Table of Contents

Approval Sheet…… ii

Declaration Sheet…… iii

Abstract……..... iv

Acknowledgement…….. vi

Table of Contents…… vii

List of Figures……. xv

List of Tables..……..... xxiv

List of Abbreviations ……..... xxvi

List of Symbols……... xxviii

CHAPTER ONE: INTRODUCTION…… 1

1.1 Motivations and Background…… 1

1.2 The role of IF Filters in Wireless Receiver…….. 6

1.3 Scope of Work…….. 7

1.4 Organizations of Thesis…… 8

CHAPTER TWO: LITERATURE REVIEW…… 10

2.1 Motivation……. 10

2.2 Analog Baseband Filter in Wireless Communication……... 11

2.3 Channel Select Filtering and Tradeoffs…… 12

2.3.1 Digital Filters……... 13

2.3.2 Sampled Data Filters ……. 13

2.3.3 Continuous Time Filters……... 14

2.3.3.1 Continuous Time Analog Filters……. 15

2.4 Receiver Architecture……... 16

2.4.1 Superhetrodyne Receiver……. 18

2.4.2 Direct Conversion Receiver……. 20

2.4.3 Wide-Band IF Receiver……... 23

2.4.4 Digital IF Receiver……... 24

2.5 Channel Selection Filters…….. 25
2.5.1 Channel Select Filtering and ADC requirement…….. 26
2.6 CMOS Continuous Time Filters……... 27
2.6.1 Active RC Filter…….. 29
2.6.2 MOSFET-C Filter……... 33
2.6.3 OTA-C Filter……... 36
2.7 CMOS OTAs……. 38
2.7.1 Single Input/Output OTAs……... 38
2.7.2 Differential OTAs…… 40
2.7.3 OTA Trends……. 42
2.7.3.1 High Frequency…… 42
2.7.3.2 High Linearity…….. 44
2.7.3.3 Low Power……... 47
2.8 OTA Topology…….. 49
2.8.1 Symmetrical OTA……... 49
2.8.2 Telescopic OTA…….. 50
2.8.3 Folded Cascode OTA…….. 50
2.9 Automatic Tuning Schme……. 52

CHAPTER THREE: DESIGN AND IMPLEMENTATION OF CMOS FOLDED CASCODE OTA……. 53
3.1 Analog Integrated Circuits…… 53
3.2 Analog Design Flow……. 55
3.2.1 The Manual Design Methodology……... 56
3.3 Challenges in Analog Design…… 58
3.4 Process Technology…….. 62
3.4.1 The CMOS Devices …… 63
3.5 Performance Metrics in Amplifier Design…… 66
3.6 Operational Amplifier……... 74
3.6.1 Operational Transconductance Amplifier…… 76

3.6.2 Single Stage OTA…… 78
3.6.3 Telescopic Topology…… 78
3.6.4 Folded Cascode Topology……... 79
3.6.5 Two Stage Topology…… 81
3.6.6 Two Stage, Telescopic & Folded Cascode Topology: Discussion…….. 82
3.7 g_m / I_d Methodology……. 84
3.8 Why Folded cascode OTA?..... 88
3.8.1 Basic Configuration of CMOS Folded Cascode OTA…… 90
3.8.2 CMOS Differential Amplifier(N-Channel) with Current Mirror…… 91
3.8.3 CMOS Differential Amplifier(P-Channel) with Current Mirror…… 94
3.8.4 What is Current Mirror……... 95
3.8.5 Cascode Current Mirror ……. 96
3.8.6 Wilson Current Mirror…… 97
3.8.7 Designed Practical Folded Cascode OTA…….. 100
3.9 Simulation Results of Wilson Current Mirror Base Folded Cascode OTA…. 103
3.9.1 Gain and Unit Gain Bandwidth(UGBW) of Wilson Current Mirror base Folded Cascode OTA……. 103
3.9.2 Phase Margin of Wilson Current Mirror base Folded Cascode OTA .. 104
3.9.3 Input/Output Swing and Offset of Wilson Current Mirror base Folded Cascode OTA……. 105
3.9.4 Slew Rate of of Wilson Current Mirror base Folded Cascode OTA … 106
3.9.5 Common Mode Gain of Wilson Current Mirror base Folded Cascode OTA…….. 107
3.9.6 Input Noise Spectral Density of Wilson current Mirror base Folded Cascode OTA…… 108
3.9.7 Output Noise Spectral Density of Wilson current Mirror base Folded Cascode OTA…… 109
3.9.8 Transient Analysis of Wilson Current Mirror base Folded Cascode OTA……... 110
3.9.9 ICMR of Wilson Current Mirror base Folded Cascode OTA…… 111
3.10 Input-Output Noise per Device ……. 112

