Digital pre-distortion architecture for RF power amplifier based on affine projection algorithm

Yeon Jung Seong, Choon Sik Cho and Jae W. Lee

The design is reported of a digital pre-distortion (DPD) architecture based on the affine projection algorithm (AP) for RF power amplifiers operating in 900 MHz band. The linearity of the RF power amplifier with an OFDM signal is significantly improved by employing the proposed DPD system, where the look-up table method is used with non-linear indexing. The proposed DPD with the AP algorithm is compared with that of the normalised least mean square algorithm, when applied to RF power amplifiers. Measurement shows improvement of the adjacent channel leakage ratio by 21 dB.

Introduction: Today's RF power amplifier is recognised as one of the most important components in wireless. Recently, digital signal processing technology has been evolved to improve the linearity of power amplifiers as applied to the digital pre-distortion (DPD) system. Various adaptive algorithms such as the least mean square (LMS) and recursive least square (RLS) algorithms have been successfully employed for realising the DPD system [1, 2]. The LMS based adaptive DPD system requires far less computational complexity than the RLS based DPD system. The number of operations required to make a complete iteration of the LMS algorithm is small. Thus, the memory capacity required to store data and programs is relatively decreased. However, since the convergence rate for the LMS algorithm is relatively slow, it is allowed to adapt the LMS algorithm slowly to a stationary environment of unknown statistics. On the contrary, the RLS algorithm increases the computational complexity because it calculates the inverse matrix with an iterative method. However, the RLS algorithm has a faster convergence rate than the LMS algorithm does. The complexity problem of the RLS algorithm makes it still difficult to embed it in hardware [2]. To overcome the drawbacks of LMS and RLS algorithms simultaneously, the affine projection (AP) algorithm is applied, leading to comparable convergence speed but far less computational complexity.

In our previous paper, we verified linearity improvement of the RF power amplifier by a look-up table (LUT) based DPD with the normalised LMS algorithm (NLMS) using *tanh* as a nonlinear indexing function [3]. The AP algorithm has been previously applied to DPD systems in the literature [4, 5]. We uniquely realise the AP algorithm based on the LUT method utilising the *tanh* function as a nonlinear indexing function. Additionally, measurement for this proposed system has been carried out for validating the performance improvement.

Proposed digital predistortion system: The proposed LUT-based DPD system for power amplifiers provides the pre-distortion functionality using the output signal along with estimation and indexing blocks as shown in Fig. 1 where the AP algorithm is used for the estimation block. The weight vector $\mathbf{w}_i$ is updated in the estimation block and the input signal is then pre-distorted by multiplying the weight vector in the pre-distortion block. The weight vector $\mathbf{w}_i$ of the AP adaptive algorithm is obtained as shown in (1):

$$\mathbf{w}_i = \mathbf{w}_{i-1} + \mu\mathbf{U}_i{*}(\mathbf{U}_i\mathbf{U}_i{*})^{-1}\mathbf{e}_i \qquad (1)$$

where $\mathbf{w}_{i-1}$ is a prior weight vector, $\mathbf{e}_i$ is an error vector, $\mathbf{U}_i$ is an N × M output data matrix from the power amplifier and μ is the step-size [6]. $\mathbf{w}_i$ and $\mathbf{U}_i$ produce the N × 1 desired response vector of the pre-distorter block as seen in (2):

$$\mathbf{d}_i = \mathbf{U}_i\mathbf{w}_i \qquad (2)$$

Simulation: We capitalise the OFDM multi-carrier modulation for generating the input signal. To realise the proposed DPD, we implement MATLAB environment where the Saleh model with non-memory effect is employed for representing the power amplifier with 0 dB input back-off [7]. For simulation, a symbol period of 4.4 Ksps and a chip period of 9.14 MHz are taken. The number of subcarriers is 955, and the signal has the bandwidth of 4.26 MHz. We compare the proposed DPD using the AP algorithm with that using the NLMS algorithm based on the LUT method. Fig. 2 shows the simulated power spectral density (PSD) of the output signal of RF power amplifiers using DPDs with AP and NLMS based on the LUT method. 'no DPD' means the PSD of the PA output without DPD, 'NLMS 8th' the PSD of the PA output with DPD using NLMS, and 'AP 8th' the PSD of the PA output with DPD using the AP algorithm, where '8th' means the iteration number of 8 arriving at convergence. When the iteration number reaches 8, the pre-distorted power amplifier using the AP algorithm improves the adjacent channel leakage ratio (ACLR) of 19 dB more than the pre-distorted power amplifier using the NLMS algorithm at the offset frequency of 5 MHz.

