Curtailed Hardware Impairments Compensation for Low-Cost MIMO Transmitters using Sample Selection Technique

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Summary

The quality of the transceiver system affects digital predistortion's accuracy and effectiveness. As a result, the primary need for the MIMO transceiver system is the avoidance of any imperfections or nonlinearities brought about by the feedback receiver. The software-defined radio system's mixer, local oscillator, low noise amplifier, and digital-to-analog and analog-to-digital converters may be to cause of the defects, which will reduce the accuracy of the system. To improve the linearization of RF power amplifiers, this work provides a compensation technique for the cancellation of MIMO transmitter-receiver imperfections. The sample selection technique is proposed to reduce the computational complexity of the system.

1. Introduction

The linearization field has extensively studied linear and quasi-linear imperfections such as DC offset, IQ imbalances and Crosstalk. Crossover Memory polynomials (COMP), Parallel Hammerstein (PH), crossover orthogonal memory polynomials (CO-OMP) and piecewise cubic spine-based memory polynomials are common modelling techniques [1]. Additionally, it is suggested that the neural network (NN) also reduces DC offset, IQ imbalance, and PA nonlinearity The literature mentioned above assumes a perfect feedback receiver. There is still room to improve linearization performance because real receivers have impairments of their own. Identification and elimination of all impairments, including weak nonlinearities of the receiver system, is the stated task.

In this article, we suggest a technique for compensating for SDR impairments. In this method, a low-cost MIMO SDR's in-band performance is enhanced (the communication signals are processed to counter interference and imperfections in the feedback receiver). The sample selection approach [2] is used to extracting main features of signal to keep the process under control, memory-light, and efficient. The sample selection employs the Singular Vector Decomposition (SVD) [3] with the proposed predistortion algorithm for computational stability. The suggested approach is simply reconfigurable and provides more accurate linearization and imperfection cancellation results. The benefit is in the greater precision and complete digital calibration with minimum computational complexity.

2. Proposed Compensation Technique

The block diagram of the experimental setup for MIMO SDR impairment compensation is shown in Fig. 1. The signal captured at the feedback receiver characterizes the receiver. After time-delay compensation, a set of training samples are used to develop the inverse model for receiver impairments. The SVD Method is the basis for the sample selection. The baseband signal data is compressed using SVD. Complex systems frequently generate data that is naturally arranged in large matrices, or more broadly, in arrays, across a wide range of disciplines. A matrix can be used to arrange a time series of data from an experiment or simulation, with each column including all the measurements at a given point in time. At each moment in time, multidimensional data can be reshaped or flattened into a high-dimensional column vector, yielding the columns of a large matrix. Surprisingly, the data generated by these systems is frequently of low rank, implying that the high-dimensional data may be explained by a limited number of prominent features. The SVD is a consistent and efficient method for extracting these patterns from data to reduce computational complexity. Conventionally COMP is the basic DPD model, as per Indirect learning architecture. Since, the MIMO SDR system has DC offset, LO leakage and crosstalk; equation 1 shows the proposed new model which is a simplified version of GMP for MIMO that caters for the compensation of all the impairments. K is the non-linearity order; M is the memory depth and L is the length of the signal extracted using the sample selection technique. a_{jm}, b_{jm}, c_{jm}, d_{jm} are the model coefficients of the receiver imperfection. By including components from other transmitters of MIMO, crosstalk can be modeled as well as other nonlinearities, impairments, and memory effects.

$$
\begin{aligned}
x_{1L}(n) = c_0 &+ \sum_{j=1}^{K}\sum_{m=0}^{M} a_{jm}^{(1)} y_{1L}(n-m)\left|y_{1L}(n-m)\right|^{j-1} + \sum_{j=1}^{K}\sum_{m=0}^{M} a_{jm}^{(2)} y_{1L}{}^{*}(n-m)\left|y_{1L}{}^{*}(n-m)\right|^{j-1} \\
&\sum_{j=1}^{K}\sum_{m=0}^{M} b_{jm}^{(1)} y_{2L}(n-m)\left|y_{2L}(n-m)\right|^{j-1} + \sum_{j=1}^{K}\sum_{m=0}^{M} b_{jm}^{(2)} y_{2L}{}^{*}(n-m)\left|y_{2L}{}^{*}(n-m)\right|^{j-1} \\
&\sum_{j=1}^{K}\sum_{m=0}^{M} c_{jm}^{(1)} y_{3L}(n-m)\left|y_{3L}(n-m)\right|^{j-1} + \sum_{j=1}^{K}\sum_{m=0}^{M} b_{jm}^{(2)} y_{3L}{}^{*}(n-m)\left|y_{3L}{}^{*}(n-m)\right|^{j-1} \\
&\sum_{j=1}^{K}\sum_{m=0}^{M} d_{jm}^{(1)} y_{4L}(n-m)\left|y_{4L}(n-m)\right|^{j-1} + \sum_{j=1}^{K}\sum_{m=0}^{M} d_{jm}^{(2)} y_{4L}{}^{*}(n-m)\left|y_{4L}{}^{*}(n-m)\right|^{j-1}
\end{aligned} \tag{1}
$$

