POWER AMPLIFIER DESIGN FOR ULTRA-WIDEBAND APPLICATIONS

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ABSTRACT

Ever since the FCC allocated 7.5 GHz (from 3.1 GHz to 10.6 GHz) for ultra wideband (UWB) technology, interest has been renewed in both academic and industrial circles to exploit this vast spectrum for short range, high data rate wireless applications. The great potential of UWB lies in the fact that it can co-exist with the already licensed spectrum users and can still pave the way for a wide range of applications. However, this wide bandwidth complicates the circuit level implementation of key RF blocks like the power amplifier (PA), transmit/receive switch, low noise amplifier (LNA) and mixers in an UWB transceiver. The inability of Narrow-Band (NB) system likes Bluetooth to deal with some important topics in nowadays technology such as security, high data rate, signal loss, and range resolution makes UWB technology an important subject to be exploited and explored. The ultimate goal is to design a Power Amplifier which covers whole range of UWB frequency from 3.1 GHz to 10.6 GHz. The design will focus on Distributed Amplifier (DA) technique which is knowingly as an easy technique for Broadband Power Amplifier design to achieve high output power and flat high gain through the UWB frequency range. The design based on simulation using Microwave Office 2006 and the output gain is 12.8 dB ± 0.5 dB with single-stage PA circuit while the output gain with two stages PA circuit is 26 dB ± 2 dB.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

UWB	-	Ultra Wide-Band
FCC	-	Federal Communications Commission
PA	-	Power Amplifier
RF	-	Radio Frequency
CRTSSDA	-	Cascaded Reactively Terminated Single Stage Distributed Amplifier
HJFET	-	Hetero Junction Field Effect Transistor
CSSDA	-	Cascaded Single Stage Distributed Amplifier
DA	-	Distributed Amplifier

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

Over recent years, the interest for ultra wideband (UWB) in Malaysia has grown tremendously due to the germination of researches and implementation of UWB applications at local university and private sectors. It caused by the modern re-incarnation of an old type of communication. The first cross Atlantic wireless transmission by Guglielmo Marconi used spark-plug transmitters that can be thought of as impulse based UWB transmission [1]. Today, the same technology provided by Guglielmo Marconi is being revivified for its immense potential in high data rate communications.

1.1 Introduction of Project

Ever since the FCC allocated for 3.1 GHz to 10.6 GHz for UWB technology, the interest has been renewed in both academic and industrial circles to exploit this huge spectrum for short range and high data rate wireless applications [2]. It's a great potential of UWB to be widely applied because it can co-exist with the licensed spectrum and can still open the path for a wide range of applications such as high definition television (HDTV) and wireless transmission at higher data rate compared to the data transfer rate in Bluetooth communications technology so it can replace the Bluetooth technology in wireless personal area network (WPAN) devices likes mobile phones, laptops, personal computers (PC), printers, GPS receivers, and video game consoles [3].

However, this wide bandwidth coverage makes the circuits design of key RF blocks of front-end transceiver system such as power amplifier, transmit/receive switch and low noise amplifier becomes more complicated. The implementation of RF power amplifier (PA) is one of the challenging aspects in emerging Ultra Wide-Band (UWB) radio frequency (RF) systems. The design of broadband amplifier introduces new difficulties which require many considerations such as linearity, efficiency, gain, insertion loss and return loss. Basically, the design of amplifier over a broad frequency range is a matter of properly designing the reactively matched circuit, traveling wave circuit, cascade single stage distributed amplifier, feedback circuit or loss matched circuit in order to compensate for the variation of frequency [6].

The Cascaded Reactively Terminated Single Stage Distributed Amplifier (CRTSSDA) was one of the broadband amplifier techniques which are an improvement from the CSSDA technique in order to functioned at large signal operational and enhanced amplifier performance in term of output power and power added efficiency (PAE). But, the CRTSSDA technique is complicated to be designed because of it high power added efficiency (PAE). CRTSSDA technique also provide an excellent performance because the input and output capacitances of the active devices are absorbed in the distributed structures. As a result, the amplifier can exhibits very low sensitivities in process variations when designing and simulate. The simple and easy technique is a Distributed Amplifier technique but it compensates the amplifier efficiency. The simulation works will be done by using Microwave Office due to its ease of implementation.

