LOW DC POWER, HIGH GAIN-BANDWIDTH PRODUCT, COPLANAR DARLINGTON FEEDBACK AMPLIFIERS USING InAlAs/InGaAs HETEROJUNCTION BIPOLAR TRANSISTORS

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Abstract

Broad band amplifiers with two Darlington feedback topologies, namely resistive biased and mirror biased, have been designed, fabricated and characterized. The HBT layers used for amplifiers were grown by MBE. To reduce the knee voltage and increase the breakdown voltage of the devices, graded base-emitter junction and low-doped, thick collector have been employed. The fabricated amplifiers have achieved 10.95dB gain with 25.5GHz bandwidth at DC power consumption of only 34.7mW. State-of-art Gain-Bandwidth-Products per dc power were achieved for both amplifiers (≥2.60GHz/mW). The fabricated amplifiers also demonstrated moderate output power (8.3 dBm) at 10 GHz with a low DC power consumption of only 40mW.

Introduction

Wide-bandwidth baseband amplifiers are key components for future millimeter-wave wireless technology in applications such as multimedia mobile access communication (MMAC) and intelligent transport system (ITS). Such baseband amplifiers can be used in various bands as general-purpose amplifiers in wireless communication, as well as, preamplifiers and data signal amplifiers in optical communication systems [1], [2], [3].

InP-based HBTs are suitable for such applications because of their superior high-speed performance. The low V_{BE} turn-on voltage of InP-based HBTs due to the low bandgap of the InGaAs base allows operation with small DC power consumption. Therefore it permits operation with low power supply voltage, which also leads to low power consumption, making InP-based HBT technology very competitive compared with GaAs, SiGe-based HBTs. GaAs-based HBTs Darlington feedback amplifiers reported in the past [6] achieved 8.2dB gain with 54.7GHz bandwidth but had a relatively high power dissipation of 60mW. SiGe-based HBTs Darlington feedback amplifiers with 9.5dB gain and 18GHz bandwidth have also been realized with a DC power consumption of 50mW [5]. In this work, Darlington feedback amplifiers with two topologies, namely mirror biased and resistor biased, have been designed and fabricated by using InP-based HBT technology. A gain of 10.95dB with 25.5 GHz bandwidth have been achieved for resistor biased amplifiers at DC power of 34.7mW while mirror biased amplifiers achieved 11.5dB with 18.2 GHz bandwidth at DC power of 26.6mW. These correspond to 2.60GHz/mW and 2.66GHz/mW Gain-Bandwidth-Product per dc power (GBP/P_{dc}) figure of merit respectively. The achieved performance is better or comparable to GaAs-based HBT (2.33GHz/mW) and SiGe-based HBT (2.54GHz/mW) circuits reported in the past [5-6]. The solutions reported here offers at the same time compatibility for potential monolithic integration of these circuits with InP-based optoelectronics systems.

This paper addresses the design, fabrication and characterization of InP-based Darlington feedback circuits for wireless and optical communication systems. In this study, InAlAs/InGaAs HBT layers were grown by MBE on 001 semi-insulating InP substrates. A 450Å InAlGaAs compositional graded layer was employed to reduce the offset voltage by eliminating the base-emitter conduction band spike while a low doped thick InGaAs collector layer (7000Å) was used to improve the breakdown voltage of the InAlAs/InGaAs HBT structure.

Device Technology

InAlAs/InGaAs HBTs based integrated circuits were fabricated using an all wet etch-based process developed at the University of Michigan. The base contacts were self-aligned to the emitters to reduce the base parasitic resistance. The emitters were then protected and the wafers were etched to the subcollector layer. The base contact also serves as an etch mask in this step. The resulting collector

[+] Presently at TRW Electronics, Redondo Beach, CA 90278 undercut led in reduction of the base-collector capacitance by ~24% and thus enhanced f_{max} performance. The lateral undercut of the base and collector material was about 0.8 μm. Ti/Pt/Au was used as n-type metal and Pt/Ti/Pt/Au was used as p-type metal for ohmic contacts. Ni/Cr thin film resistors were employed with a sheet resistance value of 20 Ω/□.

The DC characteristics of the fabricated HBTs were measured and are shown in Fig. 1. The HBTs showed a low offset voltage of 0.15V, which is about 0.23V lower than for HBTs with abrupt InAlAs/InGaAs base-emitter junction. The devices also show a high breakdown voltage exceeding 8.5V as a result of low doped, thick collector design. Moreover, the HBTs show a low knee voltage of 0.5V at a collector current of 20mA due to the small parasitic collector resistance (~15Ω). The low offset voltage of these HBTs permits operation with reduced power supply voltage and thus realization of low power dissipation circuits using this technology.

