



RFID HANDBOOK

Radio-Frequency Identification
Fundamentals and Applications



KLAUS FINKENZELLER

RFID HANDBOOK

**Radio-Frequency Identification
Fundamentals and Applications**

KLAUS FINKENZELLER

Giesecke & Devrient GmbH, Munich, Germany

*Translated by
Rachel Waddington
Swadlincote, UK*

JOHN WILEY & SON, LTD
Chichester • New York • Weinheim • Brisbane • Singapore • Toronto

Ex.1007
APPLE INC. / Page 2 of 19

First published under the title *RFID-Handbuch* by Carl Hanser Verlag
© Carl Hanser Verlag, Munich/FRG, 1998. All Rights Reserved

Copyright ©1999 John Wiley & Sons Ltd
Baffins Lane, Chichester,
West Sussex, PO19 1UD, England
National 01243 779777
International (+44) 1243 779777

e-mail (for orders and customer service enquiries): cs-books@wiley.co.uk
Visit our Home Page on <http://www.wiley.co.uk> or <http://www.wiley.com>

Reprinted June 2000, April 2001

All Rights Reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except under the terms of the Copyright, Designs and Patents Act 1988 or under the terms of a licence issued by the Copyright Licensing Agency, 90 Tottenham Court Road, London W1P 9HE, UK, without the permission in writing of the Publisher.

Neither the author nor John Wiley & Sons Ltd accept any responsibility or liability for loss or damage occasioned to any person or property through using the material, instructions, methods or ideas contained herein, or acting or refraining from acting as a result of such use. The author(s) and Publisher expressly disclaim all implied warranties, including merchantability or fitness for any particular purpose.

Designations used by companies to distinguish their products are often claimed as trademarks. In all instances where John Wiley & Sons is aware of a claim, the product names appear in initial capital or all capital letters. Readers, however, should contact the appropriate companies for more complete information regarding trademarks and registration.

Other Wiley Editorial Offices

John Wiley & Sons, Inc., 605 Third Avenue,
New York, NY 10158-0012, USA

Weinheim • Brisbane • Singapore • Toronto

Library of Congress Cataloging-in-Publication Data

Finkenzeller, Klaus.

[RFID Handbuch. English]

RFID handbook : radio-frequency identification fundamentals and applications / Klaus Finkenzeller : translated by Rachel Waddington
p. cm.

Includes bibliographical references and index.

ISBN 0-471-98851-0 (alk. paper)

1. Inventory control—Automation. 2. Radio frequency identification systems. I. Title.

TS160.F5513 1999

99-16221

658.7—dc21

CIP

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

ISBN 0 471 98851 0

Produced from PostScript files supplied by the translator

Printed and bound in Great Britain by Antony Rowe Ltd, Chippenham

This book is printed on acid-free paper responsibly manufactured from sustainable forestry in which at least two trees are planted for each one used for paper production.

Contents

PREFACE	xiii
LIST OF ABBREVIATIONS	xv
1 INTRODUCTION	1
1.1 Automatic Identification Systems	2
1.1.1 Barcode systems	2
1.1.2 Optical character recognition	3
1.1.3 Biometric procedure	4
1.1.3.1 Voice identification	4
1.1.3.2 Finger printing procedures (dactyloscopy)	4
1.1.4 Smart cards	4
1.1.4.1 Memory cards	5
1.1.4.2 Microprocessor cards	5
1.1.5 RFID systems	6
1.2 A Comparison of Different ID Systems	6
1.3 Components of an RFID System	7
2 DIFFERENTIATION FEATURES OF RFID SYSTEMS	11
2.1 Fundamental Differentiation Features	11
2.2 Transponder Construction Formats	13
2.2.1 Disks and coins	13
2.2.2 Glass housing	14
2.2.3 Plastic housing	15
2.2.4 Tool and gas bottle identification	16
2.2.5 Keys and key fobs	17
2.2.6 Clocks	19
2.2.7 ID-1 format, contactless smart cards	19