1.2 Problem Statement

The UWB technology take place in short range communication system instead of narrow-band (NB) due to NB inability to deal with some important topics in nowadays technology such as security, high data rate, signal loss, and range resolution. Narrow-band technology such as Bluetooth confront with the problem of multipath fading which is described as signal loss due to the destructive interference of continuous wave (CW) signals [5]. Next, the problem in NB is that the signals transmit are insecure because NB signals are easily detected and jammed [5]. Narrow-band signals also facing a problem of poor range resolution for tracking applications and limited data rate because narrow RF bandwidth means narrow data bandwidth [5]. In general, the RF performance of the Power Amplifier is excellent if it able to achieve the high gain, high output power, and high power added efficiency. By designing only a single stage amplifier, we cannot provide a high gain, high output power, high power added efficiency, and high stability amplifier as expected. As for the different biasing circuit, active biasing does not offer much advantage over the passive biasing circuit so the matching networks can be changed to either lumped elements, shunt stub or quarter wave matching techniques for space reduction and cost saving. The developing of amplifier based on Distributed Amplifier technique will enhance performance in term of output power but affect the power added efficiency. There is also a problem of some conventional power amplifier design not support the whole range of UWB licensed bandwidth from 3.1 GHz to 10.6 GHz.

1.3 Objectives

Ultra Wide-Band Power Amplifier (PA) is an integrated component of most RF systems. The objectives of this UWB amplifier design are to design a broadband Power Amplifier that can operate in whole UWB frequency range that is from 3.1 GHz to 10.6 GHz based on Distributed Amplifier technique and obtain the expected gain about 10 dB and constant gain (flatness gain) as possible over the whole range of UWB frequency.

The transistor type used in the design of Power Amplifier for this project is Hetero Junction Field Effect Transistor (HJFET) NE3210S01 manufactured by NEC Corporation. This project involving of familiarization and utilization of a RF amplifier design technique using Microwave Office software.

1.4 Project Scopes

The scope of works to design Power Amplifier which covers the frequency range between 3.1 GHz – 10.6 GHz can be divided into three main parts; simulation, testing and analyzing, and optimization. Simulation design of Power Amplifier will be done by using Microwave Office software version 7.0 in order to get the required results which are close to the theoretical results. The expected results should provide an overall gain of 10 dB, output power of 20 dBm from input power 0 dBm, return losses below -3 dB and gain flatness ± 1 dB. Next, it's about analyzing and calculating of the maximum gain and return loss in S-Parameters analysis - S_{21} and S_{11} parameter. Then, second part is the testing and analyzing which involving the analysis of every part in the circuit, the effect of each components of the UWB Amplifier. Last part for this project is optimization part which covers an optimization of the circuit to get the expected results.

1.5 Thesis Outline

Chapter 1 is about an introduction of project which includes an explanation of project background, a brief introduction of Ultra Wide-band (UWB) and Power Amplifier (PA), method used in PA design, objectives of project, and project scopes.

Chapter 2 of background study defines in details about UWB and PA, and also about method used in the design work.

Chapter 3 contains a details explanation of an amplifier design technique which consist a single stage amplifier design, DC biasing design, and input output matching design.

Chapter 4 contains a research methodology which includes the steps to design Power Amplifier and a brief explanation of methodology flow chart.

Chapter 5 discuss about the selection of transistor and the result from this project; which is S-parameter analysis, and all gains analysis.

Chapter 6 reveals the conclusion of this project and future works suggestion on this project.

CHAPTER 2

UWB STUDY

Interest in Ultra-wideband (UWB) has surged since the FCC's approval of a First Report and Order in February 2002 which provides spectrum for the use of UWB in various application areas because of the extremely large bandwidth available to be exploited and currently UWB technology being touted as a solution for high data rate, short-range wireless networks.

2.1 UWB Basics

By traditional definition, ultra wideband technology employs very narrow pulses, of the order of a few nano-seconds, in order to establish high data rate communications [3]. These narrow pulses translates to energy spread over a wide frequency band, and hence the name ultra-wideband (also called Impulse radio). Very high data rates can be achieved over a short distance in devices employing the UWB technology.

An integral part of designing systems for short-range wireless network application or any application is an understanding of the statistical nature of the wireless UWB channel. However, one of the important conditions is that the power levels of the UWB signal in this spectrum must be low enough to avoid interference with the already existing technologies. The FCC specifies the power emission levels suitable for co-existing with other technologies in the UWB allocated band [7]. The spectrum mask for both indoor and outdoor emissions is shown in Fig. 2.1.

