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# Optimization Analysis of Low-Noise Amplifier

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**Abstract:**

This paper mainly analyzes the important component of a wireless receiver – low-noise amplifiers (LNA). Low-noise amplifiers can reduce the effect of noise on the received signal and amplify signals. For the better development of wireless communication technology, remote control, and other related fields, it is necessary to optimize the design of low-noise amplifiers, so that low-noise operational amplifiers can finally obtain high gain, low noise figure, and other advantages. This paper analyzes the optimization design of LNA in the field of Global Navigation Satellite Systems (GNSS). This paper analyzes a low-noise amplifier design with the operation of concurrent dual-band for GNSS receivers with a single channel. The optimized design of a low-noise amplifier in this field uses a low-cost 0.18μm CMOS tube and adds load capacitances and a feedforward path to reduce the noise figure (NF) of the system. Noise figures in 1.2 GHz and 1.57 GHz bands are reduced by about 0.9 dB. In addition, the high gain, high linearity, and other excellent properties are shown in 1.2 GHz and 1.57GHz. In the application of 5G/6G network technology, the optimized design of Gallium Arsenide (GaAs) PHEMT technology with a gate length of 0.3μmm and inductively degraded common source topology phase structure is adopted. From this optimization, the noise figure is optimized to 1.3-1.4, and the gain of the system is 20-22 dB. At the same time, good linearity is also shown. Then, the prospects of semiconductor materials such as Gallium Nitride (GaN) and Indium Phosphide (InP), which have the advantages of high electron mobility and low-cost design, in optimizing low noise operational amplifiers. To a certain extent, the in-depth study of the optimal design of LNA can improve the technical level of wireless communication, aerospace, and other fields.

**Keywords:** low-noise amplifier (LNA); Global Navigation Satellite System (GNSS); 5G/6G; semiconductor.

## 1. Introduction

As wireless communication technology continues to develop, the requirements of people to receive signals are constantly improving, and it is necessary to obtain signals faster and more accurately. Low-noise amplifier is used in the RF front-end and mid-end of wireless receivers, which plays a very important role in wireless communication, aerospace, industrial control, and other fields, and is an important tool used to receive signals [1].

The design of good performance of low-noise amplifiers is conducive to improving the overall sensitivity of the system so that the received signal can be less affected by environmental noise (Such as Thermal Noise, 1/f Noise, and Shot Noise). At the same time, optimizing low-noise operational amplifiers can promote the development of areas such as wireless communications, and help us develop more convenient and beneficial technology for people.

The introduction part of this paper introduces the background and significance of low-noise amplifiers. In the main part, the advantages and disadvantages of traditional noise cancellation technology are introduced. Then, the optimization analysis of low-noise operational amplifiers is carried out from two aspects of the development of the Global Navigation Satellite System (GNSS) and wireless communication technology. The application prospect of semiconductor materials in low-noise amplifiers is introduced. Finally, the whole paper is summarized as the conclusion.

## 2. Traditional Noise Cancellation Techniques

In traditional noise cancellation techniques, low-pass filters are sometimes used to eliminate high-frequency noise components, especially when the ripple in the segmented signal is present [2]. In this noise cancellation technology, the design of low-pass filters is relatively simple, but the low-pass filter may cause signal distortion, increased power consumption, and other problems.

Sometimes grounding and shielding technology is also used to reduce noise from external surroundings. Scientific grounding and shielding design is an important means to control electromagnetic interference and ensure signal integrity in the field of broadcasting stations [3]. Shielding technology has a significant effect in the reduction of high-frequency noise, but a better selection of shielding materials may cause higher costs and processing design fees. The realization of grounding technology is relatively simple, but it may face difficulties in the design and layout of grounding wires. In addition to the above several methods, we also have power filters, differential amplifiers, temperature compensation circuits, and other ways to reduce the impact of noise on the system.

Compared with traditional noise reduction techniques, low-noise operational amplifiers can be more widely used in complex circuits. Low-noise operational amplifiers are generally widely used in satellite navigation communication equipment, broadband network signal reception, 5G/6G network development and deployment, automotive radar recognition, and some biotechnology research, so low-noise operational amplifiers need a small noise factor to reduce the noise in the circuit and improve the output signal-to-noise ratio. The requirements for low-noise operational amplifiers vary in each application area, depending on the amount of gain required by the system and the frequency range in which it operates. Therefore, it is very important to study and design the optimization and design of low-noise operational amplifiers in different fields.

