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DIGITAL QUADRATURE COMPENSATOR SCHEME FOR ANALOG IMPERFECTIONS OF QUADRATURE MODULATOR IN WIRELESS COMMUNICATION SYSTEMS

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By

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

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DEDICATION

I dedicate this thesis to my mother-a guardian angel and true symbol of dedication- and my father -a true symbol of attempt and humanity- who are my most glorious treasure and to my little sister – a true symbol of kindness and love- whose tenderness reaches my soul

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Master of Science

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By

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June 2016

Chairman : Assoc. Prof. Aduwati Sali, PhD
Faculty : Engineering

Physical imperfections are unavoidable noise existed in electronic devices. These imperfections are usually caused due to the tolerance of electronic components. Like other electronics devices, wireless communication systems are not immune to such imperfections. These imperfections cause high energy consumption as well as degradation in efficiency. In cases of wireless transmission devices these imperfections are called “analog imperfections”. Analog imperfections in transmitters are caused by inaccuracy of a component called quadrature modulator (QM). QM is responsible for creating 90 degree phase differences between real and imaginary parts of the input signal, however, in real application QM cannot create the exact required phase difference. This will result in the phase and gain imbalances in the transmitter. To solve this issue, a compensator block is added to the transmission systems. The compensator is responsible for compensating the imperfections. In order for the compensator to do its job, imperfections should be estimated. There are two methods available for channel estimation: to use no extra physical feedback, or to use an extra physical feedback. Adaptive algorithms are applied in the design of active noise control systems. Adaptive algorithms used to estimate the QM’s imperfections, operate either in online or offline mode. Online mode describes the condition in which the adaptive algorithm is operating in parallel with the transmission process. Offline on the other hand, is a mode where adaptive algorithms cannot estimate the imperfections in parallel with the transmission.

This study proposes an efficient estimation and a pilot-free compensation scheme for frequency independent I/Q imbalances in the broadband direct up conversion transmitter (DCT). For such a transmitter, the main challenge is to have the online compensation while normal transmission is in order and no dedicated pilot signal is available. I/Q imperfections –or analog imperfections- have devastating effects on the efficiency of DCT. Two different imperfection exist in each branch of I and Q while there is only one feedback existing for the compensation. The issue of only one feedback availability degrades the accuracy of channel estimation causing the final estimated values to have higher level of error. It will also result in increasing the number of iteration required to estimate the channel values In the proposed schemes, the problem of channel estimation accuracy for an adaptive algorithm named “least mean square algorithm” (LMS) with

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one feedback is avoided via a two feedback scheme. The proposed scheme provides two identical error function for each branch of I and Q separately. Adding extra feedback increased the speed of convergence as well as accuracy compared to other studies. The normalize mean square error (NMSE) of adaptive algorithm in other studies was -68dB and -59dB whereas for the proposed two feedbacks method it is -79.8 dB. The NMSE error is calculated for 128 numbers of iterations as well as 3% gain and 3° phase imbalance in QM. Further the performance of the proposed scheme is compared with other studies in terms of accuracy.

