http://dx.doi.org/10.5573/JSTS.2014.14.6.818 JOURNAL OF SEMICONDUCTOR TECHNOLOGY AND SCIENCE, VOL.14, NO.6, DECEMBER, 2014

An X-Ku Band Distributed GaN LNA MMIC with High Gain

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Abstract—**A high-gain wideband low noise amplifier (LNA) using 0.25-μm Gallium-Nitride (GaN) MMIC technology is presented. The LNA shows 8 GHz to 15 GHz operation by a distributed amplifier architecture and high gain with an additional common source amplifier as a mid-stage. The measurement results show a flat gain of 25.1±0.8 dB and input and output matching of -12 dB for all targeted frequencies. The measured minimum noise figure is 2.8 dB at 12.6 GHz and below 3.6 dB across all frequencies. It consumes 98 mA with a 10-V supply. By adjusting the gate voltage of the mid-stage common source amplifier, the overall gain is controlled stably from 13 dB to 24 dB with no significant variations of the input and output matching.**

Index Terms—**Broadband amplifiers, distributed amplifiers, gain control, low-noise amplifiers, X-Ku band**

I. INTRODUCTION

Recently, the demand for military and civilian applications, such as active phased array radars and satellite broadcasting systems, has been growing. These systems use mostly X and Ku bands. Wideband low noise amplifiers (LNA) that cover both X and Ku band are useful and efficient for multi-band systems to extend capacity and performance. The wideband LNAs are required to provide proper input and output matching at wideband frequency range and a flat gain characteristic. Distributed amplifiers are widely used for broadband applications [1]. However, a distributed amplifier comprising a couple of transistors has high power consumption and occupies large chip area [2]. Moreover, gain of the distributed amplifier is relatively low because the individual stage power is combined in an additive manner [3].

The gallium-nitride (GaN) field effect transistor (FET) on SiC substrate has outstanding power performance, high electric breakdown, and high thermal conductivity [4]. Though LNAs are not expected to amplify high power input signals, they are required to be robust to high power input signals, for example, transmitter leakage. Therefore, a limiter or an isolator is located between the antenna and the LNA to protect the LNA from high power input signals. However, insertion loss of the limiter and the isolator increases noise figure of the receiver. It may seriously degrade the receiver performance. If the LNA is robust enough and doesn't need any protective devices, it will be good for noise figure and module size reduction [5, 6]. Fortunately, GaN technology is one of the most robust technology with great power surge survivability [4].

In this paper, we implemented a high-gain wideband LNA that utilizes two independent distributed amplifiers at the input and the output and an additional common source amplifier in the middle of the two distributed amplifiers using GaN on SiC process as shown in Fig. 1. The gain of the LNA can be controlled easily through the gate voltage of the mid-stage common source amplifier, and thus receiver dynamic range can be extended [7].

Manuscript received Aug. 20, 2014; accepted Sep. 29, 2014

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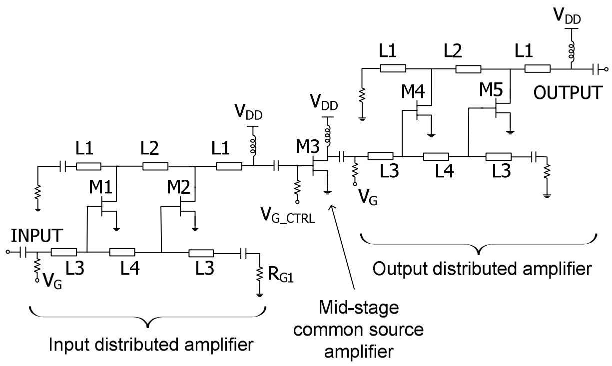

Fig. 1. Schematic of the proposed distributed amplifier.

Section II represents the design of the LNA. Section III and IV show the measurement results and conclusion.

II. GaN LNA Design

The LNA MMIC was implemented in Triquint 0.25-*μm* GaN on SiC process. The LNA is composed of two distributed amplifiers and an additional common source amplifier at the middle of the two distributed amplifiers as shown in Fig. 1. A conventional distributed amplifier has difficulty to obtain a high gain, because the powers from individual devices are not multiplied but just added, and the loss of combining transmission lines increases as the number of devices increases. Therefore, adding additional devices is not an effective way to get high gain in distributed amplifiers [8]. Most conventional distributed amplifiers have the gain of 7-14 dB [9].