## 3. Optimal Design of Low Noise Operational Amplifier

### 3.1 Application and Optimization of LNA in GNSS

With the development of satellite navigation systems, the number of satellites launched into space continues to increase, and the requirements for signal reception in the military, transportation, environment, and other fields continue to improve, which requires more optimized noise processing technology to output excellent SNR [4].

Due to the single-band GNSS receivers receiving and transmitting signals having low accuracy [5], designers have turned to the study of multi-band GNSS systems [6]. In 2024, Minoo Eghtesadi, Mohammad Reza Mousavi, and Egidio Ragonese proposed a dual-band parallel low noise amplifier design and proposed to add load capacitances and feedforward path to reduce noise figures and obtain high gain and linearity. The noise figure and gain of the system are optimized. The final LNA optimization design diagram is as follows figure 1:

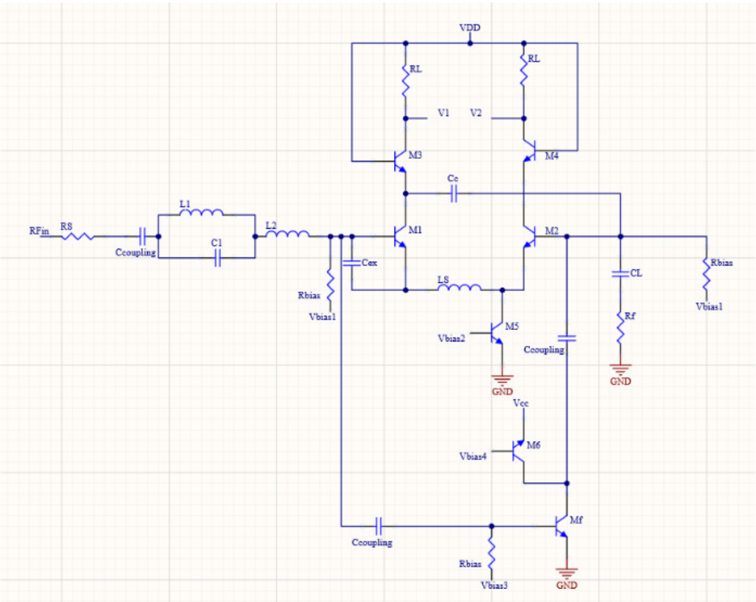


**Fig. 1 The final optimization design diagram of LNA in GNSS**

In this circuit, the input matching network consists of a parallel resonant network and a series resonant network, which can be matched simultaneously in two frequency bands of 1.2 GHz and 1.57 GHz. The compensation capacitor Cc solves the problem of LNA imbalance caused by the unequal current signals on the left and right sides of the amplifier, preventing the increase of NF and low linearity. Then, the proposed LNA optimization design uses low-cost 0.18μm CMOS, combined with the application of load capacitance and feedforward path noise reduction technology, the system noise is significantly improved, the noise coefficient of 1.2 GHz, and the 1.57 GHz band is reduced by about 0.9 dB, and the output gain is also improved. In addition, the LNA has a high linearity due to the pseudo-differential topology of the circuit and the compensation capacitance (balanced output).

This optimization design has a certain role in promoting the development of a global satellite navigation system, and we can carry out further research on this basis.

### 3.2 Application and Optimization of LNA in 5G/6G

With the development of the network era and the continuous improvement of the level of science and technology, people's demand for higher-speed wireless communication is increasing. At this stage, technicians vigorously develop broadband technology. Because a broadband LNA can better save development cost, space, and power consumption compared with the use of multiple narrowband LNAs, more emerging functions can be studied [7]. Further, broadband technology also has higher requirements for the gain, linearity, and noise factor of the system.

Mfonobong Uko, Sunday Ekpo, Fanuel Elias, and Stephen Alabi optimized LNA at 3.2-3.8GHz using GaAs PHEMT technology with 0.3μmm gate length and common source topological phase structure with induction degradation [8]. Because the semiconductor material gallium arsenide has higher electron mobility than silicon transistors, it is used as a 0.3μmm gate length transistor and can work normally at high frequencies when combined with pHEMT technology. The 0.3μmm gate length can be a system with lower noise performance.

