GaN-based Single Stage Low Noise Amplifier for X-band Applications

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2022 Microwave Mediterranean Symposium (MMS) | 978-1-6654-7110-7/22/$31.00 ©2022 IEEE | DOI: 10.1109/MMS55062.2022.9825558

***Abstract*—Source degenerated HEMTs are used to achieve good noise matching and better input return loss without degrading the noise figure and reducing the stability. This work presents an MMIC design for the frequency band of 8 – 11 GHz by using HEMTs with source degeneration in 0.15 µm GaN on SiC technology. All design work is done in the Advanced Design System. The LNA delivers more than 6.9 dB gain with better than 8.5 dB and 9.5 dB input and output return losses, respectively. In addition, the gain ripple is around 2.7 dB. The noise figure of the amplifier is achieved below 1.1 dB with P1dB of 17.2 dBm and %12.7 drain efficiency within the operating bandwidth at the bias conditions of 9 V/20 mA.**

Keywords—GaN HEMT, low noise amplifier, X-band, source degeneration, MMIC, SiC

I. INTRODUCTION

Over the past years, the emergence of GaN HEMT devices has attracted attention, most notably because of their high breakdown voltages and superior power handling capabilities. These features provide the chance to design high power amplifiers (HPA) with very high efficiency on GaN monolithic technology. The need for GaN HEMTs has made it increasingly attractive not only for HPAs, but also for switches and low-noise amplifiers (LNAs) [1], [2].

With the advent of GaN HEMT monolithic technology, the preferences for low noise amplification have also changed. GaN-based LNAs are the most important element used for receiver stages with high withstand capability or the ability to survive without performance degradation at very high input power levels [3].

Due to the inherent robustness of GaN HEMTs, LNAs designed by using these devices can operate continuously without protection circuitry. Additionally, low noise figure and high gain are the most important features in a receiver chain. In this paper, the effects of source degeneration are investigated. A MMIC LNA operating at X-band is designed by using GaN HEMTs with source degeneration.

II. GAN BASED FABRICATION

Regrown non-alloyed +InGaN ohmic contacts for ultra-low resistance ($R_c = 0.25\ \Omega \times \text{mm}$) are done to be connected to AlGaN/GaN channel on semi-insulated Silicon Carbide substrate. Then mesa isolation step is performed with Chlorine etching. A thin 75 nm Si_3N_4 thin film is deposited on the wafer with PECVD (Plasma Enhanced Chemical Vapor Deposition) to re-enforce passivation, which is used for its ability to prevent the formation of unstable oxides at the GaN surface. T-gates with Ni/Au bimetal deposition are formed for high frequency and low noise performance. Resistors consisting of a Ni-Cr thin-film metal layer are patterned by a lift-off process. A Ti/Au metal layer is deposited by using the lift-off technique to form the MIM capacitors' bottom electrodes and the first inter-connection metal. A 215 nm Si_3N_4 passivation layer with contact pad openings is deposited by the same technique as MIM capacitors' dielectric material. A 3 µm thick photoresist pad is defined for the air bridges and 4 µm second inter-connection metal is covered by electroplating. For the backside process, the wafer is thinned down to 100 µm. The via holes are achieved by dry etching with SiC etcher. A 10 µm thick gold layer is plated on the back surface to form the ground plane.

III. LNA DESING

A. HEMT Selection

HEMTs with 4-fingers and low gate width are preferred In this LNA design because of their low noise figure. Fig. 1 below shows the minimum noise figure and S-parameters measurement result of 4x50 µm HEMT with source degeneration inductors at 9 V – 100 mA/mm bias condition. According to the measurement results, the maximum available gain (MAG) value is between 10.1 dB and 11.8 dB for the 8-11 GHz frequency band. MAG is 10.6 dB at 10 GHz. The minimum noise figure is between 0.8 dB and 0.7 dB for the 8-11 GHz frequency band.