In the proposed structure, two distributed amplifiers are used for the input and output broadband matching, and a common source amplifier, which is located between the two distributed amplifiers, is adopted to enhance the gain. Each distributed amplifier at the input and output comprises two transistors to meet bandwidth requirement. The transistor of the distributed amplifier is biased at 10 V for drain and -3.5 V for gate to achieve low noise characteristic and proper gain. The mid-stage common source amplifier has frequency independent matching networks, which are comprised of high value choke inductors and high value DC block capacitors. The gain of the whole amplifier is easily controlled through the gate voltage of the mid-stage amplifier. The advantage of mid-stage gain control is that the gain control through the mid-stage gate voltage scarcely affects to the input and output matching condition.

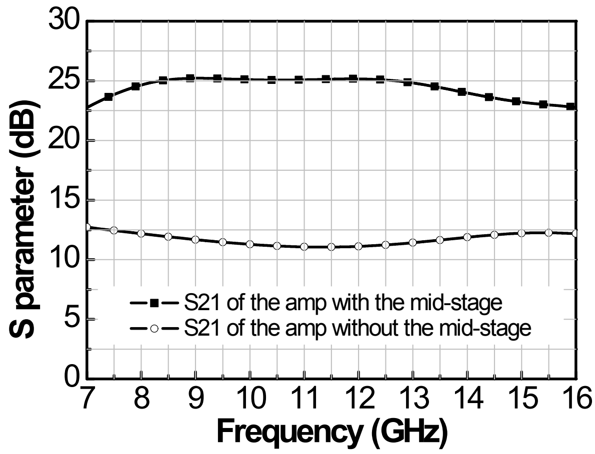

Fig. 2. Gain comparison between the proposed distributed amplifier and the amplifier without the mid-stage.

Fig. 2 shows simulated gain (S_{21}) comparison between the proposed amplifier and an amplifier consisting of two distributed amplifiers without the mid-stage. The mid-stage contributes about 10-dB gain but consumes only half power of each distributed amplifier.

The matching of the phase delays between the gate line and the drain line is important to obtain a wide bandwidth and high gain in the distributed amplifiers. Lossless phase constants of the gate and the drain lines are equal to $\beta_g = \omega\sqrt{L_g C_{gs}}$ and $\beta_d = \omega\sqrt{L_d C_{ds}}$, respectively, while L_g and L_d represent the inductance per stage, and C_{gs} and C_{ds} represent the gate-to-source and drain-to-source capacitance per stage. The forward gain of the distributed amplifier is a function of the phase constants as shown in Eq. (1) [10].

$$G_f = \frac{g_m^2 Z_{\pi d} Z_{\pi g}}{4}\left(\frac{\sin\frac{n}{2}(\beta_d - \beta_g)}{\sin\frac{1}{2}(\beta_d - \beta_g)}\right)^2 \quad (1)$$

$Z_{\pi d}$ and $Z_{\pi g}$ are the characteristic impedances of the gate line and the drain line. The number of stages is n. Wide bandwidth performance can be achieved if Eq. (1) is independent of frequency. Thus, β_g and β_d are set equal by tuning L_g and L_d. The widths of all the transistors, M1 to M5, are chosen to be 200 μm with unit finger width of 50 μm in Fig. 1. C_{gs} and C_{ds} of the single transistor are about 0.6 pF and 0.4 pF, respectively. For phase delay matching as mentioned above, transmission lines, L1 to L4, have been properly designed. L1 and L2, which have 20-μm line width, are 450 μm and 1060 μm long,

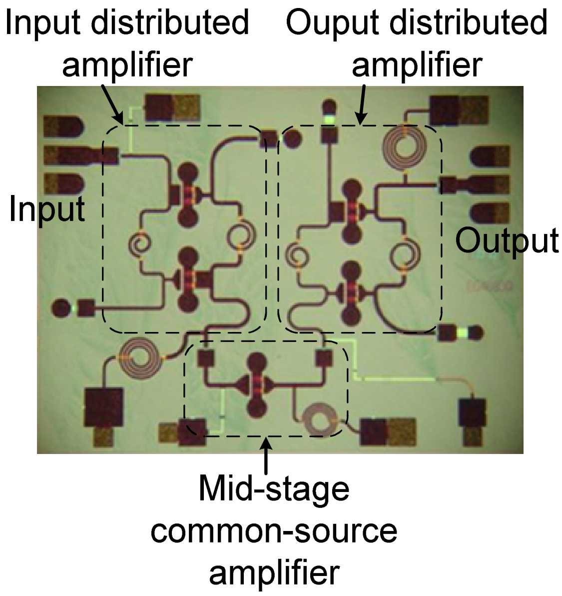

Fig. 3. Chip microphotograph of the LNA MMIC.

