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# Design of DC-3.4GHz Ultra-Wideband Low Noise Amplifier with Parasitic Parameters of FET

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**ABSTRACT**
This paper presents two low noise amplifier (LNA) circuit topologies for ultra-wideband wireless communications in 0.13μm PHEMT GaAs technology. They are with source inductive degeneration and source grounded, respectively. The simulation results show that the LNA involving source inductor possesses good performances at 120MHz-3GHz. Its noise figure(*NF*) and voltage standing wave ratios(*VSWRs*) are less than 1.173dB and 2, respectively, while the maximum gain of 12.75dB is achieved with 0.63dB flatness. In contrast, the other LNA provides a decreasing gain varying between 10.992dB and 11.964B in a wider frequency range of DC-3.4GHz. *NF* and *VSWRs* are better than 1.287dB and 2, respectively.
***Keywords* -** Low Noise Amplifier, Resistive Feedback, Source Inductive Degeneration

## I. INTRODUCTION

Low noise amplifier (LNA), one of the most important analogy blocks in wireless communication systems, must be broadband matched to a 50Ω antenna. In addition, it must provide a high voltage gain on a high impedance value capacitive output load, while adding as little noise as possible [1]. Moreover, it should be linear enough to handle strong interferers without introducing intermodulation distortion [2].

As operating frequency increases, the effects of FET parasitic parameters, especially source parasitic inductor $L_s$, on performance can no longer be neglected. As well known to us, an additional source inductor enhances stability and achieves noise matching and good linearity. Yet, its small inductance can not be controlled easily in practice. Also, a small change in the inductance has a significant impact on gain, stability, and noise figure (*NF*) of LNA [3, 4]. Excessive source inductance can lead to LNA oscillations because of gain peaks at higher frequencies [5]. Therefore, if the potential source inductor $L_s$ are not taken into consideration during simulation, it will influence the practical performances significantly. However, there are few papers concentrating on this issue.

Broadband LNA is a challenging in software defined radio (SDR)[6], and the main challenge in design such wideband LNA is to make it able to work from hundreds MHz to several GHz. In this paper, two ultra-wideband LNAs operating at 120MHz-3GHz and DC-3.4GHz respectively are presented for wireless communication systems. For better designing LNA, the parasitic parameters of FET, such as gate parasitic inductor, gate-to-source capacitor, and source parasitic inductor, are taken into consideration. At the same time, the effect of additional source inductor on the performance of LNA is investigated. In order to implement subsequent layout, the transmission lines between two elements are also considerad using microstrip lines with 50Ω characteristic impedance during simulation, but they will not be discussed below.

## II. CIRCUIT DESIGN

An extrinsic GaAs FET high-frequency model which includes parasitic elements is shown in Fig. 1.

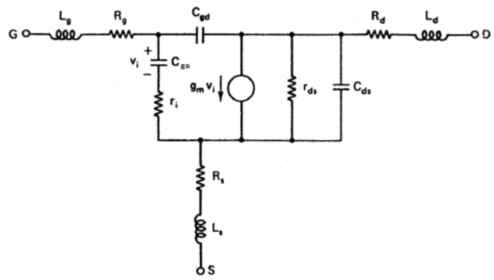


Fig. 1 A microwave GaAs FET common-source model that includes parasitic elements [7]

The meaning of the parasitic elements $C_{ds}$, $C_{gs}$, $C_{gd}$, $R_g$, $R_s$, $R_d$, $L_g$, $L_s$, and $L_d$ is self-explanatory. For GaAs MESFET with 1μm gate length and 25μm gate width, $C_{gs}$ =0.3pF, $C_{gd}$ =0.02pF, and $C_{ds}$ =0.05pF. Generally, for a packaging FET, the typical values of parasitic inductor and resistor are 0.1-0.9nH and 0.1-0.2Ω. In this paper, for simplicity, their values are set as 0.1nH and 0.15Ω, respectively. $r_i$ and $r_{ds}$ are the small gate-to-source channel resistance and the big drain-to-source channel resistance, respectively, which can be neglected.

The LNA design is based on CGY2105XHV (OMMIC Co., Ltd.), which is an extremely low noise figure amplifier with linearity suitable for applications from 500MHz to 4000MHz. The MMIC is manufactured using OMMIC's qualified 0.13μm PHEMT GaAs D01PH technology. The LNA is designed and simulated on Rogers 4003C dielectric substrate having a permittivity of 3.38, a thickness of 0.508 mm, and a loss of less than 0.0027.

**2.1 LNA with source inductive degeneration**

Fig. 2 shows the proposed common source LNA circuit topology with source degeneration inductor. The small inductor $L_{s1}$ with an inductance of $L$ nH, which can be replaced by a high impedance microstrip line with a length of $l$ mm according to the following formula:

$$l = \frac{11.81L}{Z_0\sqrt{\varepsilon_r}} \quad (1)$$

where $Z_0$ is the characteristic impedance of the microstrip line, and $\varepsilon_r$ is the relative permittivity of the layout. The use of an inductive line with a high $Z_0$ and short length achieves a good approximation of a lumped inductor [8].

