

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

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DEDICATION

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

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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 pepadanan 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.

TABLE OF CONTENTS

	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF ABBREVIATIONS	xvi
	LIST OF SYMBOLS	xvii
	LIST OF APPENDICES	xviii
CHAPTER 1	INTRODUCTION	1
1.1	Introduction	1
1.2	Problem Statement	2
1.3	Objectives	4
1.4	Scope of Project	4
1.5	Research Contributions	5
1.6	Design Specification	5
1.7	Chapter Summary	5
CHAPTER 2	LITERATURE REVIEW	7
2.1	Overview	7
2.2	Specifications of Power Amplifier	7
2.2.1	PAE (Power Added Efficiency) and Drain Efficiency	7
2.2.2	Linearity	8
2.2.3	Gain	8

2.3	Classes of PA	9
2.3.1	Linear Power Amplifier based on Class A	11
2.3.2	Conventional Power Amplifier having High Efficiency	13
2.3.3	Class J Power Amplifier	17
2.3.4	Overdrive PA: Class F Power Amplifier	19
2.3.5	Switching PA: Class D Power Amplifier	21
2.4	Class E PA	23
2.4.1	Class E Overview	23
2.4.2	Class E Amplifier Method of Operations	24
2.4.3	Class E PA Design Equations	26
2.5	Class E Technologies	27
2.5.1	Class E Implementations	27
2.5.2	Operations and Matching Networks Optimization	28
2.5.3	Analysis and Comparisons of Class E PA	35
2.6	Chapter Summary	40
CHAPTER 3	RESEARCH METHODOLOGY	41
3.1	Overview	41
3.2	Flow Chart depicting steps for Design of Dual Band Class E PA	43
3.3	Sokal's Equations	46
3.4	Load-Pull Configuration	47
3.5	Harmonic Terminations	49
3.6	Chapter Summary	50
CHAPTER 4	DESIGN AND IMPLEMENTATION	51
4.1	Overview	51
4.2	Stability and amplification capabilities of transistor	52
4.3	Transistor Characterization	55
4.4	Input Matching Configuration	56
4.5	Sokal's Class E Equations	57

4.6	Conjugate Matching and transformations to lumped elements	61
4.7	Ideal - HBTuner	62
4.8	Class E realization through lumped components	66
4.9	Class E with Band-Pass filter Integration	70
	4.9.1 Band-Pass Filter Implementation	70
	4.9.2 Class E power amplifier merged with filter	73
4.10	Verifiability of the Design	77
	4.10.1 Matching Load-Pull results of datasheet	77
	4.10.2 Design of Class E on other non-linear transistor.	79
4.11	Comparative Analysis of Class E design at multiple frequencies	85
4.12	Chapter Summary	88
CHAPTER 5	CONCLUSION AND RECOMMENDATIONS	89
5.1	Research Outcomes	89
5.2	Contributions to Knowledge	90
5.3	Future Works	90
REFERENCES		92
APPENDICES A-B		94-105

LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 1. 1	Design Specification for a Class E circuit.	5
Table 2. 1	PA Classes classification based on conduction angle (5).	15
Table 2. 2	Comparison of measured performance between original and proposed PA (15).	36
Table 2. 3	PAE comparison between FET models in AWR MWO library (19).	39
Table 2. 4	Comparison of fully integrated Class E PA.	39
Table 3. 1	Values for the passive component in Class E OMN.	47
Table 4. 1	Comparison between Class E PA using different transistors for NPTB00004.	87
Table 4. 2	Comparison between Class E PA using different transistors for NPT1012.	87

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 1. 1	Cognitive Radio Network maximizing spectrum utilization (3).	2
Figure 2. 1	Power in PA	7
Figure 2. 2	Input and output signal of (a) linear PA and (b) Non-linear PA (1).	8
Figure 2. 3	Most important PA classes: (a) Class-A/B/C. (b) Inverter-based Class-D (switched). (c) Class-E (switched). (d) Class-F (switched) (7).	11
Figure 2. 4	The biasing point of Class A amplifier based on an FET transistor showing an ideal strongly nonlinear response on the solid line while dotted line represents weakly nonlinear response (accompanied by low level harmonics) (5).	12
Figure 2. 5	(a) An amplifier circuit, (b) voltage swing of RF over the DC voltage, (c) RF current swing over midway on the maximum drain current (5).	12
Figure 2. 6	Waveform based on reduced conduction angle (5).	13
Figure 2. 7	Reduced conduction waveform based on Fourier analysis (5).	15
Figure 2. 8	Reduced conduction angle PA showing circuit and waveform (5).	17
Figure 2. 9	Class J schematic (5).	19
Figure 2. 10	Sinusoidal waveform being “squared” by third harmonic component (5).	20
Figure 2. 11	Class F PA showing the output matching network (9).	21
Figure 2. 12	Basic Class D switching amplifier (5).	22
Figure 2. 13	Class D switching amplifier waveforms (5).	23
Figure 2. 14	Basic RF switching amplifier (left), Basic RF switch waveform (right) (5).	25
Figure 2. 15	Basic Class E amplifier schematic (5).	25
Figure 2. 16	Class E current waveforms: (a) total current, (b) switch current, (c) shunt capacitor current (d) switch current, (e)	

