

# **RFID HANDBOOK**

**THIRD EDITION**

# Contents

<b>Preface to the Third Edition</b>	<b>xi</b>
<b>List of Abbreviations</b>	<b>xiii</b>
<b>1 Introduction</b>	<b>1</b>
1.1 Automatic Identification Systems	2
1.1.1 Barcode Systems	2
1.1.2 Optical Character Recognition	3
1.1.3 Biometric Procedures	4
1.1.4 Smart Cards	4
1.1.5 RFID Systems	6
1.2 A Comparison of Different ID Systems	6
1.3 Components of an RFID System	6
<b>2 Differentiation Features of RFID Systems</b>	<b>11</b>
2.1 Fundamental Differentiation Features	11
2.2 Transponder Construction Formats	13
2.2.1 Disks and Coins	13
2.2.2 Glass Housing	13
2.2.3 Plastic Housing	13
2.2.4 Tool and Gas Bottle Identification	15
2.2.5 Keys and Key Fobs	15
2.2.6 Clocks	17
2.2.7 ID-1 Format, Contactless Smart Cards	18
2.2.8 Smart Label	19
2.2.9 Coil-on-Chip	20
2.2.10 Other Formats	21
2.3 Frequency, Range and Coupling	21
2.4 Active and Passive Transponders	22
2.5 Information Processing in the Transponder	24
2.6 Selection Criteria for RFID Systems	25
2.6.1 Operating Frequency	26
2.6.2 Range	26
2.6.3 Security Requirements	27
2.6.4 Memory Capacity	28

<b>3</b>	<b>Fundamental Operating Principles</b>	<b>29</b>
3.1	1-Bit Transponder	29
	3.1.1 <i>Radio Frequency</i>	29
	3.1.2 <i>Microwaves</i>	33
	3.1.3 <i>Frequency Divider</i>	34
	3.1.4 <i>Electromagnetic Types</i>	35
	3.1.5 <i>Acoustomagnetic</i>	38
3.2	Full- and Half-Duplex Procedure	39
	3.2.1 <i>Inductive Coupling</i>	40
	3.2.2 <i>Electromagnetic Backscatter Coupling</i>	45
	3.2.3 <i>Close-Coupling</i>	48
	3.2.4 <i>Data Transfer Reader → Transponder</i>	49
	3.2.5 <i>Electrical Coupling</i>	50
3.3	Sequential Procedures	52
	3.3.1 <i>Inductive Coupling</i>	52
	3.3.2 <i>Surface Acoustic Wave Transponder</i>	55
3.4	Near-Field Communication (NFC)	57
	3.4.1 <i>Active Mode</i>	57
	3.4.2 <i>Passive Mode</i>	59
<b>4</b>	<b>Physical Principles of RFID Systems</b>	<b>61</b>
4.1	Magnetic Field	61
	4.1.1 <i>Magnetic Field Strength <math>H</math></i>	61
	4.1.2 <i>Magnetic Flux and Magnetic Flux Density</i>	66
	4.1.3 <i>Inductance <math>L</math></i>	66
	4.1.4 <i>Mutual Inductance <math>M</math></i>	67
	4.1.5 <i>Coupling Coefficient <math>k</math></i>	68
	4.1.6 <i>Faraday's Law</i>	70
	4.1.7 <i>Resonance</i>	72
	4.1.8 <i>Practical Operation of the Transponder</i>	76
	4.1.9 <i>Interrogation Field Strength <math>H_{\min}</math></i>	77
	4.1.10 <i>Total Transponder–Reader System</i>	84
	4.1.11 <i>Measurement of System Parameters</i>	100
	4.1.12 <i>Magnetic Materials</i>	106
4.2	Electromagnetic Waves	110
	4.2.1 <i>The Generation of Electromagnetic Waves</i>	110
	4.2.2 <i>Radiation Density <math>S</math></i>	112
	4.2.3 <i>Characteristic Wave Impedance and Field Strength <math>E</math></i>	112
	4.2.4 <i>Polarisation of Electromagnetic Waves</i>	114
	4.2.5 <i>Antennas</i>	116
	4.2.6 <i>Practical Operation of Microwave Transponders</i>	127
4.3	Surface Waves	144
	4.3.1 <i>The Creation of a Surface Wave</i>	144
	4.3.2 <i>Reflection of a Surface Wave</i>	146
	4.3.3 <i>Functional Diagram of SAW Transponders</i>	147
	4.3.4 <i>The Sensor Effect</i>	149
	4.3.5 <i>Switched Sensors</i>	154
<b>5</b>	<b>Frequency Ranges and Radio Licensing Regulations</b>	<b>155</b>
5.1	Frequency Ranges Used	155

