Chapter 1

Introduction

WiMAX, which was passed the certification of IEEE 802.16 group, is a rising advanced wireless communication technology. It was established for focusing on wireless metropolitan area networks (WMAN). It includes seven standards: 802.16, 802.16a, 802.16c, 802.16d, 802.16e, 802.16f, and 802.16g. Mobile application can't be supported in 802.16, 802.16a, and 802.16d, but the mobility can be provided by 802.16e. The development of future will be focus on 802.16-2004 and 802.16e.

The WiMAX standard was initiated at the National Institute of Standards and Technologies in 1998 before being turned to the IEEE to form Working Group 802.16. In June 2004, the working group got approval for the latest 802.16 standard for fixed wireless access which is known as IEEE 802.16-2004 [1]. In December 2005, an extension that addresses mobility also got approval as IEEE 802.16e-2005 [2]. Throughout the development of WiMAX, the

WiMAX Forum, which comprises a group of industry leaders such as Intel, AT&T, Samsung, Motorola, Cisco, and others, has closely supported and promoted the technology.

Due to the benefits of WiMAX's large range and high transmission rate, it can serve as a support for 802.11 hotspots for connecting to the Internet. Alternatively, WiMAX provides convenience for users connect directly to WiMAX base stations instead of 802.11 with mobile phones or laptops. Developers project this mobility of the WiMAX mobile version, which will provide the convenience of broadband Internet connection for and large coverage areas compared with 802.11 hotspots'. Mobile devices connected directly to WiMAX base stations likely will achieve a range of 5 to 6 miles so that this technology can also provide fast and cheap broadband access to the country that lacks infrastructure.

The initial version of the 802.16 standard, which was specified in 2001, specified the operation frequency ranges between 10 GHz and 66 GHz. Communication in such high frequency provides more available bandwidth, higher channel capacity, and less interference. Although operation in such high frequency alleviates those problems occurred in lower frequency, the cost will be increased because signals can't diffract around obstacles and requiring more base stations to circumvent obstacles. The standard's additions also specify operation at lower frequencies, between 2 GHz and 11 GHz, in both licensed and license-exempt bands. Focusing on this frequency ranges is mainly due to the ease and low cost. There are many important application operated in this frequency range such as WiFi, it results much interference would be expected. In order to make each system activates properly, adjusting chosen frequency and transmitted power control scheme are required to improve performance. The dynamic frequency selection chooses the operation frequency which provides high performance and the transmitted power control scheme adjusts radiated power to reduce the interference without disturbing the neighboring systems' correct operation [3].

1.1 Motivation

In portable wireless communication, such as cellular phone and WLAN, requiring large delivered output power and high efficiency is fundamental to save battery life. Off-chip components provide high quality factor to reduce the loss due to parasitic resistance and further to increase the overall power-added efficiency. An intensive effort is been focus on efficient switch PAs, Class-E in particular, because of the hard switch operation and zero voltage switching (ZVS) allows a great improvement of power efficiency. Although Class-F has been evident that it has better power efficiency than Class-E, we can obtain a good power efficiency comparing to that of Class-F with benefit of small area and low complexity. In this age of SoC, integration is also a popular issue. RF circuit implemented on CMOS is a new tendency, although there are many problems, such as the breakdown voltage of gate-to-drain or hot-carrier stress, which would be occurred when implemented on CMOS.

Device stacking Class-E topology is a visible way to release the stress on gate-to-drain breakdown voltage of active device when implementing a Class-E power amplifier and delivering the same output power. In another way, under the same stress condition higher output power would be delivered and higher power efficiency would be resulted.

In order to gain higher power efficiency, according to the publication of F. H. Raab in 2001 [4], higher order of harmonic occurred in drain terminal may fix the drain current and voltage shape and further improving the power efficiency. This result can be implemented by adjusting the loading network of Class-E power amplifier.

Besides, harmonic suppression is also an issue in wireless communication IC design. Higher harmonic terms may make the overall system fail to fit the transmission specification. We would like to add a mechanism to suppress the harmonic terms, especially second and third harmonic terms.

1.2 Specifications

1.2.1 IEEE 802.16e 2005

In IEEE 802.16-2005, the operation frequency range was specified between 10 GHz and 66 GHz initially due to more available bandwidth and less interference. The standard's subsequent additions specify the frequency range between 2 GHz to 11 GHz. Only taking the frequencies below 11 GHz of USA application into consideration and the frequency band is shown in Figure 1.

