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COMPARISION BETWEEN ADAPTIVE DIGITAL BASE BAND PREDISTORTION TECHNIQUE AND OTHER TECHNIQUES FOR POWER AMPLIFIER

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By

SOMAYEH MOHAMMADY

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

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DEDICATION

This thesis is dedicated to my wonderful parents, husband and family who have raised me to be the person I am today. You have been with me every step of the way, through good times and bad. Thank you for all the unconditional love, guidance, and support that you have always given me, helping me to succeed and instilling in me 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 Master of Science

COMPARISION BETWEEN ADAPTIVE DIGITAL BASE BAND PREDISTORTION TECHNIQUE AND OTHER TECHNIQUES FOR POWER AMPLIFIER

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SOMAYEH MOHAMMADY

April 2008

Mohd Nizar B. Hamidon, PhD

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The purpose of the Power Amplifier is to boost the radio signal to a sufficient power level for transmission through the air interface from the transmitter to the receiver. It involves solving several contradicting requirements, which are such as linearity and efficiency. Unfortunately, these requirements tend to be mutually exclusive, so that any improvement in linearity is usually achieved at the expense of efficiency, and vice versa.

A lot of studies and reviews on different classes of power amplifiers, their characteristics and distortion parameters have been done. This includes a study on different technique to improve the linearity of power amplifier, where each technique was reviewed to determine its suitability for the proposed applications.

In this research, the adaptive digital predistortion technique was been studied and compare with other techniques. The predistortion circuit inversely models the amplifier's gain and phase characteristics and, when combined with the amplifier, produces an overall system that is more linear and reduces the amplifier's distortion. In essence, "inverse distortion" is introduced into the input of the amplifier, thereby

canceling any non-linearity that the amplifier might have. This inverse distortion is the data stored in look-up table that is being multiplied into the input signal and then the customized input signal is ready to pass through power amplifier. By analyzing the output signal and the desired signal, the adaptation algorithm will update this data until finding the optimum values.

In this thesis, Saleh model was used as a model of power amplifier and been compared with the others results of the model for verification. The Saleh model was used for the adaptive digital predistortion studies to linearize the power amplifier. Simulation and results of this amplifier demonstrate between 15dB to 20dB improvements in output spectrum that means there is 60% to 65% improvement in linearization, maximum 20% improvement in Gain of Power Amplifier, 15% improvement in Power efficiency, and noticeable cancellation in constellations changes.

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

PERBANDIANGAN DIANTARA TEKNIK PENYESUAIAN DIGITAL PRA-HEROTAN JALUR TAPAK DENGAN TEKNIK-TEKNIK LAIN UNTUK PENGUATKUASA

Oleh

SOMAYEH MOHAMMADY

April 2008

Mohd Nizar B. Hamidon, PhD

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Tujuan Penguat Kuasa adalah untuk meningkatkan isyarat radio untuk satu tahap kemampuan yang mencukupi untuk pemancaran melalui antara muka udara dari pemancar kepada penerima. Ia melibatkan beberapa penyelesaian yang bercanggah dengan syarat-syarat yang telah ditetapkan seperti kelinearan dan kecekapan. Malangnya, syarat-syarat ini cenderung bersifat saling eksklusif, supaya sebarang penambahbaikan dalam kelinearan akan menyebabkan pengurangan kecekapan dan sebaliknya.

Banyak penyelidikan dan kajian semula kelas-kelas berbeza penguat-kuasa, pencirian dan parameter herotannya telah dibuat. Ini termasuk kajian teknik yang berlainan bagi meningkatkan kelinearan penguat-kuasa, di mana setiap teknik melakukan kajian semula bagi menentukan kesesuaian cadangan yang telah dibuat.