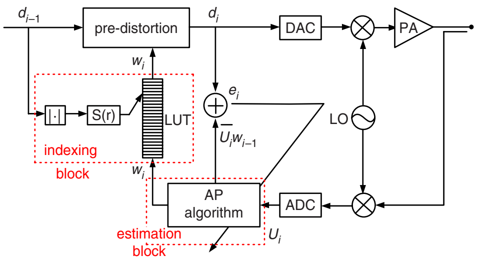

Fig. 1 *Block diagram of proposed DPD system*

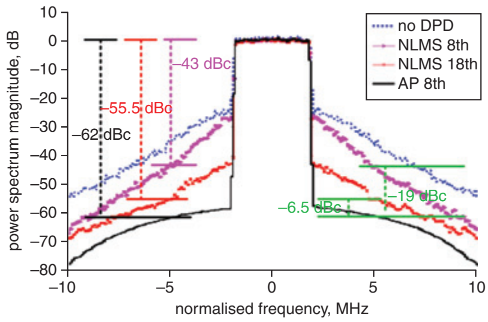

Fig. 2 *Comparison of simulated PA output spectrums using DPD with AP and NLMS algorithms*

As shown in Fig. 2, when the iteration reaches 8, the output spectrum of the pre-distorted power amplifier using the AP algorithm converges to an ACLR of −62 dBc at the offset frequency of 5 MHz. The pre-distorted power amplifier using the NLMS algorithm shows an ACLR of −43 dBc at the offset frequency of 5 MHz. As also shown in Fig. 2, when the iteration reaches 18, the output spectrum of the pre-distorted power amplifier using the NLMS algorithm converges to an ACLR of −55.5 dBc at the offset frequency of 5 MHz. Thus, it is illustrated that the AP algorithm provides better performance for linearisation than the NLMS algorithm and the DPD using the AP algorithm has a faster convergence rate than the DPD using the NLMS algorithm.

Measurement and results: Fig. 3 shows the measurement setup, where a commercial power amplifier module (ZFL-1000LN from Mini-Circuits) is used for measurement. It has a gain of 20 dB, P1 dB of 10 dBm, input VSWR of 1.5, and output VSWR of 2.0. To process this measurement setup, the MATLAB program written by the authors assists the pre-distortion, indexing and estimation blocks to work properly.

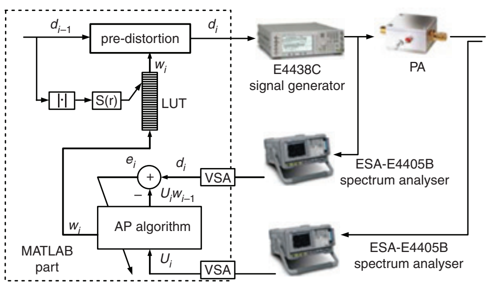

Fig. 3 *Measurement setup*

The input signal ($\mathbf{d}_{i-1}$) generated and pre-distorted at the very first stage is uploaded to the signal generator as shown in Fig. 3. We control the sample rate, carrier frequency, and signal amplitude in the signal generator. The input signal enters the power amplifier module and the output signal comes out of it. The output signal enters the spectrum analyser connected to the output port of the power amplifier. The measured output signal is collected by VSA software connected to the spectrum analyser. We also collect the measured input signal ($\mathbf{d}_i$) from the signal generator by VSA software. By using these measured input and output signals, the weight vector ($\mathbf{w}_i$) of the adaptive algorithm is updated based on (1) and the input signal of the power amplifier is finally pre-distorted by the updated weight vector. By repeated iterations, the output signal of the power amplifier is converged to some steady state value.

Fig. 4 shows the measured PSD of the output signal of pre-distorted power amplifiers using the AP and NLMS algorithms for comparison based on the LUT method. When the iteration reaches 14, the output spectrum of the pre-distorted power amplifier using the AP algorithm converges to an ACLR of −56 dBc at the offset frequency of 5 MHz. The pre-distorted power amplifier using the NLMS algorithm converges to an ACLR of −50.2 dBc at the iteration of 22 times. From the measurement result, it is verified that the DPD using the AP algorithm improves the ACLR of 5.8 dB more than that using the NLMS algorithm, and the DPD using the AP algorithm has better performance on convergence rate than that using the NLMS algorithm.

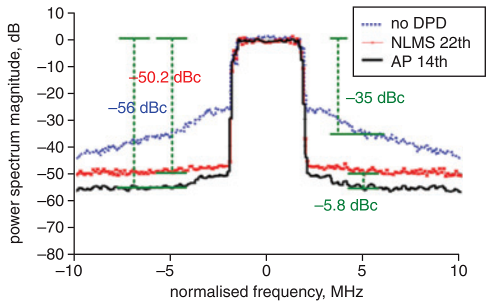

Fig. 4 *Comparison of measured PA output spectrums using DPD with AP and NLMS algorithms*

Conclusion: This Letter presents a proposed DPD power amplifier using the AP algorithm based on the LUT method. We verify that the proposed DPD power amplifier using the AP algorithm shows better linearity performance and more rapid convergence rate than that using the NLMS algorithm by simulation and measurement results.

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One or more of the Figures in this Letter are available in colour online.

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