Analog Predistorter Averaged Digital Predistortion for Power Amplifiers in Hybrid Beam-Forming Multi-Input Multi-Output Transmitter

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ABSTRACT For higher data throughput, the Massive Multi-input Multi-output (MIMO) system has been widely used in modern communication systems. Due to the circuit size and power consumption, it is difficult to integrate one Radio Frequency (RF) chain for each power amplifier (PA). As a result, MIMO transmitters with hybrid beam-forming don’t have enough RF chains, and this demands the digital predistortion (DPD) block to deal with several power amplifiers (PA) simultaneously, which causes a shared DPD problem. This article presents an Analog Predistorter Averaged DPD (A²-DPD) for hybrid beam-forming massive MIMO transmitters. To linearize more than one PAs with one shared digital predistortion unit, continuously tunable Analog Predistortion (APD) modules are employed to uniform the nonlinear behavior of PAs in each channel. Based on iterative learning control (ILC) technique, crossed normalized mean square error (CNMSE) is derived to judge the uniformity of PAs. By comparing the CNMSE of each PAs, the best similarity state of PAs can be found. The nonlinear behavior of PAs can be adjusted to a similar state by tuning the APD control voltage. The adjustment makes PAs easier to be linearized by a shared DPD. Furthermore, an averaged DPD algorithm is proposed to improve the total linearity performance for each PA. Simulations are performed to study the relationship between CNMSE and PA uniformity and further simulations show the ability of A²-DPD to deal with a multi-PA scenario. In the end, to verify the feasibility of the proposed A²-DPD, two class-AB PAs with operating frequency at 3.5 GHz with the same type transistor and similar design are tested. Experimental results show the proposed A²-DPD can significantly improve the uniformity of PAs and the Adjacent Channel Power Ratio (ACPR) can be improved by 8 dB compared with using the DPD parameter of the other PA.

INDEX TERMS Power amplifier, digital predistortion, massive MIMO, hybrid beam-forming, analog predistortion.

I. INTRODUCTION RF Power Amplifiers, as the critical components in communication base stations, have been extensively studied for many years. Due to the high power consumption of PAs, the efficiency of PAs directly affect the over-all maintenance cost of the whole base station [1]. Because of the inherent contradiction of efficiency and linearity of PAs [2], linearization technologies are crucial subsystems in transmitters to guarantee the linearity of PAs when the PAs are working in the high-efficiency region. Digital predistortion (DPD) is one of the most widely employed linearization techniques in commercial base stations as a result of the good linearity performance and low cost [3]. On the other hand, new applications bring more challenges to DPD. Firstly, as the demands of high data throughput and
multi-user access ability, high order modulation, signals with broader bandwidth and multi-bands in carrier aggregation are carried out in new-generation communication systems. These signals have higher peak average power ratios (PAPR), which make PAs have to work in a back-off state, and broader bandwidth means the nonlinear behavior of PAs becomes more complicated to be compensated by DPD. Secondly, as a key technique in 5G and future communication systems, massive MIMO technology can provide very high data throughput enhancement and spectrum efficiency of radio transmission. The MIMO transmitter, however, has to integrate more antennas up to 256, which causes the difficulty of hardware design and high power consumption [4].

Hybrid beam-forming MIMO transmitter is one of the most widely studied architectures, which is put forward over the years [5]. In hybrid beam-forming transmitters, to deal with the difficulty of high hardware integration of multi-antenna, there is no longer a one-to-one RF chain for each RF power amplifier. Instead, each RF chain has a group of PAs, and each PA has one analog phase shifter as an analog precoder. Instead, each RF chain has a group of PAs, and there is no longer a one-to-one RF chain for each RF power amplifier. In hybrid beam-forming systems, to deal with the difficulty of hardware integration and reduces the cost, hybrid beam-forming transmitters demand the DPD system to linearize all these PAs in one group simultaneously as a result of the cut of RF chains. Because the behavioral characters of each PA are not precisely the same, it is almost impossible to have excellent performance for all PAs when applying a shared DPD.