2.2.8 Other formats	21
2.3 Frequency, Range and Coupling	21
2.3.1 Close coupling	21
2.3.2 Remote coupling	22
2.3.3 Long range	22
2.3.4 System performance	23
3 FUNDAMENTAL OPERATING PRINCIPLES	25
3.1 1 Bit Transponder	26
3.1.1 Radio frequency	26
3.1.2 Microwaves	29
3.1.3 Frequency divider	31
3.1.4 Electromagnetic types	32
3.2 Full and Half Duplex Procedure	34
3.2.1 Inductive coupling	35
3.2.1.1 Power supply to passive transponders	35
3.2.1.2 Data transfer transponder → reader	37
3.2.2 Electromagnetic backscatter coupling	41
3.2.2.1 Power supply to the transponder	41
3.2.2.2 Data transmission → reader	41
3.2.3 Close coupling	43
3.2.3.1 Power supply to the transponder	43
3.2.3.2 Data transfer transponder → reader	44
3.2.4 Data transfer reader → transponder	44
3.3 Sequential Procedures	45
3.3.1 Inductive coupling	45
3.3.1.1 Power supply to the transponder	45
3.3.1.2 A comparison between FDX/HDX and SEQ systems	45
3.3.1.3 Data transmission transponder → reader	47
3.3.2 Surface acoustic wave transponder	48
4 PHYSICAL PRINCIPLES OF RFID SYSTEMS	53
4.1 Magnetic Field	53
4.1.1 Magnetic field strength H	53
4.1.1.1 Path of field strength $H(x)$ in conductor loops	55
4.1.1.2 Optimal antenna diameter	57
4.1.2 Magnetic flux and magnetic flux density	58
4.1.3 Inductance L	59
4.1.4 Mutual inductance M	60
4.1.5 Coupling coefficient k	62
4.1.6 Faraday's law	64
4.1.7 Resonance	66

4.1.8 Practical operation of the transponder	71
4.1.8.1 Power supply to the transponder	71
4.1.8.2 Voltage regulation	71
4.1.9 Interrogation field strength H_{\min}	74
4.1.9.1 “Energy range” of transponder systems	76
4.1.10 Total transponder – reader system	78
4.1.10.1 Transformed transponder impedance Z_T'	80
4.1.10.2 Influencing variables of Z_T'	83
4.1.10.3 Load modulation	90
4.1.11 Measuring the coupling coefficient k	98
4.1.12 Magnetic materials	99
4.1.12.1 Properties of magnetic materials and ferrite	99
4.1.12.2 Ferrite antennas in LF transponders	101
4.1.12.3 Ferrite shielding in a metallic environment	101
4.2 Electromagnetic Waves	102
4.2.1 The creation of electromagnetic waves	102
4.2.2 Reflection of electromagnetic waves	105
4.2.3 Radar cross section of an antenna	106
4.2.4 Modulated radar cross section	109
4.2.5 Effective length	109
4.2.6 Antenna construction formats for microwave transponders	110
4.2.6.1 Slot antennas	110
4.2.6.2 Planar antennas	110
4.2.6.3. Overview – antenna parameters	110
5 FREQUENCY RANGES AND RADIO LICENSING REGULATIONS	111
5.1 Frequency Ranges Used	111
5.1.1 Frequency range 9 – 135 kHz	111
5.1.2 Frequency range 6.78 MHz	114
5.1.3 Frequency range 13.56 MHz	114
5.1.4 Frequency range 27.125 MHz	114
5.1.5 Frequency range 40.680 MHz	115
5.1.6 Frequency range 433.920 MHz	115
5.1.7 Frequency range 869.0 MHz	115
5.1.8 Frequency range 915.0 MHz	116
5.1.9 Frequency range 2.45 GHz	116
5.1.10 Frequency range 5.8 GHz	116
5.1.11 Frequency range 24.125 GHz	116
5.1.12 Selection of a suitable frequency for inductively coupled RFID systems	116
5.2 International Licensing Regulations	119
5.2.1 CEPT/ERC 70-03	119
5.2.2 EN 300330: 9 kHz – 25 MHz	119