Dalam penyelidikan ini, teknik penyesuian digital pra-herotan telah digunakan dan perbandingan dibuat dengan teknik-teknik lain. Litar pra-herotan secara songsang memodelkan gandaan penguat-kuasa dan ciri-ciri fasa. Apabila digabungkan, ia akan

menghasilkan keseluruhan yang lebih linear dan serta mengurangkan herotan penguat-kuasa.

Dalam intipati, "herotan songsang" diperkenalkan ke dalam kemasukan penguat-kuasa yang akan memansuhkan ketidak kelinearan yang dimiliki oleh penguat-kuasa. Herotan songsangan ini adalah data yang menyimpan di dalam jadual carian yang sedang mengandakan isyarat kemasukan dan kemudian isyarat kemasukan yang telah diperbetulan bersedia melalaui penguat-kuasa. Dengan menganalisa isyarat keluaran dan isyarat yang diingini, algoritma penyesuaian akan mengemaskini data ini sehingga mendapatan nilai yang optima.

Dalam tesis ini, Model Saleh telah digunakan sebagai suatu model penguat-kuasa dan perbandingkan telah dibuat dengan keputusan lain bagi pengesahan. Model Saleh yang digunakan untuk kajian penyesuian digital pra-herotan untuk linearan penguat-kuasa. Simulasi dan hasil kajian penguat ini menunjukkan peningkata antara 15dB hingga 20dB dalam spektrum pengeluaran yang bermaksud 60% hingga 65% peningkatan kelinearan, 20% peningkatan dalam gandaan penguat-kuasa, 15% peningkatan kecekapan kuasa, dan pembatalan ketara dalam pertukaran parameter yang boleh dilihat.

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Finally, I would like to thank my Dear Parents, family and my Dear Husband that supported me to continue my studying and I hope could make them proud.

Somayeh Mohammady

Date:

I certify that an Examination Committee has met on to conduct the final examination of Somayeh Mohammady on her Master of Science thesis entitled "Adaptive Digital Base Band Predistortion for Power Amplifiers" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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

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Date: 13 November 2008

DECLARATION

I declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously and is not concurrently submitted for any other degree at UPM or at any other institution.

Somayeh Mohammady

Date: 13 November 2008

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LIST OF ABBREVIATIONS

ACIR:	Adjacent Channel Interference Ratio
ACPR:	Adjacent Channel Power Ratio
AM/AM :	Amplitude Modulation to Amplitude Modulation
AM/PM :	Amplitude Modulation to Phase Modulation
BER :	Bit Error Rate
BGA:	Ball Grid Array
CBW:	Correction Bandwidth
CDMA:	Code division multiple access
DSP:	Digital Signal Processing
E_b/N_o :	Signal to Noise Ratio
E_b/N_o	Measure of Signal to Noise ratio for a digital communication system
FF:	Feed Forward
FM:	Frequency Modulation
FSK:	Frequency-shift keying
GSM:	Global System for Mobile communications
HDL:	Hardware Description Language
IBO:	Input Back-Off
IFB:	Indirect Feed-Back
IMD:	Inter-Modulation Distortion
IP3 or TOI :	Third Order Intercept Point
LTI:	Linear Time Invariant
OIP3 and IIP3 :	Input power. Intermodulation products with odd orders such as the 3^{rd} and 5^{th} order
OPBO:	Output Power Back-Off

PA:	Power Amplifier
PEP:	Peak-Envelope Power
PD:	Predistortion
QAM :	Quadrature Amplitude Modulation
QPSK:	Quadrature phase shift keyed
RF:	Radio Frequency
SAT:	Saturation
SIMR:	Signal to Intermodulation Power Ratio
SSPA:	Solid State Power Amplifier
TWTA:	Traveling Wave Tube Amplifier

CHAPTER 1

INTRODUCTION

1.1 Power Amplifier

Power Amplifiers (PAs) are part of the transmitter front-end, and are used to amplify the signal being transmitted so that it can be received and decoded within a fixed geographical area.

