0.7 W X–Ku-Band High-Gain, High-Efficiency Common Base Power HBT

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Abstract—**Small sized AlGaAs–GaAs HBT's have achieved excellent power performance throughout the microwave frequency band. With the implementation of the multi-via -hole design, the HBT performance (gain and efficiency) is maintained as the size increases. A 0.7 W common-base (CB) power HBT with performance around 10 dB gain and 50% PAE well into the Ku band is reported. The performance is comparable to the pseudomorphic HEMT in this frequency range. The yield and uniformity are excellent. The high bias voltage (9.3 V V_{ce}) is also strongly desired from system viewpoint.**

I. Introduction

SMALL sized AlGaAs–GaAs HBT's have achieved excellent power performance throughout the microwave band [1], [2]. 68% PAE has been achieved with 0.23 W CW power and 11.3 dB gain at 10 GHz. 47% PAE has been achieved with 0.22 W CW power and 11 dB gain at 18 GHz. Multiwatt output power was reported also at 10 GHz [3]; however the gain and the PAE are lower, around 6 dB and 30%.

The general characteristics of both CE and CB HBT's, such as *S* parameters and stability, were discussed in detail in [1]. From [2] it was found that CB HBT has higher gain into Ku band than CE HBT; and the efficiency and the power density are the same for both configurations (this is also true to the Si bipolar transistor). Therefore, the common base HBT is chosen as the building block for X–Ku-band power application.

A multi-via-hole layout is adopted to minimize the grounding inductance in the HBT. The CB HBT has an emitter junction area of 360 μm^2. At 10 GHz, 0.65 W was achieved with 10 dB gain and 56% PAE. The same device achieved 0.62 W, 9.9 dB gain and 47.7% PAE at 16 GHz. The V_{cb} is biased at 8 V. The HBT size is 500 μm × 400 μm.

The CB HBT power performance at X and Ku bands is better than any other reported power HBT [3] at the same power level; and is comparable to the best 0.25-μm gate PHEMT [4]. The high bias voltage (9.3 V V_{ce}) and the high RF yield (60–90%) makes the power HBT even more attractive.

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II. HBT Device and Layout

The HBT is made by the "dual lift-off" process [5]. Two metal layers are provided for interconnection. The substrate is lapped down to 3 mils thick and through substrate via holes are made to ground the HBT. The collector is 0.7 μm long and the BV_{cbo} is 20 V. Quarters of 3″ wafers were processed.

The HBT is composed of multiple cells. Each cell has two emitter fingers of the size 2 × 10 μm^2, giving a total emitter junction area of 40 μm^2. Each cell is capable of providing 70–80 mW CW power. The power HBT has 9 cells, making the total junction area 360 μm^2. Every three cells are connected to a via hole to minimize the grounding inductance. The cell spacing is chosen based on thermal consideration. The goal is to control the temperature rise below 100°C. The cells are then interconnected to the bonding pads. Only one bonding pad for input/output was used. The layout is shown in Fig. 1.

The physical dimension of the HBT is within the dephasing limitation. The multi-via-hole approach reduces the grounding inductance and maintains the performance. The limiting factor on the HBT size is the input impedance. Low loss matching with micostrip line requires the minimum impedance level to about 1 ohm. The 9-cell HBT has 1.5 ohm input impedance.

The HBT current gain is usually between 10 and 30. The BV_{cbo} is 20 V and the BV_{ceo} is about 13 V. The small signal gain was measured with the RF probe and showed excellent uniformity in Fig. 2. The f_{max} is about 100 GHz. The small signal gain of the 9-cell HBT is the same as HBT's of 120-μm^2 and 240-μm^2 emitter junction size. The MSG is 22 dB at 10 GHz and 18 dB at 18 GHz. The C_{cb} of the 360 μm^2 CB HBT is 0.32 pF. Preliminary load pull result indicates that the load resistance is about 45–50 ohms. The imaginary part of the load impedance is in conjugate matching to the HBT's output capacitance (within experimental uncertainty). The output Q is low enough allowing broadband power amplifier design and is in the same range of MESFET.

