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CASCODE TOPOLOGY USING HEMT FET TECHNOLOGY FOR THE DESIGN AND ANALYSIS OF LOW NOISE AMPLIFIER CIRCUIT

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ABSTRACT

The current approach used the CMOS technique to produce LNA. The LNA features a two-stage common-source (CS) buffer amplifier to reduce noise and an active balun to transform single-ended signals into differential signals. This architecture will result in severe noise interference and poor gain. The "Low Noise Amplifier circuit design using Cascode topology with HEMT FET technology" is the suggested design. The main challenge and demanding aspect in digital circuit design applications is producing the necessary acceptable output with less noise, less power consumption, and fewer transistors. Any kind of electrical amplifier will boost the signal's strength and the noise level at its input, but it will increase the noise level as well. LNAs are designed to lessen this additional noise. By selecting certain parts, operating locations, and circuit topologies. Currently available low noise amplifiers use MOSFET technology to boost very low-power signals without greatly reducing their signal-to-noise ratio (SNR), which is a crucial component of digital circuit design. The purpose of LNAs is to reduce this additional noise by choosing specific components, operating points, and circuit configurations. The existing method employs low frequencies (around X), generates high noise (3.9 dB), produces gain (over 19 dB), and consumes power. Reducing excess noise must be balanced with other design goals like impedance matching and power enhancement. Therefore, a new design utilizing HEMT FET technology with a frequency in the X band was proposed using ADS (Advanced Design System) software in order to reduce the noise figure and raise the gain and linearity in order to meet the required target of acceptable output. LNA generates a gain of more than 10 dB and a noise figure of more than 3 dB, respectively, while taking into account the selection of HEMT (High Electron Mobility Transistor) topologies and the simultaneous matching approach. As a result, new digital circuit designs and communication applications may benefit from the proposed LNA with ADS 150nm software.

Keywords: low noise amplifier, feedback technique, T-shaped inductive network, and gain.

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1. INTRODUCTION

In radar, satellite receivers, and contemporary wireless systems, the Low Noise Amplifier (LNA) is a crucial front-end part of communication networks. By boosting weak signals that the antenna receives while lowering the amount of noise produced, its primary goal is to raise the system's overall signal-to-noise ratio (SNR) [1]. A well-designed LNA ensures high gain, low noise figure (NF), and adequate linearity while maintaining low power consumption. The Cascode arrangement is among the best topologies for LNA design. The cascode architecture, which includes a common-source and common-gate stage, has many benefits, including increased bandwidth, greater input-output isolation, and gain augmentation. Additionally, it lessens the Miller effect, which improves high-frequency performance and stability. Gallium Nitride (HEMT FET) technology [2] has changed the game in high-frequency and high-power applications in recent years. In contrast to conventional silicon (Si) or gallium arsenide (GaAs) technology, HEMT FET devices, such as HEMT FET High Electron Mobility Transistors (HEMTs), have better material qualities. These include: HEMT FET HEMTs may further improve LNA performance when used in a cascode topology by offering high gain, low noisefigure, and strong power handling capabilities [3]. This makes them perfect for use in satellite transceivers, radar front ends, and 5G communication systems. The design and construction of a two-stage cascode LNA using HEMT FET [4] technology are the main topics of this introduction. For contemporary RF front-end modules, the design seeks to provide broad bandwidth, high gain, low noise level, and low power usage, while guaranteeing compact integration. Section I serves as the introduction to this study. Section II is an overview of the literature. Section III: Current Approach. Section IV: Suggested Approachand Conclusion of Section V and future directions.

2. LITERATURE SURVEY

In order to amplify weak signals received from the antenna with the least amount of extra noise possible, low noise amplifiers, or LNAs, are crucial parts of RF front-end circuits. Because of its benefits for attaining high gain, broad bandwidth, and enhanced [5] isolation, the