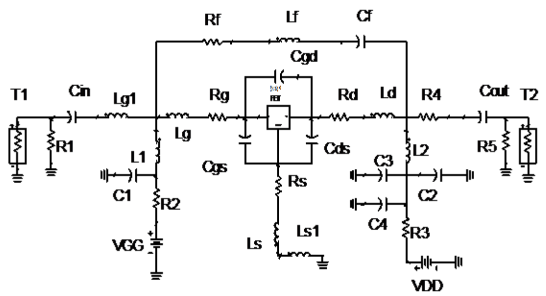


Fig. 2 LNA with source degeneration inductor

Referring to the given circuit in manual, bias circuit is designed. The LNA is biased at $V_{DS}$=3V and $I_{DS}$=50mA with supply voltage $V_{DD}$ of +5V and $V_{GG}$ of -0.58V. Shunt RC filter is introduced in the gate to improve the low-frequency stability of amplifier. In order to decrease its effect on *NF*, stable network should be connected to the drain of FET rather than to the gate [9]. The separation of RF signals from DC bias conditions is achieved through so-called radio frequency coils (RFCs).

For wideband LNA, input matching topologies include resistive termination, common gate, and resistive shunt-feedback. Since the input of a CS MOS device is primarily capacitive, we can terminate the input with a resistor $R_1$. Although greatly degrading the *NF* due to adding its own noise and dropping the gain, resistive termination provides a good power matching [1]. Neutralization cancels signal flowing through $C_{gd}$ by adding a shunt negative feedback path consisting of a resistor $R_f$, a capacitor $C_f$, and an inductor $L_f$ [10]. In addition, good gain flatness can be achieved easily in a wide bandwidth through introducing $R_f$ in the feedback [7]. Furthermore, the feedback path also enhances the stability of amplifier to some degree. $L_f$ lessens low-frequency gain, increases high-frequency gain, broadens waveband, and degrades the effect of transistor parameters on the amplifier [11].

When the GaAs FET is unconditionally stable in the frequency range of interest, the feedback capacitance $C_{gd}$ is very small and can be neglected. For simplicity, the effects of feedback path on the input and output impedances are ignored. And considering that inductors $L_{g1}$ and $L_{s1}$ are ideal, it is easy to show the input impedance of the LNA given by [7]:

$$\begin{aligned} Z_{in} &= j\omega(L_{g1}+L_g+L_s+L_{s1}) + \frac{g_m+R_s}{j\omega C_{gs}} \\ &\quad + R_s + R_g + \frac{g_m(L_s+L_{s1})}{C_{gs}} \end{aligned} \quad (2)$$

The source impedance is expressed as:

$$Z_{Source} = \frac{R_0}{1+R_0/R_1} - j\frac{1}{\omega C_{in}} \quad (3)$$

$R_0$ is the signal source impedance, usually 50Ω. In order to realize input matching, namely $Z_{Source} = Z_{in}^*$, the values of $L_{s1}$, $R_1$, $C_{in}$, and $L_{g1}$ are optimized and tuned. The output impedance of the LNA is:

$$\begin{aligned} Z_{out} &\approx [\,j(\omega L_{s1} + \omega L_s + \omega L_d - \frac{1}{\omega C_{out}} - \frac{1}{\omega C_{ds}}) \\ &\quad + R_s + R_d + R_4\,] \,||\, R_5 \end{aligned} \quad (4)$$

Due to $R_s$+$R_d$<<$R_4$ and the dominant $1/(\omega C_{out})$ of terms in the parenthesis at DC-3.4GHz, the output impedance can be simplified as:

$$\begin{aligned} Z_{out} &\approx \frac{R_5}{1+(\omega C_{out})^2(R_4+R_5)^2}[\,j\omega C_{out}R_5 + 1 \\ &\quad + (\omega C_{out})^2(R_4^2 + R_4R_5)] \end{aligned} \quad (5)$$

When $(\omega C_{out})^2(R_4+R_5)^2 > 1$ and $(\omega C_{out})^2(R_4^2+R_4R_5) > 1$, which can be satisfied easily by increasing the value of $C_{out}$, the output impedance can be further simplified as:

$$Z_{out} \approx j\frac{R_5^2}{\omega C_{out}(R_4+R_5)^2} + \frac{R_4R_5}{R_4+R_5} \quad (6)$$

A good output matching and the maximum gain is achieved when $R_4R_5/(R_4+R_5)$ approaches $R_L$ (load impedance, usually 50Ω).