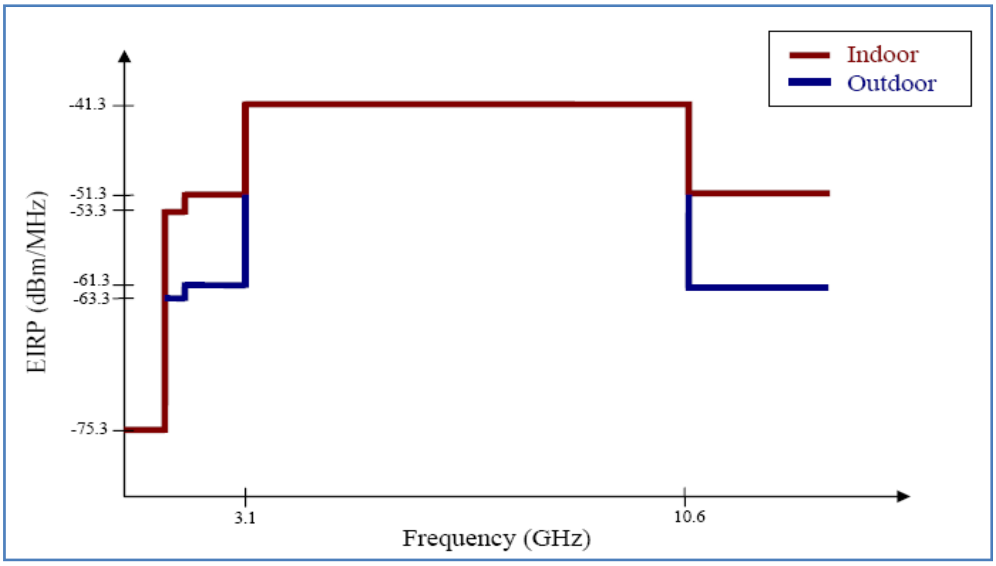

Figure 2.1 Acceptable power levels for indoor and outdoor emissions [12]

According to the FCC, a UWB system is classified using one of two different measures of bandwidth. A system can either have an instantaneous bandwidth in excess of 500 MHz or have a fractional bandwidth that exceeds 0.20 (by comparison a narrowband signal typically has a fractional bandwidth which is less than 0.01). Both metrics are defined according to the -10 dB points of the signal's spectrum. Fractional bandwidth is defined as the signal's bandwidth divided by its center frequency or more precisely as

$$BW_f = \frac{2(f_H - f_L)}{f_H + f_L} \tag{2.1}$$

where f_H is the highest frequency and f_L is the lowest frequency of the signal at the -10 dB points [8]. These definitions specify that systems with a center frequency greater than 2.5 GHz must have a bandwidth greater than 500 MHz and a system with a center frequency less than 2.5 GHz must have a fractional bandwidth greater than 0.20. Figure 2.2 below provides an illustration comparing the fractional bandwidth of a narrowband signal and a UWB signal, BW_{NB} is the narrowband signal bandwidth, BW_{UWB} is the UWB signal bandwidth, and fc is the signal's center frequency. As Figure 2.2 demonstrates a UWB signal's bandwidth can cover a large range of frequencies. It is therefore important that UWB devices use a low transmit power spectral density in order to not interfere with existing narrowband communications systems.

