Contents

Foreword		хi	
Pref	Preface		
CU/	APTER 1		
<u></u>		1	
Introduction to Body-Centric Wireless Communications			
1.1	What are Body-Centric Communications Systems?	1	
	1.1.1 Off- to On-Body Communications	5	
	1.1.2 On-Body Communications	6	
	1.1.3 Medical Implants and Sensor Networks	6	
1.2	Overview of Systems	8	
	1.2.1 Narrowband Systems	8	
	1.2.2 Wideband Systems	10	
1.3	Overview of Applications	11	
1.4	New Trends and Progress Since the First Edition	11	
	1.4.1 Propagation Characterization and Control	11	
	1.4.2 Measurement Methods	12	
	1.4.3 Antenna De-embedding	12	
	1.4.4 Materials	13	
	1.4.5 Modeling of Body Dynamics	13	
	1.4.6 Standardization	14	
1.5	Layout of the Book	14	
	References	15	
CH	APTER 2		
Elec	ctromagnetic Properties and Modeling of the Human Body	1 <i>7</i>	
2.1	Electromagnetic Characteristics of Human Tissues	17	
2.2	Physical Body Phantoms	18	
	2.2.1 Liquid Phantoms	21	
	2.2.2 Semisolid (Gel) Phantoms	22	
	2.2.3 Solid (Dry) Phantoms	22	
	2.2.4 Examples of Physical Phantoms	23	
2.3	*	27	
	2.3.1 Theoretical Phantoms	27	
	2.3.2 Voxel Phantoms	28	

2.4	Numerical Modeling Techniques for Antennas and Propogation	29
	2.4.1 Introduction of Numerical Techniques for Body-Centric Wireless	• •
	Communications	29
	2.4.2 On-Body Radio Channel Modeling	36
2.5	Modeling of Dynamic Body Effects	50
	2.5.1 Methodology	50
	2.5.2 Measurements and Model Validation	52
	References	56
СНА	PTER 3	
Ante	nna Design and Channel Characterization for On-Body	
	munications at Microwave Frequencies	63
3.1	Introduction	63
3.2	Measurement Methods	64
٠.2	3.2.1 Connection Between Antenna and Measuring Instruments	65
	3.2.2 Antenna De-embedding	67
3.3	Body-Centric Channel Measurement and Modeling	71
	3.3.1 Path Gain	71
	3.3.2 Channel Statistics	76
	3.3.3 Channel Polarization Effects	84
3.4	Antenna Design	87
	3.4.1 Performance Comparison	87
	3.4.2 Antenna-to-Surface Wave Coupling	93
	3.4.3 Antenna Match and Efficiency	101
3.5	Multiple Antenna Systems	103
	3.5.1 Antenna Diversity	103
	3.5.2 MIMO	104
	3.5.3 Interference Cancellation	105
3.6	Systems Modeling	105
3.7	Conclusions	106
	References	107
CHA	APTER 4	
Wea	rable Devices Using the Human Body as a Transmission Channel	113
4.1	Introduction of Communications Using Circuits in Direct Contact	
with	the Human Body	113
4.2	Numerical Analysis of Communication Devices Using Low Frequencies	120
	4.2.1 Whole Body Models	120
	4.2.2 Arm Models Wearing the Transmitter	122
	4.2.3 Effective Electrode Structure	123
4.3	Experiments Using Human Phantoms	125
	4.3.1 Model for Assessments	125
	4.3.2 Electric Field Distributions In and Around the Arm	126
	4.3.3 Received Signal Voltage of the Receiver	128
4.4	Investigation of the Dominant Signal Transmission Path	131

