A Dual-Band Low-Noise Amplifier with Controllable Gain

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Introduction

The WLAN systems operate in the 2.4 GHz (e.g., Bluetooth, IEEE 802.11 b/g) and 5.2 GHz (e.g., IEEE 802.11 a) frequency bands. Conventional dual-band RF circuit designs take two parallel LNAs [2], hence will take more chip area, and LC networks are usually used to match both the input and output ports at two different bands [1], [3], [5].

The fading effect tends to degrade the LNA performance, hence the LNA is desired to have an increased dynamic range of RF signals. The gain control circuit in LNA is intended to solve this problem, typical approaches include current splitting and shunt-feedback [6], [4].

In this paper, a design method of a dual-band LNA with controllable gain is proposed and fabricated in a standard TSMC 0.18 μm CMOS technology, in which LC matching network is used to match at 2.4 GHz and 5.2 GHz at four gain modes.

Circuit Design

Input matching network. As shown in Fig.1, the input matching network consists of an L_1C_2 tank connected to the gate inductor L_g. To match the input impedance to 50Ω, we have

$$\frac{g_m L_s}{C_{\rm gs}} = 50 \tag{1}$$

$$j\omega(L_g + L_s) + \frac{1}{j\omega C_{\rm gs}} + \frac{j\omega L_1}{1-\omega^2 L_1 C_2} = 0 \tag{2}$$

There are two solutions ω_1 and ω_2 to (2), which will be tuned to 2.4 GHz and 5.2 GHz, respectively, and L_s is determined by (1) to achieve good input matching in both bands.

Output matching network. At the output, an LC network consisting of two inductors and two capacitors is used to provide two different resonant frequency bands at 5.2 GHz and 2.4 GHz, respectively. The impedance of the output matching network is

$$Z_{\rm out} = \frac{R}{1+R^2X^2} + j\frac{R^2X}{1+R^2X^2} \tag{3}$$

where

$$R = r_o g_{m2}, \qquad X = \frac{(1-\omega^2 L_2 C_4)(1-\omega^2 L_3 C_5) - \omega^2 L_3 C_4}{\omega L_3 (1-\omega^2 L_2 C_4)} \tag{4}$$

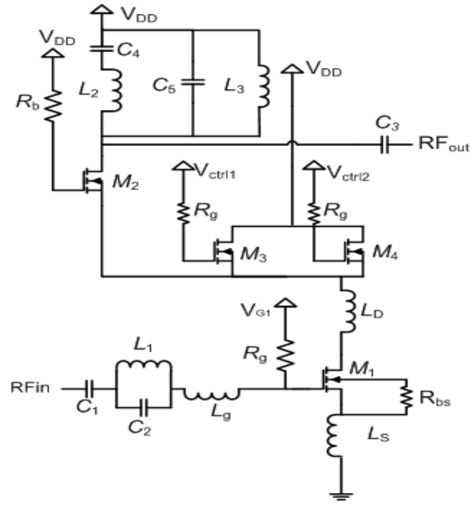

Figure 1: Dual-band low-noise amplifier.

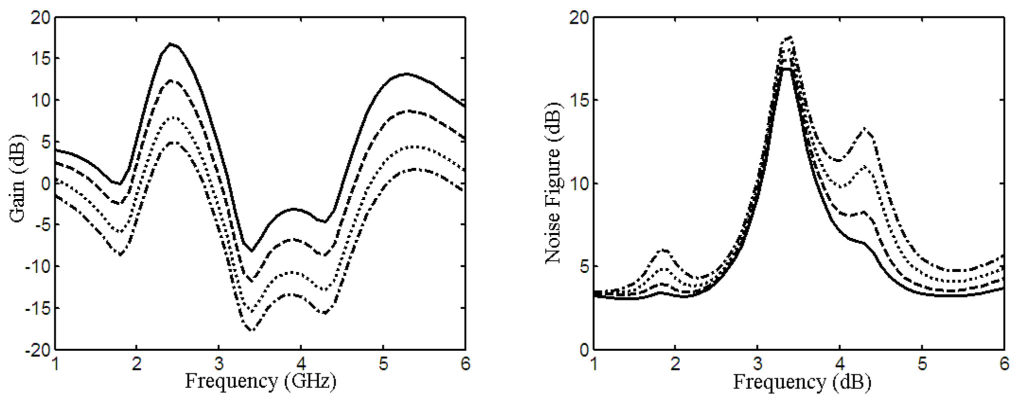

Figure 2: (a) Gain and (b) noise figure of dual-band LNA, ——:mode 0 - - - :mode 1 · · · :mode 2 -·-·-·-:mode 3

By tuning L_2, L_3, C_4, C_5, M_2, impedance matching can be achieved at both 2.4 GHz and 5.2 GHz.

