Cross-Terms Shared Digital Predistortion for Multiuser MIMO Transmitters Using Magnitude-Selective Affine Functions

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***Abstract*—The complexity of nonlinearity induced in multiuser multiple-input multiple-output (MU-MIMO) systems surpasses that of single-user MIMO (SU-MIMO) systems due to the involvement of multiple signals and multiuser beamforming algorithms. To tackle nonlinear distortions in fully-connected MU-MIMO systems, we propose a novel cross-terms shared digital predistortion (DPD) model based on the magnitude-selective affine (MSA) functions. This model is derived from a dual-variable MSA-based configuration to address distortions arising from multiple user data streams. In addition, it employs a shared cross-term architecture to reduce the complexity of the model. We validated our approach using a beamforming array of 2-user 4-antenna elements.**

***Index Terms*—Affine function, digital predistortion (DPD), multiuser multiple-input multiple-output (MU-MIMO), power amplifier (PA).**

I. Introduction

GIVEN the limited availability of spectrum and the increasing demand for high data rate and high quality communication, multiple-input multiple-output (MIMO) technology has become increasingly popular. Multiuser MIMO (MU-MIMO) stands out as a significant enhancement, optimizing transmitter capacity utilization by enabling simultaneous communication with multiple users.

Power amplifiers (PAs), being the most power-intensive components in transmitters, typically operate in high-efficiency mode, resulting in nonlinear distortion that degrades communication quality. Digital predistortion (DPD) is one of the most popular technologies for addressing the trade-off between efficiency and linearity by employing a module with the inverse characteristic of the PA in the transmit chain. However, DPD for MU-MIMO has been a subject of research for years but remains an open problem.

In this paper, we propose a DPD model based on the magnitude-selective affine (MSA) functions, incorporating shared cross terms, to linearize multiuser MIMO transmitters. Compared to the conventional Volterra series-based models, the proposed model has lower complexity, making it better suited for scenarios with high nonlinearity.

II. MSA-Based Proposed Dual-Variable DPD Model MU-MIMO System Analysis

One of the typical structures of MU-MIMO is shown in Fig. 1, consisting of K antenna elements and Q signal streams. The

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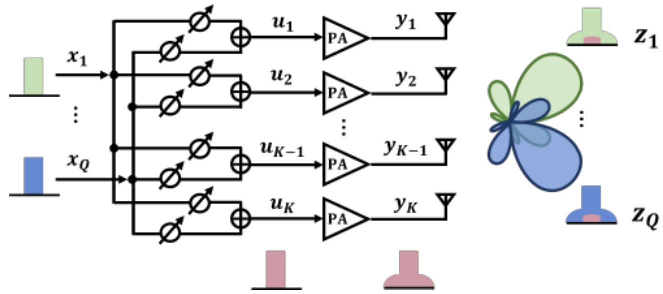

Fig. 1. The structure of the FC MU-MIMO system.

input signals can be written as $\mathbf{X} = [\boldsymbol{x_1},\ \boldsymbol{x_2},\ \ldots,\ \boldsymbol{x_Q}]^{\boldsymbol{T}}$. The inputs and outputs of PAs are $\mathbf{U} = [\boldsymbol{u_1},\ \boldsymbol{u_2},\ \ldots,\ \boldsymbol{u_K}]^{\boldsymbol{T}}$ and $\mathbf{Y} = [\boldsymbol{y_1},\ \boldsymbol{y_2},\ \ldots,\ \boldsymbol{y_K}]^{\boldsymbol{T}}$ respectively. The received signals $\mathbf{Z} = [\boldsymbol{z_1},\ \boldsymbol{z_2},\ \ldots,\ \boldsymbol{z_Q}]^{\boldsymbol{T}}$ at the user-end are composed of all the original signals.

After investigating other models, the MSA model [1], [2] building nonlinearity in a piecewise manner is more suitable here. It is achieved by selecting different coefficients for the affine function Ψ according to the coefficient selection input Φ, and the φ is to restore the phase value.

For MU-MIMO system, multi-variable DVR model is required. In the literature, [3] and [4], different types of dual-variable basis functions have been designed. The cross terms presented here combine the terms from them, giving the following formats

$$t_q(n) = \sum_{m=0}^{M} H[|x_1(n-m) + x_2(n-m)|, \\ |x_1(n) + x_2(n)|, x_q(n)] \tag{1}$$

$$d_q(n) = \sum_{m=0}^{M} H[|x_1(n-m)| + |x_2(n-m)|, \\ |x_1(n)| + |x_2(n)|, x_q(n)]. \tag{2}$$

