Crosstalk Suppression in MIMO Wireless Transmitters for 4G Networks

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***Abstract*— This paper presents new nonlinear crosstalk compensation technique in Multiple Input Multiple Output (MIMO) 4G Wireless Transmitters. It has been demonstrated that algorithm can suppress almost all distortion introduced by nonlinear crosstalk and Power Amplifier (PA) nonlinearity while significant complexity reduction compared with previously proposed Crossover Digital Predistortion (CO-DPD) technique is achieved. The technique is tested on 4x4 4G MIMO systems in the presence of large IQ imbalance.**

***Index Terms*— 4G, Crosstalk, Digital Predistortion, MIMO, Power Amplifiers.**

I. Introduction

CURRENT and especially, next-generation wireless communications systems have had very strong capacity requirements for transmitting high data rates. Using high-capacity modulation schemas and multiple access techniques bring lot of challenges for researchers and engineers in the process of the designing transceiver. The PAs that amplify 4G OFDM (Orthogonal Frequency Division Multiplexing) wideband signals with high PAPR (Peak to Average Power Ratio) produce several memory effects and nonlinearities, [1]. Also, unbalanced IQ modulator is additional distortion source in wireless transmitters [2]. Moreover, in order to increase capacity, modern wireless communication systems use MIMO that brings new undesired effects such as nonlinear before-PA crosstalk on transmitter side and antennas' crosstalk on both sides [2]. Furthermore, compensation of MIMO channel impact (fading, crosstalk) is quite more complex compared with conventional SISO channel [3].

In order to suppress PA distortion, Digital Predistortion (DPD) is most acceptable solution due to its significantly lower complexity [4], [5] in comparison with other solutions, [1]. However, DPD in MIMO systems have to compensate crosstalk and impairments introduced by PA. This paper presents extended work from [6] where it was shown that conventional polynomial DPD could not be acceptable solution for MIMO. Also proposed Crossover Digital Predistortion (CO-DPD) was introduced and tested on 2x2 MIMO systems [6].

In this work, new reduced-complexity MIMO DPD technique is introduced. In comparison with previously proposed DPDs, this technique divides signals to I and Q components and process them separately. It will be demonstrated that the proposed technique can achieve satisfied linearization performance in 4x4 4G MIMO transmitters with notably lower complexity because it uses real instead of complex number during the DPD extraction procedure. The proposed technique is also tested in the presence of large IQ imbalance.

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II. Proposed Technique

In order to compensate impairments introduced by PA and nonlinear MIMO crosstalk before PA (Fig 1), a novel technique, which combine work from [6] and [7], [8] will be introduced in this paper. This method uses PA model given in [7], [8] and Least Square (LS) algorithm extension for MIMO proposed in [6]. However, in this paper all signal processing during MIMO LS algorithm use real numbers only instead of complex due to the fact that PA model used here separately treated I and Q signal components. This PA model is the quadrature Taylor-series amplifier model given with following equations:

$$PAout(v_i) = (GI(v_i) + j * GQ(v_i)) * v_i \tag{1}$$

$$GI(v_i) = \sum_{n=0}^{N} C_n * v_i^n \tag{2}$$

$$GQ(v_i) = \sum_{n=0}^{N} D_n * v_i^n \tag{3}$$

where C_n and D_n are polynomial coefficients and N is polynomial order. As mentioned above, Crossover DPD method [6] have been extended here by separated processing of I and Q signal components. In other words, DPD coefficients $\overrightarrow{dI}_{i,j}$ and $\overrightarrow{dQ}_{i,j}$ are determined in feedback block separately for I and Q signal components with following equations:

$$\begin{bmatrix} \overrightarrow{dI}_{1,1} & \overrightarrow{dI}_{2,1} & \overrightarrow{dI}_{3,1} & \overrightarrow{dI}_{4,1} \\ \overrightarrow{dI}_{1,2} & \overrightarrow{dI}_{2,2} & \overrightarrow{dI}_{3,2} & \overrightarrow{dI}_{4,2} \\ \overrightarrow{dI}_{1,3} & \overrightarrow{dI}_{2,3} & \overrightarrow{dI}_{3,3} & \overrightarrow{dI}_{4,3} \\ \overrightarrow{dI}_{1,4} & \overrightarrow{dI}_{2,4} & \overrightarrow{dI}_{3,4} & \overrightarrow{dI}_{4,4} \end{bmatrix} = pinv\left(\left[AI_{\overline{\overline{T}}_1}\ AI_{\overline{\overline{T}}_2}\ AI_{\overline{\overline{T}}_3}\ AI_{\overline{\overline{T}}_4}\right]\right) * \left[\overrightarrow{UI}_1\ \overrightarrow{UI}_2\ \overrightarrow{UI}_3\ \overrightarrow{UI}_4\right] \tag{4}$$

$$\begin{bmatrix} \overrightarrow{dQ}_{1,1} & \overrightarrow{dQ}_{2,1} & \vec{d}Q_{3,1} & \overrightarrow{dQ}_{4,1} \\ \overrightarrow{dQ}_{1,2} & \overrightarrow{dQ}_{2,2} & \overrightarrow{dQ}_{3,2} & \overrightarrow{dQ}_{4,2} \\ \vec{d}Q_{1,3} & \vec{d}Q_{2,3} & \vec{d}Q_{3,3} & \overrightarrow{dQ}_{4,3} \\ \overrightarrow{dQ}_{1,4} & \overrightarrow{dQ}_{2,4} & \vec{d}Q_{3,4} & \overrightarrow{dQ}_{4,4} \end{bmatrix} = pinv\left(\left[\boldsymbol{AQ}_{\vec{y}_1} \boldsymbol{AQ}_{\vec{y}_2} \boldsymbol{AQ}_{\vec{y}_3} \boldsymbol{AQ}_{\vec{y}_4}\right]\right)\left[\overrightarrow{UQ}_1\ \overrightarrow{UQ}_2\ \ \overrightarrow{UQ}_3\ \overrightarrow{UQ}_4\right] \quad (5)$$

where symbols in equations (5) and (6) are defined as follows (*I/Q* is abbreviated notation for separated *I* and *Q* signal components):

$\overrightarrow{UI/Q}_i = [UI/Q_i(1) \ldots UI/Q_i(N)\ ]^T$ is an $N \times 1$ vector (N is samples' number of the input signal);

$\overrightarrow{dI/Q}_{i,j} = \left[dI/Q_{ij1}\ \ldots\ dI/Q_{ijk} \ldots\ dI/Q_{ijK}\ \right]$ is an $1 \times K$ vector of DPD polynomaial coefficients;

$$\boldsymbol{AI/Q}_{\overrightarrow{T_j}} = \begin{bmatrix} aI/Q_1\left(T_j(1)/G\right) & aI/Q_2\left(T_j(1)/G\right) \ldots & aI/Q_K\left(T_j(1)/G\right) \\ & \vdots & \\ aI/Q_1\left(T_j(N)/G\right) & aI/Q_2\left(T_j(N)/G\right) \ldots & aI/Q_K\left(T_j(N)/G\right) \end{bmatrix}$$

is $N \times K$ matrix, $\vec{T_j}$ is FB signal from *j*-th transmitter output converted to baseband and $aI/Q_k\left(T_j(n)\right)$ is defined as $aI/Q_k\left(TI/Q_j(n)/G\right) = \left(TI/Q_j(n)/G\right)^k$, where G is linear PA gain; function $pinv\,(\boldsymbol{x})$ represents Moore-Penrose pseudo inverse of the matrix x.

Running this DPD extraction process, computational complexity of CO-DPD method is reduced approximately twice because two pseudo inversion separated processes are running with real instead of one with complex numbers.

