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A concurrent dual-band low noise amplifier with gain enhancement topology for 2.4/5.2 GHz applications

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Abstract: This paper presents a dual-band low-noise amplifier (LNA)operating at 2.4/5.2 GHz for wireless local area network (WLAN) applications. The LC parallel resonance and LC series network are adopted to achieve input impedance matching and noise matching simultaneously at dual-band. Besides, a small-size capacitor with a coupled inductor is added for gain-enhancement. The simulation results show that the LNA has gains(S21) of 17.1 dB and 8.5 dB with a noise figure of 3.6 dB and 3.3 dB at 2.4 GHz and 5.2 GHz, and input return loss(S11) of -15.6 dB and -13.8 dB while output return loss(S22) of -11.7 dB and -20.7 dB at two operating frequencies, respectively. Therefore, the proposed LNA structure is an attractive alternative to WLAN applications.

Keywords: concurrent; dual-band LNA;2.4 GHz/5.2 GHz; cascade; multi-frequencies

Sočasni dvopasovni ojačevalnik z nizkim šumom s topologijo za povečanje ojačenja za aplikacije 2,4/5,2 GHz

Izvleček: V prispevku je predstavljen dvopasovni ojačevalnik z nizkim šumom (LNA), ki deluje na frekvenci 2,4 / 5,2 GHz za aplikacije brezžičnega lokalnega omrežja (WLAN). Za simultano doseganje usklajevanja vhodne impedance in šuma pri dvopasovnem delovanju je spremenjena LC paralelna resonanca in LC serija omrežja. Poleg tega je za povečanje ojačenja dodan kondenzator majhne velikosti s povezano dušilko. Rezultati simulacije kažejo, da ima LNA povečanje (S21) 17,1 dB in 8,5 dB s šumom 3,6 dB in 3,3 dB pri 2,4 GHz in 5,2 GHz in vhodno povratno izgubo (S11) od -15,6 dB in -13,8 dB medtem ko izhodna povratne izgube (S22) znašajo -11,7 dB oziroma -20,7 dB pri dveh delovnih frekvencah. Predlagana struktura LNA je zanimiva alternativa aplikacijam WLAN.

Ključne besede: sočasnost; dvopasovni LNA;2.4 GHz/5.2 GHz; kaskada; več frekvenc

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1 Introduction

With the development of the multiple standardization and miniaturization of a communication system [1], the multi-band RF front-end suitable for the interconnection between various applications receives noticeable attention.

As the first active stage of the RF receiver, a low noise amplifier (LNA) has a great impact on the performance of the RF front-end. Most of the articles about LNA published recently are based on reconfigurable LNA [2,3], broa dBand LNA [4] and concurrent LNA [5-7]. The advantages of reconfigurable LNA and broa dBand LNA are area consumption and bandwidth respectively, but

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their performance will deteriorate dramatically when applied in dual-band applications. Therefore, dual-band concurrent LNA is an attractive choice to make a trade-off between area consumption, noise, linearity and gain.

Generally, matching networks implemented in concurrent LNA are narrowband matching at input/output or inter-stage [6~9], and an external large resistor should be added for DC isolation. However, the thermal noise of the isolation resistor combining with the gate noise of MOSFET will significantly deteriorate the noise figure of LNA at high frequency. In this paper, a trap network accompanied by a series LC network is applied in the LNA for DC isolation and dual-band impedance matching, removing the effect of thermal noise of isolation resistor. Besides, a small-size capacitor with a coupled inductor is used to improve the gain.

The paper is organized as follows. Section II describes the design of the proposed circuit topology. Section III shows the layout simulation result of the LNA and section IV concludes this paper.

2 Circuit design

As shown in fig.1, the cascade structure is adopted in the proposed LNA to alleviate the Miller effect and obtain better reverse isolation. Meanwhile, the series LC combining with a parallel LC works as a dual-band impedance matching network. Besides, a capacitor with a coupled inductor is inserted to enhance the gain.

