UNIVERSITI PUTRA MALAYSIA

LINEARIZATION OF POWER AMPLIFIERS WITH MEMORY EFFECTS USING MEMORY POLYNOMIAL AND LINEARLY INTERPOLATED LOOK-UP TABLE PREDISTORTER

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By

MOHAMMED AYAD SAADOON

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

June 2017

DEDICATION

This thesis is dedicated to:

My precious Father, my beloved Mother

My Family and my friends

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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June 2017

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Power Amplifier (PA) plays a vital rule in wireless communication systems, it is used to amplify signal before transmission. Frequently, the PA needs to operate near the saturation region in order to achieve high efficiency power amplification. This will generate nonlinearities in the communication system, these nonlinearities will cause out of band distortion which increases the Adjacent Channel Leakage Ratio (ACLR) and in band distortion which increases the Bit Error Rate (BER). Likewise, the utilization of high spectrally efficient modulation techniques in modern communication systems such as Wideband Code Division Multiple Access (WCDMA) and Orthogonal Frequency Division Multiplexing (OFDM) that have high Peak to Average Power Ratio (PAPR) will be very vulnerable to PA nonlinearities and as the signal bandwidth gets wider, the PA will exhibit memory effects which will cause dynamic distortions in the PA characteristics. Therefore, linearization of the PA is required to overcome these effects. Digital Pre-Distortion (DPD), among all linearization techniques, is a low-cost and efficient method to linearize PAs exhibiting memory effects. However, the recent DPD schemes require time to find the PA inverse characteristics to be predistorted; so, in order to quickly adapt with the dynamic changes in the PA characteristics, a DPD with fast convergence is highly desirable.

In this thesis, a new DPD technique is proposed for fast linearization of power amplifiers exhibiting memory effects. The proposed technique combines Memory Polynomial (MP) model and linearly interpolated Look-up Table (LUT) predistorters that are cascaded in series to form the proposed predistorter model. The LUT addresses the highly nonlinearity distortion of the PA, while the MP compensates mild nonlinearities and memory effects.

Moreover, by utilizing the linear interpolation technique to index the LUT and indirect learning architecture to extract the MP coefficients, faster convergence is achieved. The performance of the proposed technique is verified through simulation in Matlab program using a real class-AB power amplifier, driven by two WCDMA signals of 5-MHz and 15-MHz bandwidths. The simulation results show approximately 12 dB improvement in the ACLR reduction as compared to the MP model and the overall reduction was about 30 to 35 dB. Also, about 0.3% EVM performance was achieved and the PA dynamic memory effects were compensated using the proposed model. This work shows that a high linearity performance for the PA is achieved with the proposed technique. Thus, the distortion in the output signal was removed and therefore, an improved power efficiency is attained with reduction in the transmitter power consumption.

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

LINEAR PENGUAT KUASA DENGAN KESAN MEMORI MENGGUNAKAN POLINOMIAL MEMORI DAN LINEAR PENENTU JADUAL LOOK-UP PRAHEROTAN

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Pengganda Kuasa (PA) memainkan peranan yang penting dalam sistem komunikasi tanpa wayar, di mana ia digunakan untuk menguatkan isyarat sebelum penghantaran. Lazimnya, PA perlu beroperasi berhampiran kawasan padat untuk mencapai tahap tinggi kecekapan kuasa amplifikasi. Ini akan menjana ketidaklurusun dalam sistem komunikasi, ketidaklurusan ini akan menyebabkan berlakunya herotan di luar jalur yang mana meningkatkan Nisbah Bersebelahan Kebocoran Saluran (PPHT) dan meningkatkan Kadar Ralat Bit (BER) herotan di dalam jalur. Begitu juga dengan penggunaan teknik modulasi kecekapan tinggi dalam sistem komunikasi moden seperti Capaian Berbilang Bahagian Kod Jalur Lebar (WCDMA) dan Ortogon Multipleks Bahagian Kekerapan (OFDM) yang mempunyai Puncak Tinggi kepada Nisbah Kuasa Purata (PAPR) akan mudah terdedah kepada ketidaklurusan PA dan apabila jalur lebar isyarat menjadi lebih luas, PA akan menunjukkan kesan ke atas memori yang akan menyebabkan gangguan dinamik dalam ciri-ciri PA. Oleh itu, linear daripada PA diperlukan untuk mengatasi kesan-kesan tersebut. Pra-Herotan Digital (DPD) dianggap kaedah yang murah and berkesan dalam kalangan teknik linear untuk mencapai linear penguat kuasa dengan kesan ingatan. Namun begitu, skema DPD sekarang memerlukan masa untuk mencari ciri ciri PA terbalik untuk di pra-herotan; oleh itu, untuk memastikannya dapat disesuaikan dengan perubahan dinamik pada ciri-ciri PA, DPD dengan kecepatan tumpuan amat diperlukan.