Over the years, researchers have brought out some methods to solve this problem. These techniques are mainly divided into two types. The first type is group DPD, which optimizes the linearity of one PA or calculates a compromised shared DPD for all of these PAs [6]–[8]. This type of method highly depends on the linear uniformity of PAs. Even with the same design, PAs can show distinct different nonlinear behavior. Although this won’t cause a significant decrease in drain efficiency or output power, linearity difference leads to linearization performance degradation when several PAs are sharing one common digital predistorter [6]. Due to the different linearity of each PA, it is almost impossible to achieve excellent linearity for every PA. The uniformity of PAs is crucial in group DPD. Recently, [9] proposed tuning boxes for each PA, but this structure still needs at least one digital tuning component for each PA. The other way to solve this problem is to optimize the linearity of the primary beam signal, which means bad linearity in each channel but excellent linearity in the primary direction beam after signal combination in space [10]–[14]. The tricky point of this method is the estimation of the primary beam signal, which can be performed by algorithm or hardware [12].

In this article, a novel linearization framework for hybrid beam-forming systems is presented. This framework, analog predistorter (APD) is implemented for fine-tuning the linearity characteristic of PAs in one group. APD is a good solution for linearization for its low power consumption and simple structure [15]. The optimization goal of APD is not the best linearity but the best uniformity of all PAs. With good uniformity of PAs, a shared DPD can perform better linearization ability. Hence, combining with an averaged DPD algorithm, the proposed Analog Predistorter Averaged DPD ($A^2$-DPD) can have satisfactory linearization performance for each PA. The article is arranged as follows: The shared DPD problem and PA uniformity are discussed first. Then the details of proposed $A^2$-DPD including the PA uniformity adjustment strategy and averaged-DPD are described. Finally, simulation results and experimental results are given for validation of the proposed $A^2$-DPD framework.

II. APD PREDISTORER AVERAGED DPD

A. SHARED DPD PROBLEM

The problem that this article focuses on is called shared DPD problem in hybrid BF MIMO transmitters. In a conventional MIMO transmitter, each PA has one independent DPD module. As in [2], DPD calculates a precise pre-inverse model for a PA. The DPD model coefficients are optimized to the corresponding PA. Hence, the predistorter can perform well with a sophisticated DPD technique. In a hybrid beam-forming transmitter, however, because of the restriction of the RF chain, one DPD module is dealing with several PAs. A slight difference in PA nonlinear behavior can decrease the performance of shared DPD. Consequently, sharing one DPD with other PAs causes a one-to-two or one-to-multi compensation problem.

A one-to-two problem is shown in Fig. 2 for example. Because of the difference of nonlinearity of PAs, no matter to which PA the DPD is optimized or how does the DPD model is optimized, it is impossible to find suitable parameters for both PAs. The performance directly depends on the uniformity of PAs.

B. THE UNIFORMITY OF PAs

Before talking about concurrent linearization of several PAs, the PA uniformity should be discussed to help to find the best uniformity status of PAs. Here we refer to the
behavioral similarity of PA nonlinearity as the uniformity of PA. Amplitude to amplitude modulation (AM-AM) and amplitude to phase modulation (AM-PM) figures are often applied by many researchers to describe the nonlinear characteristic of PAs. AM-AM and AM-PM can give us a direct view of PA nonlinear behavior. However, it is hard to judge the uniformity by plots like Fig. 2. It is still needed for a general metric to describe how close the nonlinearity is of several PAs.

As we know, the PA nonlinearity is divided into two types: static nonlinear and dynamic nonlinear. The later is also called the memory effect. Static nonlinear causes AM-AM and AM-PM curved, and memory effect makes AM-AM and AM-PM scattered. Due to the complexity of nonlinear character of PAs, it is impossible to use one scalar quantity to precisely describe the nonlinearity of one PA. Fortunately, to tell how different of one group of PAs in one scalar is much more comfortable with specific measurement techniques. When PAs are stimulated with the same signal, it is easy to judge the similarity of the PAs by comparing the output signals. Normalized mean square error (NMSE) of output signals is a standard metric that represents the linearity of PA and also the noise level of the measurement system. The expression of NMSE is given by:

$$NMSE = 10 \log_{10} \frac{\sum_{n=1}^{N_s} (y(n) - x(n))^2}{\sum_{n=1}^{N_s} x(n)^2}$$  \hspace{1cm} (1)$$

where $x(n)$ is the input signal, and $y(n)$ is the captured feedback signal. To make NMSE able to judge the uniformity of two different PAs, the comparison counterpart in NMSE is changed to another PA output. In this way, the crossed normalized mean square error with PA output $y$ is derived as:

$$CNMSE_{2y} = 10 \log_{10} \frac{\sum_{n=1}^{N_s} (y_2(n) - y_1(n))^2}{\sum_{n=1}^{N_s} y_1(n)^2}$$  \hspace{1cm} (2)$$

where $y_2$ is the output signal of the second PA.