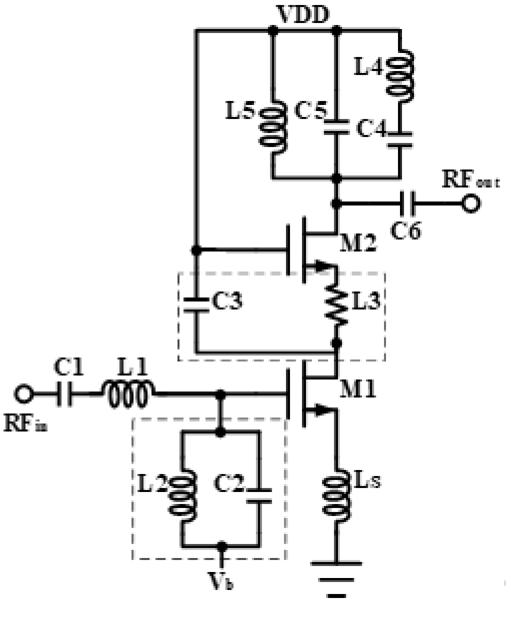

Figure 1: Schematic of the proposed dual-band LNA

2.1 Dual-band input and output impedance

Fig.2 shows the simplified small-signal equivalent circuit, and the input impedance,, can be expressed as follows:

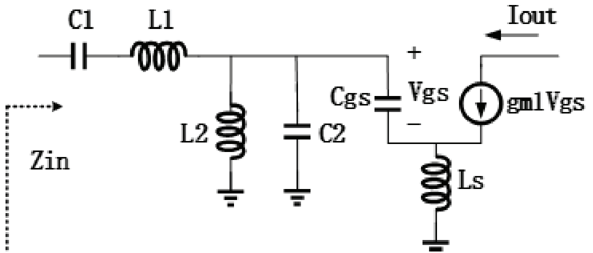

Figure 2: Small-signal equivalent circuit

$$Z_{\text{in}} = \frac{g_{m1}L_s}{C_{gs}} + j(\omega L_s - \frac{1}{\omega C_{gs}} - \frac{\omega^3 L_1 L_2 C_1 - \omega L_2}{\omega^4 L_1 L_2 C_1 C_2 - \omega^2 L_2 (C_1 + C_2) - \omega^2 L_1 C_1 + 1}) \tag{1}$$

In the equation, g_{m1} is the transconductance of M_1, Ls is the negative source fee dBack inductor, C_{gs} is the gate-source capacity of M_1, and Ω is the angular frequency related to 2.4 GHz or 5.2 GHz. To obtain dual-band impedance matching, the real part and imaginary part of Z_{in} should be equal to 50 Ω and zero respectively. And the real part of dual-band input impedance is given by:

$$\text{Re}[Z_{in}] = \frac{g_{m1}L_s}{C_{gs}} = 50\Omega \tag{2}$$

the imaginary part is given by:

$$\text{Im}[Z_{in}] = \omega L_s - \frac{1}{\omega C_{gs}} - \frac{\omega^3 L_1 L_2 C_1 - \omega L_2}{\omega^4 L_1 L_2 C_1 C_2 - \omega^2 L_2 (C_1 + C_2) - \omega^2 L_1 C_1 + 1} \tag{3}$$

As shown in Equation (4) and (5), the dual-band input impedance can be presented by the following parameters.

$$\omega_1 = (L_s, C_{gs}, L_1, L_2, C_1, C_2) \tag{4}$$

$$\omega_2 = (L_s, C_{gs}, L_1, L_2, C_1, C_2) \tag{5}$$

In the output matching network, two resonant frequencies of the network are 2.4 GHz and 5.2 GHz respectively, and Fig.3 shows how dual-frequency match-

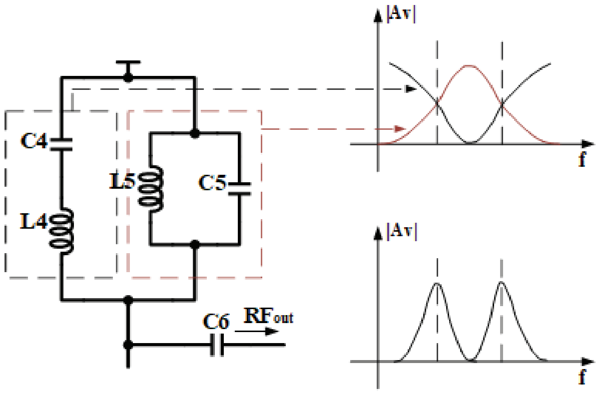

Figure 3: output matching filter

ing obtains [6]. This allows a better matching on each bandwidth.

