SCALABLE DISTRIBUTED HEMT MODEL FOR

MILLIMETRE-WAVE APPLICATIONS

by

Shah Md. Eahteshamul Hoque

MACQUARIE
UNIVERSITY
SYDNEY ~ AUSTRALIA

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Department of Engineering
Faculty of Science
Macquarie University
Sydney, Australia

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ABSTRACT

A scalable HEMT model is highly desirable for device engineers. Modern electronic devices require scalability up to high frequencies and device engineers need more flexibility to design complex circuits. For high-frequency applications the scalable model should be able to accurately predict behaviour of the device. The major drawback is lack of a proper topology to represent a full device of any size and inaccurate techniques to separate the parameters from the measured data.

This thesis explores a distributed model of a HEMT and gives an error-free linear scaling technique for the extrinsic parameters of the device. A new technique was introduced to separate the access network from the active device, and the active device was modelled using a distributed technique. A new topology of unit cell is proposed, which can be used to analyse different HEMT devices and predict the behaviour of unmeasured devices sizes for high frequencies. This model also includes the distributed effects for various widths of devices, where a signal is propagated from the gate to drain metallisation. The effect of the manifold in a distributed model is explored for various widths of devices and a figure of merit of the model is discussed.

The linear scalable model was applied to compound devices, varying in the number of fingers and widths, and showed excellent agreement. The effects of the manifold on these HEMTs are explained with respect to the gain of the devices. The model is also used to analyse the drain-current behaviour of a HEMT and establishes linear relationships for the drain current in terms of the unit cell and device metallisation.

The model is applied to the determination of the maximum achievable gain-bandwidth product as a function of gate width. This defines the upper limit of achievable performance for further work, and a new and improved manifold and finger layouts.

STATEMENT OF ORIGINALITY

This research project was in collaboration with Macquarie University and Macom Technology solutions (formally Mimix Broadband). Prof. A. E Parker was my principle supervisor and Prof. M. Heimlich was my co-supervisor. Dr S. J. Mahon from Macom Technology Solutions provided co-supervisory support and facilitated access to devices and data.

The research work contained in this thesis was conducted over a period of three and half years and some results has been published. The order of the authorship corresponds to the contribution to that publication. The supervisors have been included in recognition of their supervisory roll. Mr J. Tarazi provided raw data and assisted in measurement. The research contributions by the author are listed below, by chapter.

Chapter 1 introduces the HEMT modelling technique and states the aims, scope and synopsis for the thesis. This was written by the author.

Chapter 2 presents background on the current state-of-the-art in the field of HEMT modelling and analysis. The background review was performed by the author. The review reports the works of others. This chapter also presents the measured data and extracted parameters. The model intrinsic and extrinsic parameters were extracted by the author using the parameter extraction procedure developed by A. E. Parker with the raw data provided by J. Tarazi.

My contribution to the research and in this chapter: Concept 50%; Data collection 0%; Analysis 90%; Writing 95%.

Chapter 3 introduces the concept of a distributed model and separation of the device access network and the active device. The analysis of this distributed model has been reported in:

- **M. E. Hoque**, M. Heimlich, J. Tarazi, A. E. Parker and S. J. Mahon, *"Scalable HEMT model for small signal operations," International Conference on Electromagnetics in Advanced Applications (ICEAA)*, pp. 309-312 Sept. 20-24, 2010, Sydney, Australia.

For this paper, the idea of using a distributed model was that of A. E. Parker. The devices were provided by Macom and J. Tarazi measured the HEMTs and provided the iFET model. The author developed the distributed model and analysed data. Prof. Heimlich suggested that the access network as a cause of the end-effects of device metallisation, which the author conformed by analysis. The author proposed and tested the access network topology. The author distributed the active device into a number of cells and assembled the device model including the access network. The manuscript was written by the author. Dr Mahon facilitated Macom support.

My contribution to the research and paper: Concept 50%; Data collection 0%; Analysis 90%; Writing 90%.

Chapter 4 reports an improvement of the distributed model and a scalable distributed model proposed by the author. The results of the scalable distributed model have been reported in:

- **M. E. Hoque**, A. E. Parker, and M. Heimlich, J. Tarazi and S. J. Mahon, *"Scalable distributed small-signal millimetre-wave HEMT model," In Proc. European Microwave Integrated Circuit Conference (EuMIC)*, pp. 374-377, Oct. 10-11, 2011, Manchester, UK.

For this paper, the author proposed the linear scalable unit-cell topology, linear rules for intrinsic and extrinsic the parameters, analysed data and wrote the manuscript. Mr

J. Tarazi provided the measured data of HEMTs and devices were supplied by Macom. Profs. Parker and Heimlich provided supervisory support.

My contribution to the research and paper: Concept 50%; Data collection 0%; Analysis 90%; Writing 80%.

