A RF CMOS Low Noise Amplifier for WiMAX Applications

JENN-TZER YANG, HSIAO-PING FAN, MING-JEUI WU, AND PING-JUNG TSAI
Department of Electronic Engineer
Ming-Hsin University of Science and Technology
1 Hsin-Hsing Rd. Hsin-Fong Hsin-Chu, Taiwan
yjn@must.edu.tw and c96030006@std.must.edu.tw

Abstract: - In this paper, a radio frequency (RF) CMOS low noise amplifier (LNA) for WiMAX applications is presented. In this amplifier, it is used a high-Q active inductor with band selector and a differential output configure to operate at three different frequency bands and obtain low noise figure (NF), high enough power gain, and low power consumption. Using TSMC 0.18um process, the proposed amplifier can be simultaneously operated multi-band at 2.6GHz, 3.6GHz, and 5.5GHz for WiMAX applications. Simulation results show that the proposed LNA have the forward gain of 35.7dB, 33.4dB, and 17dB, the IIP3 of -11.6dBm, -7dBm, and -9dBm, the noise figure of 1.2dB, 1.4dB, and 0.16dB, and the 1dB compression of -14dBm, -12dBm, and -9dBm in the 2.6GHz, 3.6GHz, and 5.5GHz frequency bands, respectively. The power consumption of the proposed amplifier is about 16.4mW, 21mW, and 12.7mW at 1.8V power supply in the 2.6GHz, 3.6GHz, and 5.5GHz frequency bands, respectively.

Key-Words: - CMOS, Low noise Amplifier, Active Inductors, Multi-Band, and WiMAX.

1 Introduction
High data rate wireless local area networks have become popular for portable computing [1]. IEEE 802.16 standard heralds the entry of broadband wireless access as a major new tool to link homes and businesses to access telecommunications networks worldwide. The specifications of IEEE802.16a address frequencies from 2GHz to 11GHz, including licensed and un-licensed bands [2].

It is desirable to combine more standard frequency bands in one mobile unit [3, 4]. One of the design challenges is to realize a full integrated multi-band low noise amplifier with frequency selecting capability. Typical design strategies have used different amplifiers for different frequency bands [5]. However, this way inevitably increases cost and power consumption. Recently, various circuit techniques have been proposed by employing switched passive spiral inductors or switched capacitors for the load and the matching networking of the amplifiers [7, 8]. Nevertheless, most of these techniques demand additional passive components for the load and the input/output matching networks, leading to a significant increase in chip size and the implementation cost. An alternative method called active inductor uses the CMOS active devices as an inductor, where the equivalent inductive impedance can be implemented. The disadvantages of passive spiral inductors can be overcome by using an active inductor. The quality-factor and the inductance value are high enough to overcome the value exhibited by conventional spiral inductors. Depending on the chosen topology, the loss of an active inductor caused by the active devices can be greatly reduced and the area of an active inductor is independent of the desired inductance values [9-12]. Most of the active inductor circuits were applied in low noise amplifier and voltage controlled oscillator produced impressive results [13-17]. In this paper, using TSMC 0.18um processing, a CMOS RF low noise amplifier based on a high-quality active inductor with band selector topology acted as a load of the amplifier, used two stages common source amplifier, and applied differential output configuration can be operated at multi-band in one unit for WiMAX applications to obtain a high Q value of inductor, a low noise amplifier of high forward gain, low noise figure, high linearity, low power consumption, and decreasing chip area.

