Comparison of Conventional and Thermally-Stable Cascode (TSC) AlGaAs/GaAs HBTs for Microwave Power Applications

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Thermal effects in AlGaAs/GaAs HBTs are an important issue for power applications. To control these effects, various approaches have been used in the past including ballast resistors and thermal-shunt structures [1]-[3]. More recently, a new Thermally-Stable Cascode HBT (TSC-HBT) design was developed, which not only provides an effective solution to the thermal runaway issue, but also can improve the robustness of high power HBTs under overstressed DC or RF bias conditions [4]. In this study, we compared the DC, small-signal, and large-signal performance characteristics of conventional common-emitter (CE) to TSC-HBT to provide a direct assessment of this new design approach.

In a TSC-HBT the part of the device (common-base stage) that provides power (and therefore gets hot) is physically separated from the part that regulates the current (common-emitter stage). Because the electrothermal feedback is effectively eliminated in this configuration, the collector current remains uniformly distributed across all parts of the CB stage. The net result is that a uniform temperature distribution is achieved at all DC and RF drive conditions without thermal instability. As the results in this paper will show, this increased thermal stability is possible without compromising the microwave performance of power HBT cells.

All devices studied here were fabricated using MOCVD-grown wafers with a self-aligned emitter-base process. A constant emitter geometry $2.5\times20\ \mu m^2$ was used in all designs. The conventional CE HBT had four emitter fingers separated by 30µm. Identical cell layout approach was used in TSC-HBTs for both CE and CB stages. A virtually complete thermal isolation was provided between CE and CB stages by separating these cells by at least 100 µm. Thermal shunt structures were used for the CE stage to minimize temperature variation between emitter fingers and therefore to maintain a uniform collector current generation. The collector of each CE subcell was directly connected to the corresponding emitter of the CB subcell. No thermal shunt structures were used for the CB stage cell.

The negative slope of the collector current in the forward I_c-V_{ce} characteristics (*Figure 1*) of conventional devices indicate the strong influence of junction temperature on current gain. A similar effect was not observed with TSC-HBTs because the rise in temperature is confined mostly to the CB cell, whose current is controlled by CE cell located at a cooler temperature zone. A large-signal microwave device model including *self-heating* effects was employed to investigate the thermal characteristics for both devices. The *base-emitter* junction temperature increase was simulated and the results are shown in *Figure 2*. The TSC-HBT CE stage junction temperature was found to increase by ~ 20 C° at V_{ce} = 10V, while the temperature increase was ~ 60 C° for the conventional HBT at V_{ce} = 5V. These results prove the advantage of the TSC-HBT design to suppress electrothermal effects by maintaining a lower junction temperature increase at the CE .

The small-signal *S-parameters* of the conventional and TSC-HBT devices were measured and the results are shown in *figure 3*. The maximum available gain for TSC-HBT devices is ~13 dB higher than for conventional HBTs at lower frequencies. Above 10 GHz, the G_{max} dropped at different slopes (– 20dB/dec and – 40dB/dec for CE and TSC-HBT, respectively). The extrapolated results suggest similar f_{max} value of 92 GHz for both devices. On the other hand, $|h_{21}|^2$ is higher for TSC-HBTs in the measured frequency range (0.5- 25.5 GHz) leading to higher f_t .

On-wafer power characterization was performed at 8 GHz using a *load-pull* measurement system with electromechanical tuners. The devices were biased under the same conditions as above. The input and output impedance were optimized for maximum gain at P_{in} = 0 dBm. Under this input power level, the optimized gain was 18.47 dB and 25.4 dB for conventional and TSC-HBT devices respectively. In addition, the corresponding P_{out} was 18.11dBm and 22.98 dBm; *PAE* was 25.4%, 53.4% for each device. The power handling capabilities were investigated by measuring 1dB gain compression characteristics of each device type. The measured power and gain characteristics are shown in *Figure 4* for the TSC-HBTs. As can be seen, this device can reach a gain of 32.9dB while producing P_{out} = 21.2 dBm. This result compares very favorably with conventional CE devices, which produced a maximum -1 dB gain of 18.5 dB and P_{out} = 18.5dBm. It is clear that the TSC-HBT devices perform considerably better than the conventional devices.

In summary, we have compared the DC, small-signal and large-signal power characteristics of conventional and TSC-HBTs and found that the TSC_HBT device provides a higher power handling capability than the conventional HBTs. The CB-stage in the TSC-HBTs not only leads to lower temperature increase but also provides additional power amplification stage. The net result is that TSC-HBTs are eminently more suitable for high frequency power applications than conventional CE HBTs.

