# Design of Wideband High Gain and Low Noise Amplifiers

Yinhua Yao and Tongxiu Fan

***Abstract*—2.0-3.8GHz and 0.5-4GHz wideband low noise amplifiers for wireless communication receivers are designed using microstrip line and lumped element matching, respectively. Simulation results indicate that the amplifier within the band of 2.0-3.8GHz has a maximum gain of 18.86dB with a gain flatness of 0.7dB, a noise figure(*NF*) of no more than 2.424dB, less than 2.4 voltage standing wave ratios (*VSWRs*), and an output third-order intercept (*OIP*$_3$) of better than 33.46dBm. Having better performances, the other amplifier shows a gain of 19.4 ± 0.46dB, a *NF* below 1.894dB, and an *OIP*$_3$ above 34dBm. Output *VSWR* is always less than 2 at frequencies ranging from 0.5GHz to 4.5GHz, while input *VSWR* between 2.0 and 2.23 is seen in 0.5-0.7GHz frequency range.**

***Index Terms*—Low noise amplifier, negative feedback, wideband.**

## I. Introduction

Being the first block in receiver front-ends, low noise amplifier (LNA) involves a trade-off design among several goals. These include providing good input and output voltage standing wave ratios (*VSWR1* and *VSWR2*), minimizing the noise figure (*NF*) and supplying a gain (e.g. 20 dB) that must be high enough to lower the noise contribution of the following blocks without degrading linearity.

Wideband LNAs have several applications in emerging broadband communication systems such as multi-band mobile terminals and base stations. Wideband amplifier design commonly includes several technologies, such as combinational circuit technology, feedback technology, and balanced amplification technology [1], [2]. Negative feedback technology has gained more interest due to its advantages over other technologies. The main advantage of this technique is to immunize the circuit performances from fluctuations of components, power supply, transistor-to-transistor parameters, and temperature. Another advantage is the enhancement of input and output matchings as well as gain flatness over a wide frequency range. Besides, signal distortion is reduced and passband is increased [3]. Low *NF* and good input matching are almost never simultaneously obtained without using feedback arrangements.

As the operating frequency of a circuit increases, the parasitics of lumped elements become more noticeable. In this condition, distributed elements find wider application than lumped elements. However, most studies on the wideband LNA are still performed using lumped elements. In additions, a majority of wideband LNAs have been implemented using either differential amplifier or cascode structures [3]-[7] with concentration on the frequencies above several GHz, which always involve many transistors. However, there are only a few papers studying the LNA operating at frequencies varying from MHz to several GHz.

In this paper, two high gain and low *NF* two-stage cascaded amplifiers for wireless communication are developed. The topology chosen for the wideband LNA is a common source amplifier with source inductive degeneration and resistive negative feedback architecture. One in the range of 2.0-3.8GHz is designed using distributed element matching networks and the other one operating within a wider band of 500MHz-4GHz has lumped element matchings. Such LNAs are important building blocks for low cost and highly integrated multi-standard receivers.

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## II. Theoretical Background

### A. Negative Feedback Technology

Series and shunt negative feedback resistors are one of the most practical negative feedback technologies, as depicted in Fig. 1.

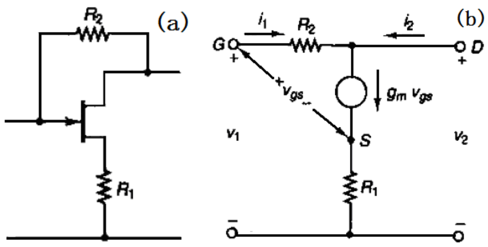


Fig. 1. (a) FET with series-shunt negative feedback resistor (b) small-signal equivalent circuit.

The $S_{21}$ parameter of this network is expressed as [1]:

$$S_{21} = \frac{1}{D}\left(\frac{-2g_m Z_0}{1+g_m R_1} + \frac{2Z_0}{R_2}\right) \tag{1}$$

$$D = 1 + \frac{2Z_0}{R_1} + \frac{g_m Z_0^2}{R_2(1+g_m R_1)} \tag{2}$$

where $g_m$ and $Z_0$ are the transconductance of transistor and the characteristic impedance 50Ω.