5.2.2.1 Carrier power – limit values for class 1 transmitters	120
5.2.2.2 Carrier power – limit values for class 2 transmitters	120
5.2.2.3 Modulation bandwidth	122
5.2.2.4 Spurious emissions	122
5.2.3 EN 300220-1, EN 300220-2	122
5.2.4 EN 300440	123
5.3 National Licencing Regulations – U.S.A	
6 CODING AND MODULATION	125
6.1 Coding in the Baseband	126
6.2 Digital Modulation Procedures	128
6.2.1 Amplitude shift keying (ASK)	129
6.2.2 FSK	132
6.2.3 PSK	133
6.2.4 Modulation procedures with subcarrier	134
7 DATA INTEGRITY	137
7.1 The Checksum Procedure	137
7.1.1 Parity checking	137
7.1.2 LRC procedure	138
7.1.3 CRC procedure	139
7.2 Anticollision	141
7.2.1 How collision arises	141
7.2.2 Anticollision procedures	142
7.2.2.1 Spatial domain anticollision procedures	142
7.2.2.2 Frequency domain anticollision procedures	143
7.2.2.3 Time domain anticollision procedures	143
7.2.3 Application example – binary search algorithm	144
8 DATA SECURITY	151
8.1 Mutual Symmetrical Authentication	151
8.2 Authentication Using Derived Keys	153
8.3 Encrypted Data Transfer	154
8.3.1 Stream cipher	155
9 STANDARDISATION	159
9.1 Animal Identification	159
9.1.1 ISO 11784 – Code structure	159
9.1.2 ISO 11785 – Technical concept	160

9.1.2.1 Requirements	160
9.1.2.2 Full/half duplex system	162
9.1.2.3 Sequential system	162
9.2 Contactless Smart Cards	163
9.2.1 ISO 10536 – Close coupling smart cards	163
9.2.1.1 Part 1 – Physical characteristics	163
9.2.1.2 Part 2 – Dimensions and locations of coupling areas	164
9.2.1.3 Part 3 – Electronic signals and reset procedures	164
9.2.1.4 Part 4 - Answer to reset and transmission protocols	165
9.2.2. ISO 14443 – Proximity coupling smart cards	165
9.2.3 ISO 15693 – Vicinity coupling smart cards	166
9.3 ISO 69873 – Data Carriers for Tools and Clamping Devices	167
9.4 ISO 10374 – Container Identification	167
9.5 VDI 4470 – Anti-theft Systems for Goods	168
9.5.1 Part 1 – Detection gates – inspection guidelines for customers	168
9.5.1.1 Ascertaining the false alarm rate	169
9.5.1.2 Ascertaining the detection rate	169
9.5.1.3 Forms in VDI 4470	169
9.5.2 Part 2 – Deactivation devices, inspection guidelines for customers	170
10 THE ARCHITECTURE OF ELECTRONIC DATA CARRIERS	171
10.1 Transponder with Memory Function	172
10.1.1 HF interface	172
10.1.2 Address and security logic	173
10.1.2.1 State machine	174
10.1.3 Memory architecture	175
10.1.3.1 Read-only transponder	175
10.1.3.2 Writeable transponder	177
10.1.3.3 Transponder with cryptological function	177
10.1.3.4 Segmented memory	179
10.1.3.5 MIFARE® application directory	181
10.2 Microprocessors	185
10.2.1 Dual interface card	187
10.2.1.1 MIFARE® plus dual interface card	189
10.3 Memory Technology	190
10.3.1 RAM	190
10.3.2 EEPROM	191
10.3.3 FRAM	192
10.3.4 Performance comparison FRAM – EEPROM	194

