High linearity GaN HEMT power amplifier with pre-linearization gate diode

Shouxuan Xie, Vamsi Paidi, Sten Heikman, Alessandro Chini,
Umesh K. Mishra, Mark J. W. Rodwell and Stephen I. Long
Department of ECE, UC Santa Barbara, CA 93106, USA

A high linearity MMIC RF power amplifier is reported in the AlGaN/GaN HEMT technology. In order to obtain high linearity, a pre-linearization gate diode is added at the input to compensate for the nonlinear input capacitance C_{gs} of the GaN HEMT device. Another single-ended Class B power amplifier without the gate diode is also designed for comparison. The circuit with the pre-linearization gate diode demonstrates at least 4dB improvement on 3rd order intermodulation distortion (IMD3) performance over the one without the diode up to its P_{1dB} output power level in two-tone measurement.

1. Introduction.

Our previously described single-ended Class B power amplifier design using GaN HEMT technology has shown that high linearity and high efficiency can be obtained simultaneously if the circuit is biased at exactly the pinch off point (Class B configuration) [1].

In order to further improve the linearity performance, linearization techniques, such as feedback, feed forward, or predistortion, could be used. Feedback is good for audio power amplifiers, but for RF power amplifiers the stability and efficiency can be compromised. System-level feed forward or predistortion can be useful for RF frequencies, but the overall efficiency will be decreased because extra components have to be added. This will also make it difficult for MMIC implementation.

In this work, three major sources of AlGaN/GaN HEMT device nonlinearity are investigated: nonlinear I-V characteristic (transfer function), nonlinear Gds and nonlinear Cgs. All the above nonlinear sources in the device will create the 3rd order intermodulation distortion (IMD3) either at the output or at the input of the circuit.

2. Nonlinear sources of GaN HEMT device.

The nonlinear I-V characteristic of the device will generate intermodulation products when two or more signals are present. It is the dominant nonlinear source when the input power exceeds the compression point. But at moderate input power level, as we discussed in [2], best linearity performance can be obtained by biasing at Class B.

For GaN HEMT devices, the output conductance Gds is a nonlinear function of the input and output signal. Moreover, substantial drain voltage dependent leakage current is observed in 0.3μm single gate devices, which is similar to the Drain-Induced Barrier Lowering (DIBL) effect in MOSFETs. This results in a threshold voltage shift, which also creates IMD3. However, by using dual-gate device, the nonlinear Gds effect can be minimized. The upper device reduces the drain voltage variation on the lower device and decreases the output conductance.

Finally, the input capacitance Cgs vs. Vgs characteristic of the AlGaN/GaN HEMT device is not linear, and it can be proved that the nonlinear Cgs characteristic can generate intermodulation distortion at the input of the circuit [3]. The distorted signal is amplified by the active device, also affecting the linearity of the circuit. The effect due to nonlinear Cgs can be compensated by adding a pre-linearization gate diode [4].

3. Pre-linearization gate diode

The nonlinear Cgs vs. Vgs characteristic can be modeled as a hyperbolic tangent function, which is an anti-symmetric function around the center point, Vc (shown in figure 1). Therefore, the idea of further improving linearity due to nonlinear Cgs is to compensate it with another nonlinear capacitance. Suppose Cgs vs. Vgs relation is modeled as $Cgs = C_1*tanH(Vgs-Vc) + C_0$, shown in figure 2, an ideal nonlinear capacitor $Cpd = -C_1*tanH(Vc-Vgs) + C_0$ can be added in parallel with Cgs such that the total input capacitance of the circuit is constant (not a function of bias voltage Vgs). This idea can be easily implemented by adding another HEMT device at the input, whose source and drain are shorted, and the gate is biased at twice of the Vc (shown in figure 3).