Assuming ideal matching condition $S_{11}$=$S_{22}$=0 yields the following equation:

$$R_1 = \frac{Z_0^2}{R_2} - \frac{1}{g_m} \tag{3}$$

Combining (1) and (2), we obtain

$$S_{21} = (Z_0 - R_2)/Z_0 \tag{4}$$

Thus, we observe that $S_{21}$ is dependent only on the resistor $R_2$. Therefore, good gain flatness can be achieved easily by

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using the negative feedback [8]. However, the negative feedback network deteriorates *NF* and lowers the maximum power gain of transistor.

Another widely used negative feedback technology is the source inductive degeneration $L_S$ [4], [9], [10], which enhances circuit stability, achieves noise matching, and provides good linearity. However, its small inductance *L nH* can not be achieved and controlled easily. What is worse, a little change in the inductance significantly influences the gain, stability, and noise figure. For instance, excessive source inductance can bring about LNA oscillations because of gain peaking at higher frequencies [11]. Therefore, such a LNA has to be designed carefully to avoid instability. To solve these problems, $L_S$ is replaced by a microstrip transmission line with the length of $l$ according to the formula:

$$l = \frac{11.81L}{Z_0\sqrt{\varepsilon_r}} \tag{5}$$

where $\varepsilon_r$ is the relative permittivity of the layout.

### B. Stability

In RF amplifier design, in order to achieve a normal amplification and avoid the occurrence of self-oscillation, the stability of amplifier should be ensured. Unconditional stability can simplify amplifier design and show a stable state for any signal source impedance and load impedance, which can be expressed by Rowlett Criteria [12]:

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{12}S_{21}|} > 1 \tag{6}$$

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| < 1 \tag{7}$$

When the stability factor $K$ is greater than unity, circuit will be unconditionally stable for any combination of source and load impedances. Otherwise, the circuit is potentially unstable with the possibility of oscillation.

### C. Noise Figure

When one designs a receiver front-end, each component has to be designed with a noise figure and gain so that the specification for the whole front-end is met. In a cascade amplifier, the total noise figure can be calculated using Friis formula [9]:

$$NF_T = NF_1 + \frac{(NF_2-1)}{G_1} + \frac{(NF_3-1)}{G_1G_2} + \cdots \tag{8}$$

where $NF_n$ and $G_n$ are the noise figure and gain of *n*-th stage amplifier, respectively. According to (8), the gain dependency of *NF* results in the fact that once the gain $G_1$ is increased, the *NF* of subsequent stages is less important. The total $NF_T$ is mainly determined by the noise figure from the first stage in the receiver chain. Therefore, trying to achieve a good *NF*, most of the design effort must be put on the first stage in the receiver chain.

### D. Gain

Power gain of 2-ports circuit network with power impedance or load impedance at amplifiers is classified into Operating Power Gain($G_P$), Transducer Power Gain($G_T$), and Available Power Gain($G_A$) [5]. The total gain of a dual-stage amplifier under linear operating conditions is derived from the equation:

$$G_T[\text{dB}] = G_1[\text{dB}] + G_2[\text{dB}] \tag{9}$$

With a low *NF*, LNA must have a high gain for processing signal applied to the input port of circuit. If the LNA does not have a high gain, then the signal will be affected by noise in LNA circuit itself and attenuated, so high gain is an important parameter of LNA.

### E. Third-Order Intercept Point

LNA should be linear enough to handle strong interferences without introducing intermodulation distortion. The linearity of an LNA is strongly coupled to the $g_m$. Nonlinearities arise from the fact that $g_m$ is not constant when a signal is applied to the gate. There are many measures of linearity, but the most commonly used benchmark for a typical receiver application is the third-order intercept ($IP_3$). The relation between the input $IP_3$ ($IIP_3$) and the output $IP_3$ ($OIP_3$) is defined as:

$$IIP_3 = OIP_3\text{-Gain} \tag{10}$$

With the rapid development of wireless communication, CDMA system has added to the challenge because of its high linearity or high $IP_3$ requirement. As discussed before, high gain in the first stage implies a low total noise figure. However, high gain in the first stage also means that the total linearity gets worse. Thus, a compromise between noise and linearity has to be made in LNA design.

