DESIGN OF DUAL-BAND MATCHING NETWORK FOR HIGHLY EFFICIENT POWER AMPLIFIER.

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electronics and Telecommunications)

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JANUARY 2019

DEDICATION

This project report is dedicated to my mom and dad for their guide and unwavering support for me throughout my entire life.

ACKNOWLEDGEMENT

In preparing this project report, I was in contact with many people including people from AWR NI as well as Modelithics. AWR NI have has provided me with constant support in order to get the know how to use their software. The transistor simulation models was provided by Modelithics and this has been a paramount help in my work.

I wish to express my sincere appreciation to my main thesis supervisor, Dr. Farid Zubir, for his great support, friendship and advice that has made me a better person. Without his continued encouragement and interest, this thesis would not have been the same as presented here not to mention the immensurable knowledge I have acquired from him. I also wish to express my thanks to Prof. Dr. Mohamad Kamal A. Rahim who has allowed me to attend his class and helped me understand the basics of RF and Microwave communications.

ABSTRACT

In the last decades wireless communications has been growing tremendously and given that the trend will most likely continue at a cumulative pace it is imperative that in the future, the transceivers designed need to operate at a near ideal energy efficiency on new frequency bands demanded by the 5G standard. Since transmitters are the corner stone of any wireless communication systems and that power amplifier (PA) is a high power consuming device within it. It is evident that the design of a highly efficient PA might tackle the significant portion of power loss within RF and microwave systems. The design of PA proposed in this work is aimed at dual band frequencies based on the LTE standards of LTE 42 and LTE 43 having range of 3.4 GHz to 3.6 GHz and 3.6 GHz to 3.8 GHz respectively. The design of a PA begins at characterizing the transistor employed then followed by conjugate matching of the input aimed at the gate. In the design for a highly efficient power amplifier, the design of the OMN plays a pivotal role. This is usually achieved by employing load pull techniques aimed at the drain to find the optimum impedance requirement at desired frequency. Then by employing band-pass filters aimed only to allow the two LTE bands to pass through will cause all the other harmonic frequencies suppression. Having an ideal efficiency of 100% and their simplistic design over other PA classes makes the Class E amplifier a viable choice. Although theoretically Class E amplifier have an ideal efficiency, we expect by achieving 60% to 80% efficiency will be an acceptable target since in practice the efficiency largely depends on the type of transistor being implemented in the PA system.

ABSTRAK

Sejak beberapa dekad yang lalu komunikasi tanpa wayar telah berkembang dengan pesat dan berkemungkinan besar akan berterusan pada kadar yang pantas. Ianya penting bahawa pada masa akan datang, gabungan pemancar dan penerima radio yang direka perlu beroperasi pada kecekapan tenaga yang ideal pada jalur frekuensi baru yang sesuai untuk piawai 5G. Oleh kerana pemancar adalah peralatan penting untuk semua sistem komunikasi tanpa wayar dan penguat kuasa adalah peranti yang memakan kuasa yang tinggi di dalamnya, maka ianya jelas bahawa reka bentuk penguat kuasa yang cekap akan dapat menangani sebahagian besar masalah kehilangan kuasa di dalam sistem frekuensi radio dan gelombang mikro. Reka bentuk penguat kuasa yang dicadangkan dalam keja ini menggunakan frekuensi dua jalur berdasarkan piawaian LTE iaitu LTE 42 dan LTE 43, masing-masing mempunyai 3.4 GHz hingga 3.6 GHz dan 3.6 GHz hingga 3.8 GHz. Reka bentuk penguat kuasa bermula dengan mencirikan jenis transistor yang ingin digunakan dan kemudian diikuti dengan pemadanan konjugasi masukkan data di ‘gate’. Dalam reka bentuk untuk penguat kuasa yang sangat cekap, reka bentuk OMN memainkan peranan penting. Ini biasanya dicapai dengan menggunakan teknik tarik beban di 'drain' bertujuan untuk mencari impedans optimum yang diperlukan pada frekuensi yang dikehendaki. Kemudian dengan menggunakan penapis band-pass yang bertujuan untuk membolehkan kedua-dua jalur LTE melepasi, menyebabkan semua frekuensi harmonik terhapus. Disebabkan mempunyai kecekapan yang ideal sebanyak 100% dan reka bentuk ringkas berbanding kelas penguat kuasa yang lain, penguat Kelas E menjadi pilihan yang terbaik. Walaupun secara teori penguat kuasa Kelas E mempunyai kecekapan yang ideal, kami menduga dengan mencapai kecekapan 60% hingga 80% ianya akan menjadi sasaran boleh terima kerana secara praktiknya kecekapan sangat bergantung kepada jenis transistor yang digunakan dalam sistem penguat kuasa.

