Simulations of High Linearity and High Efficiency of Class B Power Amplifiers in GaN HEMT Technology

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Abstract

We describe the design and simulation of highly linear and highly efficient common source Class B power amplifiers. Efficient broadband Class B Push-Pull amplifiers are not feasible at microwave frequencies as baluns with desired broadband even-mode impedance are unavailable. We find, however, that single-ended Class B amplifier with bandpass filtering has equivalent efficiency and linearity. Simulations of Class B designs predict a power added efficiency (PAE) of 48% with 40 dBc of third order intermodulation product (IMD3) performance when biased close to the pinch-off voltage.

I. Introduction

Simultaneously achieving high efficiency and low distortion is a major challenge in microwave power amplifier design. Class A amplifiers exhibit low distortion but exhibit power added efficiency well below 50%[4]. Improved efficiency is obtained with switched mode power amplifiers [5]. These, unfortunately, exhibit high intermodulation distortion in multi-tone applications. Push-Pull Class B amplifiers offer the potential for improved efficiency, at a theoretical limit of 78.6%[2], combined with distortion as low as Class A.

II. Single-ended Class B Power Amplifier

Efficient broadband Class B amplification is unfortunately not feasible at microwave frequencies due to the lack of available baluns with the required zero ohm *even-mode* impedance. With non-zero even-mode impedance, the transistor drain voltage waveform contains 2^{nd} harmonic Fourier component, and power is dissipated in the 2^{nd} harmonic, degrading efficiency. Additionally, microwave baluns are physically large (of the order $\lambda/2$), which results both in large excess consumed expensive IC die area and in large excess line losses with resulting degradation in efficiency.

We must emphasize that Push-Pull operation, through its symmetry, suppresses only even-order (2^{nd} harmonic) distortion [1]. Odd-order component in the circuit transfer function, and the resulting two-tone 3^{rd} order intermodulation distortion are not suppressed.

Third-order distortion characteristics of Class B Push-Pull circuits, therefore, do not differ from that of a single-ended Class B amplifier. Consequently, for power amplifier applications requiring less than 2:1 frequency coverage, Push-Pull operation is entirely unnecessary. Instead, 2nd harmonic Fourier components of the transistor drain current waveform can be supplied (provided with the required zero ohm impedance) through use of an output bandpass filter, centered at the signal fundamental, and a single transistor stage can be employed. Third-order intermodulation characteristics are identical for both Push-Pull and the single-ended configurations. Therefore, given an operating bandwidth requirement of less than an octave, a single-ended Class B amplifier can provide both high linearity and efficiency approaching 78.6%.

