Contents

Preface xi

Introduction 1

1 Fundamentals of Electromagnetics 7

1.1 RF and Microwave Frequency Ranges 7
1.2 Fields 9
1.3 Electromagnetics 10
1.3.1 Electric Field and Flux Density 10
1.3.2 Magnetic Field and Flux Density 17
1.3.3 Electromagnetic Field 22
1.3.4 Electromagnetic Wave 25
1.3.5 Antennas and Near Field 28
1.4 RF and Microwave Energy 30
1.4.1 Power and Energy 30
1.4.2 Influence of the Waveform 33
1.4.3 Blackbody Radiation 33
Planck's Radiation Law *34*
Rayleigh–Jeans Radiation Law *35*
Stefan–Boltzmann Law *38*
Wien Displacement Law *38*
Wien Radiation Law *39*
1.5 Penetration in Biological Tissues and Skin Effect 39
1.6 Relaxation, Resonance, and Display 44
1.6.1 Relaxation in Dielectrics 44
1.6.2 Resonance Absorption 45
1.6.3 Cole–Cole Display 47

1.7 Dielectric Measurements 49
1.7.1 RF Measurements 49
1.7.2 Microwave Measurements 50
1.7.3 Liquids 51
1.7.4 Applicators 52
1.8 Exposure 53
References 54
Problems 55

2 RF/Microwave Interaction Mechanisms in Biological Materials 63

2.1 Bioelectricity 63
2.1.1 Fundamentals 63
2.1.2 Cells and Nerves 65
2.1.3 Bioelectric Phenomena 69
2.2 Tissue Characterization 69
2.2.1 Ionization and Nonionization 70
2.2.2 Dielectric Characterization 70
Dipolar Orientation 71
Interfacial Relaxation 71
Ionic Diffusion: Counterion Polarization Effects 72
2.2.3 Dielectric Dispersion in Tissues 73
Conductivity 74
Permittivity 75
2.2.4 Measurements 75
Tissues 75
Liquids 77
Influence of Temperature 80
2.3 Thermodynamics 82
2.4 Energy 85
References 89
Problems 91

3 Biological Effects 93

3.1 Absorption 93
3.1.1 Fundamentals 93
3.1.2 Dosimetry and SAR 94
3.1.3 Thermal Considerations 96
3.2 Nervous System 100
3.2.1 General Description 101
3.2.2 Effects on Brain and Spinal Cord 103

3.2.3 Blood–Brain Barrier 104
3.2.4 Influence of Parameters of Microwave Exposure 107
3.2.5 Nervous System Modeling and Simulation 110
3.3 Cells and Membranes 114
3.4 Molecular Level 116
3.5 Low-Level Exposure and ELF Components 117
3.5.1 Microwave Syndrome 117
3.5.2 Low-Level Pulsed Exposure 118
3.5.3 ELF Components 119
3.6 Ear, Eye, and Heart 120
3.7 Influence of Drugs 123
3.8 Nonthermal, Microthermal, and Isothermal Effects 124
3.8.1 Microwaves as a Trigger 125
3.8.2 Entropy 128
3.9 Epidemiology Studies 131
3.10 Interferences 132
3.11 Radiation Hazards and Exposure Standards 134
3.11.1 Standards and Recommendations 134
3.11.2 Tissue Phantoms and SAR Measurements 136
3.11.3 Computational Methods for SAR Evaluation 139
3.11.4 Exposure of Body to Cell Phone and Base Station 140
References 142
Problems 150

4 Thermal Therapy 153

4.1 Introduction to Thermotherapy 153
4.2 Heating Principle 153
4.2.1 Foundations of Dielectric Heating Principle 154
4.2.2 RF Dielectric Heating Applicator 157
Theory 157
Actual Dielectric Heating Applicator Systems 159
4.2.3 Microwave Dielectric Heating 163
4.2.4 Foundation of Inductive Heating Principle 164
4.2.5 Actual Inductive Heating Applicator 166
4.2.6 Detailed Theory of RF Dielectric Heating 174
4.2.7 Detailed Theory of Microwave Dielectric Heating 177
4.2.8 Detailed Theory of Inductive Heating 179
4.3 Hyperthermia 182
4.3.1 Biological Background of Hyperthermia 183
Survival Rate and Hyperthermia Sensitivity of Cell 183
Oxygen Partial Pressure, pH, and Hyperthermia Sensitivity of Cell 184