10.4 Measuring Physical Variables	194
10.4.1 Transponder with sensor functions	194
10.4.2 Measurements using microwave transponders	195
11 READERS	199
11.1 Data Flow in an Application	199
11.2 Components of a Reader	200
11.2.1 HF-interface	202
11.2.1.1 Inductively coupled system, FDX/HDX	202
11.2.1.2 Microwave systems – half duplex	203
11.2.1.3 Sequential systems – SEQ	204
11.2.2 Control unit	205
11.3 Low Cost Configuration – Reader IC U2270B	207
11.4 Connection of Antennas	209
11.4.1 Antennas for inductive systems	209
11.4.1.1 Connection using current matching	209
11.4.1.2 Supply via coaxial cable	211
11.4.1.3 The Influence of the Q Factor	215
11.4.2 Antennas for microwave systems	216
11.5 Reader Designs	217
12 THE MANUFACTURE OF TRANSPONDERS AND CONTACTLESS SMART CARDS	219
12.1 Module Manufacture	219
12.2 Semi-Finished Transponder	221
12.3 Completion	222
12.4 Contactless Smart Cards	222
13 EXAMPLE APPLICATIONS	227
13.1 Contactless Smart cards	227
13.2 Public Transport	229
13.2.1 The starting point	229
13.2.2 Requirements	230
13.2.2.1 Transaction time	230
13.2.2.2 Resistance to degradation, lifetime, convenience	231
13.2.3 Benefits of RFID systems	231
13.2.4 Fare systems using electronic payment	232
13.2.5 Market potential	234

13.2.6. Example projects	234
13.2.6.1 Korea – Seoul	234
13.2.6.2 Germany – Lüneburg, Oldenburg	236
13.3 Ticketing	237
13.3.1 Lufthansa Miles & More card	237
13.3.2 Ski tickets	239
13.4 Access Control	241
13.5 Transport Systems	242
13.5.1 Eurobalise S21	242
13.5.2 International container transport	244
13.6 Animal Identification	245
13.6.1 Stock keeping	245
13.6.2. Carrier pigeon races	251
13.7 Electronic Immobilisation	253
13.7.1 The functionality of an immobilisation system	253
13.7.2 Brief success story	256
13.7.3 Predictions	257
13.8 Container Identification	257
13.8.1 Gas bottles and chemical containers	257
13.8.2 Waste disposal	259
13.9 Sporting Events	261
13.10 Industrial Automation	263
13.10.1 Tool identification	263
13.10.2 Industrial Production	266
13.10.2.1 Benefits from the use of RFID systems	269
13.10.2.2 The selection of a suitable RFID system	270
13.10.2.3 Example projects	271
14 MARKET OVERVIEW	275
14.1 Selection Criteria	275
14.1.1 Operating frequency	275
14.1.2 Range	276
14.1.3 Security requirements	277
14.1.4 Memory size	278
14.2 System Overview	278
14.3 Contact Addresses, Technical Periodicals	287
14.3.1 Industrial associations	287
14.3.2 Technical journals and events	290
14.3.3 RFID on the Internet	292

15 APPENDICES	293
15.1 Relevant Standards and Regulations	293
15.1.1 Sources of supply for standards and regulations	294
15.2 References	294
16 INDEX	299

Preface

This book is aimed at an extremely wide range of readers. First and foremost it is intended for students and engineers who find themselves confronted with RFID technology for the first time. A few basic chapters are provided for this audience describing the functionality of RFID technology and the physical and IT-related principles underlying this field. The book is also intended for practitioners who, as users, wish to or need to obtain as comprehensive and detailed an overview of the various technologies, the legal framework or the possible applications of RFID as possible.

Although a wide range of individual articles are now available on this subject, the task of gathering all this scattered information together when it is needed is a tiresome and time-consuming one – as researching this book has proved. This book therefore aims to fill a gap in the range of literature on the subject of RFID.

This book uses numerous pictures and diagrams to attempt to give a graphic representation of RFID technology in the truest sense of the word. Particular emphasis is placed on practical considerations. For this reason the chapter entitled “Example Applications” is particularly comprehensive.

Technological developments in the field of RFID technology are proceeding at such a pace that although a book like this can explain the general scientific principles it is not dynamic enough to be able to explore the latest trends regarding the most recent products on the market. I am therefore grateful for any suggestions and advice – particularly from the field of industry. The basic concepts and underlying physical principles remain, however, and provide a good background for understanding the latest developments.

At this point I would also like to express my thanks to those companies who were kind enough to contribute to the success of this project by providing numerous technical data sheets, lecture manuscripts and photographs.

Munich, January 1998

Klaus Finkenzeller

1

Introduction

In recent years automatic identification procedures (Auto ID) have become very popular in many service industries, purchasing and distribution logistics, industry, manufacturing companies and material flow systems. Automatic identification procedures exist to provide information about people, animals, goods and products in transit.

