TELKOMNIKA Telecommunication Computing Electronics and Control
Vol. 23, No. 1, February 2025, pp. 48~56
ISSN: 1693-6930, DOI: 10.12928/TELKOMNIKA.v23i1.26324

Designing common-source low noise amplifier utilizing GaN HEMT for sub-6 GHz in 5G wireless applications

Samia Zarrik, Abdelhak Bendali, Fatehi ALtalqi, Karima Benkhadda, Sanae Habibi, Zahra Sahel, Mouad El Kobbi, Abdelkader Hadjoudja, Mohamed Habibi
Laboratory of Electronic Systems, Information Processing, Mechanics, and Energy, Department of Physics, Faculty of Science, Ibn Tofail University, Kenitra, Morocco

Article Info

Article history:

Received May 2, 2024
Revised Oct 25, 2024
Accepted Nov 26, 2024

Keywords:

Advanced design system
Fifth generation
Gain
Gallium nitride
High electron mobility transistor
Low noise amplifier
Noise figure

ABSTRACT

In the domain of gallium nitride based high electron mobility transistors (GaN HEMT), this work refines a class A low noise amplifier (LNA) tailored for fifth generation (5G) wireless applications within the sub-6 GHz band. Employing a common-source topology and leveraging GaN HEMT technology, the amplifier seamlessly achieves operation at 3.5 GHz. Simulations were conducted using Advanced Design System (ADS) software. The GaN HEMT transistor manifests noteworthy intrinsic and extrinsic characteristics, with a Vds of 6 V, Vgs of -1.56 V, and Id of 1024 mA. Through meticulous optimization within the [3.3-3.9] GHz frequency band, the GaN HEMT transistor attains an impressive maximum gain of 16.225 dB, coupled with a minimal low noise figure (NF) of 1.232 dB. Additionally, the amplifier showcases noteworthy power added efficiency (PAE) of approximately 60.527%. These exceptional attributes position the amplifier as highly suitable for sub-6 GHz and millimeter-wave applications across the extensive 5G spectrum. The investigation is centered on precisely situating the LNA as a pivotal catalyst for improving 5G network front-end performance. With a dedicated focus on frequencies below 6 GHz, the research not only addresses challenges but also pioneers' advancements in 5G application LNA design, ultimately elevating the overall system performance.

Corresponding Author:

Samia Zarrik
Laboratory of Electronic Systems, Information Processing, Mechanics, and Energy
Department of Physics, Faculty of Science, Ibn Tofail University
Kenitra, Morocco
Email: samia.zarrik@uit.ac.ma

1. INTRODUCTION

In the current landscape, with the rapid proliferation of smartphones, the demand for bandwidth aligns seamlessly with contemporary trends, highlighting the growing need for high-speed capabilities in wireless networks; this has resulted in the emergence of the fifth-generation wireless communication technology, known as 5G. Positioned to address the escalating demand for services like the internet of things (IoT) and smart homes [1]. Within the receiver section of a communication system, a critical component is the low noise amplifier (LNA), abbreviated as LNA [2]. It amplifies weak signals while minimizing noise introduction. The effectiveness of these amplifiers is assessed through factors in dynamic range, matching, noise figure (NF), stability, return losses, and gain [3]. Researchers facing challenges at these frequencies are exploring alternative materials such as SiGe, SOI, GaAs, and GaN for LNAs development [4].

Motivated by the stringent specifications of the 5G era, these amplifiers using gallium nitride based high electron mobility transistors (GaN HEMT) technology must meet critical criteria, including a NF below 3 dB and gain exceeding 10 dB, while maintaining low power consumption across both sub-6 GHz and millimeter-wave operation [5]. This crucial component is essential in improving signal integrity by minimizing additional noise as the initial stage in a receiver front end [6]. LNAs play a crucial role in various applications like telemetry receivers, satellite communications, GPS, radar, and cellular phones. Their design focuses on the NF, a key determinant of the system's lower limit. They must meet specific parameters including robust input and output circuit matching, high gain, low power consumption, and excellent linearity, tailored to the system's needs [7].

In response to the demands of 5G and to address this problem, we designed a high-performance GaN HEMT LNA utilizing a single-stage common-source topology for 5G, achieving a gain of 16.225 dB, 1.232 dB NF, and 60.527% power added efficiency (PAE) at 3.5 GHz. While various studies present advancements such as a microstrip-based LNA with less than 2 dB NF and 12.7 dB gain [8], a Taiwan Semiconductor Manufacturing Company (TSMC) 0.18μm radio frequency complementary metal-oxide-semiconductor (RF CMOS) LNA with 15.2 dB gain and 1.34 dB NF [9], a CMOS LNA with cascode topology for 2.4/3.5 GHz applications showing 11 dB gain and 3.6 dB NF [10], a cost-efficient LNA with a common gate input and common drain stage achieves 15.17 dB gain and a NF of 7 dB [11], a dual-band concurrent LNA in 180 nm CMOS with achieving 10.2 dB gain and 2.02 dB NF [12].