Dalam tesis ini, satu teknik DPD baru dicadangkan untuk melinearkan kuasa amplifikasi dengan kesan ingatan. Teknik yang dicadangkan adalah berdasarkan model Polinomial Memori (MP) dan jadual lookup (LUT) yang tersisip secara linear yang disebarkan dalam siri untuk membentuk model pra-herotan yang dicadangkan. LUT menyebabkan herotan ketaklelurusan yang tinggi keatas PA, manakala MP memampas ketidaklurusan yang ringan dan kesan keatas ingatan. Tambahan lagi, dengan menggunakan teknik interpolasi linear dengan LUT dan pembelajaran tidak langsung architecture untuk mengesktrak coefficient MP, pengindeksan lebih baik dan prestasi kelinearan yang tinggi akan tercapai. Prestasi teknik yang dicadangkan disahkan melalui simulasi dalam perisian Matlab menggunakan amplifier kuasa kelas-AB sebenar, didorong oleh dua isyarat WCDMA 15-MHz dan 5 MHz jalur lebar. Keputusan simulasi menunjukkan kira-kira peningkatan sebanyak 12dB peningkatan dalam mengurangkan ACLR berbanding model MP and keseluruhan pengurangan ialah 30 ke 35 dB. Selain itu, kira-kira 0.3% prestasi EVM dicapai dan dinamik kesan keatas ingatan PA dipampas menggunakan model yang dicadangkan ini. Oleh itu, herotan dalam isyarat output telah dibuang dan kecekapan kuasa yang lebih baik tercapai dengan pengurangan dalam penggunaan kuasa pemancar.

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I certify that a Thesis Examination Committee has met on 1 June 2017 to conduct the final examination of Mohammed Ayad Saadoon on his thesis entitled "Linearization of Power Amplifiers with Memory Effects using Memory Polynomial and Linearly Interpolated Look-Up Table Predistorter" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

ACI	Adjacent Channel Interference
ACPR	Adjacent Channel Power Ratio
ACLR	Adjacent Channel Leakage Ratio
AM/AM	Amplitude Modulation to Amplitude Modulation
AM/PM	Amplitude Modulation to Phase Modulation
BER	Bit Error Rate
CDMA	Code Division Multiple Access
DPD	Digital Predistortion
DSP	Digital Signal Processing
FOM	Figure Of Merit
EVM	Error Vector Magnitude
GMP	Generalized Memory Polynomial
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
OFDM	Orthogonal Frequency Division Multiplexing
PA	Power Amplifier
PAE	Power Added Efficiency
PAPR	Peak to Average Power Ratios

PH	Parallel Hammerstein
PLUME	Parallel-Look-up table-Memory Polynomial-Enhanced Memory Polynomial
PSD	Power Spectral Density
PTNTB	Parallel Twin Non-linear Two-Box
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access

CHAPTER 1

INTRODUCTION

1.1 Background

Power Amplifier (PA) is an essential component in wireless communication systems, and it is used to amplify signals in order to be transmitted through out the antenna. However, the PA is considered as one of the most power consuming devices in a communication system (Nuyts, Reynaert, & Dehaene, 2014) .So, to achieve a high efficiency power amplification, the PA needs to be driven near to the saturation region. Accordingly, this will generate nonlinearities in the communication system which causes out of band distortion and in band distortion. The out of band distortion increases Adjacent Channel Interference (ACI) and out of band emissions, while the in band distortion reduces the Bit Error Rate (BER) of the system (Grebennikov, 2011).