III. Results

During this work, all results were generated using Matlab-Advanced Designed System (ADS) Co-Simulation System. 4G OFDM signals were generated in baseband and passed through MIMO transmitters four antennas shown in Fig. 1. Baseband equivalent Simulations' model was used here for proofing concept [9]. In those simulations, different bit streams were sent in every of four signal paths. Therefore, spatial multiplexing MIMO cases have been simulated here. During this work, asymmetric crosstalk was considered and the worst case scenario was presented. The asymmetric crosstalk effect was modelled because it represents usual phenomenon in real system. Generated 4G OFDM signals in four transmitter's branches have had 300 data subcarriers and 512 FFT size. The PA model for real Mini-Circuits ZHL-1042J power amplifier was extracted experimentally using test bed [10] and this model was used in simulations.

The simulations were performed for asymmetric nonlinear crosstalk, 5% imbalance in amplitude and 5° imbalance in phase for 4x4 MIMO system. All subcarriers of 4G OFDM signals used in those simulations were modulated with the most demanding 64QAM (Quadrature Amplitude Modulation) modulation.

In case of standard 2x2 MIMO transmitter there is no need for analysis of the presence of symmetric or asymmetric crosstalk effect, because the system has only two branches. In case of 4x4 4G MIMO transmitters the effect of crosstalk is different in different branches of the transmitter and it depends on branch position. The degradation was highest for the signal which was passed through the two middle branches of considered model. Fig. 2 shows the signal constellation of the input and constellation after applying effect of IQ imbalance on the input signal.

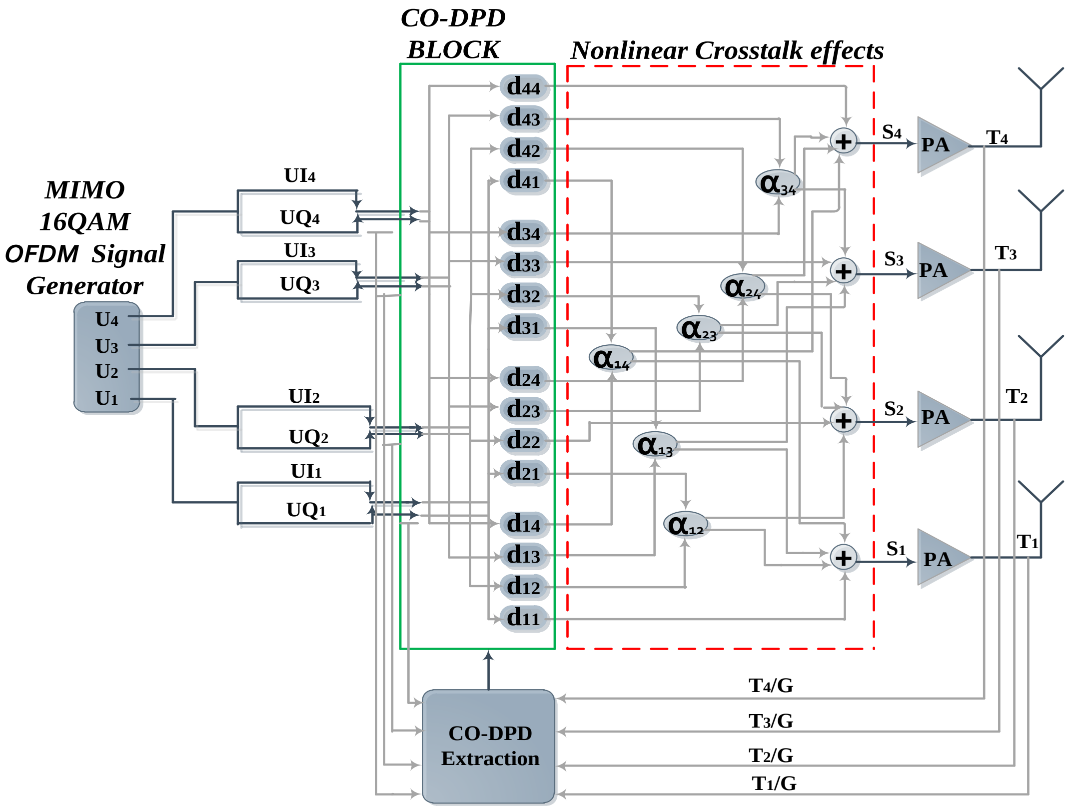
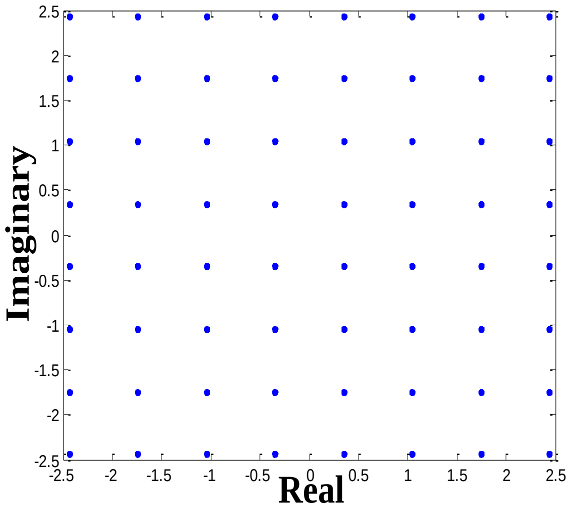
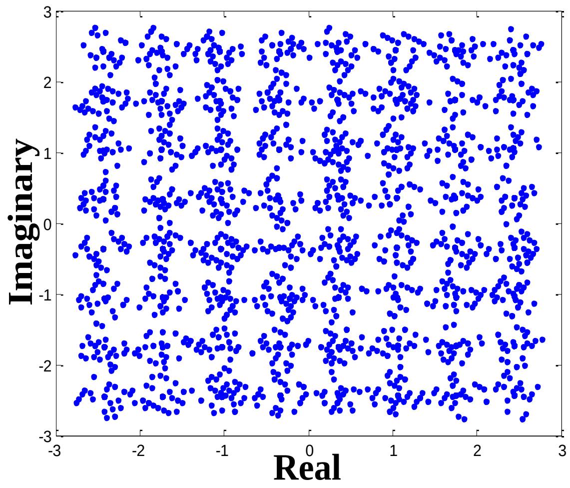


