22nd Workshop on Compound Semiconductor Devices and Integrated Circuits held in Europe
(WOCSDICE '98)
Zeuthen, Germany, May 24-27, 1998

Power Amplification using NPN and PNP InP HBTs and Application to Push-Pull Circuits

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InP/InGaAs HBTs have demonstrated very good high-frequency performance and have been implemented in various integrated circuits for electronic and optoelectronic applications. Their power capability is also promising and power levels up to 1.4mW/μm^2 have been reported by the authors using single HBT designs. Their power capability can be enhanced even further by means of double heterojunction designs and a power density of 3.6mW/μm^2 has been reported with the latter approach from Hughes Res. Labs. InP/InGaAs HBTs can consequently be employed in circuits for power amplification. The recent demand for linear power amplifiers prompted the consideration of various approaches for improved performance from existing devices. Various circuit techniques can be used for this purpose and a very promising scheme reported in this paper is the combination of NPN with PNP HBTs in a push-pull amplifier scheme that allows improvement in linearity characteristics.

Unlike NPN HBTs, PNP HBTs have attracted much less attention and little is known about their characteristics, especially under large-signal conditions. The PNP HBTs studied here had a uniformly doped 500Å thick base doped at $5\times10^{18}cm^{-3}$. A self-aligned technology was used for fabrication and Ti/Pt/Au was employed for base metallization. Devices with $5\times10\mu m^2$ emitter fingers showed ideality factors η_B and η_B equal to 1.60 and 1.00 respectively. Their maximum gain at 34kA/cm^2 and V_{CE} equal to 4.0V was greater than 30 while their breakdown was 5.6V. A study of the high frequency characteristics of the devices showed a current gain cutoff frequency of 11GHz and a maximum oscillation frequency of 31GHz. This exceeds the best-reported performance for InAlAs/InGaAs PNP HBTs which was 22GHz. The devices were characterized using load pull techniques and demonstrated a small-signal gain of 10dB, peak power-added-efficiency of 24% and maximum output power density of 0.5mW/μm^2. These characteristics are very similar to NPN InP-based HBTs fabricated with the same technology. The latter devices had slightly higher gain (+1dB) and efficiency (+5%), while the PNP HBTs produced more power (+3dBm).

A push-pull amplifier was studied using the fabricated NPN and PNP HBTs. While for single HBTs class-B operation shows better efficiency but worse linearity, push-pull amplifiers can combine these two features and maintain therefore high linearity and efficiency under class-B conditions. A coplanar circuit was developed to permit feeding of the NPN and PNP HBTs from a common input signal terminal. The devices were thinned to 200µm and mounted on 10mil alumina substrates. Electromechanical tuners were used to increase the PNP gain and match it to that of NPN devices. Testing of the circuit showed best IM3 (by ~7dBc) and small second harmonic content (by ~9dBc) compared with NPN HBTs. Overall, we report the development of PNP and NPN technology and its application to push-pull amplifier circuits with improved power performance.

Work supported by ARO-MURI (DAAH04-96-1-0001)

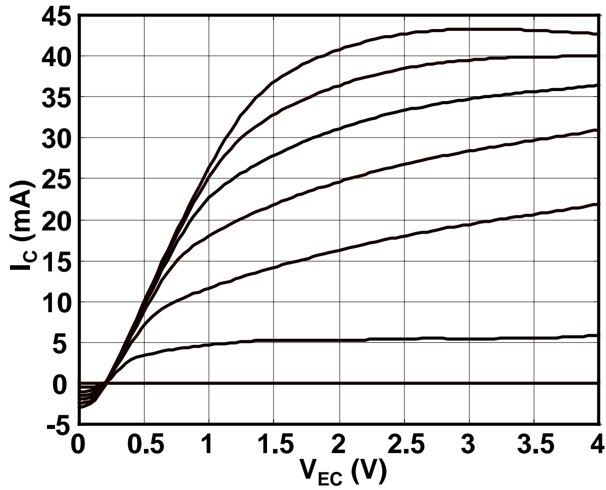

Figure 1: Forward I-V characteristics of 5×10 μm² PNP HBT. I_B = 0.5 mA/step. For this HBT, f_T =11 GHz and f_{max} = 31 GHz at J_C = 23 kA/cm².