5.1.1	<i>Frequency Range 9–135 kHz</i>	157
5.1.2	<i>Frequency Range 6.78 MHz (ISM)</i>	158
5.1.3	<i>Frequency Range 13.56 MHz (ISM, SRD)</i>	159
5.1.4	<i>Frequency Range 27.125 MHz (ISM)</i>	159
5.1.5	<i>Frequency Range 40.680 MHz (ISM)</i>	160
5.1.6	<i>Frequency Range 433.920 MHz (ISM)</i>	160
5.1.7	<i>UHF Frequency Range</i>	160
5.1.8	<i>Frequency Range 2.45 GHz (ISM, SRD)</i>	161
5.1.9	<i>Frequency Range 5.8 GHz (ISM, SRD)</i>	161
5.1.10	<i>Frequency Range 24.125 GHz</i>	161
5.1.11	<i>Selection of a Suitable Frequency for Inductively Coupled RFID Systems</i>	162
5.2	The International Telecommunication Union (ITU)	164
5.3	European Licensing Regulations	165
5.3.1	<i>CEPT/ERC REC 70-03</i>	166
5.3.2	<i>Standardised Measuring Procedures</i>	170
5.4	National Licensing Regulations in Europe	172
5.4.1	<i>Germany</i>	172
5.5	National Licensing Regulations	175
5.5.1	<i>USA</i>	175
5.6	Comparison of National Regulations	176
5.6.1	<i>Conversion at 13.56 MHz</i>	176
5.6.2	<i>Conversion on UHF</i>	178
<b>6</b>	<b>Coding and Modulation</b>	<b>179</b>
6.1	Coding in the Baseband	179
6.2	Digital Modulation Procedures	180
6.2.1	<i>Amplitude Shift Keying (ASK)</i>	182
6.2.2	<i>2 FSK</i>	185
6.2.3	<i>2 PSK</i>	185
6.2.4	<i>Modulation Procedures with Subcarrier</i>	187
<b>7</b>	<b>Data Integrity</b>	<b>189</b>
7.1	The Checksum Procedure	189
7.1.1	<i>Parity Checking</i>	189
7.1.2	<i>LRC Procedure</i>	190
7.1.3	<i>CRC Procedure</i>	191
7.2	Multi-Access Procedures – Anticollision	194
7.2.1	<i>Space Division Multiple Access (SDMA)</i>	196
7.2.2	<i>Frequency Domain Multiple Access (FDMA)</i>	197
7.2.3	<i>Time Domain Multiple Access (TDMA)</i>	197
7.2.4	<i>Examples of Anticollision Procedures</i>	199
<b>8</b>	<b>Security of RFID Systems</b>	<b>213</b>
8.1	Attacks on RFID Systems	214
8.1.1	<i>Attacks on the Transponder</i>	215
8.1.2	<i>Attacks on the RF Interface</i>	216
8.2	Protection by Cryptographic Measures	226
8.2.1	<i>Mutual Symmetrical Authentication</i>	227
8.2.2	<i>Authentication using Derived Keys</i>	228
8.2.3	<i>Encrypted Data Transfer</i>	228

<b>9</b>	<b>Standardisation</b>	<b>233</b>
9.1	Animal Identification	233
9.1.1	<i>ISO/IEC 11784 – Code Structure</i>	233
9.1.2	<i>ISO/IEC 11785 – Technical Concept</i>	234
9.1.3	<i>ISO/IEC 14223 – Advanced Transponders</i>	236
9.2	Contactless Smart Cards	240
9.2.1	<i>ISO/IEC 10536 – Close-Coupling Smart Cards</i>	241
9.2.2	<i>ISO/IEC 14443 – Proximity-Coupling Smart Cards</i>	243
9.2.3	<i>ISO/IEC 15693 – Vicinity-Coupling Smart Cards</i>	258
9.2.4	<i>ISO/IEC 10373 – Test Methods for Smart Cards</i>	263
9.3	ISO/IEC 69873 – Data Carriers for Tools and Clamping Devices	267
9.4	ISO/IEC 10374 – Container Identification	267
9.5	VDI 4470 – Anti-theft Systems for Goods	267
9.5.1	<i>Part 1 – Detection Gates – Inspection Guidelines for Customers</i>	267
9.5.2	<i>Part 2 – Deactivation Devices – Inspection Guidelines for Customers</i>	270
9.6	Item Management	270
9.6.1	<i>ISO/IEC 18000 Series</i>	270
9.6.2	<i>GTAG Initiative</i>	273
9.6.3	<i>EPCglobal Network</i>	274
<b>10</b>	<b>The Architecture of Electronic Data Carriers</b>	<b>283</b>
10.1	Transponder with Memory Function	283
10.1.1	<i>RF Interface</i>	283
10.1.2	<i>Address and Security Logic</i>	286
10.1.3	<i>Memory Architecture</i>	289
10.2	Microprocessors	300
10.2.1	<i>Dual Interface Card</i>	303
10.3	Memory Technology	307
10.3.1	<i>RAM</i>	307
10.3.2	<i>EEPROM</i>	308
10.3.3	<i>FRAM</i>	309
10.3.4	<i>Performance Comparison FRAM – EEPROM</i>	310
10.4	Measuring Physical Variables	311
10.4.1	<i>Transponder with Sensor Functions</i>	311
10.4.2	<i>Measurements Using Microwave Transponders</i>	312
10.4.3	<i>Sensor Effect in Surface Wave Transponders</i>	315
<b>11</b>	<b>Readers</b>	<b>317</b>
11.1	Data Flow in an Application	317
11.2	Components of a Reader	317
11.2.1	<i>RF Interface</i>	318
11.2.2	<i>Control Unit</i>	323
11.3	Integrated Reader ICs	324
11.3.1	<i>Integrated RF Interface</i>	325
11.3.2	<i>Single-Chip Reader IC</i>	327
11.4	Connection of Antennas for Inductive Systems	331
11.4.1	<i>Connection Using Current Matching</i>	333
11.4.2	<i>Supply via Coaxial Cable</i>	333
11.4.3	<i>The Influence of the Q Factor</i>	338
11.5	Reader Designs	338

