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# Power Amplifier Design for E-band Wireless System Communications

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**Abstract**—E-band wireless communications will become important as the microwave backhaul for high-speed data transmission. One of the most critical components is the front-end power amplifier in this system. The paper analyzes different technologies with potential in the E-band frequency range and present a power amplifier design satisfying the E-band system specifications. The designed power amplifier achieves a maximum output power of  $\geq 20$  dBm with a state-of-the-art power-added efficiency of 15%. The power is realized using InP DHBT technology. To the best of our knowledge it is the highest output power and efficiency reported for an InP HBT power amplifier in this frequency range. The predicted power-added efficiency is higher than that of power amplifiers based on SiGe HBT and GaAs pHEMT technologies. The design shows the capabilities of InP DHBT for power amplifier applications as an alternative to HEMT based technologies in the millimeter-wave frequency range.

## I. INTRODUCTION

Power generation at millimeter-wave frequencies is still an open problem and a subject of intense research [1]–[18]. Signal power generation and amplification is required in communications, imaging, and radar systems, which means that practically all millimeter-wave systems suffer from low power levels and poor efficiency for power generation. Millimeter-wave communication systems planned in the near future will operate at E-band frequencies around 70-90 GHz and require power amplifiers to boost the transmitted signal over distances of 1-2 km.

There are only few solutions available today for the power generation in this frequency range, most of these involving HEMT device technologies. However, HBT devices offer a good alternative for power amplification due to the very high power densities and the large breakdown voltage.

The specifications for a power amplifier at E-band are:  $P_{out} \geq 20$  dBm, power-added efficiency of  $\eta > 10\%$ , low harmonic and intermodulation distortion to facilitate higher-order modulation schemes, and a frequency of operation of 71–86 GHz, eventually in two bands. The paper presents an E-band power amplifier design delivering  $P_{out} > 20$  dBm output power with a record power-added efficiency of  $\eta = 15\%$ , operating at 71–76 GHz. We discuss the details of the design approach as well as the motivation for the choice of the InP DHBT technology. This amplifier will deliver record output power, power-added efficiency, and will be the first 2 stage design in this technology.

## II. TECHNOLOGY COMPARISON

The choice of the InP DHBT technology is based on a detailed analysis of the capabilities of the following technologies: SiGe HBT, InP HEMT, GaAs mHEMT, GaAs pHEMT, and GaAs HBT. The focus of the analysis was on the performance achieved in the frequency range around E-band frequencies of 71-76 GHz and 81-86 GHz. The motivation for investigating InP DHBT technology is based on the high power densities reported for these devices in the frequency range of interest, as indicated in fig. 1. It can be depicted from the figure that InP DHBT devices exhibit very high power densities outperforming HEMT and SiGe HBT devices over the whole frequency range beyond 100 GHz. However, at the same time the periphery of InP DHBT based amplifiers is relatively small as can be depicted in fig. 2. When larger peripheries are considered HEMT devices clearly outperform HBT type technologies. One of the reasons for the small periphery for

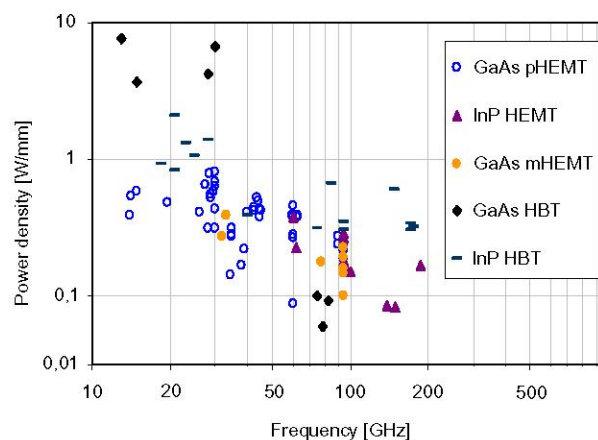


Fig. 1. Power density versus frequency for different device technologies.

the InP DHBT technology is the focus on optoelectronic high-speed circuit rather than analog circuit applications. On the other hand, power-added efficiency of InP DHBT can compete with that of HEMT devices as is demonstrated in fig. 3. It should be noted that the results for SiGe HBT are at lower frequencies compared to most of the results on InP HBT and HEMT technologies. From the figure it can be concluded that with an output power of around 100 mW and power-added efficiencies of around  $\eta_{add} \geq 15\%$  InP DHBT technology would be comparable to the InP HEMT technology, which

