Int. J. Electron. Commun. (AEÜ) 67 (2013) 144–148

Contents lists available at SciVerse ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.com/locate/aeue

A novel UWB low noise amplifier for multi-band navigation application

EnCheng Wang[a,*], ZhuoPeng Wang[b], ShaoJun Fang[c], Peng Chen[c]

[a] Information Engineering College of North China University of Technology, Beijing, China
[b] College of Information and Electrical Engineering of Shandong University of Science and Technology, Qingdao, China
[c] Information Science and Technology College of Dalian Maritime University, Dalian, China

ARTICLE INFO

Article history:
Received 3 February 2012
Accepted 8 July 2012

Keywords:
LNA
Multi-band navigation receiver
Balanced amplifier technique

ABSTRACT

Multi-band navigation receivers have been widely applied in mobile communication systems, and the low noise amplifier (LNA) is an important part of navigation receiver. This paper presents a broadband LNA based on balanced amplifier technique in order to get high gain, low noise figure and smaller size. To improve the LNA's stability, we use microstrip lines to replace traditional small inductors and achieve good results. The simulation and measurement results show that the LNA using balanced amplifier technique is absolutely stable with in the band range of 1.1–1.7 GHz, which can include the band of GPS, GLONASS, Galileo and BeiDou satellite navigation systems. Simulation and experimental results are described detailed.

1. Introduction

Nowadays, satellite navigation systems are very intensively used. The American GPS and the Russian GLONASS are already worldwide operable. The European Galileo-System and China BeiDou are expected to be ready for use in recent years. So, the application of multi-band navigation receiver is becoming a trend with the development of satellite positioning technique. Broadband LNA is very essential in multi-band navigation receiver because the signal transmitted from antenna is distributed in several bands, and the use of broadband LNA can amplify signals within different bands by one LNA. In order to ensure the system demodulates the information and data in need, LNA need enlarge the received signal and reduce the noise interference. As LNA works in the first block of the receiver, its ability to suppress noise is directly related to the whole performance of the receive system. Therefore, the performance of LNA is more and more strict, requires not only low noise figure and high gain, but also the good property of S11, S22 and in-band ripple [1]. In order to meet the design target, this paper designs a LNA with two stages, the first stage of the amplifier circuit is designed by the minimum noise figure because the multistage amplifier's noise figure is mainly determined by the first stage; the second stage is finished in accordance with the optimal gain.

2. The design of broadband balanced low noise amplifier

2.1. Circuit design of LNA

The balanced LNA technique can guarantee the good S11 and S22 while ensuring lower noise figure and it can obtain better gain flatness [2–5], so it is a practical approach to improve the performance of LNA.

The balanced amplifier technique contains two low noise amplifiers and two 3 dB couplers as shown in Fig. 1. LNA (a) and LNA (b) are two amplifiers with the same structure and performance. RF signal is divided into two signals with the same power and a phase difference of 90° through the first coupler, the amplifier LNA (a) and LNA (b) amplified the two signals. The property of S11and S22 will be good only when the two amplifiers' structure and performance are basically same. The two signals after the two amplifiers will be synthesized by the second coupler at the output of the module, and the reflection signal of the balanced LNA will be absorbed by Z0, it can also greatly reduce S22 of the amplifier circuit. If the 3 dB coupler is lossless, the gain of the balanced amplifier is the same to LNA's gain [6,7].

The amplifier tube is the key component of LNA, ATF-54143 is a high dynamic range and low noise pHEMT in the 450 MHz to 6 GHz frequency range. According to the datasheet, we choose the typical quiescent operating point, $V_d = 3$ V, $I_{ds} = 60$ mA, $V_{dd} = 5$ V, $V_{gs} = 0.59$ V and choose I_{bb} to be 2 mA [8]. The design of bias circuit as showed in Fig. 2 and it is simpler than the structure of the datasheet because we remove some unneeded capacitors from repeated manufacture and measurement.

