IMPLEMENTATION OF PRE DISTORTION CIRCUIT USING RLS LEARNING ALGORITM BASED ON MEMORY POLYNOMIALS

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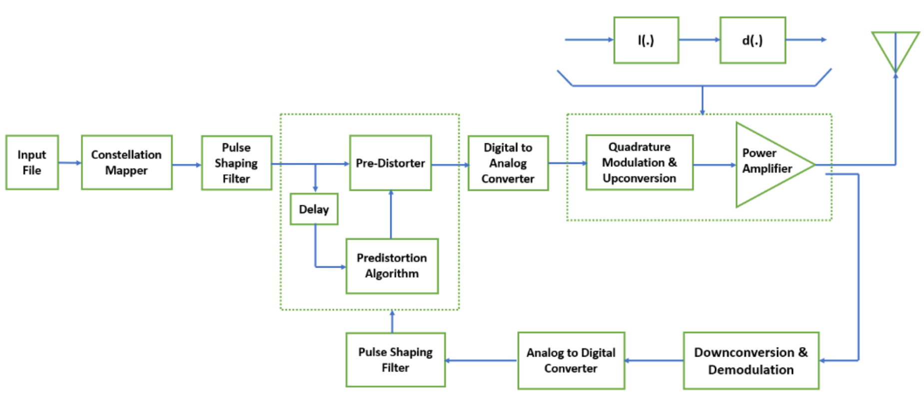
Abstract- The paper aims to implement a Digital Pre Distortion Circuit in Vivado HLS. The learning algorithm used to generate the inverse distortion in the circuit is the Recursive Least Square Algorithm. The code is separated into multiple modules, each performing an integral function in the Pre Distortion Circuit. A top function is designed to call each of the functions in a systematic manner. The amplifier used in the circuit is the Saleh Model. The distortions observed after amplification are fixed by the digital pre distortion module. The circuit essentially takes input from an input file, this input undergoes constellation mapping and pulse shaping, the values undergo digital to analog conversion -digital pre-distortion- up conversion-down conversion and digital to analog conversion, in the particular order. The outputs consist of final I and Q values, linear gain, gain in dB and output I and Q values. Hence it is observed that the input values undergo a degree of linear amplification, after digital pre distortion.

INTRODUCTION:

The project implements a pre distorter circuit in Vivado HLS. The circuit Ref. [4] uses multiple modules namely constellation mapper, pulse shaping filter Ref. [3] , a digital pre distortion learning algorithm/pre distorter block, analog to digital converter, digital to analog converter, up converter, down converter, quadrature modulator and pulse amplifier Ref [4]. Each of these blocks are functions in C++ which are called by the top function. This paper is structured into 4 sections. Section I deals with a brief overview of the circuit. Section II provides an elaborate explanation on the DPD module and the algorithms used. Section III discusses the results obtained and interpretations of Graphs. Section IV shall explain conclusions and other opportunities. The need of this implementation is to ensure linear gain in the circuit amplifier Ref [4]. The pre distorter block compensates for the distortions arising from the compressional behaviour of the power amplifier.

Section I.

Circuit Overview



Digital Predistortion Circuit

Fig 1. Block Diagram of the pre distortion circuit followed. The diagram is modelled after K. J. Muhonen, M. Kavehrad and R. Krishnamoorthy, "Look-up table techniques for adaptive digital predistortion: a development and comparison," in IEEE Transactions on Vehicular Technology, vol. 49, no. 5, pp. 1995-2002, Sept. 2000, doi: 10.1109/25.892601.

As per the block diagram Fig 1 the modules are created to perform the desired actions as given below: In the constellation mapper module, the inputs are mapped in regards to QPSK, both I and Q are mapped to their corresponding values (here 0 maps to -0.7071 and 1 maps to 0.7071). Ref. [6] The mapped signal values are fed to the PSF (Pulse shaping Filter). In the PSF, the inputs are filtered and trimmed, such that the input and their corresponding values are within the prerequisite range. This procedure utilizes the Raised Cosine Filter Ref. [3]. In the first epoch, no pre distortion takes place, instead input is directly passed on to the Power Amplifier (PA). From the second epoch onwards, pre distortion is applied in order to reduce error and provide ideal output as per the RLS model Ref. [1]. The signal undergoes conversion from discrete digital values to discrete analog values. The discrete analog form enables ease of Quadrature Amplitude Modulation of the input signal. The QAM (Quadrature Amplitude Modulator) module refers to the local oscillation generated sin and cos values stored in an LUT and applies these resultant generated values to input values Ref. [6]. The up converted modulated real signal values then serve as input to the power amplifier. The power amplifier is modelled after the Saleh Power Amplifier Model. Ref. [5] The amplified output is fed into a pulse shape filter via the feed-back loop alongside it being sent for transmission. The amplified(non-linear) output is first demodulated and down converted. The demodulated and down converted signal is passed to the DPD module. This module aims to reduce the error function by comparing previous output and input, all the while recursively calculating z(n) Ref. [1] . This adaptation method is modelled from the RLS (Recursive Least Square) method. Hence it can be observed that the pre distortion circuit reduces distortion and helps achieve a linear gain. As observed in Fig 1 the output of the power amplifier is a non-linear characteristic function represented by d(.). Ref. [4]. Whereas l(.) represents the section of the analog linear circuit of the transmitter. Ref. [4]. The implementation of the pre-distortion circuit is carried out in Vivado HLS. The project is organized into a top function, multiple sub functions which carry out the task as expected of the pre-mentioned modules and a testbench. The top function calls the other functions among which one is the predistortion algorithm. Further elaboration on the said algorithm can be found in section II.

