Contents

List of contributors *page* xi

Introduction xiii

1 Context analysis 1
1.1 Introduction 1
1.2 Historical perspective of RFID 1
1.3 RFID towards a networked society 4
1.4 Standardization 6
1.5 Circuit challenges for RFID systems 7
1.6 Materials and technology 10
1.7 Computer aided design (CAD) and optimization 11
1.8 Conclusions 12
Acknowledgment 12
References 12

2 RFID background 17
2.1 RFID system architecture 17
RFID system general frame 17
RFID regulation 19
RFID technology 23
2.2 Fundamentals and advances in RFID antenna design 27
2.3 Smart RFID tagged objects: from conventional RFID to networked RFID systems and green solutions 30
References 35

3 Energy scavenging and storage for RFID systems 38
3.1 Introduction 38
3.2 Modeling vibrational energy harvesters 41
Electromagnetic generators 43
Piezoelectric generators 44
State of the art and benchmarks in vibrational energy harvesters 46
3.3 Thermoelectric generators 48

Published online by Cambridge University Press

3.4 Scavenging architectures for vibrational and thermoelectric energy harvesters 50
3.5 Scavenging architecture for RFID rectenna and voltage multiplier 52
General purpose approach to the design of the rectenna 55
Selection of rectenna components 57
Antenna topology 57
Rectifier topology 61
Antenna(s)/rectifier(s) architecture 63
Rectenna design results 64
3.6 Design of power conversion circuits 66
References 70

4 Technologies for RFID sensors and sensor tags 76
4.1 RFID sensor concept and constraints 76
RFID sensor architecture 76
Active and passive RFID tags 76
RFID sensor technology for wireless sensor networks 77
Power constraints 78
Current technological challenges 80
4.2 SAW-based RFID sensors 82
Basic principles of SAW RFID sensors 82
Design of SAW RFID sensors 83
Fields of application 85
4.3 CMOS-based RFID sensors 85
System architecture of a CMOS RFID system 85
Multi-standard analog frontend 87
Ultra-low-power rectifier 87
Tag-to-reader communication 92
Reader-to-tag communication 92
Clock generation and clock recovery 93
Sensor interface 94
Wireless sensing 94
Timing constraint 95
Time-domain comparator 97
Digital-to-analog converter 98
Temperature sensor 102
Distance measurement 103
Local positioning 103
Modulated back-scattering with passive transponders 106
Measurement setup for distance measurement 106
User defined EPC custom command for distance measurement 106
CMOS RFID system tests 109
4.4 Comparison of SAW and CMOS RFID sensors 111
References 111

Published online by Cambridge University Press

5 Unconventional RFID systems 116
5.1 Introduction 116
Efficient and energy-aware approaches 119
RFID for location 120
RFID for household applications 121
5.2 Efficient and energy-aware approaches 121
Extending the coverage range of RFID systems 122
The radio link using multi-sine signals 123
Multi-sine power-link 124
Multi-sine data downlink 125
Multi-sine data uplink 127
Laboratory test beds and measurements 129
Measurement setup 1 129
Measurement setup 2 130
Measurement setup 3 132
Results discussion 134
Protocols for reduction of energy consumption 134
Proposed architecture and algorithm 135
Signal strength measurement 135
Preliminary measurements 137
5.3 UWB location based on passive sensors 139
5.4 RFID for household applications 143
A battery-less remote control system based on a multi-RFID scheme 143
Proposed system 144
The novel *N*-port microstrip network 146
References 150

6 Integrating tiny RFID- and NFC-based sensors with the Internet 152
6.1 Introduction 152
6.2 RFID-based networked prototypes 153
Semi-passive 153
Solar-powered UHF tag for localization 153
WISP-based 156
Concealable and flexible antennas for the WISP module 156
Multipacket reception for the RFID EPC Gen2 protocol 157
Chemical gas sensing 158
Passive 160
Paper-based ultra-high frequency sensor 160
Metallic structural strain sensor 161
6.3 NFC-based networked prototype 163
6.4 Using WSNs to interface with the internet 165
Crossbow WSN for location tracking 166
ZigBee 168
SWIM – smart wireless integrated module 168
Near-field certificate of authenticity reader 169

Published online by Cambridge University Press

IPV6-enabling 6lowPAN 169
Extensions to mobile and pico-datacenter computing 172
6.5 Conclusion 172
References 173

7 Materials for substrates 176
7.1 Introduction 176
7.2 Substrate characterization 178
Ring resonator method 178
T resonator method 180
Transmission line (TL) method for substrate loss 181
7.3 Fabrication method for various substrates 184
Subtractive processes 184
Milling 184
Lithography 184
Additive processes 185
Inkjet printing 185
Screen printing 188
Mixed processes 189
Appendix 7A: The effective width and effective permittivity 191
References 193

8 Organic conductors and semiconductors: recent achievements and modeling 195
8.1 Introduction 195
8.2 Active devices for printed RFIDs 196
Modeling tools for organic devices 196
High frequency rectifiers based on organic Schottky diodes 197
Basic devices and circuits based on organic TFT 200
8.3 Passive RFID components 203
Graphene: the wonder material 203
Basic properties of graphene 204
Analogy of ballistic transport and electromagnetic waves: a rich concept 206
Fabrication of graphene 207
Modeling of the electromagnetics-quantum transport in graphene nanodevices 208
Frequency domain: the combined Dirac–Poisson problem 209
Time domain: the combined Dirac–Maxwell problem in the ballistic regime 213
Graphene antennas for RFID and wireless applications 215
Graphene in the microwave and mm-wave range 216
Antenna design and modeling 219

Published online by Cambridge University Press

Acknowledgment 223
References 223

9 RFID enabling new solutions 228
9.1 Introduction 228
9.2 Time-domain reflectometry (TDR)-based chipless tags 230
9.3 Spectral signature-based chipless tags 231
9.4 Amplitude/phase backscatter modulation-based chipless tags 232
9.5 Other solutions? 232
9.6 Novel RFID sensor 233
9.7 Basic theory 235
Tag information encoding 236
Received reader voltages 237
Conversion products 239
Information recovery 239
9.8 Applications 240
9.9 Conclusions 243
References 244

10 Energy-efficient off-body communication using textile antennas 248
10.1 Introduction 248
10.2 Basics of textile antenna design 248
Textile materials/characterization 248
Literature overview of textile antennas 249
Design examples 249
Dual-polarized textile patch antenna 249
Textile antenna array 251
10.3 Off-body links relying on space–time coding and textile antennas 251
Introduction 251
Measurement setup 252
Measurement results 253
CDF and outage probability 254
Bit error characteristics 255
Real-time error performance 256
10.4 Off-body beam forming versus space–time coding 257
Experimental setup 257
Analysis of the received signals 260
Beam forming power gain 260
Time-dependent signal behavior 260
10.5 Energy-efficient channel tracking of off-body communication links 262
10.6 Application domains 264
10.7 Conclusions 265

Published online by Cambridge University Press

10.8 Future perspectives 265
Dynamic beam forming 265
Dominant eigenmode transmission 266
References 266

Index 268

Published online by Cambridge University Press