Fig. 1 4x4 4G MIMO transmitter with proposed approach



(a)

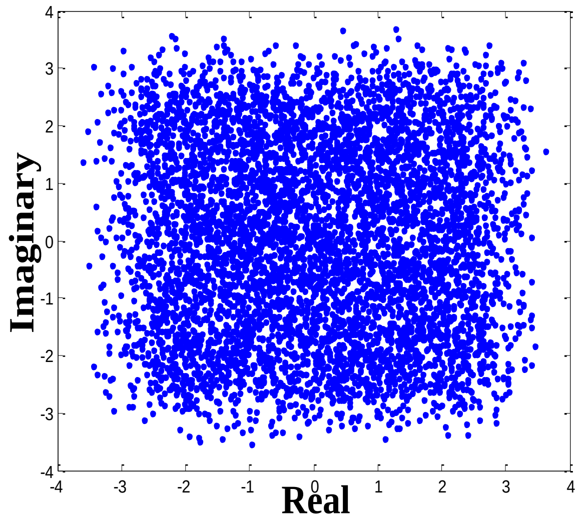


(b)

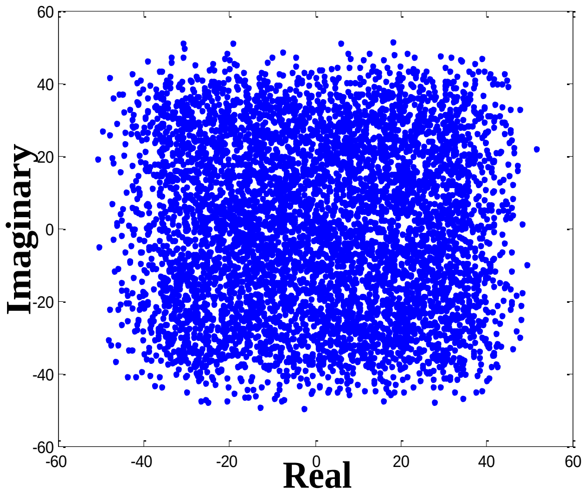
Fig. 2 Signal constellations at the input of PA (a) without IQ imbalance (b) with IQ imbalance.

