SCIENCE CHINA
Information Sciences

• LETTER •

October 2023, Vol. 66 209401:1–209401:2
https://doi.org/10.1007/s11432-022-3622-1

Collaborative gain and noise optimization: a design of 150-173-GHz cascode LNA with 22.3 dB gain and 6.92 dB NF based on the gain-noise plane

Zhongchen XU, Menghu NI, Qian XIE & Zheng WANG*

School of Electronic Science and Engineering, University of Electronic Science and Technology of China, Chengdu 611731, China

Received 10 September 2022/Revised 4 November 2022/Accepted 10 November 2022/Published online 9 August 2023

Citation Xu Z C, Ni M H, Xie Q, et al. Collaborative gain and noise optimization: a design of 150-173-GHz cascode LNA with 22.3 dB gain and 6.92 dB NF based on the gain-noise plane. Sci China Inf Sci, 2023, 66(10): 209401, https://doi.org/10.1007/s11432-022-3622-1

Owing to wideband spectrum resources, sub-terahertz technologies have significant value in high-data-rate wireless communication applications and other fields [1]. The evolving transceiver places a high demand on low-noise amplifiers (LNAs). However, in the sub-terahertz band, the increasing operating frequency causes a power gain (G_p) decrease and degradation of the noise figure (NF).

Significant efforts have been made to improve the G_p and NF of the LNA [2]. Our previous study [3] presented the gain-noise plane theory, where constant G_p circles and constant NF curves were simultaneously exhibited. Many researchers have utilized cascode topologies because of the high G_p and isolation, and some special measures have been adopted to improve the gain and noise performance, such as the emitter degeneration inductance (L_deg) and the base gain-boost inductance (L_b). However, for a cascode topology with L_deg and L_b, finding the optimal combination of these two inductors to optimize the power gain and noise collaboratively remains challenging.

In this study, a novel design approach is adopted with the gain-noise plane to find the optimal combination of L_deg and L_b for the cascode topology, as shown in Figure 1(a). In this approach, the optimal region for the design of the LNA is obtained, and the tradeoff between the power gain and noise with the opposite effects of L_deg and L_b on unilateral gain (U) and the combined effect on the gain-state point is exhibited in the gain-noise plane. In addition, the gain-noise plane and gain-state point change with the introduction of L_deg and L_b, which is utilized to achieve a good compromise between the power gain and noise. Furthermore, an optimized stagger-tuned technology is developed to reduce the in-band NF degradation by optimizing the center frequency (f_c).

Collaborative optimization between power gain and noise. The gain of the first stage of the LNA should be sufficiently large to suppress the noise of the later stages, and its noise should be sufficiently small to reduce the overall NF. Therefore, some gain-state points (blue) that represent the optimal compromise between power gain and noise on the initial gain-noise plane (black, ①) are shown in Figure 1(a). The gain-state point representing the active two-port network (A2P) should be pushed toward these points because only these points have the maximum G_p under the condition of equal NF. The optimal region (crimson) for the LNA design is determined, which is rarely obtainable using other approaches. Therefore, according to the trend shown, the gain-state point should be pushed to the upper left of the stability region to achieve optimal comprehensive performance. Subsequently, obtaining the optimal combination of L_deg and L_b can achieve this goal.

Unlike the gain-noise plane approach, the introduction of L_deg and L_b will change U and the gain-noise plane and the position of the gain-state point, respectively. As shown in Figure 1(a), with increasing L_deg, U continuously decreases and the gain-state point moves towards the upper left of the stability region (green, ②), which means that A2P achieves a higher G_p/U and approaches the optimal region. However, this does not imply that A2P obtains a larger G_p because of the decreasing U. Next, L_b is introduced to solve this problem and push the point closer to the optimal region. U increases with increasing L_b and the gain-state point keeps moving towards the upper left, and finally stops at the optimal position (red, ③). Meanwhile, the A2P obtains a larger G_p because of the higher G_p/U and increasing U. More importantly, A2P achieves minimum NF under the condition of equal G_p. In conclusion, the opposing actions of L_deg and L_b on U and the combined effect on the gain-state point movement mean the point could be moved to the optimal region with a constant or even increasing U. Therefore, the optimal comprehensive performance can be achieved based on the collaborative power gain and noise optimization.

Optimized stagger-tuned technology. In a broadband communication system, it is necessary not only to achieve a low NF at f_c, but also to ensure that the NF is within

---

* Corresponding author (email: wangzheng@uestc.edu.cn)

