# A Wideband Balanced AlGaN/GaN HEMT MMIC Low Noise Amplifier for Transceiver Front-ends

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***Abstract* — A 3-16 GHz wideband AlGaN/GaN high electron mobility transistor (HEMT) low noise amplifier (LNA), using balanced configuration with a coplanar waveguide (CPW) Lange coupler, is designed and fabricated. The LNA shows a minimum noise figure of 4 dB with associated gain of 20 dB and gain flatness of +/− 3 dB across the 3 - 16 GHz frequency range. This balanced GaN LNA is suitable for transceiver front-ends due to the low input/output VSWR, high stability and redundancy, as well as, high power handling capability of GaN HEMTs. The design, fabrication and characterization results of the GaN HEMT balanced amplifier are described together with the details of design and characteristics of the individual LNAs and the CPW coupler.**

## I. INTRODUCTION

AlGaN/GaN HEMTs are promising devices for high power and high frequency applications in commercial as well as defense systems. This is due to the superior GaN electronic material properties; such as large bandgap, high breakdown field, high peak and saturation carrier velocity and good thermal conductivity. Besides their attractive power features, AlGaN/GaN HEMTs are very promising for low noise applications, because they combine low noise figure performance with high breakdown voltage characteristics [1]. AlGaN/GaN HEMTs have for example, been recently explored for use in robust hybrid low noise amplifier circuits [2]. Monolithic Microwave Integrated Circuit (MMIC) LNAs have also been reported recently with operating frequency at X-band and below [3]-[5], as well as with wideband frequency characteristics (3-18GHz) [6]. AlGaN/GaN HEMT devices are the preferred choice in LNA front-ends due to the benefits obtained by the absence of RF limiting circuitry, which often degrades the noise performance of communication systems [3]. In addition, the balanced amplifier configuration is usually preferred in LNA applications such as base-station transceiver front-ends because it presents several advantages over single-ended amplifiers: (1) improvement of 1 dB compression point by 3 dB, (2) inherent 50 Ω input/output matching due to the coupler presence, and (3) redundancy i.e. if one of amplifiers fails, the balanced amplifier unit will still operate with reduced power gain. This paper presents for the first time the design procedure, fabrication, and characterization results of a wideband AlGaN/GaN HEMT MMIC LNA with balanced amplifier configuration utilizing 4-finger CPW Lange couplers.

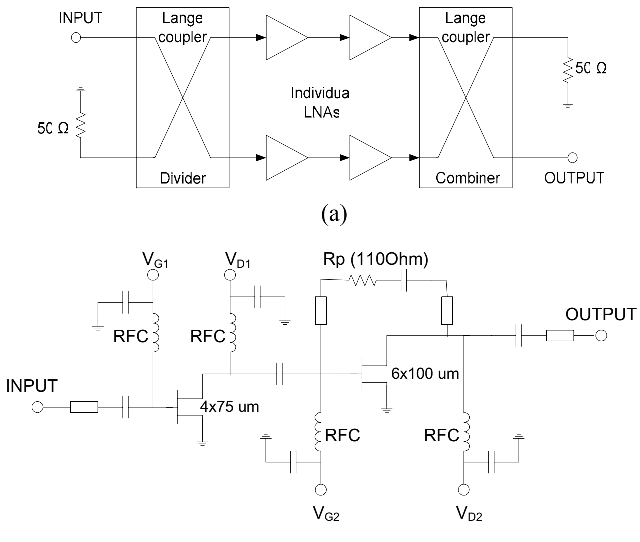


Fig. 1. Circuit schematics of balanced (a) and individual two-stage low noise amplifier design (b)

## II. DEVICE AND FABRICATION

The $Al_{0.3}GaN_{0.7}$/GaN HEMT layers used in the balanced amplifier were grown by RF-assisted nitrogen plasma Molecular Beam Epitaxy (MBE) on semi-insulating (0001) 4H-SiC substrates. TLM measurements of ohmic contacts (evaporated Ti/Al) showed contact resistance of 0.7 Ω-mm and sheet resistance of around 350 Ω. Ni/Al T-gate HEMTs with 0.15 μm length and a 1.2μm source to drain spacing were fabricated by electron beam lithography. The 4-finger 75 μm gate width device, used in the first stage of the LNA, showed a minimum noise figure ($F_{min}$) of 0.97 dB at 10 GHz and $F_{min}$ less than 1.4 dB across the 3 – 21 GHz frequency range. The 6×100 μm gate finger device used for the second stage had $F_{min}$ of 1.57 dB with an associated gain of 5.66 dB and $F_{min}$ less than 1.93 dB over the same frequency range [7]. A coplanar waveguide design was used for the amplifier transmission lines since it offers simplicity by avoiding the difficulty involved in via-hole processing on SiC substrates. CPW lines for signal and biasing paths had 5 μm-thick metal lines for low RF losses and high current density capability.

