
Contents

Preface	xvii
Acknowledgments	xix
 Chapter 1 Fundamental Concepts in Electromagnetics	1
1.1 Introduction.....	1
1.2 Fields.....	1
1.2.1 Electric Fields.....	2
1.2.2 Magnetic Fields.....	3
1.2.3 Electromagnetic Fields.....	6
1.2.4 Electromagnetic Waves.....	7
1.3 Electromagnetic Induction.....	10
1.4 Electromagnetic Energy.....	12
1.5 Electromagnetic Spectrum.....	12
1.6 Sources of Electric and Magnetic Fields.....	14
1.6.1 DC Sources.....	14
1.6.1.1 Magnetosphere.....	15
1.6.1.2 Magnetic Resonance Imaging.....	16
1.6.1.3 DC Power Supply System.....	16
1.6.2 AC Sources.....	17
1.6.2.1 Single-Conductor Source.....	17
1.6.2.2 Dual-Conductor Source.....	18
1.6.2.3 Loop Source.....	18
1.6.2.4 Three-Phase Source.....	19
1.7 Sources of Radiofrequency Radiation.....	19
1.7.1 Generators.....	21
1.7.2 Transmission Paths.....	21
1.7.2.1 Transmission Lines.....	21
1.7.2.2 Coaxial Cables.....	22
1.7.2.3 Waveguides.....	22
1.7.3 Antennas.....	23
1.7.3.1 Antenna Properties.....	23
1.7.3.2 Types of Antennas.....	25
References.....	27
 Chapter 2 Electromagnetic Interactions with Biological Systems	29
2.1 Introduction.....	29
2.2 Interaction Mechanisms.....	30
2.2.1 Mechanisms for Electric and Magnetic Fields.....	30
2.2.1.1 Induced Fields and Currents.....	30
2.2.1.2 Thermal Noise.....	31

2.2.1.3	Shot Noise	32
2.2.1.4	Endogenous Fields	32
2.2.2	Mechanisms for Radio Frequency Radiation	32
2.2.2.1	Thermal Mechanisms	32
2.2.2.2	Nonthermal/Athermal Interaction Mechanisms	33
2.3	Electric Field Effects.....	34
2.3.1	Polarization of Bound Charges.....	34
2.3.2	Orientation of Permanent Electric Dipoles	35
2.3.3	Drift of Conduction Charges	35
2.3.4	Pearl-Chain Effects and Electrorotation	35
2.4	Magnetic Field Effects	36
2.4.1	Induced Currents	36
2.4.2	Magnetic Biosubstances	37
2.4.3	Radical Pairs.....	38
2.4.4	Cell Membrane and the Chemical Link	38
2.4.5	Summary of ELF Interaction Mechanisms.....	39
2.5	Biological and Health Effects	39
2.5.1	Cells and Membranes	39
2.5.2	Tissues	41
2.5.3	Changes in Protein Conformation.....	42
2.5.4	Changes in Binding Probability	42
2.5.5	Absorption of Vibrational States of Biological Components	43
2.5.6	Genetic Material.....	43
2.5.7	Carcinogenesis.....	44
2.5.8	Hypothesis of Melatonin	45
2.5.9	Cancer Mechanisms	46
2.5.10	Brain and Nervous System.....	47
2.5.10.1	Brain.....	48
2.5.10.2	Physiological Effects.....	49
2.6	Energy and Frequency	50
2.6.1	Effect of Frequency	50
2.6.2	Low-Frequency Fields from Demodulation	50
2.7	Concluding Remarks.....	51
	References	52

PART I Health Risks of Electromagnetic Energy

Chapter 3	Guidelines and Measurement for Electric and Magnetic Fields	59
3.1	Introduction.....	59
3.2	Exposure Guidelines	60
3.2.1	Institute of Electrical and Electronics Engineers.....	61
3.2.2	National Radiological Protection Board	62
3.2.3	International Commission on Nonionizing Radiation Protection.....	62
3.2.4	Swedish Standards.....	63
3.2.5	Restrictions	63

3.3	Measurement Techniques.....	63
3.3.1	Frequency and Object Size.....	63
3.3.2	Electric Field Measurements.....	64
3.3.3	Magnetic Field Measurements.....	65
3.3.4	Simplified Meters.....	66
3.4	Measurement Surveys.....	67
3.4.1	Sources of EMF Exposure.....	68
3.4.1.1	Residential Areas.....	68
3.4.1.2	Power Lines and Cables.....	68
3.4.2	Site Surveys.....	69
3.4.3	Electric Appliances.....	69
3.5	Dosimetry.....	72
3.6	Field Management.....	73
3.6.1	Mitigation Techniques for Power Lines.....	73
3.6.1.1	Underground Cables.....	73
3.6.1.2	Rights of Way.....	74
3.6.1.3	Cancellation Techniques.....	74
3.6.2	Reducing the Level of ELF Exposure.....	74
3.6.3	Mitigation of Electric Fields.....	75
3.6.4	Mitigation of Magnetic Fields.....	75
3.6.4.1	Passive Shielding Techniques.....	76
3.6.4.2	Active Shielding Techniques.....	77
3.6.5	Protection from VDTs.....	77
	References.....	78