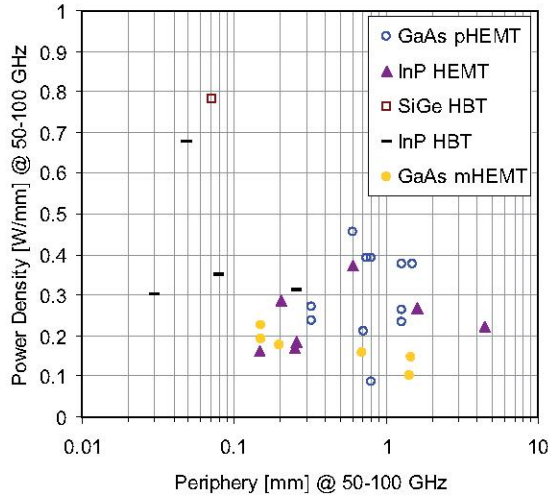


Fig. 2. Power density versus periphery for different device technologies. The data contains results in the frequency range between 50 - 100 GHz.

represents state-of-the-art performance until today for this frequency range.

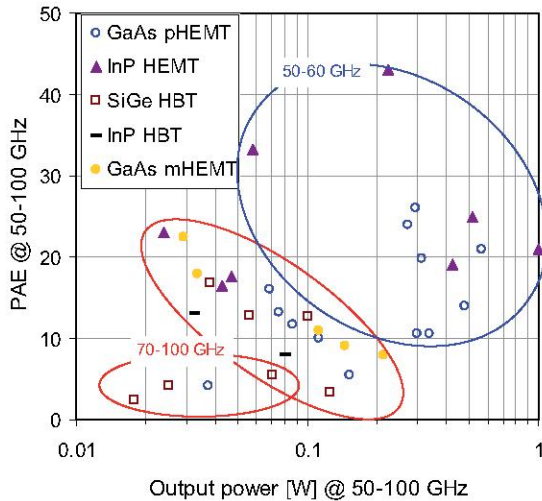


Fig. 3. Power-added efficiency versus the maximum output power for different device technologies. The data contains results in the frequency range between 50 - 100 GHz. Note that the results for SiGe HBT are for the frequency range  $50 \leq f \leq 77$  GHz.

Another import parameter is the breakdown voltage and the according bias conditions for the amplifier. A high breakdown voltage facilitates power-added efficiency and improves the matching design. In principle, the same arguments apply at millimeter-wave frequencies as those at microwave frequencies with regards to the advantages of GaN technology. Also at millimeter-wave frequency the technology with a high breakdown voltage will have a fundamental advantage in power amplifier design. The implication of the breakdown voltage

can be viewed from the data available on the bias voltage for the respective technology. In fig. 4 we show the available data on the bias voltage versus frequency. It can be depicted that InP DHBT technology operates at highest voltages in the millimeter-wave range and has an intrinsic advantage when scaling to even higher frequencies, as demonstrated by the data beyond 100 GHz operating frequency.

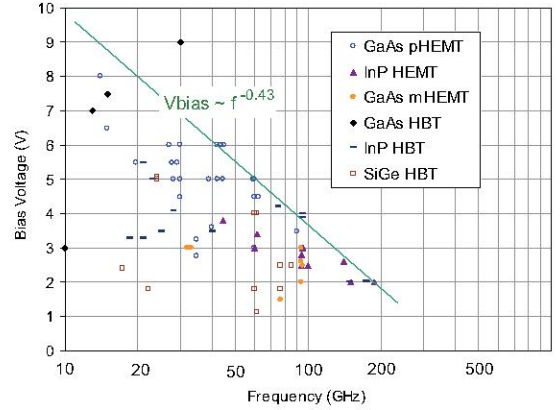


Fig. 4. Bias voltage versus frequency for different device technologies.

From the above discussion it is clear that a demonstration of a power amplifier in InP DHBT technology will provide a power amplifier with state-of-the-art performance in terms of power-added efficiency and output power.

### III. POWER AMPLIFIER DESIGN

The design of the power amplifier is based on InP DHBT technology provided by Alcatel-Thales III-V laboratory, which is the same as the one employed by the authors in an earlier publication on design of VCO for this frequency range [19]. The active device models have been developed earlier and presented in [20]. The simplified schematic is shown in fig. 5.