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cascode topology-which combines a common-source (CS) stage with a common-gate (CG) stage-has caught on in LNA designs. Additionally, by lessening the Miller effect, the cascode architecture enhances linearity and stability at high frequencies. For RF and microwave applications, gallium nitride (HEMT FET) has emerged as a promising semiconductor technology. HEMT FET-based gadgets, especially HEMT FET HEMTs (High Electron Mobility Transistors), provide: HEMT FET is a perfect fit for high-frequency LNAs because of these features, particularly for uses in military electronics, radar, satellite systems, and 5G communications.[6] used HEMT FET HEMTs in a cascode arrangement to design an X-band LNA. Achieved good linearity (IP3 > 20 dBm), a noise figure (NF) of 1.5 dB, and a gain of 20 dB. Compared to GaAs and CMOS equivalents, HEMT FET devices with cascode architecture provide better linearity and power management. used Al HEMT FET/HEMT FET HEMTs [7] on SiC substrates to demonstrate ultra-low noise figures (0.8 dB) in Ku-band LNAs. For cascode LNAs, HEMT FET's large bandgap and high electron mobility result in improved power density and reduced noise performance used a cascode HEMT FET. HEMT architecture was used to create a Ka-band LNA. Obtained a gain of 25 dB, NF of 2.0 dB, and P1dB > 10 dBm in the 28–32 GHz frequency band. LNAs can function at millimeter-wave frequencies with minimal noise because to cascode topology with HEMT FET. A broadband LNA design with a cascode architecture using HEMT FET HEMT. Achieved a bandwidth of 3–10 GHz with a gain of 15 dB [8] and an NF of less than 2.5 dB. For radar front ends, Cascode HEMT FET LNAs provide wideband performance. When it comes to high-frequency, high-power, and high-linearity applications, HEMT FET HEMTs perform better than conventional CMOS and GaAs technology. Cascode architecture is ideal for HEMT FET-based LNAs because it improves gain, bandwidth, and stability. HEMT FET cascode LNAs have superior thermal stability, which is essential for military and space applications. In order to satisfy contemporary system needs, emerging research focuses on monolithic integration, low power consumption, [9] and compact architectures. Investigate voids. Optimization of power efficiency: Despite HEMT FET devices' ability to manage high power, increasing their power efficiency is still difficult. System-on-chip (SoC) design integration: HEMT FET LNA integration into small, highly integrated RF front-end devices requires more study. Sophisticated methods for reducing noise: Pushing noise levels in higher frequency bands below 1 dB will need further research. In radio frequency (RF) front-end systems, Low Noise Amplifiers (LNAs) are vital for applications where reducing noise and increasing gain is of the utmost importance, such as in satellite, radar, and wireless communication. In the beginning, researchers tried to figure out how noise worked in high-frequency devices. GaN HEMTs, which had excellent thermal stability, breakdown voltage, and electron mobility, were the best at what they did. In order to achieve the lowest possible noise figure in microwave circuits, mathematical models like the Fukui equation were used to study the basic noise properties of GaN HEMTs [8]. Microwave and millimeter-wave LNA performance has been greatly enhanced by the development of GaN-based MMIC technology. Research has shown that GaN MMIC technology is well-suited for high-frequency applications due to its wideband functioning and ability to handle high power [2]. Achieving sub-dB noise levels and high output power, which are essential for current communication systems, were achieved by broadband GaN LNAs operating across multi-octave frequency ranges, thanks to subsequent advancements [3]. Research into wideband LNA designs has been robust, with several matching approaches investigated. Broadband impedance matching in the 3-10 GHz region has been accomplished using LC ladder matching networks, which provide enhanced noise and gain performance [7]. To improve gain and decrease noise figure, millimeter-wave LNAs have also used interstage impedance matching methods [10]. For ultra-wideband uses, CMOS-based LNAs have also been designed, with improved power efficiency and acceptable noise performance achieved by the use of current reuse methods [9]. There have been notable advancements in bandwidth and resilience for LNAs based on GaN HEMT. According to reports, there are broadband LNAs that can operate between 4 and 16 GHz, and some even reach 25 GHz. These LNAs have low noise and high gain, making them ideal for use in defence and other high-frequency applications [4,5], [6]. These designs showcase GaN technology's capacity to reliably handle high-frequency and wideband operations. Because of its benefits in increasing bandwidth, isolation, and gain, the cascode topology has been extensively used in LNA design. The cascode design is well-suited for high-frequency applications due to its ability to efficiently decrease the Miller effect and boost reverse isolation. Research has shown that wireless communication systems benefit from cascode LNAs coupled with T-matching networks because to their low noise and high gain performance [15]. Classical books like Pozar's Microwave Engineering and Razavi's RF design frameworks[11], [12] provide the theoretical underpinnings of microwave circuit design in great detail, covering topics like impedance matching, stability, and noise optimisation. These studies provide crucial pointers for developing high-performance LNAs using modern transistor technology. Improving LNA circuit stability and frequency responsiveness is also helped by using filter design methods and analogue circuit design concepts [13], [14]. A lot of recent studies have focused on how to use GaN HEMT technology to make LNAs better at handling noise, linearity, and dynamic range. Dynamic range that is high LNBecause new systems that use the C-band are more resilient and perform better in different signal environments [1]. It is clear from these developments that GaN-based LNAs will play an increasingly crucial role in WiMAX and other next-gen wireless systems [3].

