MEMORY CROSSOVER NEURAL NETWORK PREDISTORTER FOR THE COMPENSATION OF MEMORY CROSSTALK AND HPA NONLINEARITY

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ABSTRACT

In [1] and [2], authors proposed two efficient crossover predistortion schemes which are capable to compensate simultaneously HPA nonlinearity and crosstalk effects in MIMO systems. The crosstalk model considered in these papers was memoryless one. However, memory effects of crosstalk can no longer be ignored due to the broadband transmitted signal.

Then, in this paper, we demonstrate the effect of memory crosstalk on the Crossover Neural Network Predistorter (CO-NNPD) proposed in [1]. Along, we propose a new crossover predistortion structure based on this conventional CO-NNPD which is capable to enhance good performance in MIMO OFDM systems in presence of HPA nonlinearities with taken into account the memory effects of crosstalk. The Levenberg-Marquardt algorithm (LM) is used for neural network training, which has proven [3] to exhibit a very good performance with lower computation complexity and faster convergence than other algorithms used in literature. This paper is supported with simulation results for the Alamouti STBC MIMO OFDM system in terms of Bit Error Rate (BER) in Rayleigh fading channel.

Keywords- STBC, MIMO-OFDM, CO-NNPD (Crossover Neural Network Predistorter), Memory Crosstalk, HPA, nonlinearity, MLP (Multi-Layer Perceptron), LM (Levenberg-Marquardt), NN (Neural Network), MCO-NNPD (Memory CO-NNPD).

1. INTRODUCTION

MIMO techniques consist to increase the theoretical data rate proportional to the number of transmit antennas [4], they mitigate fading and significantly improve link quality. For this reason MIMO systems make the object of IEEE norms and they are used in most new technologies especially in 4G wireless systems. OFDM techniques use a set of subcarrier to transmit information (frequency division multiplexing) and they offer high performance in terms of data rate and spectral efficiency [5]. That's why, the combination of MIMO and OFDM gives the possibility to exploit the advantages of the two techniques. MIMO-OFDM technique has gained wide use in many wireless standards, such as IEEE 802.11n, IEEE 802.16e and 3GPP-LTE [2]. However, like SISO-OFDM MIMO-OFDM exhibits large Peak-to-Average Power Ratios (PAPR), i.e. large fluctuation in their signal envelopes. Indeed, the performance of the transceiver is very sensitive to nonlinear distortions caused by the HPA.

The most cost effective solution for the HPA nonlinearity is to implement a digital predistortion [3] which consists to distort the HPA input signal by a predistorter that present the inverse of the amplifier characteristics. Furthermore, in MIMO systems, multiple transmission paths are implemented in the same chipset. These implementations cause the crosstalk between those paths and it affects the signal quality and the predistorter performance [1, 2].

Several techniques have been proposed in literature to suppress the crosstalk effects in the IC design, such as buffering the LO paths [6], grounded guard ring [7], deep trench [7, 8], silicon-on-in-sulator (SOI) substrate [7]. These proposed techniques are able to minimize the crosstalk, although they cannot completely remove it.

In [1-2-6, 9], the effects of crosstalk on MIMO systems have been treated. The HPA nonlinearity effects on the performance of systems using MIMO techniques were proposed and analyzed in [10-11,12]. Indeed, it should be noted that only two previous papers [1, 2] have treated the effects of crosstalk on digital predistortion for MIMO systems and they proposed new solutions as a crossover predistorter to compensate simultaneously the crosstalk and HPA nonlinearities. However, the crosstalk model considered in these papers was memoryless one. Yet, in new generation of wireless communications which use OFDM as modulation scheme, memory effects of crosstalk can no longer be ignored due to the broadband input signal.

It is worth noting and to the best of authors knowledge that this paper is the first which study the effects of memory crosstalk on crossover predistortion. The performance of the CO-NNPD proposed in [1] are revisited here and the effect of memory crosstalk on it is demonstrated.

Along, we propose a new predistortion structure, based on CO-NNPD, to the STBC MIMO OFDM system while taken into consideration the memory crosstalk and HPA nonlinearity. The performance of the new proposed predistortion scheme are analyzed based on BER when the channel is a Rayleigh fading one.