These diverse approaches collectively advance LNA design for optimal performance at 3.5 GHz. By integrating innovative techniques, such as enhanced impedance matching and careful component selection, the design ensures high efficiency and low noise. Our design stands out by offering superior gain and noise figure (NF), which significantly enhances signal amplification for sub-6 GHz 5G, reducing power consumption, extending battery life, and improving system reliability [13].

2. METHOD

The LNA design process is detailed step by step in the following sections and is simulated and optimized using the Advanced Design System (ADS). ADS enable precise performance modeling, including gain and noise figure. Optimization ensures the LNA meets the required specifications for 5G applications [14].

2.1. Transistor selection

In the realm of LNA design, the choice of a suitable transistor holds paramount importance. Various options, including silicon germanium (SiGe), silicon bipolar junction transistors (Si BJTs), gallium arsenide (GaAs), heterojunction bipolar transistors (HBTs), metal-semiconductor field-effect transistors (MESFETs), and gallium nitride (GaN) high-electron mobility transistors (HEMTs) [15], each come with distinct specifications. The selection hinges upon factors such as the target frequency range and specific design criteria. GaN HEMTs are widely recognized for high-power applications at elevated frequencies, delivering increased output power, excellent linearity, enhanced power efficiency, and reduced self-heating. They offer higher breakdown voltage, current densities, and operational temperatures compared to GaAs, resulting in smaller device size and reduced parasitic capacitance. GaN HEMTs also exhibit excellent noise performance, making them ideal for LNA designs in emerging technologies like 5G [16]. This has led to the documentation of several GaN HEMT-based LNAs in the literature, emphasizing their potential in both sub-6 GHz and millimeter-wave applications [17], [18]. The numerous mechanical, thermodynamic, optical, electronic, structural, thermal, and electrical properties of this technology (Figure 1) make this semiconductor an attractive element for several studies in various fields.

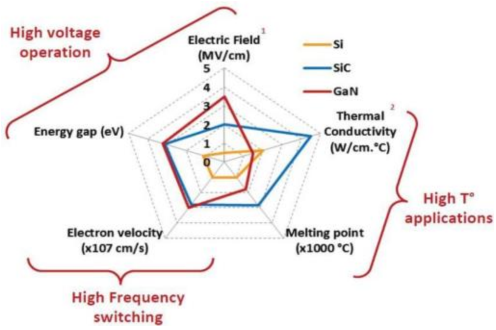


Figure 1. GaN vs. other semiconductor materials [19]

2.2. Stability factor

Stability analysis is a crucial step in LNA and microwave circuit design. [20]. It assesses the circuit's resistance to oscillation, often determined by S-parameters. Delta (Δ) represents the incremental change, while k denotes the Rollet stability factor. If K>1, the circuit remains unconditionally stable across various source and load impedance combinations. The K factor provides a rapid assessment of stability under specific frequency and bias conditions [21].

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{12}S_{21}|} \quad (1)$$

$$\Delta = S_{11}S_{22} - S_{12}S_{21} \quad (2)$$

2.3. Amplifier gain of low noise amplifier

During amplifier design, gain and stability are examined, considering transistor parameters [22]. Three types of power gain can be derived from the circuit in Figure 2.

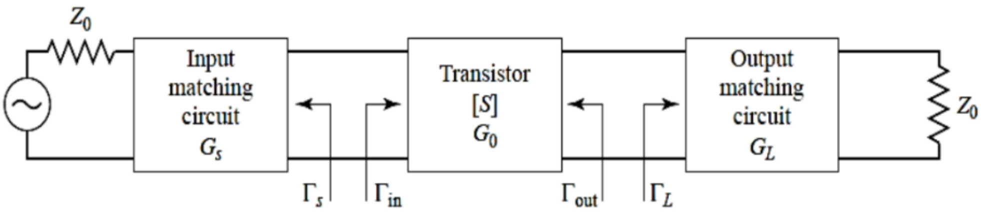


Figure 2. Circuit of transistor amplifier [23]

$$G_S = \frac{1-|\Gamma_S|^2}{|1-\Gamma_{in}\Gamma_S|^2} \quad (3)$$

$$G_0 = |S_{21}|^2 \quad (4)$$

$$G_L = \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \quad (5)$$

The total transducer gain of single-stage LNA can be expressed as (6) [24]:

$$\mathrm{G_T = G_S . G_0 . G_L} \quad (6)$$

where, G_s is source gain factor, G_0 is constant gain factor, G_L is load gain factor, Γ_L is load reflection coefficient, Γ_s is source reflection coefficient, Γ_{in} is reflection coefficient at the input, and Γ_{out} is reflection coefficient at the output.