Period and Hyperthermia Sensitivity of Biological Cell 185
Hyperthermia and Combined Effect of Radiation 186
4.4 Method of Thermometry 186
4.4.1 Invasive Thermometry 186
Measurement by Thermocouple Sensor 186
Thermometer Using Thermistor 191
Optical Fiber Thermometer 195
4.4.2 Noninvasive Thermometry 197
Thermometer Using IR Photodetector 197
Noninvasive Thermometry Using NMR Technique 198
References 199
Problems 202

5 EM Wave Absorbers Protecting Biological and Medical Environment 203

5.1 Foundation of EM Wave Absorbers 203
5.2 Classification of Wave Absorbers 204
5.2.1 Classification by Constituent Material 204
5.2.2 Classification by Structural Shape 205
Classification by Number of Layers 205
Classification by Appearance 205
5.3 Fundamental Principle 206
5.4 Fundamental Theory of EM Wave Absorbers 210
5.4.1 Single-Layer-Type Wave Absorber 210
5.4.2 Multilayer-Type Wave Absorber 213
Normal Incident Case 213
Oblique Incident Case 214
5.4.3 Taper-Type Wave Absorber 215
5.5 Application of EM Absorber 216
5.5.1 Quarter-Wavelength-Type Wave Absorber 216
5.5.2 Single-Layer-Type Wave Absorber 219
5.5.3 Multilayer Wave Absorber 219
5.5.4 Pyramidal Wave Absorber 221
5.6 EM Wave Absorbers Based on Equivalent Transformation Method of Material Constant 223
5.6.1 Microwave Absorber with Multiholes 223
Matching Characteristics 224
5.6.2 Weakly Magnetized Ferrite Absorber 232
5.6.3 Microwave Absorber with Surface-Printed Conductive Line Patterns 235
5.6.4 Integrated–Circuit-Type Absorber 239
5.7 Method for Improving RF Field Distribution in a Small Room 241

References 247
Problems 248

6 RF/Microwave Delivery Systems for Therapeutic Applications 250

6.1 Introduction 250
6.2 Transmission Lines and Waveguides for Medical Applications 251
6.2.1 Coaxial Cable 251
Cable Specifications *251*
Design Consideration *252*
Power Loss *252*
Low-Loss Fully Coaxial Cable *255*
Skin Effect *255*
Coaxial Cable for Microwave Balloon Angioplasty *256*
6.2.2 Circular Waveguide 258
Fundamentals *258*
Power Capacity of a Circular Waveguide *261*
6.3 Antennas 261
6.3.1 Fundamentals 261
6.3.2 Antenna Configurations 262
Electric Dipole *262*
6.4 RF and Microwave Ablation 264
6.4.1 Fundamentals 264
6.4.2 RF Development 267
6.4.3 Cardiac Ablation 270
6.5 Perfusion Chamber 279
6.5.1 General Description 279
6.5.2 Dose–Response Curve 282
6.5.3 Depth and Rate of Heating 282
6.5.4 Effects of Flow on Surface Temperature 284
6.5.5 Lesion Volume 284
6.5.6 Limitations 285
6.6 RF Gastroesophageal Reflux Disease 286
6.7 Endometrial Ablation 287
6.7.1 Microwave Endometrial Ablation 287
6.7.2 RF Endometrial Ablation 287
6.8 Microwave Measurement Techniques: Examples 288
6.8.1 Introduction 288
6.8.2 Method of Measuring Blood Perfusion (Flow) in Heart Muscle by Use of Microwave Energy 289
6.8.3 Lumen Measurement of Arteries Utilizing Microwave Apparatus 290
6.9 Future Research 294

6.9.1 Microwave Tissue Welding 294
In Vitro and In Vivo Experimental Studies *294*
Previous Approaches to Anastomosis *296*
Bench-Top Tests *297*
Doping Biological Solder *297*
In Vitro Vessel Anastomosis *299*
In Vivo Experiment *300*
6.9.2 Endoscopic Light Source and Microwaves for Photodynamic Therapy 301
6.9.3 Microwave Balloon Catheter 302
6.9.4 Thermally Molded Stent for Cardiology, Urology, and Other Medical and Veterinary Application 303
References 304
Problems 313

Index **315**