The remainder of this paper is organized as follows:

In section 2, we present the STBC MIMO OFDM system model in presence of HPA nonlinearity, memory crosstalk and the conventional CO-NNPD. In section 3, we propose a new Memory Crossover Neural Network Predistorter (MCO-NNPD) to compensate memory crosstalk and HPA nonlinearity effects. We present the simulation results and discussion in section 4. Finally, the conclusion is mentioned in section 5.

2. SYSTEM MODEL

2.1 STBC MIMO OFDM SYSTEM

The MIMO multiplexer chosen in this investigation is the Space Time Block Coded (STBC) 2*2 proposed by Alamouti [4].

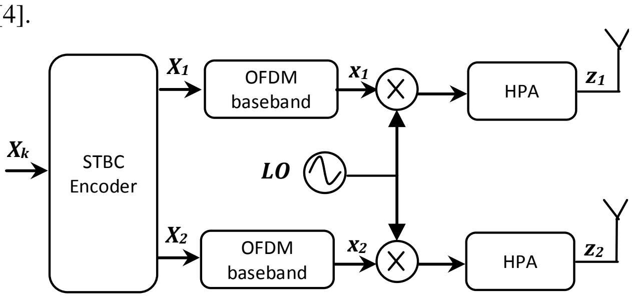

Figure 1-The communication transceiver model STBC MIMO OFDM

As shown in figure 1, the STBC MIMO OFDM transmitter is composed by the STBC encoder which takes a block of two M-array QAM or PSK symbols *X1* and *X2*, and assigns it to the two OFDM transmitters according to the following coding matrix:

$$X_A = \begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{bmatrix}^T \tag{1}$$

where T represents the time duration of the STBC transmission matrix. The OFDM signal is giving by equation 2:

$$x_1 = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} X_i e^{\frac{j2\pi in}{N}} \tag{2}$$

where N represents the number of orthogonal subcarriers.
For the HPA model we have chosen Saleh's well-established TWTA model [11], where the HPA output is as follows:

$$z(t) = A(r) exp\,(j.(\omega_c t + \varphi(t) + P(r))) \tag{3}$$

According to Saleh's model which has the advantage of exhibiting greater simplicity and accuracy than other models, the AM/AM and AM/PM conversion of the TWTA can be represented as:

$$A(r) = \frac{\alpha_a r}{1+\beta_a r^2} \quad \text{and} \quad P(r) = \frac{\alpha_p r^2}{1+\beta_p r^2} \tag{4}$$

where, r is the modulus input, α_a and β_a are the parameters to decide the non-linear level, and α_p and β_p are phase displacements. The values for these parameters are assumed to be: $\alpha_a = 2$, $\beta_a = 1$, $\alpha_p = 4$ and $\beta_p = 9$, which can be assumed a typical TWTA employed in real systems [1, 3].

2.2 Conventional Crossover Neural Network Predistorter

In order to restore the linearity and improve the efficiency of MIMO OFDM transmitters, a solution was proposed in [3] which consist on an efficient neural network Predistorter (NNPD). This NNPD forms an adaptive nonlinear device that its response can approximate the inverse transfer functions of the HPA.

Then, in MIMO system we can't ignore the crosstalk effects which are caused by the implementation of many transmission/reception paths in the same chipset. This crosstalk affects the NNPD performance, that's why, a CO-NNPD was proposed in [1] in order to eliminate HPA nonlinearity and crosstalk effects simultaneously (show figure 2).

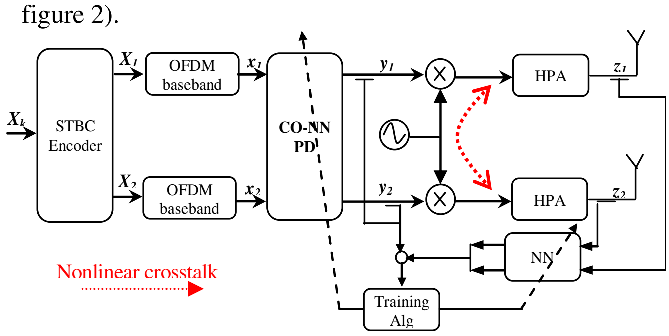

Figure 2- CO-NNPD and nonlinear crosstalk in MIMO OFDM transmitter

As shown in figure 2, we consider that only the HPA represent the nonlinear component. Then all sources of crosstalk must be added before the HPA. The HPA output affected by the nonlinear crosstalk is as follows:

$$z_1 = f_1(y_1 + \alpha y_2) \tag{5}$$

$$z_2 = f_2(\beta y_1 + y_2) \tag{6}$$

where $f_1(.)$ and $f_2(.)$ are the functions representing the nonlinear HPA responses at each branch. Since the signals in different paths use the same operating frequency and have equal transmission power, crosstalk is more likely between the paths. Then, α and β are equal.

The CO-NNPD proposed in [1] consists on a multilayer neural network, it has 4 inputs and 4 outputs, representing the I and Q components of the input signals (x_1 and x_2) and output signals (y_1 and y_2), respectively. In addition, this CO-NNPD has two hidden layers: each input is connected to all neurons of the first hidden layer in order to match the effect of the crosstalk terms. Then, the second hidden layer consists to eliminate the HPA nonlinearity. The weights of the CO-NNPD are determinate by copying the weights of a trained network (NN) which are adjusted using Levenberg-Marquardt (LM) algorithm. The structure of the neural network corresponding to this CO-NNPD is presented in figure 3.

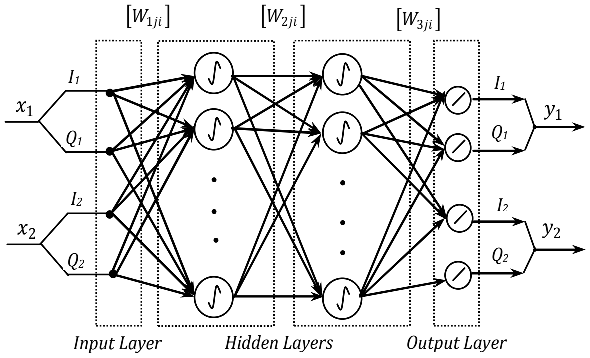

Figure 3- CO-NNPD based on a MLP neural network: the neural network has 3 layers, 4 input signals, 2 hidden layers while each layer has 9 neurons, 4 neurons in the output layer and 4 output signals.

It was demonstrated in [1] that this CO-NNPD is able to significantly compensate the HPA nonlinearity and nonlinear crosstalk simultaneously.

2.3 Memory crosstalk model

As we have said in section 2.1, the crosstalk is the result of interferences between the different paths in the same integrated circuit which's characterized by its small size. Then, this crosstalk can be linear or nonlinear, in the first case, it will be eliminated by the receiver equalizer. But in the second case the crosstalk is too harmful and it can't be corrected by the receiver. In [1] the problem of nonlinear crosstalk was being analyzed and they have proposed the CO-NNPD which allows eliminating both HPA nonlinearity and nonlinear memoryless crosstalk. Except that, in broadband systems memory crosstalk cannot be ignored and the conventional CO-NNPD is unable to keep its performance. In addition, it must be mentioned that all sources of crosstalk are added before the HPA (see figure 2).

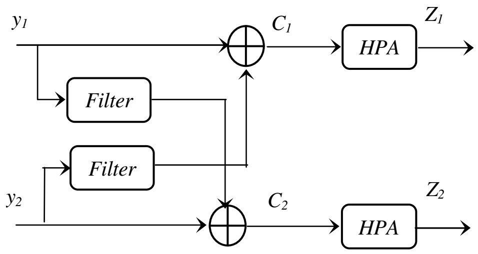

Figure 4- Memory crosstalk model

As shown in figure 4 the memory crosstalk is represented by a low-pass filter with four poles $h = \{0.3162\ \ 0.153\ \ 0.1\ \ 0.07\}$.

Then, the HPA output affected by the memory crosstalk can be modeled as:

$$z_1 = f_1(y_1 + F(y_2)) \tag{7}$$

$$z_2 = f_2(y_2 + F(y_1)) \tag{8}$$

where F represents the filter response. The AM/AM characteristic of the HPA affected by the memory crosstalk is giving by figure 5.

