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A GaAs-Based LNA with less than 1-dB measured NF for X-Band Communication Systems

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***Abstract*- In communication systems, Low-Noise Amplifiers (LNAs) with low noise performance are essential components. This work introduces a LNA for radio frequency front-end receivers with a frequency range of 8–9.6 GHz. The planned LNA contains a two-stage high-electron-mobility transistor cascade amplifier with a minimum measured Noise Figure (NF) of 0.8 dB and a peak gain of 25 dB at room temperature. The proposed LNA is based on a GaAs FET transistor (CE3512K2) because of its good low noise performance at microwave frequency bands. The measured results demonstrate that the proposed LNA is perfectly matched over the whole operational frequency spectrum of the input/output ports ($|S_{11}|$ < -10 dB, $|S_{22}|$ <-10 dB). In addition, the suggested LNA draws a current of 20 mA and operates with a +3.6 V and a -3.6 V power supply. The recommended LNA is appropriate for X-frequency band applications.**

***Index Terms*-**. Low-Noise Amplifier, Microwave Applications, GaAs FET Transistor.

I. INTRODUCTION

Communications systems that are widely used in space systems generally contain two network parts, as indicated in Fig. 1(a). Slave Terminals (SSTs) are transceivers that consist of a transmitter (Tx) and a receiver (Rx) and are typically used to broadcast audio, video, or data to the master across communication channels (Fig. 1(b)). Receivers in communication systems are responsible for demodulating and processing transmitted radio frequency signal information, as well as providing a low Noise Figure (NF) and enough amplification for signal reconstruction [1]. Low-Noise Amplifiers (LNAs) with low noise performance, in other words, are critical components in these systems. However, reaching this level of performance is difficult, and it frequently demands a compromise between noise performance, power consumption, and die area.

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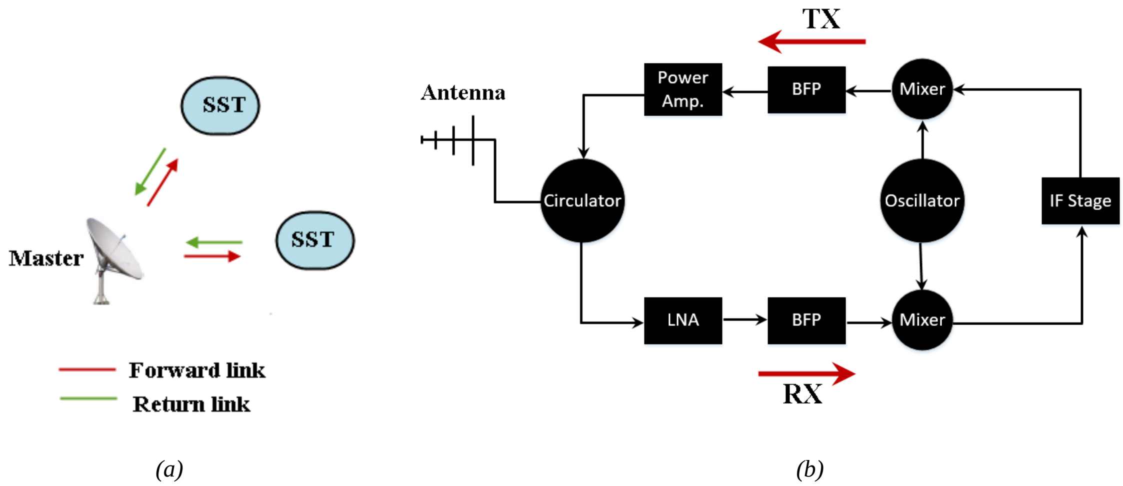
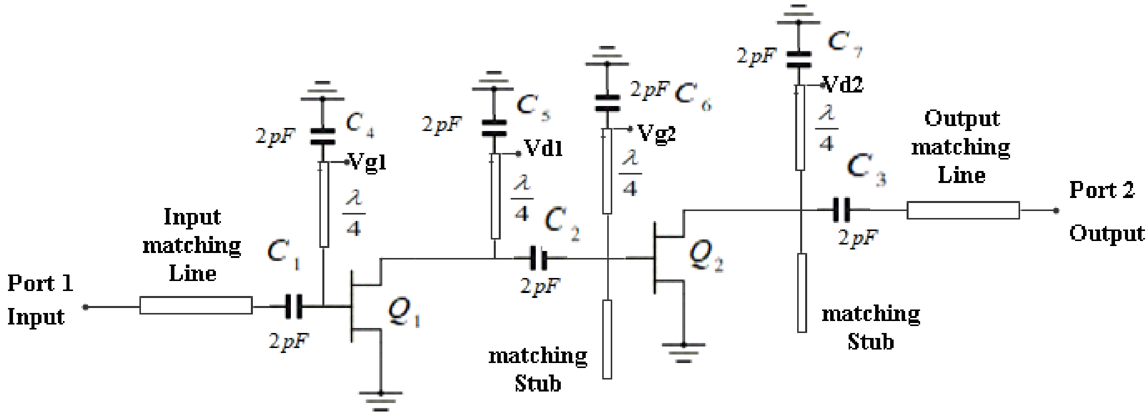