2.4. Noise figure of low noise amplifier

The NF is a critical parameter for evaluating communication systems, especially LNAs. It represents the ratio between the signal-to-noise ratio at the input (SNRi) and at the output (SNRo) [25]. NF is influenced by the transistor's inherent noise properties, specifically represented by Γ_{opt} and R_n [26].

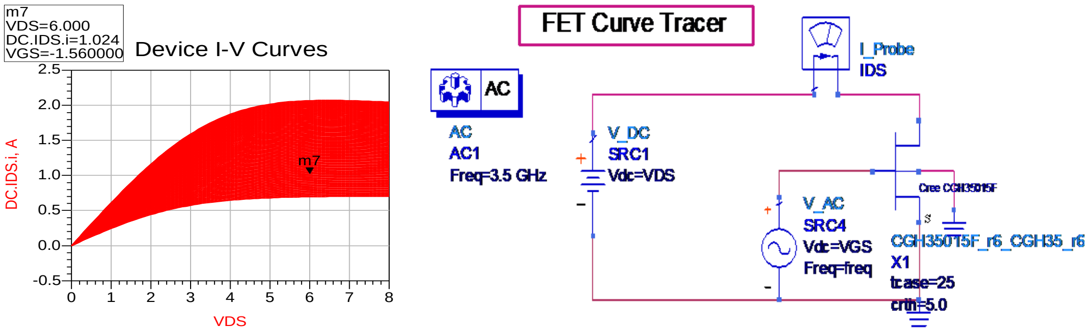
$$F = F_{min} + \frac{4R_n|\Gamma_S-\Gamma_{opt}|}{(1-|\Gamma_S|^2)\cdot|1+\Gamma_{opt}|^2} \quad (7)$$

For multi-stage amplifiers, NF is calculated as (8) [27]:

$$F = F_1 + \frac{F_2-1}{G_1} + \frac{F_2-1}{G_1G_2} + \cdots \frac{F_n-1}{G_1G_2..G_n} \quad (8)$$

The study focuses on designing an LNA using an active transistor in a single-stage circuit with a common source topology. This topology offers high voltage amplification, good impedance matching, and stability, making it versatile for electronic applications, especially below 6 GHz. The proposed LNA integrates the CGH35 transistor, utilizing GaN-based HEMT technology operating at 3.5 GHz in class A.

Specifically designed for sub-6 GHz 5G applications, covering frequencies between 3.3 and 3.9 GHz, the circuit underwent evaluation for parameters including S-parameters, gain, stability, and NF using ADS software. Analysis of the transistor's characteristics identified optimal operating conditions: Vds of 6 V, Vgs of -1.56 V, and Id of 1024 mA as shown in Figure 3(a). Following the design of the DC bias circuit (Figure 3(b)), suitable input and output matching networks were integrated into the LNA. Further optimization of LNA performance within the specified frequency range is illustrated in Figure 4.



(a) (b)

Figure 3. Transistor characteristics: (a) typical GaN HEMT DC characteristics and (b) DC bias circuit