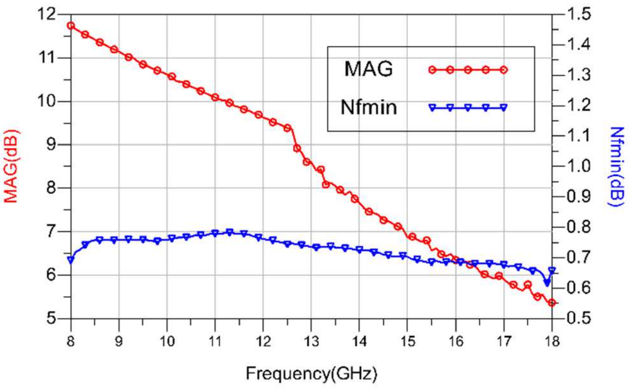

Figure 1. NF and S-parameters measurements of 4x50 µm Source degeneration HEMT

Fig. 2 shows the same small signal parameter of 4x75 µm HEMT with source degeneration inductors under the same bias condition. For this HEMT, the MAG value is between 9.4 dB and 12.9 dB for the 8-11 GHz frequency band. MAG is 10.3 dB at 10 GHz. The minimum noise figure is between 0.8 dB and 1.3 dB for the 8-11 GHz frequency band.

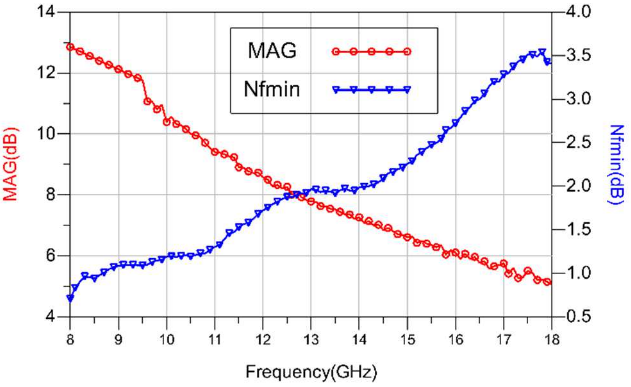

Figure 2. NF and S-parameters measurements of 4x75 µm Source degeneration HEMT

Fig. 3 and Fig. 4 show the load-pull measurement result of the corresponding HEMTs. 4x50 µm HEMT achieves a gain value between 5.3 dB and 9.4 dB with a Pout value between 12.4 dBm and 20.9 dBm in the defined impedance contours at 10 GHz at 1 dB compression point when the applied bias condition is 9 V - 100 mA/mm. Similarly, 4x75 µm HEMT with source degeneration reaches a maximum gain of 8.0 dB with a maximum output power of 25.2 dBm under the same test conditions.

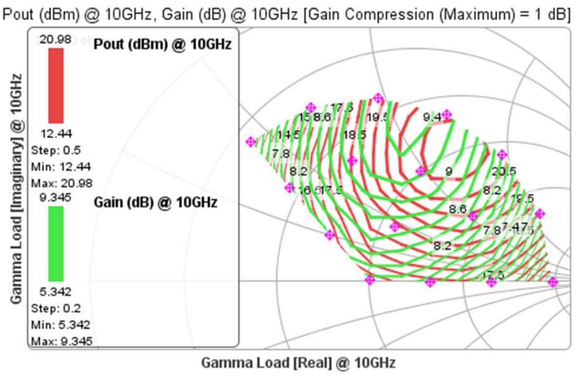

Figure 3. Load Pull measurements of 4x50 µm Source degeneration HEMT

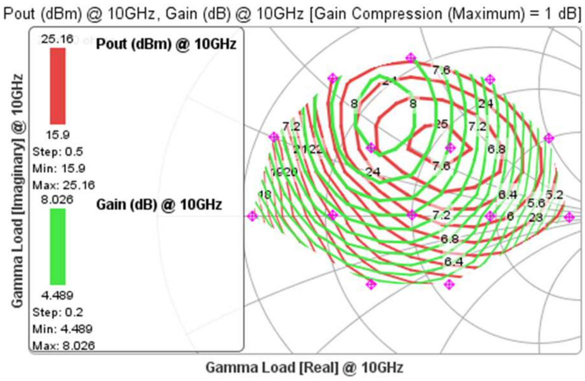

Figure 4. Load Pull measurements of 4x75 µm Source degeneration HEMT

As a result of the small and noise figure measurements of HEMTs, 4x50 µm HEMT is chosen for the LNA design due to the better trade-off between the noise and power performance.

B. MMIC Design

The schematic of the LNA design is shown in Fig. 5. LNA has input and output matching networks together with gate and drain bias networks. The stability network is preferred at the output side of the transistor included in the drain bias network for better noise performance. HEMTs with source degeneration is used to achieve easy simultaneous matching between noise and gain without degrading the noise performance and reducing stability [4]. Bypass capacitors are placed in the bias circuits to provide better isolation. [5]. Unconditional stability is obtained by using a series resistor in the drain bias circuit.

