High-Linearity Class B Power Amplifiers in GaN HEMT Technology

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***Abstract*—A 36-dBm, high-linearity, single-ended Class B MMIC power amplifier is reported in GaN HEMT technology. The circuit demonstrates high linearity, greater than 35 dBc of third-order intermodulation (IM3) suppression and high power added efficiency (PAE) of 34%. We demonstrate experimentally that Class B power amplifiers can achieve IM3 suppression comparable to Class A, while providing approximately 10% improved power added efficiency.**

***Index Terms*—GaN HEMT, high linearity, intermodulation suppression, MMIC power amplifiers.**

I. Introduction

For operation in suboctave bandwidths, a classical push-pull Class B power amplifier can be replaced by a single-ended class B power amplifier together with a low pass or band pass filter. The single-ended Class B power amplifier can achieve high power added efficiency (PAE) and high third-order intermodulation (IM3) suppression simultaneously if the I_d versus V_{gs} characteristics are linear above threshold [1]. The filter provides the required even-harmonic short-circuit termination for Class B operation. The theoretical analysis describing this in detail has been reported in [1].

II. Circuit Design and Simulation

The Class B power amplifier is designed and simulated using Agilent ADS as shown in Fig. 1. A dual gate (cascode) GaN HEMT is used to reduce Miller multiplication of C_{gd} and to increase the device breakdown voltage [2]. The input is matched with a broadband lossy network, and the output capacitance C_{ds} is absorbed into a Pi-section low pass filter which also serves as the output impedance tuning network [2]. This approach allows C_{ds} to be absorbed at the fundamental frequency while also providing a low load impedance at harmonic frequencies, as is required for Class B.

III. Circuit Fabrication and Test

The MMIC Class B power amplifier is fabricated on a SiC substrate in GaN HEMT technology [3] (Fig. 2). The 1.2 mm W_g dual gate GaN HEMT has $I_{dss} = 1$ A/mm and greater than 55 V breakdown voltage. The measured f_t for the 0.25 μm L_g device is 55 GHz.

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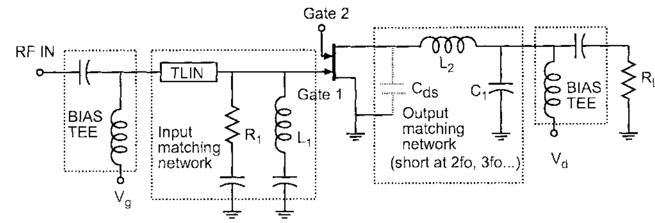


Fig. 1. Circuit schematic of the single-ended Class B power amplifier.

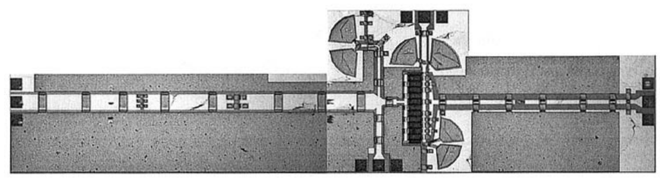
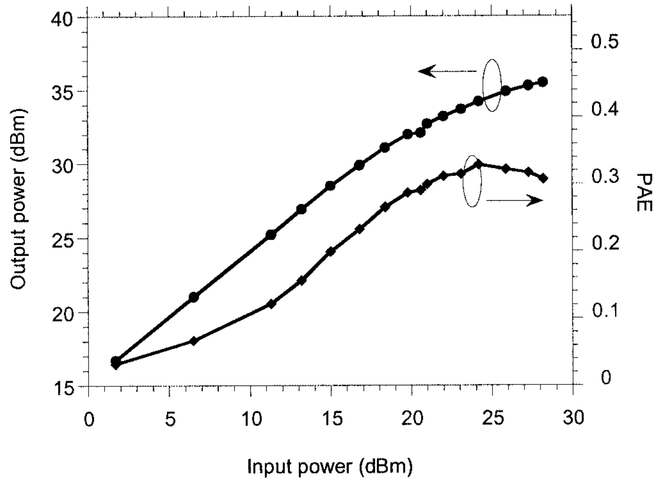


Fig. 2. Chip photograph (dimensions 6 mm × 1.5 mm).

