Generation 2 High Voltage Heterojunction Bipolar Transistor Technology for High Efficiency Base Station Power Amplifiers

Thomas Landon, Joe Delaney, Craig Steinbeiser, Oleh Krutko, Roger Branson, Rached Hajji,

Preston Page, Sam Wey, Craig Hall, and Larry Witkowski.

TriQuint Semiconductor, 500 W. Renner Road, Richardson, TX, 75080, USA

***Abstract* — A new generation of High Voltage Heterojunction Bipolar Transistor (HVHBT) technology was developed for base station high power amplifiers and multi-stage driver amplifiers. This is an improved version of previously reported InGaP/GaAs HBT capable of operating with supply voltages up to 32 V. Generation 2 HVHBT technology maintains the same high level of efficiency and compatibility with Digital Pre-Distortion (DPD) techniques but has higher gain, higher power density and greater tolerance to load mismatch and input overdrive.**

Two discrete power transistors, 120 W and 220 W, were developed using Generation 2 HVHBT technology for 2.1 GHz WCDMA/LTE applications. Both 2x120 W and 2x220 W Doherty amplifiers were designed to demonstrate gain approaching 14 dB and efficiency in excess of 55% at 6 dB operating back-off.

***Index Terms* — Heterojunction bipolar transistor, power bipolar amplifiers, power amplifiers, digital pre-distortion, Doherty amplifiers, WCDMA.**

I. INTRODUCTION

Continuous push for higher data rates along with pressure to reduce total power consumption in modern wireless communication systems created a need for new semiconductor technologies that can enable high efficiency high linearity power amplifier solutions.

TriQuint HVHBT technology has demonstrated that efficiencies nearing 60% can be achieved for two-carrier WCDMA operation in Doherty [1] and envelope tracking [2] configuration while meeting linearity requirements with commonly used DPD techniques. To the best of author's knowledge these efficiency benchmarks remain unsurpassed [3], exceeding efficiencies reported for LDMOS [4-7], and GaN [8, 9] in both Doherty and ET configuration.

At the same time HVHBT based power amplifiers had relatively low gain and were sensitive to load mismatch and overdrive conditions. In this paper we present the second generation of TriQuint HVHBT technology that was extensively optimized for higher gain and improved robustness for operating voltages up to 32 V.

Power transistors rated for 120 W and 220 W of continuous wave (CW) power in 2.1 GHz band were designed using Generation 2 HVHBT technology. These devices are characterized by RF gain of 16-17 dB and show no device failures while presented with high load mismatch at the input power corresponding to 1dB compression in matched condition. Saturated efficiency is in excess of 70%.

Doherty amplifiers have been designed to demonstrate compatibility of Generation 2 HVHBT technology with this commonly used efficiency enhancement solution. We present both 2x120 W and 2x220 W Doherty amplifiers with gain approaching 14 dB and efficiency exceeding 55% at 6 dB operating back-off from 1dB compression. These amplifiers are easily linearized to -55 dBc using DPD.

II. TRANSISTOR DESIGN AND PROCESS TECHNOLOGY

HVHBT devices are fabricated using TriQuint's proprietary InGaP GaAs process. Fabrication starts with emitter metal patterning and then selective etching down to the collector layer.

The collector layer structure is tailored for high breakdown voltage at high and low current densities. A large safe operating area enables high voltage operation without device failures. Base-collector breakdown voltage of Generation 2 HVHBT was increased to 85 V compared to 72 V for Generation 1 process. A non-planar surface requires careful optimization of subsequent process steps. The base metallization is alloyed through the emitter to form an ohmic contact to the p-type base. Device isolation is subsequently achieved through a combination of mesa etching and ion implantation. The wafers are thinned to 100 um. The process supports backside ground vias. The backside of the wafer is plated with 4 microns of gold.

The high power HVHBT transistor consists of an array of unit cells. Individual transistors are ballasted for thermal stability and unit cell design is optimized for uniform temperature distribution. The summary of comparison of performance of Gen1 and Gen 2 unit cells is shown in Table I. Collector efficiency listed in Table 1 (78%) corresponds to a maximum 1-dB compression power tune. For maximum efficiency tune, the unit cell collector efficiency reaches 84%.