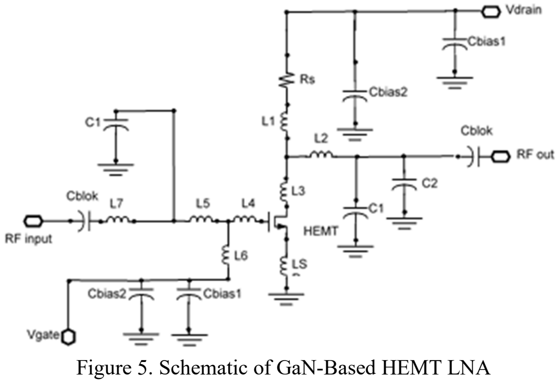

Figure 5. Schematic of GaN-Based HEMT LNA

C. *Fabrication of LNA*

Fig. 6. shows the layout of the designed LNA. The size of LNA MMIC is 3.0 mm × 1.2 mm.

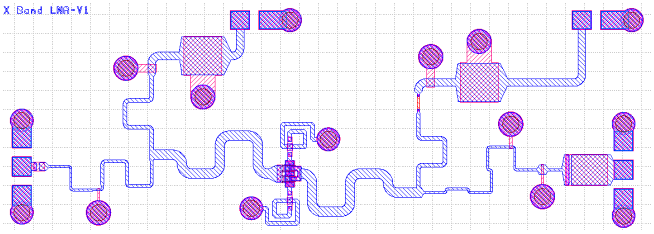

Figure 6. The layout of LNA MMIC

IV. RESULTS AND DISCUSSION

A. *Simulation Results*

In Electromagnetic (EM) simulations of designed LNA, higher than 7.3 dB of gain (9.8 dB to 7.3 dB) with input return loss (IRL) better than 8.0 dB and output return loss (ORL) better than 11.6 dB are achieved. S-parameters simulation results of the LNA design are shown in Fig. 7.

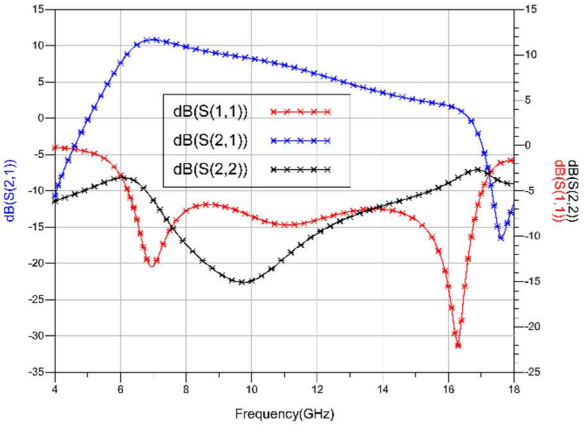

Figure 7. S-parameters Simulation Results of the LNA MMIC Design

LNA has the operation band of 8-11 GHz frequency range, and less than 1.3 dB NF (1.28 dB to 1.20 dB). The Simulation result of the noise figure of the LNA for the operating band is shown in Fig. 8.

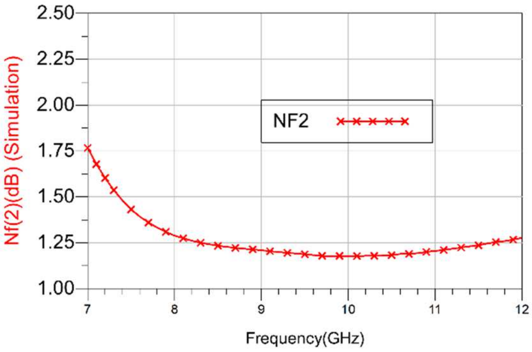

Figure 8. Noise Figure Simulation of LNA MMIC Design

Fig. 9. shows the photograph of fabricated LNA. The fabrication is completed on microstrip 0.15 µm GaN on SiC technology of NANOTAM as a 3-inch wafer.

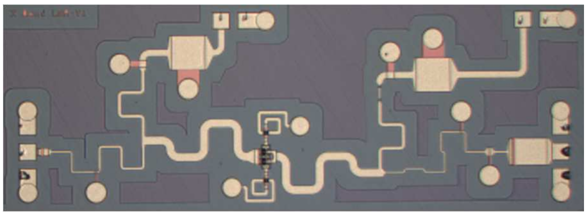

Figure 9. Photograph of the fabricated LNA MMIC

B. *Measurement Results*

Fig. 10. shows EM simulated and measured S parameters results of LNA. The measurement results for the device show a gain greater than 6.9 dB with 2.8 dB gain ripple. IRL and ORL are better than 8.5 dB and 9.5 dB, respectively. S-parameters measurement results show good agreement with the simulation.

