WIDEBAND ACTIVE-BALUN VARIABLE-GAIN LOW-NOISE AMPLIFIER FOR MOBILE-TV APPLICATIONS

by

LO KENG WAI
M-A2-6275-3

Master of Science
in
Electrical and Electronics Engineering

April 2010

Faculty of Science and Technology
University of Macau
WIDE BAND ACTIVE-BALUN VARIABLE-GAIN LOW-NOISE AMPLIFIER FOR MOBILE-TV APPLICATIONS

by

LO KENG WAI

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science (M.Sc.)
in
Electrical and Electronics Engineering

Faculty of Science and Technology
University of Macau

April 2010

Approved by ______________________________________________________________

Supervisor

___________________________________________________________

Co-supervisor

___________________________________________________________

Date _____________________________________________________________________
In presenting this thesis in partial fulfillment of the requirements for a Master's degree at the University of Macau, I agree that the Library and the Faculty of Science and Technology shall make its copies freely available for inspection. However, reproduction of this thesis for any purposes or by any means shall not be allowed without my written permission.

Signature _____________________

Date _________________________
Wideband Active-Balun Variable-Gain Low-Noise Amplifier for Mobile-TV Applications

ABSTRACT

The rapid development of wireless communications and CMOS technology has facilitated the integration of radio frequency (RF) systems as a System-on-Chip (SOC) for cost and power reductions. One of the applications is the RF TV tuner for Digital Video Broadcasting-Handheld (DVB-H). With the development of digital mobile TV industry the TV tuner system has gained wide attention recently.

Variable Gain Low-Noise Amplifier (VGLNA) is one of the most important modules in the TV tuner system. The main function of a VGLNA is to provide enough gain to suppress the noise of subsequent stages as well as adding as little noise as possible.

Recent works on wideband low-noise amplifiers (LNAs) based on an active-balun structure have shown reliable RF performances such as moderate noise figure (NF), high linearity and broadband input impedance matching. This structure has exhibited great potential in minimizing the required external components of multi-band mobile-TV tuners, i.e., an active-balun LNA requires just one radio frequency (RF) input pin and eliminates the need of external balun for each band, which is necessary in the current design.

This thesis will propose a novel active-balun LNA with forestage and poststage gain controls. With this forestage-poststage gain controls the system noise figure and linearity can be easily traded for different gain levels. In addition, the benefits of this design allow also the decrease in circuit complexity, chip area and the power consumption. In this architecture just one Single to Differential (S2D) amplifier is required.

The first part of this work will introduce the theoretical MOSFET noise model and conventional VGLNA circuits. The second part will present the circuit level design based on the proposed architecture. The VGLNA was designed with two passive attenuators inter-operating with an active core to optimize the RF performances under different reception scenarios. It was implemented in a 0.18\( \mu \)m CMOS process with 1.8V of voltage-supply.

Finally, the simulation results of the whole circuit are presented. The VGLNA supports both VHF-III (170 to 240 MHz) and UHF (470 to 860 MHz) bands while offering low NF and \( S_{11} < -10 \) dB at all gain levels. The forestage and poststage gain controls flexibly befit reception at different signal-to-interferer levels. The circuit achieves good performances in the required frequency bands and satisfies the requirements of the mobile TV tuner applications.
ACKNOWLEDGEMENTS

I would like to take this opportunity to express my gratitude to my supervisor – Dr. Pui-In Mak and co-supervisor – Prof. Rui Martins for their generous guidance and patience throughout my study. Without their support, inspiration, and patience, my work in these years would not be so fruitful. I would also like to take this opportunity to thank the colleagues in the Analog and Mixed-Signal VLSI Laboratory for giving me support and guidance which were essential and valuable in my research work.

Next, I would like to thank my friend, Mr. Sunny Chio, Mr. U-Fat Chio and Mr. Chang-Hao Chen for their technical and non-technical discussions in the past that have enhanced my knowledge quite considerably.

Special thanks should be given to the laboratory technician – Mr. Fan Ng, who helped me to solve numerous problems. Finally, I am deeply indebted to my parents for their unconditional love and support over the years. Without them, I would not have obtained my harvest by now.