Another important factor that effects the PA behavior in modern wireless communication systems is when using high spectrally efficient modulation techniques such as Wideband Code Division Multiple Access (WCDMA) and Orthogonal Frequency Division Multiplexing (OFDM) which have high Peak to Average Power Ratio (PAPR) due to the large fluctuations in their signal envelops and thus, they are more sensitive to the PA nonlinearities (Ghannouchi & Hammi, 2009), (Ghannouchi, Hammi, & Helaoui, 2015). Consequently, this will result in a very poor linearity performance. To solve this issue, the PA can be backed off to the linear region of its characteristics but this will reduce the efficiency and most of the input power will turn into heat. Or, it can be solved by using a linearization technique which is important to improve the efficiency without compromising the linearity (Gharaibeh, 2012).

Digital Predistortion (DPD) is considered one of the most cost effective and efficient linearization techniques, it can overcome the linearity problems of PAs by predistorting the original signal before being applied to the PA. The predistorter is implemented in the baseband as a nonlinear function which represents the inverse of the PA nonlinear characteristics. Thus, by cascading the PA with the digital predistorter, a linear system can be achieved (Farooq, Ahmed, & Al, 2013), (Bu, Li, & Chen, 2014), and (Abdelhafiz, Zerguine, Hammi, & Ghannouchi, 2014).

1.2 Problem Statement

The main focus of this research is on the power amplifier nonlinear behavior in modern wireless communications which causes spectral regrowth or out of band distortions that increases the ACI, and the in-band distortion that effects the BER performance of the system (Ghannouchi & Hammi, 2009). Therefore, to improve the efficiency and reduce the out of band emissions, PA nonlinearity must be reduced (Younes, Hammi, Kwan, & Ghannouchi, 2011).

Another important issue, that is being considered in this research, is the power amplifier memory effects, the main reason behind the PA exhibiting memory effects results from using signals with wide bandwidths such as in WCDMA and LTE signals, and the output of the PA starts to depend not only on the present input signal value but also on the past input values (Li, Zhu, Prikhodko, & Tkachenko, 2010) and (Kumagi, Funyu, & Maeda, 2012). The key impact of these memory effects is the dynamic changes in the AM/AM and AM/PM characteristics of the PA, which must be compensated to overcome this problem (Hammi, Kwan, & Ghannouchi, 2013).

Another issue to be addressed here is the time required to find the PA inverse characteristics to be predistorted, which makes the convergence of the DPD slow (Liang, Chen, & Chen, 2014). Therefore, choosing a proper adaptation process for the predistorter is desirable to save cost, time and reduce the complexity (Feng, Feuvrie, Descamps, & Wang, 2013).

Hence, various DPD techniques have been introduced to compensate for the PA non-linearities and memory effects. However, these techniques show limited linearization performance in addressing high PA nonlinearity, where the maximum reduction in Adjacent Channel Leakage Ratio (ACLR) is about 21 dB (Yousif et al., 2016), also it shows poor linearity performance and slow convergence speed in the presence of memory effects (Liang et al., 2014).

The DPD technique that is being introduced in this thesis has the ability to compensate for the high PA nonlinearities, where out of band distortion can be reduced up to 30 dB, and in band distortion can be corrected to 0.3%. Dynamic memory effects in the PA can also be compensated with fast convergence scheme.

1.3 Research Objectives

In this thesis, the main objectives are:

1) Propose a new DPD model combining Memory Polynomial (MP) and linearly interpolated Look-up Table (LUT) to enhance the linearity performance of power amplifiers exhibiting memory effects.
2) Evaluating and analyzing the effectiveness of the proposed DPD model in enhancing the PA linearity performance in terms of ACLR, Error Vector Magnitude (EVM), and PA dynamic changes in the AM/AM and AM/PM characteristics by using Matlab program.