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

SKIM PEMAMPAS KUADRATUR DIGITAL UNTUK KETIDAKSEMPURNAAN ANALOG MODULATOR KUADRATUR DALAM SISTEM KOMUNIKASI WAYARLES

Oleh

FARAZ TALEBPOUR

Jun 2016

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Ketidaksempurnaan fizikal adalah hingar yang tidak dapat dielakkan wujud dalam peranti elektronik. Ketidaksempurnaan biasanya disebabkan toleransi komponen elektronik. Seperti alat elektronik lain, sistem komunikasi wayarles tidak terasing daripada kecacatan tersebut. Ketidaksempurnaan ini menyebabkan penggunaan tenaga yang tinggi serta kemerosotan dalam kecekapan. Dalam kes-kes peranti penghantaran wayarles ketidaksempurnaan inilah yang dinamakan 'Ketidaksempurnaan Analog". Ketidaksempurnaan analog adalah disebabkan oleh ketidaktepatan komponen dipanggil kuadratur modulator (QM). QM bertanggungjawab mewujudkan 90 darjah fasa ijazah antara bahagian nyata dan bahangian khayalan isyarat kamasukan, bagaimanapun, dalam permohonan sebenar QM tidak boleh mencipta diperlukan perbezaan fasa yang tepat. Untuk menyelesaikan isu ini, satu blok pemampas ditambah kepada sistem penghantaran. Pemampas bertanggungjawab untuk membayar pampasan kepada ketidaksempurnaan. Dalam usaha untuk pemampas adalah tugas untuk pampasan ketidaksempurnaan perlu dianggarkan. Terdapat dua konfigurasi fizikal disediakan untuk saluran anggaran: untuk menggunakan sebarang maklum balas fizikal tambahan, atau menggunakan maklum balas fizikal tambahan. Algoritma penyesuaian digunakan dalam reka bentuk sistem kawalan hingar aktif. Algoritma penyesuaian digunakan untuk menganggarkan ketidaksempurnaan QM ini, beroperasi sama ada dalam mod dalam talian atau luar talian. Mod dalam talian menggambarkan keadaan di mana algoritma penyesuaian beroperasi secara selari dengan proses penghantaran. luar talian di sisi lain, adalah satu pendekatan di mana algoritma penyesuaian tidak boleh menganggarkan ketidaksempurnaan selari dengan penghantaran.

Kajian ini mencadangkan anggaran yang cekap dan satu skim perintis bebas pampasan bagi kekerapan bebas ketidakseimbangan I/Q dalam jalur lebar mengarahkan sehingga pemancar penukaran (DCT). Untuk apa-apa penghantar, cabaran utama adalah untuk mempunyai pampasan dalam talian dimana penghantaran normal adalah teratur dan tiada isyarat juruterbang yang berdedikasi boleh didapati. Ketidaksempurnaan I/Q –atau ketidaksempurnaan analog- mempunyai kesan yang amat buruk kepada kecekapan DCT. Dua ketidaksempurnaan yang berbeza wujud di setiap cawangan I dan Q manakala hanya

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ada satu maklum balas yang sedia ada bagi pampasan. Isu hanya satu ketersediaan maklum balas mempersendakan ketepatan saluran anggaran. Dalam skim yang dicadangkan itu, masalah ketepatan bagi algoritma penyesuaian dipanggil "Least Mean Square" (LMS) dengan satu maklum balas dielakkan melalui skim dua maklum balas. Skim yang dicadangkan menyediakan dua fungsi ralat sama untuk setiap cawangan I dan Q secara berasingan. Prestasi skim yang dicadangkan telah dibandingkan dengan kajian lain dari segi ketepatan.

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I certify that a Thesis Examination Committee has met on (date of viva voce) to conduct the final examination of Faraz Talebpour on his thesis entitled "A DIGITAL QUADRATURE COMPENSATOR SCHEME FOR ANALOG IMPERFECTIONS OF QUADRATURE MODULATOR IN WIRELESS COMMUNICATION SYSTEMS" 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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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 sciense. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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Signature ______________________________________

Name of Member Supervisory Committee : Professor Dr. Borhanuddin Bin Mohd Ali

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LIST OF ABBREVIATIONS

4G	Fourth Generation
ADC	Analog To Digital Convertor
BB	Base Band
BPF	Band Pass Filter
BW	Band Width
DAC	Digital To Analog Convertor
DCT	Direct up-Conversion Transmitter
ED	Envelop Detector
I	In phase
IF	Intermediate Frequency
IRR	Image Rejection Ratio
IRR	Image Rejection Ratio
LMS	Least Mean Square
LNA	Low Noise Amplifier
LO	Local Oscillator
LPF	Low Pass Filter
LTE	Long Term Evolution
MFI	Mirror Frequency Interference
NLMS	Normalized Least Mean Square
NMSE	Normalized Mean Square Error
PA	Power Amplifier
Q	Quadrature
QAM	Quadrature Amplitude Modulation
QDM	Quadrature Demodulator
QM	Quadrature Modulator
QMC	Quadrature Modulator Compensator
RLS	Recursive Least Square
SAW	Surface Acoustic Wave
SISO	Single Input Single Output
SYNC	Synchronized
T/R	Transmitter/Receiver
UNSYNC	Un-Synchronized

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CHAPTER 1

INTRODUCTION

1.1 Background and motivation

The 21st century is the age of communication and wireless. Much advancement has been made in this field and highly sophisticated devices have been designed, however, there is always room to improve the current technology. A big challenge in this area has always been imperfections caused by the failure of the physical components to meet the exact design requirements and keep a constant behavior under different conditions. These imperfections can cause a great deal of loss in terms of efficiency and accuracy[1]. It can also affect the output causing out-of-band and in-band distortions.