Multichannel multipoint distortion service (MMDS) includes 31 channels of 6 MHz and includes the instructional television fixed service (ITFS). The frequency range of MMDS is between 2.15-2.162 GHz and 2.5-2.69 GHz. The two wireless communications service (WCS) bands are twin 15MHz slots and its frequency range is 2.305- 2.32 GHz and 2.345-2.36 GHz. As to 3.65-3.7 GHz and 4.94-4.99 GHz, the application rules are still making in progress. The frequency band of 5.25-5.35 GHz and 5.725-5.85 GHz are the license-exempt band. The minimum channel bandwidth of each band is shown in Table 1. According to the specification of National Communication Commission (NCC) in Taiwan, 2.3-2.7 GHz has been specified for WiMAX application so that 2.3-2.7 GHz will be the operation frequency of this design.

WiMAX system uses two modulation mechanisms, OFDM and OFDMA. Proper output power level depends on what kind of modulation is used. The power class profiles of OFDM and OFDMA are shown in Table 2 and Table 3 respectively. The identifier can be recognized by In OFDM system, the maximum output power should be higher than 23 dBm, but it should be higher than 30dBm in OFDMA system.

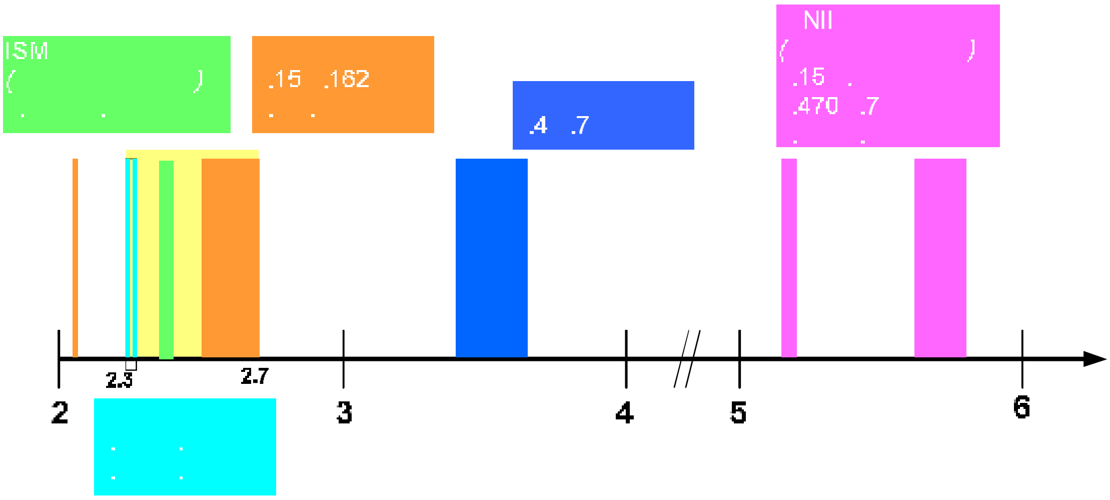

Figure 1　The frequency band of USA application

Bands (GHz)	Channel Spacing (min)
2.15~2.162	1.25MHz
2.305~2.32	5MHz
2.345~2.36	5MHz
2.5~2.69	1.25MHz
5.25~5.35	X
5.725~5.85	X

Table 1.　PHY channel spacing.

Identifier	Transmit power performance
profC3_0	$P_{Tx,max} < 14$ dBm
profC3_14	$14 \le P_{Tx,max} < 17$ dBm
profC3_17	$17 \le P_{Tx,max} < 20$ dBm
profC3_20	$20 \le P_{Tx,max} < 23$ dBm
profC3_27	$P_{Tx,max} \ge 23$ dBm

Table 2. Power classes profiles of OFDM.

($P_{Tx,max}$ are the maximum mean transmit power using all non-guard subcarriers.)

Class identifier	Transmit power (dBm)
Class 1	$17 \le P_{Tx,max} < 20$ dBm
Class 2	$20 \le P_{Tx,max} < 23$ dBm
Class 3	$23 \le P_{Tx,max} < 30$ dBm
Class 4	$30 \le P_{Tx,max}$

Table 3. Power classes profiles of OFDMA.

($P_{Tx,max}$ are the maximum average output power ratings.)