	shunt capacitor current, and (f) switch/shunt capacitor voltage (5).	26
Figure 2. 17	Photographs of the fabricated PAs (14-16, 18).	28
Figure 2. 18	Schematic of proposed class-E with ideal components (14).	29
Figure 2. 19	Load impedance over frequency (14).	29
Figure 2. 20	Network (a) can be transformed to network (b), or vice versa, by properly choosing the values of circuit elements (15).	30
Figure 2. 21	Schematic of the wideband class-E PA using the improved reactance-compensation technique (15).	31
Figure 2. 22	Second harmonic injection made possible by implementation of two following common source stages whereby the second harmonic is filtered, amplified and phase shifted, and injected back to the main stage (16).	32
Figure 2. 23	Optimum load impedances for maximum PAE and optimum source impedances for maximum gain (17).	32
Figure 2. 24	Broadband output matching circuit structure for class-E PA design (17).	33
Figure 2. 25	Input reflection coefficient simulation results of the designed input matching circuit (i.e at gate of transistor) (17).	33
Figure 2. 26	Input Matching Circuit (17).	34
Figure 2. 27	Conversion of Class E Sokal's OMN to distributed lines (18).	34
Figure 2. 28	Class E design using HBtuner2 with S11 conjugate matching along with OMN based on Sokal's equations (19).	35
Figure 2. 29	Measured results in (a) Output power and PAE versus input frequency and (b) Second and third harmonic emissions versus input frequency (14).	35
Figure 2. 30	Measured PAE and DE of the wideband class-E PA designed using the improved reactance-compensation technique (Right). Measured PAE and DE of the wideband class-E PA designed using the original technique (Left) (15).	36
Figure 2. 31	Simulated and measured results. (a) Output power (top left) (b) Power gain (top right) (c) Drain efficiency (bottom left) (d) PAE (bottom right) (16).	37

Figure 2. 32	Measurement results of frequency sweep test of the fabricated broadband class-E PA, the input power was set to 33 dBm (17).	38
Figure 2. 33	Measured efficiency and output power for dual band design for (a) first band (b) second band (18).	38
Figure 3. 1	Transistor Selection and Characterization.	43
Figure 3. 2	Flowchart for Class E design based on Sokal's Equations.	44
Figure 3. 3	Flowchart for Class E design based on Load-Pull configuration.	45
Figure 3. 4	Flowchart for final implementation of dual band Class E PA.	46
Figure 3. 5	Adjusting load-pull contour point to find reflection coefficient points.	48
Figure 3. 6	Load Pull contour lines generated by AWR NI.	48
Figure 4. 1	A conditionally stable transistor showing the stability regions when (a) $ S_{11} < 0$ (b) $ S_{11} > 0$.	52
Figure 4. 2	Stability of NPTB0004 transistor showing unconditionally stable condition at both LTE bands of 42 and 43.	53
Figure 4. 3	Test bench for stability and maximum gain capabilities of transistor.	54
Figure 4. 4	Maximum gain that the transistor can give at the particular frequency.	54
Figure 4. 5	IV curve and Dynamic load line of transistor.	55
Figure 4. 6	S_{11} conjugate matching	56
Figure 4. 7	Class E based on Sokal's Equations	57
Figure 4. 8	PAE and gain for Sokal's equation.	58
Figure 4. 9	Current and Voltage at drain with Sokal's equations.	58
Figure 4. 10	Sokal's Class E circuit implemented with S_{22} matching of the transistor.	59
Figure 4. 11	PAE and Gain by applying S_{22} conjugate with Sokal's lumped components.	60
Figure 4. 12	New current and voltage waveform for Sokal's equation.	60
Figure 4. 13	Smith Chart Utility Showing IMN circuit as well as S_{11} and S_{21} curve for IMN network.	61
Figure 4. 14	Ideal HBTuner module.	62