Lo Keng Wai (Neo)
April 2010
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATT</td>
<td>attenuator</td>
</tr>
<tr>
<td>BW</td>
<td>bandwidth</td>
</tr>
<tr>
<td>CMFB</td>
<td>common mode feedback</td>
</tr>
<tr>
<td>CMOS</td>
<td>complementary metal oxide semiconductor</td>
</tr>
<tr>
<td>CG-CS</td>
<td>common gate common source topology</td>
</tr>
<tr>
<td>DC</td>
<td>direct current</td>
</tr>
<tr>
<td>DVB-H</td>
<td>digital video broadcasting handheld</td>
</tr>
<tr>
<td>IC</td>
<td>integrated circuit</td>
</tr>
<tr>
<td>IF</td>
<td>intermediate frequency</td>
</tr>
<tr>
<td>IIP3</td>
<td>third-order input intercept point</td>
</tr>
<tr>
<td>NF</td>
<td>noise figure</td>
</tr>
<tr>
<td>OpAmp</td>
<td>operational amplifier</td>
</tr>
<tr>
<td>PSRR</td>
<td>power supply rejection ratio</td>
</tr>
<tr>
<td>RC</td>
<td>resistor-capacitor</td>
</tr>
<tr>
<td>RF</td>
<td>radio frequency</td>
</tr>
<tr>
<td>S2D</td>
<td>single-to-differential</td>
</tr>
<tr>
<td>SNR</td>
<td>single to noise ratio</td>
</tr>
<tr>
<td>SOC</td>
<td>system-on-chip</td>
</tr>
<tr>
<td>TV</td>
<td>television</td>
</tr>
<tr>
<td>UHF</td>
<td>ultra high frequency</td>
</tr>
<tr>
<td>VGLNA</td>
<td>variable gain low noise amplifier</td>
</tr>
<tr>
<td>VHF</td>
<td>very high frequency</td>
</tr>
</tbody>
</table>
# Table of Contents

Abstract I

Acknowledgements III

List of Abbreviations V

Table of Contents VII

List of Figures XI

List of Tables XIII

Chapter 1: Introduction 1

1.1 Background 1

1.2 Narrowband LNA 2

1.3 Wideband LNA 3

1.4 Noise canceling technique 6

1.5 Noise figure and linearity of LNA 6

1.6 Research objectives 8

1.7 Statement of originality 8

1.8 Thesis organization 9

1.9 References 10

Chapter 2: Low Noise Amplifier basic concepts 11

2.1 Introduction 11

2.2 Noise in MOSFET 11
2.2.1 Source of noise
2.2.2 Noise models of the MOS transistors
2.3 Basic Low Noise Amplifier Topology
2.4 Common gate common source (CG-CS) topology
   2.4.1 Balancing (balun operation)
   2.4.2 Noise canceling operation
   2.4.3 Distortion canceling
   2.4.4 Noise analysis of the CG-CS topology
2.5 References

Chapter 3: A State-of-the-Art CMOS Variable-Gain Low-Noise Amplifier
3.1 Introduction
3.2 Single-to-differential stage
3.3 Performance analysis
3.4 Attenuator design
3.5 Architecture of VGLNA
3.6 References

Chapter 4: Architecture of the proposed variable gain low noise amplifier
4.1 Introduction
4.2 MOS-Based attenuator
   4.2.1 Impedance matching and S parameter
   4.2.2 Analysis of the circuit of the MOS-based attenuator
4.3 CAP-Based attenuator
4.4 The Active-Balun LNA core
4.5 Improvement of the PSRR 45
4.6 Simulation Results 46
4.7 References 55

Chapter 5: Conclusions and Future Work 57
5.1 Conclusions 57
5.2 Recommendations for future work 58
LIST OF FIGURES