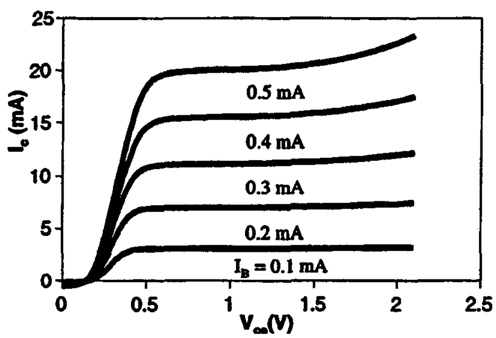

Fig. 1: DC characteristics of 5x10μm² InAlAs/InGaAs HBT used in Darlington feedback amplifiers

The high frequency performance of 5x10 μm² HBTs is shown in Fig. 2. As can be seen, the devices present a f_T of 90 GHz at V_{ce}=1.8V and I_c=18mA despite their thick collector design which was necessary for enhanced breakdown voltage characteristics. F_{max} is found to be 150GHz at the same biasing condition.

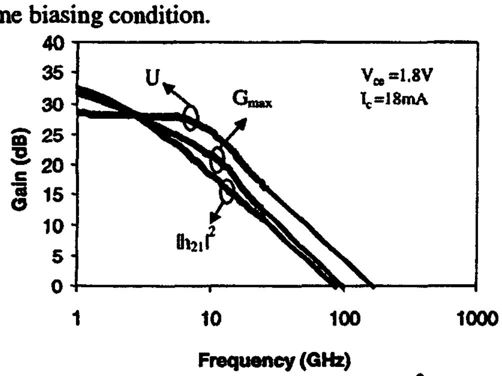

Fig. 2: Microwave Performance of 5x10 μm² InAlAs/InGaAs HBT used in Darlington feedback amplifiers

Fig. 3 shows the DC bias dependence of the microwave characteristics of the InAlAs/InGaAs HBTs. The HBTs were biased at Vce=1.6 V with different collector current levels. As can be seen, f_T and f_{max} remain relatively high over a wide bias range and therefore provide a robust design margin for MMICs using the developed HBT technology.

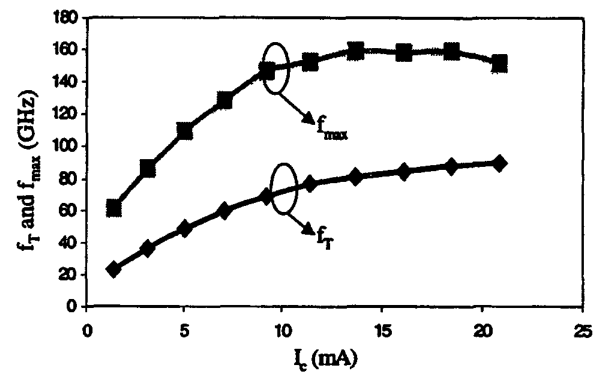

Fig. 3: f_T and f_{max} performance as a function of collector current for 5x10μm² HBT (V_{ce}=1.6V).

Circuit Design

Two Darlington feedback amplifiers with different topologies, namely resistive biased and mirror biased, were designed and fabricated using 2x30 μm² HBTs. Feedback resistors with a value of 150 Ω were used to improve the bandwidth of the amplifiers. The circuits were designed to operate at the optimum f_T and f_{max} region of the HBTs.

Circuit photographs of the mirror biased and resistive biased Darlington amplifiers are shown in Fig. 4 and Fig. 5 respectively. The chip size for both amplifiers is 0.75×1.18 mm. As can be seen, coplanar transmission line technology was used in circuit design due to its simplicity for MMIC fabrication.