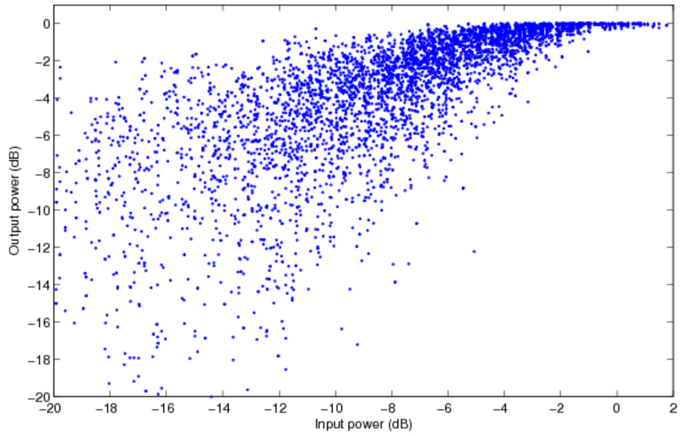

Figure 5- AM/AM characteristic

This memory crosstalk affects the performance of the conventional CO-NNPD. Thus, we require a new crossover predistortion with memory MCO-NNPD in order to correct these undesirable effects.

3. MEMORY CROSSOVER NEURAL NETWORK PREDISTORER (MCO-NNPD)

As explained in section 2.2, the conventional CO-NNPD [1] is unable to compensate memory crosstalk effects. The MCO-NNPD structure proposed, in this paper, consists on adding a tap delay line (memory effects) followed by the CO-NNPD (figure 6).

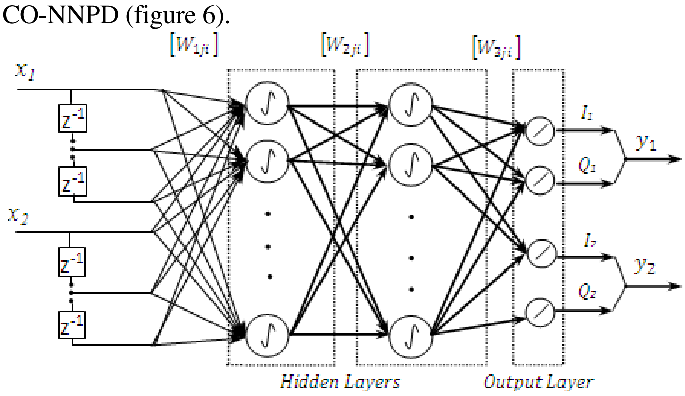

Figure 6- MCO-NNPD based on a MLP neural network

The Memory CO-NNPD has two inputs (x_1 *and* x_2) where each one is connected to a tap delay line of each branch. All tap delay line outputs are connected to all inputs of the first hidden layer of the nonlinear neural network to match the effects of crosstalk terms. Then, we have four outputs representing the *I* and *Q* component of the output signals (y_1 and y_2).

This fully connected structure aims at simultaneously mitigating memory crosstalk and HPA nonlinear effects.

It's well known that each neuron in the network is composed of a linear combiner and an activation function which gives the neuron output:

$$y_{lj} = f\left(\sum_{i=0}^{N_{l-1}} w_{l,j,i} x_{l-1,i} + b_{lj}\right) \quad (9)$$

where $w_{l,j,i}$ is the weight which connects the *i-th* neuron in layer $l-1$ to the *j-th* neuron in layer l, b_{lj} is the bias term and $x_{l-1,i}$ denotes the *i-th* component of the input signal to the neuron.