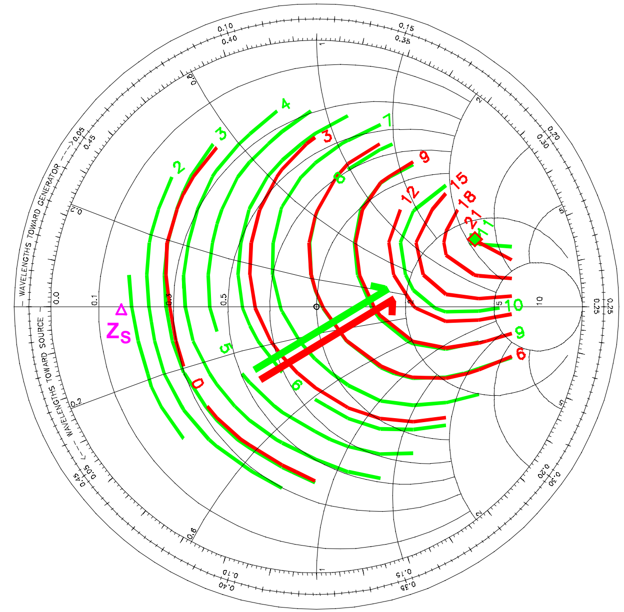

Figure 2: On-wafer load pull at 10 GHz of 5×10 μm² PNP HBT measured at P_{in} = 3.17 dBm under constant V_{EB} bias with V_{EC} = 4.0 V. Both maximum P_{out} = 0.50 mW/μm² and PAE = 24% occur at slightly higher P_{in}.

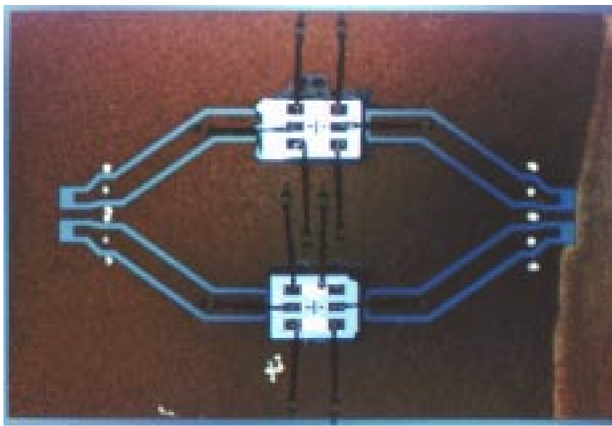

Figure 3: NPN/PNP push-pull common-emitter amplifier. The NPN and PNP HBTs were individually fabricated.

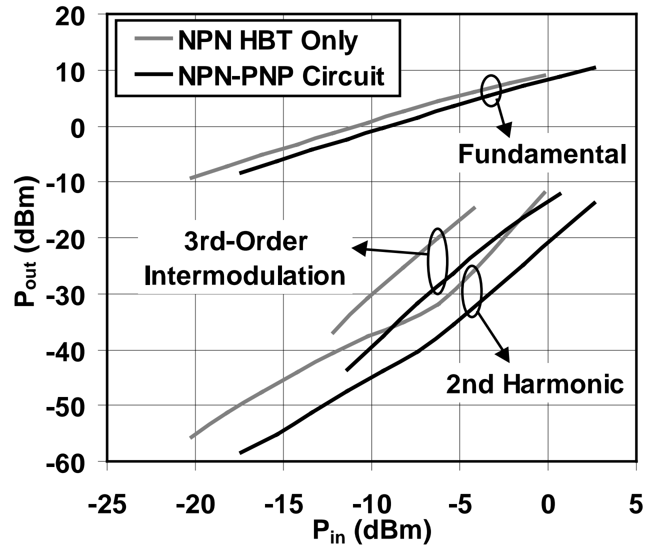

Figure 4: Power characterization of NPN/PNP push-pull common-emitter amplifier at 8 GHz. The 2nd harmonic and 3rd-order intermodulation (500 kHz separation) are improved when compared to a single NPN HBT amplifier.