High temperature accelerated tests predict median life of 10^7 hours at junction temperature of 150 C for 20% beta degradation as shown in Fig. 1. Activation energy is 1.89 eV.

978-1-4244-6057-1/10/$26.00 ©2010 IEEE

TABLE I

COMPARISON OF GEN1 AND GEN2 UNIT CELL PERFORMANCE

Process	Gmax (dB)	P1dB (dBm)	G1dB (dB)	Coll. Eff. at P1dB (%)	PAE (%)
Gen 1	20.1	35.4	16.0	78.0	76.0
Gen 2	20.7	36.2	16.3	78.0	76.2

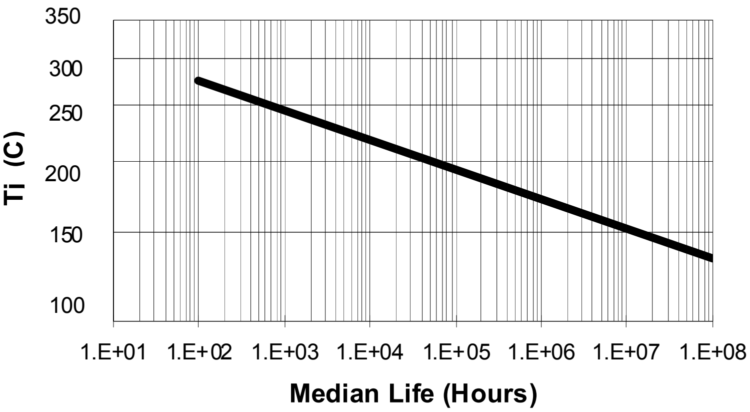


Fig. 1. Median life of Generation 2 HVHBT unit cell as a function of junction temperature.

III. MODULE DESIGN AND CLASS-AB AMPLIFIER

In this section we describe TG2H214120 and TG2H214220 that are packaged power transistors capable of delivering 120 W and 220 W of CW power at 1dB power compression, respectively. These products are partially pre-matched in 2.1 – 2.18 GHz band for ease of use.

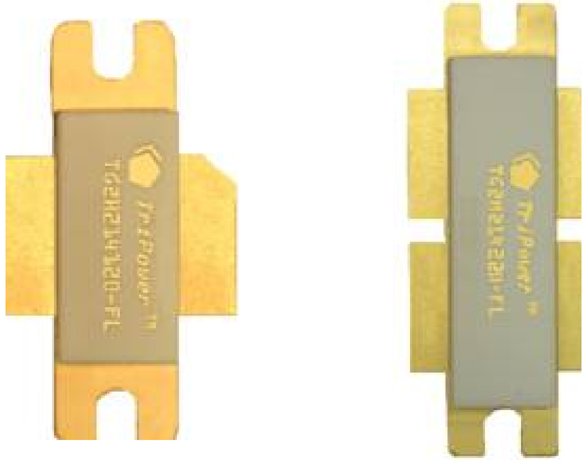
TG2H214120 is realized using HVHBT die, input pre-match die and output capacitor die, and is packaged in a single-ended standard ceramic package. Each HVHBT die is capable of delivering 60 W of CW power at 1dB compression. The photograph of the module is shown in Fig. 2a. TG2H214220 uses similar HVHBT die, input pre-match die and output capacitor die. The photograph of the module is shown in Fig. 2b.

TG2H214120 module is characterized using 50 Ohm single-ended fixture biased in class-AB with a quiescent collector current of 500mA and designed for typical operation with collector voltage of 28 V. Comparison of performance of TG2H214120 with previously published performance of TG1H214100 [1] is shown in Table II. TG2H214220 performance in single ended class-AB fixture is also summarized in Table II.

TABLE II

COMPARISON OF GEN1 AND GEN2 PERFORMANCE

	TG1H214100	TG2H214120	TG2H214220
P1dB (W)	100	120	220
Coll. Eff. at P1dB (%)	65	67	67
G1dB (dB)	13.5	15.9	15.7
VSWR at 28V	3:1	10:1	10:1



(a) (b)

Fig. 2. Photograph of (a) TG2H214120 module and (b) TG2H214220 module.