III. Power Performance

The CB power HBT's were tested at 10 and 16 GHz. The result is shown in Figs. 3 and 4. The HBT's were biased in class AB operation. The V_{cb} is biased at 8 V and V_{be} at 1.3 V. At 10 GHz 0.72 W CW power was achieved with 9.6 dB gain (1 dB compression) and 50.8% PAE. The highest PAE is 56.6% with 10.7 dB gain and 0.59 W output power.

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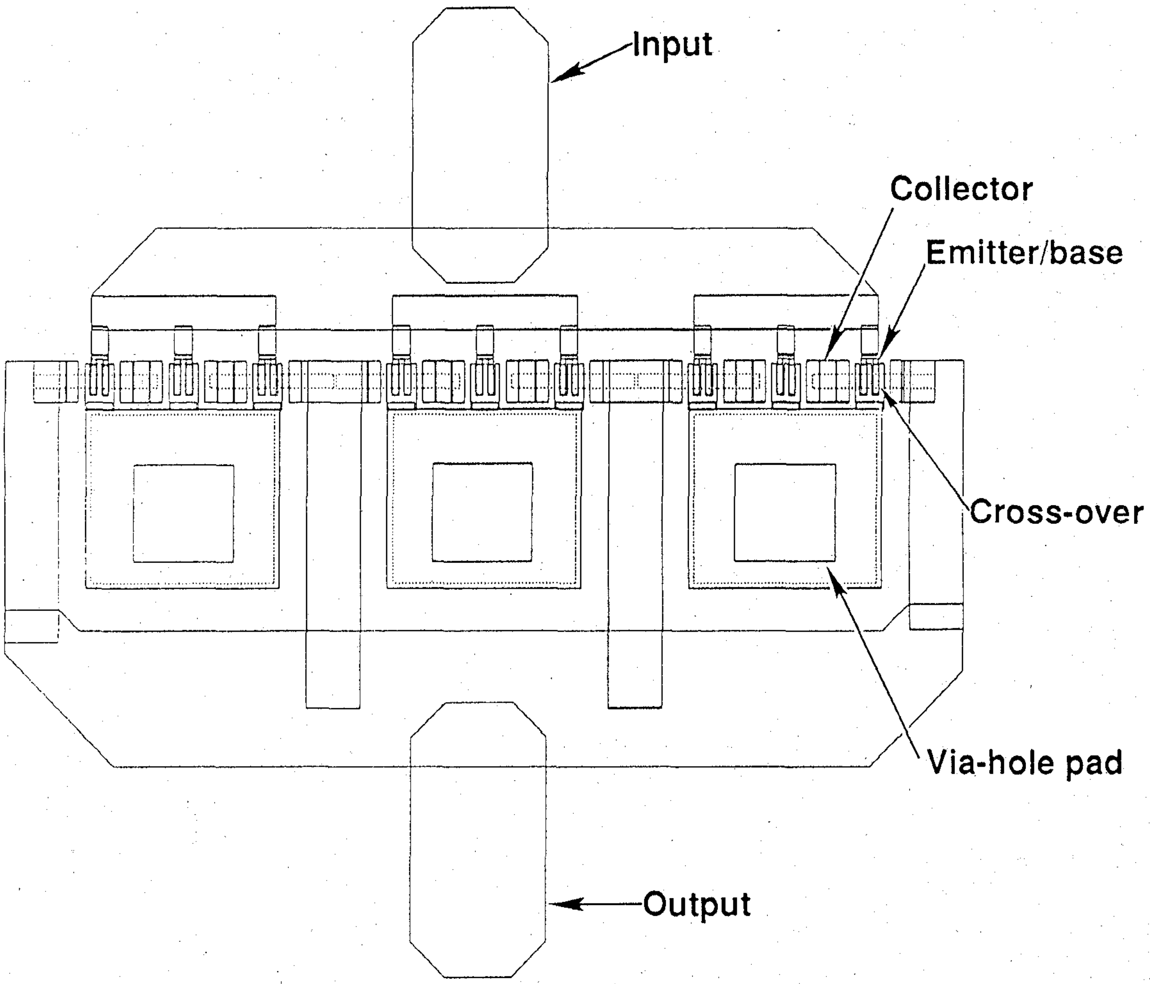

Fig. 1. 0.7 W CB power HBT layout. Three via holes are used. Only one feed is used for input/output. HBT size is 400 μm × 220 μm, and the chip size is 500 μm × 400 μm. CPW to microstrip line transitions are provided at both input and output for RF probe measurement.