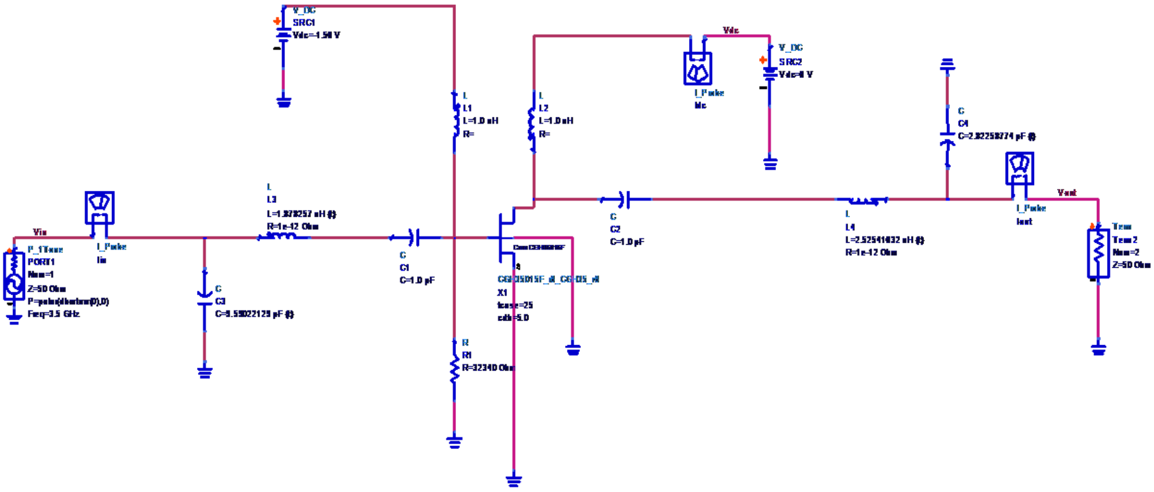


Figure 4. Schematic of the entire LNA circuit in ADS

3. RESULTS AND DISCUSSION

Significant results were obtained from our simulation, assessing the performance of our LNA for 5G applications in the 3.3 GHz to 3.9 GHz range. The simulation demonstrates that the LNA achieves excellent gain, low noise figure, and good matching, making it highly suitable for sub-6 GHz 5G systems. These performance metrics, summarized in Table 1, validate the effectiveness of the design choices and optimization strategies employed in the LNA.

Table 1. LNA design requirements and achieved performance

Parameter	Requirement	Achieved performance
K	>1	1.121
Δ	<1	0.598
Gain	>10 dB	16.225 dB
NF	<3 dB	1.232 dB
S11	<-10 dB	-23.785 dB
S22	<-10 dB	-23.516 dB

The stability result, with K=1.121 and Δ=0.598 (Figure 5(a)), that the LNA is unconditionally stable, as K>1 and Δ<1 are indicative of such operation. The stability of the LNA is determined by various factors, including passive components design such as resistors, capacitors, and inductors. Through optimization, the circuit LNA successfully realized the intended performance goals. At 3.5 GHz, the circuit showed a gain (S21) of 16.225 dB and a NF of 1.232 dB (Figure 5(b)), confirming the stability of the LNA design.

The input reflection coefficient (S11) is approximately -23.785 dB, and the output reflection coefficient (S22) is around -23.516 dB at 3.5 GHz, as shown in Figure 5(c). This indicates effective matching, which is crucial for Optimizing power transfer and reducing signal loss. The PAE of approximately 60.527% (Figure 5(d)) demonstrates the LNA's efficient power usage. These outcomes confirm the LNA's applicability for 5G sub-6 GHz applications, Guaranteeing peak signal performance in systems of wireless communication.

The input (Vin=0.312 V) and output (Vout=1.965 V) signals shown in Figure 5(e) indicate that the LNA amplifies, with sinusoidal waveforms suggesting that distortion or instability would be evident as deviations from these waveforms. Additionally, a harmonic spectrum analysis is presented (Figure 5(f)), which is crucial for assessing linearity across frequency components in the output signal. Optimal linearity is essential for distortion-free amplification, particularly in wireless communication applications.

