Contents

1 Review of Gyrotron Traveling-Wave Tube Amplifiers 1
1.1 Microwave Electronics 1
1.2 Electrons Cyclotron Maser and Gyrotron 4
1.2.1 The Principle of ECM 4
1.2.2 The Characteristics of a Gyrotron 6
1.2.3 The Category of Gyrotron Tubes 7
1.3 Gyrotron Traveling-Wave-Tube Amplifiers 10
1.3.1 The Development of Gyro-TWTs 10
1.3.2 Comments on Technologies 14
1.3.3 Problems and Prospects 19
References 21

2 Fundamental Theory of the Electron Cyclotron Maser 27
2.1 Introduction 27
2.2 Theory of the Waveguides 29
2.2.1 Theory of Uniform Dielectric-Loaded Waveguide 30
2.2.2 Theory of Periodic Dielectric-Loaded Waveguide 34
2.3 Theory of the Electron Cyclotron Maser in Waveguide System 39
2.3.1 Partitioning the Transverse Plane of an ECM System 40
2.3.2 The Linear Theory of Dielectric-Lined ECM System 42
2.3.3 The Nonlinear Theory of Dielectric-Loaded ECM System 45
2.3.4 Basic Concepts 47
2.4 Summary 50
Appendix I: Derivation of the Linear Theory in Dielectric-Lined Waveguide 50
1. The Field Expression in GCC 51
2. The Transverse Perturbed Beam Current 52
3. The Laplace Transformation 55
References 58

3 Novel Propagation Characteristics of Lossy Dielectric-Loaded Waveguides 61
3.1 Introduction 61
3.2 Dielectric Loss-Induced Modal Transition 63
3.2.1 Eigenvalue and Mode Identification 63
3.2.2 Modal Transition 66
3.2.3 Modal Degeneration 69
3.2.4 Modal Selection 71
3.3 Periodic DL Waveguide with Suppressed Property of Periodicity 74
3.3.1 Eigenvalue and Mode Identification 75
3.3.2 Influence of Dielectric Slot Ratio 75
3.3.3 Modal Transition in a Periodic Dielectric Waveguide System 78
3.3.4 Suppressing the System Periodicity Using Dielectric Loss 81
3.4 Mode Mapping 82
3.5 Conclusion 87
References 88

4 Instability Competition in an Ultrahigh Gain Gyro-TWT Amplifier 91
4.1 Introduction 91
4.1.1 Analysis Method of the Instability Competition 92
4.1.2 The Key Factors of Instability Competition 93
4.2 Balance Between the Backward Wave and Forward Wave in an Absolute Instability 94
4.2.1 Internal Feedback Dynamics of an Absolute Instability 96
4.2.2 Magnetic Tuning 98
4.2.3 High-Order Axial Mode 101
4.2.4 Waveguide Wall Loss 104
4.2.5 A Multistage Interaction Gyro-TWT Circuit 106
4.3 Oscillation with Multi-steady States 109
4.3.1 Self-Consistent Nonlinear Instability Study 109
4.3.2 Attenuation Strength of the Lossy Linear Stage 110
4.3.3 Multi-steady States of Absolute Instability Oscillation 111
4.3.4 Applying Magnetic Field Tapering to Enhance Nonlinear Stage Stability 114
4.3.5 Influence of the Downstream Port Reflection 116
4.3.6 Pre-bunched ECM Radiation 117
4.4 Summary 118
References 119

5 A Lossy Ceramic-Loaded Millimeter-Wave Gyro-TWT Amplifier 121
5.1 Introduction 121
5.2 Propagation Characteristics Approximation 123
5.2.1 The Propagation Characteristics of the Dielectric-Loaded Waveguide 123
5.2.2 Linear and Nonlinear Instability Study 126
5.3 Linear Study of Full-Wave Interaction in Dielectric-Loaded Waveguide 132
5.3.1 Linear Instability Competition Study 133
5.3.2 Linear Growth Rate Study 135
5.4 Nonlinear Study of Full-Wave Interaction in Dielectric-Loaded Waveguide 137
5.4.1 Nonlinear Instability Competition Study 138
5.4.2 Amplification Characteristics 140
5.5 Beam-Wave Coupling Strength 143
5.6 Summary 149
References 149

6 Exploring New Mechanisms for High Power Millimeter-Wave Gyrotron Amplifiers 151
6.1 Introduction 151
6.2 An ECM-Cascaded Amplifier 153
6.2.1 The Concept of ECM-Cascaded Amplifier 154
6.2.2 Beam-Wave Interaction in an ECM-Cascaded Amplifier 155
6.2.3 Discussion 157
6.3 High-Order Mode Drift Tube 158
6.3.1 The Concept of High-Order Mode Drift Tube 158
6.3.2 Beam-Wave Interaction in Overmoded Drift Tube 159
6.3.3 Discussion 161
6.4 High-Power Gyrotron Amplifier Based on Bi-modes Operation 161
6.4.1 The Concept of Bi-modes Operation 161
6.4.2 The Principle of Bi-modes Operation 163
6.5 High-Power Gyrotron Amplifier Based on ECM-Cascade and Pre-bunching Scheme (Gyro-CPA) 164
6.5.1 Key Technologies Related to a Gyro-CPA 164
6.5.2 Principle of Amplifier Based on ECM Cascade and Pre-bunching Excitation 165
6.5.3 Discussion 171
6.6 Conclusion 171
References 172

7 Technologies Related to Gyrotron Amplifiers 175
7.1 Introduction 175
7.2 Input Coupler 176
7.2.1 A Ka-Band TE_{11} Mode Input Coupler 177
7.2.2 A Ka-Band TE_{01} Mode Input Coupler 178
7.2.3 A W-Band Multichannel TE_{01} Mode Converter 178
7.3 Broadband Output Window 181
7.3.1 A Ka-Band TE_{11} Mode Output Window 181
7.3.2 A Ka-Band TE_{01} Mode Output Window 182
7.4 A Small-Orbit Gun 182
7.5 Measurement of Lossy Dielectric Materials 185
7.6 Summary 190
References 191