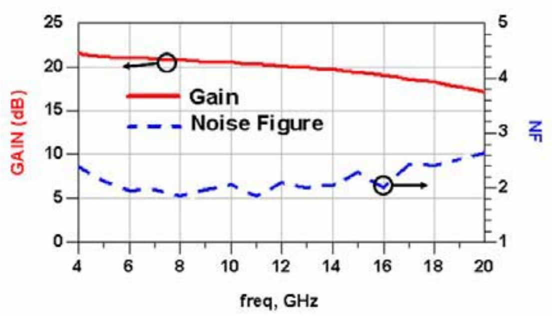


Fig. 2. Simulated gain and noise figure of individual LNAs

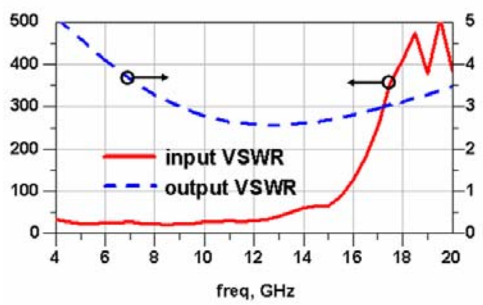


Fig. 3. Simulated input and output VSWR of individual LNAs

## III. CIRCUIT DESIGN AND SIMULATION

### *A. Individual LNA Design*

As can be seen in Fig.1, the wideband amplifier design is based on the use of individual low noise amplifiers consisting of 2-stages; the first stage used a 4 × 75 μm gate AlGaN/GaN HEMT for low noise and high gain while the second stage used a 6 × 100 μm gate device for higher gain and linearity. The circuit design was based on measured S-parameters and noise parameters for the first and second stage devices under biasing conditions, corresponding to $V_{ds}$ = 5 V with $I_{ds}$ = 67 mA and $V_{ds}$ = 10 V with $I_{ds}$ = 240 mA respectively. Parallel feedback with an 110Ω on-chip resistor and capacitor was used in the second stage for improving gain flatness and bandwidth. The EM electrical characteristics of all lumped elements including spiral inductors and metal-insulator-metal (MIM) capacitors were simulated with Agilent MOMENTUM. Agilent ADS was used for simulating the individual LNAs and the simulation results of the individual LNAs are shown in Fig. 2 and Fig 3. Matching of individual LNA stages was optimized for low noise and flat gain characteristic rather than input and output voltage standing wave ratio (VSWR), which turned out to be high. Since the VSWR characteristics of the balanced amplifier is dependent on the coupler, this should not be a handicap for the circuit. The simulated gain was found to be around 20 dB and had only 4.3 dB fluctuation over the 4-20 GHz frequency range. The noise figure was less than 2.6 dB at the same frequency range. As explained earlier, the input and output VSWR (see Fig. 3) were high due to the fact that prime emphasis was placed on noise matching of the balanced amplifier. However, the overall VSWR was much smaller (< 2.4) while maintaining the same gain and noise characteristics.

| Dimension | L | D | W | S |
|---|---|---|---|---|
| Values | 2.5 mm | 15 μm | 30 μm | 10 μm |

TABLE I

DIMENSIONS OF THE CPW LANGE COUPLER

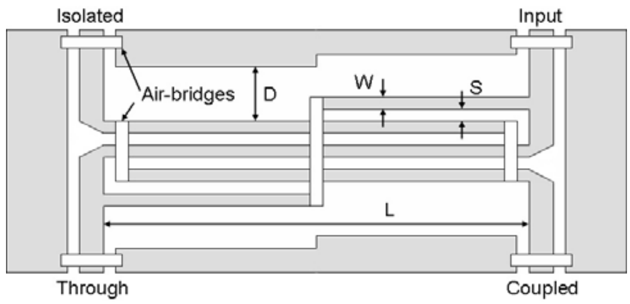


Fig. 4. Schematic of a four-finger CPW Lange coupler

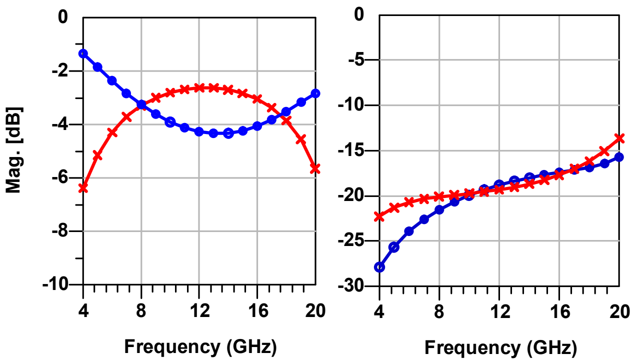


Fig. 5. (a) Simulated through (o) and coupled (x), (b) Simulated return loss (o) and isolated (x) port of the CPW Lange coupler.

