UNIVERSITI PUTRA MALAYSIA

POWER AMPLIFIERS LINEARIZATION BASED ON COMPLEX GAIN MEMORY PREDISTORTION

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By

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DEDICATION

This thesis is dedicated to my lovely wife Somayeh who support me and help me to complete this thesis. She is everything in my life. I also dedicate this thesis to my parents and family who raised me and support me to continue my studying. Thank you for all the unconditional love, guidance, and support that you have always given me, helping me to succeed and the confidence that I am capable of doing anything I put my mind to.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of doctor of philosophy

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Power Amplifiers (PAs) are important components in communication systems and are nonlinear. The nonlinearity creates out of band distortion beyond the signal bandwidth, which interferes with adjacent channels. It also causes distortions within the signal bandwidth, which decreases the bit error rate at the receiver. Digital predistortion is one of the most cost effective ways among all linearization techniques to compensate for these nonlinearities.

In this thesis a novel technique for compensating memory effects and out of band distortions is proposed and is called Complex Gain Memory Predistortion (CGMP). The main advantage of the CGMP technique as compared to the memory polynomial technique is the ability of this technique to compensate all the memory effects inside the PA. Two structures of the CGMP technique are proposed. The CGMP technique is examined using two approaches, simulation and experiment. Power amplifiers are

modeled with memory polynomial technique to examine the effects of the memory that causes increment in Adjacent Channel Leakage Ratio (ACLR). To implement this method, the complex divider is required. This complex divider is then designed and implemented in Field Programmable Gate Array (FPGA) and combined with other parts to make the predistortion block. The CGMP is implemented in Virtex 5 FPGA and simulated using Xilinx blocks in Matlab. In the experimental approach the CGMP is examined with the actual power amplifier ZVE-8G from Mini Circuit. Finally the CGMP technique is compared with memory polynomial method and validated using a 1.9 GHz 60W LDMOS power amplifier that is designed in simulation and various signals such as 2-carrier WCDMA with 10 MHz carrier spacing and Mobile WiMAX with 10 MHz bandwidth. The simulations results showed between 25 to 30 dB improvement in ACLR and almost 5 dB improvement as compared to the memory polynomial method. The experimental results also show around 10 dB reduction in ACLR with applying QPSK signal with 1 MHz bandwidth. The improvement of 7 percent in Power Added Efficiency (PAE) is also achieved.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah doktor falsafah

PELELURUSAN PENGUAT KUASA BERDASARKAN PRAHEROTAN INGATAN GANDAAN KOMPLEKS

Oleh

POORIA VARAHRAM

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Penguat Kuasa (PAs) merupakan komponen yang penting dalam sistem komunikasi dan ia tidak linear. Ketaklinearan ini menghasilkan herotan di luar kelebaran jalur isyarat. Ia juga menyebabkan herotan di dalam lebar jalur isyarat yang mengakibatkan kesalahan kadar bit pada penerima. Praherotan digital merupakan kaedah yang paling efektif dikalangan teknik pelinearan yang ada untuk mengatasi masalah ketaklinearan ini.

Dalam tesis ini, satu teknik novel untuk mengatasi masalah ingatan memori dan herotan di luar kelebaran jalur menggantikan kesan-kesan sedemikian dicadangkan. Ia dinamakan praherotan ingatan gandaan kompleks (CGMP). Kelebihan teknik CGMP ini dibandingkan dengan teknik memori polynomial adalah kebolehannya untuk menandingi semua kesan memori yang terdapat dalam PA. Oleh itu, dua struktur CGMP adalah dicadangkan.

Teknik CGMP ini diuji menggunakan teknik simulasi dan eksperimen. Penguat kuasa dimodelkan bersama teknik memori polinomial untuk menguji kesan ingatan yang menyebabkan peningkatan kepada kadar kebocoran saluran bersebelahan (ACLR). Untuk melaksanakan kaedah ini, pembahagi kompleks diperlukan. Ia direkabentuk dan di-hasilkan menggunakan tatasusunan get boleh program (FPGA) dan digabungkan bersama komponen lain untuk menghasilkan blok praherotan. Teknik CGMP dilaksanakan pada Virtex 5 FPGA dan disimulasi menggunakan blok Xilinx yang terdapat pada Matlab. Eksperimen CGMP ini diuji menggunakan penguat kuasa sebenar ZVE-8G daripada Mini Circuit. Seterusnya, teknik ini dibandingkan dengan teknik memori polinomial dan diuji menggunakan 1.9 GHz 60W LDMOS penguat kuasa dan pelbagai saluran seperti pembawa 2 WCDMA dengan pembawa jarak 10 MHz dan Mobile WiMAX dengan jalur lebar 10 MHz lebar jalur. Hasil simulasi menunjukkan peningkatan 25-30 dB dalam ACLR dan peningkatan hampir 5 dB jika dibandingkan dengan teknik memori polinomial. Hasil kajian ini juga menunjukkan pengurangan hampir 10 dB dalam ACLR dengan menggunakan 1 MHz lebar jalur saluran QPSK. Peningkatan sebanyak 7 peratus untuk kuasa tambahan (PAE) turut tercapai.