## III. Circuit Implementation

The LNA design has been based on ATF-531P8 enhanced pHEMT (Agilent Co., Ltd.). The device is ideal as a single-voltage high linearity, low-noise, and medium-power amplifier. With a permittivity of 3.38, a thickness of 0.508 mm, and a loss of less than 0.0027, Rogers 4003C dielectric substrate has been selected. The proposed LNA topology is basically a two-stage common source (CS) amplifier due to its better noise characteristic than a common gate (CG) amplifier.

### A. Design with Distributed Elements

Fig. 2 shows the topology of the amplifier designed using distributed elements. Shunt feedback resistor in two stages and source microstrip line in the second stage are utilized to obtain good gain flatness and keep the amplifier stable.

The LNA is biased at $V_{DS}$=4V and $I_{DS}$=135mA with supply voltage $V_{CC1}$ of +5V. $C_3$ and $C_4$ are filtering capacitors, and the voltage divider consists of resistors $R_2$ and $R_3$, through which $V_{CC1}$ provides an adequate gate voltage. Drain resistor $R_1$ is used to ensure a proper drain voltage. For narrow band amplifiers, $\lambda/4$ microstrip lines used for RF blocking are always introduced in gate and drain bias circuits [13]. In this paper about wideband amplifier, the length of transmission lines $TL_{19}$ and $TL_{20}$ are close to $\lambda/4$ at the center frequency of the desired passband. The bias circuit of the second stage amplifier is the same as that of the first one.

The 1000pF capacitors $C_{in}$, $C_6$, and $C_{out}$ at input/output ports and inter-stage are used as DC blocking capacitors. Input/output and inter-stage matching networks are the single short-circuit stub matchings designed using Smith Chart matching techniques. Short-circuit stub requires a shorter length than open-circuit stub, which is due to the fact that the open-circuit stub models a negative susceptance. Transmission lines $TL_1$ and $TL_2$ with a length of 4mm and a width of 1.12mm are not only the input and output pads but also the parts of matching networks. To obtain good simulation results, the microstrip line dimensions and nominal values of the lumped elements are optimized and tuned by trial and error in the simulation.

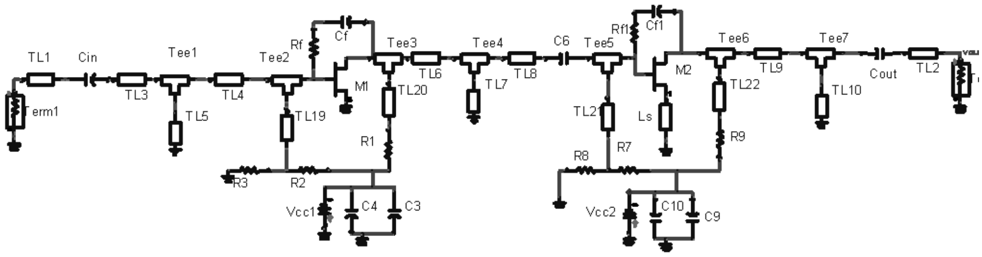



Fig. 2. Topology of the amplifier designed with distributed elements.

## B. Design with Lumped Elements

Fig. 3 shows that the amplifier with lumped element matching has a bias circuit similar to that of the former LNA. Differently, the separation of RF signals from DC bias conditions is achieved through so-called radio frequency coils (RFCs), which play a role in charging reactance. It should be noted that the inductance chosen carelessly will cause self-oscillation. As operating frequency increases, designers can no longer neglect the effects of the gate-drain capacitor $C_{gd}$ on the performance of amplifier. 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 $L_f$ [14]. Now, the gain flatness is mainly determined by the impedance $Z_f$ of feedback path:

$$Z_f = j(\omega L_f - \frac{1}{\omega C_f}) + R_f \tag{11}$$

The $L_f$ lessens low-frequency gain, increases high-frequency gain, broadens waveband, and degrades the effect of transistor parameters on the amplifier [12]. When the imaginary part of $Z_f$ denoted by Im($Z_f$) equals zero, the feedback path becomes the one discussed before.