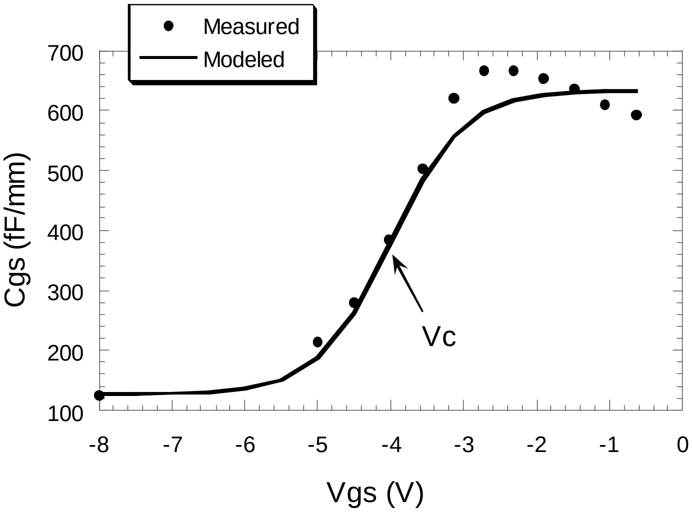

Figure 1: Nonlinear Cgs vs. Vgs characteristic of AlGaN/GaN HEMT

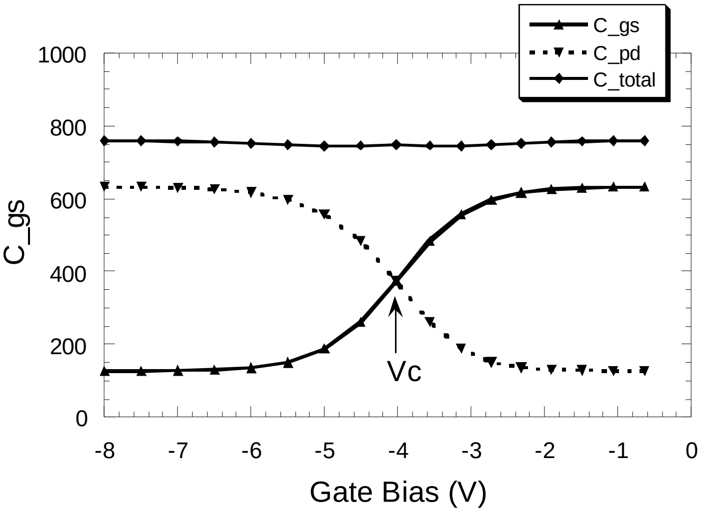

Figure 2: Pre-linearization gate diode to further improve linearity due to nonlinear Cgs

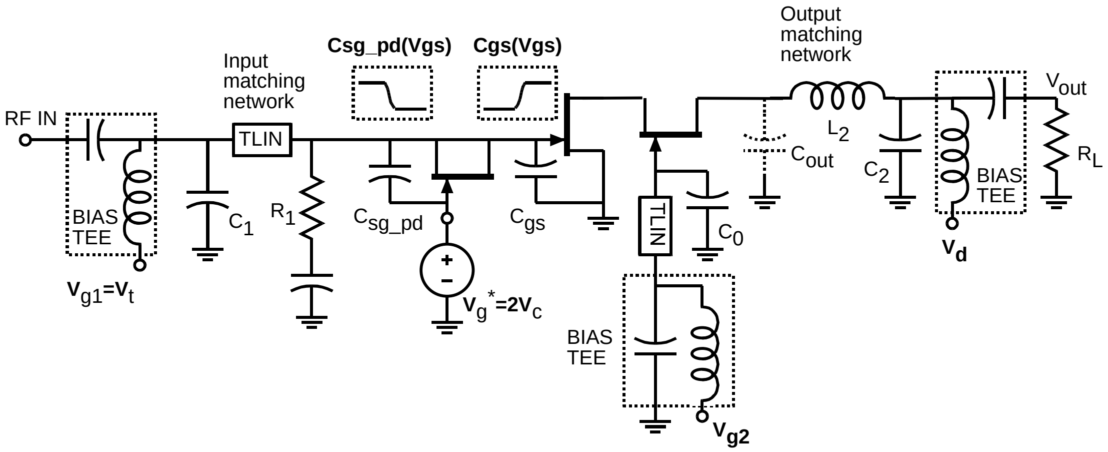

Figure 3: Circuit schematic of the dual-gate Class B PA with the pre-linearization diode

4. Circuit design and simulation result.

The dual gate Class B power amplifier with the prelinearization gate diode is designed at 10GHz. The Curtice cubic model (C_FET3) is used to model the GaN HEMTs device and the circuit is simulated using Agilent ADS. The circuit schematic and IC layout are shown in Figures 3 and 4. Both the input and output matching networks are on chip. In the output matching network, the output capacitance of the device Cout is absorbed into the Pi low pass filter. A 10pF on-chip capacitor C_0 is needed as close to the second gate as possible to provide a good AC ground at the frequency of interest. The prelinearization gate diode is beside the main device, both of which have the same gate area. Another single-ended Class B power amplifier without the gate diode is also designed for comparison. According to simulation using a model which only includes nonlinear Cgs, the IMD3 performance can be improved by about 4dB with the pre-linearization gate diode at all power levels (shown in Figure 5).