The main performance parameters for the power amplifier are the level of output power that can be achieved, depending on the targeted application, linearity, and efficiency. There are two basic definitions for the efficiency of the power amplifier:

1- The drain efficiency is the ratio between the Radio Frequency (RF) output power to the dc consumed power.
2- The power added efficiency (PAE) which is the ratio between the difference of the RF output power and the RF input power to the dc consumed power.

The PAE is a more practical measure as it accounts for the power gain of the amplifier. As the power gain decreases, more stages will be required. Since each stage will consume a certain amount of power, the overall power consumption will increase, thus decreasing the overall efficiency [1].

The main characteristics of an amplifier are linearity, efficiency, output power, and signal gain. In this chapter linearity, as an important factor that effects on the power amplifier's efficiency has been discussed while the other characteristics have been discussed in next chapter.

1.2 Linearity

A system is considered linear if the output quantity is linearly proportional to the input quantity. The ratio between the output and the input is called the gain of the system, and in accordance with the definition presented above, it is not affected by the applied signal amplitude.

An amplifier is said to be linear if it preserves the details of the signal waveform, that is to say,

$$V_o(t) = A \cdot V_i(t) \qquad (1.1)$$

Where, V_i and V_o are the input and output signals respectively, and A is a constant representing the amplifier gain. But if the right side of equation 1.1 contains the higher power of V_i, such as V_i^2 and V_i^3, then the amplifier produces nonlinear distortion. There are many methods to increase linearity in amplifiers, in this way non-linearity or distortion is a very important factor of every power amplifier which is being explained in section 1.3.6.

1.3 Power Amplifier Linearity Measures:

The third-order Intercept Point (IP3), Adjacent Channel Power Ratio (ACPR), 1 dB compression point, Saturation point, Back-off and Distortion characteristics are various measures of linearity of power amplifiers.

1.3.1 Third Order Intercept Point (IP3):

In telecommunications, the Third Order Intercept Point (IP3) is the input signal level, when the fundamental tone intensity at the input coincides with the third harmonic level and it is a measure for systems with less non-linearity, for example receivers, linear amplifiers and mixers. The third harmonic curve is shown in Figure 1.1. The IP3 is based on the idea that the device nonlinearity can be modeled using a low order polynomial, derived by means of Taylor series expansion. The third-order intercept point relates nonlinear products caused by the 3rd order term in the nonlinearity to the linearly amplified signal.

The intercept point is a purely mathematical concept, and does not correspond to a practically occurring physical power level. In many cases, it lies beyond the damage threshold of the device. Third order inter-modulation products are of interest in characterizing amplifier performance because third order products are very close in frequency to the desired signal. The IP3 can be specified by either the input power at which the 3rd order products equal the desired signal or the output power at which the 3rd order products are equal to the desired signal. It is possible that this point is beyond the maximum output power of the amplifier. In this case the point is located at the intersection of input vs. output power gain curves as shown in Figure 1.1. If referenced from the output power this is called the OIP3 and IIP3 if referenced from the input power. Inter-modulation products with odd orders such as the 3rd and 5th order products are considered because they can create interference within the bandwidth of the desired signal.

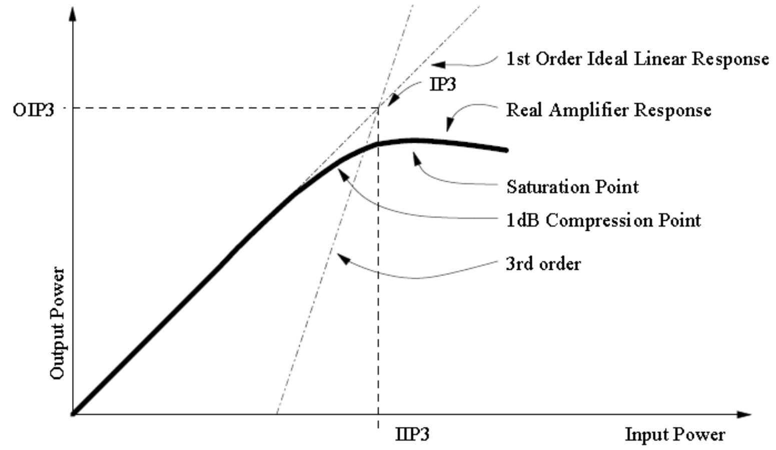

Figure 1.1: Inter-modulation Compression, and Saturation Points [2]

