Effects of Output Harmonic Termination on PAE and Output Power of AlGaN/GaN HEMT Power Amplifier

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***Abstract*—This letter experimentally investigates and discusses the effects of output harmonic termination on power added efficiency (PAE) and output power of an AlGaN/GaN high electron mobility transistor (HEMT) power amplifier (PA). The AlGaN/GaN HEMT PA with gate periphery of 1 mm was built and tested at L-band. Large-signal measurements and comparisons of the PAE and output power were carried out at different dc bias conditions from 50% of saturated drain current (I_{dss}) to 1% of I_{dss} for the PA with and without output harmonic termination. For class-AB operation at 25% of I_{dss}, an increase of about 10% in peak PAE and 1 dBm in output power were observed in saturated output power range. Improvements of up to 9% in PAE and 1.2 dBm in output power were achieved over the measured dc bias conditions provided the output harmonics are properly terminated.**

***Index Terms*—AlGaN/GaN high electron mobility transistor (HEMT), harmonic termination, power added efficiency, power amplifier.**

I. Introduction

FOR PHASED array radars and wireless communication systems, there is an increasing demand for developing AlGaN/GaN high electron mobility transistor (HEMT) power amplifiers (PAs). AlGaN/GaN HEMTs on SiC substrate offer higher breakdown voltage and better thermal conductivity, as well as good electron transport characteristics compared to GaAs- and InP-based devices. Thus, AlGaN/GaN HEMTs and their PAs have been extensively investigated and developed for high frequency and high power applications [1]–[3].

High efficiency is an important power amplifier characteristic which allows for smaller and lighter power sources and reduced cooling requirements. High efficiency PAs have been investigated and realized via controlling output harmonics from the nonlinear active devices biased at class-B or class-AB [4]–[6]. However, few studies have been done which investigate the effects of harmonic termination on AlGaN/GaN HEMT PAs and the improvement in efficiency they provide.

In this letter, we experimentally study the effects of output harmonic termination on power added efficiency (PAE) and output power of an AlGaN/GaN HEMT PA. This is done by comparing measured performances with and without output harmonic termination, as a function of input power, frequency, and dc bias condition.

Manuscript received February 13, 2002; revised May 28, 2002. This work was supported by BMDO under Contract DASG60-00-1-0001. The review of this letter was arranged by Associate Editor Dr. Ruediger Vahldieck.

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Digital Object Identifier 10.1109/LMWC.2002.805532

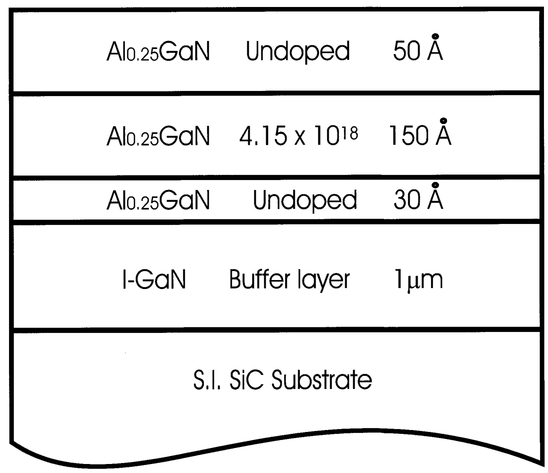

Fig. 1. Detailed HEMT layer structure.

II. Design and Fabrication of AlGaN/GaN HEMT Power Amplifier

A. AlGaN/GaN HEMT on SiC

The AlGaN/GaN HEMT layer structure was grown using metallic organic chemical vapor deposition (MOCVD) on semi-insulating SiC substrate. The HEMT epitaxial layer was composed of a Si-doped AlGaN layer that provides two dimensional electron gas and an intrinsic GaN buffer layer. In Fig. 1, the detailed HEMT layer structure is shown. The UCLA AlGaN/GaN HEMT fabrication process includes ohmic metallization formed by Ti/Al/Ni/Au with 900 °C and 40 s rapid thermal annealing, yielding a typical resistance of 0.4 Ω-mm [2]. Device isolation is realized by ion implantation using As^+ and He^+ followed by a gate metallization process utilizing a Pd/Au bi-layer and Si_3N_4 passivation. An air-bridge process completes fabrication. The drain-to-source space of the HEMT was 3 μm while the gate-to-source space was 1 μm. From the fabricated AlGaN/GaN HEMT, 600 mA/mm I_{dss} and 165-mS/mm peak transconductance were recorded.