* Corresponding author.
E-mail address: dlenchw@hotmail.com (W. EnCheng).

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http://dx.doi.org/10.1016/j.aeue.2012.07.003

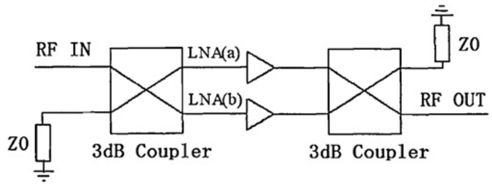

Fig. 1. The structure of the balanced amplifier.

2.2. Stability design

The stability is very important for LNA. The unconditional stability of LNA can ensure the network to be stable for all passive source and load impedance [9]. We use series negative feedback at source to ensure the LNA to be unconditional stability, the advantage of this method is to get lower S22 and noise figure while ensuring unconditional stability. At the same time, we add two small inductors in the source of ATF-54143. We replace the two small inductors with microstrip lines because of the small value of the inductor. We can calculate the length of microstrip line by the following formula: $l = 11.81L/(Z_0\sqrt{\varepsilon_r})$, where l is the length of microstrip line, its unit is in, L is the value of inductor, its unit is nH, Z_0 is characteristic impedance of microstrip line.

The width of microstrip line is 0.5 mm and its characteristic impedance is 87.4593 Ω by calculation. The stability coefficient curves of LNA are shown in Fig. 3. The simulation results without and with microstrip lines are shown in Fig. 3(a) and (b). We can see that the stability coefficient is more than 1 after we add microstrip lines and the system is unconditional stability.

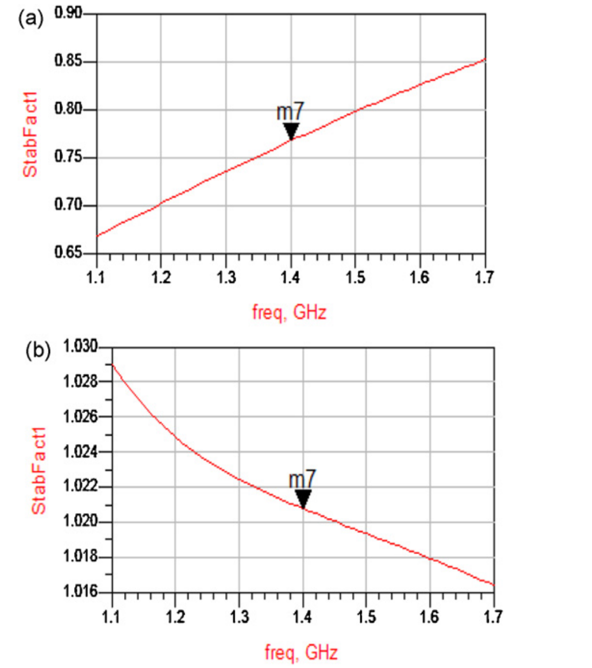

Fig. 3. (a) Stability of the LNA without microstrip. (b) Stability of the LNA with microstrip.

2.3. Low noise figure design

For multistage LNA, the NF is calculated with the following equation:

$$NF = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \cdots \frac{NF_n - 1}{G_1 G \ldots G_{n-1}}$$