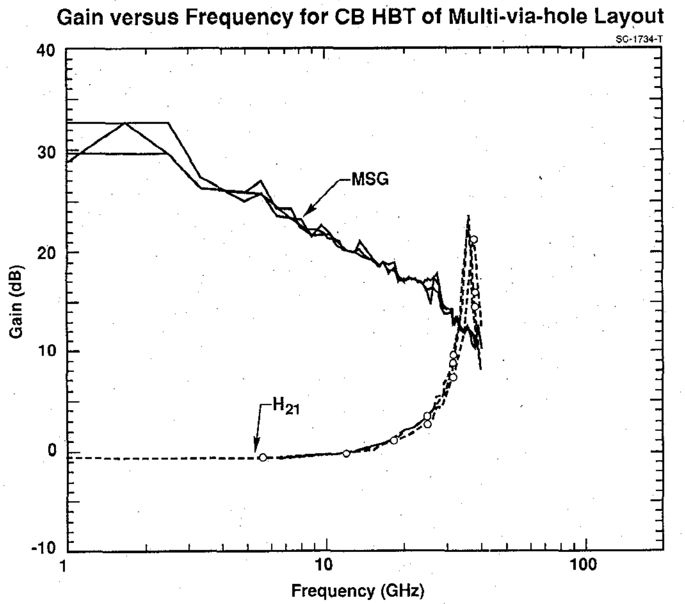

Fig. 2. Several CB HBT's were measured and showed excellent uniformity in the small signal gain. Rise of H_{21} at high frequency is caused by the output side parasitic inductance.

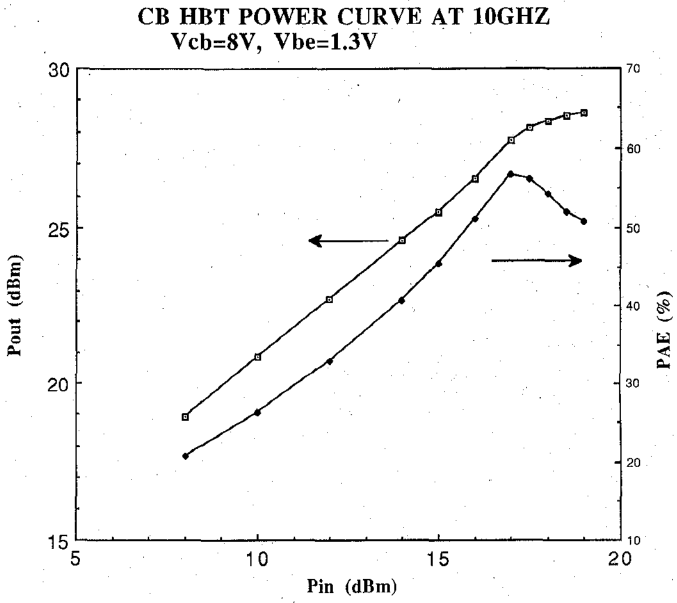

Fig. 3. Power saturation curve at 10 GHz. 0.72 W is achieved with 51% PAE and 9.6 dB gain. Peak efficiency is 56.6% with 0.59 W. V_{cb} is biased at 8 V and V_{be} at 1.3 V.

