

## 誌 謝

首先我要感謝我的兩位指導教授：鄭裕庭教授與郭建男教授，在這兩年來的悉心地指導與教誨。尤其是在做研究的方法，態度，以及思考邏輯上，他們耐心的教導讓我獲益良多。在此由衷地獻上最深最深的敬意。

此外，感謝 MIL 實驗室的伙伴們：已經畢業的偉哥、小光光、川哥，，以及達拉、黑臉巴克、愛將胖子、梨暖學姐、達軋、Chando、小 B、小文、助理小筑，在研究過程中提供我莫大的協助與鼓勵。RFIC 實驗室的傅昶綜學長、小馬學長、卓宏達學長、岡田兄、仰鵬姐，在我需要幫助時，皆毫不吝惜的伸出援手，相當感謝。也感謝奇蹟蹟和清大材料葉竣銘兄在模擬與實驗上適時的幫助。還有一起住了 3 年的兩位室友：小誠哥和小油哥，和在這兩年中所有幫助過我的朋友們，在此一併謝過。最後，我要特別感謝我的父母親以及我的阿公與阿嬤，有了他們的支持與關心，我今日才能全心全意地完成學業。



黃俊凱

2005. 8. 17

# Contents

摘要.....	i
<b>Abstract.....</b>	<b>iii</b>
誌謝.....	v
<b>Contents.....</b>	<b>vi</b>
<b>Figure Captions.....</b>	<b>viii</b>
<b>Table Captions.....</b>	<b>x</b>

## Contents

<b>Chapter 1 Introduction.....</b>	<b>1</b>
1.1 Overview.....	1
1.2 Thesis Organization.....	4
<b>Chapter 2 Basic Concepts of Micro-Machined Carrier.....</b>	<b>5</b>
2.1 Introduction.....	5
2.2 The Micro-machined inductor.....	5
2.2.1 The loss mechanism of inductor.....	6
2.2.2 The Equivalent Circuit Model of the Inductor.....	9
2.2.3 Definition of Inductor Quality Factor.....	10
2.2.4 The Optimized Micro-machined Inductor.....	11
2.3 The LNA circuit.....	16
2.3.1 Circuit Architecture.....	16
2.3.2 UWB Tunable Load.....	17
2.4 Flip-Chip Bonding.....	18
2.4.1 The Advantages.....	20
2.4.2 The Bumps.....	21
2.4.3 The Flip Chip Process.....	22

## **Chapter 3 Modeling, Simulation, and Optimized Design of**

<b>Micro-machined inductor</b> .....	<b>23</b>
3.1 Introduction.....	23
3.2 Inductance Calculation.....	25
3.2.1 Self-inductance.....	25
3.2.2 Mutual Inductance.....	27
3.2.3 Other Contribution.....	30
3.3 Capacitance Calculation.....	32
3.3.1 Distributed Capacitance Model.....	32
3.3.2 The Evaluation of Capacitance $C_s$ .....	33
3.4 Series Impedance Calculation.....	37
3.5 Simulated Method.....	37
3.6 Optimized design.....	39

## **Chapter 4 Fabrication Process of Silicon Carrier and**

<b>Gold-Gold Thermocompression Bonding</b> .....	<b>41</b>
4.1 Introduction.....	41
4.2 Consideration of layout.....	41
4.3 Passive Components on Carrier.....	43
4.4 Gold-Gold Thermocompression Bonding.....	47
4.5 Joining test.....	49

## **Chapter 5 Experimental Results and Discussions**.....

<b>Chapter 5 Experimental Results and Discussions</b> .....	<b>51</b>
5.1 Experimental Results for Modeling.....	51
5.1.1 Fabrication of test inductors.....	51
5.1.2 Measurement results.....	53
5.2 Chip Assembly.....	59

## **Chapter 6 Summary and Future Works**.....

<b>Chapter 6 Summary and Future Works</b> .....	<b>62</b>
6.1 Summary.....	62

6.2 Future Works.....	63
<b>References.....</b>	<b>65</b>
<b>Vita and Publication.....</b>	<b>67</b>

## Figure Captions

### Chapter 1

Fig. 1-1 The Bluetooth module yielded by Philips Corp in 2004.....	3
Fig. 1-2 The conceptive chart that a silicon carrier is assembled with the LNA chip made in standard process.....	3