IV. DOHERTY AMPLIFIER

HVHBT technology is well suited for symmetric and asymmetric Doherty operation due to very high efficiency at 2*Zopt and 3*Zopt, where P1dB efficiency exceeds 73%, resulting in a highly efficient carrier amplifier. In addition, the off-state impedance is very high, permitting the peaking amplifier to present a near ideal open at the output combiner for power levels at and below the target back-off.

Fig. 3 shows the CW drive up performance for the TG2H214120 in a Doherty amplifier configuration. In this configuration, the TG2H214120 achieves 65W and 56% collector efficiency at 6dB back off from 1dB compression.

WCDMA linearity was characterized with a 2-carrier side-by-side WCDMA signal with 6.5dB PAR. Linearization was accomplished using a Texas Instruments DPD test system. Collector efficiency of 57% at 48.1dBm (64.5W) average output power has been demonstrated while achieving –55dBc linearized ACPR at 5MHz offset. The 2x120W Doherty amplifier spectral output plot is shown in Fig. 4. A photograph of the Doherty amplifier is shown in Fig. 5.

Fig. 6 shows the CW drive up performance for the TG2H214220 in a Doherty amplifier configuration. In this configuration, the TG2H214220 achieves 117W and 55% collector efficiency at 6dB back off from compression.

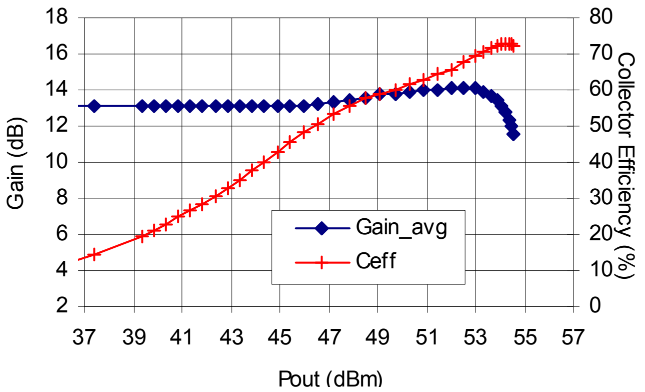


Fig. 3. CW drive up performance of the TG2H214120 in a Doherty amplifier configuration.

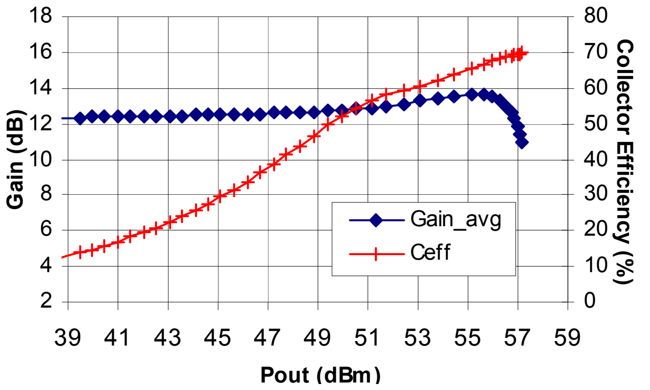


Fig. 6. CW drive up performance of the TG2H214220 in a Doherty amplifier configuration.

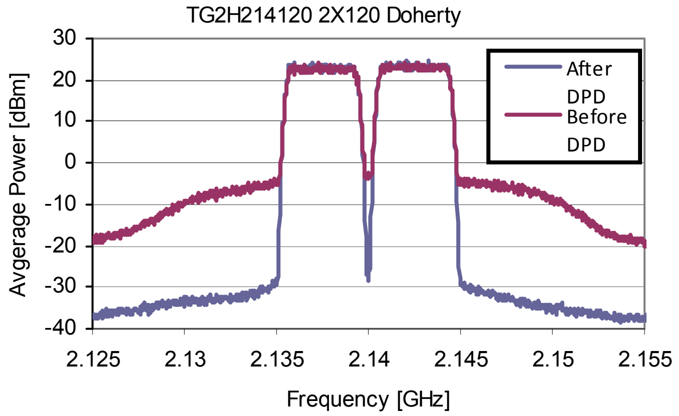


Fig. 4. Spectral plot for the 2x120W Doherty amplifier, with and without DPD correction. Poavg = 48.1dBm, Gain = 13.7dB, Coll Eff = 57.1%, PAE = 54.7%, & ACPR = -55.2dBc.