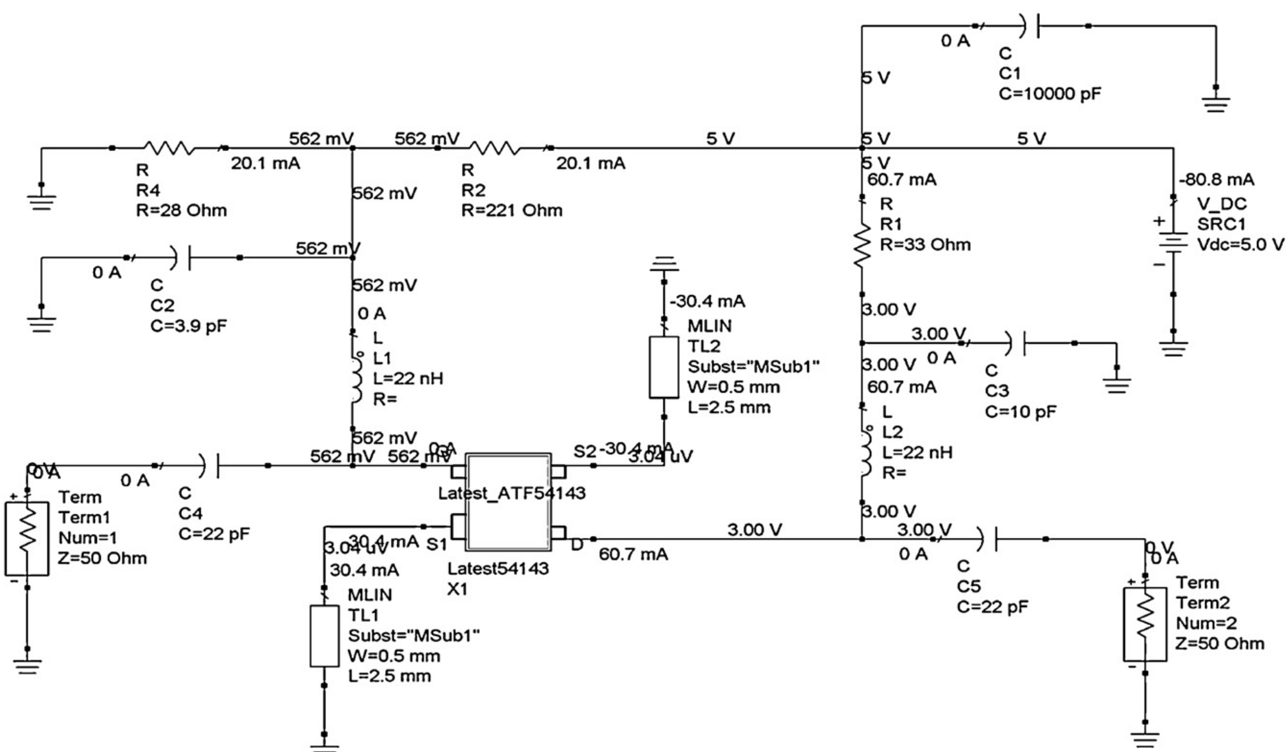

Fig. 2. The design of bias circuit.

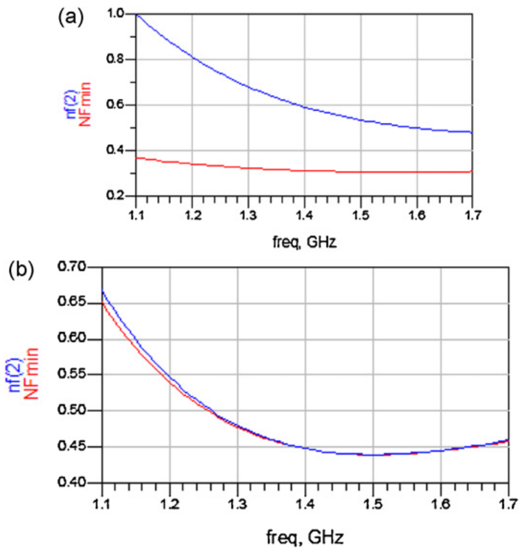

Fig. 4. (a) Noise figure of the LNA designed by optimal gain. (b) Noise figure of the LNA designed by the minimum noise figure. (For interpretation of the references to color in text, the reader is referred to the web version of this article.)

where NF is the noise figure of the system, NF_n is the noise figure of the NO.n stage, G_n is the gain of the NO.n stage. From the equation, we can see that the noise performance of the first stage is very important to the whole system. Thus, the first stage should be ensured to have a low noise figure [10,11]. In Fig. 4, the red line represents the minimum noise figure of the transistor and the blue lines represents noise figure of the system, we can see that the noise figure is relatively large when the matching network designed by optimal gain and it is very close to the minimum noise figure of the transistor when it is designed by the minimum noise figure.