Fig. 1. (a) Scheme of the link between master and SSTs. (b) Scheme of SST's architecture.

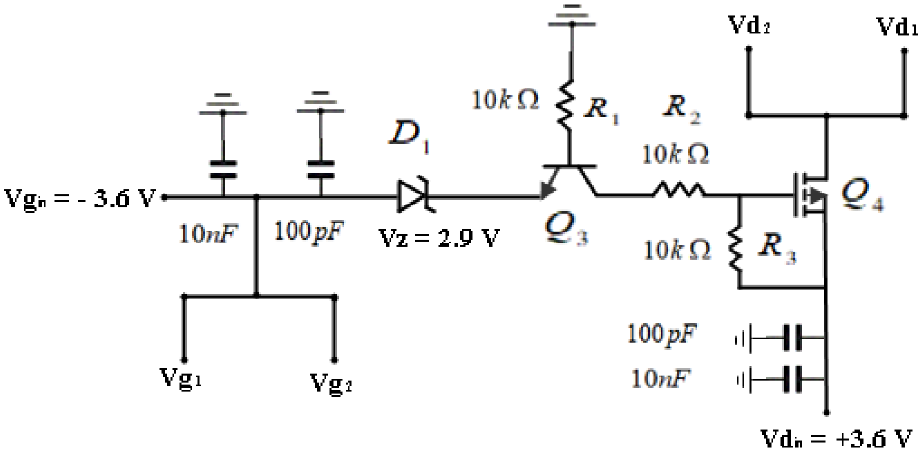
High-Electron-Mobility Transistor (HEMT) technology, which includes GaAs and InP, and SiGe Heterojunction Bipolar Technology (HBT) are the two most common semiconductor transistor technologies used in contemporary amplifiers. Amplifiers based on SiGe HBT have recently been proven to have low noise and high gain [1]. They're a good option for superconducting qubits and radio astronomy systems.

The number of amplification stages in the HBT LNA should be increased to achieve high gain values for the X (ranging from 8 to 12 GHz) frequency bands. As a result, the overall power dissipation rises, making the system unstable to operate. Modern HEMT technology, on the other hand, enables the implementation of amplifiers with large gain values over a wide frequency range, up to tens of gigahertz [2]. The majority of them use Monolithic Microwave Integrated Circuit (MMIC) technology, which produces excellent noise characteristics in the X-frequency band. For some applications, however, a flexible amplifier design is required. Indeed, discrete component-based LNAs have been schematically realized [3]. Some other work on low-power LNAs are reported in [4-6]. The proposed LNA in [4] has a wide impedance matching. However, it suffers from a high level of NF. The recommended LNA in [5] utilizes DC current in multiple circuits while the proposed LNA in [6] uses a folded structure. However, the noise performance is notably poor in both of them. Some other HEMT transistor-based LNAs are reported in [7-9].

As semiconductor technology advances, the modern market now has access to state-of-the-art commercially accessible transistors that can replace older varieties. For the LNA in this work, a novel type of commercially accessible transistor was utilized. A microwave frequency LNA design based on commercially available HEMT transistors needs accurate and exact matching as well as the right passive components. The experimental features of the provided amplifier reveal that in the frequency range from 8 to 9.6 GHz, it does not offer NF values of more than 1 dB.