However, the difference between PA output signals cannot directly represent the difference between the required DPD signals. This work aims to improve the shared DPD performance, which means a shared DPD signal is applied for several PAs. Each PA has its particular ideal DPD signal. Due to the different nonlinear character, these ideal DPD signals are different. Comparing these ideal DPD signals can help to find the nonlinear differences of the PAs. Here the iterative learning control (ILC) technique is applied to find the ideal DPD signals. ILC is a technique which, has been widely used in industrial control such as motion control, robotic manipulators, and process control [16]. ILC adjusts the controller using the error from output signals iteratively.

Researchers found that the ILC technique can also help to find the ideal DPD signal for a PA [17]. The trained ILC signal can be considered as the ideal predistortion signal. If the ILC signals of two PAs are close enough, DPD with the same DPD model should have good linearization performance with these PAs. The CNMSE is derived as the following form by changing Equ.2 to compare the ILC signal.

$$CNMSE_{2z} = 10 \log_{10} \frac{\sum_{n=1}^{N_s} (z_2(n) - z_1(n))^2}{\sum_{n=1}^{N_s} z_1(n)^2}$$  \hspace{1cm} (3)$$

where $z_1$ and $z_2$ are the ILC signals of the first PA and the second PA. Furthermore, to compare the uniformity of a group of PAs, the averaged ILC signal $z_{ave}$ can be applied as an intermediate variable to construct the CNMSE:

$$CNMSE_{Kz} = 10 \log_{10} \frac{\sum_{k=1}^{K} \sum_{n=1}^{N} (|z_k(n) - z_{ave}(n)|)^2}{\sum_{k=1}^{K} \sum_{n=1}^{N} |z_k(n)|^2}$$  \hspace{1cm} (4)$$

where $z_{ave}(n) = \frac{1}{K} \sum_{k=1}^{K} z_k(n)$, $K$ is the total number of PAs. By applying CNMSE defined here, the uniformity of one group of PAs can be quantified, and the best fitting state of PAs can also be found by comparing CNMSE. Here, we note that directly using the PA output $y_k$ to calculate CNMSE without the ILC process can still work (replacing the $z$ in Equ.4 with $y$). Without ILC process, the DPD performance is reduced. PA output can be applied if the time cost has a higher priority.

**C. ANALOG PREDISTORTER AVERAGED DPD**

In this section, the proposed Analog Predistortion Averaging DPD ($A^2$-DPD) is described in detail. The prototype structure hybrid beam-forming transmitter with proposed $A^2$-DPD is shown in Fig. 4. APD units are inserted to adjust the PA nonlinear with a continuously tunable interface for AM-AM modulation [18]. The APD can directly adjust the RF nonlinear behavior of PA and has a low power consumption, so APD won’t badly reduce the total efficiency, which will be discussed later. The APD module applied here is a continuous tunable AM-AM analog predistorter, the nonlinear character of APD can be tuned by changing the APD control voltage (ACV). Combination of APD and DPD can reduce the linearization difficulty of DPD and save the coefficient number [19] with fine-tuning of APD. Whereas, here the APD is not applied as a linearizer but a uniformity adjuster.

The flow chart of $A^2$-DPD is given by Fig. 3. In $A^2$-DPD, the first step is to find the best fitting ACV. All ACV is extensively scanned in the possible range for each PA. At the same time, the ILC signals of PAs at each state...
are calculated and stored. Then compare the uniformity by applying the CNMSE to find the best uniformity fitting state and the corresponding ACV. The third step is to calculate the averaged ILC signal of the chosen state of PAs. The averaging process will be discussed in the last part of this section. Then use the averaged ILC signal to train the parameters of $A^2$-DPD.

1) CONTINUOUSLY TUNABLE APD
The APD module applied here is implemented by two pi-type networks and four diodes. Different length and width of the microstrip lines of the π-type network can affect its operation mode, which can show the characteristics of expansion or compression in gain and phase. The applied APD module is carefully designed with a constant phase characteristic, and its gain characteristic can be tuned from a semi-linear state to a high expansion state by changing its bias voltage. Although the gain expansion is not an accurate inverse characteristic for the PAs, the ability of continuously tuning from linear state to the expansion state makes it possible to adjust the AM-AM character of PAs.