2 Active Inductor with Band Selector
The simple grounded active inductor circuit and its equivalent circuit are shown in Fig.1. Each MOS transistor is modeled by the equivalent device components including $g_{m}$, $g_{ds}$, $C_{gs}$, and $C_{gd}$. Assumed that $g_{m} >> g_{ds}$, and $C_{gs} >> C_{gd}$ are established, and then the equivalent input impedance ($Z_{in}$) of this inductor can be derived as Eq. (1). According to the Eq. (1), the conductance (G) and the inductance (L) of the inductor can be expressed from Eq. (2) and Eq. (3). The Q value and the resonant frequency $\omega_0$ are shown in Eq. (4) and Eq. (5), respectively.
where $g_{mi}$, $g_{dsi}$, and $C_{gsi}$ are the transconductance, the output conductance, and the gate-source capacitance of correspondence transistors, respectively. By Eq. (2), the increasing parallel conductance loss of (G) will reduce the Q value of the inductor. Therefore, in order to improve the performance such as the Q value, a high-Q active inductor using a feedback resistor is proposed.

The improved high-Q active inductor circuit and the equivalent circuit are illustrated in Fig. 2. This circuit is composed of common-source transistor $M_4$, common-drain transistor $M_3$, feedback resistor $R_f$ and two biasing current sources $I_1$ and $I_2$. Feedback resistor and transistor $M_4$ construct a gain network. This network produces a gain factor to reduce the parallel conductance loss (G). Hence, the equivalent internal loss of the inductor will be decreased, and then the Q value will be increased. Moreover, the inductance (L) is also increased due to the feedback resistor. At high frequency, this circuit is equivalent to a resonator as well, which is the same as Fig. 2. The conductance (G) values and the inductance (L) of this inductor including three parameters, $C_{gsi}$, $g_{dsi}$, and $g_{mi}$ are derived as Eq. (6) and Eq. (7). The Q value and the resonant frequency $\omega_0$ are shown in Eq. (8) and Eq. (9), respectively.

$$G \approx g_{ds1} + \frac{g_{m4}}{1 + R_f g_{ds4}}$$  \hspace{1cm} (6)

$$L \approx \frac{C_{gs3}}{g_{m3}} \frac{1 + R_f g_{ds4}}{g_{m3}}$$  \hspace{1cm} (7)

$$Q \approx \sqrt{\frac{g_{m4} g_{m3} C_{gs3}}{g_{ds4} C_{gs4}} \left(1 + R_f g_{ds4}\right)}$$  \hspace{1cm} (8)

$$\omega_0 \approx \sqrt{C_{gs4} C_{gs3} \left(1 + R_f g_{ds4}\right)}$$  \hspace{1cm} (9)

By Eq. (6) and Eq. (7), the effect of the factor, $(1+R_f g_{ds4})$, is designed to be a value greater than unity. This factor will result in the equivalent conductance loss (G) to be minimized and the equivalent inductance (L) to be increase as well. From Eq. (8) and (9), the Q value is promoted with the feedback resistance by the $\sqrt{1 + R_f g_{ds4}}$ factor and the resonant frequency $\omega_0$ is inverse proportion of the $\sqrt{1 + R_f g_{ds4}}$ factor.

In order to change the characteristics of the active inductor, the active inductor can use a simple network to control the feedback resistance. In Fig. 3 this simple network, including different feedback resistances can be selected by using binary code to form a band selector. The band selector can choose all kinds of resistance using different binary code, and then the inductance, the Q-value, and the resonating frequency $\omega_0$ of the inductor will be changed.

$$L \approx \frac{C_{gs3}}{g_{m3}} \frac{1 + R_f g_{ds4}}{g_{m3}}$$  \hspace{1cm} (7)

$$Q \approx \sqrt{\frac{g_{m4} g_{m3} C_{gs3}}{g_{ds4} C_{gs4}} \left(1 + R_f g_{ds4}\right)}$$  \hspace{1cm} (8)

$$\omega_0 \approx \sqrt{C_{gs4} C_{gs3} \left(1 + R_f g_{ds4}\right)}$$  \hspace{1cm} (9)

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3 Band Selector Circuit

In Fig. 4 shows the circuit of the band selector to select the feedback resistor. It is formed by using six transmission gates and two inverters to select the resistance. As input binary code \((S_1S_0)\) of the multiplex apply with individual 00, 01, and 10, and then the feedback resistance of \(R_{2600}, R_{3600},\) and \(R_{5500}\) will be selected respectively.