1.4 Thesis Scope

In this work, the DPD technique among all linearization techniques was selected due to its high efficiency and low cost in linearizing PAs, which are the main cause of nonlinear distortions in the transmitter. Other parts which also cause distortion in the transmitter such as the digital to analog converter (DAC) and the oscillator were neglected since the predistorter is implemented in the baseband. Moreover, a class-AB power amplifier was selected for this study to validate the linearization capability of the proposed predistorter since it has more linearity compared to other classes using two WCDMA signals with 5 and 15 MHz Bandwidths both generated using Matlab. Figure 1.1 shows the research study module of the proposed technique in which the flow of the research is shown by shaded boxes.

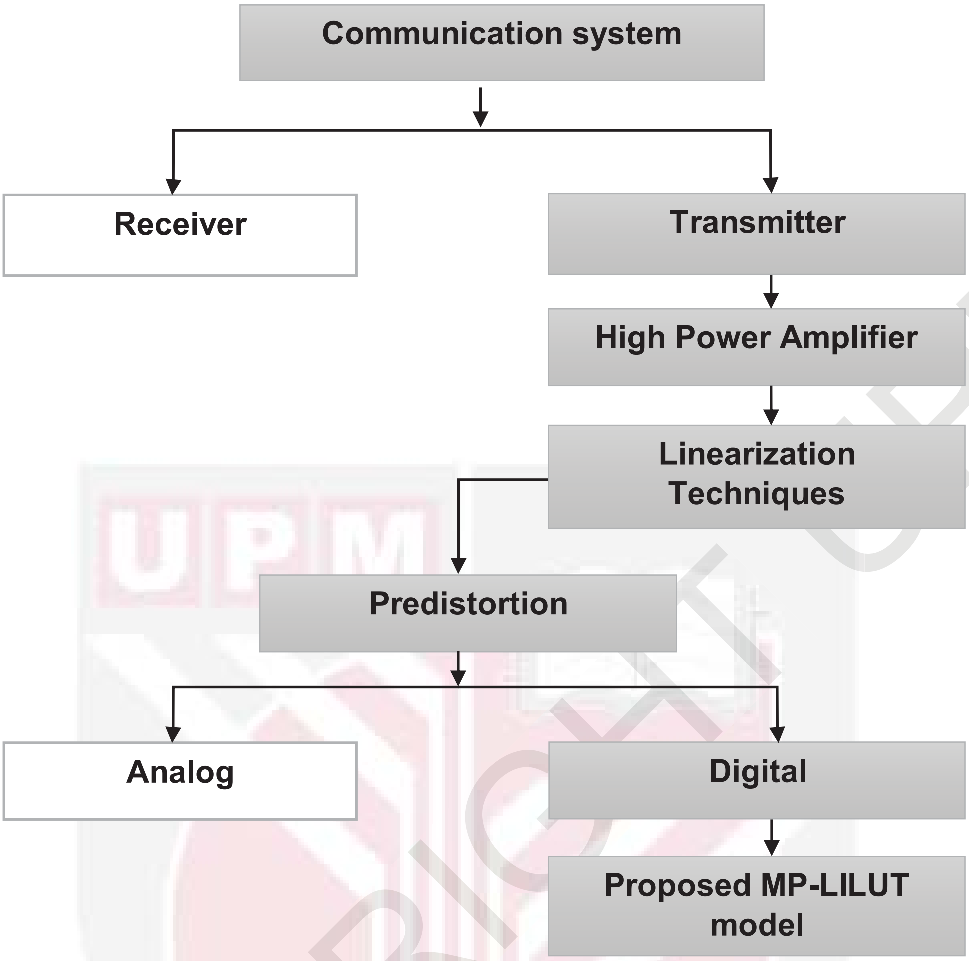

Figure 1.1 : Block diagram for study module of the proposed technique

1.5 Research Methodology

The methodology for conducting this research is going to be on two stages: stage one contains the proposed design methodology which will be explained in chapter 3. Stage two contains the simulation environment and will be explained in chapter 4. The two stages are summarized in the flowchart shown in Figure 1.2.

The design methodology is going to be on two steps: the first step is to design a new predistorter model using theoretical analysis which combines the memory polynomial and a linearly interpolated LUT. The second step is to identify the modeling procedure of the proposed model first for the MP and then for the linearly interpolated LUT. After that, the coefficients of the proposed predistorter are extracted using the proposed identification procedure.

