Common Base Amplifier with 7- dB gain at 176 GHz in InP mesa DHBT Technology

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***Abstract* — We report common base power amplifiers designed for 140-220-GHz frequency band in InP mesa double heterojunction bipolar transistor (DHBT) technology. A single stage common base tuned amplifier exhibited 7-dB small-signal gain at 176 GHz. This amplifier demonstrated 8.77 dBm output power with 5-dB associated power gain at 172 GHz. Two-stage common base amplifier exhibited 8.1 dBm output power with 6.35 dB associated power gain at 176 GHz and demonstrated 9.13 dBm of saturated output power. This two stage common base amplifier exhibited 10.3 dBm output power with 3.48-dB associated power gain at 150.2 GHz.**

***Index Terms* — InP heterojunction bipolar transistor, millimeter-wave amplifier, MMIC amplifiers.**

I. Introduction

G-Band (140-220 GHz) amplifiers have applications in wide-band communication systems, atmospheric sensing and automotive radar. High electron saturation velocity of InP material system and deep submicron scaling result in wide-bandwith transistors with high available gain in this frequency band. In a transferred substrate InP HBT process, 6.3 dB gain is reported at 175 GHz with a single stage amplifier [1]. State-of-the-art results in InP HEMT technologies include a three stage amplifier with 30-dB gain at 140 GHz [2], a three stage amplifier with 12-15-dB gain from 160-190 GHz [3], and a three-stage power amplifier with 10-dB gain from 144-170 GHz [4].

Recent work in scaled InP/InGaAs/InP mesa DHBT with 30 nm Carbon-doped InGaAs base with graded base doping, and 150 nm of total depleted collector thickness achieved wide-bandwidth transistors with 370 GHz ft and 459 GHz fmax [5][6]. In this paper, we describe how this technology is used to realize several power amplifiers in 140-220-GHz frequency band.

II. InP Mesa DHBT Process

The transistors in the circuit are formed from an MBE layer structure with a highly doped 35 nm InGaAs base and 210 nm collector and are fabricated in a triple mesa process with both active junctions defined by selective wet etch chemistry. The increased collector thickness is intended to increase f_{max}. Polyimide passivates and planarises the devices. One level of metal deposition is used for circuit interconnects and making the electrical contacts to the transistors and resistors. SiN metal-insulator-metal (MIM) capacitors and coplanar waveguide transmission lines are employed to synthesize the tuning elements. Low parasitic plated airbridges are used to bridge the ground planes.

III. Amplifier Design and measurements

A. Device Modeling and Simulations

The Spice model parameters for the transistors used in the simulations are extracted using measured two-port S-parameters. The simulations of the amplifiers are performed using Agilent Technologies Advanced Design System software. A planar method-of-moments EM simulator (Momentum) is used to model the coplanar waveguide structures and the MIM capacitors.

B. Device results

The common base breakdown voltage ($V_{br,cb0}$) is more than 7V. The fabricated devices have shown 240 GHz f_t and 290 GHz f_{max} when the devices are biased at 3mA/μm^2 current density and 1.7V V_{ce}. The degradation in f_{max} relative to [5] is due to larger base mesa intended to improve yield and relatively poor base ohmic contacts in this process run.

C. Layout Parasistics and Their Influence

The Common base topology is chosen as it has higher MSG in this band when compared to common emitter and common collector topologies. However, layout parasitics including base inductance (L_b) and collector to emitter overlap capacitance (C_{ce}) severely reduce MSG and, if not modeled in the designs could potentially cause instability. Base inductance is due to the thin long base stripes on either side of the emitter. Lack of accurate models to predict L_b create an uncertainty in the stability analysis. Collector to emitter overlap capacitance (C_{ce}) through the polyimide dielectric is process variant as the thickness of the polyimide passivation layer is dependent on the polyimide etchback process which cannot be controlled accurately. Potential instability in the small-signal characteristics due to L_b and C_{ce} was observed in the first generation amplifier measurements. In second generation designs, the collector to emitter overlap capacitance was significantly reduced by employing single-sided collector contacts as opposed to double-sided collector contacts. This increases the collector resistance and thus, improves circuit stability. NiCr resistors are used to stabilize the amplifiers further.