During the matching network design, we find that it is indeed difficult to achieve a good input matching of CS structure at a wide frequency band [15]. Here, $\pi$ -type network considered as a low-pass filter is used to design the input matching. Without involving resistors in input port that greatly increase *NF*, a good gain performance can be achieved. The input port pad $TL_1$ also plays an important role in implementing input matching at frequencies below 2GHz. *VSWR1* can be lessened by prolonging the length of $TL_1$. Another solution to lower the low-frequency *VSWR1* is the introduction of gate series inductor $L_g$. The source degeneration technique and shunt feedback resistor are also used to facilitate the input matching to source impedance.

For simplicity, the effects of negative feedback path on the input and output impedances are ignored. Considering that inductors $L_g$ and $L_s$ are ideal, it is easy to show the input impedance of the LNA given by [11]:

$$Z_{in1} = j\omega(L_g + L_s) + \frac{1}{j\omega C_{gs}} + \frac{g_m L_s}{C_{gs}} \tag{12}$$

where $C_{gs}$ is the gate-source capacitance of the transistor. The source impedance is given by:

$$Z_{Source} = R_{Source} + j\omega_0 L_{Source} \approx R_s \tag{13}$$

$$R_{source} = \frac{R_s + L_{g1} + \omega_0^2 C_1^2 R_s^2 L_{g1}}{(1-\omega_0^2 C_1 C_2 L_{g1} R_s)^2 + (R_s C_2 + R_s C_1 + L_{g1} C_2)^2 \omega_0^2} \tag{14}$$

$$L_{Source} = \frac{-(R_s C_2 + R_s C_1 + L_{g1} C_2) R_s}{(1-\omega_0^2 C_1 C_2 L_{g1} R_s)^2 + (R_s C_2 + R_s C_1 + L_{g1} C_2)^2 \omega_0^2} - \frac{(R_s + L_{g1} + \omega_0^2 C_1^2 R_s^2 L_{g1}) L_{g1} C_2}{(1-\omega_0^2 C_1 C_2 L_{g1} R_s)^2 + (R_s C_2 + R_s C_1 + L_{g1} C_2)^2 \omega_0^2} \tag{15}$$

$R_S$ is the signal source impedance, usually 50Ω. With given values of $g_m$ and $C_{gs}$, we can obtain the desired impedance $g_m L_s / C_g$, the real part of $Z_{in1}$ denoted by Re($Z_{in1}$), to match $R_S$ and acquire a good gain performance. However, the optimum source impedance to achieve the best *NF* is not the same as the one that achieves the maximum gain. The imaginary part of $Z_{in1}$ is cancelled at resonance frequency:

$$\omega_0 = \sqrt{\frac{1}{(L_s + L_g)C_{gs}}} \tag{16}$$

The output matching involves an inductor $L_d$ and a resistor $R_d$ in series with signal output line. The output impedance of the LNA is:

$$Z_{out2} \approx j(\omega L_{s2} + \omega L_d - \frac{1}{\omega C_{out}} - \frac{1}{\omega C_{ds}}) + R_d \tag{17}$$

where $C_{ds}$ is the drain-source capacitance of transistor. From (17), we can minimize the effect of $C_{ds}$ on performances by adjusting the values of elements in output matching. A good output matching and the maximum gain is obtained in the conditions of $R_d = R_L$ (load impedance, usually 50Ω) and Im($Z_{out2}$)=0 at resonance frequency:

$$\omega_{02} = \sqrt{\frac{1/C_{ds} + 1/C_{out}}{L_d + L_{s2}}} \tag{18}$$

However, the condition of $\omega_0 = \omega_{02}$ can not always be satisfied. Thus, the optimized resistance of $R_d$ is not 50Ω but 19Ω in this paper. $R_d$ can adjust the low-frequency gain and improve the circuit stability. Besides the input and output matching networks, the configuration of LNA features an additional so-called inter-stage matching network for matching the output of the first stage amplifier with the input of the second stage amplifier. For M2, the condition of reaching matching is $Z_{in2} = Z_{out1}^*$.