The training algorithm chosen is the Levenberg-Marquardt (LM) one. This algorithm was designed to approach second-order training speed without having to compute the Hessian matrix. Then, as demonstrated in [3], the LM gives more accurate results in terms of convergence speed and lower computation complexity than other algorithms proposed in literature. Under the assumption that the error function is some kind of squared sum, then the Hessian matrix can be approximated as:

$$H = J^T J \quad (10)$$

The gradient can be computed as

$$g = J^T e \quad (11)$$

where J is the Jacobian matrix that contains first derivatives of the network errors with respect to the weights and biases, the Jacobian matrix determination is computationally less expensive than the Hessian matrix, e is a vector of network errors. Then, the new weight vector x_{k+1} can be adjusted as:

$$x_{k+1} = x_k - [J^T J + \mu I]^{-1} J^T e \quad (12)$$

The parameter μ is a scalar controlling the behaviour of the algorithm. For $\mu = 0$, the algorithm follows Newton's method, using the approximate Hessian matrix. When μ is high, this becomes gradient descent with a small step size [3].

4. SIMULATION RESULTS

Simulation results concentrate on comparing between the conventional CO-NNPD and the MCO-NNPD in the presence of memory crosstalk. In this case, we have considered the same system as in [1], which's a base-band STBC MIMO OFDM two-antenna system with $N = 512$ subchannels employing BPSK using 10^7 randomly generated OFDM symbol blocks. We considered a Rayleigh fading channel, and we suppose that the channel is quasi stationary on two successive OFDM symbols. Also, we need a criterion to show how much power back-off is needed for optimum power efficiency, throughout the simulations we define the input back-off (IBO) as:

$$IBO = 10log_{10}\left(\frac{A_0^2}{P_{in}}\right) \quad (13)$$

where A_0 is the maximum output modulus and P_{in} is the average input power.

Figure 7 shows the performance of the conventional CO-NNPD on the presence of -10 dB memoryless crosstalk with different values of IBO. Then, according to these results we deduce that the conventional CO-NNPD gives good performance for a low IBO compared to the linear HPA and system with no predistortion.

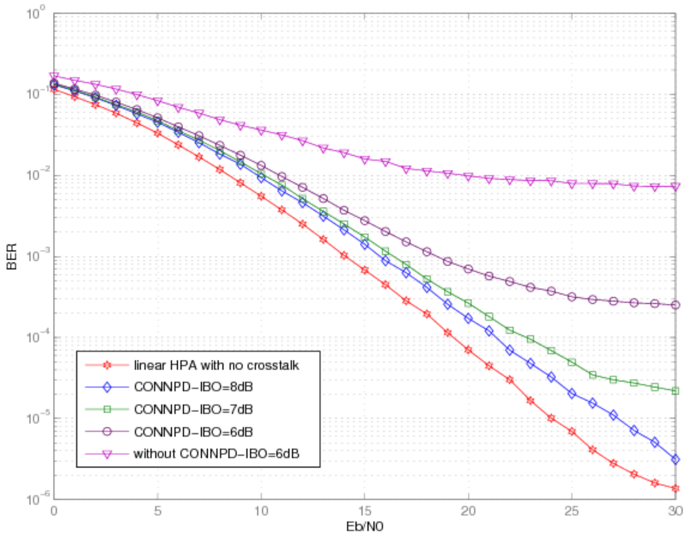

Figure 7- BER vs SNR for STBC MIMO OFDM system with CONNPD on the presence of -10 dB memoryless crosstalk with different values of IBO. BPSK modulation, 512 subcarriers and Rayleigh fading channel

As shown in figure 7, for a fixed IBO of 8dB, the CO-NNPD is very close to the performance of an ideal linear amplifier. By decreasing the IBO value (6 dB for example) the CO-NNPD looses its performance which's justified by the fact that the input signal modulus can be higher than $A_0$with a strong probability which gives an irreducible error at higher SNR. Then, we deduce that the CO-NNPD is competent to decrease the BER compared with a system with no predistortion.

Figure 8 shows the effects of memory crosstalk on the conventional CO-NNPD.