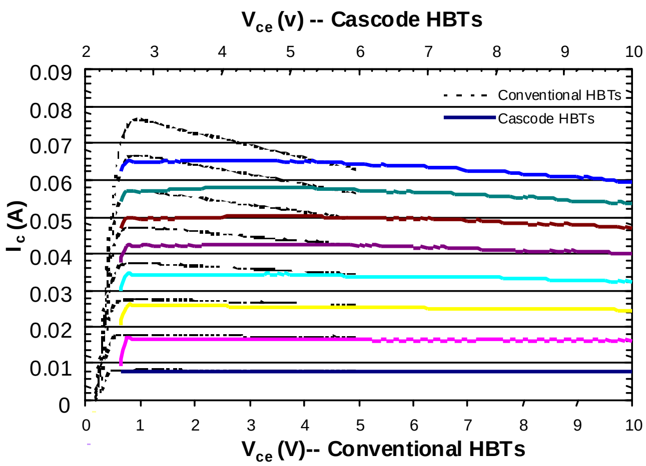

Figure 1. *Forward I_c/V_{ce} characteristics for conventional and cascode HBTs. I_b = 0.3, 0.6,.., 2.4 mA, V_{ce} = 0 – 5 V for conventional HBT and 2.5 – 10 V for cascode HBTs.*

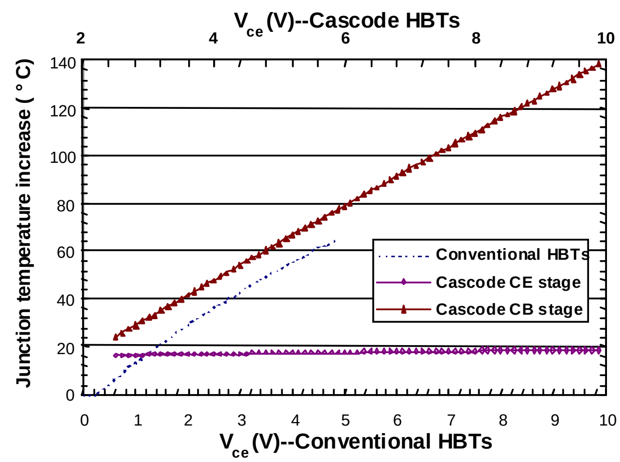

Figure 2. *Simulated junction temperature increase for conventional, cascode CE stage and CB stage HBTs. I_b = 2.4 mA, Vce = 0 – 5 V for conventional HBTs and 2.5 – 10 V for cascode HBTs.*

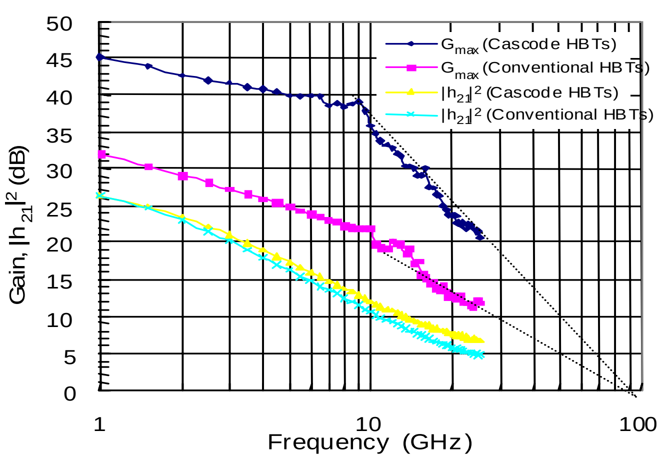

Figure 3. *G_{max} and $|h_{21}|^2$ for conventional and cascode HBTs. I_b = 2.4 mA, I_c = 65.06 mA, V_{ce} = 4V for conventional HBTs, I_b = 2.1 mA, V_{b2} = 2.5, Ic = 57.44 mA, V_{ce} = 7V for cascode HBTs.*

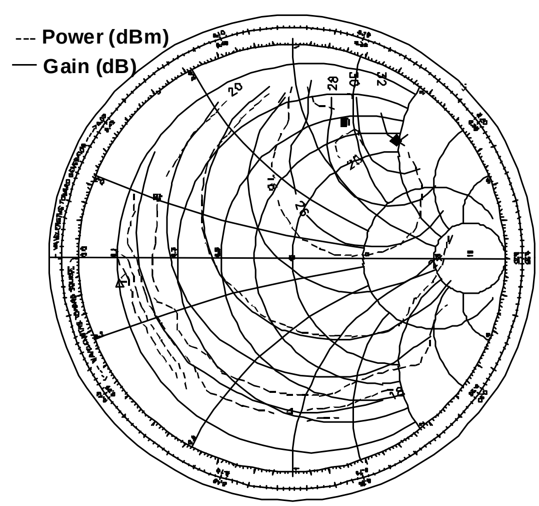

Figure 4. *One dB gain compressed on-wafer load pull measurement for cascode HBTs. Maximum Gain = 32.9 dB and P_{out} = 21.2 dBm.*

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[References]

[1] G. Gao, et al, *IEEE Trans. Electron Devices, Vol. 38, 1991, pp. 185-196.*
[2] W. Liu, et al, *IEEE Trans. Electron Devices, Vol. 41, 1994, pp. 1698-1707.*
[3] B. Bayraktaroglu et al, *IEEE Trans. Electron Devices Letter, Vol. 14, 1993, pp. 493- 495.*
[4] M. Salib and B. Bayraktaroglu, *IEEE MTT-S Int. Microwave Symp. Dig. 1997, pp. 897-899.*