linear output signal. To ensure linear operation of the power amplifier, the corresponding output of r_{in} should be r_{out_pd}, namely the point B in the figure. Find the abscissa r_{in_pd} corresponding to the point C with output r_{out_pd} on the characteristic curve of power amplifier. Adjust r_{in} to r_{in_pd}, and then pass through the power amplifier, then the corresponding output r_{out_pd} of r_{in} can be achieved. Therefore, the operation of the pre-distorter would be adjusted r_{in} to r_{out_pd}, which is to ensure the linear output of power amplifier [16]. The pre-distortion coefficient mentioned previously is defined as Formula (4.1) shown.

$$r_{coeff} = r_{in\_pd} / r_{in} \tag{4.1}$$

In Figure7, the maximum output of power amplifier determines the maximum input value that can be corrected by pre-distorter, which is the point D in the figure. If the input signal is higher than the point D, we can know that the corresponding linear output value is greater than the maximum output value of power amplifier. If so, the nonlinearity will not be able to get compensation.

Because the semi-automatic pre-distorter has measured the characteristic curve of power amplifier previously, pre-distortion coefficients corresponding to the input signal of semi-automatic pre-distorter can be obtained depending on the fitted characteristic curve of power amplifier, then write pre-distortion coefficients in lookup table for semi-automatic pre-distorter calls. Pre-distortion coefficient is calculated as follows:

(1) Determine the size $size$ of lookup table amp_lut and linear magnification times of power amplifier, and then quantify the characteristic curve of power amplifier into $size$ parts. Store the result in a table with size $size$, and set the input signal amplitude $i/size$, and store

the corresponding output value passing through the power amplifier in the $table[i]$.Since the range of normalized input of power amplifier is $[0,1]$, taking $size$ as the size of the lookup table, it is equivalent to quantify range of $[0,1]$ for $size$ sections , which means take one point per $1/size$ interval to determine pre-distortion coefficient. The linear magnification times of power amplifier can be obtained from the measured characteristic curve.

(2) For any input signal amplitude $r_{in} \in [0,1]$, set integer value k for $r_{in} \times size$, and the corresponding pre-distortion coefficient is stored in $amp\_lut[k]$. Calculate the linear output value $G \cdot r_{in}$ of r_{in}, and then find the corresponding input r_{in_pd} when the output value is $G \cdot r_{in}$ on the characteristic curve of power amplifier. The algorithm is as follows:

1) Identify $l_{\min}$, $l_{\min}$ meet the conditions: $table[l_{\min}] = \max[table]$, $l_{\min}$ indicates the corresponding minimum table item location when the table entry value of amplitude lookup table is maximum;

2) Search corresponding table entry value from item 1 to item $l_{\min}$ in Table A, and compare with $G \cdot r_{in}$, and find the corresponding position k_{pd} which is closest to the table entry value. If $G \cdot r_{in} > table[l_{\min}]$, there will be $k_{pd} = l_{\min}$;

3) $r_{in\_pd} = k_{pd} / size$;

4) After r_{in_pd} is solved, pre-distortion coefficient（is） $r_{coeff} = r_{in\_pd} / r_{in}$,namely $amp\_lut[k] = r_{coeff}$

b. Matlab simulation

According to the principle described in the previous section, Matlab simulation is done for the whole process. The model used in the simulation is the measured solid power amplifier with segmented fitting. The whole simulation process is as follows: First, quantize $[0,1]$ to 1,024 points, obtain 1024 pre-distortion coefficients correspond to range of $[0,1]$,and store them in the look up table amp_lut , and then create a multi-carrier system DTMB, and introduce the measured power amplifier in this system. Verify in two cases: First, the signals directly go through the power amplifier without pre-distortion operation; second, do pre-distortion operation before the signals going through the power amplifier. Last, draw the AM / AM characteristic curve of power amplifier respectively in both cases. The simulation result is shown in Figure 4.2.

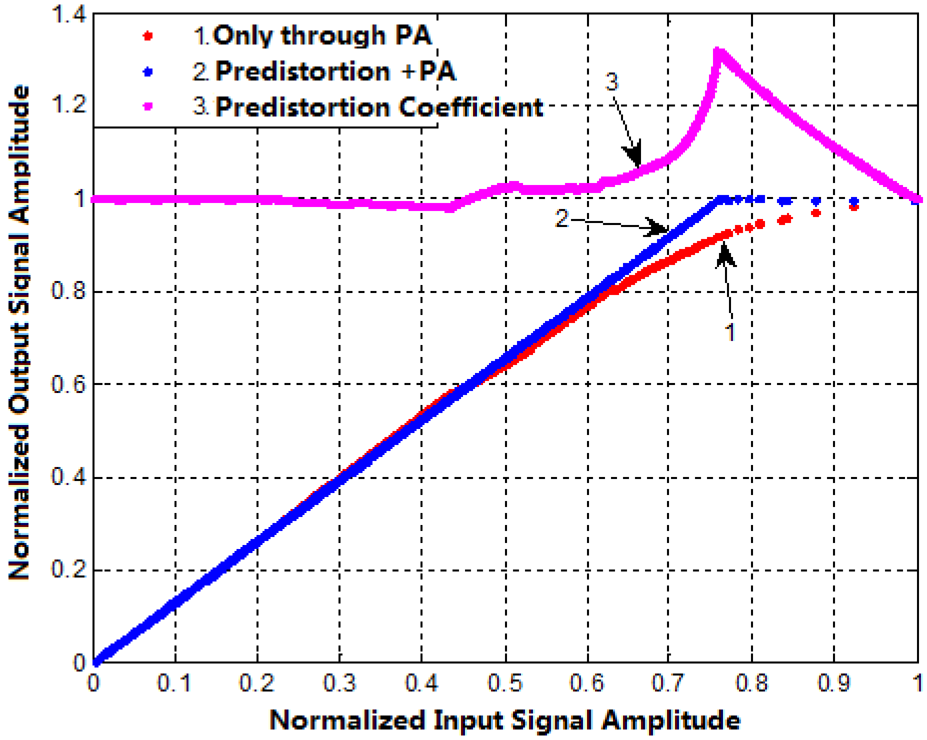

Figure 4.2: Simulation Result of Semi-automatic Pre-distorter

In Figure 4.2, the curve 1 represents the AM / AM characteristic curve of power amplifier with the signal going through the power amplifier directly without pre-distortion. The curve 2 represents the AM / AM characteristic curve of power amplifier when the signal has done pre-distortion firstly before going through the power amplifier. The curve 3 represents the curve of pre-distortion coefficient. The comparison shows that, after the pre-distortion processing, the relationship between the input signal and output signal of power amplifier is linear, so the methods used can improve the linearity of power amplifier.

V. CONCLUSION

The multi-carrier model of DTMB uses TDS-OFDM modulation technique innovatively. In order to solve the problem that Doherty power amplifier is with high efficiency but poor linearity in OFDM technology, this article base on the point of view of improving Doherty power amplifier linearity performance, analyzes the characteristics of nonlinear power amplifier model, and proposes a method for the nonlinear fitting performance and a kind of effective semi-automatic pre-distorter. Doing the simulation by using the generated nonlinear model makes the linear performance of power amplifier greatly improved.

VI. ACKNOWLEDGEMENTS

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