Noises from $R_4$ and $R_5$ are attenuated by the LNA gain. Thus, the extrinsic noise sources are mainly associated with $R_1$ and $R_f$, the increase in which will enhance the *NF*. In addition, the conditions of Re($Z_{in}$+$Z_{source}$)>0 and Re($Z_{out}$+$R_L$)>0 are met, which ensure the unconditional stability of the LNA[11].

**2.2 LNA with source grounded**

The other LNA schematic with source grounded is shown in Fig. 3. Besides the same bias circuit omitted here, this LNA has similar *L*-type matching networks to the former one. What is the biggest difference between two LNA circuit topologies is the source grounded directly of this LNA, and $L_{s1}$ is replaced by $L_3$. Similarly, the input and output impedances of the LNA are written as:

$$Z_{in} = j\omega(L_{g1+}L_g + L_s) + \frac{g_m + R_s}{j\omega C_{gs}} + R_s + R_g + \frac{g_m L_s}{C_{gs}} \qquad (7)$$

$$Z_{out} \approx [\, j(\omega L_s + \omega L_d + \omega L_3 - \frac{1}{\omega C_{out}} - \frac{1}{\omega C_{ds}}) + R_s + R_d + R_4 ] \,||\, R_5 \qquad (8)$$

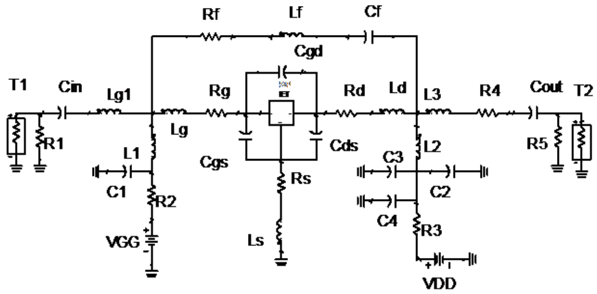


Fig. 3 LNA with source grounded directly

The equation (6) still holds here when the hypotheses stated above are satisfied. The source impedance of this LNA can also be expressed by equation (3). Comparing the formulae of $Z_{in}$ and $Z_{Source}$ of two LNAs, it is noted that $R_1$ in this LNA should be larger to reach the input matching. However, an increasing $R_1$ brings about the negative results as stated above. Seen from formulae (7) and (8), the input and output impedances are independent each other, as a result of which, better *VSWRs* representing impedance matchings can be obtained in this LNA. In the process of design, it is found that a small change in the values of parasitic parameters except for $L_s$ has ignorable effects on the performances. This is in good agreement with the statement in Introduction Section, and it can be understood easily from equations (2) and (4) that $L_s$ affects both the input and output impedances. Besides, this LNA is also unconditionally stable due to Re($Z_{in}$+$Z_{source}$) and Re($Z_{out}$+ $R_L$) above 0.

## III. Simulation Results

Fig. 4 illustrates the simulation results of LNA with source inductive degeneration. It can be seen from Fig. 4(a) that the LNA is unconditionally stable in full waveband (DC-20GHz), which is consistent with analysis before. Seen from Fig. 4(b), output voltage standing wave ratio (*VSWR2*) is below 2 at the frequencies between 10MHz and 4GHz, while input *VSWR1* increases to 2.022 when the frequency decreases to 120MHz from 4GHz. And the good *VSWR1* and *VSWR2* are hardly obtained simultaneously at frequencies lower than 120MHz. The reason is attributed to the effect of $L_{s1}$ and inherent $L_s$. Based on the relationship between *VSWR1* and input reflection coefficient ($S_{11}$), $S_{11}$ is below -9.4dB. Fig. 4(c) shows that the maximum forward gain $S_{21}$ is 12.755dB, and the minimum value is 12.126dB over the frequency band of 30MHz-3GHz. *NF* less than 1.173dB also meets the specified requirement across the desired frequency range.

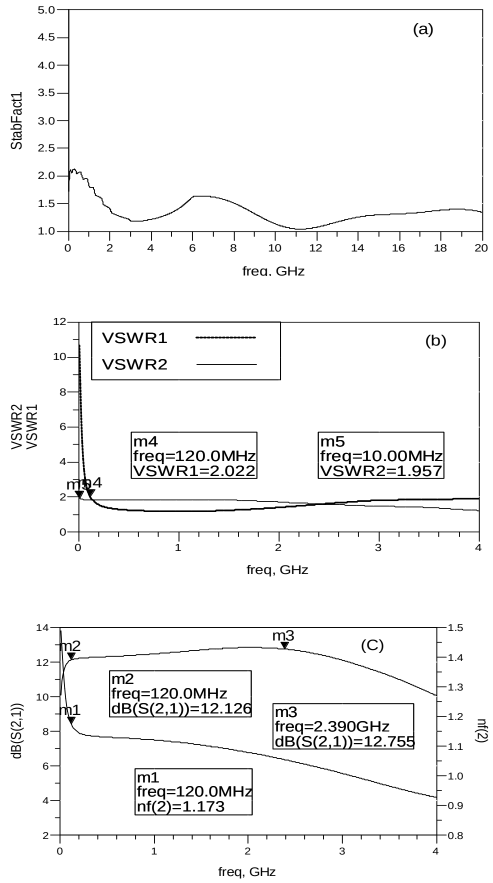


Fig. 4 Simulation results of LNA with source inductive degeneration (a) stability factor (b) *VSWRs* (c) $S_{21}$ and *NF*

