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255-GHz InP HBT Power Amplifiers Using Custom-designed Two-finger Devices

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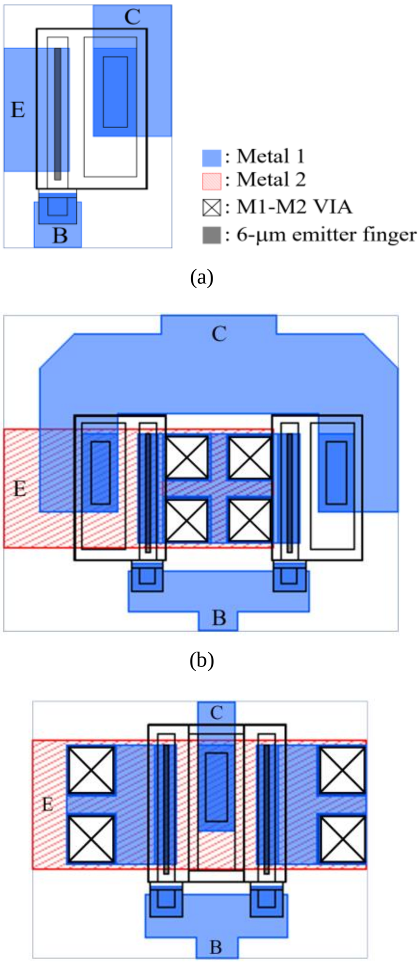
Abstract - **This paper investigates the possible advantages in using two-finger InP heterojunction bipolar transistors (HBT) for WR-3.4 (220 GHz – 320 GHz) power amplifiers (PA). The two-finger HBT is designed by combining two 6-µm emitter length single-finger HBTs provided by Teledyne. Expected performances of two versions of two-finger device are simulated. One is designed with two separate isolation layers and the other one with single joined isolation layer. Both two-finger devices have better power performance but shows poor f_{max} and MAG compared to a single-finger device. Two PA designs in common-base differential configuration utilizing two types of custom two-finger devices are fabricated. The joined-isolation-device PA shows better performance with the peak gain of 10.5 dB at 255 GHz and P_{1dB} and P_{sat} of -1.7 dBm and 5.2 dBm while the separated-isolation-device PA shows peak gain of 4.6 dB at 255 GHz and P_{1dB} and P_{sat} of -8.5 dBm and 4.4 dBm.**

Keywords—**Multi-finger HBT devices, Terahertz power amplifiers, WR-3.4 integrated circuits**

I. INTRODUCTION

Power amplifiers are the most important component for most radio frequency systems and often placed in the final stage of the transmitter to provide high transmit power [1]. The performance of the communication systems is mainly determined by the output power of the RF chain. Increasing the maximum output power of an amplifier has been an important issue. Teledyne presented PA that produces 180mW of output power at 214 GHz using common-emitter and common-based HBTs in a cascode topology, with 4-fingers x 6-µm for each device [2]. The physical size of this PA is 2.51 mm x 2.22 mm which is taking up a huge chip area. Broadband and high-gain power amplifiers working in the 180-265 GHz range with 17-24 dBm output power [3] and PA exhibiting a maximum output power of 13.5 dBm at 301 GHz [4] have been also demonstrated.

In 2012, a two-finger common-base device and a four-finger common-emitter device, both with the total device periphery of 24 µm were examined for high-power amplifiers operating above 200 GHz [5]. Compact four-way combiners combining powers from four-finger devices in common-base configurations obtained 16.8 dBm at 270 GHz [6].



(a)

(b)

(c)

Fig. 1. Layouts for three types of 6-µm HBT devices; (a) standard single-finger device (b) separated isolation-layer device (c) joined isolation-layer device

Communications application requires up to 200mW of transmitter power, which still requires a great deal of research and development efforts. As a first step toward this goal, our internal research goal to design a single PA chip to produce 25mW of output power using very small chip area. Single finger HBT device only produces 5mW, much less

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than the desired 25mW. The only way to improve the power amount is to employ the maximum numbers of fingers for a single device. In this paper, our initial investigation of two-finger device designs is presented.