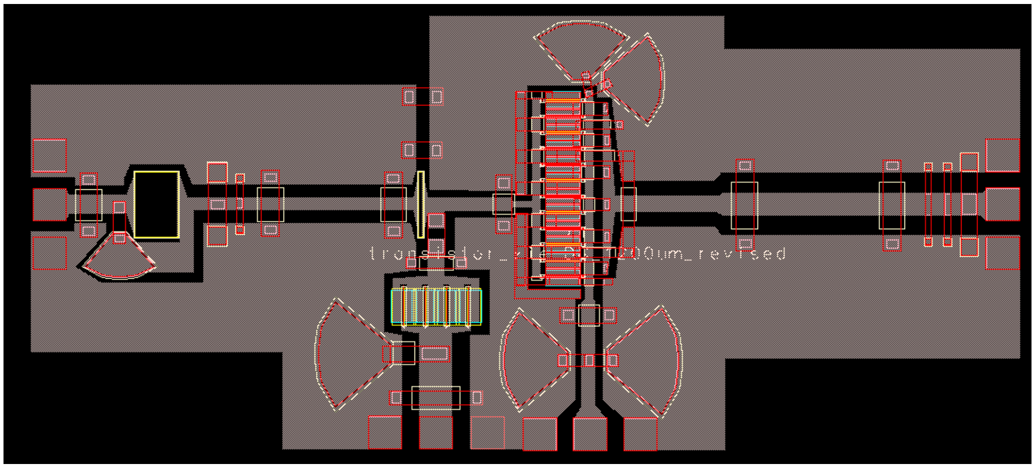

Figure 4: IC layout (dimensions 3mm x 1.5mm)

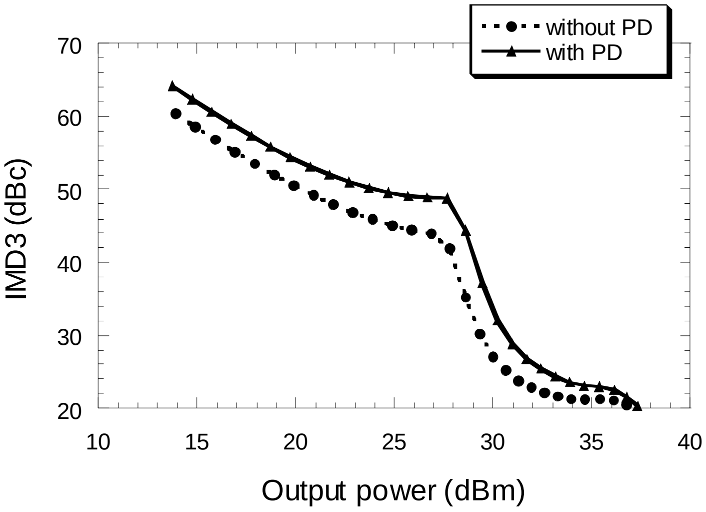

Figure 5: Simulation result on IMD3 improvement with the pre-linearization diode

5. Measurement results.

All the MMIC Class B power amplifiers are fabricated on a SiC substrate in the standard AlGaN/GaN HEMT technology [5] [6] and then tested. The 1.2mm dual gate GaN HEMT gives 1A/mm of I_{dss} and a breakdown voltage of approximately 55V. The measured f_t for the 0.3µm L_g dual gate device is 50GHz.