11.5.1	<i>OEM Readers</i>	338
11.5.2	<i>Readers for Industrial Use</i>	338
11.5.3	<i>Portable Readers</i>	338
11.6	Near-Field Communication	339
11.6.1	<i>Secure NFC</i>	341
<b>12</b>	<b>The Manufacture of Transponders and Contactless Smart Cards</b>	<b>347</b>
12.1	Glass and Plastic Transponders	347
12.1.1	<i>Chip Manufacture</i>	347
12.1.2	<i>Glass Transponders</i>	348
12.1.3	<i>Plastic Transponders</i>	351
12.2	Contactless Smart Cards	352
12.2.1	<i>Coil Manufacture</i>	352
12.2.2	<i>Connection Technique</i>	356
12.2.3	<i>Lamination</i>	359
<b>13</b>	<b>Example Applications</b>	<b>361</b>
13.1	Contactless Smart Cards	361
13.2	Public Transport	362
13.2.1	<i>The Starting Point</i>	362
13.2.2	<i>Requirements</i>	363
13.2.3	<i>Benefits of RFID Systems</i>	363
13.2.4	<i>Fare Systems using Electronic Payment</i>	365
13.2.5	<i>Market Potential</i>	366
13.2.6	<i>Example Projects</i>	366
13.3	Contactless Payment Systems	372
13.3.1	<i>MasterCard<sup>®</sup></i>	374
13.3.2	<i>ExpressPay by American Express<sup>®</sup></i>	374
13.3.3	<i>Visa<sup>®</sup> Contactless</i>	374
13.3.4	<i>ExxonMobil Speedpass</i>	375
13.4	NFC Applications	375
13.5	Electronic Passport	380
13.6	Ski Tickets	383
13.7	Access Control	385
13.7.1	<i>Online Systems</i>	385
13.7.2	<i>Offline Systems</i>	385
13.7.3	<i>Transponders</i>	387
13.8	Transport Systems	388
13.8.1	<i>Eurobalise S21</i>	388
13.8.2	<i>International Container Transport</i>	390
13.9	Animal Identification	391
13.9.1	<i>Stock Keeping</i>	391
13.9.2	<i>Carrier Pigeon Races</i>	395
13.10	Electronic Immobilisation	398
13.10.1	<i>The Functionality of an Immobilisation System</i>	399
13.10.2	<i>Brief Success Story</i>	401
13.10.3	<i>Predictions</i>	402
13.11	Container Identification	403
13.11.1	<i>Gas Bottles and Chemical Containers</i>	403
13.11.2	<i>Waste Disposal</i>	404

---

13.12	Sporting Events	405
13.13	Industrial Automation	409
	13.13.1 <i>Tool Identification</i>	409
	13.13.2 <i>Industrial Production</i>	410
13.14	Medical Applications	417
<b>14</b>	<b>Appendix</b>	<b>419</b>
14.1	Contact Addresses, Associations and Technical Periodicals	419
	14.1.1 <i>Industrial Associations</i>	419
	14.1.2 <i>Technical Journals</i>	421
	14.1.3 <i>RFID on the Internet</i>	422
14.2	Relevant Standards and Regulations	423
	14.2.1 <i>Standardisation Bodies</i>	423
	14.2.2 <i>List of Standards</i>	423
	14.2.3 <i>Sources for Standards and Regulations</i>	428
14.3	Printed Circuit Board Layouts	429
	14.3.1 <i>Test Card in Accordance with ISO 14443</i>	429
	14.3.2 <i>Field Generator Coil</i>	435
	14.3.3 <i>Reader for 13.56 MHz</i>	435
	<b>References</b>	<b>441</b>
	<b>Index</b>	<b>449</b>