The devices have a gain of  $G = 6.3\text{dB}$  at 73GHz and operate at a bias point of  $V_{bias} = 2.4\text{V}$  and  $I_{bias} = 20\text{mA}$ . This operating conditions gives sufficient safe-operating margin and linear operation as required in communications systems.

As depicted in the figure the amplifier is based on a driver stage and a high power stage. Each stage is constructed using 8 emitter fingers, which provides a driver circuit saturating at high power levels and improves the linear performance.

The optimum load impedance for the power stage devices is  $Z_L = (48 + j38)\Omega$ . The interstage matching transforms the optimum large-signal input impedance of the power stage into the optimum load impedance of the driver stage. The input of the driver stage is matched using small-signal impedance levels for minimum small-signal reflections. All networks are additionally simulated using EM simulation tools. The layout of the amplifier is presented in fig. 7

Great care has been put on the stabilization of the amplifier. In fact, the amplifier circuit is unstable when matched for maximum power, and the base resistance is used for both



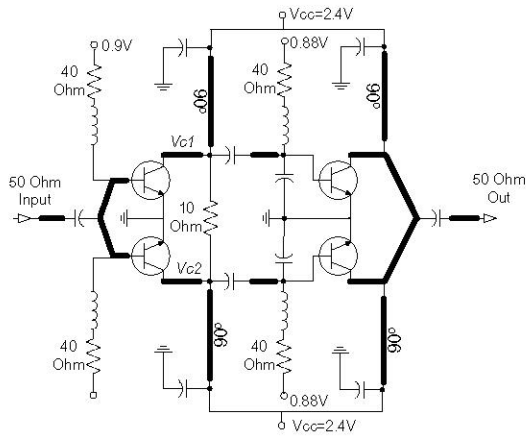


Fig. 5. Principal circuit diagram of the power amplifier.

electrical and thermal stabilization of each amplifier stage. We have achieved a Rollet constant of above 2.5 over the overall frequency range.

Another stability test is performed such that the two parallel transistor-cells are excited in odd mode and oscillations are observed. If the oscillations decrease with time and vanish, the circuit is regarded to be stable to this mode. The results of such a study are presented in fig. 6, where the time waveforms for two different conditions are shown as a function of time. It can be seen that without the stabilizing resistors, an odd mode excitation is potentially excited and will lead to strong oscillations. Introducing a  $10\Omega$  resistor eliminates the instability problem.

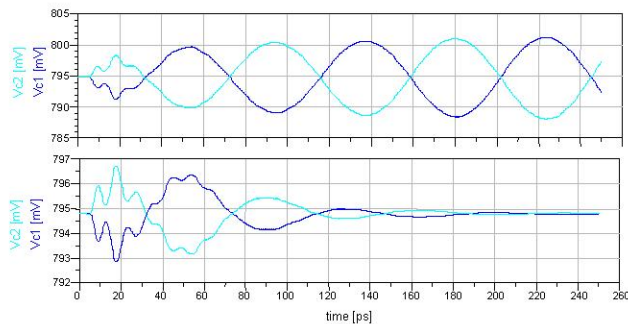


Fig. 6. Time evolution of an odd mode excitation to test the stability of the amplifier. The lower time waveform represents results for a circuit containing a  $10\Omega$  stabilizing resistor.

#### IV. POWER AMPLIFIER PERFORMANCE

The power amplifier circuit described above achieves an output power in excess of 20 dBm. The 1dB compression point power level is just below the 20 dBm resulting in  $P_{1dB} = 19.6\text{ dBm}$ . The output power versus input power is illustrated in fig. 8 together with the power-added efficiency and gain characteristics. It can be concluded from the figure that the power-added efficiency peaks at around  $\eta = 15\%$  around the