2.4. Matching network design

In the design of LNA, the input and output matching network make the input and output impedance transform to 50 Ω impedance in the condition of good noise figure and gain [12]. The first stage is designed on the basis of the minimum noise figure; in order to meet the requirement of high gain, the second stage is designed by optimal gain.

Fig. 5 is the schematic diagram of first stage; it includes bias network design, stability, input and output matching networks. The two 3 dB couplers that connect two amplifiers are to achieve balanced amplifier design. The values of capacitances and inductances in the matching network generated by Smith Chart are not the common capacitance, so we must replace them with common nominal capacitances.

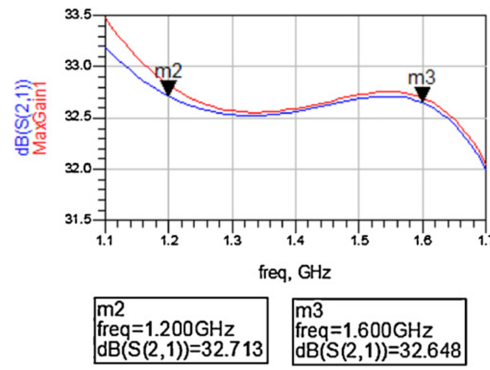

Fig. 6. Simulated gain of the LNA.

3. Simulation and measurement results

The simulation results of the two stages circuit are shown in Figs. 6–8. As shown in Fig. 6, the gain is more than 32 dB and meets the requirements in the frequency range of 1.1–1.7 GHz; the in-band ripple is less than 1 dB. From Figs. 7 and 8, we can see that the stability factor of LNA is bigger than 1 and the system is stable, the max value of the noise figure is 0.548. Fig. 9 shows that S11 and S22 of the LNA are less than −15 dB and the performance of matching network are very well.