II. CIRCUIT DESIGN

A. Two-Finger HBT Device Layouts

Fig. 1 shows three types of 6-µm HBT device layouts. The nonlinear device model used in our simulation is provided by Teledyne Scientific Company and it is compensated with extra parasitic components of 1 pH and 5.5 Ohm added to the base. The simulations results are obtained by combining the nonlinear device model together with s-parameter files from ADS Momentum analysis. The simulation was continued using a common base topology by grounding base. Two terminations are connected to emitter and collector. Fig. 2 demonstrates the simulated maximum available gain (MAG) plots and Fig. 3 shows the output power simulation results. TABLE I is the summary of the estimated figures of merit for three different devices in Figure 1, physical size, MAG, maximum frequency of oscillation (f_{max}), 1dB gain compression point (P_{1dB}), saturation output power (P_{max}).

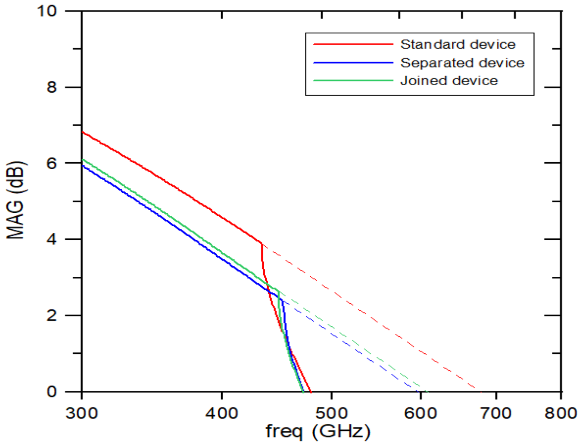


Fig. 2. Simulated maximum available gain (MAG) results for the three devices. -20dB/dec line is indicated by dashed lines.

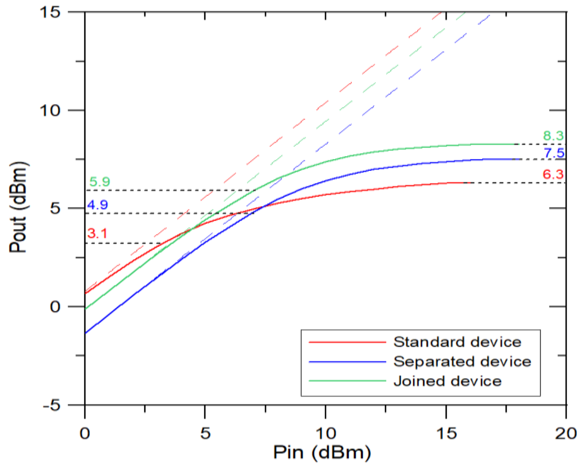


Fig. 3. Power simulation results for three different devices.

Standard single-finger device shown in Fig. 1 (a) is the basic single-finger device and has MAG of 8dB at 255GHz, where the gain of the power amplifier is the highest. f_{max} is 678GHz which is estimated by extrapolating the MAG data with a slope of -20dB/decade [7]. Standard single-finger device shows highest MAG and f_{max}. The physical size is 6um x 11um, which is the smallest among these four devices. P1dB is 3.1dBm and Pmax is 6.3dBm.

Two types of two-finger device layouts are illustrated is Fig. 1 (b) and (c). Separated isolation-layer device in Fig. 1 (b) is designed by simply connecting two single-finger HBTs. With physical size of 19-µm x 16-µm, MAG and f_{max} are 7.2dB and 596GHz. Due to additional via and line wiring each base, collector, and emitter, separated isolation device shows MAG and f_{max} lower than standard device. P_{1dB} is 4.9 dBm and P_{max} is 7.5 dBm which is higher than standard device.

Joined isolation-layer device in Fig. 1(c) is designed by sharing collector of two single-finger HBTs making custom two-finger device. With size of 15 µm x 12 µm, each MAG at 255 GHz and f_{max} are 7.4 dB and 608 GHz. Joined isolation device shows similar performance with device B in MAG and f_{max}. P_{1dB} is 5.9 dBm and P_{max} is 8.3 dBm which is highest among three device interconnections. Power performance of the joined isolation device appears best because it has low parasitic components.