Figure 1.1: Block diagram of direct conversion receive. 1
Figure 1.2: Source degeneration LNA. 3
Figure 1.3: Configuration of shunt-series amplifier. 4
Figure 1.4: Combining balun and LNA into a single Balun-LNA integrated circuit. 5
Figure 1.5: Dynamic Range of a system. 6
Figure 2.1: Drain current noise model. 12
Figure 2.2(a): Gate noise circuit model. 13
Figure 2.2(b): Equivalent voltage noise source model. 13
Figure 2.3: Flicker noise model. 16
Figure 2.4(a): MOSFET noise model. 16
Figure 2.4(b): Equivalent input referred noise model. 16
Figure 2.5(a): Resitive termination. 18
Figure 2.5(b): $1/g_m$ termination. 18
Figure 2.5(c): Shunt-series feedback. 18
Figure 2.5(d): Inductive degeneration. 18
Figure 2.6: The basic CG-CS topology in which the noise of the CG-transistor can be canceled at the outputs. 20
Figure 2.7: Small signal equivalent of a CG-stage. 21
Figure 2.8: Noise Figure (NF), voltage gain ($A_V$) and gain imbalance ($\Delta A_V$) versus impedance scaling factor ‘$n$’ for three different cases. 26
Figure 3.1: Schematic of single-to-differential circuit. 31
Figure 3.2: A modified S2D circuit. 31
Figure 3.3: Noise figure analysis for S2D. 33
Figure 3.4: A five steps resistive attenuator. 34
<table>
<thead>
<tr>
<th>Figure 3.5</th>
<th>Simplified schematic of VGLNA.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 4.1</td>
<td>VGLNA with two S2Ds and an on-chip capacitor $C_1$.</td>
</tr>
<tr>
<td>Figure 4.2</td>
<td>Proposed VGLNA with Forestage-Poststage Gain Controls.</td>
</tr>
<tr>
<td>Figure 4.3</td>
<td>Schematic of the proposed VGLNA with Forestage-Poststage Gain Controls.</td>
</tr>
<tr>
<td>Figure 4.4</td>
<td>MOS-based ATT., $m_{LG}$ is control switch, $G_0 \sim G_3$ are transistors biased at triode region.</td>
</tr>
<tr>
<td>Figure 4.5</td>
<td>Two-Port Network.</td>
</tr>
<tr>
<td>Figure 4.6</td>
<td>MOS-based ATT and its equivalent circuits at different attenuation levels.</td>
</tr>
<tr>
<td>Figure 4.7</td>
<td>CAP-based ATT., transmission gates are employed for all switches.</td>
</tr>
<tr>
<td>Figure 4.8</td>
<td>Transmission gate switch characteristic.</td>
</tr>
<tr>
<td>Figure 4.9</td>
<td>NF and IIP3 at all gain steps at VHF-III band.</td>
</tr>
<tr>
<td>Figure 4.10</td>
<td>NF and IIP3 at all gain steps at UHF band.</td>
</tr>
<tr>
<td>Figure 4.11</td>
<td>Simulated S21 at different gain steps.</td>
</tr>
<tr>
<td>Figure 4.12</td>
<td>Voltage gain versus gain steps at UHF band.</td>
</tr>
<tr>
<td>Figure 4.13</td>
<td>Voltage gain versus gain steps at VHF-III band.</td>
</tr>
<tr>
<td>Figure 4.14</td>
<td>NF versus frequency at UHF band</td>
</tr>
<tr>
<td>Figure 4.15</td>
<td>NF versus frequency at VHF-III band.</td>
</tr>
<tr>
<td>Figure 4.16</td>
<td>IIP3 simulation at UHF band.</td>
</tr>
<tr>
<td>Figure 4.17</td>
<td>IIP3 simulation at VHF-III band.</td>
</tr>
<tr>
<td>Figure 4.18</td>
<td>Simulated $S_{11}$ versus frequency in VHF-III and UHF band.</td>
</tr>
<tr>
<td>Figure 4.19</td>
<td>Simulated PSRR- versus frequency.</td>
</tr>
<tr>
<td>Figure 4.20</td>
<td>Simulated PSRR+ versus frequency.</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 4.1: Gain control of the MOS-based attenuator. 42
Table 4.2: Gain control of the CAP-based attenuator. 43
Table 4.3: Summary and Performance Comparison. 53