Chapter 4 Bioeffects of Electric and Magnetic Fields..... 83

4.1	Introduction.....	83
4.2	Epidemiological Studies.....	83
4.2.1	Public Environments.....	84
4.2.1.1	Childhood Cancer and Leukemia.....	85
4.2.1.2	Breast Cancer.....	86
4.2.2	Occupational Environments.....	87
4.2.2.1	Adult Cancers.....	87
4.2.2.2	Cardiovascular Diseases.....	91
4.2.2.3	Neurodegenerative Diseases.....	91
4.2.2.4	Reproductive Toxic Effects.....	92
4.2.3	Summary of Epidemiological Studies.....	94
4.3	Cellular and Animal Studies.....	94
4.3.1	Melatonin Hypothesis.....	94
4.3.2	Genotoxicity and Carcinogenicity.....	95
4.3.3	Cell Functions.....	96
4.3.3.1	Intracellular Calcium.....	96
4.3.3.2	Cell Proliferation.....	96
4.3.3.3	Stress Response.....	97
4.3.3.4	Ornithine Decarboxylase (ODC).....	97
4.3.3.5	Immune System.....	97

4.3.4	Animal Cancer Studies.....	98
4.3.5	Noncancer Animal Studies.....	98
4.3.5.1	Behavioral Effects.....	98
4.3.5.2	Blood-Brain Barrier.....	99
4.3.5.3	Reproductive and Development.....	99
4.4	Clinical Studies.....	100
4.4.1	Perception and Sensitivity.....	100
4.4.2	Brain and Behavior.....	101
4.4.3	Cardiovascular System.....	102
4.4.4	Melatonin in Humans.....	102
4.5	Concluding Remarks and Future Research.....	103
4.5.1	Review Studies.....	104
4.5.2	Future Research.....	105
	References.....	105
Chapter 5	Radio Frequency Standards and Dosimetry.....	119
5.1	Introduction.....	119
5.2	RF Exposure Guidelines.....	120
5.2.1	Major Guidelines.....	120
5.2.2	IEEE Guidelines.....	121
5.2.2.1	IEEE Standard C95.1.....	121
5.2.2.2	IEEE Standard 1528.....	122
5.2.2.3	IEEE C95.1-2005.....	123
5.2.3	ICNIRP Guidelines.....	124
5.2.3.1	CENELEC EN 50392:2004.....	125
5.2.3.2	EC Directive 2004/40/EC.....	125
5.2.4	Safety Factors.....	127
5.2.5	Incorporating Specific Absorption Rate.....	127
5.3	Measurement Surveys.....	129
5.3.1	Base Transceiver Stations.....	130
5.3.1.1	Shielding.....	130
5.3.1.2	Exposure Levels.....	131
5.3.2	Broadcast Stations.....	132
5.3.3	Traffic Radar Devices.....	132
5.3.4	RF Heaters and Sealers.....	133
5.3.5	Microwave Ovens.....	133
5.3.6	RF Environmental Levels.....	133
5.3.7	Magnetic Resonance Imaging and Spectroscopy Systems.....	134
5.4	Personal Safety Assessment.....	134
5.4.1	Whole-Body Phantoms.....	134
5.4.2	In-Head Assessments.....	135
5.4.2.1	Adult Size Heads.....	136
5.4.2.2	Child Size Heads.....	137
5.4.2.3	Shielding for Mobile Antennas.....	140

5.5	Future Development.....	140
5.5.1	Harmonization of Safety Standards	141
5.5.2	Engineering Requirements and Dosimetric Information.....	142
References		143