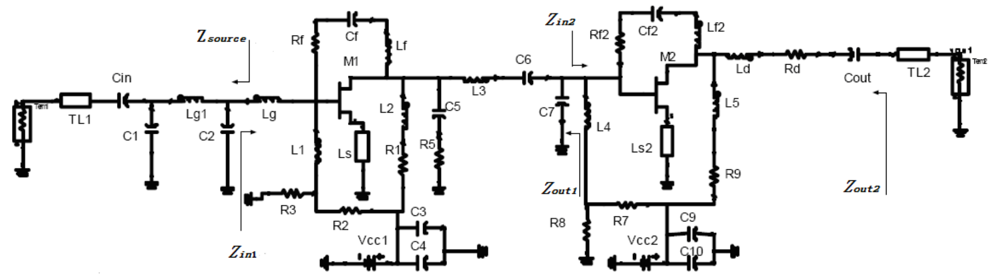



Fig. 3. Topology of the amplifier designed with lumped elements.

$$Z_{in2} = j\omega L_{s2} + \frac{1}{j\omega C_{gs}} + \frac{g_m L_{s2}}{C_{gs}} \quad (19)$$

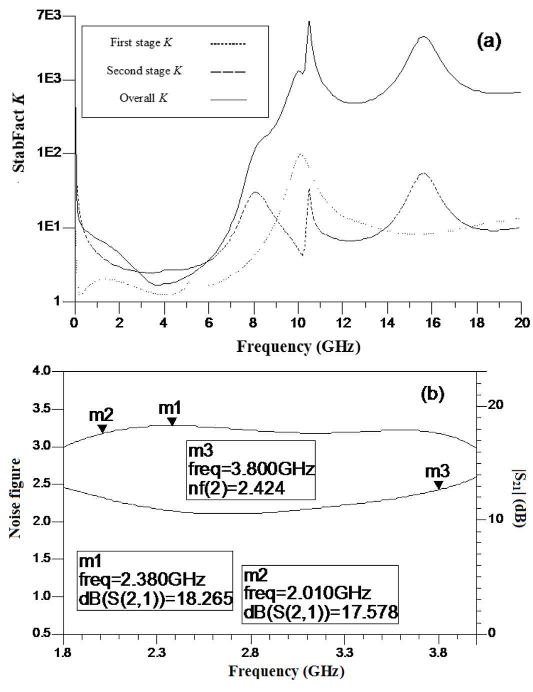
$$Z_{out1} \approx [j(\omega L_3 - \frac{1}{\omega C_6} - \omega C_{ds} R_5^2) - \frac{C_{ds} R_5}{C_5}] \| \frac{1}{j\omega C_7} \quad (20)$$

$R_5$ and $C_7$ in the inter-stage matching network is used to dissipate the high gain at low frequencies and condition the gain flatness. With respect to LNA stabilization, it is easy to meet the conditions of Re($Z_{in1}$+$Z_{source}$)>0 and Re($Z_{out2}$+ $R_L$)>0 and obtain the unconditional stability.

## IV. Simulation Results

### A. Amplifier with Distributed Elements

Seen from Fig. 4(a), the each stage and the overall $K$ are above 1, so the proposed LNA is unconditionally stable in full waveband. To be close to the actual results, united simulation considering the coupling between microstrip lines is conducted. Fig. 4(b) illustrates that the $NF$ is no more than 2.424dB, and the largest forward-gain $S_{21}$ is 18.26dB with a gain flatness of 0.7dB. The maximum values of *VSWR1* and *VSWR2*, 2.330 and 2.385, are obtained at 3.26GHz and 3.06GHz, respectively. The linearity of the LNA has also been taken into consideration. As shown in Fig. 7(d), the $OIP_3$ level shows the minimum of 33.461dBm at 3.8GHz. These results meet requirements of LNA design.