### *B. Four-finger CPW Lange Coupler Design*

The Lange coupler [8] can be made of four or six coupled lines with interconnections and could provide strong 3dB coupling. Its design tends to compensate the differences in even- and odd-mode phase velocities and as a result, bandwidth can be very high. Lange couplers on CPW were recently implemented based on classical strip line design methods [9]-[10]. In this work, a traditional microstrip design method with airbridge interconnection between lines was used. As can be seen in Fig. 4, the critical dimensions of the coplanar Lange coupler are the coupled line length (L), coupled line width (W), gap between lines (S), and distance (D) from coupled lines to ground plane. The L, W, and S values were calculated based on computed values of the even- and odd-mode impedances and effective dielectric constants using the assumption of coupled microstrip lines. These values were then adjusted for CPW configuration using optimized values of the distance D obtained with Agilent MOMENTUM. Transmission line loss was considered and the height of the air-bridge was assumed to be 10 μm in the simulations. The optimum coupler values are listed in Table 1. In Fig. 5, the simulation results are shown for all four ports of the coupler. The coupling bandwidth covered 6.5 - 18.5 GHz and was centered at 13 GHz with an amplitude of -3.3 ± 0.8 dB.

*C. Balanced amplifier design*

The wideband amplifier was designed based of the 2.5D simulation results of the CPW Lange coupler and employed two identical individual LNAs connected to the coupler input and output as can be seen in Fig. 6. The isolated ports of the Lange coupler were terminated by on-chip thin-film 50 Ω resistors. Figs. 7 and 8 show the simulated associated gain together with the noise figure and input and output VSWR of the balanced LNA. Compared with the individual LNA simulation results, gain flatness was improved but noise figure was slightly increased due to the use of the Lange coupler. Noticeable performance improvement was observed for the input and output VSWR which were found to be less than 2.4 over the frequency range of 4-20 GHz, This was due to the fact that the VSWR of the balanced amplifier is dictated by the coupler characteristics.

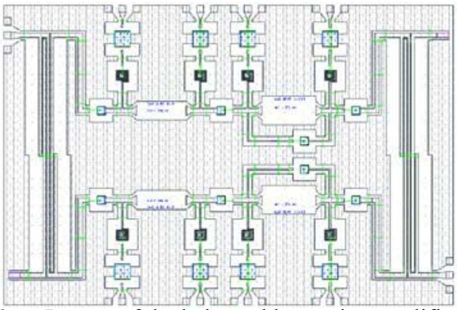

Fig. 6. Layout of the balanced low noise amplifier.

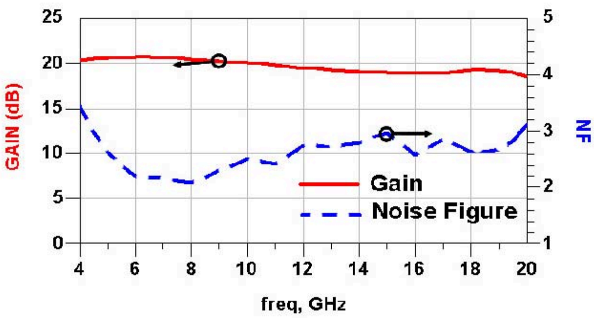


Fig. 7. Simulated gain and noise figure of Balanced LNA

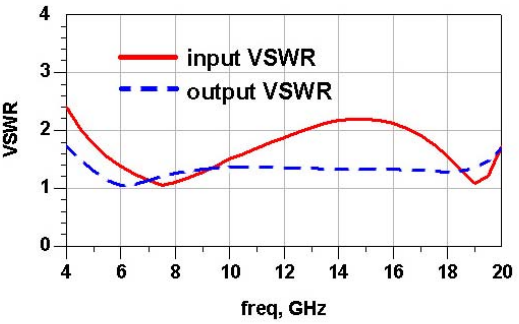


Fig. 8. Simulated input and output VSWR of Balanced LNA

## IV. Characterization of The Wideband Amplifier

A photograph of the fabricated chip is shown in Fig.9. The amplifier chip size is 3187 μm × 4800 μm

