UNIVERSITI PUTRA MALAYSIA

OPTIMUM SPACING FOR A QUADRATICALLY INTERPOLATED LOOK-UP TABLE PREDISTORTER FOR CELLULAR POWER AMPLIFIERS

DINAAGAREN A/L SELVADURAI

OPTIMUM SPACING FOR A QUADRATICALLY INTERPOLATED LOOK-UP TABLE PREDISTORTER FOR CELLULAR POWER AMPLIFIERS

By

DINAAGAREN A/L SELVADURAI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

August 2017

DEDICATION

This thesis is dedicated to my beloved family and supervisor for their unconditional support, their encouragements and their prayers during hard times.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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August 2017

Chairman : Associate Professor Roslina Mohd Sidek, PhD
Faculty : Engineering

One of the major barriers in modern wireless communication system is the trade-off between the linearity and power efficiency of cellular power amplifier (PA). On the other hand, the non-constant envelope of spectrally competent modulated signals such as wideband code division multiple access (WCDMA) and long term evolution (LTE) interrelates with PA's non-linearity, causing in-band and out-band distortions. These distortions violate the out-of band emanation requirements which consequents reduce the power efficiency. Digital predistortion (DPD) is one of the most promising techniques to linearize a non-linear power amplifier (PA) in order to reduce the intermodulation distortion (IMD) and enhance the power efficiency. By far, lookup table (LUT) predistorters are the most commonly used approach to alleviate the effects of non-linear PA. This dissertation provides a theoretical analysis of an optimum spacing of a quadratically interpolated LUT predistorter which reduces the quantization error introduced by the LUT approximation supported by extensive simulation experiments. This technique provides better rejection of intermodulation distortion compared to conventional quadratic interpolated LUT, linear interpolated LUT and non-linear interpolated LUT predistorters respectively. Simulation results show that the proposed technique provides an improvement of 20% to 30% of error vector magnitude (EVM) and an improvement of 3 to 4 dBc of adjacent channel leakage ratio (ACLR) at a minimal memory usage for the wideband code division multiple access (WCDMA) and long term evolution system (LTE). This dissertation also proposes an adaptive Least Mean Square (LMS)-based predistorter that is optimized for error compensation introduced by LUT interpolation.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMISAHAN OPTIMUM BAGI PRA-PENGHEROT JADUAL LIHAT RUJUKAN PENENTU DALAMAN QUADRATIK BAGI PENGUAT KUASA SELULAR

Oleh

DINAAGAREN A/L SELVADURAI

Ogos 2017

Pengerusi : Profesor Madya Roslina Mohd Sidek, PhD
Fakulti : Kejuruteraan

Salah satu kekangan utama dalam sistem komunikasi tanpa wayar moden adalah keseimbangan antara kelinearan dan kuasa kecekapan penguat kuasa selular (PA). Ketidakseimbangan isyarat termodulat seperti kod jalur lebar pelbagai akses (WCDMA) dan evolusi jangka panjang (LTE) beinteraksi dengan penguatkuasa bukan linear yang menyebabkan herotan jalur-dalam dan jalur-luar. Herotan jalur-dalam dan jalur-luar in menyebabkan pengurangan dari segi kecekapan kuasa. Digital pra-pengherot (DPD) adalah salah satu teknik yang paling berpotensi untuk melinearkan penguatkuasa (PA) bukan linear untuk mengurangkan herotan intermodulasi (IMD) dan meningkatkan kecekapan kuasa. Setakat ini, pra-pengherotan LUT adalah pendekatan yang paling kerap digunakan untuk mengurangkan kesan penguat kuasa bukan linear. Disertasi ini menyediakan analisis teori bagi "Pemisahan Optimum Pra-herotan Penentu Quadratik LUT Penguat Kuasa Selular". Teknik ini meningkatkan prestasi dalam pengurangan herotan intermodulasi berbanding teknik konvensional penentu quadratik LUT, interpolasi linear LUT dan interpolasi tak linear LUT. Keputusan simulasi menunjukkan bahawa kaedah yang dicadangkan memberikan peningkatan 20% ke 30% dari segi magnitud vektor ralat (EVM) dan peningkatan 3 ke 4 dBc bagi nisbah kebocoran saluran bersebelahan (ACLR) pada penggunaan memori yang minimum untuk kod jalur lebar pelbagai akses (WCDMA) dan evolusi jangka panjang (LTE). Dissertasi ini juga mengesyorkan adaptasi predistorsi berdasarkan kuasa dua purata terkurang (LMS) yang dioptimumkan untuk memberikan pampasan ke atas kesalahan yang diperkenalkan oleh interpolasi LUT.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Borhanuddin Mohd.Ali, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
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Signature: ______________________________

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LIST OF ABBREVIATIONS

ACI	Adjacent Channel Interference
ACPR	Adjacent Channel Power Ratio
ACLR	Adjacent Channel Leakage Ratio
ADC	Analog to Digital Converter
AM/AM	Amplitude Modulation to Amplitude Modulation
AM/PM	Amplitude Modulation to Phase Modulation
BER	Bit Error Rate
CDMA	Code Division Multiple Access
CGC	Complex Gain Convergence
DAC	Digital to Analog Converter
DPD	DPD
DSP	Digital Signal Processing
EER	Envelope Elimination and Restoration
EVM	Error Vector Magnitude
FPGA	Field Programmable Gate Array
IBO	Input Power Back Off
IF	Intermediate Frequency
IMD	Inter Modulation Distortion
LINC	Linear amplification with Nonlinear Components
LTE	Long Term Evolution
LUT	Look Up Table
MP	Memory Polynomial
NMSE	Normalized Mean Square Error