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LIST OF ABBREVIATIONS

PAE	-	Power Added Efficiency
OMN	-	Output Matching network
CR	-	Cognitive Radio
PA	-	Power Amplifier
HEMT	-	High-Electron-Mobility Transistor

LIST OF SYMBOLS

λ	-	Wavelength of RF and microwave signal
α	-	Conduction angle

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The progress of telecommunication technology comes together with the market demands and government regulations which forces new development and application in wireless communication. With the coming of 5^{th} generation wireless systems, the bandwidth spectrum usage of the wireless communication system is going to be saturated. The reason for this is that size of internet users is accumulating everyday as the Internet can be accessed in cafes, airports and mostly anywhere therefore the communication system we have now is soon going to be congested.

To counter such congestions there is need of an efficient and cost effective and most importantly reliable transmission communication systems which is implementable on Cognitive Radio systems (1). The term Cognitive radio was initially instituted by J. Mitola in the year 1999 for effective spectrum usage. The Cognitive Radio gadgets uses the spectrum left out by primary radio hubs and it does so by changing and adjusting their parameters according to which spectrum is unused. This somewhat creates an openness of the frequency spectrum and reintroduces the already used spectrum for a bigger network (2). The main usage of CR is to make use of bandwidth spectrum that are unallocated as well as ameliorate spectrum utilization (3).

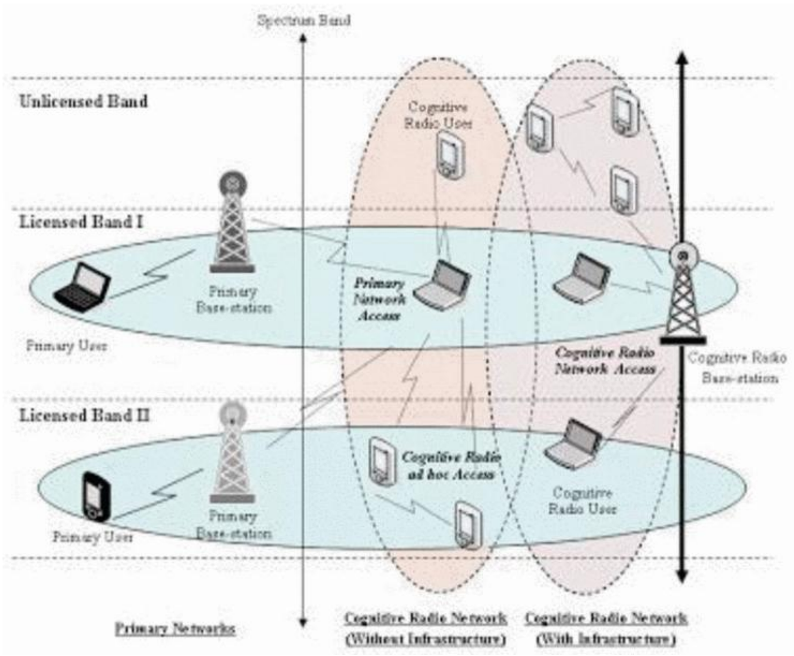

Figure 1. 1 Cognitive Radio Network maximizing spectrum utilization (3).

To enable roaming across multiple systems numerous mobiles are operating in multi-modes and this is done in the RF industry by designing multi-band components since the complexity and power consumption will be reduced. One of such components is Power Amplifiers (PA) (4). The definition of a PA can be said to be an amplifier which is designed in such a way that maximum power is transferred only for a selection of active devices such as transistors (5). It has been stated in (1) that the most troublesome design in a RF front-end system is the design of power amplifiers.