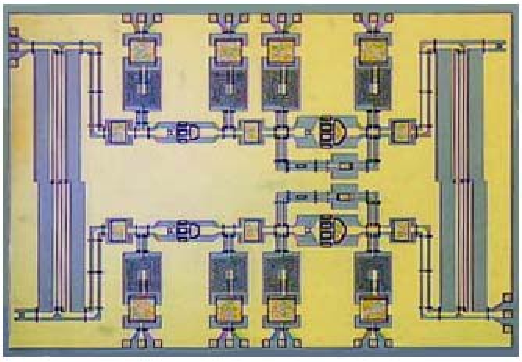

Fig. 9. Photograph of the Wideband HEMT LNA Chip

The measured small-signal gain ($S_{21}$) is shown in Fig. 10 for different amplifier bias points. The blue curve (squares) was measured with $V_{ds}$ = 5 V for the 1st stage and $V_{ds}$ = 10 V for the 2nd stage. The measured gain was about 20 dB with gain flatness of +/−3 dB over a wide bandwidth of 3 - 16 GHz.

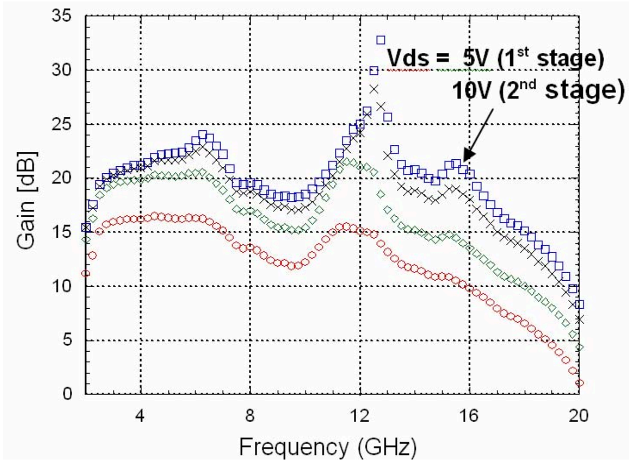


Fig. 10. Measured Gain Characteristics of the Wideband Amplifier with various bias conditions.

The noise performance and associated gain of the amplifier are shown in Fig. 11. The data were taken with Vds (1st stage) = 5 V and Vds (2nd stage) = 10 V. The minimum Noise Figure was ~ 4 dB with an associated gain of 20 dB and the Noise Figure was less then 7.5 dB over the 4~20 GHz range.

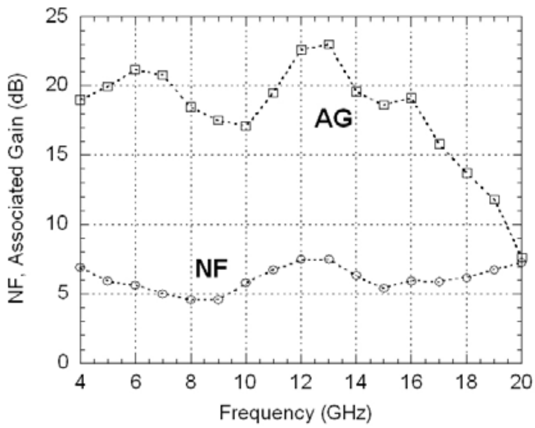


Fig. 11. Noise performance and associated gain of the amplifier at Vds (1st stage) = 5 V and Vds (2nd stage) = 10 V.

The measured noise was found to be 2 ~ 4 dB higher than the simulated values and the associated gain decreased drastically above 16GHz, which was not expected by the simulation. The main reason for the discrepancies between simulation and measured results was assumed to be the imperfect on-chip thin-film resistors used for 50 Ω terminations and the 100 Ω feedback resistors used in invididual LNAs. These reduced the coupling bandwidth of the Lange couplers and gain flatness at frequencies over 16 GHz.

## V. Conclusion

A balanced AlGaN/GaN HEMT MMIC LNA was demonstrated with broad bandwidth of 3-16 GHz and high gain of ~ 20dB for the first time, using a coplanar waveguide (CPW) Lange coupler. The MMIC LNA shows a minimum noise figure of 4dB with an associated gain of 20dB. The results suggest that the balanced GaN HEMT LNA is a promising candidate for robust LNA applications such as transceiver front-ends.

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