Final Report Summary - IN-POWER (InP DHBT MMIC Technology for Millimeter-Wave Power Applications)

The progress in semiconductor device technology, in particular compound semiconductor transistors such as High Electron Mobility Transistor (HEMT) and Heterojunction Bipolar Transistor (HBT) devices enables the development of wireless communication circuits operating at frequencies well above 100 GHz. The main bottleneck in these millimeter-wave wireless communication systems today is the power amplifier (PA) which sets the limit on the available transmission range. The overall objective of the "IN-POWER" project has been to develop an InP HBT technology optimized for millimeter-wave power applications. In order to evaluate the capabilities of the optimized InP DHBT technology, PA MMIC designs at E-band and higher mm-wave frequencies has been implemented.

The specific scientific and technological objectives of the "IN-POWER" project were the following:

- To optimize the circuit-oriented InP DHBT technology at III-V Lab towards power applications at mm-wave frequencies. This involves an optimization of the vertical structure and geometry of the existing devices for high fmax (approaching 500 GHz), high breakdown voltage (>6 V), and extended safe-
• To exploit commercially available software tools for thermal and electromagnetic (EM) simulation of power cell structures based on single- and multi-finger devices.
• To develop accurate electro-thermal large-signal models to aid the design of the mm-wave MMIC’s.
• To develop innovative design techniques for PA MMIC design at mm-wave frequencies. This includes techniques for effective on-chip power combination.

Starting from an existing InP DHBT technology for high-speed mixed-signal applications, the epitaxial structure of a single-finger DHBT has been optimized to fulfill the requirements set for the design of the power cell in terms of maximum cutoff frequency $f_{\text{max}}$ and breakdown voltage. The static and high-frequency performances of devices with different geometrical layout dimensions have been investigated to select the unit finger device with $f_{\text{max}} = 420$ GHz and breakdown voltage $> 7$ V. Single-finger devices have been combined in multi-finger structures to increase total output power. An approach based on 3D thermal simulations has been proposed to study heating effects in multi-finger devices and to extract thermal parameters for the device large-signal model. An optimized 4-finger device structure has $f_{\text{max}} = 370$ GHz and can deliver $P_{\text{out}} = 16$ dBm at $30$ GHz to an optimal load under class-A operation. As a further improvement to reduce thermal effects in multi-finger devices, a ballasting solution has been proposed as a trade-off between the improvement in device Safe Operating Area (SOA) and the degradation of high-frequency performances.

To extend the power capabilities of the InP DHBT technology at millimeter-wave frequencies, the possibility of applying the stacked-transistor concept has been investigated in details. An evaluation of the maximum number of stacked transistors for positive incremental power and gain has also carried out. To validate the analysis, two-, three-, and four-stacked matched power cells have been realized as monolithic microwave integrated circuits (MMICs) and tested for E-band operation. Various power amplifiers featuring parallel power combining have been designed as well. Promising results are obtained from a four-way combined three-stacked configuration and from a two-stage eight-way combined power amplifier, which achieves an output power higher than $21.4$ dBm. Ballasted multifinger devices have also been successfully applied to the design of E-band power amplifiers using InP DHBT technology.

The MMICs being demonstrated within the IN-POWER project represent a significant contribution suitable for further development of modern mm-wave wireless communication systems and high-resolution radar. For more information, please consult the project website [http://www.in-power.ems.elektro.dtu.dk/](http://www.in-power.ems.elektro.dtu.dk/).

**Last update:** 20 June 2018  
**Record number:** 231390