Output impedance is described by equation(6):

$$Z_{out} = \frac{1}{j\omega C_6} + \left(\frac{j\omega L_5}{1-\omega^2 L_5 C_5}\right) \| \, j(\omega L_4 - \frac{1}{\omega C_4}) \quad (6)$$

2.2 Noise analysis

This section describes the combination of impedance matching and noise optimization. And the equivalent circuit for noise analysis of the proposed LNA is shown in Fig.4.

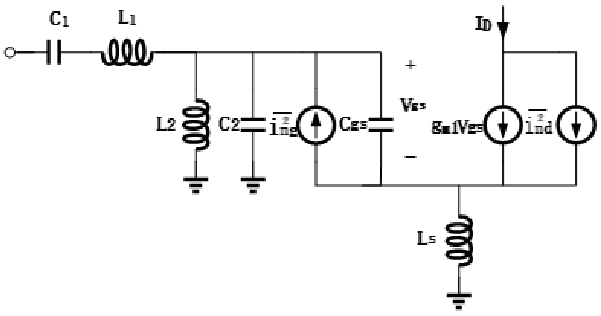

Figure 4: the equivalent circuit for noise analysis

The noise factor is described by equation [7]:

$$F = F_{\min} + \frac{R_n |Y_S - Y_{opt}|^2}{G_S} \quad (7)$$

In equation [7], R_n represents the source resistance, and G_s, Y_s, and Y_{opt} are the source conductance, the source admittance and the optimum source admittance respectively. And the parameters can be expressed as the following equations.

$$R_n = \frac{\gamma}{\alpha}\frac{1}{g_{m1}} \quad (8)$$

$$Y_S = Y_{opt} = \frac{1}{Z_{opt}} \quad (9)$$

In the equation, α is the constant related to the process, which α = g_m/g_{do}, g_{do} is the drain-source conductance when the drain-source voltage Vds is equal to 0.γ is the channel noise figure of the transistor, which is related to the channel length.

When Y_s is equal to Y_{opt}, the minimum value of F is equal to F_{min}. According to Thomas theory [12], the noise factor F_{min} of the LNA can be expressed as:

$$F_{\min} = 1 + \frac{2}{\sqrt{5}}\frac{\omega}{g_{m1}/C_{gs}}\sqrt{\gamma\delta\left(1-|c|^2\right)} \quad (10)$$

In the equation, δ is the gate noise figure, and c is the correlation coefficient between the gate current noise and the leakage current noise, which is approximately equal to j0.395 in theory [13], reflecting the coupling capacitance between the channel and the gate induced noise source.

The optimum noise impedance is given by:

$$Z_{opt} = \frac{\alpha\sqrt{\frac{\delta}{5\gamma}(1-|c|^2)} + j(1-\alpha|c|\sqrt{\frac{\delta}{5\gamma}})^2}{\omega C_{gs}\left\{\frac{\alpha^2\delta}{5\gamma}(1-|c|^2) + \left(1-\alpha|c|\sqrt{\frac{\delta}{5\gamma}}\right)^2\right\}} - \left(j\omega L_s + \frac{j\omega L_2}{1-\omega^2 L_2 C_2 + \frac{\omega^2 L_2 C_1}{\omega^2 L_1 C_1 - 1}}\right) \quad (11)$$

It is obvious that Re [Y_{opt}]) Re [Z_{in}] and Im [Z_{opt}]= Im [Z_{in}]. Therefore, noise matching and impedance matching can be obtained simultaneously.

2.3 Gain enhancement technology

Generally, the LNA consists of two stages or more to obtain high gain. To reduce area consumption, a cascade structure with gm enhancement was implemented in the proposed single-stage LNA. Traditional technology adopts a cascade structure to eliminate the Miller effect and provide better reverse isolation [14]. Base on the small-signal analysis, the gain of the LNA without LC resonance network can be derived as:

$$A_{v1} = -\mathrm{k}\bullet[1+\left(g_{m2}+g_{mb2}\right)r_{o2}]g_{m1}r_{o1} \quad (12)$$

