THE EFFECTS OF NONLINEAR C_{BC} ON THE LINEARITY OF HBT

WOONYUN KIM, MINCHUL CHUNG, KYUNGHO LEE, YOUNGOO YANG,
SANGHOON KANG, AND BUMMAN KIM
Dept. of E. E. Eng., and Microwave Application Research Center, POSTECH
San 31, hyoja-dong, Nam-gu, Pohang, Kyoungbook, Republic of Korea
E-mail: kwn@postech.ac.kr

It is commonly known that C_{BC} is a very strong nonlinear source of HBT. To investigate the contribution of the nonlinear C_{BC} to the linearity, HBTs with punch-through collector and normal collector were fabricated. At 2 GHz, the punch-through HBT and normal one exhibit the power gain of 16.6 dB and 16.9 dB, output power of 28.9 dBm and 28.6 dBm, and P.A.E. of 51 % and 59 %, respectively at 1 dB gain compression point. Two-tone tests were carried out for both power devices. The normal and punch-through HBTs showed the IMD3 (third-order intermodulation distortion) levels of –25 dBc and –20 dBc, respectively at 1 dB gain compression point; for both cases, IMD3 dropped to –30 dBc at 1.6 dB output power back off. Because C_{BC} of HBT with punch-through is linear at small input signal, the IP3 power of the HBT is higher than that of the normal HBT by 15 dB. We found that RF grounding at the collector terminal is on efficient way of the third-order IM power reduction.

1 Introduction

The transmitter of the handset of digital mobile communication systems requires highly efficient linear power amplifiers [1-4]. HBTs are widely used for the amplifiers due to their superior power characteristics with only a positive supply and small chip size [2]. In spite of the good experimental results, the mechanism responsible for the good linear behavior of AlGaAs/GaAs HBTs has not been clearly explained so far [5-8]. However, it is commonly known that C_{BC} is a very strong nonlinear source and should be linearized to reduce the third-order intermodulation (IM) distortion of HBT [7, 9-11]. In this work, to investigate the contribution of the nonlinearity of C_{BC}, HBTs with punch-through collector and normal collector were fabricated. Two-tone testing was carried out for both the HBTs. It was found that the HBT with punch-through collector has lower third-order IM distortion than the other HBT at a low power level. But, at a high power range, their nonlinear behaviors are nearly the same because the large signal converts the C_{BC} of punch-through HBT to a nonlinear element. It may be related to the charge injection into the collector depletion region and to the reduced collector voltage. We also studied harmonic termination effects on the linearity of HBT.

2 Device Fabrication and Characteristics

The AlGaAs/GaAs HBT epi structure grown by MOCVD consists of an n+-InGaAs cap layer, an n-GaAs layer, an n-AlGaAs emitter layer, a C-doped p+-GaAs base layer, an n-GaAs collector layer, and an n+-GaAs sub-collector layer. The HBTs with punch-through collector and normal collector have the same structures except their collector thicknesses. The HBT with the punch-through structure has a 0.4 μm-thick collector doped to 2×10^{16} cm^{-3} and the other one has a 1.0 μm-thick collector doped to 2×10^{16} cm^{-3}.
Fig. 1 shows a photograph of the fabricated power HBT, which has 32 unit cells of 2 × 2 μm × 11 μm emitter. Total emitter area is 1408 μm^2. The HBTs were fabricated using self-aligned base metal process technique with mesa structure for isolation. The thick gold metal layer was deposited on the emitter to improve the electrical and thermal performances. We also used the emitter widening process using polyimide. Substrate was lapped to 100 μm thickness and emitter is grounded with via hole.