1.3.2 Adjacent Channel Power Ratio (ACPR):

Adjacent Channel Power Ratio (ACPR) is a measurement of the amount of interference, or power, in the adjacent frequency channel. ACPR is usually defined as the ratio of the average power in the adjacent frequency channel (or offset) to the average power in the transmitted frequency channel. In communication systems, the ACPR is commonly used to characterize the performance of power amplifiers. It is a critical measurement for CDMA (Code Division Multiple Access) transmitters and their components. It describes the amount of distortion generated due to nonlinearities in RF components. The Adjacent Channel Power Ratio or ACPR is the power contained within the upper and lower adjacent channels divided by the power in the main channel [3].

1.3.3 One dB Gain Compression Point:

An amplifier maintains a constant gain for low-level input signals. However, at higher input levels, the amplifier goes into saturation and its gain decreases. The 1 dB compression point shows the power level that causes the gain to drop by 1 dB from its small signal value.

Compression points might be specified for particular amounts of compression. Other commonly specified points are 3 dB and 0.1 dB below ideal gain. The amplitude modulation to amplitude modulation distortion (AM/AM) curve can be used to determine these points.

1.3.4 Saturation Point of Amplifier:

The saturation point is defined as the point where any increase in input power does not produce a corresponding increase in output power.

As it is shown in Figure 1.2, at saturation point the output is 'clipped' to a maximum voltage, and gain compression results until a maximum power is achieved. Saturation also causes phase modulation of the signal by the power amplifier.

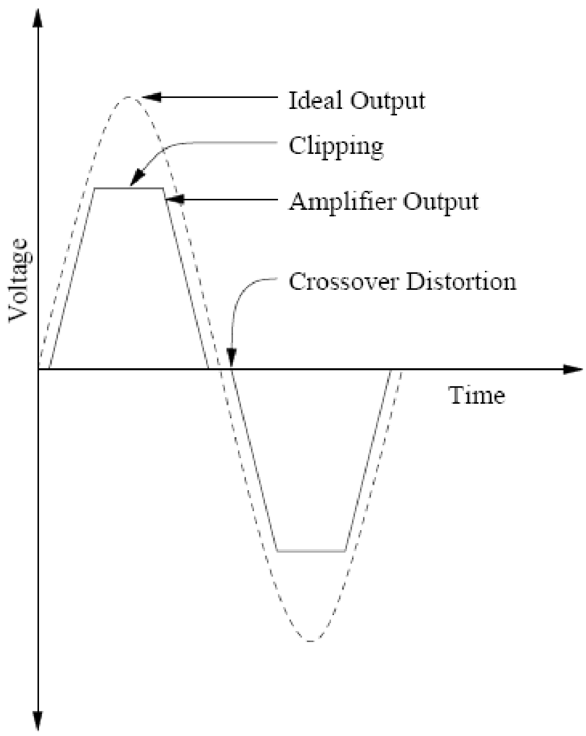

Figure 1.2: Example of Crossover Distortion and Clipping [2]

1.3.5 Back-off:

In order to know which region the PA is working, back-off is the value that relates the PA work point with the PA 1dB compression point which in this area when the input power of amplifier is increased, the output power approaches a maximum or saturation and the parameter of Input Back-Off (IBO) is defined by equation 1.2 to be the ratio of the input power required to achieve saturation to the average input power [2].

$$IBO = 10\log_{10}\frac{P_{in_{sat}}}{P_{in}} \quad (1.2)$$