The tuning range of the control voltage of the APD board is 0 to 4 V, and the Maximum bias current of APD is 15 mA. So the maximum Direct Current (DC) power of the APD is 0.06 watt. The insert loss of the APD board is 1-1.5 dB. The power consumption caused by the insert loss depends on the input power. Since the APD board deals with small signals, the insert loss does not bring much power consumption. The efficiency reduction caused by APD is limited, considering the typical gain and output power in the base-station. The operation frequency of the APD board is 3.5 GHz, and the APD board has 300 MHz bandwidth, which allows wide-band signal applications. Other details of the APD, such as design theory and layout, can be found in [18].

2) TUNABLE CONDITION
Because the APD board applied in this work has only one control variable. The AM-AM changing is continuously from a semi-linear state to a gain expansion state during the ACV range. The difference of AM-AM for the aimed PAs should not be too complicated. Ignoring the dynamic distortion, the difference of PA AM-AM should be positive definite or negative definite, which mean the AM-AM adjustment only have one direction. Fortunately, in the scenario of MIMO transmitters, the applied PAs have the same design and the difference of PAs is simple.

3) AVERAGED DPD
DPD algorithm is also modified to deal with shared DPD problem. As described in [7], applying one of the PA’s output can linearize all of these PAs but with linearity regression of non-centered PAs. Due to the machining error, PAs with the same type of transistor and with the same design still have slightly different nonlinear behavior. To acquire a better compromise performance of all these PAs, an improved Averaged DPD is introduced in this section. As described in [17], the ILC signal can be considered as the ideal DPD signal of the training PA. In a shared DPD problem, all PAs are stimulated by the same test signal. The output signals are all normalized to the same average power when the ILC process is conducted. The gain difference of PAs is normalized to a specific value in base-band. The base-band linearization can affect the linearity of PA in the corresponding power range of each PA. Thus, the difference in ILC signals can directly represent the difference in PA nonlinearity. Averaging the ILC signals helps to find a best-compromised ideal DPD signal, which has the least mean square error to all these ILC signals.

In averaged DPD, we calculate the ILC signal of each PA with linear ILC algorithm first:

$$z_k^{(i+1)}(n) = z_k^{(i)}(n) + u(x(n) - y_k(n))$$

(5)

where $z_k^{(i)}$ is the $i$th iterated ILC signal of the number $k$ PA. $y_k$ is the captured PA output signal from the $k$th PA. $u$ is the update step which is a constant value. After several iterations, the spectrum regression can be compressed close to the noise background level by optimizing the ILC signal. After repeating the ILC training process for each PAs, the averaged ILC signal can be calculated by arithmetic mean:

$$\bar{z} = \frac{1}{K} \sum_{k=1}^{K} z_k$$

(6)
Then parameters of the DPD model can be calculated from the averaged ILC signal by the least square algorithm

\[
w = \left( X^H X \right)^{-1} X \cdot \bar{z}
\]  
(7)

where \( X \) is the nonlinear basis matrix, it includes each order nonlinear waveform of the PA model.

\[
X = [\psi_1(x) \cdots \psi_P^0(x) \psi_1^1(x) \cdots \psi_M^P(x)]
\]  
(8)

\[
\psi_m^p(x) = |x|^{m-1} x \quad (m=1,2,\ldots)
\]  
(9)

Here we give the form of memory polynomial as an example [20]. \( P \) is the nonlinear order, and \( M \) is the memory depth. Other models can be applied in similar way.

### III. SIMULATION RESULTS

#### A. SIMULATION FOR THE RELATIONSHIP OF CNMSE AND ACPR

It is not easy to conduct numerous experiments for shared DPD with different PAs, which is why simulations are carried out to verify the relationship between CNMSE of particular pairs of PAs and the performance of shared DPD with the corresponding PAs (in ACPR).

In these simulations, the Saleh model is employed as the PA model. Firstly, the parameters of PA models are varied to represent different PA nonlinear characters. We choose the first PA and each of the other PAs to be one comparison pairs. Let the number of PAs is \( N \), and there are \( N-1 \) comparison pairs. In each comparison pair, the first PA is PA-A. The other PA is called PA-B. Next, the averaged ILC signal of each comparison pair is calculated. In each comparison pair, the averaged ILC, self ILC signal, and ILC signal of the other PA are applied to stimulate the both PAs. The ACPR of each PA output with these signals is calculated to verify the linearization performance.