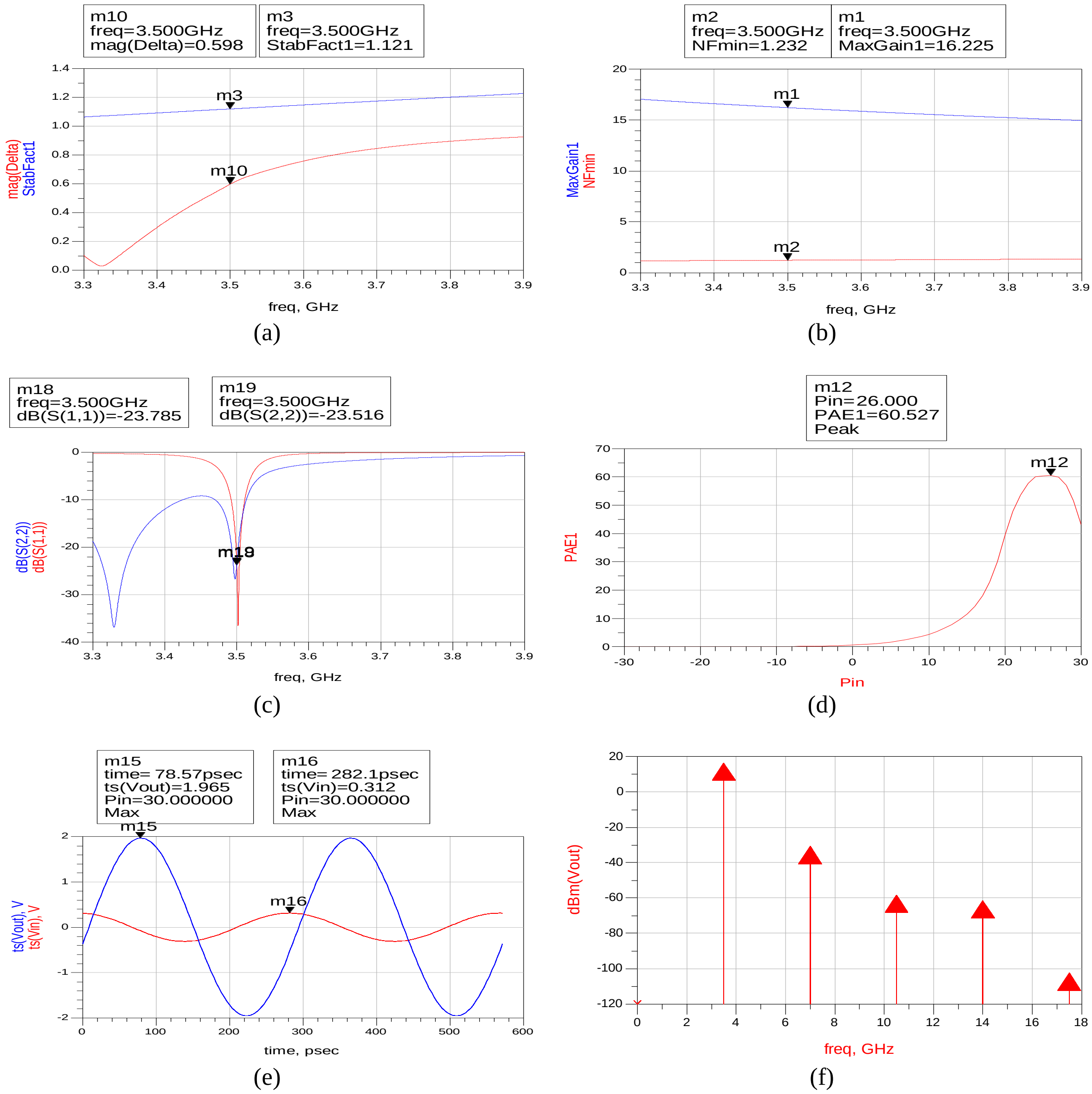


Figure 5. Performance metrics of the designed LNA: (a) stability factor K and delta Δ, (b) NF and power gain, (c) S-parameters, (d) PAE versus output power, (e) output and input signals, and (f) harmonic spectrum

The key findings of this study demonstrate that our designed LNA achieves high performance in terms of gain, NF, and impedance matching, making it suitable for 5G applications. The gain of 16.225 dB and NF of 1.232 dB indicate that the LNA efficiently amplifies the signal while maintaining low noise levels, which is critical for high-quality wireless communication. Compared to previous studies [28]-[30], our LNA design shows improvements in both gain and NF. For instance, similar studies using different technologies have reported gains in the range of 10-15 dB and NF around 1-3 dB as shown in Table 2.

Table 2. Performance overview and comparison of the present study with existing LNAs

Reference	[28]	[29]	[30]	This work
Technology	GaN HEMT	180 nm CMOS	GaAs FET	GaN HEMT
Frequency	3.5 GHz	3.5 GHz	3.5 GHz	3.5 GHz
Application	Cellular system	Sub-6 GHz of 5G	Sub-6 GHz of 5G	Sub-6 GHz of 5G
Transistor model	ATF-38143	UMC	s8834	CGH35
Gain [dB]	7.2	15	15.436	16.225
NF [dB]	1.2	3.2	1.908	1.232
S11 [dB]	-14.4	-10	-10.469	-23.785
S22 [dB]	-15.5	-	-14.190	-23.516

Our design not only surpasses these values but also maintains stability, as indicated by the stability factors (K=1.121 and Δ=0.598). The effective impedance matching (S11=-23.785 dB, S22=-23.516 dB) further highlights the superiority of our design. One of the strengths of this study is the use of GaN HEMT technology, which provides higher electron mobility and superior thermal conductivity compared to traditional silicon-based designs. However, one limitation is the conditional stability observed, which necessitates careful design of passive components to maintain stability across the operating frequency range. An unexpected result was the high PAE of 60.527%, which exceeded our initial expectations and indicates highly efficient power usage.

Finally, our LNA stands out itself with its combination of low NF, and high gain, establishing it as a component of preferred for applications of sub-6 GHz 5G. This significantly contributes to the overall optimization of system performance, highlighting the efficacy of the LNA in meeting the stringent requirements of 5G systems. Future work will focus on optimizing the cascade topology and integrating the LNA with other RF components to further enhance performance in terms of gain, noise, and linearity. Additionally, we plan to explore its adaptation for millimeter-wave 5G applications.