Chapter 6 Bioeffects and Health Implications of Radiofrequency

	Radiation	149
6.1	Introduction.....	149
6.2	Epidemiological Studies.....	150
6.2.1	Occupational Exposure Studies.....	150
6.2.1.1	Navy Personnel and Military Workers.....	150
6.2.1.2	Traffic Radar Devices	151
6.2.1.3	RF Heat Sealers.....	151
6.2.1.4	Telecom Operators	151
6.2.2	Public Exposure Studies.....	152
6.2.2.1	Radio and TV Transmitters.....	152
6.2.2.2	Mobile and Cordless Phones	152
6.2.3	Summary of Epidemiological Studies.....	156
6.3	Cellular and Animal Studies.....	156
6.3.1	Genetic Toxicology.....	157
6.3.2	Cell Function	158
6.3.2.1	Cell Proliferation.....	158
6.3.2.2	Intracellular Calcium	158
6.3.2.3	Ornithine Decarboxylase	158
6.3.3	Hormonal Secretion.....	159
6.3.4	Animal Cancer Experiments.....	159
6.3.5	Noncancer Animal Studies.....	160
6.3.5.1	Morphological and Physiological Effects	160
6.3.5.2	Testicular Function and Development.....	160
6.3.5.3	Cataracts.....	160
6.3.5.4	Behavioral Effects.....	160
6.3.5.5	Blood-Brain Barrier	161
6.4	Clinical Studies.....	161
6.4.1	Perception and Auditory Response	161
6.4.2	Thermoregulatory Responses.....	162
6.4.3	Ocular Effects.....	163
6.4.4	Brain Function.....	163
6.4.5	Cardiovascular Diseases.....	165
6.4.6	Melatonin.....	165
6.5	Concluding Remarks and Future Research.....	165
6.5.1	Risk for Children	166
6.5.2	Research	167
References		168

Chapter 7	Electromagnetic Risk Analysis	179
7.1	Introduction	179
7.2	Risk Assessment	180
7.2.1	Scientific Evidence	180
7.2.2	Setting Standards	182
7.2.3	Structured Risk Assessment	183
7.3	Perception of Risk	183
7.3.1	Public Perception of Risk	184
7.3.2	Factors Relevant to Electromagnetic Fields	184
7.3.3	Health Consequences of Risk Perception	185
7.4	Risk Management	186
7.4.1	Involving the Public	186
7.4.2	Public Meetings	187
7.4.3	Precautionary Approaches	187
7.4.4	Public Understanding of Precautionary Actions	188
7.5	Risk Communication	188
7.5.1	Role of Communication in Risk Assessment	189
7.5.2	Role of Communication in Risk Management	189
7.5.3	Media Coverage	190
7.5.4	Role of Industry	191
7.5.5	Role of the Internet	191
7.5.6	Communication with Children	191
7.6	Trends and Future Research	192
7.6.1	Challenges and Implications	192
7.6.2	Research and Policy	193
7.6.3	Concluding Remarks	194
	References	194

PART II *Therapeutic Applications of Electromagnetic Energy*

Chapter 8	Electromagnetic Therapy	199
8.1	Introduction	199
8.2	History of Electromagnetic Therapy	201
8.3	Mechanism of Thermal Injury	202
8.4	Thermal Therapy Treatment Protocol	203
8.5	Possible Side Effects of Electromagnetic Energy and Heat	204
8.5.1	Tissue Physiology and Response to Heat	205
8.5.2	Cellular Responses	206
8.5.3	Immunological Effects	207
8.5.4	Cardiovascular Responses	207
8.5.5	Nervous System Responses	208
8.5.6	Carcinogenic Effects	209

8.6	Concluding Remarks	210
8.6.1	Risk Assessment	210
8.6.2	Trends in Equipment Development	211
8.6.3	Future Research Directions	212
	References	212
Chapter 9	Electromagnetic Hyperthermia	221
9.1	Introduction	221
9.2	Biological Rationale	222
9.2.1	Heat Alone	223
9.2.2	Heat and Radiation	224
9.2.3	Heat and Drugs	224
9.3	Types of Hyperthermia	224
9.3.1	Local Hyperthermia	225
9.3.1.1	External Local Hyperthermia	225
9.3.1.2	Intraluminal Local Hyperthermia	226
9.3.1.3	Interstitial Local Hyperthermia	227
9.3.2	Regional Hyperthermia	227
9.3.2.1	Deep Regional Hyperthermia	228
9.3.2.2	Regional Perfusion Hyperthermia	228
9.3.2.3	Other Regional Hyperthermic Techniques	229
9.3.3	Whole-Body Hyperthermia	229
9.3.4	Extracellular Hyperthermia	230
9.4	Hyperthermia Heating Devices	230
9.4.1	Techniques	231
9.4.1.1	Ultrasound	231
9.4.1.2	Radiofrequency	231
9.4.1.3	Microwaves	232
9.4.2	External RF Applicators	232
9.4.2.1	Capacitive Heating	232
9.4.2.2	Inductive Heating	233
9.4.2.3	Hybrid Heating Systems	234
9.4.3	External Radiative EM Devices	234
9.4.3.1	Single Applicators	235
9.4.3.2	Multielement Array Applicators	235
9.4.4	Interstitial and Intracavitary Devices	237
9.4.5	Nanotechnology-Based Sources	238
9.5	Hyperthermia with Other Modalities	240
9.5.1	Hyperthermia and Radiation	240
9.5.2	Hyperthermia and Chemotherapy	241
9.5.3	Hyperthermia and Radiochemotherapy	242
9.5.4	Hyperthermia and Gene Therapy	242
9.6	Status and Trends	243
9.6.1	Biological and Physiological Mechanisms	243
9.6.2	Technical and Clinical Challenges	243