TABLE I. Figures of merit for three devices using nonlinear HBT model

Device	Physical Size (µm x µm)	MAG at 255GHz (dB)	f_{max} (GHz)	P_{1dB} (dBm)	P_{sat} (dBm)
Standard Device	7 x 11	8	678	3.1	6.3
Separated Isolation Device	20 x 16	7.2	596	4.9	7.5
Joined Isolation Device	16 x 12	7.4	608	5.9	8.3

B. Two-stage Amplifier Designs using Custom Devices

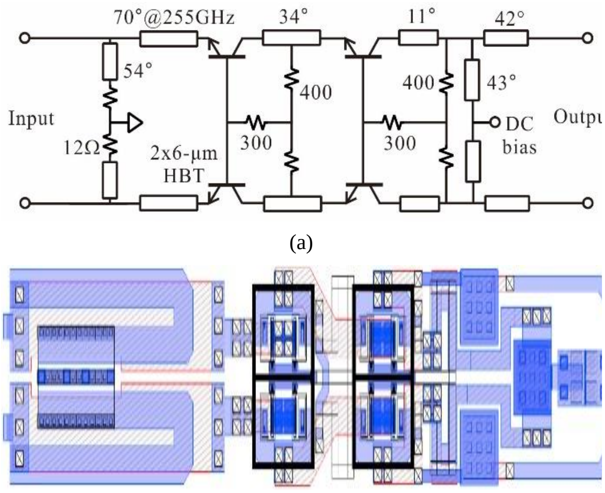
The layout for the common-base power amplifier differential chain is shown in Fig. 4. Separated isolation device and joined isolation device are to be placed in the black box in the same amplifier chain design. In this paper, PA design using separated isolation device is called 'Separated PA' and PA using joined isolation device is called 'Joined PA'. Both PAs are designed with common-base configuration and each collector is self-biased. Devices are in two-stage to increase gain and output power. Fig. 5 is the photograph of the fabricated PA chip, and the physical size of the whole PA chip size is 587 µm x 270 µm. The bias voltage is 4V for both separated PA and joined PA. A balun is attached on both ends of the circuit to convert the differential feed into a single-end RF probe pad and vice versa. In small-signal simulation shown in Fig. 5, separated PA shows peak gain (S_{21}) of 4.4 dB at 260 GHz and joined PA shows peak gain of 12 dB at 260 GHz.

.III. POWER AMPLIFIER PERFORMANCE

A. Small-signal Performance

The measured and simulated small-signal S_{21}, S_{11} and S_{22} plots for separated and joined PA are illustrated in Fig. 6. The bias voltage for separated PA is 3.9 V and current is 41 mA. In measurement, separated PA shows peak gain (S_{21}) at 255 GHz, and the value is 4.6 dB and there is no oscillation.

The bias voltage for joined PA is 4V and current is 39 mA. The measured peak gain is 10.5 dB at 255 GHz, which is 6dB higher than that of the separated PA. The peak frequency is down shifted 5 GHz compared to the simulation results. There is no oscillation in both separated and joined PA since S_{22} doesn't exceed 0dB. The reflection coefficient S_{22} is worse than the separated PA.



(a)

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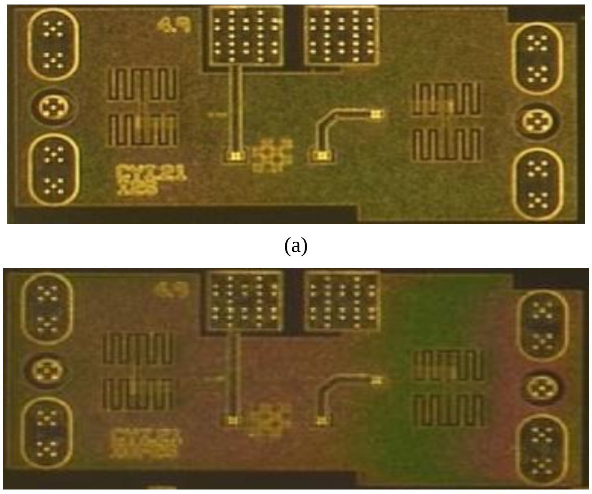
Fig. 4. Two-stage common-base PA differential chain (a) circuit schematic and (b)layout. The four boxes represent the locations for two-finger devices.



