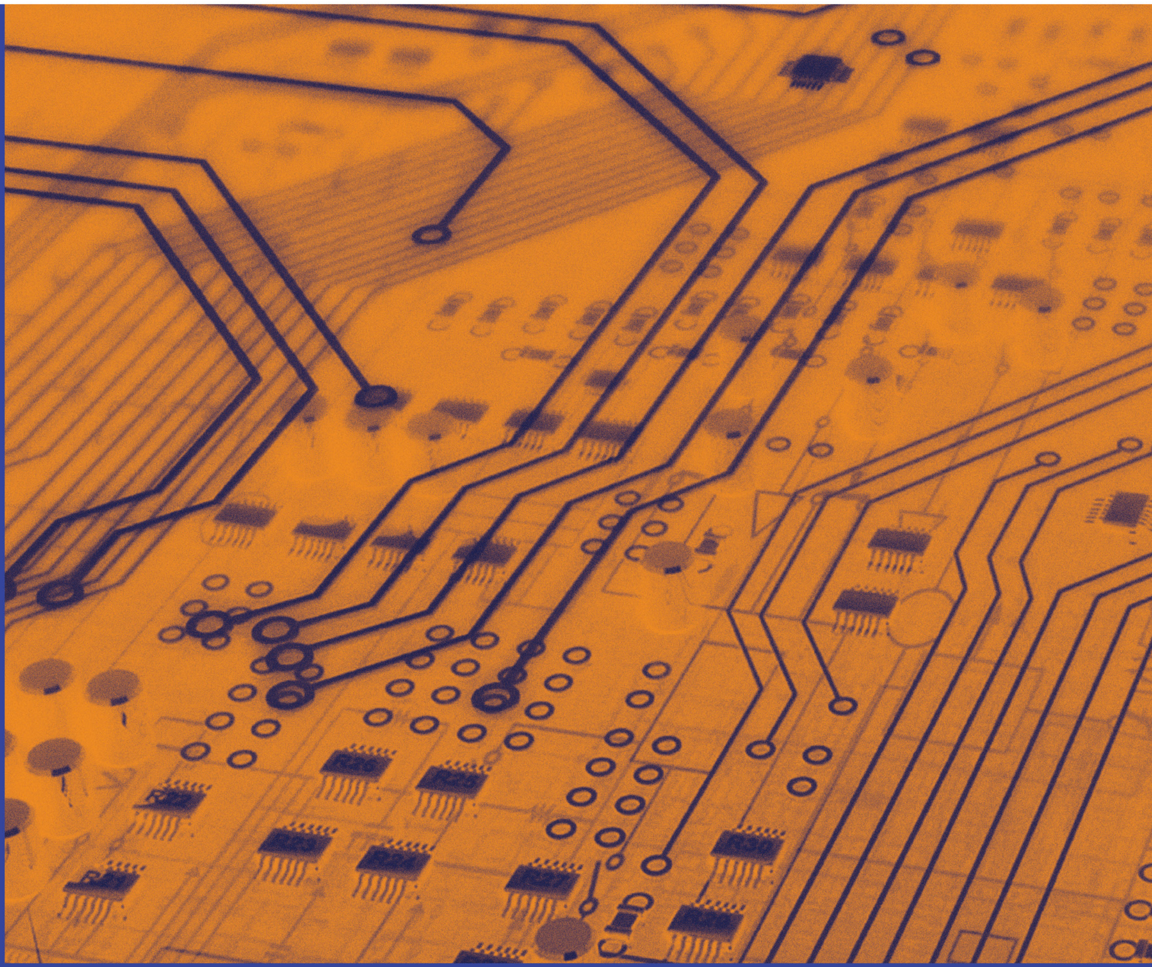

RADIO FREQUENCY WIDEBAND CMOS POWER AMPLIFIERS

DESIGN AND ANALYSIS

ROHANA SAPAWI

RADIO FREQUENCY WIDEBAND CMOS POWER AMPLIFIERS: *DESIGN AND ANALYSIS*

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Preface

Recently, wideband wireless communication system, namely the ultra-wideband (UWB) is a new radio technology that has the capability to transmit higher data rate for short range over a wide frequency with low power. The UWB wireless system operation ranges from 3.1 to 10.6 GHz frequency and these advantages and capabilities have attracted great attention in both academia and industry to investigate more issues on the related technology to lead new innovation and greater quality of service to the end users. Futhermore, wireless communication together with semiconductor technologies have directly contributed to several economic and social aspects of daily life and contribute to the fast growth of portable-electronic device market especially in both home and office. Therefore, the demand for higher data rates has also increased. For such applications, UWB is becoming popular since UWB based system can meet the demand of high data rate at a low power and low cost. Therefore, implementing wideband PA using CMOS technology has become one of the most significant topics in the radio frequency (RF) circuit design due to the challenge to meet high efficiency, output power, broadband input matching and output matching, high power gain and linearity at such high frequencies and wide bandwidth. This is due to the weaknesses in CMOS process such as breakdown voltage, low transconductance capacity and poor passive device. Until now, expensive technology such as SiGe or GaAs has been used for transceiver realization but the essential objective is to have a single chip and low cost solution. The solution to this by using only CMOS technology that can provide a higher level of integration and a low fabrication cost as compared to compound semiconductor technologies such as Silicon Germanium (SiGe) or Gallium Arsenide (GaAs). This book deals with the design and analysis of CMOS power amplifier for UWB system, highlighting the detailed concept and fundamentals theory that students, IC designers and engineers need to master in today's industry. A few approaches have been proposed to develop CMOS power amplifier for UWB system to enable the reader to understand the design concept of designing power amplifier with very wide range of frequency.

The first chapter defines the introduction and the motivation, including the main objectives of this book. In Chapter 2, the fundamental of RF power amplifier (PA) is introduced. The PAs classes of operation, including linear and non-linear PAs are briefly described. Lastly, four main performance criteria of PAs are discussed.