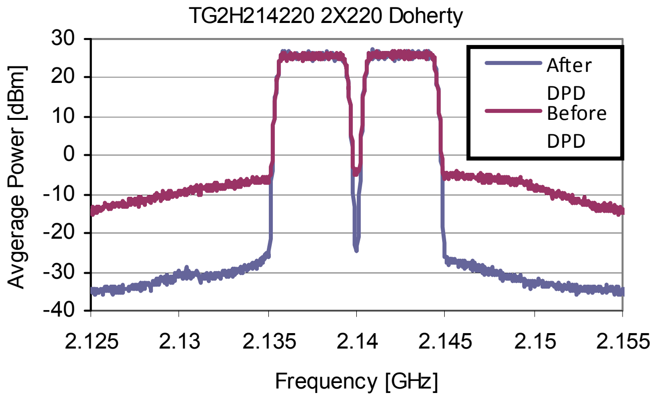


Fig. 7. Spectral plot for the 2x220W Doherty amplifier, with and without DPD correction. Poavg = 50.8dBm, Gain = 13.2dB, Coll Eff = 54.2%, PAE = 51.6%, & ACPR = -55.3dBc.

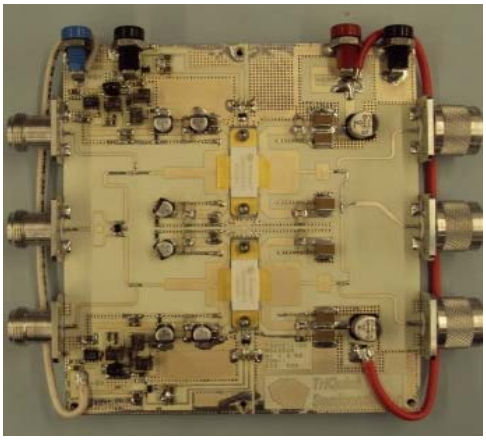


Fig. 5. Photograph of the 2x120W Doherty amplifier board.

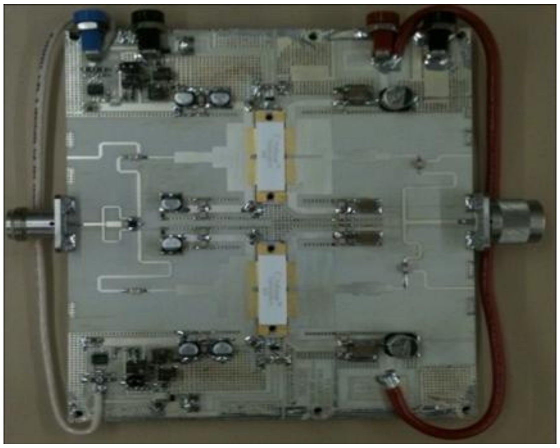


Fig. 8. Photograph of the 2x220W Doherty amplifier board

WCDMA linearity was also characterized on the 2x220W Doherty amplifier using a 2-carrier side-by-side signal at 6.5dB PAR. Collector efficiency of 54% at 50.8dBm (120 W) average output power was achieved while maintaining a -55dBc linearized ACPR at 5MHz offset. The 2x220W Doherty amplifier spectral output plot is shown in Fig. 7. A photograph of the Doherty amplifier is shown in Fig. 8.

