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Pattern Sensing Based Digital Predistortion of RF Power Amplifiers under Dynamical Signal Transmission

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***Abstract*—In this paper, a pattern sensing based digital predistortion (DPD) technique for radio frequency (RF) power amplifiers (PAs) under dynamical signal transmission is proposed. Unlike conventional methods where real time re-calibration is required, this approach utilizes a low resolution amplitude-modulation to amplitude-modulation (AM/AM) pattern to sense PA characteristics and then quickly select proper DPD coefficients to linearize the PA. Experimental results show that the proposed method can provide an efficient a nd e ffective w ay to deal with complex dynamic signal transmission scenarios and maintain very good linearization performance, which is very suitable for future 5G applications.**

***Index Terms*—Digital predistortion, pattern sensing, power amplifier**

I. Introduction

In the fifth g eneration c ommunication s ystem (5G) and beyond, dynamic data traffic w ill w idely e xist. Specifically, power, carrier frequency and signal characteristics can vary from time to time. For example, the transmit power will change according to real-time traffic, k nown a s dynamical power transmission [1] and the carrier frequency of the signal may also change depending on the availability of spectrum. The dynamic configuration o f c arrier a ggregation w ill bring a large change to signal characteristics, particular the peak-to-average power ratio (PAPR). Under such complex circumstances, radio frequency (RF) power amplifier (PA), a s a critical component in wireless transmitters, will be working at multiple states when excited by such signals with variant power, frequency and characteristics. In other words, different nonlinear behaviors of PA will be introduced dynamically. How to effectively characterize and compensate for such different nonlinear behaviors of the PA is a key problem to be solved.

Usually, digital predistortion (DPD) is commonly used to compensate for the nonlinear behavior of the PA. However, most conventional DPD models are based on PA with one fixed n onlinear b ehavior [2]. T o a pply t hese m odels for the dynamical circumstances, there are very few solutions in the literature [1], [3]. Generally, there are mainly two approaches. One is based on close-loop online parameters updating method, in which the DPD coefficients will be updated in real time when the change of the PA state is detected. Since re-calibration takes some time, the duration allowed for coefficients updating may not be long enough, especially in future 5G or beyond 5G systems, signal quality will be seriously affected during the transition period. The other approach is to use open-loop methods, such as look up table (LUT), in which parameters of different states are pre-calculated and stored in LUT and indexed by the state number. However, much more memory is needed for storing the DPD coefficients under multi-dimensional states, such as power, frequency, and signal type. Fortunately, the PA behavior will exhibit similar characteristics, it is reasonable to group the similar states which can be compensated by the same DPD block. To select the right group for DPD coefficients, a fast and accurate state sensing is required, due to the complicated PA characteristics.

In this paper, a pattern sensing-based DPD technique is proposed by employing a novel metric, that is, amplitude-modulation to amplitude-modulation (AM/AM) pattern, to realize the quick and accurate PA state sensing. For simple illustration, the PA state change under different power levels is taken for an example to demonstrate the core idea. Experimental results show that proposed method can quickly and effectively sense the PA state and provide very good linearization performance, which is very promising for dealing with complex dynamical scenarios.

II. Proposed Method

In this paper, the power level is taken for example to illustrate the basic concept. Generally, the PA behavior will change with the power around a small region as shown in Fig. 1a. Therefore, it is possible to group the similar states. This paper will focus on how to quickly find the right group. Thus, we employ the evenly-distributed power level for grouping here. The main concept of the proposed method is to utilize the AM/AM pattern that is directly linked to the linearization performance to index the group, which can be divided into the following parts.