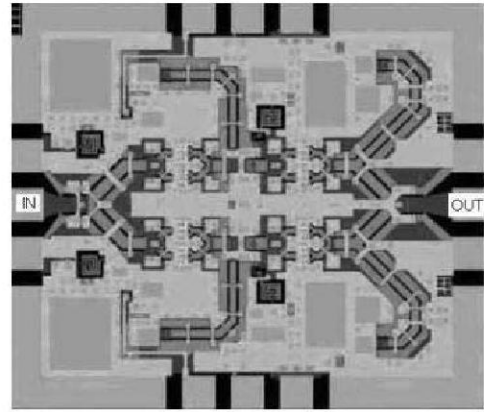


Fig. 7. Layout of the power amplifier

saturation point and is  $\eta > 10\%$  at 1dB compression point. The associated gain is around  $G = 8.5\text{ dB}$ . The achieved 1dB-bandwidth is 63.5 – 75.5 GHz, which is equivalent to 12% relative bandwidth, with a stability constant value of  $K = 3.2$ . The output periphery for the amplifier is  $160\text{ }\mu\text{m}^2$  and the

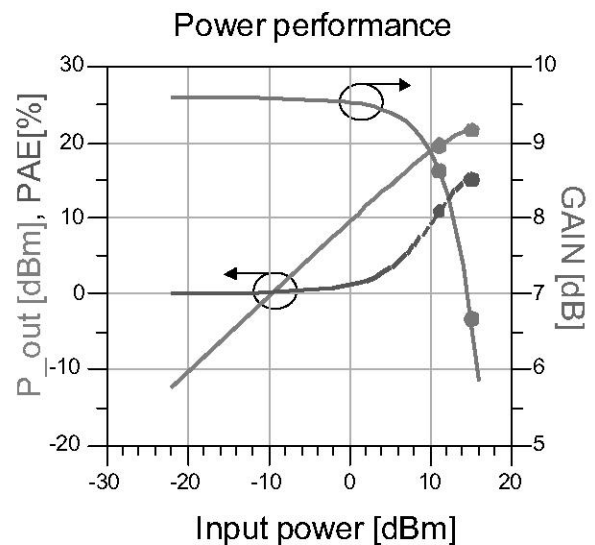


Fig. 8. Output power, power-added efficiency and gain as a function of available input power for the E-band power amplifier.

total current consumption is 330 mA. In the frequency range of operation the return loss is  $RL > 12\text{ dB}$  for both the input and output of the amplifier.

#### V. CONCLUSIONS

We have presented an E-band amplifier based on InP DHBT technology exhibiting a record saturated output power greater than 100mW and 1 dB output power around 95mW. The power-added efficiency predicted from simulations is 15% at saturated power. The circuit design is based on an HBT model developed earlier by the authors. The stability of the overall

amplifier is ensured using resistive loading and dedicated transient simulations with odd-mode excitation have been performed to verify the stability in all operating conditions.

The choice of the technology is based on a detailed analysis of different device technologies at E-band frequencies. The paper demonstrates that InP DHBT devices offer very high power densities and high breakdown voltages. These two parameters are regarded as key parameters in achieving good power amplifier performance.