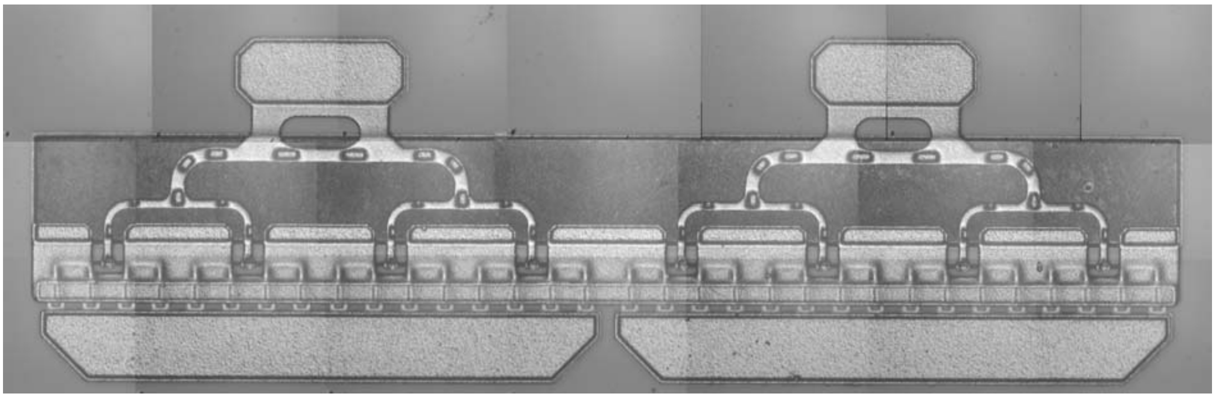
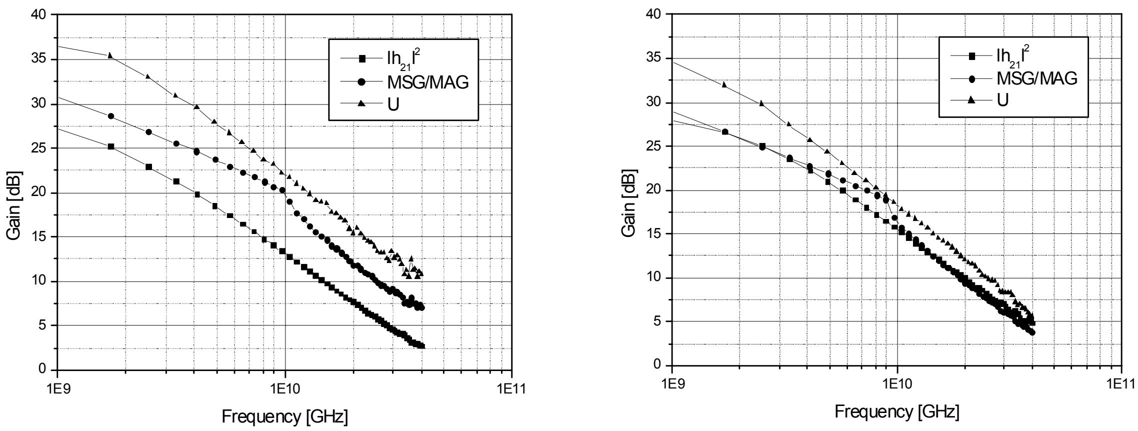


Fig. 1: Photograph of the AlGaAs/GaAs HBT, which is 1.0 × 0.31 mm^2 in size.



(a) (b)

Fig. 2: Frequency dependence of $|h_{21}|^2$, MSG/MAG and U as determined by s-parameter measurements and numerical calculations. (a) HBT with normal collector structure (b) HBT with punch-through collector

The maximum current gains of both HBTs are about 20. The breakdown voltage at an open base, BV_{ceo} is 10 V for the punch-through collector structure and 17 V for the normal structure. Small signal performances of the fabricated HBTs with emitter area of 44 μm^2 are shown in Fig. 2. The f_T and f_{max} are 70 GHz and 62 GHz respectively at Ic=18 mA and Vce=2.0 V for the punch-through collector structure, and 55 GHz and 88 GHz at Ic=16 mA and Vce=2.3 V for the normal collector structure.

3 Nonlinear Characteristics

Fig. 3 illustrates the RF output power and power-added efficiency (P.A.E) as a function of RF input power for both HBTs at 2 GHz. The DC bias point is Ic=350 mA and Vce=3.5 V. The punch-throughed HBT and normal one exhibit the power gain of 16.6 dB and 16.9 dB, output power of 28.9 dBm and 28.6 dBm, and P.A.E. of 51 % and 59 %, respectively at 1 dB gain compression point. The source and load pulls using automatic tuner are done to find matching points for maximum gain and output power. Input matching impedances for punch-through device and normal one are 5.24-j1.05 and 4.74-j1.51, respectively. And output matching impedances are 6.33-j2.70 and 5.61-j7.87, respectively. They have similar performances at single tone test. Two-tone test is carried out. Fig. 4 shows the two-tone test measurement setup. Two-tone spacing is 1 MHz to reduce the thermal effects on the linearity of AlGaAs/GaAs [12]. Their third-order IM distortion signal behaviors are remarkably different. At a low input signal, the HBT with punch-throughed collector has much lower IM3 than the normal HBT has. The IP3 difference is 14.8 dB (39.5 dBm vs. 24.7 dBm). As an input power level increases (above –8.26 dBm in our case), the IM3 of the normal HBT grows at a lot slower pace than the normal 3:1 slope of the input signal level. However, at a large input power, the slope again increases larger than 3:1 slope. As shown in the figure, in this region, IMD3 of the HBT with punch-through collector is even larger than that of the normal HBT. At 1 dB gain compression point, the IMD of the punch-through HBT is –20 dBc, which is about 5 dB higher than that of the normal HBT. Those behavior can be explained as follows: While the device with the thin collector at the punch-through bias has a linear C_{BC} at a small input signal, the normal HBT's C_{BC} is highly nonlinear. At the higher power level, a large amount of charges are injected into the collector, and during the some portion of RF cycle, the collector bias may be reduced to below the punch-through condition. These behaviors convert the linear C_{BC} to a nonlinear element.