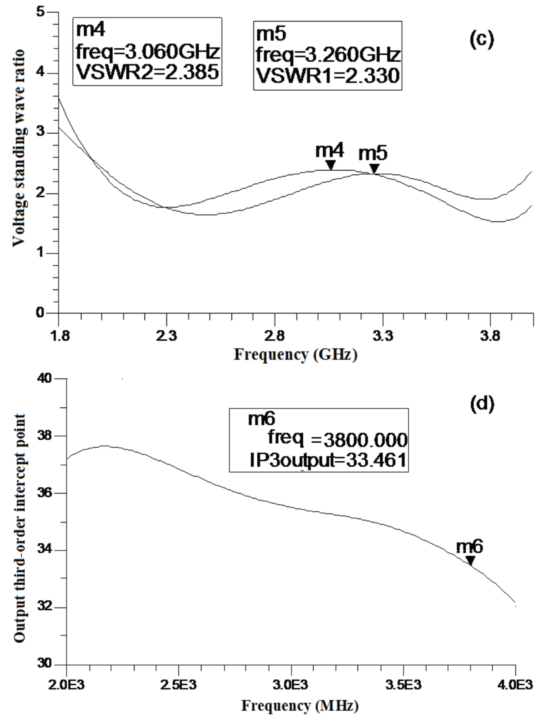




Fig. 4. Simulation results (a) stability factor (b) gain and noise figure (c) input and output *VSWRs* (d) output third-order intercept point.

### B. Amplifier with Lumped Elements

It is thought that the inductor's frequency dependency lowers the bandwidth. However, this paper results in the fact that compared with the amplifier with distributed elements, the LNA designed with lumped elements has a higher gain, a lower $NF$, and smaller *VSWRs* in a wider frequency band. From Fig. 5(a), the amplifier is also unconditionally stable in full band. Fig. 5(b) represents the gain- and $NF$-frequency characteristics. The minimum value of $S_{21}$ within 500MHz-4GHz band is 18.936dB with a variation of 0.46dB, and meanwhile $NF$ is less than 1.89dB, which satisfies the requirements of a RF circuit very well. Therefore, the $NF$ of the following blocks becomes less important due to the high gain of the LNA. Fig. 5(c) shows that the *VSWR2* is always under 2 over 0.5-4GHz, while *VSWR1* varies between 2 and 2.23 at the frequency decreasing from 700MHz to 500MHz. With this design technique, not only can a high gain be obtained, but also a low $NF$ can be achieved simultaneously. Furthermore, from the simulation results, the LNA may obtain good performances in the broadened frequency range of 100MHz-4.5GHz. What is difficult is that low *VSWR1* still can not be achieved in such a wide frequency band by trial and error. Fig. 5(d) illustrates an $OIP_3$ of 34dBm above, better than the result before. Compared with the performances in [16]-[18], a higher gain with a low *NF* and a high $OIP_3$ is achieved in a wider frequency band in this paper. Although Chaudhari et al [19] presented a LNA over a wider frequency band of 0.08-7 GHz, the obtained *NF* is much higher, 6-8dB.

