A Low-Power Monolithic Reconfigurable Direct-Conversion Receiver RF Front-end for 802.11a/b/g Applications

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Abstract—A low power monolithic reconfigurable direct-conversion receiver RF front-end for 802.11a/b/g applications is presented. It consists of a reconfigurable LNA and a high linearity quadrature down-converter. The LNA could be switched between two operation bands by utilizing a fully-differential switchable inductor. With a positive feedback, the noise figure of the common gate LNA is lowered down. The quadrature down-converter could be shared for multi-band multi-mode applications due to its wide band characteristics. The RF front-end has been implemented in 180nm CMOS process and the experimental results show that the front-end could achieve a NF of 3.6dB at 2.4GHz and 6.6dB at 5GHz while providing a gain of 33dB at 2.4GHz and 24 dB at 5GHz. The front-end consumes 18mW power and the die area is 1.2mm × 1mm.

Index Terms—CMOS, reconfigurable, RF, direct conversion receiver, switchable inductor

I. INTRODUCTION

The rapid growth of wireless communication market results in various wireless standards. Even only for wireless local area network (WLAN) applications, there are four standards: IEEE 802.11a/b/g/n. So it is urgent to develop the monolithic reconfigurable receiver. The receiver should be compatible with different standards, being able to be reconfigured into different modes to satisfy the requirements of various standards. Due to the high integration level and simple baseband circuit, the direct conversion (Zero-IF) architecture is the most attractive one for the reconfigurable receivers among various architectures. However, there still exist many challenges to implement such a reconfigurable receiver in deep-submicro CMOS process.

During the implementation of the reconfigurable receiver, one of the most challenging issues is the large dynamic range requirement since the receiver should satisfy the performance demands for various standards. The design should be traded off among gain, noise, linearity, die area and power consumption.

In this paper, a low power reconfigurable direct-conversion receiver RF front-end for 802.11a/b/g applications is presented. It includes a reconfigurable LNA and a quadrature down-converter.

II. RECEIVER ARCHITECTURE

There exist several methods to implement the multi-band multi-mode receivers. The simplest method is to use multi paths, each path for one signal band [1]. Its advantage is that the receiver can be optimized separately for each application, and the disadvantages include the high power consumption and the large die area.

To maximize the block sharing, a reconfigurable receiver RF front-end architecture with only one signal path is more attractive [2]. Figure 1 shows its architecture. The receiver utilizes the direct-conversion architecture for its high integration level and simple baseband circuit. It consists of a reconfigurable LNA and a high linearize quadrature down-converter. The LNA could be switched between two operation bands by a digital control signal. Following the LNA, the quadrature down-converter could be shared for multi-band multi-mode applications due to its wide band characteristics. The challenges during the design are how to achieve the highest performance while sharing the components as much as possible.

III. CIRCUIT DESCRIPTIONS

A. Reconfigurable LNA

The reconfigurable LNA should provide sufficient power gain to lower down the noise contribution of the following blocks while keeping a low noise figure and matching with the 50Ω impedance in each operation frequency band. Since the performance of the transistor and the inductor is lowered down along with the frequency, the LNA in higher frequency band should draw more attentions during the implementation.

Figure 1. The presented reconfigured receiver RF front-end
A traditional method, which can achieve better performance, is to use multiple parallel LNAs, each LNA special for one frequency band. But the disadvantage is obvious, such as the large die area and high power consumption. The circuit presented in this paper utilizes a switchable on-chip inductor to achieve the reconfigurable operation. The presented LNA could be reconfigured to work in 2.4GHz or 5.2GHz frequency band for 802.11a/b/g applications. The performance optimization should consider two frequency bands since the signal path is shared through the switchable inductor, which is a great challenge for the reconfigurable LNA.

Among various LNA topologies, the source degeneration common-source amplifier is the most popular one since it can achieve good input impedance matching and low noise figure at the same time [3]. But the switches in the input nodes of the reconfigurable LNA would much lower down the noise figure performance.

Another popular topology is the common gate amplifier which is utilized in our work, but a positive feedback loop is added to realize switchable input impedance matching and the output load resonance at the same time [4]. This LNA consists of two stages, as shown in Figure 2.

