Contents

Introduction **1**

1 Modelled HEMT Technologies **4**
1.1 Strained-Si/SiGe mHEMT 4
1.2 Low Noise- and Power AlGaAs/GaAs pHEMT 9
1.3 InGaAs/InP pHEMT 11

2 Modelling of Frequency Dispersion in HFETs **13**
2.1 Physical- Versus Empirical Large-Signal Modelling 13
2.2 Effects of Frequency Dispersion in HFET Devices 16
2.3 State-of-the-Art Modelling Approaches 18
2.3.1 Thermal models 18
2.3.2 Static- and Dynamic Current Sources 19
2.3.3 Equivalent Voltage Sources 21
2.4 Importance of a Dispersion Model in Circuit Design 22
2.4.1 Static Analysis 22
2.4.2 Small-Signal Circuits 23
2.4.3 Large-Signal Frequency Domain Circuits 24
2.4.4 Large-Signal Time Domain Circuits 25
2.4.5 System Level 26
2.5 Obtaining Dynamic IV Characteristics 26
2.5.1 Pulsed-IV Characterisation 27
2.5.2 Numerical Integration of Dynamic Trans- and Output Conductance . 28

3 Universal Large-Signal HFET Model **33**
3.1 Advanced De-embedding Technique 33
3.2 Static Model 37
3.2.1 Modified COBRA drain current model 37
3.2.2 Gate current model 43
3.3 Dynamic Model 45
3.3.1 Multi-Bias Small-Signal Model Extraction 45
3.4 Nonlinear Capacitance Model 47

3.4.1 A Unified Approach to Charge-Conservative Capacitance Modelling . 48
3.4.2 A Universal HFET Capacitance Model 50
3.5 Multiple Time-Constant Dispersion Model 54
3.5.1 Physical Motivation 54
3.5.2 Single Time-Constant Dispersion Model 55
3.5.3 Multiple Time-Constants 57
3.5.4 Determination of Dispersion Time Constants 58
3.6 Parameter Extraction Software FETfit 66
3.7 Model Implementation 66
3.7.1 Implementation of nonlinear capacitance 69
3.7.2 Schematic level parameters 71
3.8 Small- and Large-Signal Model Verification 72

4 MMIC Applications 78
4.1 SiGe mHEMT Travelling-Wave Amplifiers 78
4.1.1 Transmission Line- and Active Device Models 79
4.1.2 Common-Source Stage Distributed Amplifier 80
4.1.3 Cascode Stage Distributed Amplifier 86
4.2 GaAs pHEMT Travelling-Wave Mixer and Variable Gain Amplifier 89
4.2.1 Unit Cell Topology and Operation Principle 89
4.2.2 Circuit Design and Layout 91
4.2.3 VGA Operation 92
4.2.4 Mixer Operation 98

5 Conclusion 102

Bibliography 105

List of Acronyms and Symbols 117

A Dynamic Small-Signal FET Model Equations 121

B Model Parameters, Equations and Derivatives 122

C Detailed Model Parameters and Verification 131
C.1 Strained-Si/SiGe mHEMT 131
C.2 Low-noise AlGaAs/GaAs pHEMT 136
C.3 Power AlGaAs/GaAs pHEMT 141
C.4 InGaAs/InP pHEMT 145

D SiGe mHEMT Two Metal Layers Process 150