The signals in the simulation are 20MHz LTE signals with 7dB PAPR, and the sample rate of the signal is 122.88MHz. In these series of simulations, the same signals are applied as the original input signal to stimulate different PA models. The PA model applied in simulation is Saleh model [21] which is given by:

\[
y = \frac{a_1 |x|}{1 + b_1 |x|^2} \exp \left( \psi + \frac{a_2 |x|^2}{1 + b_2 |x|^2} \right)
\]  
(10)

where \( a_1,a_2,b_1,b_2 \) are coefficients, and \( \psi \) is the phase of \( x \) in angle. The parameters are varied to obtain different PA character. The range and step are given in Table 1. Since \( a_1 \) is a linear factor of \( |x| \), and we want to investigate the nonlinear effect of PA, \( a_1 \) is kept constant. Other parameters are varied in 0.1 for enough PAs. We have 847 different PAs in the simulation.

The simulation result is shown in Fig. 5 and Fig. 6. The Ave-ACPR is the averaged ACPR of the upper and the lower band of the PA output. Fig. 5 is the ave-ACPR result of PA-A with different stimulation: 1) ILC signal of PA-B (blue points) 2) averaged ILC signal(red points) 3) self ILC signal of PA-A(green points). Fig. 6 is the ave-ACPR result of PA-B with different stimulation: 1) ILC signal of PA-A (blue points). 2) averaged ILC signal(red points) 3) self ILC signal of PA-B(green points). Note that in all these comparison pairs, PA-A is the same PA (The first PA). PA-B in each pair changed from the second PA to the last PA. So the points in Fig. 6 scatters much more than Fig. 5.

As illustrated in both Fig. 5 and Fig. 6, the curves show a similar tendency: The ave-ACPR appears approximately linear growth with CNMSE when the CNMSE is under \(-32 \) dB. The slope decreases when CNMSE is higher than \(-32 \) dB. The tendency of both Fig. 5 and Fig. 6 supports the usage of CNMSE to judge the PA uniformity. The application of averaged ILC signal shows about 5 dB improved in
ave-ACPR compared with directly using the ILC signal of the other PA. The DPD result of the self ILC signal is $-73$ dBc. When the CNMSE of the chosen pair is close to $-70$ dB, the ave-ACPR is also close to this level. The threshold of CNMSE is about $-35$ dB if the ACPR requirement is set to $-45$ dB.

B. SIMULATION OF A THREE-PA $A^2$-DPD SCENARIO

For validation for $A^2$-DPD in a multi-PA scenario, a numeric simulation with three PAs and APDs is conducted. The PA model in this section is the Saleh model with memory effect. The input signal firstly passes through an FIR filter, which is set as 3 order FIR filter in this simulation. Thus the PA model has 7 parameters, and each PA has different parameters, which are given in Table 2. $f_1$, $f_2$, $f_3$ are the parameter of 1-3 order parameter of the FIR filter. We propose an APD model in this simulation which is based on the tuning character of the applied APD board:

$$y = ((1 - b)|x| + b|x|^a) \exp(\psi(n)) \quad (11)$$

$b$ is the bending point parameter, which controls the banding position of the AM-AM curve. $b$ is set to 0.5 in this simulation. $a$ is a power exponential parameter, which controls the degree of curve bending. $a$ is set as a real number in the range of $[1, 3]$ for approximating the character of the APD board.

The simulation flow is the same as Fig. 3. Firstly, the APD state with PA is scanned, and the ILC signal of each state is trained. Secondly, CNMSE of each state is calculated as Eq.4. By searching the best CNMSE, the corresponding APD parameters are $[1.9, 1.95, 2.2]$ when the best CNMSE is $-48.38$.

Applying averaging the ILC signal as Eq.6, the averaged ILC is imported to the APD and PAs. The AM-AM and AM-PM of simulated PAs are shown in Fig. 7 and Fig. 8. The AM-AM and AM-PM of APD-tuned and final linearized PAs are given by Fig. 9 and Fig. 10. From Fig. 7 it can be seen that the applied three PAs have different nonlinear behavior. Fig. 9 shows the APD can tune the nonlinearity of PA to a similar state, and averaged DPD can linearize these PAs at the same time.

