Preface

This licentiate thesis is composed of three different parts: a brief introduction, a report treating the main topic of modelling the Si/SiGe Heterojunction Bipolar Transistor (HBT) and four separate papers. Three of the papers have been previously published and one is at the moment in the reviewing process.

Report: Staffan Bruce
Report on HBT model

Paper 1: S. Bruce, A. Rydberg, H. Schumacher, U. Erben, J-F. Luy, M. Karlsteen and M. Willander
Development, implementation and verification of a physics-based SI/SiGe HBT model for millimetre-wave non-linear circuit simulations.
Published in Proc. of the 26th European Microwave Conference, vol 2, pp 903-905, 1996

Paper 2: S. Bruce, M. Kim, A. Rydberg, K. M. Strohm and F. Beiβwanger
On the design of a 55 GHz Si/SiGe HBT frequency doubler operating close to f_{max}
Published in Proc. of the 26th European Microwave Conference, vol 1, pp 297-299, 1996

Paper 3: S. Bruce, A. Trasser, M. Birk, A. Rydberg and H. Schumacher
Extraction of thermal time constant in HBTs using small signal measurements
Published in Electronics Letters, vol. 33, pp. 165-167, 1997.

Paper 4: S. Bruce, A. Rydberg, M. Kim, F. Beiβwanger, J-F. Luy, H. Schumacher, U. Erben, M. Karlsteen and M. Willander
Design and realization of a millimeterwave Si/SiGe HBT frequency multiplier
Submitted for publication in Microwave Theory and Techniques.

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Introduction

With a progress in SiGe technology, fabrication of high performance HBTs has become feasible and devices with f_{max} of 90 GHz in a common emitter configuration [1] have been achieved repeatably. This gives the possibilities of designing circuits operating in the millimeterwave region. In order to be able to account for large-signal effects occurring in such applications, e.g., power amplifiers, mixers and doublers, a large-signal model has to be developed.

Such a model, described in the report and paper 1, has been developed. The model is based on a modified Ebers-Moll model, where emphasis has been put on deriving model parameters from technological data, e.g., device geometry, and semiconductor physics. By partitioning the currents in the device between holes and electrons respectively, effects of the bandgap difference within the device are effectively accounted for which leads, e.g., to an easier modelling of the thermal effects. The thermal model is connected to the electrical model through an interface. Through the interface the internal power dissipation of the device is output as a current which, in the thermal model, is converted to a voltage corresponding to a temperature elevation of the device that is fed back to the electrical model. With the separation of the two models better convergence is achieved in the simulations. It is also possible to model different types of devices through a variation in thermal modelling, e.g., multi emitter-finger devices by coupling several electric model via a thermal network.

Comparisons between measured and calculated data of both DC and RF characteristics show that the model well predicts device performance within normal bias ranges, given a fitting of fundamental parameters towards measured data. The fitting towards measured data is necessary in order to account for variations in the fabrication process and non-ideal currents.

Using the transistor model, a frequency doubler for millimetre wave applications has been designed and is described in paper 2 and 4. With an output frequency of 55 GHz it operates close to the f_{max} of the transistor which in this case is 67 GHz. The rule of thumb for an oscillator is that the operating frequency should be smaller than one third of the f_{max}. It would thus mean that an f_{max} of approximately 165 GHz would be necessary. Such devices have been fabricated, but to achieve a higher reproducibility the demands should be lowered to an f_{max} of about 80 to 100 GHz which would yield an oscillator operating with, at highest, 30 GHz of output frequency. With an active frequency doubler it is instead possible to use gain in the device to amplify at the comparably low fundamental frequency which then is converted to its second harmonic.

Applications that a signal generator like the one designed can be used in are for example:

- car-to-car and car-to-road communication for the so called ‘intelligent highways’, operating at 60 GHz.
- car radar operating at 77 GHz for obstacle detection and active cruise controls.

- radio link operating at 55 GHz.

The design of the circuit has been done in MDS. To find the correct parameters for the embedding structure around the transistor, an iterative process has been employed. Ideal S-parameter blocks have initially been connected to the input and output of the transistor to find optimal matching circuits for doubler operation. With the acquired S-parameter blocks, an optimisation for matching circuits consisting of coplanar waveguide (CPW) elements is done. Due to the difference between ideal S-parameters blocks and the circuits consisting of CPWs, optimisation with an ideal S-parameter block for either input or output needs to be reiterated.

Measured results of a fabricated doubler showed a conversion from input at 27.5 GHz to output at 55 GHz of better than -12 dB which is comparable with a doubler circuit realised with a III-V HFET as active device [2]. Performance of the doubler circuit calculated using the large-signal model compare well with measured data. Prediction by the model using harmonic balance simulation at 55 GHz shows that a conversion efficiency for the Si/SiGe HBT of about 5 dB can be expected from future optimised circuits.

So far many models incorporate thermal modelling in the shape of an RC-circuit where the capacitive part accounts for the transient effects. Due to the thermal time constant, the circuit does not reach steady state instantaneously. Some papers have been published on the extraction of the thermal resistance, but very little have however been done for the capacitance. The work in paper 3 is aimed at addressing this question as it can be of great importance for applications where the large signal effects make the power dissipation vary greatly in very short moments of time, thus causing a variation in junction temperature which can affect operating point and thus also behaviour. The common method for finding the thermal time constant necessitates a good control of the power fed to the device during a very short period of time. In larger devices the time resolution can be allowed to decrease somewhat, but in applications using very small components, the time constant itself makes well controlled measurements in the time domain more difficult to control and a different method needs to be employed. The benefit with the now developed technique is that it operates in the frequency domain using small signal measurements which makes the need of a good power control somewhat obsolete. Furthermore the proposed method facilitates measurements of time constants down to 1 μs with very simple equipment. Simple refinements of the measurement equipment can also expand the range.

The common method should however not be ruled out as it does give a possibly more accurate value of the large-signal thermal time constant in structures. Since the common method measures the actual time for heating a circuit from a low level to a high level of power dissipation it may also account for secondary effects like crossheating between devices which is a very slow process compared to the internal heating and also will not occur during small signal measurements. A complete characterisation should therefore employ both methods.

In a wider perspective the proposed method should be usable for other three terminal devices where the transition between steady state and transient operation regarding the thermal effects can be clearly distinguished. Transitions relating to electrical effects, e.g., parasitics with similar time constants to the one of the thermal may obscure the results and complicate the extraction. A component that should show interesting properties for using this new measurement technique is the FET. The thermal dependence of the mobility in the channel causes a conductivity modulation which alters the electrical properties. For small devices this temperature increase may be too quick to measure with conventional methods.

References

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[2] H. Zirath, I. Angelov, N. Rorsman, C. Karlsson, and E. Kollberg, “A balanced W-band HFET doubler,” Proc. 23rd European Microwave Conf., pp. 837-839, Madrid, 1993.