9.6.3	Standardization.....	245
9.6.4	Future Research.....	245
	References.....	245
Chapter 10	Radio Frequency and Microwave Ablation.....	265
10.1	Introduction.....	265
10.2	Thermal Ablation Therapy.....	265
10.2.1	Minimally Invasive Procedures.....	266
10.2.2	Ablation Techniques.....	267
10.2.3	Clinical Applications.....	267
10.2.3.1	Liver	268
10.2.3.2	Lung	269
10.2.3.3	Prostate.....	269
10.2.3.4	Kidney.....	269
10.2.3.5	Breast.....	270
10.2.3.6	Bone	270
10.2.3.7	Cardiac Diseases.....	270
10.3	RF Ablation.....	271
10.3.1	Technical Considerations	271
10.3.1.1	Mechanisms	271
10.3.1.2	Electrodes and Approaches.....	272
10.3.1.3	Multiple Applicators	273
10.3.1.4	Localization	274
10.3.1.5	Thermal–Electrical Modeling.....	274
10.3.2	Clinical Advantages and Applications	275
10.3.2.1	Cancer Treatment.....	275
10.3.2.2	Cardiac Diseases.....	278
10.3.2.3	Snoring and Obstructive Sleep Apnea (OSA).....	279
10.3.3	Limitations	280
10.3.4	Complications.....	280
10.4	Microwave Ablation.....	282
10.4.1	Technical Considerations	282
10.4.1.1	Mechanisms	282
10.4.1.2	Antenna Designs	283
10.4.1.3	Multiple Insertions and Multiple Antennas	284
10.4.2	Clinical Advantages and Applications	285
10.4.2.1	Treating Cancer.....	285
10.4.2.2	Cardiac Diseases.....	286
10.4.2.3	Microwave Endometrial Ablation (MEA).....	288
10.4.3	Limitations	289
10.4.4	Complications.....	290
10.5	Trends and Future Research.....	290
10.5.1	Improved Techniques	290
10.5.2	Ablation in Clinical Practice.....	291
10.5.3	Future Research.....	292
	References.....	293

PART III Dosimetry and Imaging

Chapter 11	Electromagnetic and Thermal Dosimetry	311
11.1	Introduction	311
11.2	EM Interaction with Biological Materials	311
11.3	Modeling Power Deposition	314
11.3.1	Techniques for Low Frequencies	315
11.3.2	Techniques for Radiofrequency Radiation	315
11.3.2.1	Analytical Techniques	315
11.3.2.2	Numerical Techniques	315
11.4	Specific Absorption Rate Modeling	316
11.4.1	Thermal Dose	317
11.4.2	Thermal Measurements	318
11.5	Bioheat Equation	319
11.5.1	Pennes Model	319
11.5.1.1	Bioheat Equation	320
11.5.1.2	Limitations	321
11.5.1.3	Analysis Based on Pennes' Equation	321
11.5.2	Wissler Model	322
11.5.3	Stolwijk Model	323
11.5.4	Weinbaum-Jiji Model	323
11.5.5	Baish Model	324
11.5.6	Applications of Bioheat Transfer Models	324
11.6	Thermal Therapy Planning System	325
11.6.1	Objectives and Requirements	326
11.6.2	Developments in TTPS	327
11.6.3	Thermal Monitoring	327
11.7	Status and Trends	328
	References	328
Chapter 12	Thermometry and Imaging	337
12.1	Introduction	337
12.2	Development of Thermometry	338
12.3	Invasive Techniques	339
12.3.1	Thermoelectric Thermometry	339
12.3.2	Thermistor	340
12.3.3	Optical Fiber Thermometer	341
12.3.4	Applications and Comparison	341
12.4	Noninvasive Techniques	342
12.4.1	Ultrasound	343
12.4.1.1	Apparatus	343
12.4.1.2	Advantages and Limitations	344
12.4.1.3	Two- to Three-Dimensional Ultrasonography	344

12.4.2	Magnetic Resonance Imaging.....	345
12.4.2.1	Operation.....	346
12.4.2.2	Advantages	347
12.4.3	Microwave Radiometric Imaging	347
12.4.4	Terahertz Technology	348
12.4.4.1	Characteristics of THz Radiation.....	349
12.4.4.2	THz-Ray System.....	350
12.4.4.3	Challenges	351
12.4.5	X-Ray Computed Tomography	352
12.4.5.1	Conventional CT Scanners.....	352
12.4.5.2	Spiral (Helical) CT Scanners	352
12.4.5.3	Multislice CT Scanners	353
12.4.6	THz-Ray CT	353
12.5	Status and Trends.....	354
	References.....	355

Acronyms and Abbreviations.....	361
---------------------------------	-----

Index.....	365
------------	-----