4. CONCLUSION

This study presents a LNA optimized for sub-6 GHz 5G applications, utilizing GaN HEMT technology to achieve impressive performance metrics. The LNA demonstrates a NF of 1.232 dB and a gain of 16.225 dB at 3.5 GHz, addressing critical challenges in signal amplification and noise minimization. With a PAE of 60.527%, it not only meets but exceeds performance expectations, highlighting its efficiency in power usage. The design addresses key issues in LNA performance, including linearity and noise reduction, making it a valuable component for enhancing 5G wireless systems. Despite some challenges with potential instability, the LNA's competitive performance suggests that it is a strong candidate for sub-6 GHz 5G applications. Future research should focus on further optimizing the design, particularly by exploring stability improvements and integration with other RF components to maximize overall system performance. This work lays a solid foundation for advancing LNA technology and contributing to the evolution of high-performance 5G networks.

REFERENCES

[1] Á. Rocha and M. Serrhini, Eds., *Information Systems and Technologies to Support Learning*, vol. 111. Cham: Springer International Publishing, 2019.
[2] K. H. Kishore, V. S. Rajan, R. Sanjay, and B. Venkataramani, "Reconfigurable low voltage low power dual-band self-cascode current-reuse quasi-differential LNA for 5G," *Microelectronics J.*, vol. 92, no. June, p. 104602, 2019, doi: 10.1016/j.mejo.2019.104602.
[3] B. Umate and S. S. Shriramwar, "Low-Noise Amplifier for 5G Applications," *Int. Res. J. Mod. Eng. Technol. Sci.*, vol. 868, no. 06, pp. 200–205, 2023, doi: 10.56726/irjmets41377.
[4] M. M. Abbasi and M. A. Jabbar, "Design and Performance Analysis of Low-Noise Amplifier with Band-Pass Filter for 2.4-2.5 GHz," M.S. thesis, Dept. of Science and Technology, Linköping University, Sweden, 2012.
[5] B. Cui and J. R. Long, "A 1.7-dB Minimum NF, 22–32-GHz Low-Noise Feedback Amplifier With Multistage Noise Matching in 22-nm FD-SOI CMOS," *IEEE J. Solid-State Circuits*, vol. 55, no. 5, pp. 1239–1248, May 2020, doi: 10.1109/JSSC.2020.2967548.
[6] K. Harrouche and F. Medjdoub, "GaN-Based HEMTs for Millimeter-wave Applications," in *Nitride Semiconductor Technology*, Wiley, 2020, pp. 99–135.
[7] O. M. Abbas and A. Jarndal, "On the Design of GaN Low Noise Amplifier for 5G Applications," *2022 Int. Conf. Electr. Comput.*