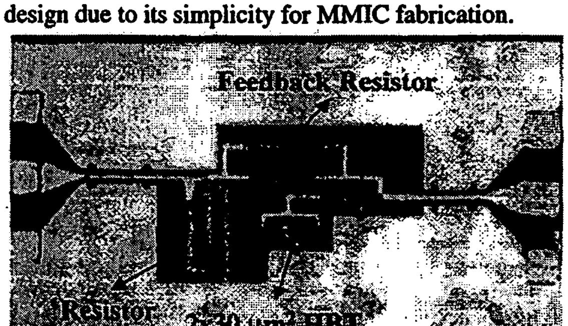

Fig. 4: Photograph of mirror biased Darlington Amplifier

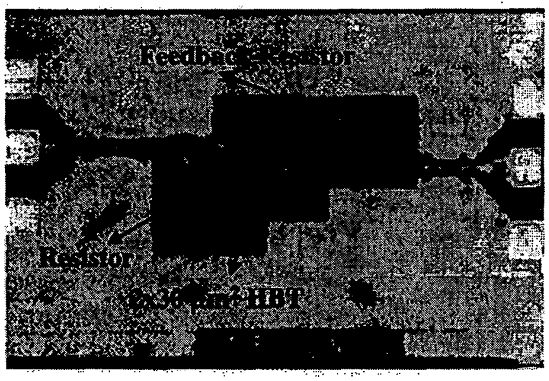

Fig. 5: Photograph of resistor biased Darlington Amplifier

Experimental Performance

Fig. 6 shows the small signal microwave performance of mirror biased feedback amplifiers along with its circuit diagram at a biasing current of 20mA and 30mA respectively. A Gain of 14.2dB and bandwidth of 17 GHz were achieved at I_{bias}=20mA while a gain of 15.2dB and bandwidth of 16.5GHz were achieved at I_{bias}=30mA. S_{11} and S_{22} less than -12 dB were measured from DC to 26 GHz.

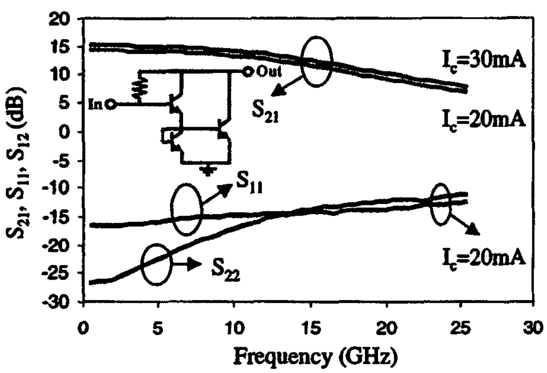

Fig. 6: Measured S-parameters for mirror biased Darlington feedback amplifiers

The small signal microwave performance of resistive biased Darlington feedback amplifiers is shown in Fig. 7 at a biasing current of 20mA and 30mA respectively. At I_{bias}=20mA, the feedback amplifier achieved 12.1dB gain with 23 GHz bandwidth while at I_{bias}=30mA, it shows 14.7dB gain with 20.7 GHz bandwidth. From DC to 26 GHz, S_{11} was less than −17dB and S_{22} was less than −13 dB for the resistive biased feedback amplifier.

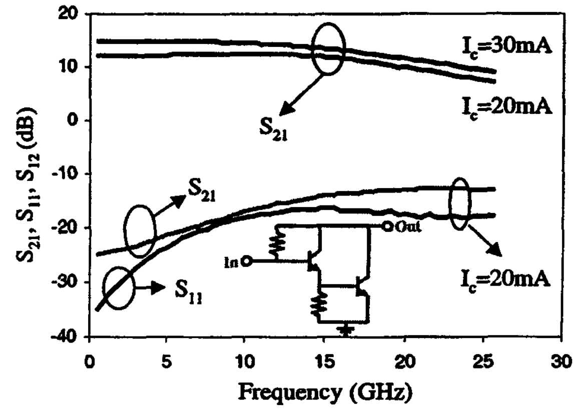

Fig. 7: Measured S-parameters for resistor biased Darlington feedback amplifiers

Fig. 8 shows the gain/bandwidth performance of both Darlington feedback amplifiers as a function of DC power consumption. As can be seen, for both amplifiers, the gain increases as the DC power increases. The bandwidth manifests a peak value at certain DC power consumption and then decreases as the DC power increases. As an example, for the resistive feedback amplifier, the gain increases from 10.95dB at P_{DC}=34.7mW to 15.5dB at P_{DC}=96mW, while the bandwidth decreases from 25.5GHz to 20 GHz.

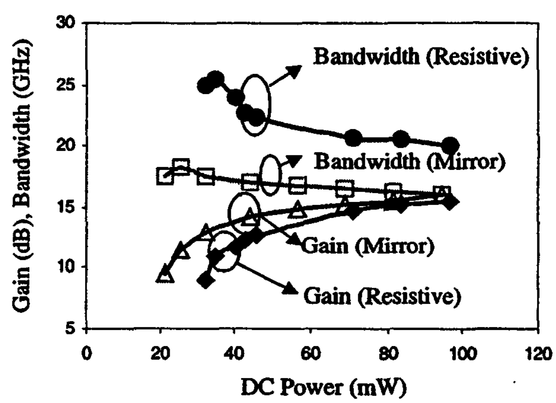

Fig. 8: Gain and bandwidth performance as a function of DC power consumption for resistive and mirror biased Darlington feedback amplifiers

Fig. 9 shows the Gain-Bandwidth-Product per DC power figure-of-merit (GBP/P_{DC}) as a function of DC power consumption for both resistive biased and mirror biased Darlington feedback amplifiers. As can be seen, the resistive Darlington amplifier achieved a GBP/P_{DC} of 2.60GHz/mW at DC power consumption of 34.7mW while the mirror biased Darlington amplifier achieved 2.66GHz/mW at DC power of 26.6mW. Both values are comparable or better than the previously reported state-of-art figures, such as 2.26GHz/mW [4] for InP-based HBTs, 2.54GHz/mW [5] for Si-Ge HBTs and 2.33GHz/mW for GaAs-based HBTs [6].