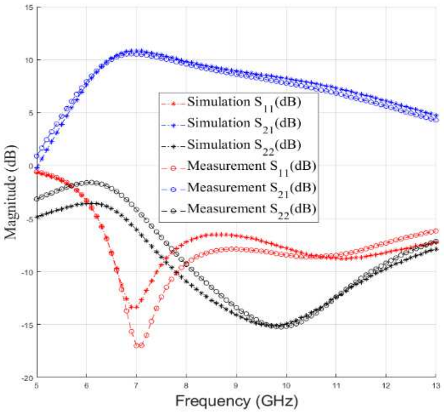

Figure 10. Simulated and Measured S-parameters Comparison of LNA

Fig. 11 shows the EM simulated and measured noise figure results of the LNA. Measurement of noise figure is Nf(4), simulation of noise figure is Nf(2). Measured noise figure is less than 1.1 dB. After fabrication, when the simulation and measurement results were compared, the noise figure results are similar.

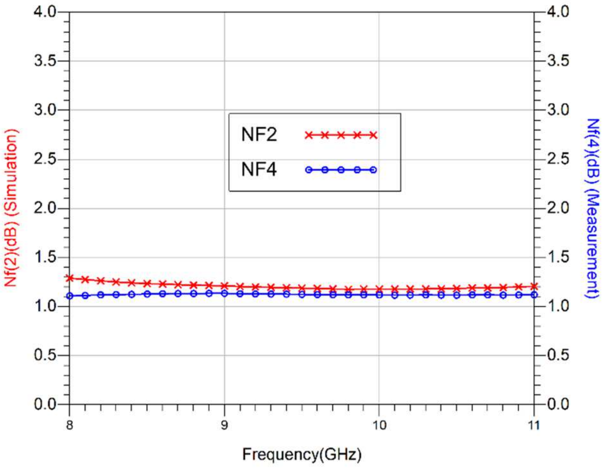

Figure 11. Noise Figure Simulation and Measurement Result of LNA

A large signal performance of LNA is measured to observe the output power and efficiency up to 1-dB compression point at the center of the operating band, 10 GHz. Gain, output power and drain efficiency curves are shown in Fig. 12. Output power of more than 17.19 dBm is achieved with a drain efficiency of %12.64 and 8.14 dB small signal gain at 1-dB compression.

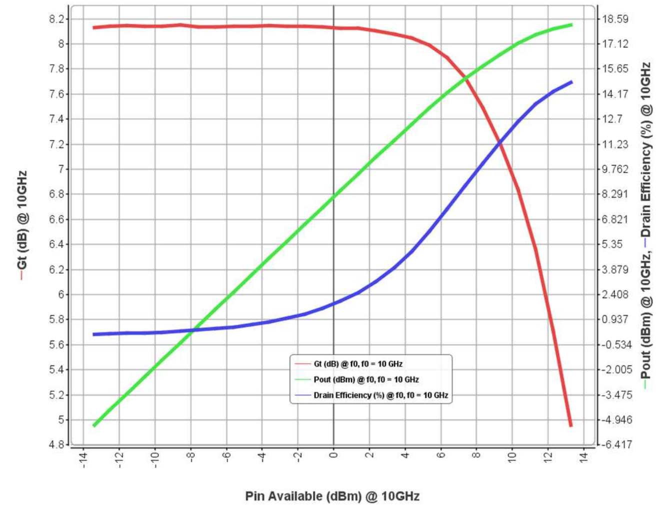

Figure 12. Large Signal Measurement Result of LNA

The analysis of the results obtained in this study with the data of other published LNA designs is summarized in Table-1. LNA is good in terms of IRL and ORL parameters. All of the LNAs are 3-stage, except for the work done in 2020. According to the results obtained in this study, it got better results than all studies in terms of noise figure performance. The size of the LNA has become the ideal design for receiver systems in X-band Radar and communication systems in terms of NF performance.