		131
		134
4.5		135
	References	136
CHA	PTER 5	
Ultra	wideband Technology for Body-Centric Wireless Communications	139
5.1	Overview	139
5.2	UWB Antennas for Body-Centric Wireless Communication	140
	5.2.1 Design and Analysis	141
	5.2.2 Measurements	158
	- 1	160
5.3		161
	5.3.1 Simulation of the Radio Propagation in Body-Centric	
	Communication Scenarios	161
	5.3.2 Measurement of the Radio Propagation in Body-Centric	
	Communication Scenarios	162
	5.3.3 Concluding Remarks	172
5.4	Channel Characterization and Modeling	173
	5.4.1 General Aspects	173
	5.4.2 Personal Area Network Scenarios	175
	5.4.3 Body Area Network Scenarios	180
	5.4.4 UWB Multiband-OFDM Based System Modeling and Performance	
	Evaluation for Body-Centric Wireless Communications	195
5.6	Concluding Remarks	202
	References	204
CH/	PTER 6	
	rable Antennas: Advances in the Design, Characterization, and	209
	lication .	
6.1		209
6.2	Review of the Literature	211
	6.2.1 Antenna Types	211
	6.2.2 Body Placement, Bending, and Crumpling	216
	6.2.3 Fabric Material Properties and Antenna Manufacture Methods	216
6.3	Wearable Antennas: Critical Design Issues	218
6.4	Textile Materials	219
6.5	Effects of Substrate Materials: An Example of Fabric GPS Antenna 6.5.1 Effects of Ground Plane Size Attached to the Fabric Substrate	222
	on GPS Antenna Performance	224
6.6	Effect on Various Conductive Materials of Patch Antennas:	
An	Example of WLAN Antenna on Fleece Fabric	228
6.7	Dual Frequency Wearable Antenna Design: An Example of a	
U-S	ot Patch	233
6.8	Wearable Electromagnetic Bang Gap Antenna (WEBGA):	
An	Example of WLAN Antenna	237

	6.8.1	Remarks on Antenna Bending	239
		ble Antennas Near the Human Body: An Example of a	244
WLE	AN Ant		244
		Models and Methods	246
<i>(</i> 10		Results	247
6.10		rable Antenna Environmental Performance Issues	250
		The Effect of Ice, Water, and Snow on Wearable Antenna	252
	Perform		252
		Example of Environmental Test During an Iridium Phone Call	255
6.11		Destructive Antenna Tests clusions	256
0.11			261 262
	Refer	owledgments	262
	Keler	ences	263
CHA	PTER 7		
bernesen 2005		■ r Networks for Space and Military Applications	271
7.1	Introd		271
7.2		sor System and Basics of Biomedical RF Telemetry	272
	7.2.1	Implantable Pressure Sensor	273
	7.2.2	Integrated Inductor/Antenna	273
- 2	7.2.3	External Pick-Up Antenna	275
7.3		na Design for Body Sensors	275
	7.3.1	Implantable Antennas	276
	7.3.2	Antennas for External Handheld Devices	285
7.4	_	Military, and Civilian Applications	289
	7.4.1	Sensors for Space Environment	289
		Battlefield Sensors	290
		Sensors in Hospitals and Smart Homes	290
	Refere	nces	290
CHA	APTER 8		
	Apple the street line	m nd Propagation for Telemedicine and Telecare:	
	Body Sy		293
8.1		edicine and Telecare Applications	293
0.1	8.1.1		295
	8.1.2	Physiological Signals for Patient Monitoring Technologies for Ward-Based Systems	293
	8.1.3	Technologies for Home-Based and Full Mobility Systems	297
	8.1.4	·	297
	8.1.5	Emerging Technologies and Novel Applications Windows Telemodicina Link Decima	298
0 2		Wireless Telemedicine Link Design	300
8.2	8.2.1	nas and Human Body Interaction in Personal Telemedicine Antenna-Body Effects (< 1 GHz)	303
	8.2.2	•	303
	8.2.3	Antenna–Body Effects (> 1 GHz) Emerging Antennas	310
8.3		n Design Issues	314
0.5	8.3.1	Channel Effects	314
	8.3.2	Radio Frequency Interference and Inter-BAN Interference	318
	0.0.4	readio recours interference and inter-data interference	210

8.4	Concl	usion	319
	Refere	ences	320
CHA	PTER	9	
Med	lical Im	plant Communication Systems	325
9.1	Introd	luction	325
	9.1.1	Inductive Coupling	326
	9.1.2	MICS Standard	327
	9.1.3	The 2.4-GHz ISM Band	328
9.2	Anten	nas in Lossy Dispersive Medium	328
	9.2.1	Matter	329
	9.2.2	Material Data and Measurements	330
	9.2.3	Phantoms	331
	9.2.4	Skin Depth	334
	9.2.5	Wave Propagation: One-Dimensional FDTD Simulations	334
	9.2.6	Influence of Patient	337
	9.2.7	Phantom Influence on Antenna	338
9.3	Low-Profile Antennas for Implantable Medical Devices		339
		What Is the Antenna?	341
	9.3.2	Antenna Efficiency Calculations in Matter	341
	9.3.3	Electric vs. Magnetic Antennas	343
	9.3.4	•	347
	9.3.5	•	353
	9.3.6	SAR	353
9.4	Conc	lusion	355
	Refer	ences	355
CH	APTER	10	
	clusior		359
Abo	ut the	Authors	365

Index

375