1.2 Problem Statement

Upcoming wireless communication systems demands extremely gigantean data rates as well as efficient spectrum utilization. This means that there should be non-constant envelope modulation schemes and RF and microwave waveform having great peak-to-average power ratios (PAPR). In avertedly, it can cause the power amplifier (PA) at the transmitter to function at large power back-off where previous design of power amplifiers i.e. conventional power amplifiers display unsatisfactory level of efficiency. Efficiency of the power amplifier is a paramount criteria to be considered in portable wireless devices since lower efficiency of the power amplifier easily drains the longevity of the battery functioning time. Considering applications where mobility is no considered such as base station applications, then the implementation of high efficiency PAs are an absolute must for reducing power consumption and heat sinking costs (6). Up till now even with the massive technological advancement, the design of power amplifiers (PAs) in transmitters are a serious "headache" to RF and Microwave engineers. It is widely known that linear PA is usually termed as Class A or AB design with the embedded benefits of low modulation distortion and high dynamic range. The drawback here is that linear PA needs power back-off to avert the nonlinearities and its ill-effects and this usually happens with a trade-off of high efficiency. Even nowadays The efficiency for the whole transmitter is still constraint to approximately only one device which is the linear PAs, even for the case of dual-mode or dual-band transmitters (4). By now the majority of microwave systems employed makes use of conventional PA systems, hence due to low efficiency of these systems, most input power is wasted and since power cannot be destroyed the wasted energy happens in terms of heat dissipation.

This can be resolved by employing matching networks designed for Class E amplifier as it is a PA that has a theoretical efficiency of 100% however it is to be expected that here the trade-off is non linearity. The significant increase in wireless communication has caused a near saturation of the frequency bands being used by the mobile sector. Also when dealing with Class E amplifiers, harmonics are always present as it is a nonlinear system and this affect the performance of the device whether it is smoothness of the waveform or power gain. Thus a new type of Class E PA systems need to be implemented that can work on multiple frequencies i.e. on different LTE bands (in this case LTE band 42 and 43) as well as efficiently tackling the problem of harmonics.

1.3 Objectives

- Design of a Class E power amplifier for high efficiency performances with implementation of load-pull techniques.
- To understand the practicality of employing harmonic filters beyond the 2^{nd} harmonic vis- à-vis efficiency and gain.
- To analyze the effect of implementing Sokal's equation and his design at the OMN for Class E operation versus load pull techniques employed within this work.
- To design a highly efficient Class E power amplifier aimed at dual-band operation based on the LTE band 42 and 43.

1.4 Scope of Project

Class E amplifier will be implemented in this project due to their ideal efficiency of 100% and their simplicity of design. The frequency band is based on LTE 42 and LTE 43 having frequency range of 3.4-3.6 GHz and 3.6-3.8 GHz respectively. The two techniques that are being studied are by using load-pull configuration and the use of Sokal's equation. Initially at the beginning of the design of the Class E amplifier, Sokal implemented his techniques on a BJT transistor at 3.9 MHz. It is important to test the validity of his technique on a newer version of transistor capable of operating at much higher frequency and to analyze whether it can be implemented for multiple band of frequencies. Another crucial aspect to consider is to terminate the harmonics, and so here a band-pass filter will be employed as opposed to the current trend of using open circuiting. Power added efficiency (PAE) versus gain will be observed, analyzed and discussed in this project with respect to the harmonics. The software used for simulation is National Instrument NI AWR while the models for the transistor is obtained from Modelithics.

1.5 Research Contributions

The design of PA in this project can be implemented for a Class E amplifier for dual band operation which can be used for applications where tackling power efficiency is of great importance on all the while capable of operating on more than a single band. This work also contribute to the study of the tradeoff between harmonic terminations versus efficiency and gain which has been a headache for RF designers. The simulations done will be benchmarked against previous researches to show its improvements and feasibility as a highly efficient power amplifier and provide a better understanding of matching networks employed for Class E operations.

1.6 Design Specification

Table 1. 1 Design Specification for a Class E circuit.

Parameters	**Class E Circuit Specifications**
Operating Frequency Range	LTE 42 and LTE 43
Transistor Model	NPTB00004 - GaN
Target PAE	>65%
Loaded Quality Factor Q_L for 50% duty cycle (based on Sokal's equation)	10
Input Power	22 dBm
Target Gain	Greater than 7 dB

1.7 Chapter Summary

This chapter explain the importance of power amplifier having a high efficiency which has been a headache to RF designers for a long time. This will be greatly useful when implementing 5G as wireless communication is booming especially in the mobile sector hence the high demand of energy efficient devices. This will lead to a major bottleneck as even 5G technology is slowly creeping its way in our society the higher the frequency we are using but the applicability of switching the transistors is the major concern hence there should be an effective way to implement amplifiers where the transistors can undergo switching mode efficiently thereby the design of PA comes in the picture. The objective and scopes mentioned defines this project work into creating a Class E PA by using matching techniques aimed at load pull contours and Sokal's methods for a high efficiency PA at high frequency operation.

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