![Figure 2. The schematic of the two stage LNA](image)

In this LNA, the input impedance deeply depends on the load impedance of the first stage, which can be described by the following formula:

\[ Z_{in} = \frac{1}{\frac{g_{m1}}{1-g_{m2}Z_{load}}} \]  

(1)

Here, \( Z_{in} \) is the input impedance, \( Z_{load} \) is the load impedance of the LNA’s first stage and \( \frac{g_{m1}}{g_{m2}} \) is the transconductance of M1 and M2. The formula shows that the input impedance could be adjusted by changing the load impedance. When the load LC tank resonates, \( Z_{load} \) becomes a real value, \( Z_{in} \) could be adjusted to 50Ω by controlling the value of \( g_{m1} \) and \( g_{m2} \). If the load LC tank is reconfigurable and could resonate at two different frequency bands, the input impedance could be controlled to provide 50Ω impedance also at two different frequency bands.

An additional advantage of the positive feedback loop is the improvement of the noise performance by increasing \( g_{m1} \), while transconductance of the traditional common gate LNA is limited to 20mS by the input impedance matching requirement.

The noise factor of this LNA can be described by the following equation:

\[ NF = 1 + \frac{\gamma}{g_{m1}R_s} + \gamma g_{m2}R_s + \frac{(1+g_{m1}R_s)^2}{g_{m1}^2R_sR_{load}} \]  

(2)

\( R_s \) is the source resistance, usually setting to 50Ω, and \( R_{load} \) is the resistance of the load LC tank of the first stage at resonance. The parameter \( \gamma \) has a value of unity in short-channel devices and decrease toward a value of 2/3 in long-channel devices. The noise figure can be reduce by increasing the transconductance of M1, also controlling \( g_{m2} \) in an acceptable value. A larger resistance of LC tank at resonance also makes a better noise performance.

The wide-band second stage is added to improve the power gain of the LNA, in order to reduce the noise contribution from the following blocks such as the down-converter. The overall gain of the LNA is:

\[ \text{Gain} = \frac{g_{m1}R_{load}g_{m3}R_{load3}}{1+g_{m1}R_s(1-g_{m1}R_{load})} \]  

(3)

\( g_{m3}R_{load3} \) is the gain of the second stage.
A switchable differential inductor is used as the load component, and it resonates with the node parasitic capacitance to provide the load impedance. It is implemented as an on-chip inductor with an inner diameter of 180um and metal width of 10um, outer diameter of 324um and metal width of 14um. The inductor utilizes the top metal of 20kA, tapping out from the third turn of the total five turns, and Figure 3 gives out its layout. The differential inductor is used here since it has higher quality factor and occupies smaller die area.

B. A Large Dynamic Range Down-Converter

In this integrated direct conversion receiver RF front-end, a large dynamic range down-converter covering 2.4GHz and 5.2GHz frequency bands is also critical. The double balance Gilbert architecture is chosen here to achieve a high IIP2 (Figure 4), which is a critical issue in direct-conversion receiver [5]. Different from the LNA, the power supply voltage is improved to 1.8V to achieve a larger dynamic range.

The input of the down-converter is directly connected to the output of the LNA, resonating with the load inductance at two frequency bands. The tail current source is taken away to allow a larger swing. The input stage of the down-converter is biased at a current of 1.1mA to get a sufficient conversion gain. The size of the switch pairs is carefully optimized to reach a good trade off between noise figure and linearity.

With a double balance active mixer topology, the down-converter can easily achieve a conversion gain with a small bias current. Also the isolation between RF and LO is better than a passive mixer.

IV. EXPERIMENTAL RESULTS

The presented reconfigurable receiver RF front-end is implemented in 180nm CMOS process. The die area, is 1.2mm × 1mm, including pads and ESD protection circuits. Figure 5 gives out its layout.

The fully integrated front-end performs well in both two bands. Figure 6-9 show the experimental S-parameter, noise figure, IIP3 and conversion gain of the whole RF front-end.

The presented mixer’s load provides the different output pole frequencies for each mode, i.e. 20MHz for 802.11a and 8.6 MHz for the 802.11b-g. A common mode feedback is brought in by an operational amplifier to stabilize the output common mode voltage level.
Table 1 summarizes the performance of the presented reconfigurable RF front-end. The whole front-end consumes a low power consumption while achieving the performance requirements in each band. The die area is reduced by utilizing the fully-differential on-chip inductors as the loads.

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<td>24</td>
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<td>6.6</td>
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V. CONCLUSION

This paper describes a monolithic low power reconfigurable direct conversion receiver RF front end for 802.11a/b/g applications in 180nm CMOS process. In this front end, a reconfigurable LNA is implemented as an improved common gate LNA with positive feedback loop, which lowers down the noise performance. A high linearity direct-converter is presented. The signal path is shared between two bands. The experimental results show that the RF front-end has achieved the performance requirements in both bands.

REFERENCES