(a)



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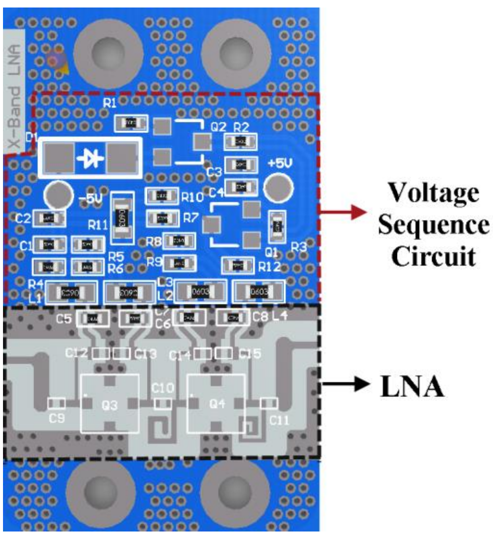


(c)

Fig. 2. The Schematic of the proposed LNA. (a) LNA Circuit. (b) Sequencer circuit. (c) Layout.

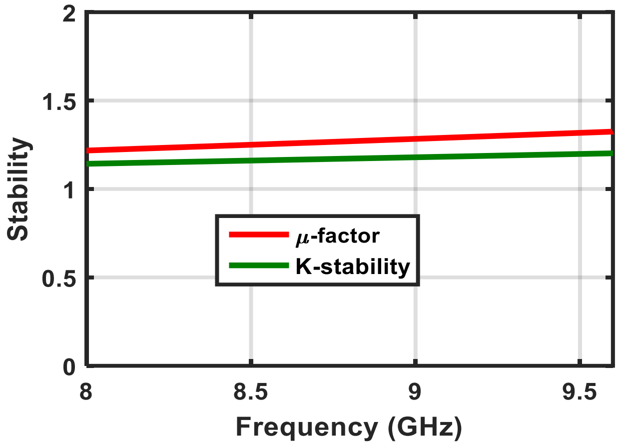


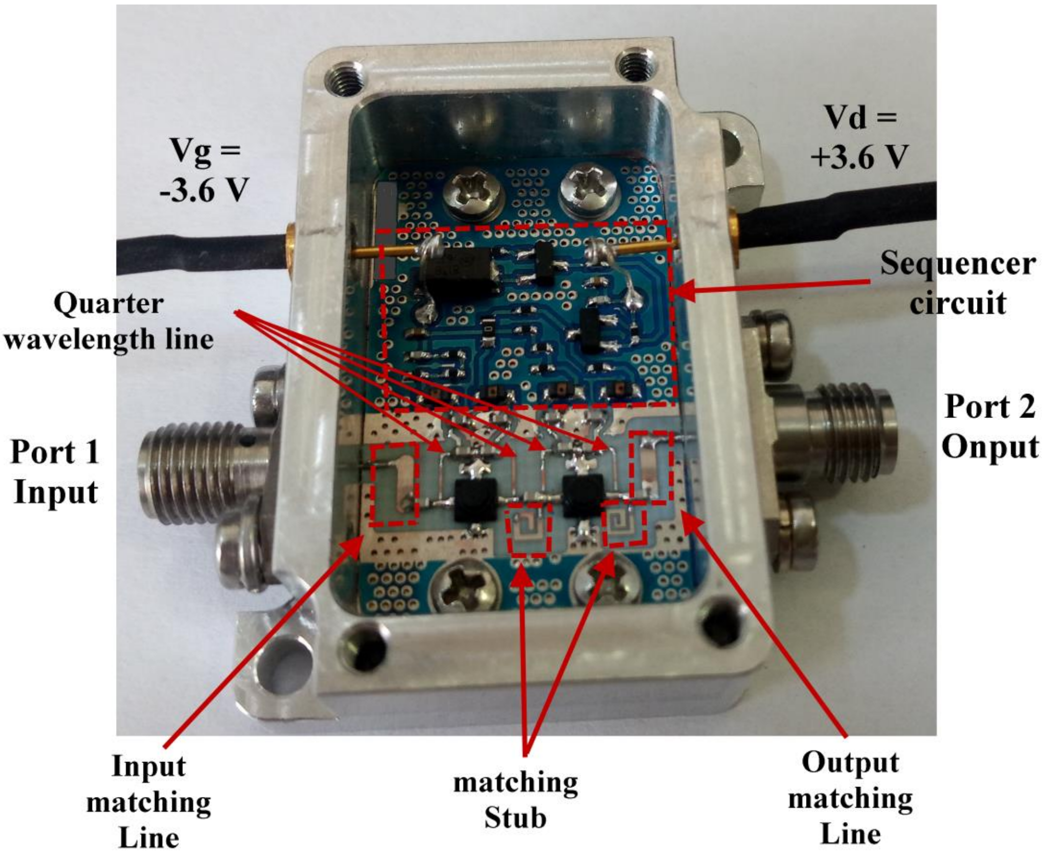
Fig. 3. The LNA stability results. The simulation shows that LNA is stable in all bandwidth.