Technol. Appl. ICECTA 2022, no. 2, pp. 178–181, 2022, doi: 10.1109/ICECTA57148.2022.9990078.
[8] M. Boumalkha *et al.*, "Implementation of an LNA Using a Microstrip Coupler as a DC-Block for Sub-6 5G Communication Systems," *Russ. Microelectron.*, vol. 52, no. 6, pp. 547–555, Dec. 2023, doi: 10.1134/S106373972370066X.
[9] M. A. Bashir, Y. Yu, Y. Wu, C. Zhao, and K. Kang, "A High Linearity Low Noise Amplifier for 5G Front-End Modules," *2019 Int. Conf. Microw. Millim. Wave Technol. ICMMT 2019 - Proc.*, no. 2006, pp. 7–9, 2019, doi: 10.1109/ICMMT45702.2019.8992297.
[10] S. A. Z. Murad, A. Azizan, F. A. Bakar, A. F. Hasan, A. Marzuki, and T. Z. A. Zulkifli, "High linearity multi-band CMOS low noise amplifier at 2.4/3.5 GHz for 4G/5G applications," *The 6th Int. Conf. Electron. Des. (ICED 2022)*, 2024, p. 030002, doi: 10.1063/5.0192323.
[11] R. Hazarika and M. P. Sharma, "Design of a Linear LNA for 5G Applications using 45 nm Technology," *WSEAS Trans. Commun.*, vol. 20, pp. 128–132, Aug. 2021, doi: 10.37394/23204.2021.20.17.
[12] Y. Sawayama, T. Morishita, K. Komoku, and N. Itoh, "Dual-Band Concurrent LNA with Low Gain Deviation and Low Noise Figure," in *2020 IEEE Asia-Pacific Microwave Conference (APMC)*, Dec. 2020, pp. 1006–1008, doi: 10.1109/APMC47863.2020.9331392.
[13] W. Gao, "Average Power Tracking Power Amplifier with Multilevel Supply Voltage for Wi-Fi Applications," in *ICC 2020 - 2020 IEEE Int. Conf. Comm. (ICC)*, Jun. 2020, pp. 1–6, doi: 10.1109/ICC40277.2020.9149236.
[14] S. Nidhyananthan, S. Dhas, and M. Venkatesh, "Design and Simulation of LNA using Advanced Design Systems (ADS)," *GRD J. Eng.*, vol. 5, no. 11, pp. 57–62, 2020.
[15] M. Božanić and S. Sinha, "Device Technologies and Circuits for 5G and 6G," in *Mobile Communication Networks: 5G and a Vision of 6G*, 2021, pp. 99–154, doi: 10.1007/978-3-030-69273-5_4.
[16] A. Jarndal, A. Hussein, G. Crupi, and A. Caddemi, "Reliable noise modeling of GaN HEMTs for designing low-noise amplifiers," *Int. J. Numer. Model. Electron. Networks, Devices Fields*, vol. 33, no. 3, pp. 1–13, 2020, doi: 10.1002/jnm.2585.
[17] M. Chen *et al.*, "A 125 GHz GaN HEMT MMIC low-noise amplifier," *IEEE Microw. Wirel. Components Lett.*, vol. 20, no. 10, pp. 563–565, 2010, doi: 10.1109/LMWC.2010.2059002.
[18] P. Chehrenegar, "GaN HEMT Low Noise Amplifiers for Radio Base Station Receivers," M.S. thesis, Dept. of Microtechnology and Nanoscience, Chalmers University of Technology, Goteborg, Sweden, 2012.
[19] T. Bieniek, G. Janczyk, A. Sitnik, and A. Messina, "The "first and euRopEAn siC eigTh Inches pilot line" - REACTION project as a Driver for key European SiC Technologies focused on Power Electronics Development, *TechConnect Briefs*, no. June, 2019.
[20] J. Wang and X. H. Zhang, "Design and simulation of low-noise amplifier," *Hedianzixue Yu Tance Jishu/Nuclear Electron. Detect. Technol.*, vol. 34, no. 3, pp. 359–361, 2014.
[21] S. Kassim and F. Malek, "Microwave FET Amplifier Stability Analysis using Geometrically-Derived Stability Factors," *2010 Int. Conf. on Intell. and Adv. Syst*., Kuala Lumpur, Malaysia, 2010, pp. 1-5, doi: 10.1109/ICIAS.2010.5716171.
[22] H. Chen, H. Zhu, L. Wu, W. Che, and Q. Xue, "A Wideband CMOS LNA Using Transformer-Based Input Matching and Pole-Tuning Technique," *IEEE Trans. Microw. Theory Tech.*, vol. 69, no. 7, pp. 3335–3347, Jul. 2021, doi: 10.1109/TMTT.2021.3074160.
[23] J. A. R. Suaña, "Design of a low-noise amplifier for radar application in the 5 GHz frequency band," M.S. thesis, Faculty of Engineering And Sustainable Development, University of Gävle, June 2017.
[24] A. Belmecheri and M. Djebari, "A Large Signal GaN HEMT Transistor Based on the Angelov Model Parameters Extraction Applied to Single Stage Low Noise Amplifier," *Trans. Electr. Electron. Mater.*, vol. 23, no. 6, pp. 595–608, Dec. 2022, doi: 10.1007/s42341-022-00390-z.
[25] G. Morthier, G. Roelkens, and R. Baets, "Optical Versus RF Free-Space Signal Transmission: A Comparison of Optical and RF Receivers Based on Noise Equivalent Power and Signal-to-Noise Ratio," *IEEE J. Sel. Top. Quantum Electron.*, vol. 28, no. 2, pp. 1–8, Mar. 2022, doi: 10.1109/JSTQE.2021.3129250.
[26] M. Santos, M. Bilher, S. Matos, and L. Severo, "Projeto de um Amplificador de Baixo Ruído com Polarização Ativa para Receptores ADS-B," *XXXVIII Simpósio Brasileiro De Telecomunicações E Processamento De Sinais - Sbrt 2020*, 2020, pp. 22–25, doi: 10.14209/sbrt.2020.1570658178.
[27] D. D. K. S. Mrunal A. Marihal, "IRJET- Design of PHEMT based Low Noise Amplifier for L and S Bands," *Irjet*, vol. 8, no. 11, pp. 347–350, 2021.
[28] A. M. Gamal, H. N. Ahmed and M. A. El-Kfafy, "A quad-band 0.9/1.8/2.45/3.5 GHz, multi-standard, concurrent LNA using a dual-band impedance transformer," *2015 Asia-Pacific Microwave Conference (APMC)*, Nanjing, China, 2015, pp. 1-3, doi: 10.1109/APMC.2015.7411598.
[29] J. Pradeep, S. C. Gladson, and M. Bhaskar, "A low power wideband low-noise amplifier with input series peaking and g-{m} enhancement for 0.5 - 3.5 GHz applications," *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, vol. 2019-Octob, no. 2, pp. 1225–1230, 2019, doi: 10.1109/TENCON.2019.8929627.
[30] S. Zarrik *et al.*, "Design of a GaAs-FET Based Low Noise Amplifier for Sub-6 GHz 5G Applications," *ICAISE: The International Conference on Artificial Intelligence and Smart Environment*, 2024, pp. 179–188, doi: 10.1007/978-3-031-48573-2_26.