Section II.

Digital Pre-Distortion Module

The Digital Pre-Distortion (DPD) module is the principal module of the Pre-Distortion Circuit. Its operation assists in achieving linear gain in the circuit. The DPD module consists of 3 primary blocks: - The Pre-Distortion block, the DPD-Algorithm block and a delay element. The algorithm used to compare and generate inverse distortion is RLS algorithm. Ref. [1].The weighted coefficients of the algorithm are obtained by calculation of the orthogonal polynomials. Ref. [1].

$$\varphi_m(z) = \sum_{m=1}^{M} b_m |z|^{m-1}\ z$$

Fig 2. Formula for calculation of Phi (Orthogonal polynomial coefficients) H. Huaming, T. Liang, Z. Chunsheng, Y. Bin, Y. Kai and B. Zhiyong, "An adaptive pre-distortion method based on orthogonal polynomials," Proceedings of the 31st Chinese Control Conference, Hefei, China, 2012, pp. 5573-5576

The calculated polynomial coefficients are then applied to find the weighted coefficients as follows

$$u(n) = u(n-1) + v(n)e^{*}(n)$$

where $\mathbf{e(n)}$ – **error signal** and $\boldsymbol{g}(\mathbf{n})$ – **time varying gain vector**

$$g(n) = \frac{\lambda^{-1} f(n-1)\, y^{T}(n)}{1 + \lambda^{-1} y^{*}(n) f(n-1) y^{T}(n)}$$

Where $y(n) = [\varphi_1(y(n)); \varphi_1(y(n-1)) \ldots \varphi_1(y(n-Q)); \ldots \varphi_K(y(n)); \varphi_k(y(n-1)) \ldots \varphi_k(y(n-Q))]$

$$f(n) = \lambda^{-1} f(n-1) - \lambda^{-1} v(n) y^{*}(n) f(n-1)$$

Fig 3. Formula for calculation of w (weighted DPD coefficients) H. Huaming, T. Liang, Z. Chunsheng, Y. Bin, Y. Kai and B. Zhiyong, "An adaptive pre-distortion method based on orthogonal polynomials," Proceedings of the 31st Chinese Control Conference, Hefei, China, 2012, pp. 5573- 5576.

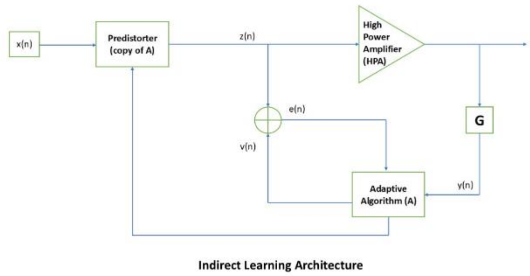


Fig 4. Indirect Learning architecture used error comparison and RLS implementation for digital pre distortion based off H. Huaming, T. Liang, Z. Chunsheng, Y. Bin, Y. Kai and B. Zhiyong, "An adaptive pre-distortion method based on orthogonal polynomials," Proceedings of the 31st Chinese Control Conference, Hefei, China, 2012, pp. 5573-5576.

As per Fig 4, it can be observed that z(n) is the output of the pre distortion applied. This is calculated computing the error function by subtracting the PA (Pulse Amplifier) output y(n) from the desired signal v(n) considered as i_ref and q_ref. The DPD module follows the Indirect Learning Architecture,

Here the polynomial coefficients are generated as per Fig 2. The error function and z(n) are calculated recursively. The generated wight coefficients are then called in the pre distorter where they are applied to the input signal via complex multiplication. The generation and application of these coefficients therefore follow the memory polynomial model. Hence the architecture combines both pre and post distortion to the input signals.

Results

An amplification gain was observed both in linear scale and in dB scale.

The outputs along with the inputs are presented in a table below.

It is observed that after x number of iterations the expected characteristics are achieved.

The learning rate however has been determined by trial and error and too high value may lead to overshoot whereas a too small value leads to non-convergence.

References:

[1] H. Huaming, T. Liang, Z. Chunsheng, Y. Bin, Y. Kai and B. Zhiyong, "An adaptive pre-distortion method based on orthogonal polynomials," Proceedings of the 31st Chinese Control Conference, Hefei, China, 2012, pp. 5573-5576. keywords: {Polynomials; Nonlinear distortion; OFDM; Power amplifiers; Mathematical model; Gaussian distribution; Orthogonal Polynomials; Pre-distortion; Recursive Least Square; Nonlinear Distortion},

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[4] K. J. Muhonen, M. Kavehrad and R. Krishnamoorthy, "Look-up table techniques for adaptive digital predistortion: a development and comparison," in IEEE Transactions on Vehicular Technology, vol. 49, no. 5, pp. 1995-2002, Sept. 2000, doi: 10.1109/25.892601. keywords: {Table lookup; Predistortion; Power amplifiers; Linearization techniques; Transmitters; Linear circuits; Distortion measurement; Performance analysis; Bit error rate; Indexing},

[5] K. J. Muhonen, M. Kavehrad and R. Krishnamoorthy, "Look-up table techniques for adaptive digital predistortion: a development and comparison," in IEEE Transactions on Vehicular Technology, vol. 49, no. 5, pp. 1995-2002, Sept. 2000, doi: 10.1109/25.892601.keywords: {Table lookup; Predistortion; Power amplifiers; Linearization techniques; Transmitters; Linear circuits; Distortion measurement; Performance analysis; Bit error rate; Indexing},

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