In this study, a two-stage cascade LNA with a sequence circuit is constructed. This is tweaked to achieve low power dissipation, excellent linearity, a decent S-parameter, and a high NF. According to simulation findings, the suggested LNA has a minimal noise figure of 1 dB throughout the whole bandwidth of 8–9.6 GHz. It also shows that the input and output reflection coefficients (S_{11} and S_{22}) is less than -10 dB and the reverse reflection coefficient (S_{12}) is around -30 dB. Because of Rollet's Factor, the LNA is determined to be unconditionally stable using the signal flow theory and the S-parameter. At 8.5 GHz, the maximum available gain (MAG) is 25 dB. For this design, output P1dB and input P1dB are, respectively, +4 dBm, and -19 dBm.

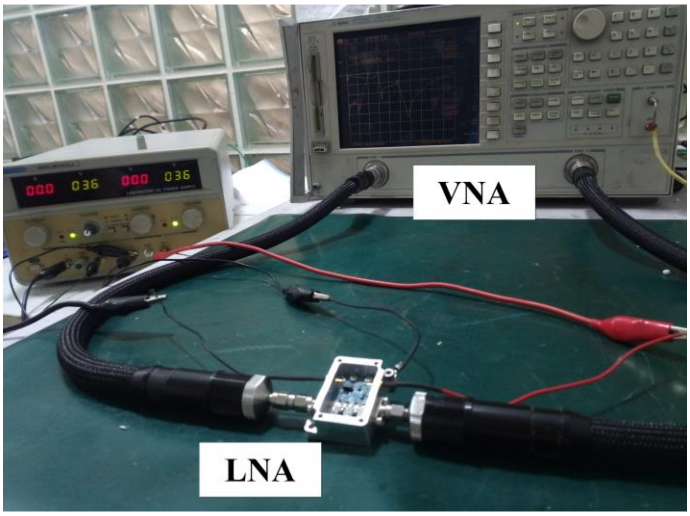
II. DESIGN OF LNA

In terms of design, Fig. 2(a) illustrates the two-stage LNA circuit. The amplifier was designed with minimal noise, enough gain, and proper input/output matching in mind. The transistor selected was CE3512K2 (Q_1 and Q_2) because of its performance at microwave frequency bands in a specific X band. The transistors were chosen based on two parameters: a minimum NF of 0.5 dB and a minimum needed value of associated gain of 13 dB specified by its datasheet. The frequency range covered by the design was 8 to 9.6 GHz. EM simulations were done in the Keysight Advanced Design System (ADS) with Momentum simulation tools.

For the matching circuit design, we employed the transistor's accessible S-parameters. In the frequency range of 8 to 9.6 GHz, a circuit simulation with perfect components yielded a minimal gain value of more than 20 dB. The true S-parameters of passive circuit components put on a dielectric substrate were employed in the following stage. The proper selection of capacitance in an LNA's RF chain is critical for amplifier implementation. The capacitance utilized in this design is from



(a)



(b)

Fig. 4. (a) A fabricated sample of the LNA. (b) Measurement setup of S-parameter of the LNA at room temperature.