Fig. 3 shows effect of IQ imperfection and asymmetric crosstalk as well as application of the proposed DPD on the constellation plot for the 4x4 4G MIMO systems. Plot at Fig. 3(a) represents the transmitted demodulated equivalent version of 64QAM OFDM signal before it is passed through the PA while plot at Fig. 3(b) represents constellation of the transmitted 64QAM signal after it is passed through the PA. Finally, Fig. 3(c) represents constellation of the transmitted 4G OFDM 64QAM signal with proposed DPD coefficients at the output of the PA.

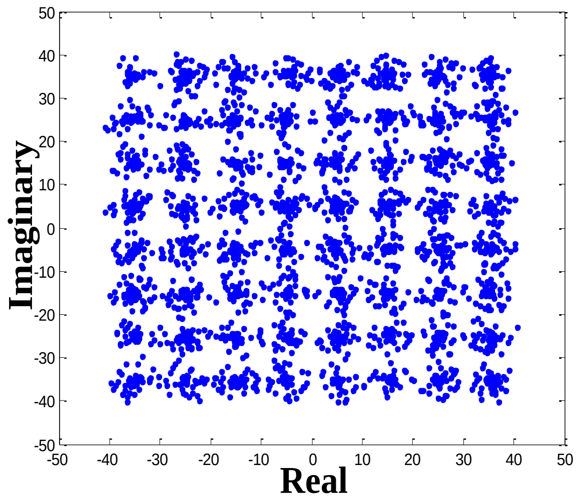
It can be noticed that both impairments IQ imbalance and nonlinear crosstalk notably degraded the quality of signals and it must be taken into account. After applying proposed method, the performance of the system is much better and the effect of nonlinear crosstalk is eliminated. However, the whole effect of IQ imperfection cannot be eliminated using this algorithm.



(a)



(b)



(c)

Fig. 3 (a) The constellation of the signal with IQ imbalance and asymmetric nonlinear crosstalk in the 4x4 MIMO transmitter. a) Befor PA. b) After PA. c) after PA with proposed algorithm.

Table I shows the EVM values in 2x2 and 4x4 4G MIMO system with 64QAM for three different cases: the input signal which is affected with IQ imbalance, signal affected with both, IQ imbalance and nonlinear crosstalk after it passed through PA without and with proposed technique. The results in Table I represent the conformation of what was already written from analysis of the constellation diagrams. Also, it can be noticed that by increasing the number of transmitter branches from two to four, the effects of IQ imperfection and asymmetric nonlinear crosstalk introduces much higher distortion level to the signal. However, the proposed digital predistortion approach for MIMO systems can successfully compensate nonlinear distortion in case of 4x4 4G MIMO transmitter. The residual distortion at the output of the PA is presented because IQ imbalance imperfection is not included in the proposed model.

Table I. EVM for different cases

EVM	***[%]***
Input signal with IQ imbalance in 2x2 MIMO	31.7
Input signal with IQ imbalance and nonlinear crosstalk after PA in 2x2 MIMO	42.40
Input signal with IQ imbalance, nonlinear crosstalk and proposed technique, after PA in 2x2 MIMO	3.45
Input signal with IQ imbalance in 4x4 MIMO	31.7
Input signal with IQ imbalance and nonlinear crosstalk in 4x4 MIMO	53.68
Input signal with IQ imbalance, nonlinear crosstalk and proposed technique, after PA in 4x4 MIMO	3.7

IV. CONCLUSION

In this paper, new digital predistortion technique for spatial multiplexing MIMO systems has been introduced. Firstly, the technique was successfully applied in order to jointly suppress nonlinear crosstalk and PA nonlinear distortion in MIMO transmitter with four antennas while technique complexity was significantly reduced compared with previous DPD techniques for MIMO. The method is performed well in presence of large IQ imbalance, but it cannot suppress distortion introduced by unbalanced IQ modulator. According to results given, this work is an excellent starting point for developing low-complexity MIMO DPD applicable in real MIMO transmitters' applications.

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