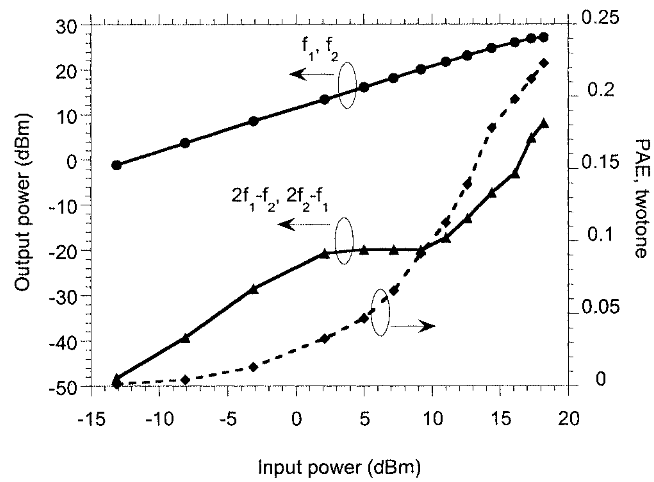
All input and output networks are on chip. Bias feeds for gate 1, gate 2 and drain were provided through off-wafer bias tees for convenience in testing. The circuit is tested with four different bias conditions: $V_{gs} = -3.1$ V for Class A ($I_{ds} = 460$ mA), -4 V for Class AB ($I_{ds} = 250$ mA), -5.1 V for Class B ($I_{ds} = 50$ mA), and -5.5 V for Class C ($I_{ds} = 10$ mA), respectively, keeping $V_{ds} = 20$ V in all cases. Single-tone and two-tone measurements were performed. The 3rd order distortion output powers, $2f_1 - f_2$ and $2f_2 - f_1$, are also measured with two input signals at $f_1 = 8$ GHz, and $f_2 = 8.001$ GHz.

For an idealized transistor having f_t and $f_{\max}$ much greater than the signal frequency and having negligible on-state resistance, theoretical limits on PAE for unsaturated Class A and Class B operation are 50% and 78.5%, respectively. In contrast, when such amplifiers are operated at output power levels approaching or beyond the 1 dB gain compression point ($P_{1\text{ dB}}$), the transistor is driven strongly into both pinch-off and saturation on the peaks of the signal swing, resulting in both increased PAE and increased distortion. It is therefore important to compare the PAE of Classes A and B as a function of the IM3 level.

The circuit under Class B bias conditions exhibits 13 dB gain with 3 GHz bandwidth. Gain under Class AB or A bias conditions was approximately 6 dB greater, as is expected theoretically. 36 dBm saturated output power and 34% maximum PAE are obtained under Class B bias conditions for a single-tone input [Fig. 3(a)], and high IM3 suppression is obtained over a wide output power range for two-tone input signals [Fig. 3(b)].



(a)



(b)

Fig. 3. Class B bias power amplifier. (a) Single tone output power and PAE. (b) Two-tone output power and IM3 suppression.

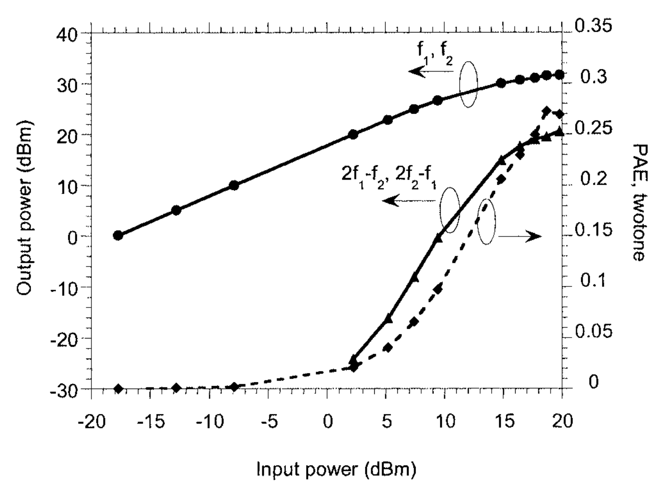


Fig. 4. Two-tone output power and IM3 suppression under Class A bias condition.