3.11 Summary of Simulated Results of Wilson Current Mirror base Folded Cascode OTA ……. 113
3.12 Layout and 3-D process of Wilson Current Mirror base Folded Cascode OTA……. 114
3.13 Post Layout Simulation Results of Wilson Current Mirror Base Folded Cascode OTA…….. 117
3.13.1 Gain and Unit Gain Bandwidth(UGBW) of Wilson Current Mirror base Folded Cascode OTA…….. 117
3.13.2 Phase Margin of Wilson Current Mirror base Folded Cascode OTA …… 118
3.13.3 Input/Output Swing and Offset of Wilson Current Mirror base Folded Cascode OTA…….. 119
3.13.4 Slew Rate of of Wilson Current Mirror base Folded Cascode OTA 120
3.13.5 Common Mode Gain of Wilson Current Mirror base Folded Cascode OTA…… 121
3.13.6 Input Noise Spectral Density of Wilson current Mirror base Folded Cascode OTA…….. 122
3.13.7 Output Noise Spectral Density of Wilson current Mirror base Folded Cascode OTA……. 123
3.13.8 Transient Analysis of Wilson Current Mirror base Folded Cascode OTA……. 124
3.13.9 ICMR of Wilson Current Mirror base Folded Cascode OTA……. 125
3.14 Pre and Post Layout Simulated Result Comparison of Wilson Mirror base Folded Cascode OTA……... 126
3.15 Monte Carlo Analysis of Wilson Mirror base Folded Cascode OTA…….. 127
3.15.1 AC Analysis with change NMOS Threshold Voltage……. 127
3.15.2 AC Analysis with change PMOS Threshold Voltage…….. 128
3.15.3 AC Analysis with change both NMOS and PMOS Threshold Voltage……. 129
3.15.4 Input-Ouput Noise Spectral Density Analysis with both NMOS and PMOS Threshold Voltage……. 130

3.15.5 AC Analysis with Change Oxide Thickness……. 131
3.16 Cascode Current Mirror Improved Folded Cascode OTA Design……. 132
3.17 Noise and its Analysis…… 134

CHAPTER FOUR: DESIGN AND IMPLEMENTATION OF DUAL BAND CMOS Gm-C IF FITLER FOR GSM AND FM BAND... 141

4.1 Introduction…….. 141
4.2 Operational Transconductance Amplifier and simple circuits……. 142
4.2.1 Grounded Resistor…… 143
4.2.2 Floating Resistor…….. 144
4.2.3 Integrator……. 144
4.2.4 Lossy Integrator ……. 145
4.2.5 Amplifier …… 146
4.2.6 Weighted Summer…….. 146
4.2.7 Positive Impedance Inverter ……. 147
4.3 Filter Fundamentals……. 149
4.4 Filter Architecture…… 151
4.4.1 Sensitivity…… 151
4.4.2 Cascade Realizations…….. 152
4.4.3 Multiple-Loop Feedback Realization……. 154
4.4.3.1 Leapfrog Topology …… 154
4.4.3.2 Summed-Feedback Topology……. 155
4.4.3.3 LC Ladder Simulation…… 156
4.4.3.4 Performance comparison of the three different architecture….. 157
4.5 Active CMOS Gm-C Filters ……. 159
4.5.1 Introduction……. 159
4.5.2 Design of First order Filter……. 164
4.5.3 Design of Second Order Filter…… 167
4.6 Implementation of Active CMOS Gm-C Band Pass Filters …….. 175
4.6.1 Introduction …….. 175
4.6.2 Filter Specifications…….. 179