1.2.2 Architecture

Polar loop transmitter is adopted in the system architecture as shown in Figure 2. Direct conversion does suffer from I/Q mismatch, LO pulling, and requiring bulky image rejection filters. Polar loop transmitter dismisses all these disturbing problems. With the usage of nonlinear power amplifier such as Class-E PA, the overall power efficiency will not only be increased but the output power capability will also be improved, however its linearity is poor. Linearity of the transmission is accomplished by accurate amplitude modulation of the phase-carrying carrier.

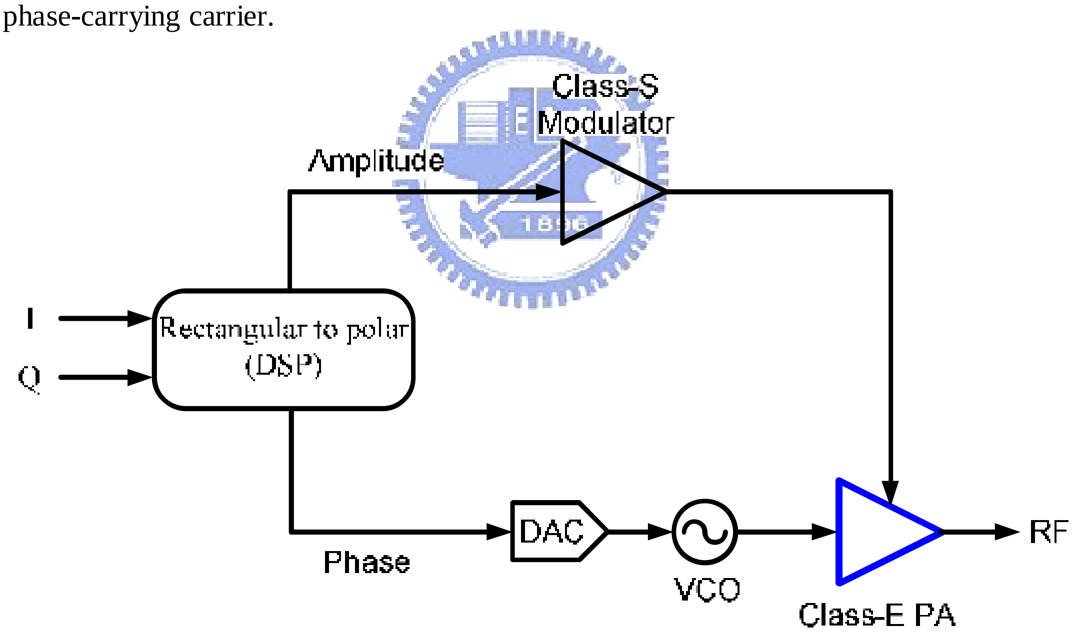

Figure 2　Polar-loop transmitter for WiMAX TX application.

The DSP converts the digital information directly into polar format, or into I/Q format and then uses equation (1.1) to produce the envelope (magnitude) and phase components. The baseband envelope signal is passed to amplitude modulation circuitry and then linearly amplified through Class-S modulator with high power efficiency while phase signal controls a phase modulator that modulates the RF carrier through the VCO. Taking modulated signal as the input of Class-E PA with amplified envelope as supply voltage provides the desired output shaping to antenna. Due to the intrinsic characteristic of such a transmitter, the need for IFs in the frequency translation is omitted and hence obviates the need of the filters required in super-heterodyne architecture, therefore allowing multimode transmission application.

$$\begin{aligned} A(t) &= \sqrt{I^2(t)+Q^2(t)} \\ \phi(t) &= \tan^{-1}\frac{Q(t)}{I(t)} \\ I(t) &= A(t)\ \cos\ \phi(t) \\ Q(t) &= A(t)\ \sin\ \phi(t) \end{aligned} \tag{1.1}$$

Class-E PA takes an important role in polar loop transmitter. It amplifies the modulated phase signal with proper supply voltage produced by magnitude signal and radiates the required output power with drawing large current. Improving the efficiency of Class-E PA is a key to save the overall efficiency of this transmitter. High efficiency design is the main target of this design.

1.3 Organization

The organization of this thesis is overviewed as follows. Chapter 2 discusses the advantages and disadvantages of the Class-E power amplifier topologies and its loading networks that have been proposed before. It also demonstrates a design of high efficiency Class-E PA. Chapter 3 reveals the analysis of a Class-E PA design and chooses cascode Class-E topology with harmonic suppression loading network for high efficiency application. The design considerations of the implemented cascode Class-E PA with harmonic suppression loading network and the proposed power-related behavioral model are revealed and discussed in chapter 4. Chapter 5 concludes with a summary of achievements and suggestions for future work.