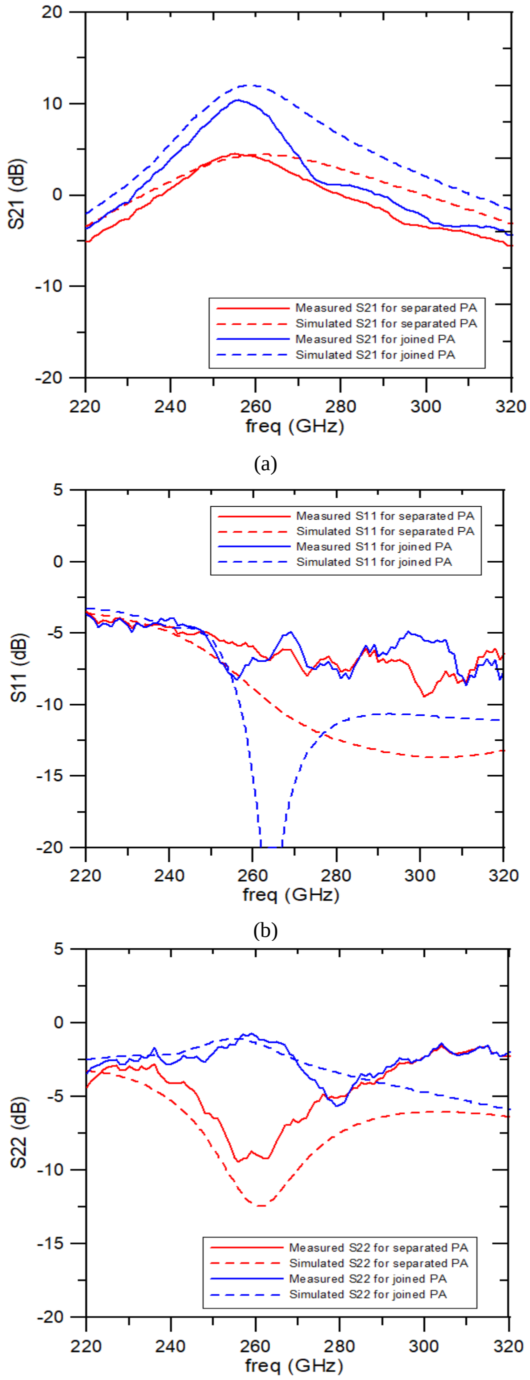
(a)

(b)

Fig. 5. Photograph of fabricated PA chip (a) using separate-isolation and (b) using joined-isolation devices.

B. Power Performance

Fig. 7 shows the nonlinear power measurement setup. VDI PM4 power meter measures the output power and 1-inch WR-10 waveguide is attached. Cascade WR-3.4 RF probe loss is around 3 dB which is estimated with the datasheet provided by Cascade. The loss includes 0.1dB for 1-inch WR-10 waveguide, 0.4 dB for WR3-to-WR10 waveguide transition, and 1.3 dB for 2-inch WR-3.4 waveguide.



(a)

(b)

(c)

Fig. 6. Small-signal performances of the PA's using two types of devices; (a)S_{21} (b)S_{11} (c)S_{22}

In advance of analyzing output power measurement results, we need to examine the accuracy of the loss estimation. The power gain is estimated by subtracting input power from output power. P_{in} of -12 dBm is already causing output power compression. As shown in Fig. 7, the measured gain using the power setup gives similar results as the network analyzer gain. Thus, the loss estimation is accurate, and the power measurement results shown in Fig. 8 are reliable.