The quadrature modulator (QM) is an essential component in modern wireless communication systems. This unit is used in different manners and applications, including cellular phones and wireless data communication systems. In order to efficiently design and optimize a quadrature modulator, one must understand how it works in different applications, and how the physical impairments such as nonlinear distortion, DC offset, and gain/phase imbalances impact the system's performance [2]. Judicious design decisions can be made only after gaining such knowledge in order to achieve optimized circuit and system designs. Another concern in quadrature modulator design is finding a way to quickly and accurately characterize the quadrature modulator physical impairments. Mathematical behavioral modeling techniques are desired because they can simulate faster with less memory demands than circuit models. Recent literature addresses the modeling of the electrical characteristics of mixers at the circuit level and a considerable amount of work has been done for modeling the nonlinear characteristics of power amplifiers, but very little has been done on system-level nonlinear behavioral modeling of quadrature modulators. Because the nonlinear distortion in a quadrature modulator can cause significant performance degradation in terms of waveform quality, it is desirable to implement the nonlinear behavioral modeling techniques in power amplifiers to quadrature modulators for characterization of the nonlinear distortion and other physical imperfections. Although some studies propose methods of compensation for the physical imperfections, these methods mainly require high level of iterations and are affected by DC offset.

1.2 Problem statement

Due to the increasing demand of high data rate, more sophisticated modulation techniques such as 64 quadrature amplitude modulation (QAM), orthogonal frequency division multiplex (OFDM) and direct up-conversion transmitter (DCT) architecture have being used [3-6]. These modulation techniques are sensitive to small imbalances between the In-phase (I) and Quadrature (Q) paths of DCT. Their performance can be severely affected by these RF impairments called I/Q imbalances [7, 8], hence, I/Q imbalance has been identified as an important front-end effect for DCT systems. Moreover, degrading efficiency of available spectrum as result of these impairments causes Mirror-Frequency Interference (MFI) in receiver side [9].

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I/Q imperfections influences the Pre-distortion used for Power Amplifier (PA) linearization and it degrades the baseband (BB) pre-distortion [10]. I/Q imbalance consist of a frequency-independent part and frequency selective part. Frequency selective effects are mainly caused by unequal electronics components in I and Q branches such as analog low pass filters used for signal reconstruction and noise filtering. In normal conditions low pass filters (LPF) in the both hands of QM are required to have the same frequency response. In practical situations due to the differences in physical components used, each hand would have different frequency responses [11]. These effects are generally frequency selective between signal's band width (BW). Nowadays due to the demand of high data rate for communication systems, large BW is required and having large BW increases the effects of frequency dependent imperfections effects. Frequency independent effects are mainly caused by local oscillator instability and finite tolerance of capacitors and receivers value. With a good analog design, these effects can be limited just to 2% of gain imbalance and 2 degrees in phase imbalance but as it has been observed in other studies [8], even this low 2 % off frequency independent error increases about 30 dB increases out of band distortion compared with no I/Q imbalances. This imbalance parameters are very slow time variant hence they can be modeled as time invariant for simplicity.

For accurate modeling and compensation, in case of broadband systems such as fourth generation long term evolution (4G LTE) , both frequency independent and dependent have to be taken into account [8, 12-14]. To date, several techniques have been proposed to estimate and compensate the Quadrature Modulator (QM) imperfections in DCT [10, 12-18]. The method presented in [12] considers a digital post correction at the receiver side, compensation only in receiver side is not enough due to the fact that high proportion of I/Q impairments are created in transmitter side. These imperfections would have more devastated effects in receiver end since power amplifier distortions are also being added to the system. To estimate and compensate the I/Q imbalance, some methods have been proposed based on training signals [12, 13]. Training signals are not available in practical cases since it is not encourage-able to pause the process of data transmission to compensate the imperfections. The QM imperfections in receiver side are compensated using Least Mean Square (LMS) algorithm in [14, 15].