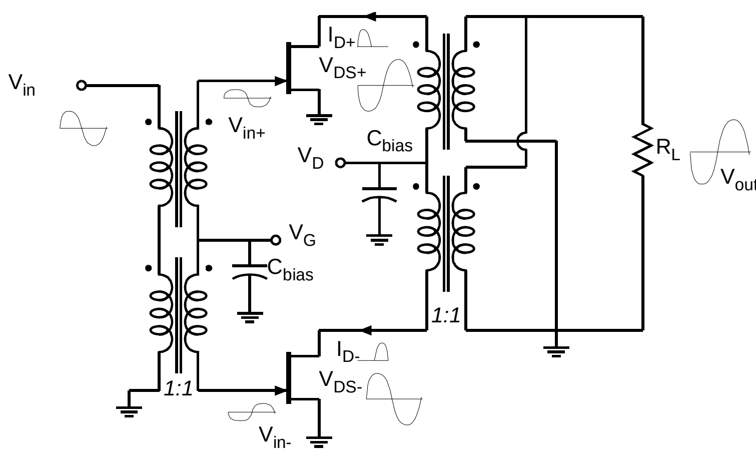

Fig. 1. Circuit Schematic of Push-Pull Class B

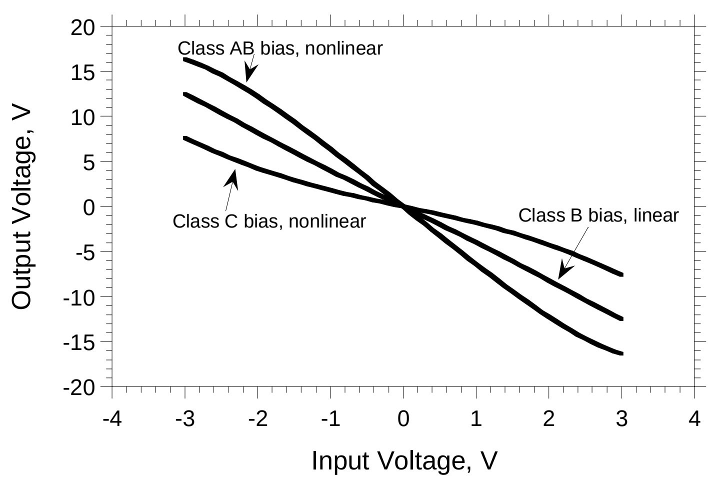

Fig. 2. Transfer function of Common Source Amplifier as a function of bias

Two-tone third order distortion characteristics depend critically upon the Class B bias point, whether for single-ended or for the equivalent Push-Pull configuration. Bias design is, however, most easily discussed in the framework of the Push-Pull stage (Fig.1), with drain current $I_d(V_{in})$, the Push-Pull output current is $I_o=I_d(V_{in})-I_d(-V_{in})$. Given the threshold characteristic typical in HEMT (Fig. 4), third-order distortion is strongly reduced for Class B biased precisely at the HEMT threshold voltage (Fig. 3), and degrades as the bias is set either above (Class AB) or below (Class C) the threshold voltage. Transfer characteristics with Curtice GaN HEMT model are shown in Fig. 2 for Classes AB, B and C.

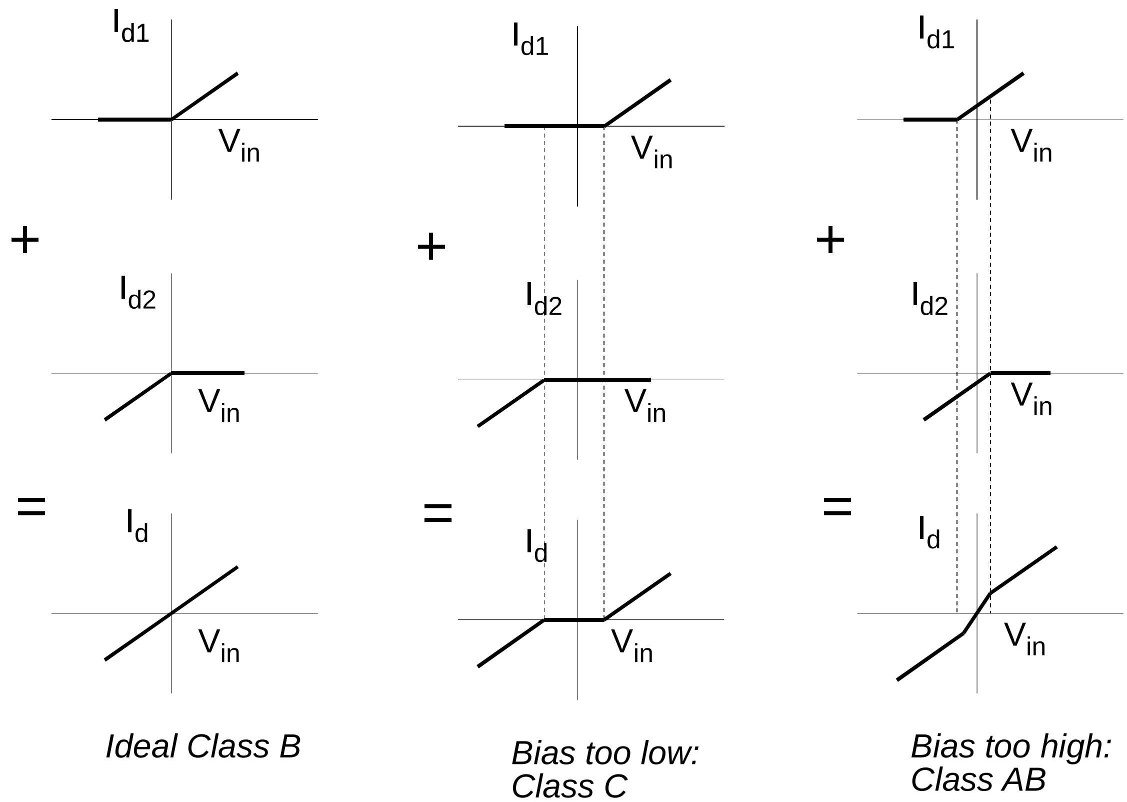

Fig. 3. Bias design for good linearity performance

III. Design and Simulations

Designs have been developed for UCSB's GaN HEMT MIMIC process. Designs were developed using the model of a 0.2μm L_g device, resulting in 50 GHz f_t and 100 GHz f_{max} [3]. The modeled devices have 50V breakdown and I_{dss} is 650mA/mm. These device parameters are representative of better GaN HEMTs fabricated at UCSB.

The circuit is simulated using Agilent ADS and the Curtice HEMT model. The measured HEMT drain current-gate bias characteristics (Fig. 4) and input capacitance characteristics (Fig. 5) are precisely modeled, as those parameters are crucial for linearity simulations. In particular, IMD3 is generated if the input capacitance C_{gs} is not purely antisymmetric about the gate bias voltage. The GaN HEMT on SiC has very nearly linear current-voltage characteristic if biased at the pinch-off voltage, a bias condition which is also desirable for high efficiency.