Chapter 3 consists of power amplifier for a UWB system. The basics of the UWB technology are discussed. Two main standards and the frequency allocation for UWB system are explained. Also, the application of UWB is explained in this chapter. The main specifications for UWB PAs such as frequency range, gain flatness and group delay are presented and the recently published CMOS UWB PAs are reviewed.

Chapter 4 presents the details concerning the proposed design of 3.1-10.6 GHz UWB PA. First, the proposed design of full band PA is described. Next the theoretical analysis of group delay variation is explained. Following that, the experiment measurements are discussed.

In Chapter 5, the design of low band PA from 3.1-6 GHz for UWB applications is presented. This section begins with an explanation of proposed design of PA. In this chapter, linearity analysis, and measurements also discussed.

In Chapter 6, the design of wideband range CMOS PA with improved group delay variation and gain flatness for UWB transmitters is explained. The circuit design, transfer function analysis, group delay analysis, and measurement results are discussed.

Chapter 1

Introduction

1.1 Background

In recent years, ultra-wideband (UWB) technology is becoming increasingly popular due to its capability of offering wide spectrum of frequency bands with low power and high data rate. Therefore, CMOS technology serves as a good solution due to the advantages of price, small size, mass production and increasing stringent demands on the integrated circuits (ICs) that constitute the building blocks of wireless systems [1]-[2].

There are a number of techniques in wireless communication and this include wireless local area network (WLAN), worldwide interoperability for microwave access (WiMAX), wireless personal area network (WPAN), ultra wideband, etc. Among this, UWB is considered to be a comparatively new technique that has the capability to transmit higher data rate over a wide frequency for short range with low power and provide low cost alternative. Hence, UWB technology has become the most popular solution for future high-speed wireless data communication and short-range with low power applications such as home server and cable less PC system. In 2002, the regulation for UWB technology has been officially released by the Federal Communication Commission (FCC) in United States with the emission limits of the allocated 7.5 GHz band unlicensed use for commercial UWB communication devices. The UWB advantages from 3.1 GHz to 10.6 GHz has attract many researchers to exploit this vast spectrum for short range, high data rate wireless applications. The excellent potential of UWB is able to share the spectrum with other users with very wide range of application.