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2.1 Research Gap

Despite significant advancements in LNA design using GaN HEMT technology, several challenges remain. Most existing works focus on broadband performance or high power capability, but limited attention has been given to the systematic integration of cascode topology with HEMT devices for achieving an optimal trade-off between noise figure, gain, and stability. While cascode configurations are known to improve isolation and bandwidth, their implementation with GaN HEMT devices requires careful design of matching networks and biasing conditions, which has not been fully explored in existing literature. Furthermore, many studies emphasize wideband operation but lack detailed analysis of noise optimization and stability under varying operating conditions. There is also limited work addressing compact, high-gain, and low-noise LNA designs suitable for modern RF front-end systems using HEMT-based cascode configurations. Therefore, there is a need to develop a comprehensive design and analysis of a cascode LNA using HEMT FET technology, focusing on achieving low noise figure, high gain, wide bandwidth, and stable operation. This motivates the proposed work, which aims to bridge these gaps by integrating cascode topology with optimized matching networks for enhanced LNA performance.

2.2 Existing Method

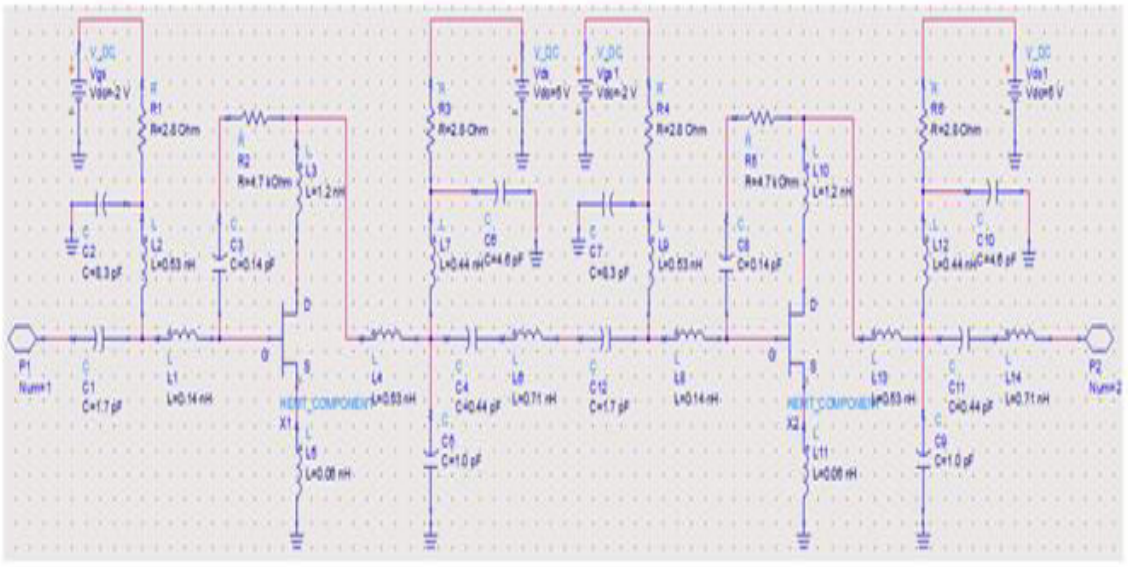


Figure-1. Existing method low noise amplifier.