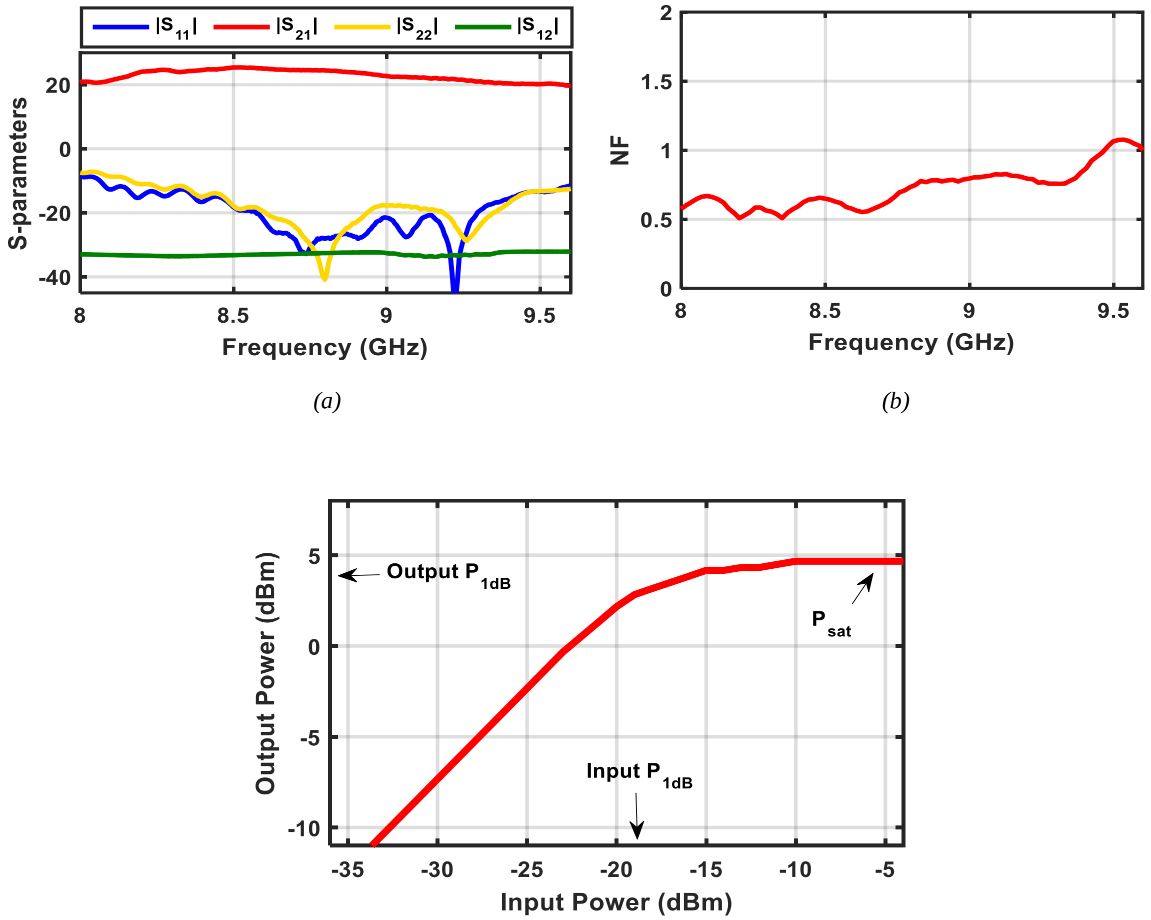
American Technical Ceramics (ATC) and comes in a 0402 SMD package size (C_i, i=1,2,3). For both stages, microstrip open stub lines were employed for initial impedance matching. For gate and drain power supply circuits, quarter-wavelength microstrip lines with capacitance were employed (C_i, i=4,5,6,7).

The CE3512K2 transistor has a gate, drain, and source. The gate of the transistor controls the current from the drain to the source by applying an electric field, which in turn controls the flow of electrons through the channel. The polarity of the gate control voltage is dependent on the type of device used. For CE3512K2, a negative voltage on the gate will cut off current flow from the drain to the source. In this case, 0V will allow for high current flow from the drain to the source. Because 0V on the gate results in a high current through the FET, it is important that the gate voltage be applied prior to the drain voltage in order to avoid damage to the device. This is typically accomplished with a "bias sequencing circuit" which senses for a negative voltage prior to the application of a positive voltage to the drain.

There are several different topologies that could be utilized to sequence the bias in an LNA. The topology chosen in this work utilizes a few parts and therefore minimizes additional cost to the amplifier stage. Fig. 2(b) shows the schematic of the bias sequencing circuit as implemented with the proposed LNA. The biasing circuit is primarily made up of the components D_1, Q_3, and Q_4. Q_4 is a P-Channel MOSFET and is used to switch the positive voltage in and out of the drain. D_1 is a 2.9 V Zener diode that is used to drop the negative voltage, and Q_3 is used to apply a negative voltage to the gate of the MOSFET. Resistors R2 and R3 are used to set the proper gate voltage.

When -3.6V is applied to the gate circuit, the Zener diode will turn on and pull up the -3.6V by 2.9V to -0.7V. The base of Q_3 is tied to the ground through the 10K resistor R1 and turns on when -0.7V is applied to its emitter. Approximately -0.7V will then be applied to the resistor R2. Since the gate of the MOSFET is high impedance, virtually no current will flow into it. As a result, the majority of the current will flow through R_2 and R_3 into the 3.6V supply. The current through resistors R_5 and R_6 is approximately 0.2mA, resulting in a -2V voltage drop across the resistors. In order to turn on the MOSFET, the Gate to Source (VGS) voltage of Q_4 must be much less than the threshold voltage of -0.55V. Since the voltage drop across the gate to source (VGS) of Q_4 is the same as R_3 (-2V), Q_4 is turned on and 3.6V is applied to the drain of Q_1 and Q_2. When 0V is applied to the gate circuit, D_1 and Q_3 are off, and the gate of Q_4 is pulled up to 3.6V. VGS is now 0V, which is greater than the threshold voltage of -0.55V. Q_4 is off and no voltage is applied to the drain of Q_1 and Q_2.