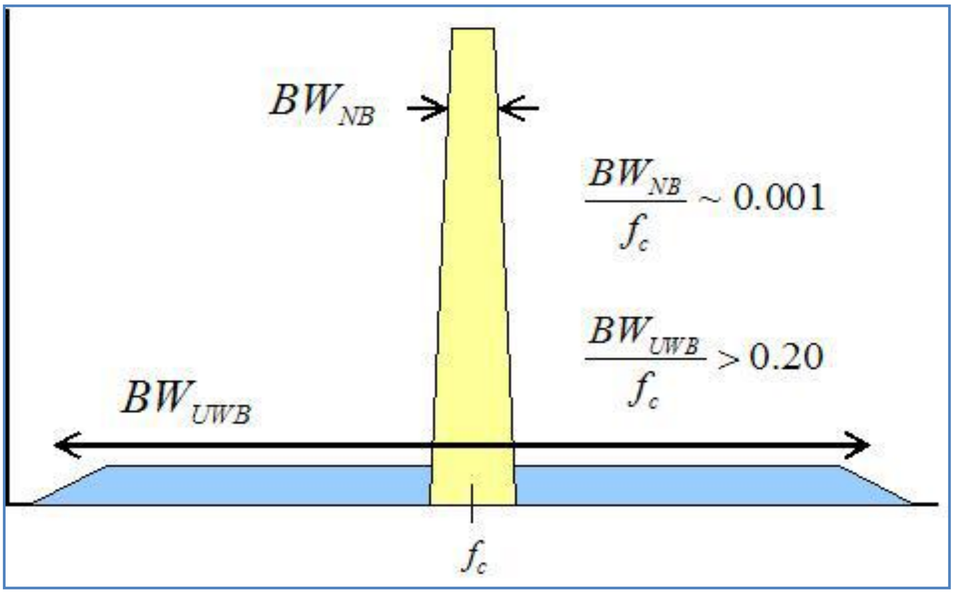

Figure 2.2 Fractional bandwidth comparison of a narrowband and UWB signal [12]

2.2 UWB Applications

The wide spectrum allocated to UWB directly translates into a wireless channel with high spatial capacities. This is obtained from the famous Shannon's channel capacity theorem

$$C = B \log_2 (1 + SNR) \qquad (2.2)$$

where C is the channel capacity in bits/second, B is the bandwidth in Hertz and SNR is the Signal-to-Noise Ratio.

Expression 2.2 shows a linear relation of the channel capacity with bandwidth and logarithmic relation with the SNR. Unlike narrowband systems whose data rate is limited by the bandwidth and SNR, UWB systems can achieve high data rates while operating below the noise floor. Nevertheless UWB is power limited which indirectly limits the overall channel capacity.

With attractive features like excellent multi-path immunity and good immunity to external interference, UWB technology is projected to revolutionize a wide array of applications. The key for several applications is also the lower frequency content involved. Some of the potential applications of UWB include:

- Military communications
- Short range covert communication devices
- Collision avoidance sensors
- Ground-penetrating Radar
- Through-the-wall Radar
- Emergency motion and imaging
- Security devices
- Home networking without physical connections
- Radio Frequency Identification (RFID) devices

2.3 UWB Power Amplifier

Power amplifiers (PA) are a part of the transmitter front-end used to amplify the transmitted signal so the signal can be received and decoded within a fixed geographical area. Power Amplifier boost the signal power high enough such that it can propagate the required distance over the wireless medium. Typically, this power is delivered to an antenna which acts like a 50 Ω load. The main PA performance parameter is the output power level the PA can achieve, depending on the targeted application, linearity, and efficiency. It can range from a few mili-watts for home networks to hundreds of watts at base stations. Power amplifiers can be categorized several ways depending on whether they are broadband or narrowband, and whether they are intended for linear operation (Class A, B, AB and C) or constant-envelope operation (Class D, E and F). This application note focuses on the design of narrowband and linear PA's.

In UWB systems, the power level from the UWB transmitter should be small enough not to interfere with the already existing communication systems. The output power levels need to achieve less than -41.25 dBm/MHz (as specified by the FCC). As a result, UWB systems need not require large transistors as part of the power amplifier circuit and this indirectly translates to lower power consumption. However, achieving a high gain and good impedance match over the entire frequency band makes the design a challenging task.

2.4 Specifications of the PA

The most important trade-off in PA design is between efficiency and linearity. Most Power Amplifiers employ a two-stage configuration, with a matching network placed at the input, between the stages, and at the output. In this section, some of the important terms and specifications related to a PA are discussed.

2.4.1 Frequency range of operation

In a narrowband application, the PA is designed for a particular frequency range and all the parameters are measured at that frequency. However, the frequency range to be covered for UWB is wide range from 3.1 GHz to 10.6 GHz. So the Power Amplifier considered in this thesis target the 3.1 to 10.6 GHz range.

2.4.2 Output power

This parameter determines the amount of power that needs to be delivered to the load. As mentioned earlier, UWB transmitters are required to deliver very low output power of the order of a few hundreds of micro-watts. The output power level standard stated by FCC should be less than -41.25 dBm/MHz. It means that the output power from 3.1GHz to 10.6GHz should be in the range of 23.66 dBm ~ 28.75 dBm.