Examine several LNA amplifier topologies in this section. Figure-1 depicts the fundamental architecture of the suggested amplifier, which uses a cascade topology. The cascade structure really includes a common source transistor (CS) surrounded by a few passive components for input and output impedance matching. A alternative simulation of S parameters in the X-band is displayed in Figure-4 [10]. In this frequency range, the input reflection coefficient S11 is less than -5.6 dB, and at 10.5 GHz, it reaches its lowest value of roughly -12.6 dB. Likewise, the output reflection coefficient S22 is precisely less than - 4 dB and is always negative. The transmission coefficient, S12, also remains below -21.86 dB. Throughout the frequency range of this band, the transmission coefficient S21, which is around 11 dB, is nearly constant. The maximum achievable gain and related power gain are two important considerations for low-noise amplifiers. The following graphic illustrates the MAG's range of 13.25 dB to 14.28 dB. At 8 GHz, the power gain is approximately 11.51 dB. It reaches its maximum of 11.77 dB at 9.25 GHz, after which it slightly drops [11] to 10.73 dB at 12 GHz (Figure-5). Figure 6 shows the stability of the proposed structure on the X-band and the results of the simulation of the NFmin noise factor. We discover that this component is unconditionally stable because the NFmin varies between 1.91 dB and 2.23 dB and the stability factor is continuously greater than unity over the whole frequency range.

3. PROPOSED METHOD

The purpose of an essential component of communication systems, the Low Noise Amplifier (LNA) increases weak signals while decreasing excessive noise. Its primary goal is to raise the signal-to-noise ratio (SNR) of the incoming signal [12], ensuring more reliable and transparent communication. The source, input matching circuit, transistor, DC biasing circuit, output matching circuit, and load are the main parts of an LNA's fundamental construction. A major problem in communication systems,[13] such as antennas, radio communications, GPS receivers, and satellite communications, is amplifying low-noise signals and receiving low-frequency signals with increased gain, improved linearity, and decreased noise. By boosting low

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frequency signals, eliminating undesired noise and high-frequency interference, and delivering the intended signals with high gain, low noise levels, and exceptional linearity,[14] all while using very little power, low-noise amplifiers(LNAs) solve this problem. Because of these characteristics, LNAs are in greatdemand in contemporary digital circuit Designand production methods.

Developed to satisfy certain specifications, the current cascode low-noise amplifier (LNA) architecture performed worse in crucial areas, including gain, linearity, and noise figure. ADS technology with a HEMT process is used in a unique design to overcome these drawbacks. In addition to sophisticated methods like feedback networks, RLC combinations, and degeneration, this updated design includes a cascode network. By enhancing gain and linearity and overcoming the limits of the current design, these improvements seek to improve overall performance and efficiency. Figure-2 describes the proposed method low noise amplifier using ADS software.