The $H(\Psi, \Phi, \varphi)$ in (1) and for (2) is the MSA function and can be written as

$$H(\Psi, \Phi, \varphi) = \begin{cases} (A_1\Psi + B_1)\varphi, & 0 \le \Phi < \beta_1 \\ (A_2\Psi + B_2)\varphi, & \beta_1 \le \Phi < \beta_2 \\ \quad\vdots & \\ (A_P\Psi + B_P)\varphi, & \beta_{P-1} \le \Phi < \beta_P \end{cases} \tag{3}$$

where A_p and B_p are the model coefficients, and β_p is the threshold value that divides the input range into P partitions.

$$
\begin{aligned}
z_1(n) = & \sum_{m=0}^{M} a_{1m} x_1(n-m) + \sum_{m=0}^{M} H[|x_1(n-m)|, |x_1(n)|, x_1(n-m)] && \cdots\cdots \mathbf{I} \\
& + \sum_{m=0}^{M} a_{2m} x_2(n-m) && \cdots\cdots \mathbf{II} \\
& + t_1(n) + d_1(n) && \cdots\cdots \mathbf{III}
\end{aligned} \tag{4}
$$

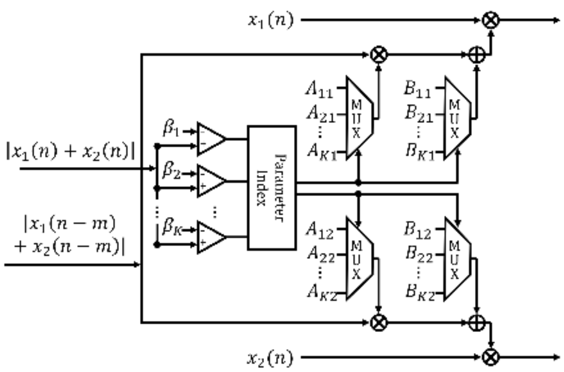

Fig. 2. The proposed DPD scheme and the hardware implementation

TABLE I
NMSE AND ACPR RESULTS OF BEAM1

Beam1	NMSE(dB)	NMSE after linear decomposition (dB)	ACPR (dBc)
Without	-15.25	-28.74	-39.16/-38.95
Proposed	-15.47	-39.89	-48.81/-48.69

TABLE II
NMSE AND ACPR RESULTS OF BEAM2

Beam1	NMSE(dB)	NMSE after linear decomposition (dB)	ACPR (dBc)
Without	-14.47	-28.35	-39.68/-38.16
Proposed	-15.30	-38.54	-47.40/-47.40

The full MSA-based MU-MIMO models for the first user can be expressed as (4). The coefficients can be divided into two parts, the coefficient corresponding to the single-various basis function and the basis function corresponding to the cross distortion. It can be seen that cross terms for different users have the same form, so the affine functions and coefficient selection inputs of the last two terms can be shared, and only need to be calculated once. By multiplying different coefficients, the basis function of the corresponding DPD model can be obtained. The complexity of the proposed DPD model can be reduced by sharing terms, thus dramatically saving hardware resources in DPD implementation.

III. EXPERIMENTAL RESULTS

To validate the proposed DPD method, a 2-user 4-antenna element MIMO test platform was set up. Normalized mean square error (NMSE) and adjacent channel power ratio (ACPR) results for both beams are listed in Table I and Table II. As can be seen from the tables, the performance of both NMSE and ACPR has been greatly improved, which also gives proof to the validity of the proposed method. The linear decomposition here means subtracting the linear components of other signals from the received signal. Fig. 3 shows the constellation diagrams and the EVM of beam1 and beam2 without DPD after liner decomposition is 3.47% and 3.35% respectively. After the proposed DPD, the EVM is 0.85% and 0.88% respectively.

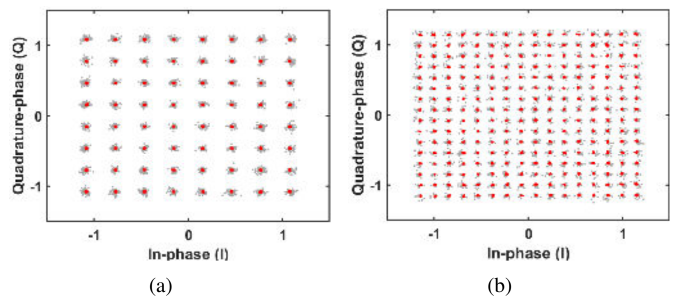

Fig. 3. (a) constellation diagram of beam1, (b) constellation diagram of beam2.

IV. FELLOWSHIP IMPACT AND CAREER PLAN

It was my great honor to receive the MTT-S Graduate Fellowship Award and attend the IMS2024 in Washington, DC, USA. This fellowship not only supported my research on the multi-beam digital predistortion project but also gave me the opportunity to meet researchers from various fields. Here I would also like to thank my supervisor Professor Anding Zhu for his guidance. Now I am still engaged in DPD research.

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