The omnipresent barcode labels that triggered a revolution in identification systems some considerable time ago, are being found to be inadequate in an increasing number of cases. Barcodes may be extremely cheap, but their stumbling block is their low storage capacity and the fact that they cannot be reprogrammed.]

The technically optimal solution would be the storage of data in a silicon chip. The most common form of electronic data carrying device in use in everyday life is the smart card based upon a contact field (telephone smart card, bank cards). However, the mechanical contact used in the smart card is often impractical. A contactless transfer of data between the data carrying device and its reader is far more flexible. In the ideal case, the power required to operate the electronic data carrying device would also be transferred from the reader using contactless technology. Because of the procedures used for the transfer of power and data, contactless ID systems are called *RFID systems* (Radio Frequency Identification).

The number of companies that are actively involved in the development and sale of RFID systems indicates that this is a market that should be taken seriously. Total worldwide sales of RFID systems for the year 2000 are estimated at above 2 billion US\$. The *RFID market* therefore belongs to the fastest growing sector of the radio technology industry, including mobile phones and cordless telephones.

Furthermore, in recent years contactless identification has been developing into an independent interdisciplinary field, which no longer fits into any of the conventional pigeon holes. It brings together elements from extremely varied fields: HF technology and EMC, semiconductor technology, data protection and cryptography, telecommunications, manufacturing technology and many related areas.

As an introduction, the following chapter gives a brief overview of different auto ID systems, that perform similar functions to RFID.

specific parts of the programme are not loaded into the EEPROM until after manufacture and can be initiated via the operating system.

Microprocessor cards are primarily used in security sensitive applications. Examples are smart cards for GSM mobile phones and the new EC (electronic cash) cards. The option of programming the microprocessor cards also facilitates rapid adaptation to new applications [rankl].

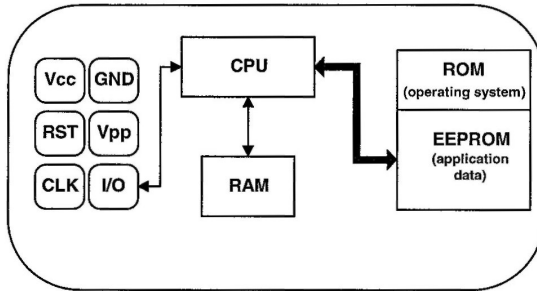


Figure 1.5: Typical architecture of a microprocessor card

1.1.5 RFID systems

RFID systems are closely related to the smart cards described above. Like smart card systems, data is stored on an electronic data carrying device – the transponder. However, unlike the smart card, the power supply to the data carrying device and the data exchange between data carrying device and reader are achieved without the use of galvanic contacts, using instead magnetic or electromagnetic fields. The underlying technical procedure is drawn from the fields of radio and radar engineering. The abbreviation RFID stands for radio frequency identification, i.e. information carried by radio waves. Due to the numerous advantages of RFID systems compared with other identification systems, RFID systems are now beginning to conquer new mass markets. One example is the use of contactless smart cards as tickets for short-distance public transport.

1.2 A Comparison of Different 1D Systems

A comparison between the identification systems described above highlights the strengths and weakness of RFID in relation to other systems. Here too, there is a close relationship between contact based smart cards and RFID systems, however the latter circumvents all the disadvantages related to faulty contacting (sabotage, dirt, unidirectional insertion, time consuming insertion, etc.).

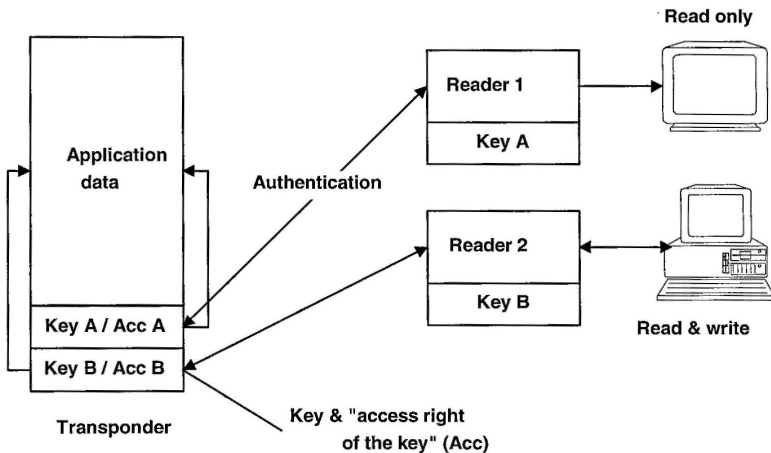


Figure 10.10: A transponder with two key memories facilitates the hierarchical allocation of access rights, in connection with the authentication keys used