Table 1. Comparison of proposed single stage source degenerated LNA with reported data of LNAs in X-band

Ref.	Freq. (GHz)	S11 (dB)	S22 (dB)	S21 (dB)	Nf (dB)	Design
[6] 2013	9.7-12.9	>2	>6	20	< 2.1	2 Stage
[7] 2016	8-10	>2	>12	25.5	< 1.3	3 Stage
[7] 2016	8-12	>10	>10	24.8	1.3-1.75	3 stage
[8] 2016	8-11	>6	>10	>23	< 3	3 stage
[9] 2017	9-11 8-11	>11	>4	>13.5 >11	< 2.2	Cascode
[10] 2018	8-11	>9.1	>10	>22	< 2	3 stage
[11] 2020	8-11	>9.8	>12.8	>8	< 1.4	1 stage
[11] 2020	8-11	>8.8	>10	>16.8	< 1.7	2 stage
This work	8-11	>8.5	>9.5	>6.9	< 1.1	1 stage

CONCLUSION

We have established the MMIC design of a low noise amplifier. LNA is designed at X-band by using GaN-based source degenerated HEMT configuration. This configuration provides an improved noise figure with reasonably good input and output return losses for wide operation bandwidth. LNA s-parameters measurement results are well consistent with simulations. This amplifier can be used for electronic systems operating in the X-band due to its very low noise performance; especially for communication receivers, radar and satellites.

ACKNOWLEDGMENT

I would like to thank the Nano Technology Research Center (NANOTAM) and the fabrication team for the production and process.

REFERENCES

[1] C. Campbell, C. Lee, V. Williams, M. Y. Kao, H. Q. Tserng, P. Saunier and T. Balisteri, "A Wideband Power Amplifier MMIC Utilizing GaN on SiC HEMT Technology," *IEEE Journal of Solid-State Circuits,* vol. 44, no. 10, pp. 2640-2647, 2009.

[2] X. Yu, H. Sun, Y. Xu ve W. Hong, «C-band 60 W GaN Power Amplifier MMIC Designed With Harmonic Tuned Approach,» *Electronics Letters,* cilt 52, no. 3, pp. 219-221, 2016.

[3] S. Colangeli, A. Bentini, W. Ciccognani, E. Limiti ve A. Nanni, «GaN-Based Robust Low-Noise Amplifiers,» *IEEE Transactions on Electron Devices,* cilt 60, no. 10, pp. 3238-3248, 2013.

[4] M. Sabzi and A. Medi, "Analysis and design of multi-stage wideband LNA using simultaneously noise and impedance matching method.," *Microelectronics Journal,* no. 86, pp. 453-456, 2019.

[5] M. Tasci ve O. Sen, «An S-Band High Gain AlGaN/GaN HEMT MMIC Low Noise Amplifier,» %1 içinde *1st European Microwave Conference in Central Europe Conference (EuMIC)*, Prague, 2019.

[6] W. Chang, J. Mun ve L. Sangheung, «X-band low noise amplifier MMIC using AlGaN/GaN HEMT technology on SiC substrate,» *Microwave and Optical Technology Letters,* cilt 56, no. 1, pp. 96-99, 2014.

[7] M. Vittori, S. Colangeli, W. Ciccognani, A. Salvucci ve G. Po, «High performance X-band LNAs,» %1 içinde *Emerging and Non-CMOS Technologies II*, Italy, 2017.

[8] B. Kim ve W. Gao, «X-Band Robust Current-Shared GaN Low Noise Amplifier for Receiver Applications,» %1 içinde *IEEE Compound Semiconductor Integrated Circuit Symposium (CSICS)*, 2016.

[9] K. W. Kobayashi, C. Campbell, C. Lee, J. Gallagher ve A. Botelho, «A reconfigurable S-/X-band GaN cascode LNA MMIC,» %1 içinde *2017 IEEE Compound Semiconductor Integrated Circuit Symposium (CSICS)*, Miami, 2017.

[10] O. Kazan, F. Kocer ve O. A. Civi, «An X-Band Robust GaN Low-Noise Amplifier MMIC with Sub 2 dB Noise Figure,» %1 içinde *2018 48th European Microwave Conference (EuMC)*, Madrid, 1202-1204.

[11] S. Zafar, S. Osmanoglu, M. Ozturk, B. Cankaya, D. Yılmaz, A. Kashif ve E. Ozbay, «GaN based LNA MMICs for X-Band Applications,» %1 içinde *17th International Bhurban Conference on Applied Sciences and Technology (IBCAST)*, Pakistan, 2020.