Moreover, the proposed active inductor, due to the DC bias current does not pass through the band selector. The voltage drop of the band selector is zero. Hence, the DC voltage drop of the band selector will not be affected the characters of the inductor during the feedback resistor is changed. Therefore, the power consumption of the active inductor can be retained constant.

4 Proposed Multi-Band LNA design

An active inductor can be applied in a multi-band amplifier design to obtain multiple bands, high gain, high linearity, low noise figure, and low power consumption. Typically, the inductance load is applied with a passive spiral inductor. However, inherently low Q-factors and occupied large chip area, the gain and the cost-performance of the amplifier designs will be significantly decreased. Hence, an active inductor can employ in the load of the amplifier to improve above these disadvantages.

\[
Z_{in} \approx \frac{1}{g_{m1} + g_{m2} + j\omega C_{gs2} + j\omega C_{gs1}} \approx \frac{1}{g_{m2}} \quad (10)
\]

In the Fig5, the multi-band low noise amplifier circuit consists of common gate configuration, active inductor loads, and the differential output, which formed single input port and double output ports. Large gain and low noise figure (NF) can be obtained on the differential output. On the left-handed side of the circuit is a common gate, a common source, an active inductor, and a buffer. On the right-handed side have a common source, an active inductor, and a buffer. Transistors \(M_1\) and \(M_2\) is the common gate of the input stage which can be easily matched. In the common-gate configuration, transistors \(M_1\) and \(M_2\) are employed as the input stage for input impedance matching. The input impedance \((Z_{in})\) of this amplifier can be approximated as Eq. (10). Where \(g_{m1}, g_{m2}\) and \(C_{gs}\) are the transconductance, the output conductance, the gate-drain capacitance, and the gate-source capacitance of correspondence transistors, respectively. Hence, the input matching of the amplifier can be easily achieved by setting \(1/g_{m2}\). The Q value of the active inductor is high, enhancing the performance of the circuit. \(M_4\) and \(M_13\) are formed two stages common-source configuration to obtain an inverse signal to output. \(M_6 \sim M_9\) are the transistors of the buffer for output match.
A large gain of differential output is obtained from $V_{out+}$ and $V_{out-}$, but the signal path does not affect the phase of noise. If the noise of two output ports is closer, the noise will be canceled by differential output.

**5 Simulation Results of the LNA**

After careful design and simulation, the multi-band low noise amplifier is designed by using TSMC 0.18-um processing to develop the WiMAX systems. The proposed low noise amplifier can be operated at 2.6GHz, 3.6GHz, and 5.5GHz bands have a good performance as compared to the conventional ones. Fig. 6 and Fig. 7 show that the forward gain of 35.7dB, 33.4dB, and 17dB and the noise figure of 1.2dB, 1.4dB, and 0.16dB at 2.6GHz, 3.6GHz, and 5.5GHz frequency bands, respectively. The Fig. 8 displays the input reflection $S_{11}$ of -11.5dB, -12.7dB, and -8.4dB at 2.6GHz, 3.6GHz, and 5.5GHz bands, respectively. From the simulation results of the proposed amplifier, the characteristics of the proposed amplifier are satisfied the specifications for WiMAX applications. The comparisons with other literatures are shown in Table 1, which the performance is better than other works.

**6 Conclusions**

In this paper, a multi-band low noise amplifier using an active inductor with band selector for WiMAX applications is obtained. The amplifier can operate at 2.6GHz, 3.6GHz, and 5.5GHz frequency bands, which uses two bits binary controlled codes. In this amplifier, the high enough forward gain, the reasonable input and output reflection coefficients, high linearity, low power consumption, and the low noise figure operating at the selected frequency bands can be obtained.

**References:**


Table 1 Comparisons with other literatures

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