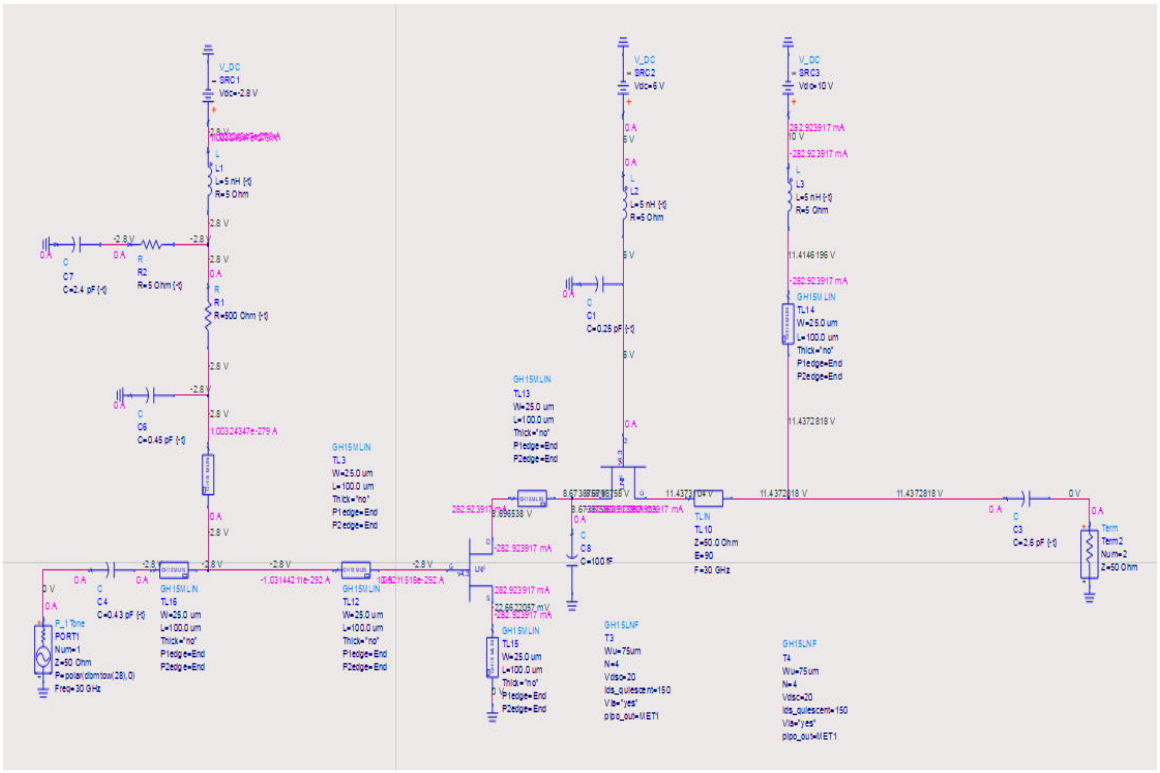


Figure-2. Proposed method low noise amplifier using ADS software.

4. RESULTS AND DISCUSSIONS

Figure-3 describes the Simulation outcomes of the suggested low noise amplifier technique with ADS software. Transistor width adjustment is essential for improving the S-parameters, particularly the output return loss (S22) and input return loss (S11), which are intended to be at an acceptable level, and for lowering the noise figure. The system uses a certain amount of electricity in its present configuration. Nonetheless, the suggested design drastically lowers power usage. [15] The suggested design delivers a far larger gain than the current system, which only offers a small increase. Further improving the overall system performance is the noise figure at a 12 GHz X-band frequency. On the Smith chart, a noise circle denotes each source reflection coefficient (Γs) that contributes to the same RF amplifier noise figure (NF). The optimal source reflection coefficient (Γopt), which produces the lowest noise figure (Fmin), is shown by the center of the noise rings. On the Smith chart, a gain circle denotes each source or load reflection coefficient that provides the same gain (available gain or operational power gain) to an RF amplifier. Gain circles, centered at the conjugate matching point, are used to choose impedances that provide the required amplifier gain. Figure-4 describes the suggested low-noise amplifier's simulation results of Gain and noise circle. Table-1 shows the comparison of the proposed and existing method.

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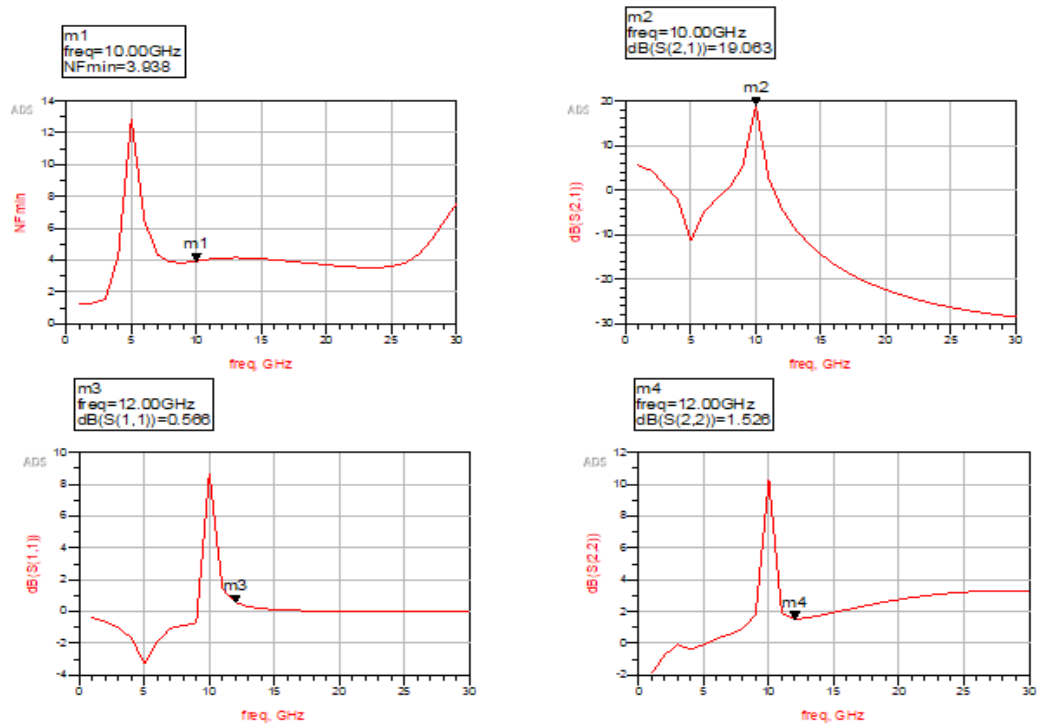


