7.5–14-GHz CE HBT MMIC Linear Power Amplifier

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Abstract—**A common-emitter (CE) AlGaAs–GaAs HBT MMIC amplifier was made to operate in X-band. 1W CW output power was achieved in saturated power operation from 7.5 to 12 GHz. In class A linear power operation, it provides 26-dBm CW power. The amplifier shows low two-tone intermodulation distortion: better than −20 dBc IM_3 at 1-dB compression point throughout the 7.5–14-GHz bandwidth. The low third-order intermodulation distortion is a direct result of the excellent linear power performance of the CE AlGaAs–GaAs HBT. The combination of good efficiency, low third-order intermodulation distortion, and broad bandwidth in this MMIC amplifier clearly demonstrats the potential of the CE HBT in communication transmitter applications.**

I. Introduction

AlGaAs–GaAs HBT's demonstrate very low third-order intermodulation distortion, and very high IP_3/P_{dc} figure of merit [1]. However the mode of operation reported in [1] is only appropriate for receiver applications. In communication system transmitter application, both high efficiency and low intermodulation distortion are desired simultaneously. For such applications, the CE HBT shows suitable linear power performance [2] in class A operation. In this work, a CE HBT MMIC amplifier was designed and fabricated. The amplifier was designed to cover 7–11 GHz, with a saturated output power of 1 W. The amplifier was tested in both saturated power (class AB) and linear power (class A) operation. The performance in the two operation modes will be presented, and the differences will be discussed.

II. HBT Performance and Circuit Design

The power CE HBT used in this study has an emitter junction area of 360 μm^2 [3]. In class A operation, where the linearity is best, the collector is biased at 7 V to restrict the temperature rise to no more than 90°C. Fig. 1 displays both single-tone and two-tone test results for a CE HBT at 7 GHz with a frequency separation of 5 MHz. 23.8-dBm output power was measured in the single tone test, and 18.8 dBm (per tone) was achieved in the two-tone test. At the 1-dB compression point in the two-tone test, PAE (power-added efficiency) per tone of CE HBT reaches 12.5% with an IM_3 of −21 dBc. With 1.5-dB backoff of the CE HBT output power from 1-dB compression point, the IM3 improves to −30 dBc. Load pull revealed that the load resistance is 65.4 Ω and the reactive part is conjugately matched to the 0.32-pF output capacitance.

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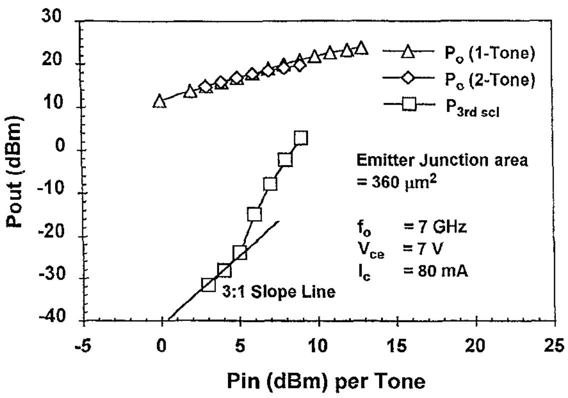

Fig. 1. Two-tone and single-tone test results of a CE HBT at 7 GHz with a frequency separation of 5 MHz. $P_{o\ 1tone}$ is the output power in single-tone test, $P_{o\ 2tone}$ is the output power for each tone in the two-tone test, and $P_{3rd\ scl}$ (single carrier level) is the third-order intermodulation distortion power for each spectrum line.

Based on load pull data and two-tone test results, a broadband linear power amplifier was designed with two CE power HBT's. The load line was chosen to provide a good compromise between class B saturated power operation and class A linear power operation. The output matching circuit is composed of a three-section band-pass filter to cover the 7 to 11 GHz range, which also serves as a 2:1 power combiner. The input matching circuit serves a gain equalization function by adjustment of the input return loss across the band. For class B operation, the amplifier can be biased up to 9 V to provide 1-W output power. In class A mode, the V_{cc} is designed to be 7 V. The chip occupies 2.15 mm by 1 mm, with a 3-mils thick substrate. The circuit layout is shown in Fig. 2.

III. Microwave Test Result

Fig. 3 shows the test result of the class B operation. It operates over 7.5 to 12 GHz bandwidth with 30-dBm CW output power at 9-V collector bias. The peak PAE (power added efficiency) is 38.5% with 7.7-dB gain. The gain and PAE slope down to the high end of the band. It is caused by a lower-than-expected MIM capacitance as well as the poor modeling of the cross-talk in the input matching circuit. The amplifier was not tested beyond 12 GHz, because of the low PAE and overheating problems.

In class A operation, the MMIC was biased at 7-V collector voltage and 130-mA collector current to maintain the junction temperature rise below 75°C as measured by liquid crystal method. 26-dBm peak output power was achieved at 10 GHz with a gain of 8.9 dB and PAE of 33.6%. Two tone tests were done with 5-MHz signal separation from 7.5 to 14 GHz. The results at 1-dB gain compression point across the 7–14-GHz