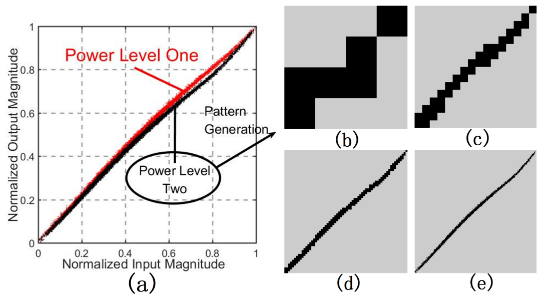

Fig. 1. AM/AM pattern generation (a) Original AM/AM characteristics at two different power levels (b)(c)(d)(e) AM/AM pattern with 2/4/6/8-bit quantization at power level two

A. Bit-controlled Pattern Generation

In the pattern generation as shown in Fig. 1b-e, the x-axis and y-axis for AM/AM will be divided into small grids used as the coordinates, which is based on the pattern resolution. The grids will be filled when the pair of input and output falls into that region, otherwise will be blank. Therefore, the AM/AM pattern can be generated based on different quantization precision. Since our concern is only to recognize the pattern, the resolution with few segments will be enough, such as 8 to 16-segments, as shown in Fig. 1c. Thus, the precision of analog-to-digital converter (ADC) can be significantly reduced to only 3 to 4-bit for data acquisition, which can largely reduce the cost and power consumption. Based on this operation, the input and output will be normalized to construct a matrix, which is filled by 0 and 1 to represent the pattern, e.g. 3-bit quantization matrix, that is,

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{1}$$

B. Pattern Sensing

Since the AM/AM pattern is directly linked to the linearization performance, the power level will no longer be required. The current pattern can be compared with the stored ones to choose the proper DPD coefficients for the specific group. In the same group, the patterns are similar, two states can employ the same DPD operation, leading to significant reduction for DPD complexity.

The procedures can be described in detail as follows. Firstly, when the PA is running, a current matrix can be generated, e.g. 3-bit quantization matrix with 3-bit ADC,

$$\mathbf{B} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{2}$$

Secondly, this matrix will be compared with the pre-calibrated one by employing exclusive OR (XOR) operation. Since there are only '1's and '0's in these matrixes, this operation is very simple, which can be processed very quickly. After this operation, the outcome can be obtained as:

$$\mathbf{C} = \mathbf{A} \text{ XOR } \mathbf{B} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{3}$$

Thirdly, the L_0-norm operation can be employed to calculate the number of 1, that is

$$d = ||C||_0 = 1 \tag{4}$$

where d will be utilized to represent the pattern difference of two PA states. By repeating the same procedure with all pre-calibrated patterns, the DPD coefficients for current state are selected by the pattern which has the minimum d.

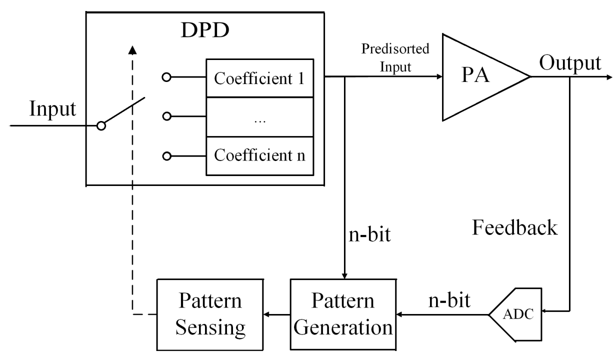

Fig. 2. Proposed digital predistortion system

C. The Complete Architecture

The proposed system can be built as shown in Fig. 2, including a low-bit-precision ADC, a pattern generation module, a pattern sensing module and a DPD coefficient LUT. Low-bit-precision input and output signal will be fed into pattern generation module and then the current AM/AM pattern will be sensed to generate an index for the DPD LUT. Finally, the predistorted input can be generated to feed into PA. It is worth mentioning that since proposed algorithm utilized AM/AM pattern for indexing DPD coefficients, different DPD coefficients should be employed if two different AM/AM patterns are sensed, even if both states are indexed at the same power level.

III. Experimental Results

To validate the proposed method, a test bench is setup as shown in Fig. 3. A 20-MHz long term evolution (LTE) baseband signal with 6.2 dB PAPR is generated in PC and then downloaded into the signal generator (R&S SMW 200A). The baseband signal will be up-converted and fed into a GaN Doherty PA operated at 2.45 GHz. The output will be captured by the spectrum analyzer (Keysight N9030) for DPD. Different AM/AM patterns can be realized by tuning the power level of the input signal.