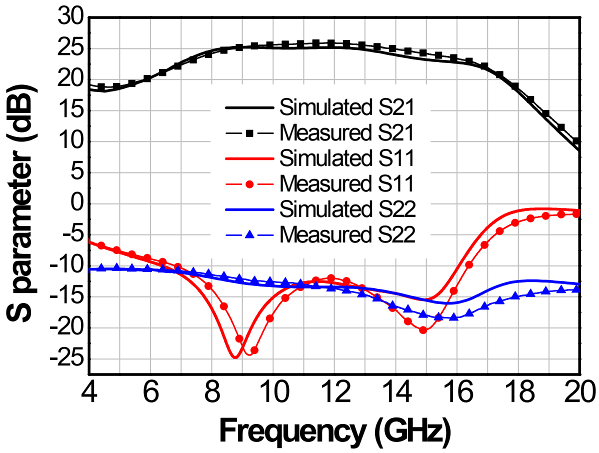

Fig. 4. Simulated and Measured S-parameters.

respectively. L3 and L4 are 300 μm and 600 μm long with 14-μm line width, respectively. Furthermore, L2 and L4 have been replaced with spiral inductors for area reduction.

Ideal termination resistance is 50 Ω for wide bandwidth in distributed amplifiers. However, low termination resistance is advantageous to noise figure [10, 11]. The designed distributed amplifier has 35 Ω of R_{G1} in Fig. 1 to get low noise figure and reasonable input matching.

III. MEASUREMENT RESULTS

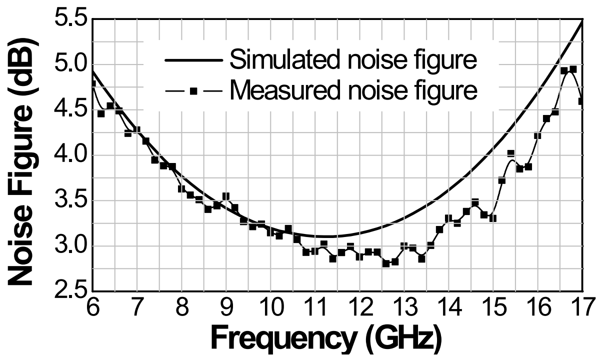

Fig. 5. Simulated and Measured noise figure.

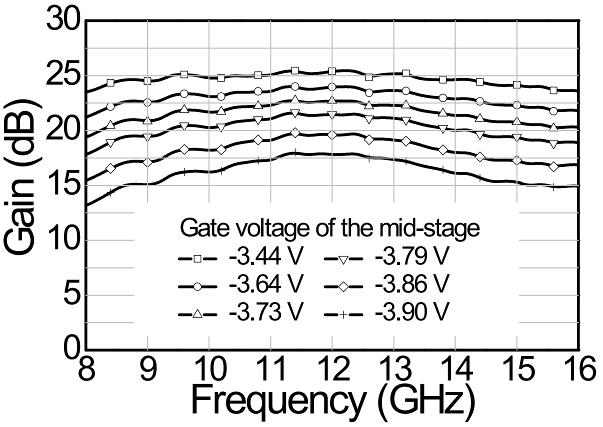

Fig. 6. Measured gain versus frequency for different gate voltage of the mid-stage common source amplifier.

Fig. 3 shows the chip microphotograph of the LNA MMIC fabricated in a GaN process. The Total chip area including bond pads is 1.87 mm x 2.5 mm. Simulated and measured S-parameters of the LNA are shown in Fig. 4. It was measured using Anritsu 37397D vector network analyzer with on-wafer probing. Fig. 4 shows that the measured results follow the simulated results very closely. The LNA has a flat gain (S_{21}) of 25.1±0.8 dB at 8 to 16 GHz. Input (S_{11}) and output (S_{22}) reflections are less than -12 dB while the gate voltage of the transistors in the distributed amplifiers is -3.5 V and the gate voltage of the mid-stage transistor is -3.41 V. Simulated and measured noise figures are shown in Fig. 5. The measured noise figure is below 3.6 dB at 8 to 15 GHz, and below 4.3 dB at 7 to 16 GHz. The minimum noise figure is 2.8 dB at 12.4 GHz.