In the equation, r_{o1} is the output resistance of M_1, r_{o2}, is the output resistance of M_2, g_{m2} is the transconductance of M_2, g_{mb2} is the substrate transconductance of M_2, r_{o2} is the output resistance of M_2, and parameter k, X, β, are given by:

$$\mathrm{k}=\frac{\chi Z_L}{r_{o2}+Z_L+[1+(g_{m2}+g_{mb2})r_{o2}]\cdot\beta} \tag{13}$$

$$\chi=\frac{\dfrac{j\omega L_s}{1-\omega^2 L_s C_2}}{j(\omega L_1-\dfrac{1}{\omega C_1}+\dfrac{\omega L_2}{1-\omega^2 L_2 C_2})} \tag{14}$$

$$\beta=\mathrm{r}_{o1}+(1+g_{m1}r_{o1})sL_s \tag{15}$$

When the LC resonance network is added, parameter k is expressed as k1, which is given by:

$$\mathrm{k}_1=\frac{\chi Z_L}{(\mathrm{r}_{o2}+Z_L)x_1+[1+(g_{m2}+g_{mb2})r_{o2}]x_2} \tag{16}$$

where, $x_1=\left(1+\dfrac{\beta}{sC_3}\right)$ and $x_2=\left(sL_3+\dfrac{L_3}{C_3}\beta\right)$. It is obvious that the gain can be enhanced by making an adjustment of L3/C3, which is presented in the simulation results.

3 Simulation results

This section presents the simulation results of the proposed dual-band LNA operating at 2.4 GHz and 5. 2 GHz.The layout of the proposed LNA is shown in Fig.5. S-parameters, NF and P1 dB of the LNA are shown in Fig 6-11 respectively. The proposed LNA is implemented on the SMIC 0.13um 1P8M CMOS process, and the chip size of the layout is 642.6 x910.1 . The simulation results of the LNA exhibits S11 of -15.6 dB and -13.8 dB, S22 of -11.7 dB and -20.7 dB at 2.4 GHz and 5.2 GHz, which are shown in Fig. 6-7. The LNA exhibits 17.1 dB of gain, 3.6 dB of noise figure, -16.49 dBm of P1 dB at 2.4 GHz; 8.5 dB of gain,3.3 dB of noise figure, -9.53 dB of P1 dB at 5.2 GHz, which are shown in Fig.7-10. With a supply voltage of 1.2V , the power consumption of the receiver is 9.8 mW. As a summation, table1 shows all the simulation results.