In Chapter 5, the author reports the distributed effects in a HEMT by considering the device metallisation. The phase variation of RF signal propagating from gate to drain was analysed by the author. Prof. Parker suggested this line of investigation, which the author carried out. These phase responses are also reported in:

- **M. E. Hoque**, A. E. Parker, and M. Heimlich, J. Tarazi and S. J. Mahon, *"Scalable distributed small-signal millimetre-wave HEMT model," In Proc. European Microwave Integrated Circuit Conference (EuMIC)*, pp. 374-377, Oct. 10-11, 2011, Manchester, UK.

The minimum width of a unit cell with respect the RF signal wavelength was identified by the author. Prof. Heimlich suggested maximum available gain as a performance criteria of HEMT and the author determined the maximum achievable gain, and also identified the effect of the access network on the gain.

In Chapter 6, the author applied the scalable distributed model into multi-finger devices. Profs. Heimlich and Parker suggested a manifold model. The author modified and implemented various manifold models. The author analysed the effects of parallel fingers and spacing between the gates on gain for various widths of HEMT. The effects of manifold on gain at various frequency and a trade-off between number of parallel fingers and device widths was determined by the author. These results have been reported in:

- **M. E. Hoque**, A. E. Parker, M Heimlich and S. J. Mahon, *"Scalable HEMT distributed model for millimetre-wave applications," In Proc. Asia Pacific Mi-*

crowave Conference (APMC), pp. 351-354 Dec. 5-8, 2011, Melbourne, Australia.

For this paper, the author measured the parallel finger devices in the laboratory for verification of multi-finger device model. The manuscript was written by the author. Profs. Parker and Heimlich and Dr Mahon provided supervisory support.

My contribution to the research and paper: Concept 60%; Data collection 80%; Analysis 90%; Writing 90%.

The author carried out a simulation study in Chapter 7, that provides a case study of drain-current characterisation in terms of device metallisation for various frequency, device widths and number of fingers. These results have been reported in:

- **M. E. Hoque**, M. Heimlich, A. E. Parker and S. J. Mahon, *"Performance analysis of distributed HEMT model with geometry," In Proc. Wireless and Microwave Technology Conference (WAMICON)*, pp. 1-4, April 15-17 2012 Florida, USA.

In this paper, the relation between the unit cell drain current and the whole device drain current was analysed by the author using rules proposed by the author. The manuscript was written by the author. Prof. Parker and Heimlich provided supervisory support. Dr Mahon facilitate access to devices and data.

My contribution to the research and paper: Concept 100%; Data collection 50%; Analysis 95%; Writing 95%.

In Chapter 8 the author summarises the outcomes of this thesis and provides a guideline to improve the performance of the device for future work.

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Shah Md. Eahteshamul Hoque (Student ID 41458141)

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Finally, I would like to thank my parents and wife who have always been proud of me and were always there for me. I could never ask for more.

To My Parents and Wife

Abbreviations

AlGaN	Aluminium Gallium Nitride
BJT	Bipolar Junction Transistor
CAD	Computer Aided Design
CCCS	Current Controlled Current Source
dc	Direct Current
DUT	Device Under Test
FET	Field-Effect Transistor
GaAs	Gallium Arsenide
GaN	Gallium Nitride
HBT	Heterojunction Bipolar Transistor
HEMT	High Electron Mobility Transistor
HFET	Heterostructure FET
EM	Electromagnetic (Simulations)
IMD	Intermodulation Distortion
MESFET	Metal Semiconductor Field-Effect Transistor
MMIC	Monolithic Microwave Integrated Circuit
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
N	Number of unit cells
N_F	Number of gate fingers

N_{MIN}	Minimum number of unit cell in the device
PDA	Personal Digital Assistant
P_F	Pair of gate fingers
pHEMT	Pseudomorphic High Electron Mobility Transistor
RF	Radio Frequency
Si	Silicon
TEGFET	Two-dimensional Electron Gas FET
UC	Unit Cell
W	Width per gate finger
W_T	Total width of device
W_{uc}	Width of one unit cell
W_{ucMAX}	Maximum width of one unit cell
2DEG	Two Dimensional Electron Gas

List of Publications

- **M. E. Hoque**, M. Heimlich, A. E. Parker and S. J. Mahon, *"Performance analysis of distributed HEMT model with geometry," In Proc. Wireless and Microwave Technology Conference (WAMICON)*, April 15-17 2012 Florida, USA.

- **M. E. Hoque**, A. E. Parker, M Heimlich and S. J. Mahon, *"Scalable HEMT distributed model for millimetre-wave applications," In Proc. Asia Pacific Microwave Conference (APMC)*, pp. 351-354 Dec. 5-8, 2011, Melbourne, Australia.

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