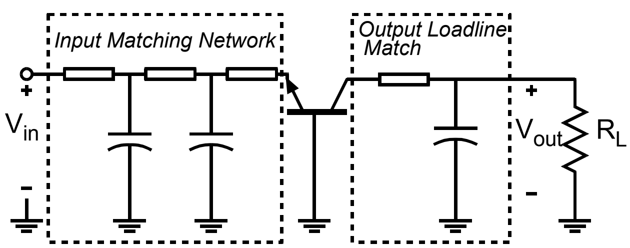

Fig. 1. Circuit Schematic of single-stage common base amplifier.

The circuit schematic of the single stage amplifier is shown in fig. 1. Shunt capacitors are either SiN_x MIM capacitors or CPW open circuit stubs. Two stage amplifiers (Fig. 2) are designed by cascading two identical single stage designs depicted in fig. 1. The output of the first stage is large signal matched avoiding premature power gain compression in the first stage.

D. G-band Small-signal Measurements

The amplifiers are measured on wafer in the G-band. The measurements are made using an HP 8510C VNA with Oleson Microwave Labs Millimeter Wave VNA extensions. The test-set extensions are connected to GGB Industries coplanar wafer probes via WR-5 waveguides. The amplifier measurements are calibrated using off-wafer TRL calibration kit.

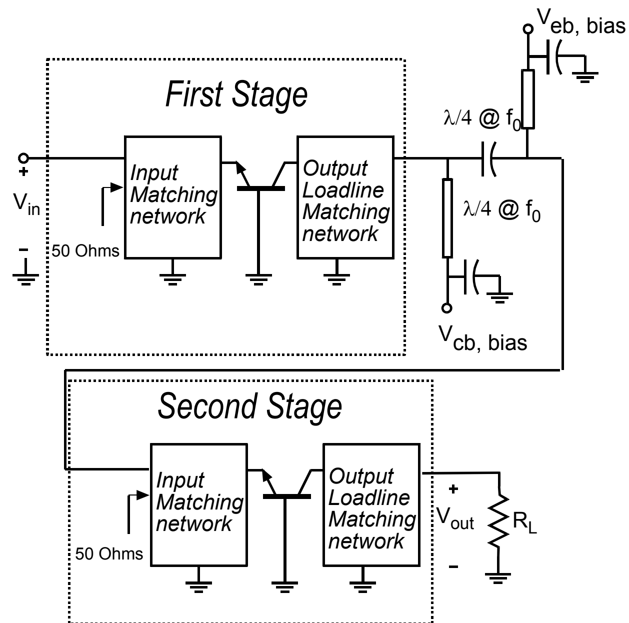

Fig. 2. Circuit Schematic of two-stage common base amplifier.

E. Power Measurements in 170-180-GHz Band

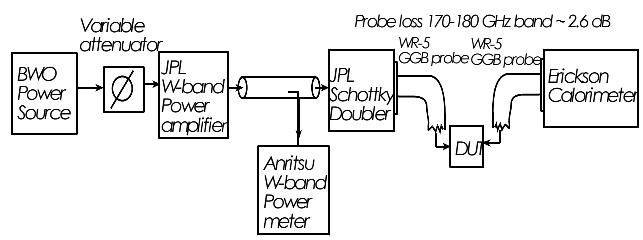

Fig. 3. Power measurement setup in 170-180 GHz band.

Power measurements in G-band are performed at JPL. The measurement setup for 170-180 GHz power measurements is shown in Fig. 3. W-band power from a BWO power source is amplified and the frequency is doubled using a JPL Schottky frequency doubler. The Schottky frequency doubler output drives the input of the power amplifier. The output power is measured using an Erickson calorimeter. Because the input and output power are measured separately, the saturated power gain measurements are subject to approximately ±1-dB drift in gain. The saturated output power measurement is not subject to this drift, and we estimate the output power data is accurate to ±0.5-dB. Data is corrected for measured probe losses.

E. Power Measurements in 148-152 GHz Band

The setup for 148-152 GHz measurements is shown in Fig. 4. A 150 GHz Gunn oscillator drives the input power amplifier. A variable attenuator adjusts the input power.

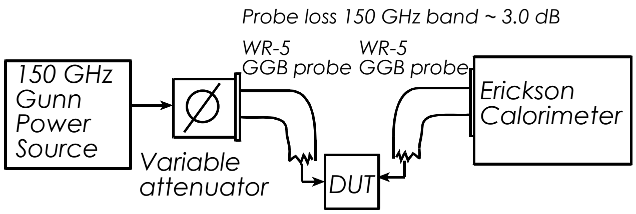

Fig. 4. Power measurement setup in 148-152 GHz band.