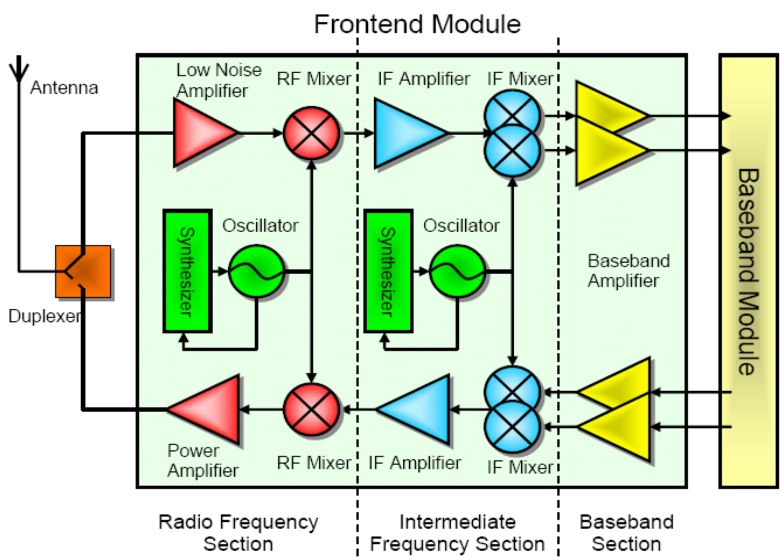

Figure 1.1: RF CMOS Transceiver block diagram

Figure 1.1 shows the radio frequency (RF) Transceiver Front-End as a main part of the wireless communication. It comprises of three main parts: first part is the RF section, second part is the IF section and the final part is the baseband section. The upper part is receiver section and the bottom part is transmitter section. In transmitter, the IF signal incoming from baseband is up-converted to RF frequency through this mixer, further the RF signal is amplified by power amplifier (PA) and transmit through this antenna. In this book will focus on designing CMOS PA as one part of RF transceiver front-end for UWB system.

The Radio Frequency Power Amplifier (RF PA) is an essential component in wireless transmitter. The main role of PA is to amplify the signal and generate the required RF power that allows transmissions of the signal over the appropriate range. The power amplifier is most critical and power hungry block in UWB transmitter, its efficiency directly correlates to batteries autonomy as well as the heat generated and thermals design problems [2]. Formerly, RF PAs in cellular products were implemented with a few discrete devices. Then, PA with simple integrated circuits and external impendence matching networks was replaced. Later, more complex integrated circuits needing only power supply decoupling circuitry and external output matching is introduced. Nowadays, RF PA modules consist of all the necessary components in a single package are produced. For example, cellular products need at least one unit of RF PA, while multiband frequencies would need and three or more RF PAs. Thus, cost generally becomes a major player in high volume businesses. But, low cost and attaining a high level of performance in a small package remaining a challenging task in designing PAs for wireless applications [2]. Therefore, the better solution to this problem would be complementary metal oxide semiconductor (CMOS) technology that has the ability to provide high volumes of inexpensive, highly complex digital circuitry, and great versatility. Nevertheless, several difficulties such as low oxide breakdown voltage, low current drive capability, substrate coupling, and low quality and high tolerances of on chip passives are hindering the realization of a fully-integrated CMOS radio due to the intrinsic drawbacks of standard CMOS processes from the RF perspective [3]-[6]. Thus, it is a critical challenge to design and implement CMOS transmitters mainly when designing in GHz frequencies range.

Chapter 2

Fundamentals of RF Power Amplifier

2.1 Introduction

Power amplifiers are final parts in the transmitter front-end. Generally, the main function of PAs is to amplify the signal being transmitted so that it can be received and decoded within geographical zone [7]. In other words, PA is a type of electronic amplifier that is used to convert a low power RF signal to a larger signal of significant power, usually for driving the antenna of a transmitter [8]. This is the reason the PAs are the most power-hungry building block of RF transceiver. In order to have high efficiency, good gain, good return loss at the input and output, low power consumption and high output power compression optimization need to be done.

Thus, this chapter will discuss the main concept of PAs design. It includes the PAs classes of operation; the linear and non-linear PAs. The important performances' criteria of PAs are gain, linearity, efficiency and output power are discussed. The classes of operation are chosen either linear or non-linear PAs once the standard is selected for target PA design. All the specification such as output power, gain, linearity, efficiency, and etc, need to be understood before designing the PA.