Figure 4. 15	Load-Pull circuit.	63
Figure 4. 16	Load-pull for Ideal-circuit	64
Figure 4. 17	Ideal response of PAE and gain from ideal HBtuner circuit.	64
Figure 4. 18	Current and voltage for Ideal circuit.	65
Figure 4. 19	Ideally generated harmonic spectrum for 3.4 GHz as 1 st harmonic.	66
Figure 4. 20	Implementation of whole Class E power amplifier	67
Figure 4. 21	PAE and gain for realized Class E circuit using lumped components (wideband).	67
Figure 4. 22	Current and voltage waveform for Class E realized using lumped components.	68
Figure 4. 23	Harmonics at Class E with lumped components (wideband).	69
Figure 4. 24	1dB compression point for wideband Class E.	69
Figure 4. 25	Attenuation versus normalized frequency for maximally flat filter prototypes (20).	71
Figure 4. 26	Element values for maximally low pass filter.	71
Figure 4. 27	Band pass filter for elimination of harmonics.	72
Figure 4. 28	S_{11} and S_{21} parameters of the band-pass filter.	72
Figure 4. 29	Class E power amplifier with bandpass filter for harmonics terminations.	73
Figure 4. 30	Harmonics spectrum after filter is implemented.	74
Figure 4. 31	Current and Voltage waveform at drain after addition of filter network.	75
Figure 4. 32	PAE and gain of the Dual-Band Class E power amplifier.	76
Figure 4. 33	1dB compression point for the Dual Band Class E amplifier.	76
Figure 4. 34	Load-Pull from simulations from AWR (left) and load-pull from datasheet of NPTB00004 (right).	78
Figure 4. 35	Tabulated results of load-pull from datasheet	78
Figure 4. 36	IV curve of NPT1012.	79
Figure 4. 37	IV curve of NPT1012 from datasheet	79
Figure 4. 38	Load-pull of new transistor at 3.4 GHz	80

Figure 4. 39	Load-pull circuit for NPT1012.	80
Figure 4. 40	Efficiency versus gain of Class E PA using NPT1012 (load-pull).	81
Figure 4. 41	Lumped components of Class E PA using NPT1012	81
Figure 4. 42	Efficiency and gain from translated lumped components of Class E PA at 3.4 GHz.	82
Figure 4. 43	Load-pull simulation of NPT1012 at 900 MHz simulated (left), from datasheet (right).	82
Figure 4. 44	Efficiency and output power at 900MHz of NPT1012 (datasheet).	83
Figure 4. 45	Lumped components for Class E design at 900 MHz.	83
Figure 4. 46	Efficiency and gain at 900 MHz of lumped components Class E design.	84
Figure 4. 47	Stability of NPT1012 at (a) 3.4 GHz (b) 900MHz	85
Figure 4. 48	Efficiency and Gain of Class E design using NPTB00004 at (a) 700 MHz and (b) 1.5 MHz.	86

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

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
Appendix A	NPTB00004 Datasheet	94
Appendix B	NPT1012 Datasheet	105

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 5th 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).

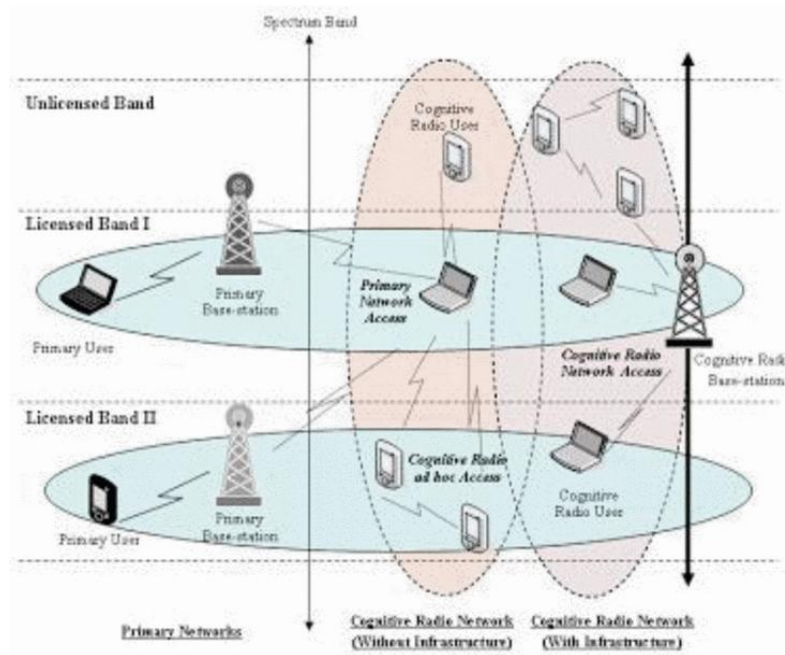


Figure 1. 1 Cognitive Radio Network maximizing spectrum utilization (3).

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 gigantic 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 2nd 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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