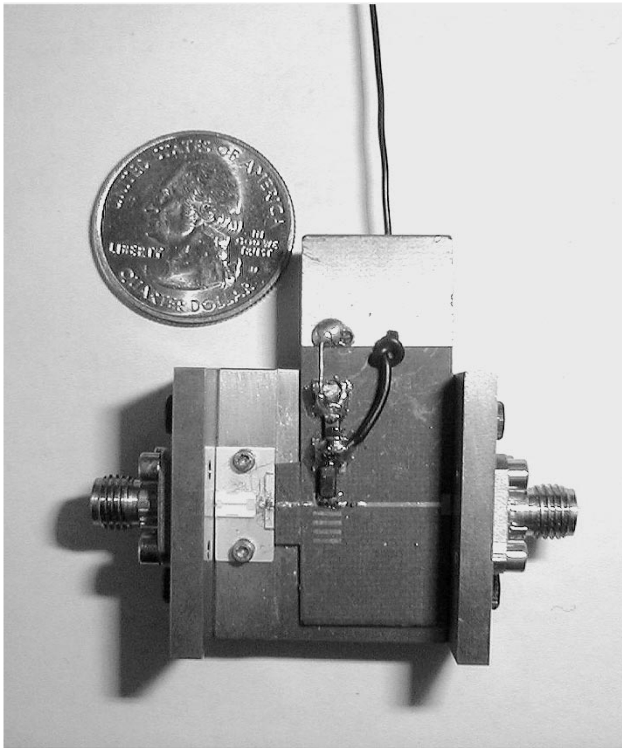

Fig. 2. Fabricated PA mounted on a test jig.

B. AlGaN/GaN HEMT Power Amplifier

An AlGaN/GaN HEMT with gate width of 1 mm and gate length of 0.8 μm provided the sufficient gain at L-band. A conventional amplifier matching technique based on the measured small-signal S-parameters was employed at both input and output sides, transforming the gate and drain impedance to 50 Ω. The input matching network was implemented on Alumina with dielectric constant of 9.8 and thickness of 15 mils. For ease of tuning, the output matching network was built on RT/Duroid with dielectric constant of 2.33 and thickness of 31 mils. We have also considered the effect of the Au bonding by factoring in an equivalent inductance [3]. The PAE can be enhanced when the harmonic load impedances are properly terminated. Specifically, the circuit is designed such that the load impedance at the second harmonic is short-circuited while appearing to be open-circuited at the third harmonic [5], [6]. In this work, an external filter was used and the output matching network was optimized so that proper harmonic tuning was done for maximum PAE in the saturated output power range. The fabricated PA was mounted on a test jig as shown in Fig. 2. The metal fixture efficiently dissipates heat generated from the AlGaN/GaN HEMT so that accurate power performance measurements can be made.

III. Experimental Results

In order to have the sufficient drive power, large-signal measurements were performed using a microwave synthesizer in conjunction with a microwave amplifier as a power source. The amplifier was first biased at class-AB operation with the bias current at 25% of I_{dss} and drain voltage (V_{ds}) of 18 V. The measured input power-dependent large-signal performance is shown in Fig. 3 for the AlGaN/GaN HEMT PA module with and without harmonic termination at 1.5 GHz. 57% peak PAE and 31 dBm saturated output power with linear gain of 12.6 dB have been achieved for the PA with output harmonic termination while 48% PAE and 30.1 dBm with 12.1-dB gain from the PA without termination. In saturated output power range, dramatic increase of more than 10% in peak PAE was observed due to proper harmonic termination. Note that for all of these results, loss of the harmonic termination was accounted for.