Under either Class A (Fig. 4) or Class B [Fig. 3(b)] bias conditions, the IM3 output power increases rapidly with increased input power, making IM3 suppression very poor at power levels

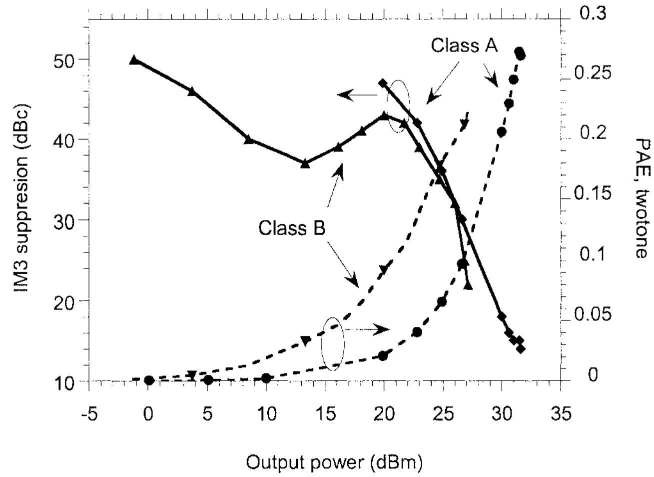


Fig. 5. Two-tone PAE and IM3 suppression of Class B and Class A.

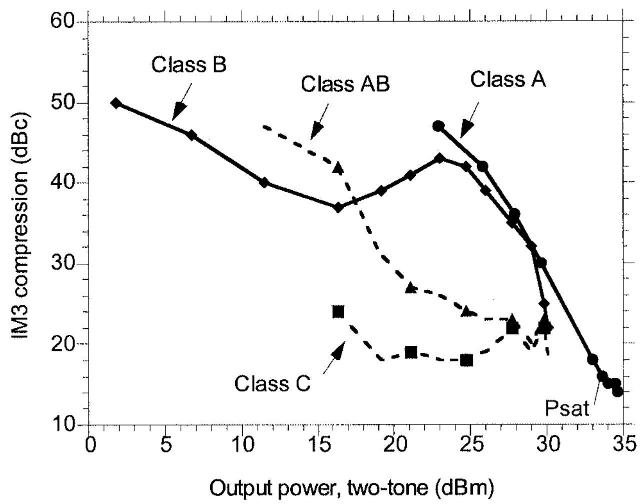


Fig. 6. Summary of IM3 suppressions for all bias conditions.

approaching the $P_{1\ \mathrm{dB}}$. Fig. 5 compares PAE and IM3 suppression vs. output power of Class A and Class B. At low output power levels, Class A shows high IM3 suppression ($>$ 50 dBc), whereas IM3 suppression of Class B also maintains a $>$ 40 dBc level. At high power levels approaching saturation, however, IM3 suppression is similar in Class B and Class A. At an output power level of 26 dBm, corresponding to 32 dBc IM3 suppression for both classes, the Class B amplifier exhibits 20% PAE, as compared to 8% PAE for Class A. Fig. 6 shows that Class AB and Class C bias conditions result in much higher IM3 distortion than either Class A or B.

IV. Conclusions

We have demonstrated that single-ended Class B amplifiers can obtain both high IM3 suppression and high PAE. Unlike push-pull designs, single-ended Class B designs avoid the difficulty of fabricating balun transformers with correct harmonic termination at microwave frequencies. In a detailed analysis of Class B stages [1], it can be shown that push-pull and single-ended Class B configurations have equal PAE and IM3. The

Class B mode of operation can be nearly as linear as Class A if the V_{gs} bias point is set close to pinch-off, and can yield more than a 10% increase in PAE over class A.

Acknowledgment

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