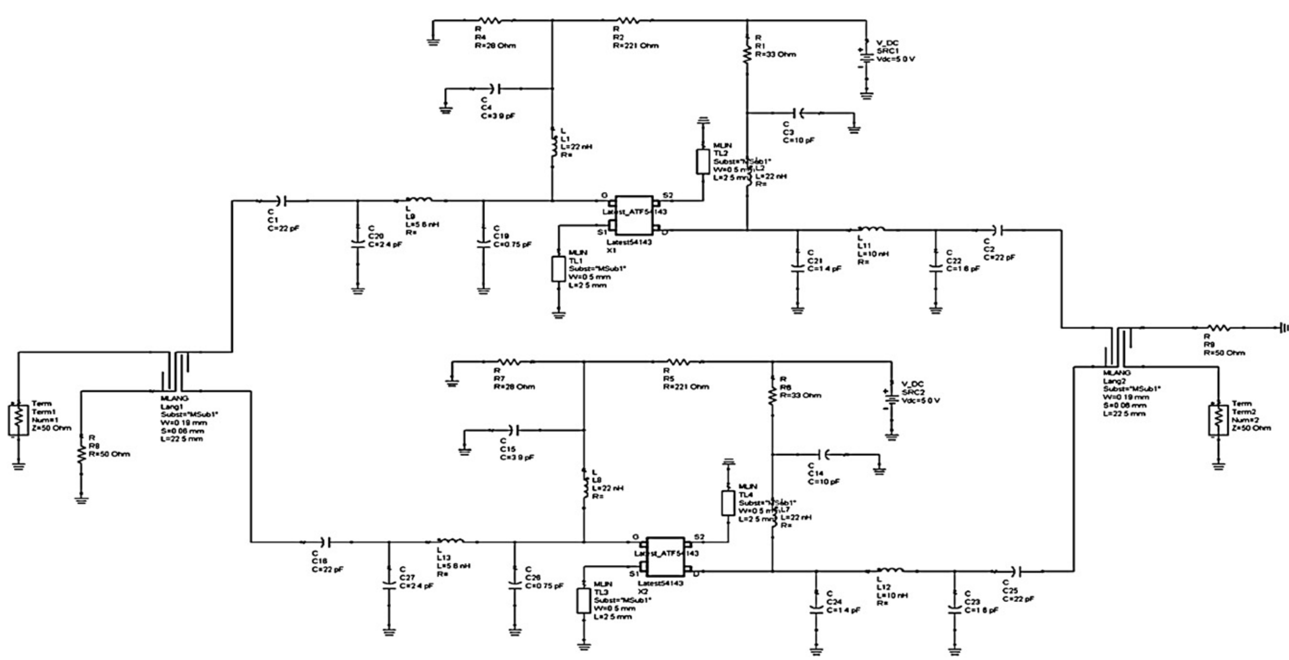

Fig. 5. First stage of the LNA.

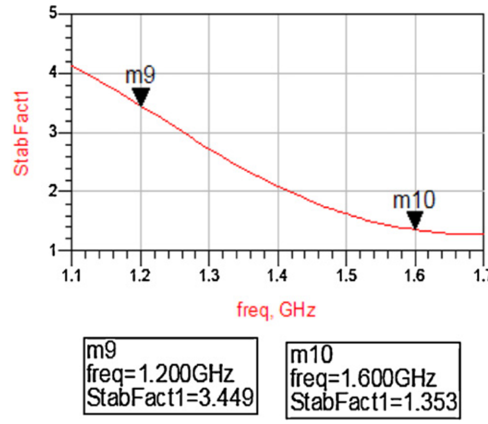

Fig. 7. Simulated stability factor of the LNA.

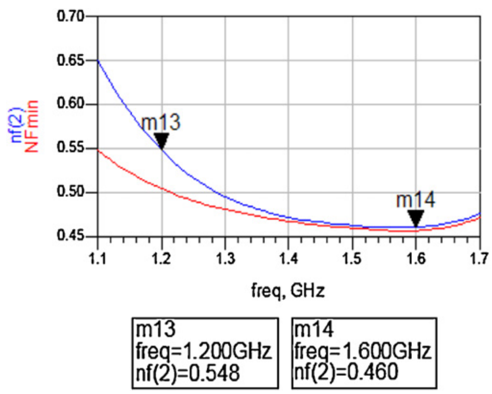

Fig. 8. Simulated noise figure of the LNA.

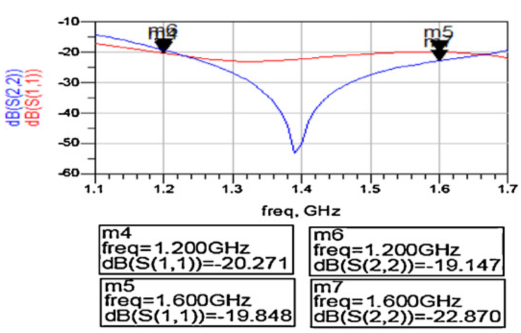

Fig. 9. The simulation result of S11 and S22.

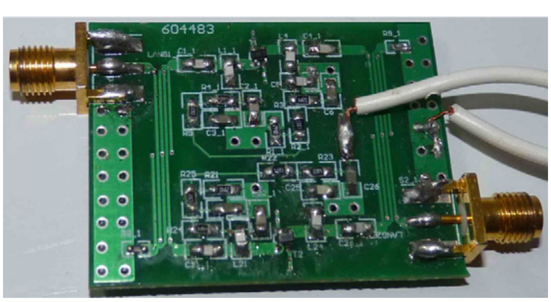

Fig. 10. The actual circuit board of the LNA.