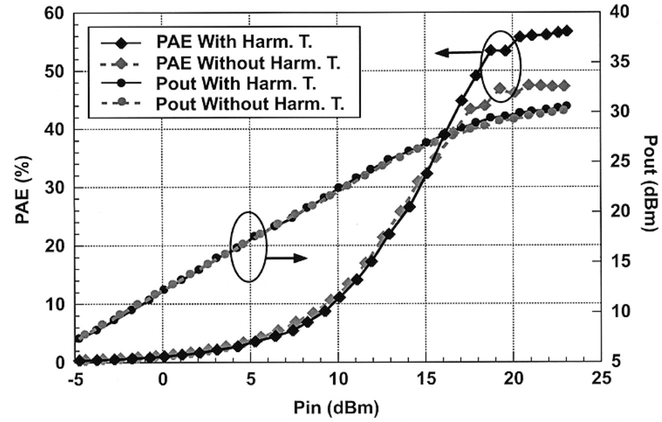

Fig. 3. Measured input power-dependent large-signal performance.

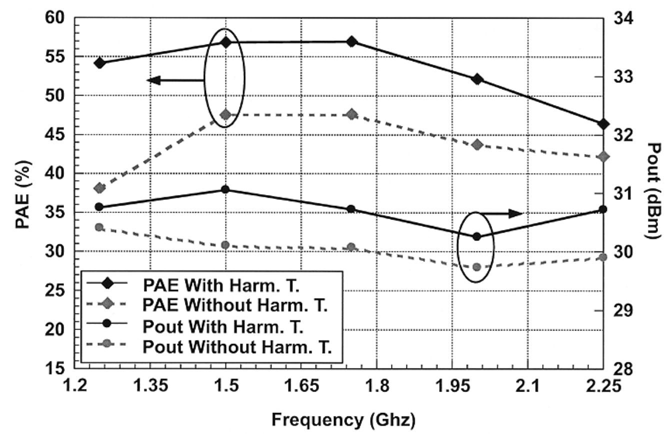

Fig. 4. Frequency-dependent large-signal performance.

In Fig. 4, the frequency dependent large-signal performance is shown at L-band for the PA with and without harmonic termination. Improvements from 4.2 to 16.1% in PAE and 0.35 to 0.95 dBm in output power are observed within the considered frequency range when using harmonic termination. Fig. 5 shows measured PAE and output power of the PA as a function of dc drain bias current at 1.5 GHz. At 300-mA dc bias current signifying class-A operation, improvements of 3% in PAE and 0.3 dBm in output power were observed when using harmonic termination. As the dc current level decreases, these improvements increase to 9% better PAE at 150 mA and 1.2 dBm more output power at 70 mA. This trend can be explained by nonlinearity encountered when choosing operating class.

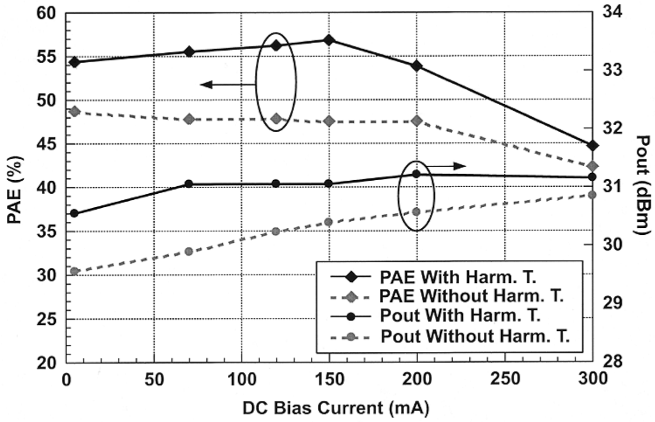

Fig. 5. Measured PAE and output power of the PA as a function of dc drain bias current at 1.5 GHz.

IV. SUMMARY

In this work, the effects of output harmonic termination on PAE and output power of an AlGaN/GaN HEMT PA have been investigated as a function of input power, frequency, and dc bias condition. By implementing a low-pass filter and tuning matching network, output harmonics have been properly terminated. Thanks to output harmonic termination, an increase of 10% in peak PAE and 1 dBm in output power were observed in saturated output power range for class-AB operation. Up to 9% improvement in PAE and 1.2 dBm in output power were achieved over the measured dc bias conditions from 50% to 1% of I_{dss}. This work demonstrates that AlGaN/GaN HEMTs can be successfully used to produce high efficiency power amplifiers required for phased array radar and wireless communication systems, provided that proper output harmonic termination is used.

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