Fig. 6 shows gain controllability of the distributed amplifier in measurement. The gain has been changed from 13 dB to 24 dB with the mid-stage gate voltage of -3.9 V to -3.44 V. Since the input and output broadband

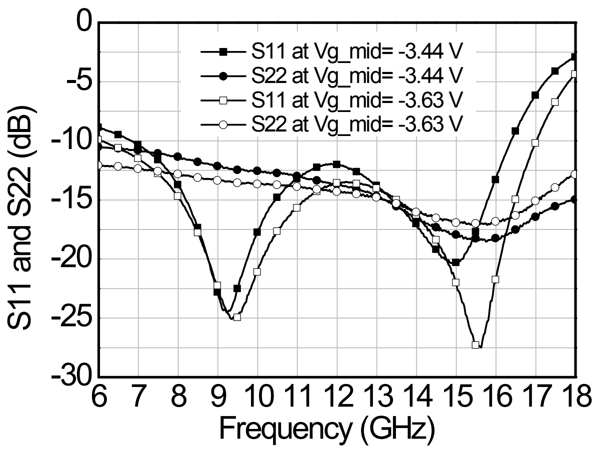

Fig. 7. Measured S_{11} and S_{22} versus frequency for different gate voltage of the mid-stage common source amplifier.

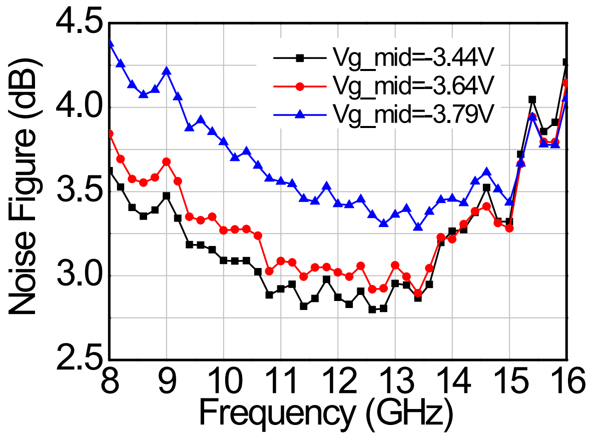

Fig. 8. Measured noise figure versus frequency for different gate voltage of the mid-stage common source amplifier.

matching characteristics are achieved by the distributed topology, the matching is not much affected by the gate voltage change of the mid-stage. The gate voltage of the two distributed amplifiers located at the input and the output is fixed at -3.5 V in several cases shown in Fig. 6. Fig. 7 shows the input and output reflection while the gate voltage of the mid-stage is varied from -3.63 V to -3.44 V. The overall gain is changed uniformly without significant variations of the input and output matching. Fig. 8 shows measured noise figure for different gate voltage of the mid-stage common source amplifier. As the gate voltage of the mid-stage decreases, the noise figure increases up to 4.4 dB at -3.79 V.

The LNA consumes 98 mA with a 10-V supply. The performances of the GaN LNA MMIC are summarized and compared with those of previous works in Table 1. Though bandwidths and bands are different, this work has the highest gain, good input and output return loss, and the unique gain controllability with comparable power consumption and chip size.

Table 1. Performance comparison with previous works in GaN technology

Ref.	[6]	[12]	[13]	[14]	This work
Frequency (GHz)	2-18	1.2-16	0.3-3	1-18	8-15
Gain (dB)	23	13.3	18	16	13.1-24.3
Noise figure (dB)	4.7	3	4	4	3.6
Power (W)	12	0.5	1	9	0.98
Topology	Distributed	Feedback	Feedback	Distributed	Distributed
S_{11} (dB)	<-8.5	<-6	<-8	<-15	<-12
S_{22} (dB)	<-8.5	<-7	<-15	<-15	<-12
IP_{1dB} (dBm)	-1		2	10	-9 ~ 3
Chip size (mm^2)	11	3.2	4.9	4.8	4.7
Tech.	0.25-μm GaN	0.25-μm GaN	0.2-μm GaN	0.2-μm GaN	0.25-μm GaN

V. CONCLUSIONS

An X-Ku Band LNA MMIC was designed using 0.25-μm GaN technology. The LNA consists of two distributed amplifiers and a mid-stage common source amplifier, which is introduced to achieve high gain. It shows 25.1±0.8 dB flat gain and has a below 3.6 dB noise figure at 8 GHz to 15 GHz with good input and output matching. Gain control through the gate voltage of the mid-stage amplifier achieves 13 dB to 24 dB of gain without no significant variations on input and output matching. The proposed distributed amplifier presents a high gain, good wideband matching, and a simple gain control method with the aid of the mid-stage common source amplifier.

ACKNOWLEDGEMENTS

The authors would like to thank G. Pyo, and T. Joo of the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea. This work was supported by IDEC.

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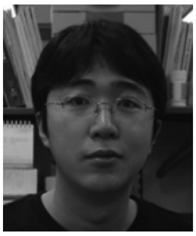

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