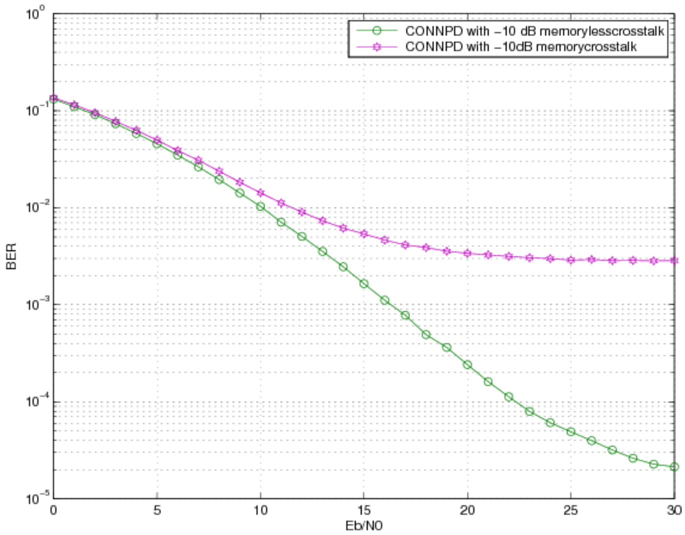

Figure 8- Effects of memory crosstalk on the conventional CO-NNPD for a crosstalk of -10 dB

For an IBO of 7 dB, we approve that the conventional CO-NNPD is unable to conserve its performance on the presence of memory crosstalk (see section 2.3) compared to the one with memoryless crosstalk. Then, we need to improve this conventional predistortion by adding a memory bloc in order to compensate memory crosstalk effects.

Then, many neuronal predistortion structures have been tested. MCO-NNPD (*TD5,x-y,4*) represents a neural network (see figure 6) with four outputs and two hidden layers using x and y neurons, respectively. The tap delay line length chosen is five memory cells.

Figure 9 shows the performance of several predistorters on the considered STBC MIMO OFDM system for an IBO of 7dB in presence of memory crosstalk.

We present the BER performance of the conventional CO-NNPD (case i), the MCO-NNPD (TD5,9-9,4) performance (case ii), MCO-NNPD (TD5,15-15,4) performance (case iii) and linear HPA (case iv).

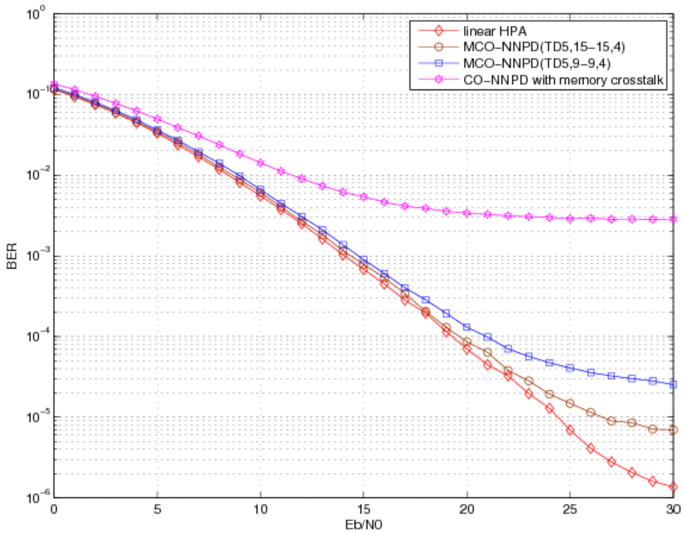

Figure 9-BER vs SNR for STBC MIMO OFDM system with predistorter in presence of memory crosstalk, BPSK modulation, 512 subcarriers, IBO of 7 dB and Rayleigh fading channel.

All neural predistorters with memory (MCO-NNPD) can reduce considerably the BER compared to the conventional CO-NNPD. The one that gets the best performance is the MCO-NNPD(TD5,15-15,4) which represents a multilayer neural network with tap delay line (memory). It has four outputs, two hidden layers using fifteen neurons per layer and activation functions of hidden layer are hyperbolic tangent while the ones of the output layer are linear.

5. CONCLUSION

In this paper, The CO-NNPD performance were revised and we approve that it gives good performance in presence of memoryless crosstalk. Then, in MIMO OFDM systems the memory crosstalk can't be ignored due to the broadband input signal. Thus, we have studied the effects of memory crosstalk on the performance of this conventional CO-NNPD and we have demonstrated that it's unable to properly conserve its performance.

Then, we have extended this conventional CO-NNPD by proposing a new predistortion structure which is capable to compensate simultaneously HPA nonlinearity and memory crosstalk. This new memory CO-NNPD (MCO-NNPD) consists on adding a tap delay line (memory) to a nonlinear neural network with two hidden layers and four outputs.