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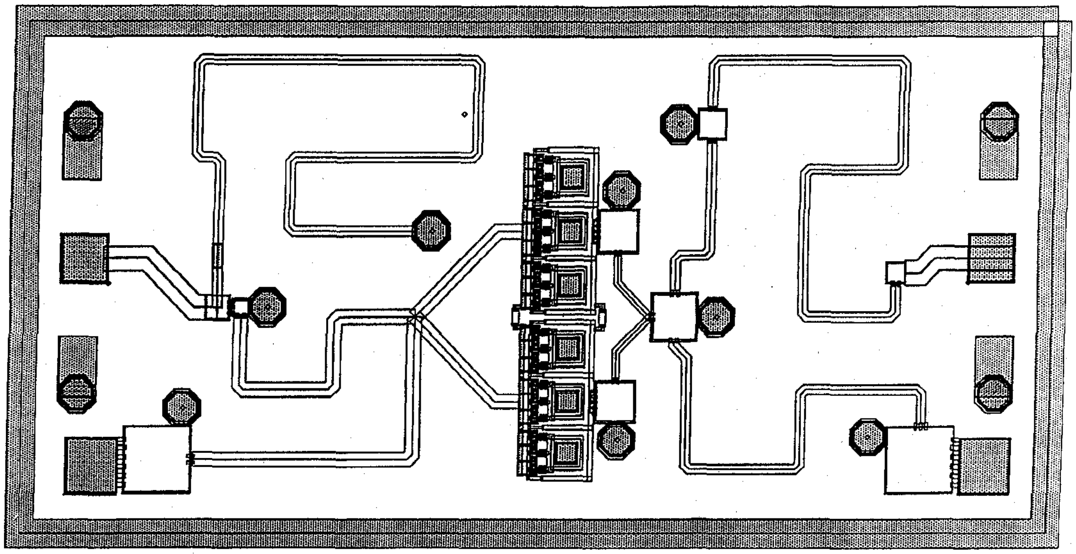

Fig. 2. Layout of the CE HBT MMIC amplifier using two power HBT's. Chip size is 2.15 mm by 1 mm. Quiescent collector current was less than 10 mA and the amplifier reaches over 200 mA with full RF drive.

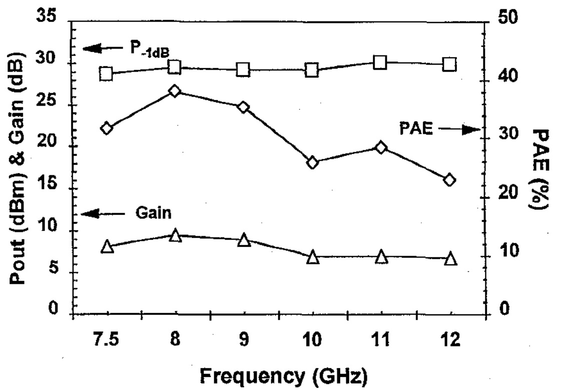

Fig. 3. Power performance of the CE HBT amplifier in class B operation. Collector is biased at 9 V. 1-W CW output power was achieved.

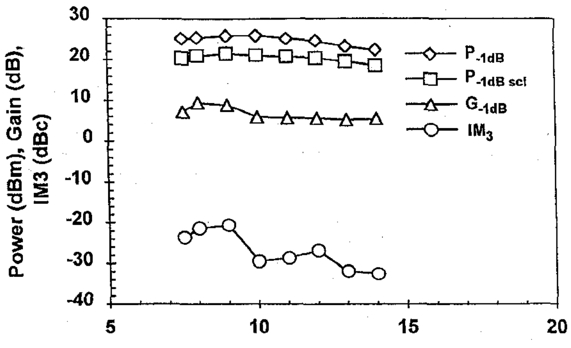

Fig. 4. Power performance of the CE HBT amplifier in class A operation: the two-tone test result is displayed alongside the single-tone result. At 1-dB compression point, the IM_3 is better than -20 dBc over the 7.5 to 14-GHz band at $V_{ce} = 7$ V and $I_c = 150$ mA. P-1dB scl is the 1-dB compression output power for a single carrier level (per tone) in the two-tone test.

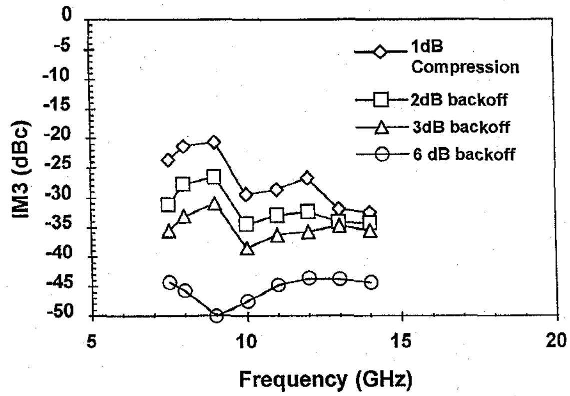

Fig. 5. IM_3 at various backoff levels. At 3-dB input power backoff, it is better than -30 dBc. At 6-dB input power backoff, or 5-dB output power backoff, it is better than -44 dBc.

band is shown in Fig. 4. The IM_3 is between -20 dBc and -30 dBc at the 1-dB compression point, with PAE per tone between 6 and 12.8%. Fig. 5 shows the IM_3 at different input power backoffs. At 3-dB input power backoff (about 2.3-dB output power backoff), the IM_3 is better than -30 dBc over the 7.5 to 14-GHz band. This excellent linear power performance is a direct result of the superior characteristics of the CE HBT.

IV. Conclusion

A broad-band CE HBT MMIC power amplifier has been demonstrated. Using the load pull data, a design was accomplished to achieve high performance in both class B saturated power and class A linear power operation. The MMIC amplifier provides 1-W saturated power over 7.5 to 12 GHz; and 26-dBm power at 1-dB compression in class A operation. Two-tone testing produced lower than -20-dBc IM_3 over the entire band at 1-dB compression point. These results clearly show a substantial performance advantage of the CE HBT over alternative device technologies in communication transmitter application.

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