The following figure 2 is the topology diagram:

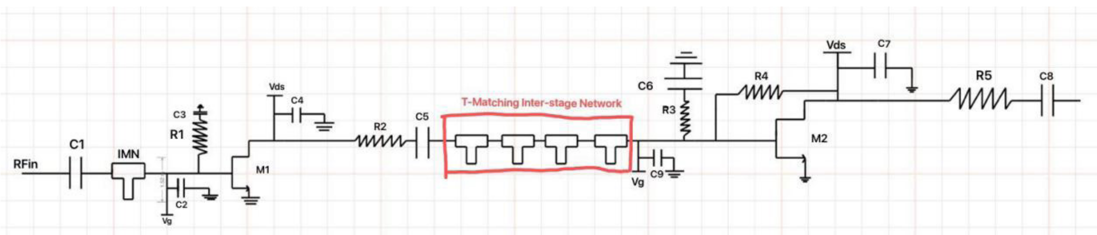


**Fig. 2 The topology of the circuit**

The performance of the low-noise amplifier in this design can be attributed to the adoption of GaAs PHEMT technology and a common source topology with good high-frequency noise characteristics and the best impedance matching between the input and output networks. After optimization, the predicted noise factor of the final system is 1.3-1.4 dB, the gain is 20-21 dB, and the OIP3 is 18 dBm [8]. This successful design will facilitate the development of higher-performance wireless communications.

## 4. Discussion

Because semiconductor materials are susceptible to temperature, and there may be material defects, and carrier flow, the types of noise that need to be overcome mainly include thermal noise, 1/f noise, and shot noise. The high electron mobility of semiconductor materials allows them to be applied to millimeter wave frequency bands. At the same time, with the development of semiconductor technology in recent years, we have applied semiconductor materials to integrated circuits, which can also help us improve the overall circuit performance and reduce the impact of noise. Therefore, more and more designers choose to use semiconductor materials to make low-noise amplifier components.

In addition to the Gallium Arsenide mentioned above, semiconductor materials such as Gallium Nitride and Indium Phosphide are used in the design optimization of low-noise operational amplifiers. Gallium Nitride HEMT devices are mainly used in high power and frequency applications [9] for their low noise performance, simplicity of design, low cost and high voltage resistance, and high power density. Like gallium nitride, indium phosphide can also be used in high-frequency and high-power applications, but the cost of indium phosphide is higher and more difficult to manufacture, so this limits its design applications in low-noise operational amplifiers.

With the increasing demand for higher data rate wireless communications, there has been a strong interest in millimeter wave frequencies [10]. Therefore, we need to design a low-noise operational amplifier with a lower noise figure. Only in this way can we meet the development of wireless communication technology, better help us improve the overall performance of the system, and improve the sensitivity of the received signal. In the design optimization, we can give priority to the selection and use of appropriate semiconductor materials. It is possible that we can design a more stable low-noise amplifier.

## 5. Summary

As an important part of the RF front-end and mid-end of the radio frequency receiver, a low-noise amplifier needs to be optimized to have a lower noise figure, high gain, high linearity, and other excellent performance. In this way, the overall performance of the system can be improved, the impact on environmental noise can be reduced, and more accurate signals can be obtained. Traditional noise cancellation technology is easy to be disturbed by the outside world and may have problems such as high cost and difficult design. So, in the millimeter band and some sophisticated technology, we generally do not use traditional noise cancellation technologies. But the traditional noise cancellation technology also can provide us with some optimization ideas. Low-noise amplifiers are better designed than traditional noise reduction techniques and can be applied to more complex circuits. Therefore, optimizing the design of low-noise operational amplifiers enables us to reduce noise in some key applications such as aerospace and wireless communications. In the GNSS field, load capacitance and feedforward path are used to optimize the LNA parameters. Then, noise figures in both 1.2 GHz and 1.57 GHz bands are reduced by about 0.9 dB. In the 5G/6G network, the topological circuit and gallium arsenide PHEMT technology are combined to optimize the low-noise operational amplifier. The noise figure of this design is optimized to 1.3-1.4, and the gain of the system is 20-22 dB. The noise performance of the low-noise amplifier is improved by the two optimization design methods.

Combined with the advantages of Gallium Arsenide (GaAs) materials used for LNA optimization design in 5G/6G networks, similarly, low-cost, high-electron mobility semiconductor materials such as Gallium Nitride (GaN) and Indium Phosphide (InP) have high development prospects in the design and optimization of low-noise opamps.

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