In [17], authors proposed a technique to jointly compensate the amplifier nonlinearity and QM errors based on minimization of the out-of-band power. However, the effects of QM imperfections have shown jointly with Power Amplifier's imperfections and are not being investigated separately. This is also achieved at the expense of complexity. In [1, 18] adaptive technique proposed which can jointly compensate the PA nonlinearity and QM with the help of an additional feedback. In summary, the previous studies have lack of improvement in the speed and accuracy in QM's imperfection estimation (known as phase and gain imbalances). Methods presented in previous studies require high number of iterations for the channel estimation process. Because of the existing DC offset error in QM, channel values could not be estimated perfectly using the adaptive algorithms and later resulted in compensation with low level of image rejection ratio (IRR). Using only one feedback to estimate the channel imperfections was the factor which caused lower level of channel estimation and lower IRR value after the compensation. Moreover, in some cases effects of the phase and gain imbalances in QM on IRR has not been shown separately.

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1.3 Objective

The main aim of this study is to propose a method capable of compensating the frequency independent imperfections in online mode. Proposed method should meet the requirement of high level of accuracy in compensation for broadband wireless systems such as 4G LTE.

Specific objectives of the current research can be mentioned as:

1. To design and simulate a new adaptive algorithm along and adaption scheme for estimating the QM imperfections with lower number of iterations and higher level of accuracy.
2. To design and evaluate an online compensation technique in which process of adaption and compensation would not interfere with transmission of signal.
3. To propose method of DC offset adaptation without a need in adaptive algorithm.

1.4 Thesis scope

In this work a novel compensation and estimation technique using one extra feedback is proposed to overcome the drawbacks of current compensation systems with one or no feedbacks. Sequentially, the proposed model is used to develop an adaptation scheme based on least mean square technique. The work is restricted to single input, single output (SISO) system. The feed forward strategy is used to estimate the imperfections created by QM. All the transfer function and components are assumed to be linear. The work involves designing, modeling and simulating the imperfections as well as the proposed compensative method. At adaptation stage, an alternative two feedbacks model is proposed and compared with currently existing one feedback scheme in terms of accuracy and speed of convergence. Figure 1.1, illustrates the research flow chart which is covered during this argumentation.

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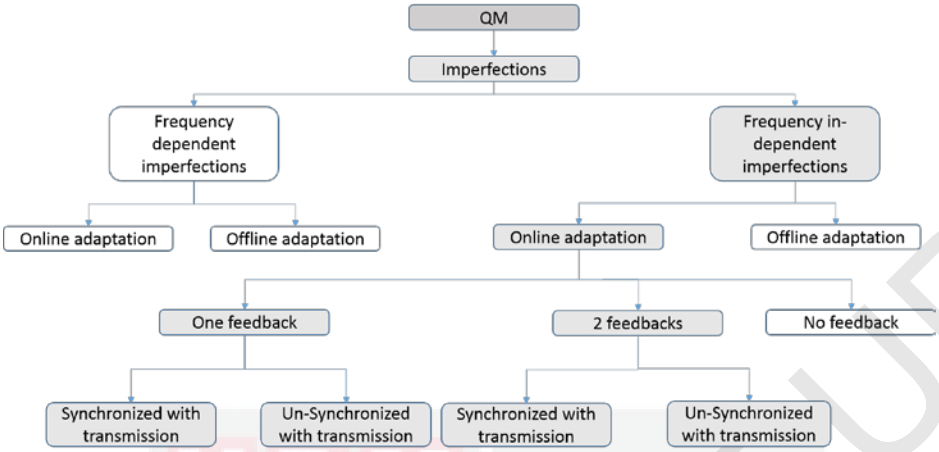

Figure 1.1 Research flow chart

1.5 Thesis organization

This thesis is organized in five chapters. First chapter presents the introduction, problems statement, objectives of this research, research aim and methodology of the study. Chapter 2 presents the literature survey related to the structure of transmitter unit in a sample wireless communication device as well as imperfections existed and different methods of compensating them. In chapter 3, QM's imperfections mathematical models are extended and the compensator model is derived. Three novel method of channel adaptation methods are proposed and mathematical equations required for modeling is derived from the original QM model. Least mean square algorithm's parameters are defined (LMS) to estimate the imperfections using the proposed methods. In chapter 4, the proposed methodology is evaluated by means of simulation and is compared to other studies. Finally, chapter 5 presents the conclusion of the work and possible future perspective of the work.

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