BIOGRAPHIES OF AUTHORS

Samia Zarrik was born in 1995 in Rabat, Morocco. She obtained her master's degree in "Telecommunications Systems" from Ibn Tofail University in Kenitra in 2020. Currently, she is pursuing her doctoral studies at the same university's Laboratory of Electronic Systems, Information Processing, Mechanics, and Energy "SETIME". Her research interests focus on the design of low noise amplifiers. She can be contacted at email: samia.zarrik@uit.ac.ma.

Abdelhak Bendali was born in 1982 in Sefrou, Morocco. He earned his master's degree in Telecommunication and Microwave Devices from the National School of Applied Sciences of Fez, Morocco, in 2011. He obtained his Thesis in Electronics and Telecommunication from the Faculty of Sciences of Kenitra, Morocco, in 2019. He has been a member of the Laboratory "SETIME" since 2017. His work focuses on the Front-End parity of the 5G transmission chain. He can be contacted at email: bendaliabdelhak@gmail.com.

Fatehi ALtalqi Ph.D. student in Telecommunication Systems Engineering at Ibn Tofail University in Kenitra, Morocco. He obtained his master's degree in Embedded Electronic and System Telecommunication from Ibn Tofail University in Kenitra, Morocco, in 2020. He earned his bachelor's degree in Automatic Electrical Electronics from Hassan I University in 2017. He can be contacted at email: fatehi.abdullah2009@gmail.com.

Karima Benkhadda is a Ph.D. student in Telecommunication Systems Engineering at the University of Kenitra, Morocco. She received her Master's degree in Teaching and Training Professions in Physics-Chemistry from the University of Kenitra in 2019 and her bachelor's degree in "Networks and Telecoms" from the University of Kenitra in 2011. She can be contacted at email: karima.benkhadda@uit.ac.ma.

Sanae Habibi was born in 1992 in Kenitra, Morocco, she completed her Master's degree in embedded electronics and telecommunications systems at the Faculty of Sciences, Department of Physics, Ibn Tofail University, Kenitra, Morocco, in 2018. Currently, she is pursuing her doctoral studies at the Laboratory "SETIME" at the same university. Her research focuses on the security of the front-end of the transmission chain for UHF RFID technologies. She can be contacted at email: sanae.habibi@uit.ac.ma.

Zahra Sahel obtained her Master's degree in Microelectronics from the Faculty of Sciences, Department of Physics, Ibn Tofail University, Kenitra, Morocco, in 2009. Currently, she is pursuing her doctoral studies at the Laboratory "SETIME at the same university. Her research focuses on the design of the front-end of the transmission chain for UHF RFID technologies, with a specific focus on the design of the energy harvesting block. She can be contacted at email: zahra.sahel@uit.ac.ma.

Mouad El Kobbi obtained a master's degree in Telecommunication and Microwave Devices from the National School of Applied Sciences of Fez, Morocco, in 2011. He is PhD at the Laboratory of Telecommunication Systems and Engineering of Ibn Tofail University, Faculty of Science, Department of Physics, Kenitra, Morocco, since 2019. His current research focuses on the design of power amplifiers. He can be contacted at email: mouad.elkobbi@uit.ac.ma.

Abdelkader Hadjoudja is a Professor of Electronics at Ibn Tofail University in Kenitra. In 1997 He received a Ph.D. in Microelectronics from the National Polytechnic Institute of Grenoble in France. Following that, he worked as a Consultant in Design and Reuse, and as a PLD Leader Engineer Software at Atmel, Grenoble in France for six years. He can be contacted at email: abdelkader.hadjoudja@uit.ac.ma.

Mohamed Habibi is currently a Professor of Electrical Engineering at Ibn Tofail University, Department of Physics in Kenitra, Morocco. In 1985 he obtained his Third Cycle University Thesis (Electronics) from the University of Sciences and Technology, Lille Flanders Artois, France. In 1993 He received the State Doctorate Thesis (Electronics) from Mohammed V University, Mohammadia School of Engineering in Rabat, Morocco. He has been a member of the Electronics and Communications Laboratory since 1989 at the Mohammadia School of Engineering, Rabat, where he has held various roles, including responsibility for the Laboratory of Automatics and Microwaves (LAMO) and membership in the Laboratory of Telecommunications Systems and Decision Engineering (LASTID) from 805 onwards. He has been a member of the Laboratory "SETIME" since January 14, 2020. She can be contacted at email: habibi.mohamed@uit.ac.ma.