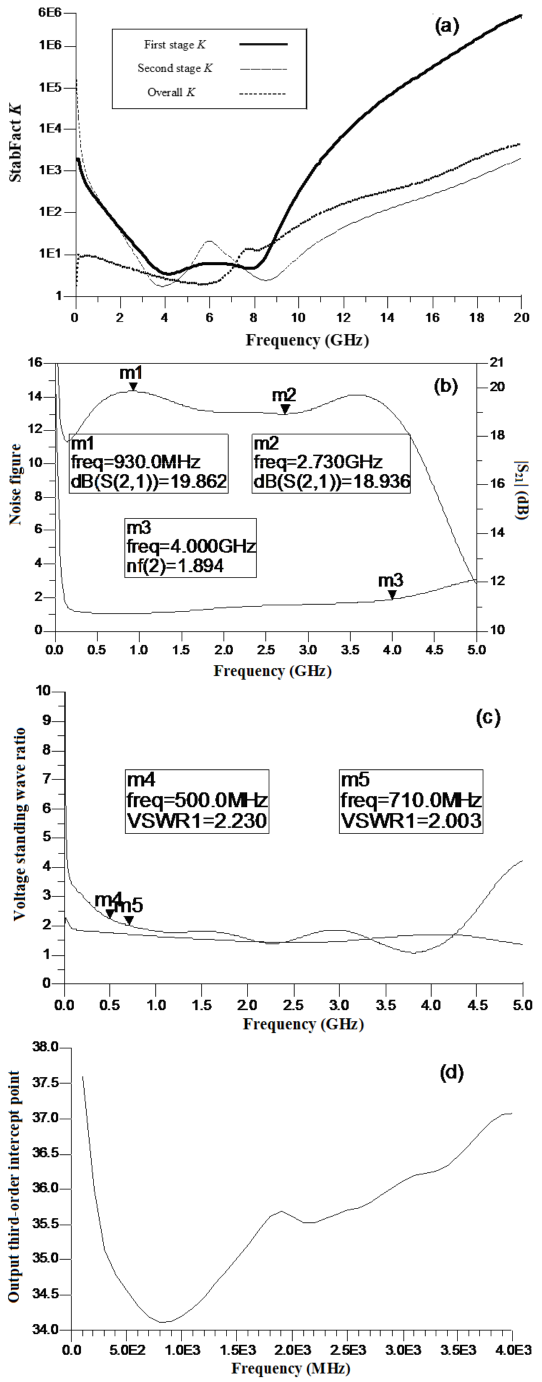



Fig. 5. Simulation results (a) stability factor (b) gain and noise figure (c) input and output *VSWRs* (d) output third-order intercept point.

## V. Conclusion

This paper presents two wideband low noise amplifier designed with microstrip lines for 2.0-3.8GHz range and with lumped elements for 0.5-4GHz using shunt resistive feedback and source inductive degeneration technologies. Simulation results of the LNA with microstrip lines matching show the maximum gain of 18.86dB with a gain flatness of 0.7dB, the maximum *NF* of 2.4dB, less than 2.4 *VSWRs*, and an $OIP_3$ above 33.461dBm. The other LNA obtains better performances and trade-off among them. Therefore, the lumped elements are still employed to design LNA at high frequencies by many authors. The LNA has a 19.4 ± 0.46dB gain, a *NF* less than 1.894dB, and an $OIP_3$ above 34dBm. Its *VSWR2* are always under 2 at frequencies ranging from 0.5GHz to 4.5GHz, while *VSWR1* varies between 2.0 and 2.23 over the frequency band of 0.5-0.7GHz. These results are better than those in other papers. Such LNA can be applied in the front-end of WCDMA and WLAN infrastructures to reduce the noise figures of the following blocks and improve the gain.

## References

[1] J. X. Zhao, M. R. Lu, and J. Deng, *Fundamentals of Radio Frequency Circuit*, 2nd ed., Xi'an: Xidian University Press, 2011, ch. 4, pp. 107-110.

[2] G. S. Kong, Z. X. Luo, T. L. Zhang, and K. Yang, "Design of 1-4 GHz broadband low noise amplifier," *Research & Progress of Solid State Electronics*, vol. 31, no. 2, pp. 165-168, Apr. 2011.

[3] O. Garcia-Perez, D. Segovia-Vargas, L. E. Garcia-Munoz, J. L. Jimenez-Martin, and V. Gonzalez-Posadas, "Broadband differential low-noise amplifier for active differential arrays," *IEEE Trans. Microwave Theory Tech.*, vol. 59, no. 1, pp. 108-115, Jan. 2011.

[4] P. Andreani and H. Sjöland, "Noise optimization of an inductively degenerated CMOS low noise amplifier," *IEEE Trans. on Circuits and Systems—II: Analog and Digital Signal Processing*, vol. 48, no. 9, pp. 835-841, Sep. 2001.