According to simulation results, we approve that, in presence of memory crosstalk, the proposed MCO-NNPD (TD5,15-15,4) decreased the used SNR to 12 dB at BER equal to 3×10^{-3}, which is an improvement of more than 18 dB compared to the conventional CO-NNPD.

REFERENCES

[1] R.Zayani, R.Bouallegue and D. Roviras "Crossover Neural Network Predistorter for the Compensation of Crosstalk and Nonlinearity in MIMO OFDM Systems", IEEE PIMRC2010, Istanbul, Turkey.

[2] S. A. Bassam,, M. Helaoui and F. M. Ghannouchi, "Crossover Digital Predistorter for the Compensation of Crosstalk and Nonlinearity in MIMO Transmitters", IEEE Transactions on Microwave Theory And Techniques, VOL. 57, NO. 5, MAY 2009.

[3] R.Zayani, R.Bouallegue and D. Roviras, "Adaptive Pre-distortions based on neural Networks associated with Levenberg-Marquardt algorithm for satellite Down links", EURASIP Journal on Wireless Communications and Networking. Volume 2008 (2008), Article ID 132/29 15 pages, doi:10.1155/2008/132729.

[4] S. M. Alamouti, "A simple transmit diversity technique for wireless communications," IEEE Journal on Selected Areas in Communications, vol. 16, no. 8, pp. 1451–1458, 1998.

[5] Ye. Li, H. Jack, R. Nelson, "MIMO OFDM for wireless communications: signal detection with enhanced channel estimation", IEEE Transactions on communications, vol.50, no.9, September 2002.

[6] Y. Palaskas, A. Ravi, S. Pellerano, B. R. Carlton, M. A. Elmala, R. Bishop, G. Banerjee, R. B. Nicholls, S. K. Ling, N. Dinur, S. S. Taylor, and K. Soumyanath, "A 5-GHz 108-Mb/s 2×2 MIMO transceiver RFIC with fully integrated 20.5-dBm P1 dB power amplifiers in 90-nm CMOS", IEEE J. Solid-State Circuits, vol. 41, no. 12, pp. 2746–2756, Dec. 2006.

[7] M. Kumar, Y. Tan, and J. K. O. Sin, "Excellent cross-talk isolation, high-Q inductors, and reduced self-heating in a TFSOI technology for system-on-a-chip applications", IEEE Trans. Electronic Devices, vol. 49, no. 4, pp. 584–589, Apr. 2002.

[8] C. S. Kim, P. Park, J.-W. Park, N. Hwang, and H. K. Yu, "Deep trench guard technology to suppress coupling between inductors in silicon RF ICs", in IEEE MTT-S Int. Microw. Symp. Dig., Jun. 2001, pp. 1873–1876.

[9] W.-C. Hua, P.-T. Lin, C.-P. Lin, C.-Y. Lin, H.-L. Chang, C. W. Liu, T.-Y. Yang, and G.-K. Ma, "Coupling effects of dual SiGe power amplifiers for 802.11n MIMO applications", in IEEE Radio Freq. Integr. Circuits Symp., Jun. 11–13, 2006, pp. 4–4.

[10] A. I. Sulyman and M. Ibnkahla, "Performance analysis of non-linearly amplified M-QAM signals in MIMO channels," Eur. Trans. Telecommun., vol. 19, no. 1, pp. 15–22, Jan. 2008.

[11] S. A. Bassam, M. Helaoui, S. Boumaiza, and F. M. Ghannouchi, "Experimental study of the effects of RF front-end imperfection on the MIMO transmitter performance", in IEEE MTT-S Int. Microw. Symp. Dig., Atlanta, GA, Jun. 2008, pp. 1187–1190.

[12] Jian Qi and Sonia Aissa, "On the Effect of Power Amplifier Nonlinearity on MIMO Transmit Diversity Systems", in Proc. IEEE ICC'09.

[13] A.A.M. Saleh, "Frequency-independent and frequency-dependent nonlinear models of TWT amplifiers", IEEE Trans. Commun. 29 (1981) 1715–1720.