Figure-3. Simulation outcomes of the suggested low noise amplifier technique with ADS software.

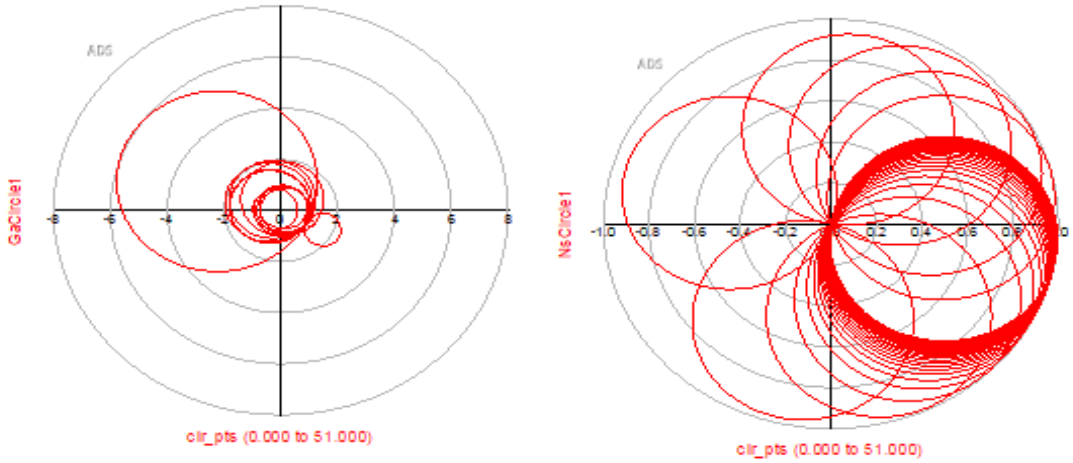


Figure-4. The suggested low-noise amplifier's simulation results of Gain and noise circle.

Table-1. Comparison of proposed and existing method.

Ref.	Technology	Freq. [GHz]	Operation Class	Stages	G1 [dB]	Nfmin
[1]	0.15µm HEMT FET	9.8-11.5	cascade	1	11-12.5	5.21
[2]	0.14µm HEMT FET	9.8-11.5	Cascode	1	7-12	4.3
Proposed method	0.15um HEMT FET	8-12	Cascode	2	19.06	3.9

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5. CONCLUSIONS

The research and suggested design of a HEMT FET-based Low Noise Amplifier (LNA) for X-Band frequencies demonstrate how well suited it is for contemporary radar and communication applications. The LNA is the perfect option for high-performance systems like military radar and satellite communication because it uses the benefits of HEMT FET technology to deliver a high gain, good impedance matching, and a low noise figure. In order to fulfill the exacting requirements of X-Band frequency operations, two-stage cascode architecture with emitter degeneration is used, which further improves stability, isolation, and linearity. In terms of important metrics like gain, noise Figure, and S-parameters, the simulation and layout results demonstrate the design's higher performance over current designs, validating its efficacy. The suggested LNA proves to be a dependable and effective solution for practical high-frequency applications because to its remarkable durability, power management, and efficient.

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