PA	Power Amplifier
PAPR	Peak to Average Power Ratios
PH	Parallel Hammerstein
PSD	Power Spectral Density
PSF	Pulse Shaping Filter
PTNTB	Parallel Twin Non-linear Two-Box
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
VSA	Vector Signal Analyzer
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access

CHAPTER 1

INTRODUCTION

1.1 Power Amplifier

Power amplifiers (PA) are crucial devices in communication systems and they possess a non-linear characteristic. The non-linearity of the PA causes spectral regrowth, which leads to adjacent channel interference and intermodulation distortions (IMD) that violates the out-of-band emanation requirements [1]. Besides, this non-linearity also generates in-band distortions, which mortify the bit error rate (BER) performance. In order to reduce the non-linearity, the PA is backed off to be operated in a linear region of its operating curve. However, this backing off technique degrades the efficiency of the PA when it comes to the modern transmission formats such as Wideband Code Division Multiple Access (WCDMA) and Long Term Evolution (LTE). These modern transmission formats has a high peak average power ratio (PAPR) and wider bandwidth which requires the PA to be backed off far from saturation point, this in turn results in a very low efficiency of the PA whereby the power is lost and evaporates into heat [1]. In order to overcome this problem, the improvement of PA efficiency without conciliating its linearity is indispensable. Several linearization techniques has been proposed to date [1]-[8] to compromise PA's non-linearity and DPD is one of the most efficient techniques to linearize the PA. Theoretically, the cascading of the predistorter and the PA becomes linear and the original input of the PA is amplified by a constant gain. The existence of predistorter drives the PA to be operated beyond its saturation point while preserving a fine linearity performance, which provides better efficiency improvement significantly. Practically, the PA characteristics vary over time according to the temperature, component and other tolerances. Thus, the predistorter should also have the capacity to adapt the variation of the PA. Most of the DPD techniques in the current literature are on the PA without memory or memoryless non-linearity whereby the current output very much dependent on the current input which is a non-linear operation. The non-linearities of the PA is often characterized as AM/AM and AM/PM effects of the PA, whereby the amplitude and phase of the output signal of the PA are given as the function of the amplitude of its instantaneous input. As the modern transmission of RF signals are non-constant envelopes such as in WCDMA and LTE, PA starts to exhibit severe spectral regrowth and bit error degradation [1]. This spectral regrowth and bit error degradation has a significant consequences for high PA's that operates at wireless base station. Besides, memory effects turn out to be prominent due to this non-constant envelope radio signal whereby the current output of the PA are not only dependent to the current input but also on the precedent input values. These effects are caused by the attribution of the thermal constants of the active components in a biasing network that have frequency dependent behavior for PA's with memory. This main aim of this dissertation is to reduce the level of intermodulation noise resulting from predistorter approximation errors and implements more efficient complex-gain predistorter configuration, whereby the real and imaginary parts of the predistorter mapping function are quantized rather than the magnitude and the phase.

1.2 Problem Statement

The ideal performances of DPD are very much dependent to the robust predistorters that can absolutely compensate for the non-linearities that caused by the PA. However, the actual implementation of DPD in real world scenario is very much possible with fast convergence and superior rejection of intermodulation noise. Non-Interpolated LUT has a very complex computational complexity as the number of LUT samples that is required to model the inverse PA characteristics are very large, hence increases the convergence time [29]. To reduce computational complexity of LUT-based predistorter, two types of interpolation techniques, linear and quadratic interpolations have been used [30], [32]**.** Linear Interpolated LUT (Lin-LUT) has a faster convergence time and minimal memory usage but lacks in terms of accuracy on modeling the inverse PA characteristic that degrades the performance of the LUT-predistorter. Meanwhile, Quadratic Interpolated LUT (Quad-LUT) has a slower convergence time, bigger memory usage but better accuracy on modeling the inverse PA characteristics however it introduces a quadratic approximation error that degrades the performance of the LUT-predistorter.

1.3 Objective

The aim of this dissertation is to design a DPD system for better linearization performance of memoryless PA.

- To formulate a new adaptive-based predistorter which reduces the level of intermodulation (IMD) distortion that exist due to approximation errors.
- To optimize the LUT spacing of PA predistorter using the new companding function in order to improve the performance without degrading the linearity
- To evaluate the performance of parameters such as Error Vector Magnitude (EVM), Adjacent Channel Leakage Ratio (ACLR) and the size of LUT entries

1.4 Outline

The dissertation is organized as follows:

The literature review of modeling and predistortion of PA's is explained in detail. In Chapter 2, the memoryless PA is described in a form of AM/AM and AM/PM responses. To linearize those PA's, a memoryless predistorter considered to be adequate. For a memory PA, various modeling techniques are available to identify the non-linear behavior of the PA, which includes Volterra series, the Wiener model, the Hammerstein model, and the Wiener-Hammerstein model. Generally literature component focuses only on odd-order non-linear terms when it comes to PA's modeling and predistorters design in the baseband. In Chapter 3, the methodology of the proposed technique "Optimum Spacing of a Quadratically Interpolated LUT" are analyzed and discussed in detail. In Chapter 4, the simulations of the proposed method are presented in terms of adjacent channel leakage ratio (ACLR), error vector magnitude (EVM) distortion and intermodulation (IMD) distortion. In Chapter 5, the future work (practical implementation of the proposed technique) is discussed.

1.5 Scope of the research

In this dissertation, the performance improvement of optimum spacing of Quad-LUT [32] is theoretically derived and validated through simulations with memoryless PA (Saleh Model PA) as the research are mainly on iterative LUT techniques. The impact of the optimal spacing is evaluated in terms of error vector magnitude (EVM), adjacent channel leakage ratio (ACLR) and intermodulation (IMD) compared with other LUT techniques.

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