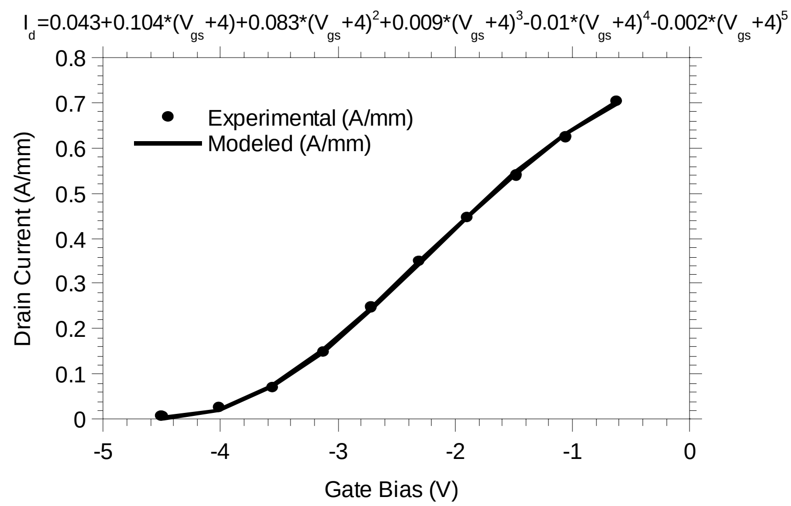

Fig 4. I_d-V_{gs} characteristic of GaN HEMT on SiC

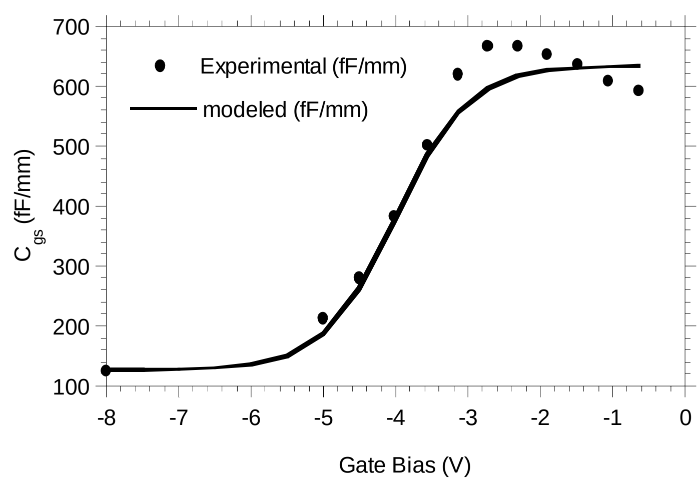

Fig. 5. Input Capacitance characteristic of GaN HEMT

Circuit simulations (Fig. 6, Fig. 7, Fig. 8, Fig. 9, Fig. 10) predict 36dBm output power with a saturated efficiency of 48 percent. Two-tone circuit simulations predict IMD3 levels of -40dBc when the output power is 3dB below the 1-dB gain compression point. The zero-input-signal dissipation is low, which will result in high PAE, when a broadband amplifier is constructed by frequency-multiplexing an array of class-B amplifiers. A systematic study of the influence of bias point on PAE and linearity was performed (Fig.

10). The optimum operating point is found to be very close to pinch off confirming the theoretical predictions. The cascode version of this circuit is being fabricated in GaN HEMT technology at UCSB.