The PCB layout of the final LNA is shown in Fig. 2(c). The amplifier was assembled on a Rogers RO4003 substrate with ε_r = 3.55 and tanδ = 0.0027, and the matching circuits were carried out as microstrip lines at the input and output ports. To minimize dielectric losses, a thin substrate with a height of 0.2 mm was utilized. The thickness and conductivity of copper-cladding are 18 μm and 38.66×10^6 S/m, respectively. The LNA input port has been matched to the smallest NF, and the output port has been matched to supply maximum power and greater gain by leveraging transmission lines, in order to decrease noise performance and boost gain. During the stability analyses, it is shown that the LNA is stable over all the frequency bandwidths, as seen in Fig. 3. It is noticeable that if the K-



(a) *(b)*

(c)

Fig. 5. The measured results of proposed LNA. (a) S-parameters. (b) NF. (c) 1dB linearity.

stability factor > 1, the device is unconditionally stable. Also, this note is applicable to the µ-factor. It means that larger values of µ imply greater stability. *K*-stability factor and *µ*-factor are respected according to equations 2 and 3 [10].

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| < 1 \quad (1)$$

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

$$\mu = \frac{1 - |S_{11}|^2}{|S_{22} - \Delta S_{11}^*| + |S_{12}S_{21}|} \geq 1 \quad (3)$$

Table I. Comparison of the proposed design and references

Ref.	Operating frequency (GHz)	NF (dB)	Gain (dB)	P1dB (dbm)
[4]	3.1 - 10.6	7.4	16	NA
[5]	2 - 10	6.7	20	NA
[6]	0.1 - 3.85	8.4	12.1	-12.83 @ 3.2 GHz
[7]	1 - 3	1.2	32	28 @ 1 GHz
[8]	80 - 105	2.5	6	-6.7 @ 90 GHz
[9]	0.5-2.5	2.8	17	40 @ 2 GHz
This work	8 - 9.6	1	20	4 @ 9 GHz

III. LNA MEASUREMENT

A fabricated sample of the LNA is shown in Fig. 4(a). The S-parameters of the proposed LNA module were measured at room temperature with a vector network analyzer (Fig. 4(b)). The LNA's measured S-parameters are shown in Fig. 5(a). Within 8–9.6 GHz, the measured $|S_{11}|$ and $|S_{22}|$ results are approximately below -10 dB, demonstrating that the LNA is perfectly matched. At a maximal gain frequency of 8.5 GHz, the LNA produced a 25 dB gain for the forward transmission coefficient (S_{21}). The reverse reflection coefficient (S_{12}) is roughly -30 dB, as seen in Fig. 5(a). The LNA S-parameters were measured at their bias conditions for minimum noise. The optimum low-noise bias was Vd = 2 V and Id = 20 mA. Also, noise measurements were carried out using the Y-factor method with a noise figure analyzer. The LNA's measured NF is shown in Fig. 5(b). The NF of the LNA changes from 0.5 to 1 throughout the whole bandwidth, as seen in Fig. 5(b). Measurement results for output power versus input power are shown in Fig. 5(c) that is obtained at 9 GHz. The linearity metric input and output-referred 1-dB compression point have been specified in Fig. 5(c). The performance of this proposed circuit is summarized and compared with other work in Table 1. As can be seen, the suggested LNA has good performance from the point of view of NF, gain, and output P1dB.

IV. CONCLUSION

In this work, for microwave applications, an X-band low noise amplifier has been developed. This work constructs the construction of a two-stage cascade amplifier with a sequence circuit in the designed LNA. The suggested LNA has a noise figure (NF) of less than 0.8 dB throughout the whole bandwidth of 8–9.6 GHz, according to measured findings. This design uses a +3.6 volt and a -3.6 volt power source and draws 20 mA of electricity. At a maximal gain frequency of 8.5 GHz, the LNA exhibited 25 dB for S_{21}.

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