Gain-controlled mechanism. The current splitting technique will be used to conrtol the LNA gain [6]. The bias voltages of gain-control MOSs M_3 and M_4 are adjusted to achieve variable gain. The control voltages V_{ctrl1} and V_{ctrl2} are used to turn on/off M_3 and M_4, respectively. The four modes, mode 0, mode 1, mode 2, and mode 3, will correspond to (V_{ctrl1}, V_{ctrl2}) = (low, low), (low, high), (high, low), and (high, high), respectively, where low means 0 V and high means 1.6 V. The gain step can be adjusted by tuning the size and finger number of MOSs. In this design, the gain step is 3.97 dB, and the dynamic range of gain is 11.9 dB.

Results and Conclusions

Based on the above approach, a dual-band LNA at 2.4 GHz and 5.2 GHz with gain-control mechanism is designed and fabricated with the 0.18 μm TSMC CMOS process. Four gain modes are provided by switching the bias voltage of two MOSs.

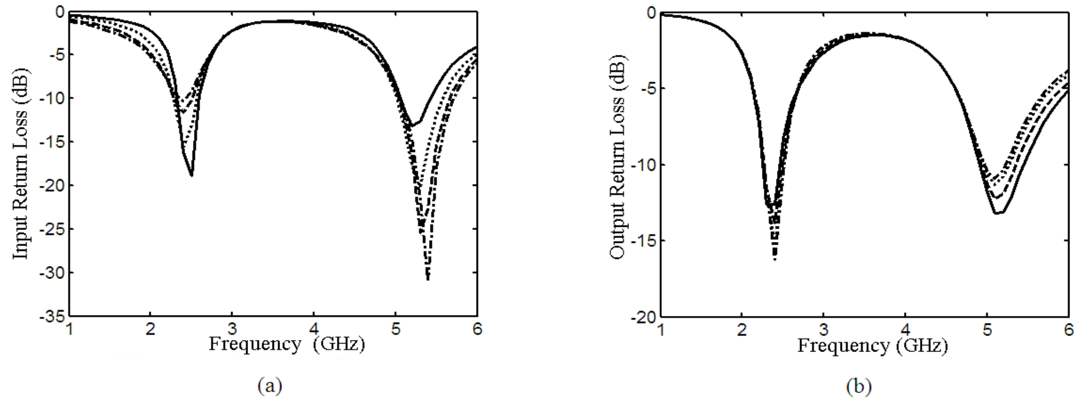

Figure 3: (a) Input return loss (b) Output return loss of dual-band LNA, ——:mode 0 - - - :mode 1 · · · :mode 2 -·-·-·-:mode 3

Table 1: Simulation results at 2.4 GHz

Parameter	mode 0	mode 1	mode 2	mode 3
S_{11} (dB)	−11.6	−16.7	−14.2	−12.2
S_{22} (dB)	−12	−13.2	−14.5	−15.2
GainS_{21}(dB)	16.1	11.9	7.6	4.6
Noise figure (dB)	3	3.2	3.5	3.9
Power consumption (mW)	12.5	13.5	13.7	13.8
$P_{1\text{dB}}$ (dBm)	−14.6	−12.5	−1.02	3.7

Fig.2(a) shows the gain of this LNA in different modes. The maximum gain is 16.1 dB at 2.4 GHz, and is 12.2 dB at 5.2 GHz. The dynamic range of gain is 11 dB and an interval of about 4 dB at both 2.4 GHz and 5.2 GHz

Fig.2(b) shows the noise figure of this LNA. At 2.4 GHz, the maximum noise figure is 3.9 dB and the minimum is 3 dB. At 5.2 GHz, the maximum noise figure is 4.9 dB and the minimum is 3 dB. The noise figure is higher than that of a single-stage LNA because the input matching network contains two indutors, in which the parasitic resistance will increase the noise figure.

Figs.3(a) and 3(b) show the input return loss and output return loss, respectively, of this LNA. Both are lower than −10 dB in four different modes. The minimum $P_{1\text{dB}}$ is -14.6 dBm at 2.4 GHz, and is -9.1 dBm at 5.2 GHz. The maximum power consumption is 13.8 mW, under a power supply voltage of 1.5 V. Tables I and II list the performance parameters of the four modes at 2.4 GHz and 5.2 GHz, respectively.

Table 2: Simulation results at 5.2 GHz

Parameter	mode 0	mode 1	mode 2	mode 3
S_{11} (dB)	-11.3	-13.7	-13.3	-12.4
S_{22} (dB)	-10.9	-10.3	-9.6	-9.2
GainS_{21}(dB)	12.2	7.9	3.6	0.86
Noise figure (dB)	3	3.4	4.1	4.9
Power consumption (mW)	12.5	13.5	13.7	13.8
$P_{1\text{dB}}$ (dBm)	-9.1	-4.2	3.2	6.3

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