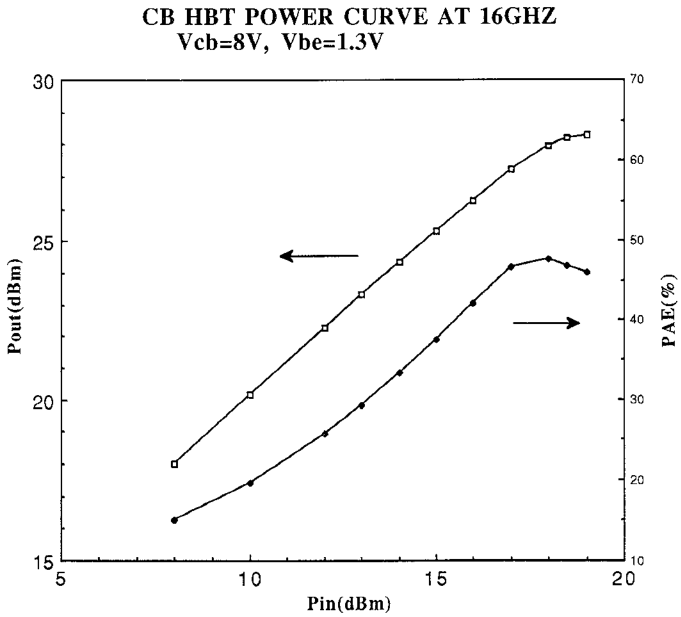

Fig. 4. Power saturation curve at 16 GHz. 0.67 W is achieved with 46% PAE and 9.3 dB gain. Same bias condition as at 10 GHz is used. Output power is only slightly less at any given driving power level as compared with 10 GHz operation.

At 16 GHz and under the same bias voltages, 0.67 W CW power was achieved with 46% PAE and 9.3 dB gain. The highest PAE is 47.7% with 9.9 dB gain and 0.62 W output power. As compared with the operation at 10 GHz, the bias current is about the same under the same RF driving power. The gain is slightly lower at 16 GHz, which causes the PAE and the output power be lower too.

HBT's with three and six cells were also tested. The small signal gain is the same. The power performance is also similar. The gain is about 10 dB and the output power is proportional to the HBT size. Table I summarizes the result.

The scaling of the power to the HBT size indicates that the power HBT design indeed minimizes all the parasitic and thermal problems frequently encountered in power transistor design.

The nearly identical performance at 10 and 16 GHz is another important feature of CB HBT. From the *T*-model representation of bipolar transistor, it is clear that the feedback from collector to emitter is minimum and the CB HBT is almost a unilateral transistor (but not CE HBT). The input impedance is nearly resistive. Therefore the power gain (with the same load line) is almost flat, and is reduced slightly into higher frequency by these small feedback terms. Therefore it is very easy to design broad band power amplifier with CB HBT without the need to level the gain.

The HBT performance compares favorably with the 0.5 μm gate MESFET at 10 GHz. In Ku band, it is also comparable to 0.25-μm gate PHEMT [4]. The HBT bias voltage is high, with V_{ce} = 9.3 V and BV_{cbo} of 20 V. In contrast the 0.25 μm gate HEMT [4] has a breakdown voltage of 7.2 V only. The RF yield of the power HBT, as defined by the ratio of the number of HBT's with the output power within 1 dB of the values in Table I to the total sampled number, is in the 60–90% range on good wafers. Since the MMIC amplifier matching circuit must also serve the power splitting/combining function, each transistor feed requires a port being provided by the matching circuit. The single feed makes this power HBT a true building block for power amplifier, as compared to some power transistors with multiple feeds (an ensemble of small transistors).

TABLE I
COMPARISON OF POWER PERFORMANCE AT 10 GHz

HBT Size	Gain	Power
120 μm^2	9.9 dB	23.9 dBm
240 μm^2	10 dB	27 dBm
360 μm^2	9.6 dB	28.6 dBm

IV. Conclusion

A 0.7 W power HBT is developed for X–Ku-band operation. Excellent power gain of 10 dB and PAE around 50% are obtained. The rf yield of power HBT is over 60%, and the bias voltage is high with V_{ce} = 9.3 V. The power gain is almost flat from 10 to 16 GHz due to the unilateral property and the resistive input impedance of the CB HBT. Therefore, the CB power HBT is a very attractive building block for broad band power amplifier.

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