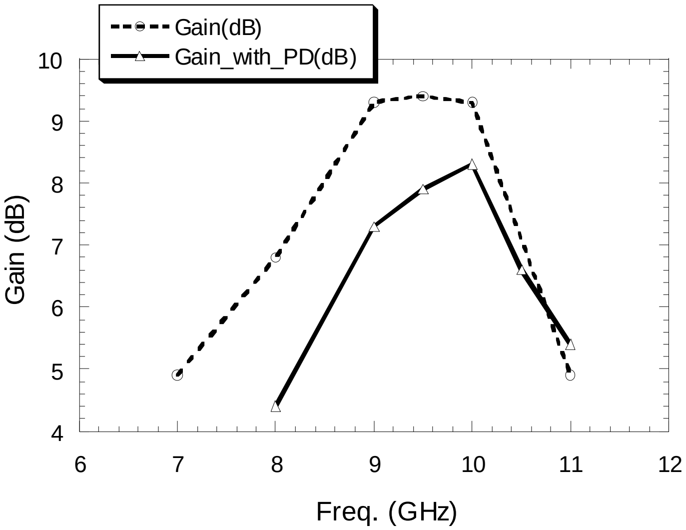

Figure 6: Measurement result: Gain vs. Freq.

The single tone and two tone measurement results of the two circuits are shown in figures 6, 7 and 8. For single tone measurement, the circuit without the gate diode demonstrates 30dBm output power at 1dB gain compression point (P_{1dB}) with 9.5dB gain from 9GHz to 10GHz, while the circuit with the gate diode demonstrates 29.1dBm of P_{1dB} output power with 8.4 dB gain at 10GHz. For two-tone measurement around 10GHz, a peak of 51dBc IMD3 is obtained with the gate diode MMIC at around 21dBm per tone output power. A 4dB improvement in IMD3 is obtained for the whole power range up to this point.

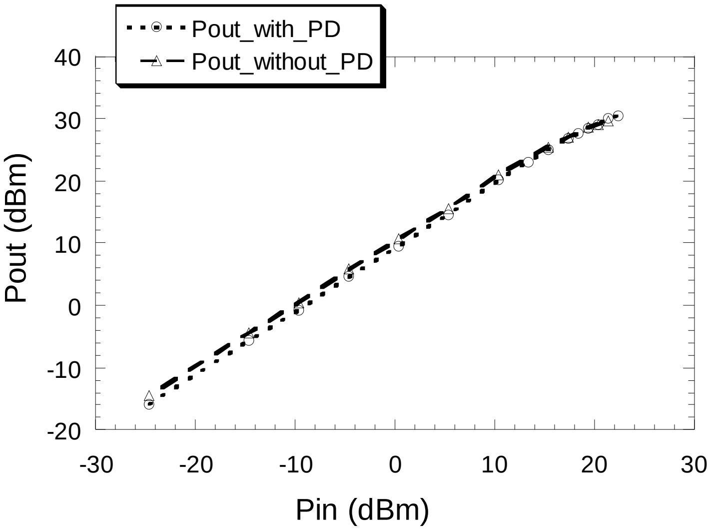

Figure 7: Single tone measurement result Pout vs. Pin

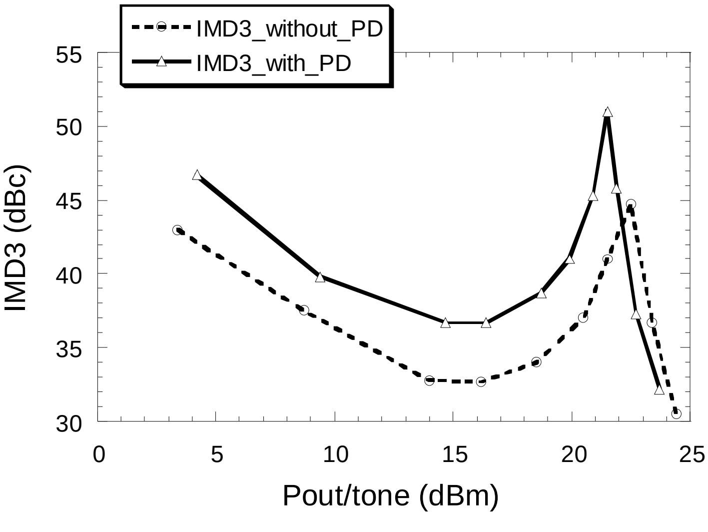

Figure 8: Two-tone measurement result IMD3 vs. Pout

6. Conclusions.

A high linearity MMIC RF power amplifier is reported in the AlGaN/GaN HEMT technology. Three major nonlinear sources of the GaN HEMT device are identified and investigated. To further improve linearity, a pre-linearization gate diode is added at the input to compensate the nonlinear effect of Cgs. The circuit with the pre-linearization gate diode demonstrates at least 4dB improvement on IMD3 performance over the useful power range in two-tone measurement.

7. Acknowledgement.

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8. References

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