[5] A. B. Ibrahim, A. R. Othman, M. N. Husain, and M. S. Johal, "Low noise, high gain LNA at 5.8GHz with cascode and cascaded techniques using T-matching network for wireless applications." *International Journal of Information and Electronics Engineering*, vol. 1, no. 2, pp. 146-149, Sep. 2011.

[6] S. Anderssony, C. Svenssony, and O. Drugge, "Wideband LNA for a multistandard wireless receiver in 0.18 μm CMOS," in *Proc. 29th European Solid-State Circuits Conf.*, Estoril, Sep. 2003, pp. 655-658.

[7] M. Sumathi and S. Malarvizhi, "Performance comparison of RF CMOS low noise amplifiers in 0.18μm technology scale," *International Journal of VLSI design & Communication Systems*, vol. 2, no. 2, pp. 45-53, June 2011.

[8] G. Gonzalez, *Microware Transistor Amplifiers Analysis and Design*, 2nd ed., New Jersey: Prentice Hall, 2003, ch. 4, pp. 333-338.

[9] B. M. Liu, C. H. Wang, M. L. Ma, and S. Q. Guo, "An Ultra-Low-Voltage and Ultra-Low-Power 2.4 GHz LNA Design," *Radioengineering*, vol. 18, no. 4, pp. 527-531, Dec. 2009.

[10] R. C. Liu, C. R. Lee, H. Wang, and C. K. Wang, "A 5.8-GHz two-stage high-linearity low-voltage low noise amplifier in a 0.35 μm CMOS technology," in *Proc. IEEE Radio Frequency Integrated Circuits Symposium*, Seattle, 2002, pp. 221-224.

[11] A. P. Adsul and S. K. Bodhe, "Performance evaluation of different LNA's having noise cancellation and phase linearity characteristics for IR-UWB systems," *International Journal of Engineering and Technology*, vol. 3, no. 6, pp. 419-428, Dec. 2011.

[12] R. Ludwing and G. Bogdanov, *RF Circuit Design Theory and Application*. 2nd ed., New Jersey: Prentice Hall, 2000, ch. 9, pp. 470-477.

[13] F. Yang, Y. W. Zhou, Y. Z. Ma, and H. T. Wang, "Design and implementation of an S-band GaN high power amplifier," *Fire Control Radar Technology*, vol. 40, no. 3, pp. 86-89, Sep. 2011.

[14] D. J. Cassan and J. R. Long, "A 1-V transformer-feedback low-noise amplifier for 5-GHz wireless LAN in 0.18μm CMOS," *IEEE Journal of Solid-State Circuits*, vol. 38, no. 3, pp. 427-435, Mar. 2003.

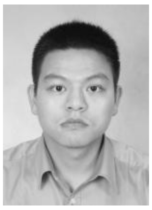
[15] F. Zhang and P. R. Kinget, "Low-power programmable gain CMOS distributed LNA" *IEEE Journal of Solid-state Circuits*, vol. 41, no. 6, pp. 1333-1343, June 2006.

[16] Y. L. Wang, M. L. Her, and H. H. Lin, "Design and implementation of LNA with high gain and low power consumption for UWB system," in *Proc. 15th Asia-Pacific Conf. Communications*, Shanghai, 2009, pp. 422-425.

[17] C. W. Kim, M. S. Kang, P. T. Anh, H. T. Kim, and S. G. Lee, "An ultra-wideband CMOS low noise amplifier for 3–5-GHz UWB system," *IEEE Journal of Solid-state Circuits*, vol. 40, no. 2, pp. 544-547, Feb. 2005.

[18] F. Bruccoleri, E. A. M. Klumperink, and B. Nauta, "Wide-band

CMOS low-noise amplifier exploiting thermal noise canceling," *IEEE Journal of Solid-state Circuits*, vol. 39, no. 2, pp. 275-282, June 2004.
[19] J. Chaudhari, R. Jani, and S. Oza, "A 0.08-7 GHz low power low noise amplifier design using 0.18 μm CMOS technology," *International Journal of Computer Science & Emerging Technologies*, vol. 4, no. 20, pp. 513-519, Aug. 2011.



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