III. Amplifier Results

A. Single Stage Common Base Power Amplifier

A chip photograph of a fabricated single-stage amplifier is shown in Fig. 5.The transistor used in the amplifier consists of two separate 0.8 μm X 12 μm fingers. The input matching network is designed for high bandwidth. The output of the transistor is large signal load-line matched for maximum saturated output power as opposed to a small signal match for maximum gain. The amplifier exhibited 7-dB small signal gain at 176 GHz when biased at I_c = 30 mA and V_{cb} = 1.0V. (Fig. 6)

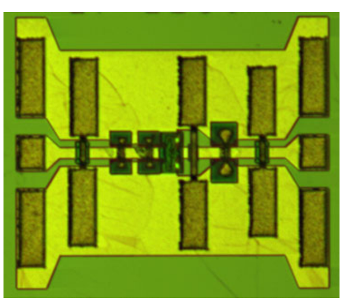

Fig. 5. Chip photograph of the single stage common base MMIC amplifier measuring 0.36 mm X 0.3 mm.

This power amplifier is designed to obtain 16.5 dBm saturated output power at 180 GHz, when biased at I_c = 30 mA and V_{cb} = 2.5V. The output power vs. input power characteristic is shown in fig. 7. The amplifier exhibited a saturated output power of 8.77 dBm with an associated power gain of 5-dB at 172 GHz when biased at I_c= 40 mA and V_{cb} = 2.06V. The circuit exhibited 7.9 dB low power gain under the above conditions at 172 GHz. Measured S-parameter data exhibits potential instablility in 140-170-GHz band due to feedback parasitics L_b and C_{ce} and process variations.

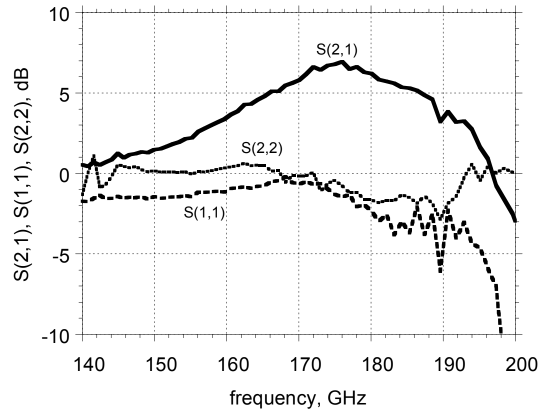

Fig. 6. Measured S-parameters of the single stage amplifier.

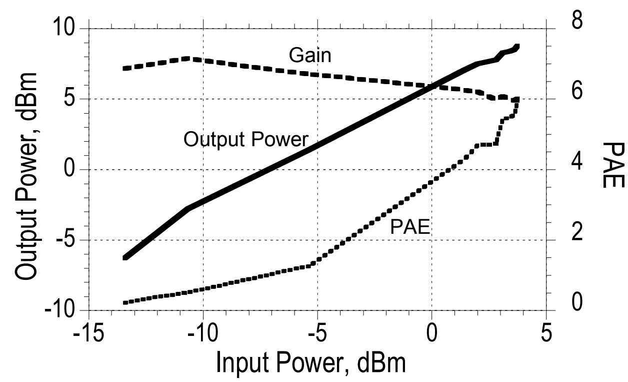

Fig. 7. Output power, PAE vs. input power of the single stage common base power amplifier .

B. Two Stage Common Base Power Amplifier

A chip photograph of the two stage amplifier is shown in Fig. 8. This power amplifer is a cascaded version of two individual common base power amplifiers designed for 50Ω input resistance and 50Ω load. Each stage employs two separate 0.8 μm X 12 μm HBT fingers. The small-signal measurements are performed with the first stage biased at I_c=25 mA, V_{cb}=1.0V and the second stage is biased I_c=30 mA, V_{cb}=1.0V. Small-signal measurements indicate 7-dB gain at 176 GHz and 13-dB gain at 150 GHz. There is a potential instability in S(2,2) in 140-150 GHz range. (Fig. 9)

This amplifier exhibited 8.1 dBm output power with 6.35 dB associated power gain at 176 GHz and demonstrated 9.13 dBm of saturated output power (Fig. 10). These measurements are performed when the first stage is biased at I_c=45 mA, V_{cb}=2.05 V, and the second stage is biased at I_c=49 mA, V_{cb}=1.84V. At 150.2 GHz, the power amplifier exhibited 10.32 dBm output power with 3.48-dB associated power gain (Fig. 11). The first stage is biased at I_c=40 mA, V_{cb}=2.04V and the second stage is biased at I_c= 51 mA, V_{cb}=2.11V. Low power gain at 150.2 GHz is 9.23-dB.

