The Design and Simulation of Dual-band Beidou Navigation Receiver LNA

Jinchang Liu\textsuperscript{1}, Baoquan Liao\textsuperscript{1}, Zhonggang Ma\textsuperscript{1}, Sheng Ma\textsuperscript{1}, Ping Gao\textsuperscript{1} \textbf{and} Huawei Yang\textsuperscript{2}, *

\textsuperscript{1}State Grid ShenWang LBS (BeiJing)CO., LTD, Beijing, China
\textsuperscript{2}Fujian Fuda Beidou Communication Technology Co., Ltd, Fuzhou, China

*Corresponding author e-mail: yanghw@fudabd.com

Abstract. The Beidou satellite navigation receiver requires receiving multi-band signals to ensure more accurate and reliable positioning and navigation. According to the working frequency bands B3I and L1 of the system, we propose a low-noise amplifier which is based on Infineon's BFP740FESD transistor. We employ the ADS software to simulate and optimize the low-noise amplifier input, and adopt the conjugate matching two-stage amplifier circuit. The simulation results show that the gain $\text{Gain} \geq 30\,\text{dB}$ in the L1 and B3 dual frequency band, the input and output standing wave ratio $\text{VSWR} < 1.5$, the noise coefficient $< 1.0\,\text{dB}$, and the out-of-band suppression is more than $-40\,\text{dB}$, which effectively reduces the out-of-band noise interference.

1. Introduction

Beidou positioning system is currently widely used in ships, aircraft, mobile equipment, etc. [1-4]. The front end of Beidou navigation receiver is mainly amplified by low-noise amplifier and down-converted filter output. Low-noise amplifier plays an important role in this process. The reception sensitivity of wireless communication system is mainly affected by the performance of low-noise amplifier noise [5]. The receiving frequency of the dual-band Beidou receiver is between 1.25GHz and 1.6GHz high frequency bands. The higher the frequency, the more attenuation of the electromagnetic wave signal propagating in the air. Therefore, the higher the noise performance of the low-noise amplifier is required.

Existing design schemes mostly adopt the two-stage ATF54143 cascade amplification method in the corresponding frequency band [6]. When sufficient gain is met, the noise coefficient will usually increase accordingly [7]. In addition, the out-of-band suppression effect is generally [8], the signal interference to the receiving end is greater [9]. According to the relevant requirements of Beidou navigation receiver, this paper designed a two-stage amplification method of Infineon ultra-low noise SiGe transistor BFP740FESD, which is suitable for L1 frequency band (L1 central frequency: 1615.68, bandwidth: 4.08MHz), B3 frequency band (B3 central frequency: 1268.52, bandwidth: 8MHz) low-noise amplifier with dual-frequency.

The design circuit uses discrete components to improve the circuit structure, and in the form of a two-stage amplification circuit, the entire system can simultaneously meet high gain and the best noise coefficient. Compared with the high-level requirements of out-of-band suppression, the performance of the existing solution is much improved.
2. The design of Low noise amplifier

2.1. BFP740FESD RF transistor
In this paper, we design the low-noise amplifier based on the BFP740FESD transistor of Infineon. It is a silicon-germanium-carbon (SiGe: C) broadband bipolar RF transistor with high stability, high gain and good linearity. According to the chip manual, it can be obtained that its operating frequency band is 150MHz-10GHz and the following partial information, as shown in Table 1.

| Frequency (GHz) | NFmin (dB) | Gms (dB) |
|----------------|------------|----------|
| 0.9            | 0.55       | 30.5     |
| 2.4            | 0.6        | 26       |

Table 1. Noise coefficient and gain information.

2.2. Design indicators
Operating frequency range: 1250MHz ~ 1620MHz; Center frequency is 1550MHz, requires full-band stability; Gain $\geq$ 30dB; Noise coefficient < 1.0dB, input and output standing wave ratio $VSWR < 1.5$, gain flatness $\leq$ 0.5dB, out-of-band suppression up to -40dB.

2.3. The structure of low noise amplifier system
Fig. 1 is the system structure layout. The two stages in the figure use Infineon's low noise amplifier transistor BFP740FESD. The entire system has three matching networks. The input matching network should minimize the noise factor NF. The inter-stage matching network can pull up the first-stage gain output relatively while reducing the noise coefficient. The main goal of the output matching network is to increase the gain. The two-way conjugate matching method is selected between the two stages, and the two ends are matched to the characteristic impedance of 50 ohms to ensure the impedance matching is complete.

![Figure 1. System structure diagram.](image)

2.4. Design of DC bias circuit
It can have a certain impact on the noise performance of the amplifier by adjusting the circuit transistors. We choose a suitable static operating point, put the amplifier in the amplification area, and make it work in a stable amplification state.

Refer to the BFP740FESD chip manual, Fig. 2 and Fig. 3 are the noise coefficient and gain curve, respectively. When the bias voltage $V_{CE} = 3V$, the bias current $I_C = 25mA$, the operating frequency is
900MHz, $NF_{\text{min}} = 0.55\text{dB}$, the maximum gain is 30.5 dB; at 1.5GHz, $NF_{\text{min}} = 0.55$, the maximum gain reaches 28dB.