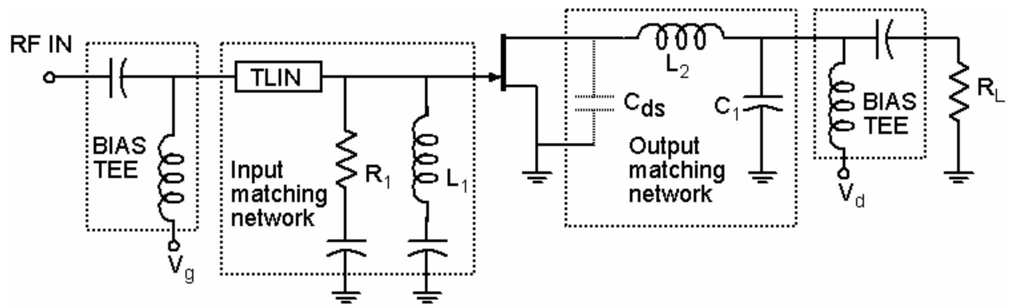

Fig. 6. Circuit Schematic for Single-ended Class B

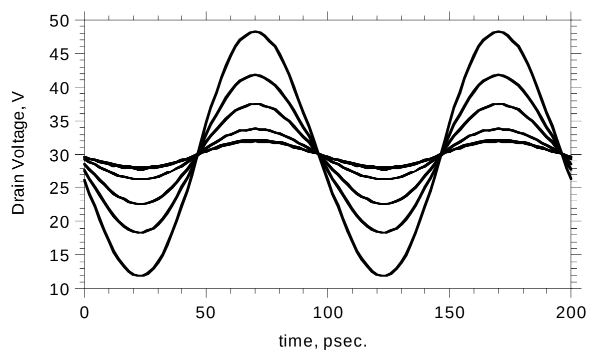

Fig. 7. Drain voltage waveform

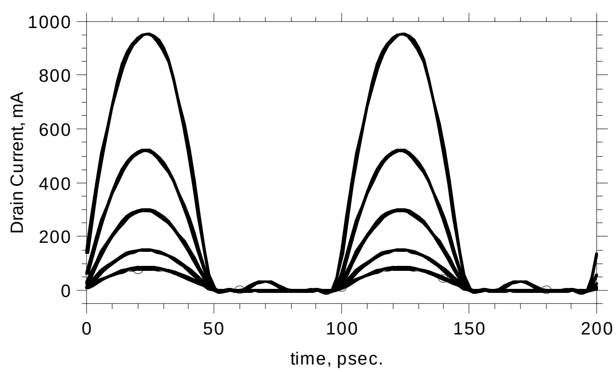

Fig. 8. Drain current waveform

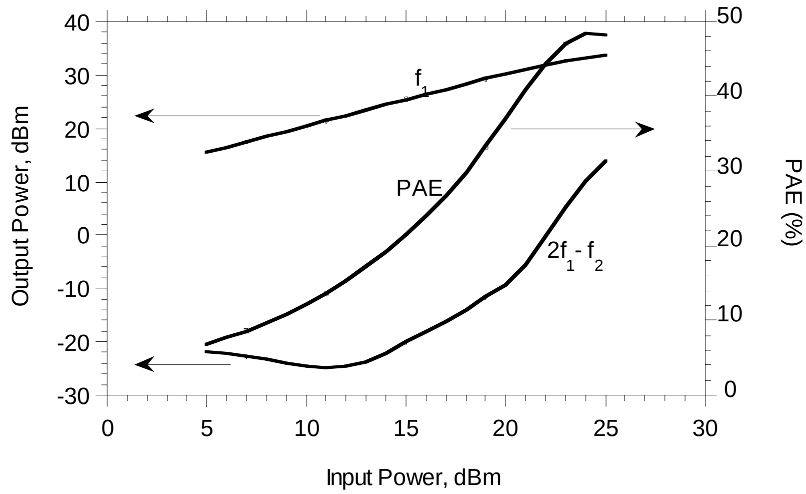

Fig. 9. PAE and IMD3 performance of Class B power amplifier

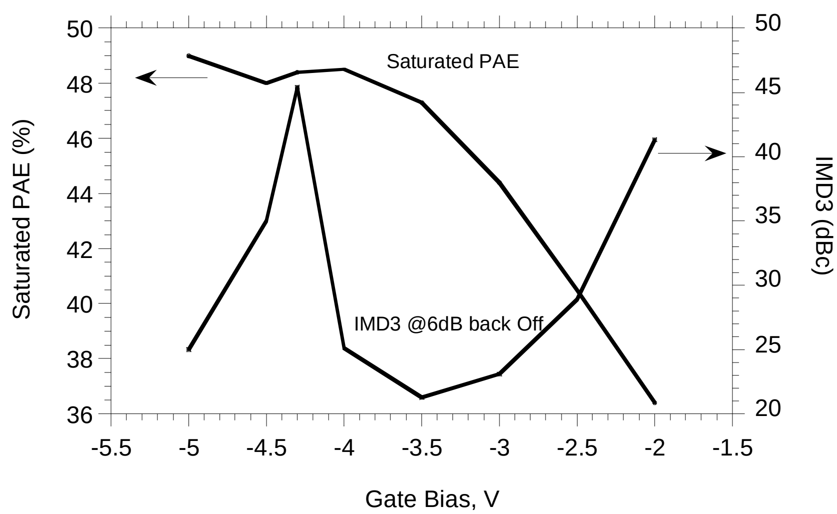

Fig. 10. Bias dependence of PAE and IMD3

IV. Conclusions

The Push-Pull configuration is unnecessary and can be replaced by a single ended configuration with adequate filtering. The common source Class B can be linear if the transfer characteristics are linear. This configuration has shown ~40dBc of linearity at 10GHz with approximately 48% PAE.

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Acknowledgment

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