## REFERENCES

- [1] L. Marosi, M. Sholley, J. Goel, A. Faris, M. Siddiqui, D.I. Stones, and K. Tan. 94 ghz power amplifier using pHEMT technology. *IEEE MTT-S International Microwave Symposium Digest*, 3:1597–1600, 1995.
- [2] Fraunhofer IAF. Mmics for 200 ghz and higher. Brochure.
- [3] Fraunhofer IAF. Power amplifier design for lmds and radar applications. Annual Report, 2001.
- [4] TriQuint Semiconductor. 2W Q-Band High Power Amplifier, TGA4046. Datasheet, September 2005.
- [5] A. Bessemoulin, S. Mahon, A. Dadello, G. McCulloch, and J. Harvey. Compact and Broadband Microstrip Power Amplifier MMIC with 400-mW Output Power Using 0.15- $\mu\text{m}$  GaAs PHEMTs. *European Gallium Arsenide and Other Semiconductor Application Symposium, GAAS 2005*, pages 41–44, 2005.
- [6] P.M. Smith, C.T. Creamer, W.F. Kopp, D.W. Ferguson, P. Ho, and J.R. Willhite. A high-power q-band pHEMT for communication terminal applications. *1994 IEEE MTT-S International Microwave Symposium Digest (Cat. No. 94CH3389-4)*, pages 809–12 vol.2, 1994.
- [7] M.V. Aust, A.K. Sharma, O. Fordham, R. Grundbacher, R. To, R. Tsai, and R. Lai. A highly efficient q-band mmic 2.8 watt output power amplifier based on 0.15 $\mu\text{m}$  ingaas/gaas pHEMT process technology. *Compound Semiconductor Integrated Circuit Symposium, 2005. CSIC '05. IEEE*, pages 228–231, 2005.
- [8] F.Y. Colomb and A. Platzker. A 3-watt q-band gaas pHEMT power amplifier mmic for high temperature operation. *Microwave Symposium Digest, 2006. IEEE MTT-S International*, pages 897–900, 2006.
- [9] L. Samoska, A. Peralta, M. Hu, M. Micovic, and A. Schmitz. A 20 mW, 150 GHz InP HEMT MMIC Power Amplifier Module. *Microwave and Wireless Components Letters, IEEE*, 14(2):56–58, 2004.
- [10] P. Huang, R. Lai, R. Grundbacher, and B. Gorospe. A 20-mw g-band monolithic driver amplifier using 0.07- $\mu\text{m}$  inP hEMT. *Microwave Symposium Digest, 2006. IEEE MTT-S International*, pages 806–809, 2006.
- [11] A. Tessmann, A. Leuther, C. Schwoerer, and H. Massler. Metamorphic 94 ghz power amplifier mmics. *Microwave Symposium Digest, 2005 IEEE MTT-S International*, page 4 pp., 2005.
- [12] Dong Min Kang, Ju Yeon Hong, Jae Yeob Shim, Jin-Hee Lee, Hyung-Sup Yoon, and Kyung Ho Lee. A 77 ghz mHEMT mmic chip set for automotive radar systems. *ETRI Journal*, 27(2):133–139, 2005.
- [13] J.R. Guthrie, M. Urteaga, D. Scott, D. Mensa, T. Mathew, Q. Lee, S. Krishnan, S. Jaganathan, Y. Betser, and M.J.W. Rodwell. HBT MMIC 75 GHz and 78 GHz power amplifiers. *Conference Proceedings. 2000 International Conference on Indium Phosphide and Related Materials (Cat. No. 00CH37107)*, pages 246–9, 2000.
- [14] Vamsi K. Paidi, Zach Griffith, Yun Wei, Mattias Dahlstrom, Miguel Urteaga, Navin Parthasarathy, Munkyo Seo, Lorene Samoska, Andy Fung, and Mark J. W. Rodwell. G-band (140-220 GHz) and W-band (75-110 GHz) InP DHBT medium power amplifiers. *IEEE Transactions on Microwave Theory and Techniques*, 53(2):598–605, 2005.
- [15] S. Reynolds, B. Floyd, U. Pfeiffer, and T. Zwick. 60ghz transceiver circuits in sige bipolar technology. *2004 IEEE International Solid-State Circuits Conference (IEEE Cat. No. 04CH37519)*, pages 442–538 Vol.1, 2004.
- [16] Ullrich R. Pfeiffer, Scott K. Reynolds, and Brian A. Floyd. A 77 ghz sige power amplifier for potential applications in automotive radar systems. *Digest of Papers - 2004 IEEE Radio Frequency Integrated Circuits (RFIC) Symposium and IEEE Radio Frequency Integrated Circuits Symposium, RFIC, Digest of Technical Papers*, pages 91–94, 2004.
- [17] U.R. Pfeiffer. A 20dbm fully-integrated 60ghz sige power amplifier with automatic level control. *Solid-State Circuits Conference, 2006. ESSCIRC 2006. Proceedings of the 32nd European*, pages 356–359, 2006.
- [18] Abbas Komijani and Ali Hajimiri. A wideband 77ghz, 17.5dbm power amplifier in silicon. *Custom Integrated Circuits Conference, 2005. Proceedings of the IEEE 2005*, pages 571–574, 2005.
- [19] D. Hadziabdic, T.K. Johansen, V. Krozer, A. Konczykowska, M. Riet, F. Jorge, and J. Godin. 47.8 ghz inP hbt quadrature vco with 22 *Electronics Letters*, 43(3):153–154, 2007.
- [20] T.K. Johansen, V. Krozer, A. Konczykowska, M. Riet, and J. Vidkjaer. Large-signal modeling of high-speed inP dhbts using electromagnetic simulation based de-embedding. *2006 IEEE MTT-S International Microwave Symposium Digest (IEEE Cat. No. 06CH37734C)*, page 4 pp., 2006.