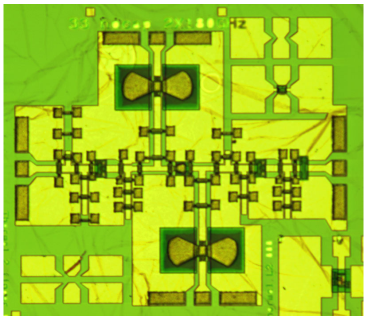

Fig. 8. Chip photograph of a two stage common base MMIC amplifier measuring 1mm X 0.7 mm.

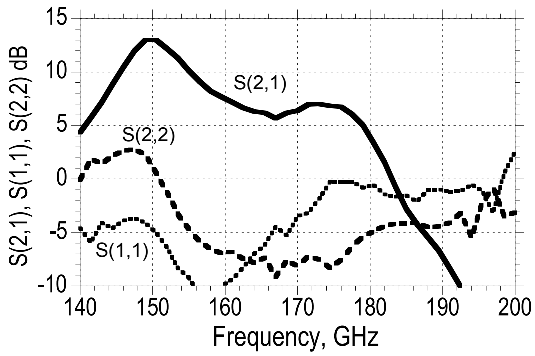

Fig. 9. Small-signal measurements of the two stage Common base power amplifier.

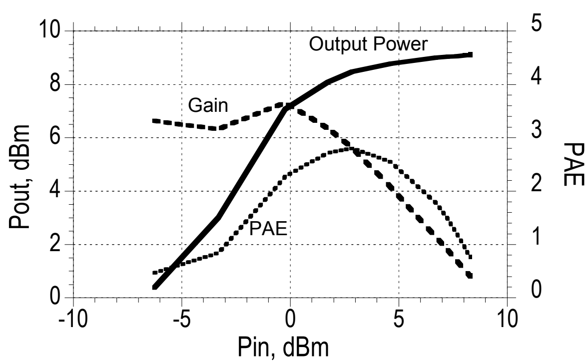

Fig. 10. Power measurements of the two stage Common base power amplifier at 176 GHz.

IV. Conclusions

Common base high gain G-band power amplifiers in InP mesa DHBT technology are presented. A single stage common base tuned amplifier exhibited 7-dB small-signal gain at 176 GHz. This amplifier demonstrated 8.77 dBm output power with 5-dB associated power gain at 172GHz. A two-stage common base amplifier exhibited 8.1 dBm output power with 6.3 dB associated power gain at 176 GHz and demonstrated 9.1 dBm of saturated output power. This amplifier exhibited 10.3 dBm output power at 150.2 GHz. Feedback parasitics, L_b and C_{ce} created potential instability in the existing designs. Improved device performance and accurate modeling of the feedback parasitics would result in superior power amplifier performance. This result demonstrates the potential of InP DHBT technology for high performance ultra-high-frequency millimeter-wave circuit applications.

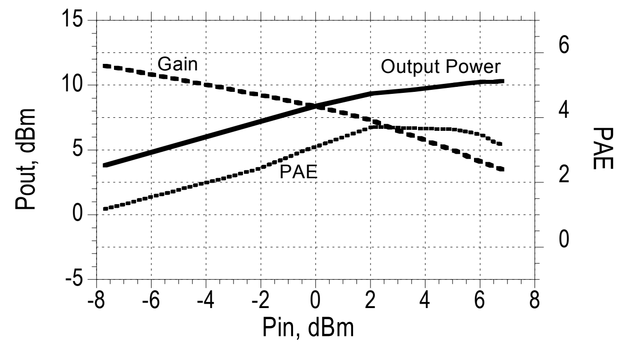

Fig. 11. Power measurements of the two stage Common base power amplifier at 150.2 GHz.

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