V. CONCLUSIONS

In this paper we announced Generation 2 High Voltage Heterojunction Bipolar Transistor (HVHBT) technology developed by TriQuint Semiconductor for high efficiency and high linearity base station power amplifiers and driver amplifiers. Generation 2 HVHBT products described in this paper demonstrated improvements in output power, gain, reliability, and robustness over Generation 1 products, while maintaining best in class efficiency. The 2x220W Doherty amplifier achieved 120W average output power with a gain of 13.2dB at 54% collector efficiency. The 2x120W Doherty amplifier achieved 64.5W average output power with a gain of 13.7dB at 57% collector efficiency. Both amplifiers were easily linearized to -55dBc using standard DPD technology.

These results illustrate the capability of GaAs HVHBTs, in combination with advanced amplifier architectures, to achieve dramatic improvements in power amplifier efficiency and multiple opportunities for green base station development.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance and support of John Hitt, Gary Burgin, Barry Lin, Frank Chau, Howard Bartlow, Nick Sims, Justin Everman, Faye Rangel, Billy Orosco, Rodney Brown, and Khushminder Mann.

REFERENCES

[1] C. Steinbeiser, T. Landon, C. Suckling, J. Nelson, J. Delaney, J. Hitt, L. Witkowski, G. Burgin, R. Hajji, and O. Krutko, “250 W HVHBT Doherty with 57% WCDMAefficiency linearized to -55 dBc for 2c11 6.5 dB par,” *IEEE J. Solid-State Circuits,* vol. 43, no. 10, pp. 2218–2228, October 2008.

[2] Jeong Jinseong, D.F. Kimball, Kwak Myoungbo, P. Draxler, Hsia Chin, C. Steinbeiser, T. Landon, O. Krutko, L.E. Larson, P.M. Asbeck, “High-efficiency WCDMA envelope tracking base-station amplifier implemented with GaAs HVHBTs,” *IEEE Journal of Solid State Circuits,* vol. 44, no. 10, pp. 2629-2639, October 2009.

[3] C. Steinbeiser, T. Landon, G. Burgin, O. Krutko, J. Haley, P. Page, D. Kimball, P. Asbeck, “HVHBT Doherty and Envelope Tracking PAs for High Efficiency WCDMA and WiMAX Basestation Applications,” *IEEE Power Amplifier Symposium,* January 2009.

[4] M. LeFevre, D. Runton, J. Kinney, J. Wright, J-C Nanan, J-J Bouny, “Digital Pre-Distortion Application of an LDMOS 200W Doherty Amplifier” *IEEE Power Amplifier Symposium,* January 2006.

[5] P. Draxler, S. Lanfranco, D. Kimball, C. Hsia, J. Jeong, J. Van de Sluis, and P.M. Asbeck, “High Efficiency Envelope Tracking LDMOS Power amplifier for W-CDMA”, *IEEE MTT-S Int. Microw. Symp. Dig.*, Jun. 2006, pp. 1534-1537.

[6] C. Hsia, D. Kimball, P. Draxler, J.J. Yan, J. Kinney, E. Toulouse, J. Wood, and P.M. Asbeck, “High Efficiency Envelope Tracking Overdriven Class-A LDMOS Power Amplifier for Base Station Applications”, *IEEE Power Amplifier Symposium*, Jan. 2007.

[7] Chin Hsia, D. Kimball, P. Draxler, J. J. Yan, P. M. Asbeck, J. Kinney, E. Toulouse, J. Wood, “High Efficiency LDMOS Power Amplifier for Wireless Base Stations Using Envelope Tracking”, *TECHCON*, Nov. 2008.

[8] N. Ui, H. Sano, S. Sano, “A 80W 2-stage GaN HEMT Doherty Amplifier with –50dBc ACLR, 42% Efficiency 32dB Gain with DPD for W-CDMA Base station”, *IEEE International Microwave Symposium Digest*, pp. 1259-1262, June 2007.

[9] Kimball, D.; Draxler, P.; Jeong, J.; Hsia, C.; Lanfranco, S.; Nagy, W.; Linthicum, K.; Larson, L.; Asbeck, P.;”50% PAE WCDMA base-station amplifier implemented with GaN HFETs”, IEEE *Compound Semiconductor Integr. Circuit Symp.*, pp. 1-4, Oct. 2005.