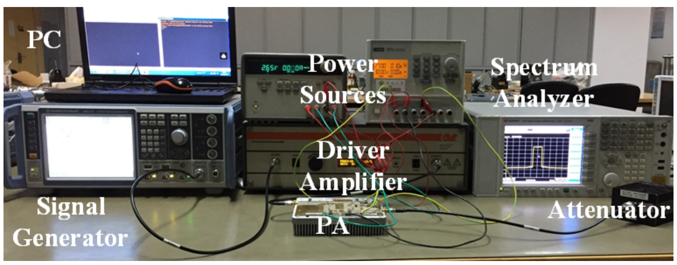

Fig. 3. Test bench setup

Here, we set 11 states with the step of 0.2 dB to generate 2 dB range (-19.0 to -21.0 dBm) of the average input power. For simple illustration, the 11 states will be divided into three categories at the input power of -19.0 dBm (C1), -20.0 dBm (C2) and -21.0 dBm (C3). For these three power levels, the corresponding pattern will be pre-generated with 5-bit precision and DPD coefficients will be pre-calculated by memory polynomial (MP) model [4]. Then, the system will generate the pattern with 5-bit precision automatically at the specific input power level from -19.0 dBm to -21.0 dBm and compare them with the pre-generated three patterns. The sensing results and DPD performance, such as, adjacent channel power ratio (ACPR) and normalized mean square error (NMSE), are shown in Table I, where we can see that all states has been sensed into three groups with very good DPD performance.

It is noticed that at the input power of -19.4 dBm, based on the usual 'power nearest' principle, the DPD coefficients pre-calibrated at -19.0 dBm will be used because -19.4 is nearer to -19.0 than -20.0 or -21.0. While proposed method can sense the working status at -19.4 dBm as -20.0 dBm by the sensing result, as shown in Fig. 4, so the DPD coefficients at -20.0 dBm will be used. Similar situation happens at the input power of -20.4 dBm.

IV. Conclusion

In this paper, AM/AM pattern is chosen as a novel index for DPD under the scenarios of dynamical signal transmission,

TABLE I
DPD Performance

$\mathrm{P_{in}}$ (dBm)	Pattern Diff. d			Sensing Result	NMSE (dB)	ACPR (dBc)
	C1	**C2**	**C3**			
-19.0	6	14	23	C1	-42.99	-54.50/-52.65
-19.2	4	18	27	C1	-39.83	-53.39/-53.29
-19.4	11	9	18	C2	-37.37	-48.82/-49.45
-19.6	14	8	15	C2	-40.01	-51.19/-51.70
-19.8	19	1	10	C2	-42.37	-53.43/-53.80
-20.0	25	5	12	C2	-42.27	-54.11/-54.12
-20.2	22	2	7	C2	-39.22	-52.69/-52.73
-20.4	28	8	5	C3	-38.51	-49.28/-49.79
-20.6	27	7	6	C3	-41.19	-51.15/-51.73
-20.8	30	10	3	C3	-42.22	-52.67/-53.01
-21.0	33	13	6	C3	-42.52	-53.58/-53.86

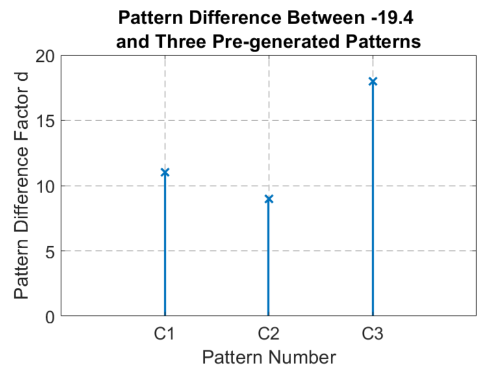

Fig. 4. Pattern Difference Comparison

leading to quick and accurate sensing results with great linearization performance. By adding a simple sensing block with low ADC precision at output of PA, the propose algorithm can effectively sense changes of PA characteristic and provide a novel linearization solution to deal with PA with changing behaviors. In future work, multiple-dimensional variables, such as power, frequency, signal type, will be jointly investigated to expand it to more complex scenarios.

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