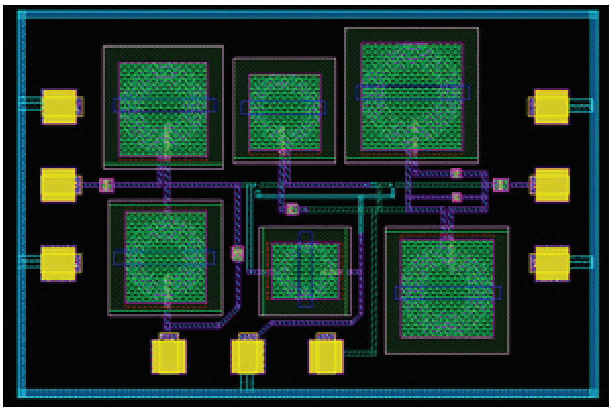

Figure 5: The layout of the Low Noise Amplifier

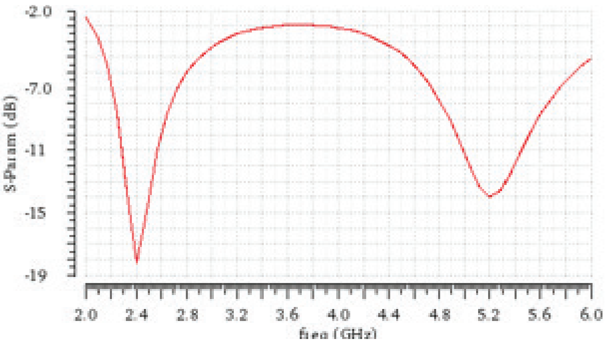

Figure 6: Simulated input loss (S11) of the dual-band LNA

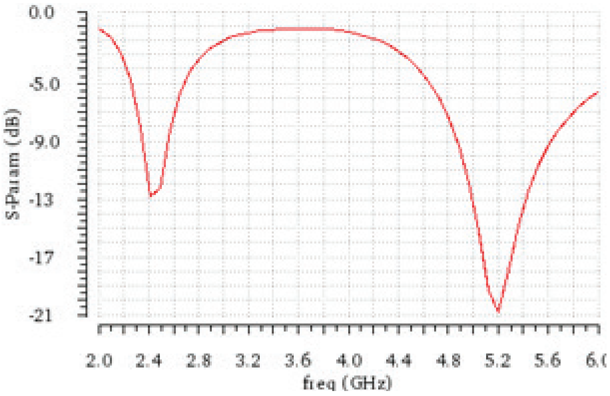

Figure 7: Simulated output loss(S22) of the dual-band LNA

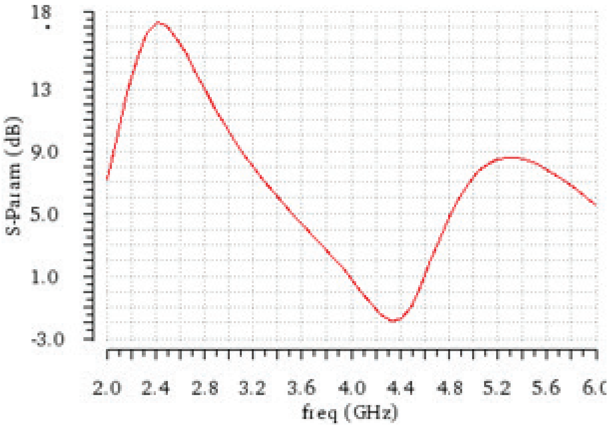

Figure 8: Simulated gain(S21) of the dual-band LNA

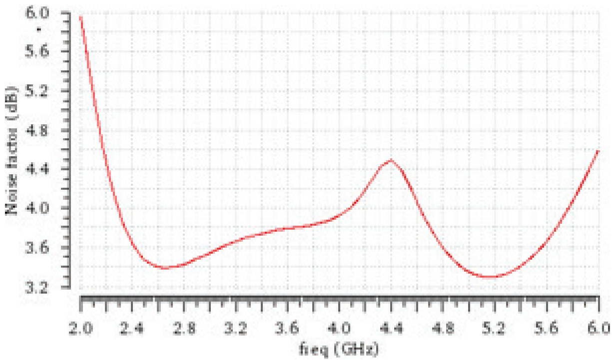

Figure 9: Simulated noise figure(NF)

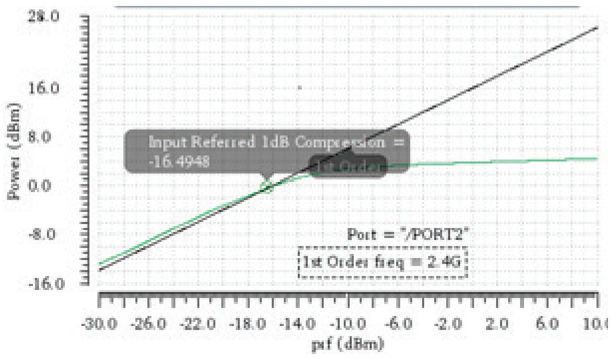

Figure 10: Simulated P1 dB compression point at 2.4 GHz

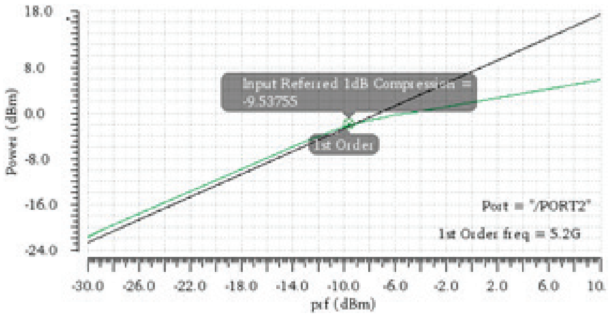

Figure 11: Simulated P1 dB compression point at 5.2 GHz

The performance of the proposed LNA is summarized in Table 1, which is compared to other papers published working at 2.4 GHz and 5. 2 GHz.The performance shows a good trade-off between impedance matching, noise, linearity and gain. However, the proposed LNA consists of one-stage, which is designed under the limitation of minimum noise figure. And multi-stage cascade structure can be adopted to reduce the design difficulty without the limitation of area consumption and power dissipation. Besides, folded cascade structure with lower supply voltage is an attractive choice for low power applications.

4 Conclusions

A dual-band concurrent LNA operating at 2.4 GHz and 5.2 GHz with gain enhancement technology is presented in this paper. The LNA designed shows a noise figure below 3.6 dB and the input /output return loss is better than-10 dB. And the power consumption is 9.8mW with a power supply voltage of 1.2V. As the performance mentioned above exhibits, the proposed concurrent dual-band LNA is suitable for multi-frequencies RF systems like WLAN.

5 Conflict of interest

We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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