### Chapter 2

Fig. 2-1 The non-uniform current distribution of planar spiral.....	7
Fig. 2-2 The substrate lumped circuit model of metal track.....	8
Fig. 2-3 When the magnetic field passed through substrate, the opposite-direction eddy current will be induced.....	9
Fig. 2-4 The equivalent circuit model of inductor.....	9
Fig. 2-5 The equivalent circuit model of the inductor with the substrate removal.....	10
Fig. 2-6 The SEM photographs of suspended inductor, (a) The oblique view of the fully suspended inductor, (b) the deformation on the corner region.....	12
Fig. 2-7 The SEM photographs of those fabricated suspended spiral inductors with cross membrane supporting. (a) the cross-sectional view, (b) the oblique view, (c) the TEOS oxide underneath the corner of the inductor is removed.....	13
Fig. 2-8 For the around 4nH micro-machined inductor, (a) the variation of inductance under 80°C, (b) the inductance and Q value of inductor. <b>S</b> : the suspended inductor; <b>M</b> : the suspended inductor with blanket membrane support; <b>CM</b> : the suspended inductor with cross membrane support.....	15
Fig. 2-9 The schematic of the tunable LNA for 3~8 GHz.....	17

Fig. 2-10 (a) the switched inductor. The equivalent model when (b) switch turned on, (c) switch turned off.....	18
Fig. 2-11 Chip to package or substrate interconnection techniques.....	20
Fig. 2-12 Reflowed solder bump on electroless nickel-gold UBM.....	22

## Chapter 3

Fig. 3-1 A square spiral inductor with three turns.....	24
Fig. 3-2 The equivalent circuit model of micro-machined inductor with the substrate removal.....	24
Fig. 3-3 An inductor with $n = 3.5$ turns is decomposed into segments.....	26
Fig. 3-4 Two parallel-filament geometry (a) with equal length, and (b) with different length.....	27
Fig. 3-5 (a) Segments on the opposite sides of the square spiral inductor contribute to the negative mutual inductance. (b) Segments on the same sides of the square spiral inductor contribute to the positive mutual inductance.....	30
Fig. 3-6 (a)The layout of square planar spiral inductor, (b) the oblique view.....	31
Fig. 3-7 (a)The voltage profile of a planar spiral inductor. (b) Distributed capacitance model of the $n$ -turn on-chip planar spiral inductor.....	34
Fig. 3-8 (a) The simulated environment, (b) Ground-signal-ground (GSG) pads are connected to the micro-machined inductor.....	39
Fig. 3-9 The rule of Optimized design for micro-machined RF spiral inductor.....	40

## Chapter 4

Fig. 4-1 The layout of micro-machined carrier with a LNA circuit.....	43
Fig. 4-2 The process flow of passive components on the carrier.....	45
Fig. 4-3 The joining process of Au-Au TC bonding between the micro-machined carrier and UWB tunable LNA chip.....	48
Fig. 4-4 The process flow of plating Au layer for joining.....	48
Fig. 4-5 The equipments setup of electroless plating for Ni and Au layer.....	49
Fig. 4-6 The test vehicles with and without copper studs are both coated with electroless	

Au layers and bonded with each other at 390°C . After separation, the copper stud has been torn away on **A1** and transferred onto another test vehicle **A2** by means of Au-Au bond. Consequently, it shows that the strength of Au-Au bond is enough to form the electrical and mechanical interconnection.....50

## Chapter 5

Fig. 5-1 The SEM photograph of suspended micro-machined inductor with cross membrane supporting. (a) Top view. (b) Oblique view. (c) The connected section of bridge.....	52
Fig. 5-2 The summary of comparison for a 2.3 nH micro-machined inductor. (a) <b>S11</b> and <b>S12</b> on Smith Chart. (b) <b>S11</b> . (c) Phase of <b>S11</b> . (d) <b>S12</b> . (e) Phase of <b>S12</b> . (f) The inductance and quality factor.....	55
Fig. 5-3 The summary of comparison for a 1.1 nH micro-machined inductor. (a) <b>S11</b> and <b>S12</b> on Smith Chart. (b) <b>S11</b> . (c) Phase of <b>S11</b> . (d) <b>S12</b> . (e) Phase of <b>S12</b> .....	58
Fig. 5-4 The photograph of a silicon carrier with cross-membrane micro-machined inductors.....	59
Fig. 5-5 The new type of opening area is used to control substrate etching rate well. _	60
Fig. 5-6 The integration of a MEMs carrier and LNA chip using Au-Au TC bonding_	61

## Table Captions

### Chapter 2

Table 2-1 Chip-level connection parameters.....	20
---	----

### Chapter 3

Table 3-1 The rule of Optimized design for micro-machined RF spiral inductor.....	40
---	----

### Chapter 6

Table 6-1 The summary of simulation performance between the LNA circuit switched with MIM capacitors and with MEMs inductors.....	63
---	----