The simulation results of LNA with source grounded are depicted in Fig. 5. The LNA is also unconditionally stable, with a higher stability factor. In contrast, the LNA shows a little degraded but still satisfied performance even at the frequency lessening to 10MHz and climbing to 3.4GHz. The gain decreases by about 0.8dB, varying between 10.992dB and 11.964dB. *NF* is below 1.287dB over the target bandwidth and it is a reasonably good noise performance for UWB applications. The relatively smaller gain and higher *NF* can be explained by the larger $R_1$. Moreover, *VSWRs* are not more than 2 in the frequency range of 10MHz-3.4GHz. According to the value of *VSWR1*, $S_{11}$ is below -10dB. The curve of *VSWR2* is similar to the former one, which is ascribed to the same approximated output impedance. Table.1 summarizes the performance of the LNA along with results from recently published papers.

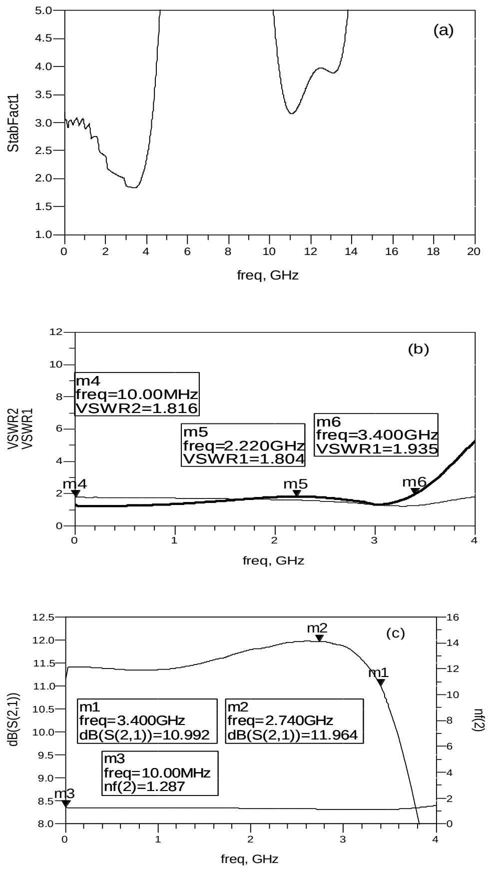


Fig. 4 Simulation results of LNA with source grounded directly (a) stability factor (b) *VSWRs* (c) $S_{21}$ and *NF*

Table 1 Performance summary of published CMOS LNAs

| | BW (GHz) | $S_{21}$ (dB) | $S_{11}$ (dB) | NF (dB) | Topology |
|---|---|---|---|---|---|
| [6] | 0.1-2.5 | 22 | <-10 | 2-2.4 | Feedback |
| [12] | 0.5-7 | 22 | <-9 | 2.3-2.9 | Feedback |
| [13] | DC-11.5 | 13.2 | <-8 | 5.6 | Feedback |
| [14] | 3.1-10.6 | 13.7-16.5 | <-10 | 2.1-2.8 | Feedback |
| [15] | 0.6-6 | 17 | <-10 | 2.3-2.96 | noise-cancelling |
| This work | 0.12-3 | >12 | <-9.4 | <1.173 | Feedback |
| This work | DC-3.4 | >11 | <-10.8 | <1.287 | Feedback |

## IV. CONCLUSION

This paper investigates the effects of source inductive degeneration on the performance of LNA, which involves parasitic parameters. The source parasitic inductor has a significant influence on the input and output impedances. In the 120MHz-3GHz band, the LNA with source inductor has a maximum gain of 12.755dB with a gain flatness of 0.63dB, a noise figure less than 1.173dB, and *VSWRs* below 2. In contrast, the other LNA with source grounded achieves reasonably acceptable performances in a wider frequency range of DC-3.4GHz. A decreasing gain of 11.964dB with a variation of 0.972dB is obtained, while the noise figure is no more than 1.287dB. Besides, the LNA accomplishes better input and output matchings, and *VSWRs* are smaller than 2. Compared with results published in previous studies, much lower noise figures are provided in this paper. Such LNAs can find wide application in software defined radio, receiver front-end, and other wireless communication systems.

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