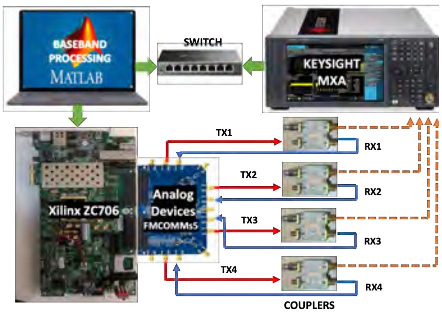

Figure 1. Experimental Setup

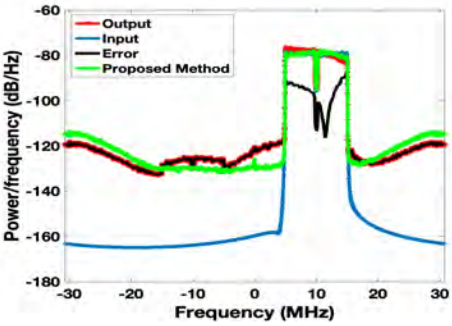

Figure 2. Power Spectral Density Plot for LO Leakage Correction

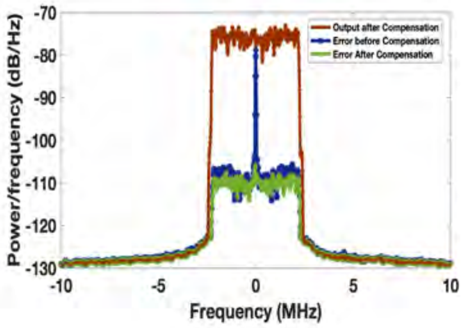

Figure 3. Power Spectral Density Plot for DC Offset Correction

3. Experimental Setup

To illustrate the problem statement, we used a low-cost SDR system, as illustrated in Fig. 1. For baseband processing, the experimental SDR configuration uses a Xilinx ZynqZC706 SoC and an FMCOMMs5 RF-Front end. A Long-Term Evolution (LTE) 10 MHz and 5MHz bandwidth baseband signals, uploaded to the Zynq-ZC706, is used to describe the hardware impairments. FMCOMMs5 is a 4 transmitter, and 4 receiver RF Card. It does digital to analog conversion and frequency up-conversion. With proper attenuation, the output RF signal is received on a vector signal analyzer (VSA) or at the SDRs receiver port. The SDR is linked to the laptop through a USB connection, and the VSA is connected via LAN to operate as a receiver to analyze transmitted signals. To further investigate MIMO SDR's linear imperfections, we have provided a digital intermediate frequency (IF) shift to the baseband signal. The experiments are performed at a 3.5 GHz frequency band with 5 MHz and 10MHz signal bandwidth.

4. Results and Discussion

The proposed Hardware impairments compensation technique applied to the experimental setup shown in Figure 1 demonstrates by Figure 2; LO leakage has been compensated. Due to the IF shift, the LO can be seen clearly in the PSD plot. Figure 3 shows the DC Offset in the error plot which is compensated substantially after correction. The in-band performance is measured in terms of normalized mean square error (NMSE). The adjacent channel power ratio (ACEPR) is used to assess out-of-band performance. Table I shows NMSE and ACPR improvement for the proposed method which depicts that both in-band and out-of-band errors are compensated to a great extent. The sample selection technique is applied for data extraction due to which the matrix size reduces which leads to low computational complexity. The condition number is a statistic to determine a matrix's numerical stability. It calculates the flow of error from the matrix to the Least Square solution. The lower the condition number, the better the numerical stability. Table I shows that the proposed method with sample selection technique prevails in numerical stability, computational stability, in-band performance, out-of-band performance, and impairments eradication. The extension of this work is to implement Digital Predistortion for the power amplifier nonlinearity in a MIMO system after impairments compensation.

TABLE I

PERFORMANCE COMPARISON IN TERMS OF NMSE AND ACPR

Method	System NMSE (dB)	Matrix Size (KB)	Condition Number	ACPR (dBc)
-	3.19	NA	NA	25.61
Delay Compensation	-25.45	NA	NA	44.55/41.86
Proposed Receiver Correction without Sample Selection	-36.01	1721	640	48.29/50.13
Proposed Receiver Correction without Sample Selection	-38.95	280	107	50.23/51.33

References

[1]. Shipra, G. C. Tripathi and M. Rawat, "Power Amplifier Linearization in the Presence of Crosstalk and Measurement Noise in MIMO System," in *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 69, no. 10, pp. 3988-3992, Oct. 2022.

[2]. J. Kral, T. Gotthans, R. Marsalek, M. Harvanek and M. Rupp, "On Feedback Sample Selection Methods Allowing Lightweight Digital Predistorter Adaptation," in *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 67, no. 6, pp. 1976-1988, June 2020.

[3]. V. Klema and A. Laub, "The singular value decomposition: Its computation and some applications," in *IEEE Transactions on Automatic Control*, vol. 25, no. 2, pp. 164-176, April 1980.