Figure 2. The relationship between Gain and $I_C$ at different frequencies.  

Figure 3. Frequency $f$ and noise coefficient.

2.5. Stability analysis

Only when the circuit reaches a stable state can the amplifier work normally. When the suitable static operating point is satisfied, the entire frequency band can always work normally and the amplifier is in an absolutely stable state with the circuit bias. At the same time satisfy:

Stability factor:

$$K = \frac{1 - \frac{|S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2 |S_{11}| |S_{21}|}} > 1$$  (1)

Auxiliary stability factor:

$$B1 = 1 + \frac{|S_{11}|^2 + |S_{22}|^2 - |\Delta|^2}{2} > 0$$  (2)

Where

$$|\Delta| = \left| S_{11} S_{22} - S_{12} S_{21} \right|$$  (3)

General measures to stabilize the system: (1) Connect an inductor in series at the collector grid of the amplifier tube as a negative feedback network. (2) Series and parallel small resistors at the input or output of the circuit. Both methods can make the circuit stable, but we often take a variety of ways to ensure that the circuit is stable and does not oscillate in the design. In this paper, add the actual physical length of the microstrip line to the two emitters of the die: $W = 0.2\text{mm}, L = 0.45\text{mm}$ as a small inductor, providing negative feedback, as shown in Fig. 4. There is a coupling effect between the ports of the radio frequency circuit. The stability of one port can keep the two ports stable. The design choice is to
stabilize at the output end. The serial and parallel resistance elements at the input end will cause the thermal noise interference of the amplifier to reduce the noise performance of the amplifier. Connect a 120Ω resistor R in parallel at the output to eliminate the negative resistance component in the impedance, as shown in Fig. 5. Fig. 6 shows the stability curve of the amplifier after the simulation. The figure shows that the frequency is 1.55GHz and $K > 1$ in the whole frequency band, indicating that the circuit has been working in an absolutely stable state.

Figure 4. Add negative feedback.

Figure 5. Parallel resistance at output.
3. Optimized design and simulation verification

3.1. Design of matching network

The amplifier input front-end performs Smith circle matching and impedance matching between stages, which can realize the maximum signal transmission and minimize the signal reflection. In the RF circuit, the parasitic parameter effect is often caused by the circuit using discrete devices, resulting in deviations in the actual test matching. Therefore, the front-end matching network adopts a parallel Γ-shaped structure that adds microstrip lines and microstrip stubs, and adjusts the parameter values of TL15 and TL16 by tuning to make the noise coefficient as small as possible. Combined with the characteristics of the BFP740FESD die, it can be effectively enhanced out-of-band signal suppression.

![Figure 6. Stability curve.](image)

![Figure 7. Amplifier front-end Γ-shaped matching circuit.](image)
The signal source impedance and the load impedance can be matched to the best state. The input matching circuit is designed to achieve the lowest possible noise, that is, the input impedance $Z_{in}$ of the amplifier is equal to the conjugate value $Z_{opt}^*$ of the source impedance. For the gain circle, the impedances at both ends of the match are not necessarily exactly equal, which makes it impossible to reach the maximum power gain. Therefore, it is often necessary to sacrifice some gain to make the best when matching the best noise. After balancing the relationship between the two, the best noise coefficient circle and gain circle are shown in Fig. 8.

![Figure 8. Gain and noise coefficient circle chart.](image)

Multi-stage amplifier design needs to consider the connection between the two stages. There are two types of inter-stage connection methods: One is to design each stage amplifier with its own input and output network. They are matched to the same impedance, and then use a transmission line for inter-stage connection; the second type is the first-stage output network and the second-level input network performs conjugate matching. In this paper, we employ the first method. The first-stage output and the second-stage input are matched to 50Ω characteristic impedance at the same time to achieve their minimum noise coefficient and maximum gain. Fig. 9 shows the connect the two stages to form an inter-stage match.
4. Optimization simulation results

Fig. 10 and Fig. 12 show the circuit noise coefficient and S-parameters optimized by ADS simulation. The return loss of the input port $S_{11} = 24.289$dB, the return loss of the output end $S_{22} = 29.771$dB, the available input and output standing wave ratio $VSWR < 1.5$. In the stable range of the circuit, the fluctuation of $S_{21}$ in the 1.25GHz-1.6GHz frequency band is less than 0.5dB. The simulation after optimization is shown in Fig. 11. The results show that the gain flatness of the circuit has met the requirements. The signal suppression outside the front-end band has reached more than $-40$dB. The simulation result of the noise coefficient is less than 1 dB in the 1.25GHz-1.6GHz band.

Figure 9. Inter-stage matching circuit.
5. Conclusion
In this paper, we designed and implemented a low-noise amplifier that works in the L1 and B3 frequency bands, which can be used in actual engineering applications such as signal reception, transponders, and anti-interference. It employed a two-stage amplification stage matching method, which has high out-of-band inhibition effect and ideal performance parameters. It meets the requirements of the Beidou navigation receiver for low noise. The simulation results verify the effectiveness of the design and can be used for future practical research.

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