IV. EXPERIMENTAL RESULTS

A series of experiments are implemented for validation of the proposed $A^2$-DPD. The experimental setting is demonstrated in Fig. 11. Vector signal generator (VSG) SMW200A from Rohde & Schwarz generates continue modulated LTE signals with 20MHz bandwidth. The peak to average ratio (PAPR) of the signal is 8 dB. Spectrum Analyzer FSW 43 from Rohde & Schwarz were applied as receiver to capture the output sequence of PAs. Attenuator placed before the receiver for preventing the power overload of the spectrum analyzer. The AM-AM tuning APD module is assorted before PAs. In this experiment, two class-AB PAs designed with Cree 40010 transistors are tested. The experiments are conducted...
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FIGURE 10. APD-DPD Simulation results of PAs in AM-PM.

FIGURE 11. Experiment setup.

FIGURE 12. AM-AM of PAs with APD and with APD-DPD.

FIGURE 13. AM-PM of PAs with APD and with APD-DPD.

FIGURE 14. APD scan result: CNMSE with Different APD control voltage.

at 3.5 GHz when the average output power of each PA is 35 dBm. The drain efficiency is 25.8 % and 26.3 %.

The first step is to scan the APD control voltage (ACV) and iteratively calculate the ILC signal of the cascaded system of APD and PA. The ACV scan range is from 0 V to 4 V. The scan step of ACV is 0.1 V. At each ACV point, the ILC process as Equ.5 is executed 10 times. After finishing all these measurements for PA 1 and PA 2, the stored ILC signals are applied to calculate the CNMSE for searching the most similar PA state. As given in Fig. 12, PA 1 and PA 2 have similar static nonlinear behavior in AM-AM but still have some differences (not overlap perfectly). APDs with proper ACV can tune the AM-AM compression curve of PAs to a uniformed state, which is also shown in Fig. 12. The CNMSE results of different ACV pairs are illustrated in Fig. 14 in the color chart. It can be seen from Fig. 14 that the CNMSE has three main areas: two yellow zones and one blue zone. The ACVs of the two PAs are profoundly different in the yellow zones. In the blue zone, ACVs are at the close level in which range the APD can adjust the PA nonlinear slightly. It can be found that the best CNMSE is in the blue zone when ACV1 is 4.0 V, and ACV2 is 3.3 V. The original and tuned AM-PM curves of both PAs are shown in Fig. 13. After the tuning by APD, the AM-AM is highly uninformed, and the AM-PM does not bend severely.

After finding the best fitting ACV, the averaged ILC signal is calculated, and a shared DPD model is trained from the averaged ILC signal. General Memory Polynomial (GMP) has good fitting performance [22] and acceptable model complexity. GMP is chosen as the DPD model in the test. The nonlinear order of GMP is set to 7. Memory depth is 5, and both lagging and leading depth are 2. The total parameter number is 175. The results of $A^2$-DPD are measured, and for comparison, the results of PA 1 centered DPD (P1-DPD) for PA 2, and PA 2 centered DPD (P2-DPD) for PA 1 are also measured [7]. The AM-AM and AM-PM after $A^2$-DPD can be found in Fig. 12 and Fig. 13. The ACPR results are shown in Table 3. The PA output spectrum is illustrated by Fig. 15 and Fig. 16.
by PA output is also important. Measurements with the ACV combination determined by the PA output is also performed. By calculating the CNMSE of PA output signals, the chosen ACV combination is 4.0 V and 3.6 V. The same process with ILC training at the chosen ACV and averaging DPD have been conducted. The ACPR and EVM results are shown in Table 3 as $A^2$-Y-DPD. The DPD performance in ACPR decreased 3 dB compared with ACV combination calculated by ILC signals. The EVM result of $A^2$-Y-DPD is 2.91% and 2.92%, which means the in-band error doesn’t reduce much when applying the PA output to choose the ACV.

V. CONCLUSION

In this article, an Analog Predistorter averaged DPD for Hybrid Beam-forming MIMO transmitter is proposed. Continuously tunable APD modules are applied for the total uniformity of PAs. Based on ILC technology, the CNMSE is derived to judge the uniformity of PA for linearization and help to find the best fitting status of APD. From simulations, CNMSE shows approximately linear correlated with the uniformity of PAs. Further simulation valid the theory with the multi-PA scenario. Experimental results show that by adjusting APD control voltage, the nonlinear behavior of PAs can be unified, and the averaged DPD algorithm can suppress ACPR of both PAs under -51 dBc. This work gives a potential solution for the shared DPD problem in a hybrid BF MIMO transmitter. Although this work leaves unsolved problems, such as adaptation $A^2$-DPD to Doherty and efficiently deal with a large number of PAs with low-time-consumption methods.

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