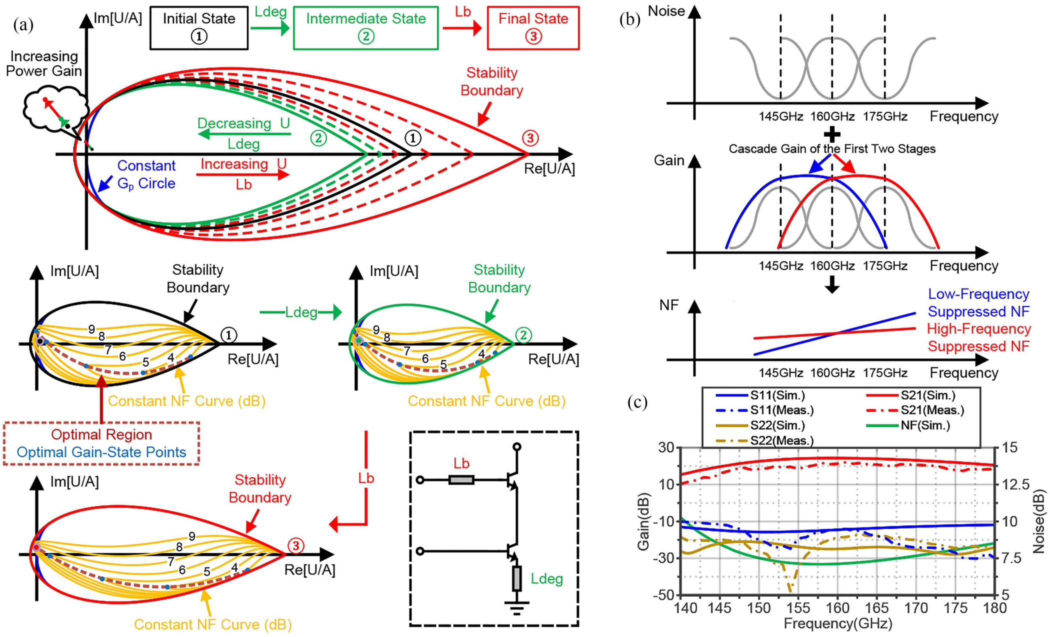

Figure 1 (Color online) (a) Collaborative gain and noise optimization with $L_{\rm deg}$ and $L_{\rm b}$ on the gain-noise plane; (b) effects of two options for cascading the first two stages on the in-band noise degeneration; (c) results of S-parameters and NF of the LNA.

a reasonable range at the boundary, which ensures that the communication system can work properly in the entire 3 dB band. Additionally, stagger-tuned technology is utilized in pursuit of a wide bandwidth, and the central frequencies of the three stages are placed at 145, 160, and 175 GHz [4]. Because the NF of the following stage can be suppressed by the $G_{\rm p}$ of the front stage, $f_{\rm c}$ of the input stage is selected to be 160 GHz to reduce the in-band noise deterioration. Next, as shown in Figure 1(b), the critical issue is the selection of $f_{\rm c}$ for the intermediate stage. Assuming that $f_{\rm c}$ of the intermediate stage is set to 145 GHz, the cascade gain of the first two stages (blue) is insufficient at the operating frequency of the output stage around 175 GHz, implying that the NF of the entire LNA deteriorates sharply at high frequencies. Therefore, $f_{\rm c}$ of the intermediate stage is set to 175 GHz, which suppresses the high-frequency noise and reduces the in-band NF degradation.

Circuit design and measurement. Considering the layout area and to achieve better comprehensive performance, this work utilizes cascode topologies for the input and intermediate stages and a two-stage common-emitter topology to construct the output stage for implementing broadband output matching without gain degeneration. The emitter of the core transistor in this study is chosen as a combination of four units, each of which covers 0.9 μm × 0.07 μm. $L_{\rm b}$ is placed between the base of the common-base transistor and alternating current (AC) ground to boost the power gain, and $L_{\rm deg}$ is placed between the emitter of the common-emitter transistor and the ground, which is beneficial for simultaneous input noise and power matching.

The chip is fabricated using 130-nm SiGe BiCMOS technology, and the area of the core circuit is 0.23 mm × 0.76 mm. The power consumption of the overall circuit is 35 mW, and the measured input-referred 1 dB power compression point achieves −19 dB at 160 GHz. The results of the S-parameters and noise figure are shown in Figure 1(c), and the maximum S21 is 22.3 dB. The power gain of the circuit is above 19.3 dB from 150 to 173 GHz, which indicates the 3 dB bandwidth of the LNA is 23 GHz. The measured and simulated results show good agreement, and the discrepancy is mainly due to the inaccuracies of the active devices models and the electromagnetic simulations of the passive components. The measured S11 and S22 are less than −15 dB, indicating that the proposed LNA achieves good input and output matching. Because relevant noise sources above 100 GHz are lacking, the measurements of the noise figure are not performed, and the simulated NF reaches 6.92 dB at 160 GHz, the degeneration of the in-band NF is only 0.7 dB, and the NF flatness is 0.03 dB/GHz, considering the bandwidth.

In conclusion, a high $G_{\rm p}$ and a low NF are simultaneously achieved with minor in-band noise degeneration and appropriate power consumption and bandwidth, while the input and output ports are well matched. More importantly, the validity of the proposed collaborative optimization methodology is verified.

Acknowledgements This work was supported by National Natural Science Foundation of China (Grant Nos. 62034002, 61874022).

References

1 Wang Z Q, Du Y, Wei K J, et al. Vision, application scenarios, and key technology trends for 6G mobile communications. Sci China Inf Sci, 2022, 65: 151301

2 Wang Z, Heydari P. A study of operating condition and design methods to achieve the upper limit of power gain in amplifiers at near-$f_{\max}$ frequencies. IEEE Trans Circuits Syst I, 2017, 64: 261–271

3 Xu Z C, Xie Q, Wang Z. A study of collaborative gain/noise optimization for LNAs at near-$f_{\max}$ frequencies based on a novel gain-noise plane approach. IEEE Trans Circuits Syst II, 2023, 70: 51–55

4 Kim J, Buckwalter J F. Staggered gain for 100+ GHz broadband amplifiers. IEEE J Solid-State Circuits, 2011, 46: 1123–1136