Low Noise Hybrid Amplifier Using AlGaN/GaN Power HEMT Devices

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Abstract - This work reports on efforts to demonstrate AlGaN/GaN Low Noise Amplifiers (LNAs) in epitaxial material designed to build power transistors. The hybrid LNA circuit produced a noise figure of 3 dB, a gain of 8.5 dB, an input return loss of -6.5 dB and an output return loss of -9 dB at 4 GHz. Further, devices in an enhanced process have improved noise characteristics and more realizable match conditions. These device enhancements will enable robust X-band LNA demonstrations.

I. Introduction
Numerous research groups have demonstrated the potential of Gallium Nitride (GaN) semiconductors for microwave components and systems. High breakdown fields, high electron density, and wide temperature range operation make them excellent devices for microwave power generation [1]. Several groups have reported GaN based transistors that set record power and power densities for microwave devices [2,3]. GaN devices have also shown excellent noise characteristics [4,5] that, along with their breakdown and carrier velocity performance, make them very attractive for Low Noise Amplifier (LNA) circuits. Typical receiver configurations include limiting diodes on the input to protect the LNA devices from damaging signals. This protection circuitry increases complexity and introduces additional noise to the receiver sub-system. GaN devices show the potential to be robust enough to reduce the need for front-end limiters. Figure 1 shows large-signal gate diode testing of different microwave technologies. GaN devices have the ability to operate at 20 dB more drive power before gate current begins to rise. Since noise performance of a FET is proportional to the gate current, GaN-based LNAs should be more robust and have a larger dynamic range than other technologies. Both the power and the noise characteristics of AlGaN/GaN HEMTs enable a transmit/receive module to be built monolithically if both power and noise can be achieved in the same epitaxial design. This work studied the feasibility of LNA circuitry using devices built in an epitaxy grown for power devices.

II. Device Characteristics
The devices used in the hybrid LNA were AlGaN/GaN HEMTs on a sapphire substrate fabricated at TRW, Inc. The gate length was 0.35 μm with a 30-μm gate width split between two equal width fingers. The source-drain spacing was 4 μm. The total footprint of the device was 10 mils by 10 mils, while the chips containing the devices were 20-mils long by 70-mils wide. These devices had an I, of 1.2A/mm, a peak transconductance of 300 mS/mm, a Vhw of 6 V, and a breakdown voltage greater than 50 V. The fT and fMAX were 20 GHz and 140 GHz, respectively. A 1-mm device showed a

![Large Signal Gate Current](image1)

**Fig. 1.** Gate current vs. frequency for various microwave device technologies.

![Minimum Noise and Associated Gain](image2)

**Fig. 2.** Noise and associated gain of a 30-μm AlGaN/GaN HEMT, Vd = 5V, Id = 10mA.
Semiconductor Parameter Analyzer for biasing. Noise figure was measured on a HP 8971B Noise Figure Test Set with a HP 8970B Noise Figure Meter. The circuit achieved a gain of 8.5 dB, an input return loss of $-6.5\, \text{dB}$, an output return loss of $-9\, \text{dB}$, and a noise figure of 3 dB. The results were obtained with no additional tuning of the circuit.

While this paper reports the initial results of GaN-based LNAs, the noise performance is not state-of-the-art. However, these were initial GaN-based devices built in a power device epitaxy. Efforts are continuing to improve the GaN device technology that will provide improved noise and power characteristics, allowing monolithic integration.

V. Improved Device Performance

Next generation AlGaN/GaN HEMTs were fabricated on Silicon Carbide (SiC) substrates. These devices were fabricated with a 0.2-μm gate length and a 2-μm source-drain spacing. Figure 9 shows some sample DC curves from the new devices. This data was measured on a four-finger device with a total gate width of 80 μm. The measured Idss was 800 mA/mm and peak transconductance was 366 mS/mm. This device had a $V_{tht}$ of 6 V, a breakdown voltage greater than 50 V, and an $f_t$ of

30 GHz. Figure 10 shows the minimum noise figure and the associated gain versus frequency for a four-finger device with a total gate width of 120 μm. The data from one of the previous 30-μm devices is shown for comparison. This data shows a dramatic improvement in the device performance. At 4 GHz, the initial design frequency, the minimum noise figure dropped from 1.8 dB to 1 dB while the gain rose from 13.7 dB to 15.9 dB. There is also a reasonable minimum noise figure of 1.8 dB and gain of 10 dB at 10 GHz. The device performance at 10 GHz now enables the LNA design to be shifted to X-band. Additionally, the improved noise performance was achieved on a 120-μm device rather than a 30-μm device, which simplifies the noise impedance matching. Figure 11 shows the optimal match locations for the two devices at their minimum noise biases. For the 120-μm device, the 4 GHz match impedance is 165 +j163.5 ohms (3.3 +j3.27 normalized) as compared to 560 + j460 (11.2 +j9.38)
for the 30-μm device. The noise resistance, an indication of noise match sensitivity, dropped to 40 Ω for the new device from 240 Ω for the old device. The optimum noise match swings towards the center of the Smith Chart with higher frequency. Therefore, the optimum noise impedance match becomes more realizable at higher frequencies. Power measurements were also taken on devices from the same wafer. Figure 12 shows the power performance of an 80-μm device at 10 GHz. This device produced 22.7 dBm of power, which equates to a power density of 2.3 Watts/mm. Additionally, it had a power added efficiency of 17 % and a linear gain of 13 dB in a Class-A bias.

The device characteristics mentioned above show that these AlGaN/GaN HEMTs are rapidly improving. This last set of devices benefited from being grown on a SiC substrate, shorter gate length, shorter source-drain spacing, and continuous effort in improving the device processing. However, these devices are still not fully mature. Their full potential for excellent noise characteristics is limited by higher than ideal gate leakage current. The gate leakage was approximately the same for the two sets of devices. Therefore, the improved noise characteristics on the new set of devices are attributed to the reduced device dimensions and the improved process. Gate leakage is currently being addressed by focusing on material and process issues. As the issues of processing and material quality are resolved, the noise characteristics of these power devices are expected to improve.

VI. Conclusions
To our knowledge, this paper reports the first LNA fabricated with power GaN technology. The simulations and measurements show good agreement. These results demonstrate the feasibility of using a GaN technology normally associated with power to realize high, dynamic-range LNAs. The circuit implementation is in place and is ready to incorporate optimized devices. As the devices are further optimized, all aspects of the LNA are expected to improve. The next round of devices has already shown greatly improved noise characteristics. Even if the minimum noise figure of these devices is not better than their GaAs counterparts, the benefits of possibly eliminating front end protection, extending the dynamic range by 20 dB, and being able to build high-power and low-noise components in the same epitaxial material make this material system very attractive to future military and commercial microwave systems.

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References