Now, for the simulation stage, first, The MRF18060B class-AB power amplifier is simulated through Matlab in order to obtain the AM/AM and AM/PM as well as the PSD of the PA without the predistorter. Later, the proposed predistorter model is cascaded with the PA to evaluate the linearization capability of the proposed model, which is done by simulating the system in order to obtain the PSD at the PA output, the ACLR performance, The AM/AM as well as AM/PM characteristics and the EVM performance. Moreover, a comparison is done between the proposed model other DPD models to illustrate the linearization improvements when using the proposed model.

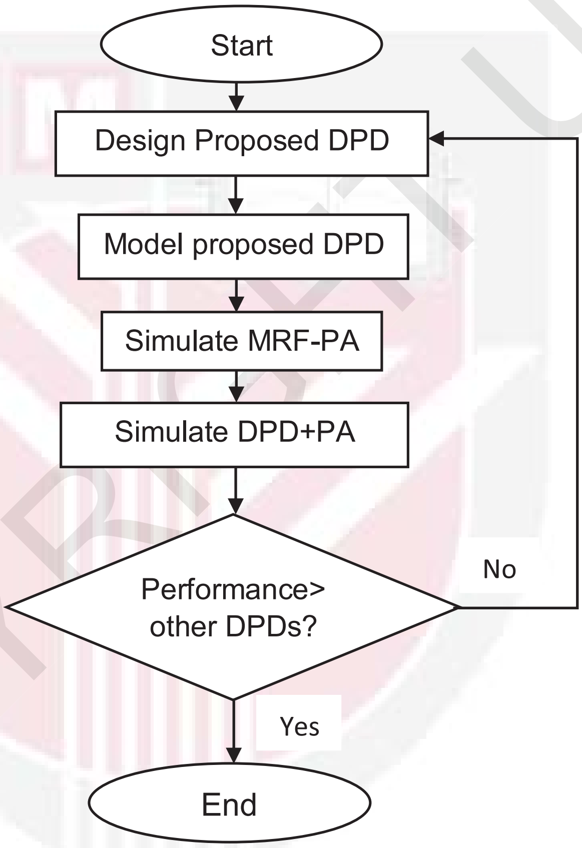

Figure 1.2 : Flowchart of the research methodology

1.6 Thesis Contribution

In this thesis, the contribution is to design a robust predistorter model combines the memory polynomial and a linearly interpolated LUT for linearizing PAs with high nonlinearity distortion in order to reduce the out of band emissions in the communication system which increases the ACLR. Additionally, the proposed model has the ability to compensate for PAs memory effects which cause dynamic changes in the PA characteristics when used with wideband signals utilized in modern communication system.

Latest DPD models show poor linearity performance in linearizing PAs with strong nonlinearity or limited memory effects compensation. So, it is important to design a predistorter model that can overcome these problems and achieve high linearization capability in order to save power and improve the efficiency.

1.7 Thesis Organization

In this thesis, the linearization of PAs using DPD technique is discussed and the organization of the thesis is as follows:

Chapter 1 describes the problem statement, objectives, research methodology and contribution of this work.

Chapter 2 presents the PA parameters and methods of amplification, as well as the trade-off between efficiency and linearity. Also, an overview of the most existing linearization techniques is presented including the latest digital predistortion methods with memory effects.

In chapter 3, a new predistorter design is proposed for linearizing PAs with memory effects. Also, the identification procedure for extracting the model coefficients of the proposed design is described.

In chapter 4, the proposed predistorter is verified through simulation environments using Matlab program. The MRF class AB power amplifier is utilized in simulation using two WCDMA input signals in order to evaluate the linearization capability of the proposed predistorter. The simulation results are based on linearity performance in terms of ACLR reduction, dynamic AM/AM and AM/PM characteristics of PAs, and EVM performance to show the effectiveness of the proposed model. Also, the simulation results are compared with other DPDs techniques.

In chapter 5, the conclusion of this research is shown as well as suggestions for future work.

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