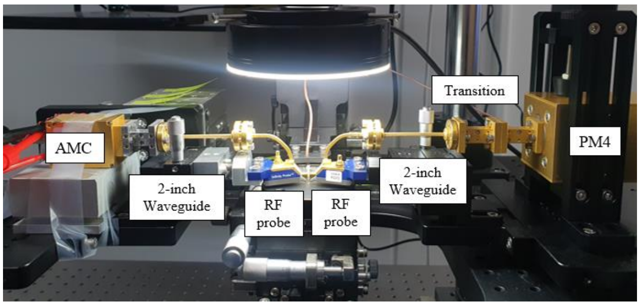


Fig. 7. Photograph of the nonlinear power measurement setup.

The output power and gain for separated PA and joined PA are plotted in Fig. 9. This measurement was carried out at 255 GHz where separated PA and joined PA show highest gain. The gain is calculated by subtracting input power from output power shown in Fig. 9 (b). The gray dashed lines represent 10dB/dec where power saturation has not occurred. The 1 dB gain compression point (P_{1dB}) for separated PA and joined PA is -8.3 dBm and -1.9 dBm respectively. P_{1dB} is the output power when the difference between gray dashed line and measured P_{out} line is 1 dBm. Both separated and joined PA show low P1dB due to early saturation. P_{sat} is 4.4 dBm for separated PA and 5.2dBm for joined PA. Joined PA shows better P_{1dB} and P_{sat} and linearity is improved compared to separate PA.

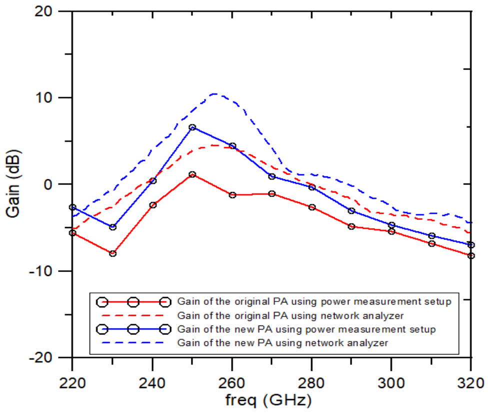
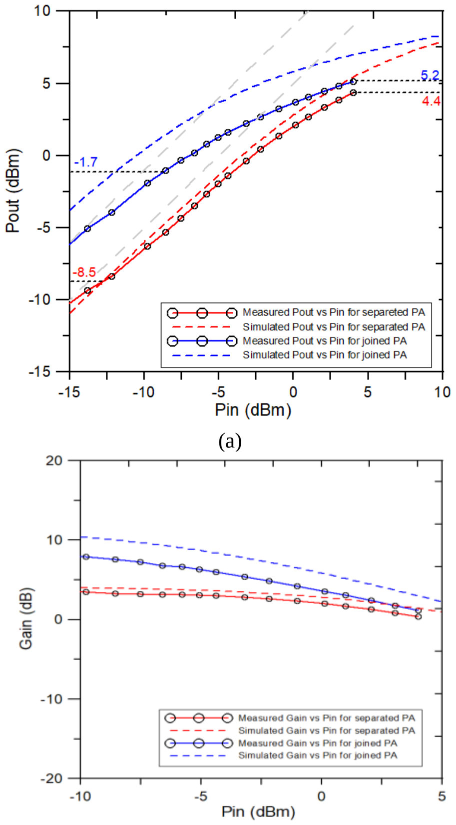


Fig. 8. Measured gains using network analyzer (dashed line) and power measurement setup (solid line). The power setup uses -12 dBm of input power.

TABLE II. Summary of the PA performance comparison

Device type	Peak gain (dB)	P_{1dB} (dBm)	P_{sat} (dBm)
Separated	4.6	-8.5	4.4
Joined	10.5	-1.7	5.2



(a)

(b)

Fig. 9. Output power and the gain for separated PA (red) and joined PA (blue) at 255 GHz (a) Pout vs Pin (b) Gain vs Pin

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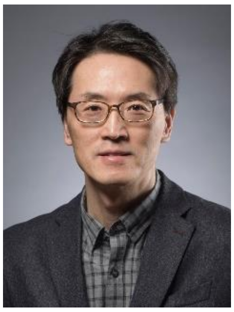

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