4.6.3 General Biquad Implementation for Second order CMOS Gm-C Band Pass Filter…….. 179
4.7 Simulations Results of GSM 70MHz IF Biquad Second Order CMOS Gm-C Filter ……... 186
4.7.1 70MHz IF Second Order CMOS Gm-C Low Pass Filter Response…... 186
4.7.2 70MHz IF Second Order CMOS Gm-C High Pass Filter Response….. 187
4.7.3 70MHz IF Second Order CMOS Gm-C Band Pass Filter Response….. 188
4.7.4 70MHz IF Second Order CMOS Gm-C Band Stop Filter Response …. 189
4.8 Layout of GSM 70MHz IF Biquad Second Order CMOS Gm-C Filter…… 190
4.9 Post Layout Simulation Results of GSM 70MHz IF Biquad Second Order CMOS Gm-C Filter…… 191
4.9.1 70MHz IF Second Order CMOS Gm-C Low Pass Filter Response….. 191
4.9.2 70MHz IF Second Order CMOS Gm-C High Pass Filter Response…. 192
4.9.3 70MHz IF Second Order CMOS Gm-C Band Pass Filter Response…. 193
4.9.4 70MHz IF Second Order CMOS Gm-C Band stop Filter Response…. 194
4.10 Pre and Post Layout simulated Result comparison of 70MHz IF Second Order CMOS Gm-C Filter…… 194
4.11 Monte Carlo Simulations for 70MHz IF CMOS Gm-C Band Pass filter with NMOS Threshold Voltage ……... 195
4.12 Temperature Variations in 70MHz IF CMOS Gm-C Band Pass filter…….. 196
4.13 Supply Voltage Variations in 70MHz IF CMOS Gm-C Band Pass filter…. 200
4.14 Simulations Results of FM 10.6MHz IF Biquad Second Order CMOS Gm-C Filter……. 201
4.14.1 10.6MHz IF Second Order CMOS Gm-C Low Pass Filter Response 201
4.14.2 10.6MHz IF Second Order CMOS Gm-C High Pass Filter Response……. 202
4.14.3 10.6MHz IF Second Order CMOS Gm-C Band Pass Filter Response …… 203
4.14.4 10.6MHz IF Second Order CMOS Gm-C Band stop Filter Response……. 204
4.15 Layout of FM 10.6 MHz IF Biquad Second Order CMOS Gm-C Filter…. 205

4.16 Post Layout Simulation Results of FM 10.6MHz IF Biquad Second Order CMOS Gm-C Filter…….. 206
4.16.1 10.6MHz IF Second Order CMOS Gm-C Low Pass Filter Response…….. 206
4.16.1 10.6MHz IF Second Order CMOS Gm-C High Pass Filter Response…….. 207
4.16.1 10.6MHz IF Second Order CMOS Gm-C Band Pass Filter Response…….. 208
4.16.1 10.6MHz IF Second Order CMOS Gm-C Band Stop Filter Response…….. 209
4.17 Pre and Post Layout simulated Result comparison of 10.6MHz IF Second Order CMOS Gm-C Filter……... 209
4.18 Monte Carlo Simulations for 10.6MHz IF CMOS Gm-C Band Pass filter with NMOS Threshold Voltage…….. 210
4.19 Temperature Variations in 10.6MHz IF CMOS Gm-C Band Pass filter….. 211
4.20 Power Supply Variations in 10.6MHz IF CMOS Gm-C Band Pass filter… 215
4.21 S-Parameter…….. 216
4.21.1 S-parameter Simulation Results for 70MHz GSM IF …….. 218
4.21.1.1 S-Parameter S_{21} Simulation Result……... 218
4.21.1.2 S-Parameter S_{21} and S_{11} Simulation Result……. 219
4.21.1.3 S-Parameter S_{21} and Angle of Transmission Simulation Result……... 220
4.21.1.4 Simulation Result of Smith Chart for S_{11} …… 221
4.21.1.5 Simulation Result of Smith polar plot for S_{21} ……. 222
4.21.2 S-parameter Simulation Results for 10.6MHz FM IF…….. 223
4.21.2.1 S-Parameter S_{21} Simulation Result…….. 223
4.21.2.2 S-Parameter S_{21} and S_{11} Simulation Result……. 224
4.21.2.3 S-Parameter S_{21} and Angle of Transmission Simulation Result ……. 225

4.21.2.4 Simulation Result of Smith Chart for S_{11} …… 226

4.21.2.5 Simulation Result of Smith polar plot for S_{21} …….. 227

4.22 Dual Band Filter Measurement Results……. 228

4.23 Automatic Tuning Scheme…… 229

4.23.1 Existing Tuning Method…… 229

4.23.2 Proposed Tuning Method…….. 231

4.23.3 Comparator and Analog Switch Layout…… 238

4.24 Comparison with Previously Reported Work…….. 239

CHAPTER FIVE: CONCLUSION AND FUTURE SCOPE…… 240

5.1 Conclusion ……... 240

5.2 Summary of Work…… 243

5.3 Future Scope…… 245

List of Publication based on Research Work……..... 246

Appendix A: BSIM3V3 Level 49 Model Parameter……..... 247

Appendix B: AC Small Signal Models ……..... 249

References……... 257