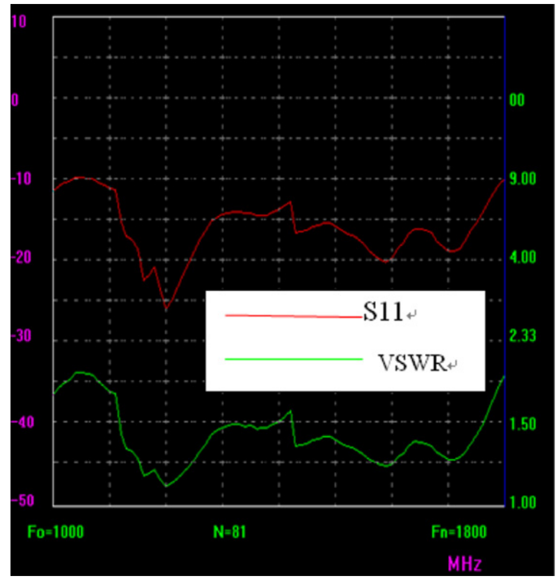

Fig. 11. Measured S11 of the LNA.

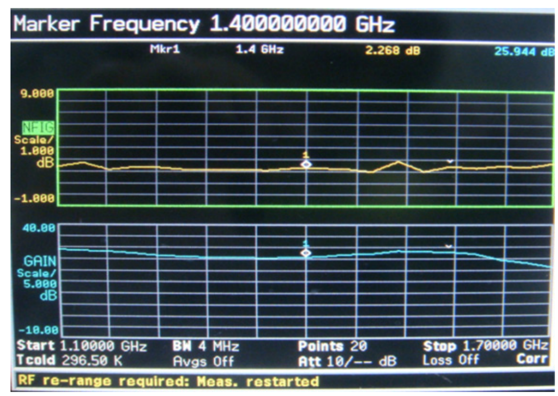

Fig. 12. Measured noise figure and gain of the LNA.

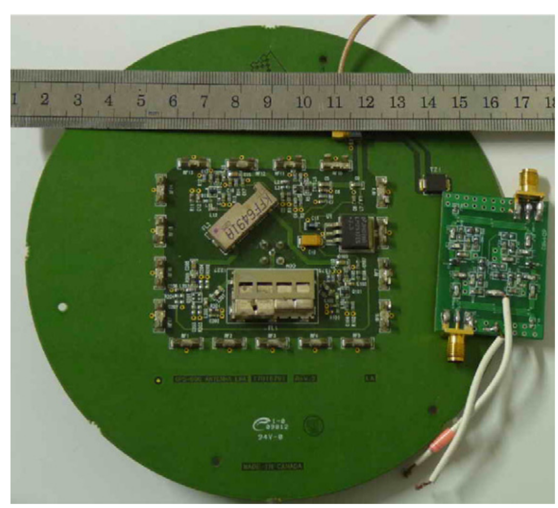

Fig. 13. Comparison of this LNA and a LNA for GPS receiver.

The actual circuit board is fabricated and is shown in Fig. 10. From Fig. 11, we can see that the return loss is less than -15 dB in the band range of 1.1–1.7 GHz. From Fig. 12, we can see that the gain of the LNA is about 26 dB and the noise figure is less than 2.5 dB in the band for navigation. Fig. 13 is the comparison of this LNA and a LNA for GPS receiver made in Canada; the fabricated LNA has smaller size.

4. Conclusions

A balanced LNA with bandwidth of 1.1–1.7 GHz was designed, which can include the band of GPS, GLONASS, Galileo and BeiDou satellite navigation systems. We designed the LNA with the balanced amplifier technique to get high gain, low noise figure and smaller size. To improve the LNA's stability, we use microstrip lines to replace traditional small inductors and simplify the design of bias circuit. The measurement results show that the LNA is absolutely stable; the gain can reach 29 dB, the S11 and S22 are all below −15 dB, and the noise figure is below 2.5 dB in the whole band. The measurement results show that the LNA can fulfill the requirements in multi-band navigation receiver.

Acknowledgments

This work was supported by the General projects of Beijing Education Committee (No. KM201010009005), National Natural Science Foundation of China (No. 61071044).

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