2.2 Power Amplifier Classification

Up to now, RF power amplifier can be categorized under many classes (e.g. A, AB, B, C D, E and S, etc). The power amplifier classification is influenced by DC bias condition, output terminations at fundamental and harmonics, and conduction angle. However, sometimes the classification became uncertain where the amplifier could fall in two or more classes and sometime one class may converge to another as operating conditions change. The power amplifier can therefore be categorized into two: linear power amplifier and switching power amplifier as shown in Figure 2.1. It clearly can be seen that for linear power amplifiers can be categorized as Class A, Class B, Class AB, and Class C and switching power amplifiers can be classified as Class D, Class E, and Class F. The summary of each classes of power amplifier are shown in Table 2.1.

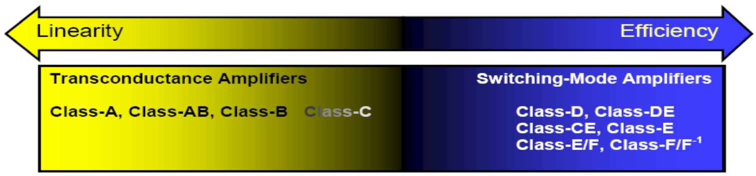

Figure 2.1 Category of power amplifier

Table 2.1: Comparison PA classes

Class	Linear power amplifier				Switching power amplifier		
	A	AB	B	C	D	E	F
Maximum Efficiency (%)	50	50-78	78	78-100	100	100	100
Typical Efficiency (%)	25	35-60	60	70	75	80	75
Linearity	Excellent	Good	Good	Poor	Poor	Poor	Poor
Gain	Large	Moderate	Moderate	Small	Small	Small	Small
Output power capability	Large	Medium	Medium	Low	Large	Large	Large

2.21 Class A, B, AB and C Power Amplifiers

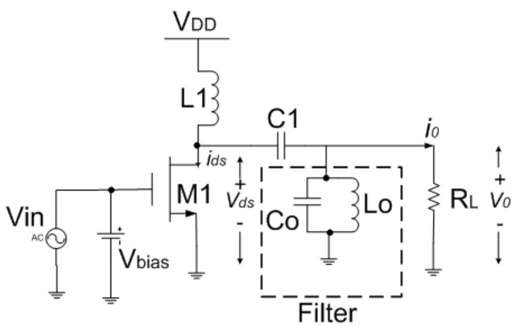

Figure 2.2: A basic linear amplifier

Basically, these types of power amplifier have analogous circuit configuration, distinguished primarily by biasing condition as shown in Figure 2.2. It clearly shows the basic form of a linear amplifier consists of transconductance device M_1, RF chock L_1, DC block C_1, output filter and load R_L. M_1 is employed to change the input voltage, V_{IN} to current and changed back to voltage at the output by the output load R_L. Filter at the output is used to reduce the voltage swing at the drain of the transistor, and RF chock provides the DC current from the power supply.

2.2.1.1 Class A Power Amplifier

Class A is the most linear of all power amplifier types. It means that the output signal of the amplifier have almost the same signal with input signal. Class A is defined as the input signal drive level is kept small enough to avoid driving the transistor in cut-off region. It means that the transistor conduction angle is 360°, where the transistor is in its active region for the entire input cycle. In Figure 2.3 shows the bias point is situated in the middle of I-V characteristics of the transistor.

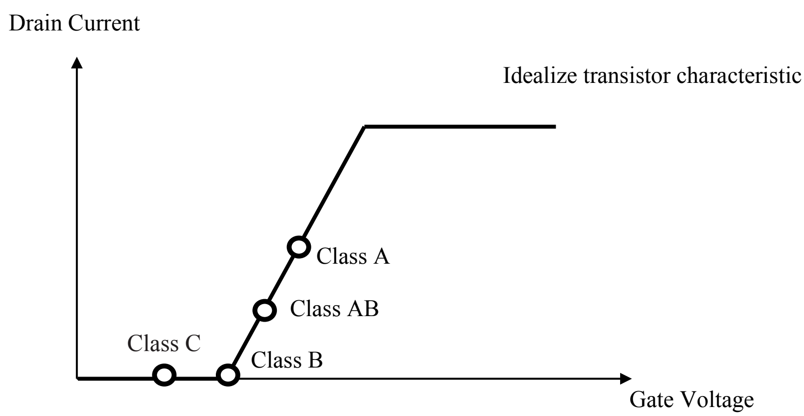

Figure 2.3: Bias point of linear amplifiers [8]