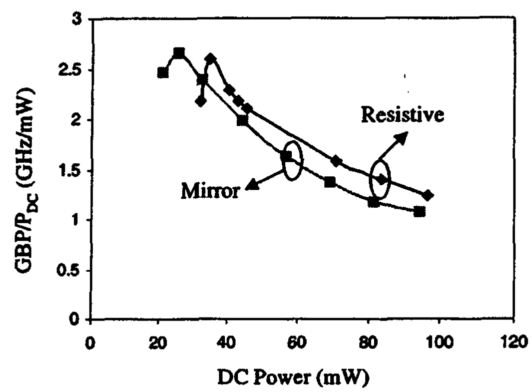

Fig. 9: Gain-Bandwidth-Product per dc power (GBP/P_{DC}) as a function of DC power consumption for resistive and mirror biased Darlington amplifiers

Fig. 10 shows the results of the large signal evaluation of the mirror biased Darlington amplifiers at 10GHz. As can be seen from this figure, at a DC power consumption of 40mW, an output power of 8.3dBm was achieved at 1dB-compression. For a higher DC power of 75mW, the output power was 9.5dBm. The low DC power consumption (40mW) reported here is due to the low offset-voltage and low knee voltage achieved by using graded InAlGaAs layer to eliminate the base-emitter conduction band spike.

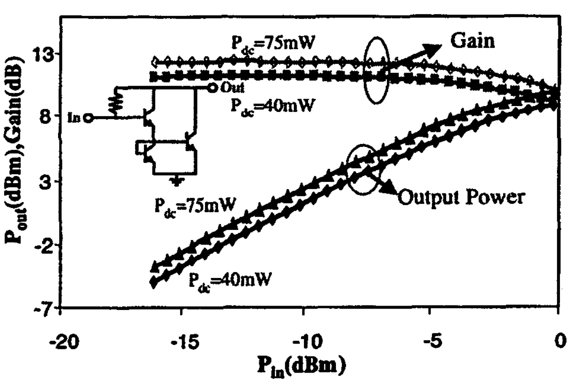

Fig. 10: Power performance for mirror biased feedback amplifier

Conclusion

In this study, InAlAs/InGaAs single HBTs with low knee voltage and high breakdown voltage have been employed to design and fabricate broad band amplifiers using Darlington feedback topologies. Successful operation of the developed HBT technology for moderate output power, high Gain×Bandwidth applications have been demonstrated. State-of-art Gain-Bandwidth-Products per DC power (GBP/P_{DC}) were achieved for the resistive biased (2.60GHz/mW) and mirror biased (2.66GHz/mW) feedback amplifiers. At DC power consumption of 40mW, the fabricated Darlington amplifiers demonstrated 8.3mW of output power at 10GHz.

Acknowledgements

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Reference

[1]. S. Kimural, Y. Imai, and Y. Miyamoto, "Direct-Coupled Distributed Baseband Amplifier IC's for 40-Gb/s Optical Communication", IEEE J. Solid State Circuits, Vol. 31, pp. 1374-1379, 1996

[2]. K. W. Kobayashi, L. T. Tran, J. Cowles, T. R. Block, A. K. Oki and D. C. Streit, " Low DC Power Hign Gain-Bandwidth Product InAlAs/InGaAs HBT Direct-Coupled Amplifiers", IEEE GaAs IC Symp., pp. 141-144, 1996.

[3]. K. W. Kobayashi, J. Cowles, L. T. Tran, T. R. Block, A. K. Oki and D. C. Streit, "A 2-50 GHz InAlAs/InGaAs-InP HBT Distributed Amplifier", IEEE GaAs IC Symp., pp. 207-210.

[4]. R. K. Montgomery, D. A. Humphrey, P. R. Smith, B. Jalali, R. N. Nottenburg, R. A. Hamm, and M. P. Panish, "A DC to 20 GHz High Gain Monolithic InP/InGaAs HBT Feedback Amplifier", IEEE IEDM, pp. 36.5.1-36.5.4, 1991.

[5]. H. Schumacher, A. Gruhle, U. Erben, H. Kibber, and U.Konig, "A 3V Supply Voltage, DC-18GHz SiGe HBT Wideband Amplifier", IEEE BCTM Dig., pp. 190-193, 1995.

[6]. Y. Suzuki, h. Shimawaki, Y. Amamiya, N. Nagano, T. Niwa, H. Yano, and K. Honjo, "50-GHz-Bandwidth Baseband Amplifiers Using GaAs-Based HBTs", IEEE J. Solid State Circuits, Vol. 33, pp. 1336-1340, 1998.