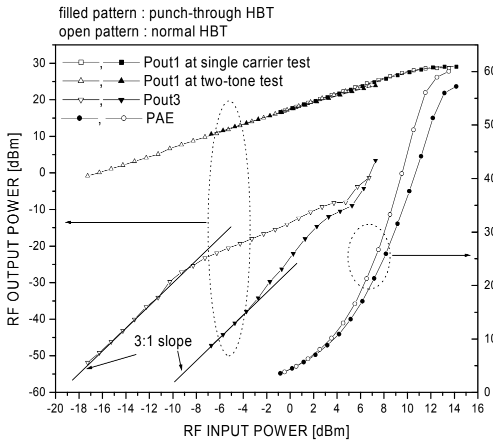


Fig. 3: Single-tone and two-tone test results.

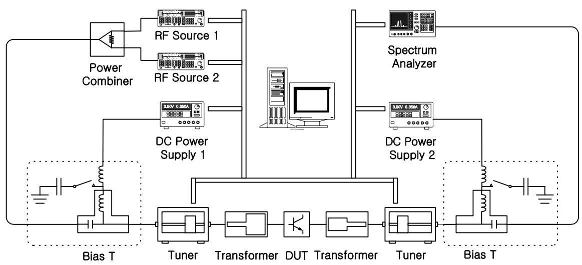
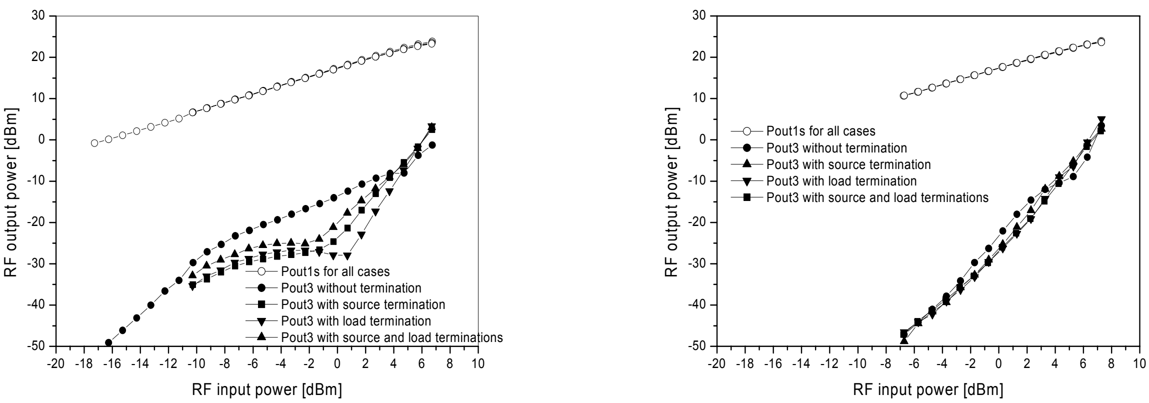


Fig. 4: Two-tone test measurement setup



(a) (b)

Fig. 5: Two-tone test results for low-frequency termination effects. Open-circled symbol is the fundamental output power. Filled-circled symbol is Pout3 with no termination. Upper-triangle symbols and down-triangle ones mean Pout3 with source and load termination, respectively. Square symbols are Pout3 with source and load termination. (a) normal HBT (b) punch-through HBT

We have also studied the low-frequency harmonic termination effects to the linearity of the HBT. Common emitter amplifier is RF grounded at base and collector terminals at (f2-f1) frequency using 10 μF capacitor. For the HBT with the normal collector, the low-frequency harmonic termination remarkably improves the linearity of the HBT. RF grounding at the collector terminal is especially useful and it reduces the third-order IM power by 17 dB compared with no termination case. In case of the HBT with punch-through collector, the low-frequency harmonic termination effect has little effects, under 5dB. At a high power level, the harmonic termination does not have any strong effects.

4 Conclusions

The C_{BC} of HBT is one of the dominant nonlinear elements in HBT and it should be linearized to improve the linearity of HBTs. To study the C_{BC} effects on the linear characteristics, HBTs with punch-through collector and normal collector were fabricated and tested. At 2 GHz, the punch-through HBT and normal one exhibit the power gain of 16.6 dB and 16.9 dB, output power of 28.9 dBm, and 28.6 dBm, and P.A.E. of 51 % and 59 %, respectively at 1 dB gain compression point. Two-tone tests were carried out for both power devices. The normal HBT and punch-through HBT showed –25 dBc IMD3 and –20 dBc, respectively at 1 dB gain compression point; IMD3 dropped to –30 dBc at 1.6 dB output power back off. Because C_{BC} of HBT with punch-through is linear at a small input signal, the IP3 of the HBT is higher than that of the normal HBT by 15 dB. It is also found that for the normal HBT, RF grounding at the collector terminal reduces the third-order IM power by as much as 17 dB compared with no termination case.

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