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LIST OF ABBREVIATIONS

ACPR	Adjacent Channel Power Ratio
ACLR	Adjacent Channel Leakage Ratio
AM-AM	Amplitude Modulation to Amplitude Modulation
AM-PM	Amplitude Modulation to Phase Modulation
BB	Base Band
BER	Bit Error Rate
CDMA	Code Division Multiple Access
CGMP	Complex Gain Memory Predistortion
CORDIC	COordinate Rotation Digital Computer
DPD	Digital Predistortion
EDK	Embedded Development Kit
EVM	Error Vector Magnitude
FPGA	Filed Programmer Gate Array
GPIB	General Purpose Interface Bus
IBO	Input Power Back Off
IF	Intermediate Frequency
IMD	Inter Modulation Distortion
LINC	Linear amplification with Nonlinear Components
LTI	Linear Time Invariant
LUT	Look Up Table
MEMR	Memory Effect Modeling Ratio
OFDM	Orthogonal Frequency Division Multiplexing
OPBO	Output Power Back Off
PA	Power Amplifier

PAE	Power Added Efficiency
PAPR	Peak to Average Power Ratios
PSD	Power Spectral Density
QPSK	Quadrature Phase Shift Keying
RAM	Random Access Memory
RF	Radio Frequency
SCPI	Standard Command for Programmable Instruments
SER	Symbol Error Rate
VSA	Vector Signal Analyzer
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

CHAPTER 1

INTRODUCTION

1.1 Background

Power Amplifiers (PAs) are necessary components in communication systems and they are nonlinear in a certain operation region. The nonlinearity generates spectral regrowth, which leads to Adjacent Channel Interference (ACI) and violations of the out of band emission. To reduce the nonlinearity, the power amplifier can be backed off to operate within the linear portion of its operating curve. However, transmission formats such as Wideband Code Division Multiple Access (WCDMA) and Orthogonal Frequency Division Multiplexing (OFDM), have high Peak to Average Power Ratios (PAPR), it means the large fluctuations in their signal envelopes. This means that the power amplifier needs to be backed off far from its saturation point, which results in very low efficiencies, typically less than 10% (Wright, 2002), more than 90% of the dc power is lost and turns into heat. With increasing the number of the base stations and then the number of power amplifiers improvement in efficiency of the power amplifier reduce the cost of the system. To improve the power amplifier efficiency without compromising its linearity, power amplifier linearization is essential.

Another important fact is with the increasing the number of users, greater amount of bandwidth is required. One of the effective ways to increase the bandwidth is to use diversity techniques, which have been applied in most of the 3G (Third Generation) standards specifications (Vuolvei, 2003). But, with each additional antenna, an additional transceiver is required which can significantly increase the system cost.

Another method is the Digital Predistortion (DP) technique. The DP technique overcomes the linearity problem of PAs, enabling the use of non-linear PAs that are cheaper, so reducing the cost of the overall system (Kenington, 2000). Digital predistortion among all linearization techniques is the one that is low cost and with high efficiency and also high flexibility. By applying digital predistortion which is implemented in baseband of the communication systems the nonlinearity of the power amplifier is reduced and it allows the use of high power amplifier with high efficiency in the systems.

Another important fact in studying PA is the memory effects that are the main issue of this research. The focus here is on the short term memory effects which cause the characteristics of PA to vary with time. This effect is more important where the high bandwidth signals are applied. The memory effects cause an increase in Adjacent Channel Leakage Ratio (ACLR) and also Error Vector Magnitude (EVM) which will be explained in Chapter 2. The other factor which might cause problem to the performance of the predistortion is the effect of the noise. Noise here can be result of the analog part such as DAC, mixer and so on which in this thesis are not considered, because the predistortion here is implemented in base band. The other noise source also can be from power amplifier which will be under memory effects and with the feedback that is in the adaptive predistortion that noise will be cancelled. In this thesis the linearization techniques of the power amplifiers mainly class AB are investigated, then digital predistortion technique is chosen as it is the most cost effective and most efficient among all the linearization techniques. The class AB power amplifier is chosen because of the more linearity of it as compare to other classes. A new technique has been developed, simulated and experimentally

measured to validate this new technique. Finally the simulation and experimental results are compared together.

1.2 Problem Statement

The main problem of this research is the out of band distortions or spectral regrowth that cause increment in ACLR. The reason that this happens is because of the nonlinearity of the power amplifier that should be reduced to overcome the loss of energy and also the adjacent channel interference.

The other problem is the power amplifier memory effects that cause the characteristics of power amplifier to change especially dynamic AM-AM (Amplitude Modulation to Amplitude Modulation) and AM-PM (Amplitude Modulation to Phase Modulation) (Ding, 2004). These effects should be considered also in this thesis and the method for overcoming these problems are investigated. The main impact of the memory effects is dynamic AM-AM and AM-PM which is discussed in this thesis. The technique that is introduced as the contribution of this thesis overcomes the problem of the memory effects. The other main problem while implementing the new predistortion technique is in calculating the inverse of the input signal which should be done by a divider. This function is not available in FPGAs and needs to be constructed by other blocks. This will be addressed in this thesis. The new method for complex division is introduced which has many advantages from the other dividers (Ercegovac, 2003; Agrawal, 2006). There are some other problems that are not very critical but need to be investigated specially the effects of gain factor on the convergence rate of the predistortion and also the effects of the hardware resources. Here the concentration is on these problems and study them. There are some