The access rights to the transponder's two access registers A and B are configured such that, after successful authentication using key A, the system only permits the deduction of monetary amounts (the devaluation of a counter in the transponder). Only after authentication with key B may monetary amounts be added (the revaluation of the same counter).

In order to protect against attempted fraud, the readers in vehicles or subway entrances, i.e. devaluers, are only provided with key A. This means that a transponder can never be revalued using a devaluer, not even if the software of a stolen devaluer is manipulated. The transponder itself refuses to add to the internal counter unless the transaction has been authenticated by the correct key.

The high-security key B is only loaded into selected secure readers that are protected against theft. The transponder can only be revalued using these readers.

10.1.3.4 Segmented memory

Transponders can also be protected from access by readers that belong to other applications using authentication procedures, as we described in a previous chapter. In transponders with large memory capacities, it is possible to divide the entire memory into small units called segments, and protect each of these from unauthorised access with a separate key. A *segmented transponder* like this permits data from different applications to be stored completely separately.

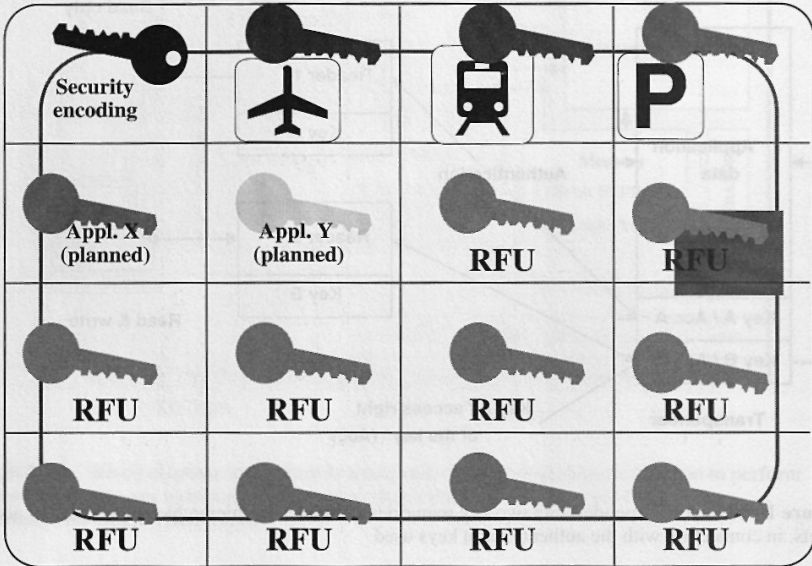


Figure 10.11: Several applications on one transponder – each protected by its own secret key

Access to an individual segment can only be gained after successful authentication with the appropriate key. Therefore, a reader belonging to one application can only gain access to its “own” segment if it only knows the *application’s own key*.

The majority of segmented memory systems use fixed segment sizes. In these systems, the storage space within a segment cannot be altered by the user. A fixed segment size has the advantage that it is very simple and cheap to realise upon the transponder’s microchip.

However, it is very rare for the storage space required by an application to correspond with the segment size of the transponder.

In small applications, valuable storage space is wasted on the transponder, because the segments are only partially used. Very large applications, on the other hand, need to be distributed across several segments, which means that the application specific key must be stored in each of the occupied segments. This multiple storage of an identical key also wastes valuable storage space.

A much better use of space is achieved by the use of variable length segments. Here, the memory allocated to a segment can be matched to the requirements of the application using the memory area. Because of the difficulty in realising *variable segmentation*, this variant is rare in transponders with state machines.

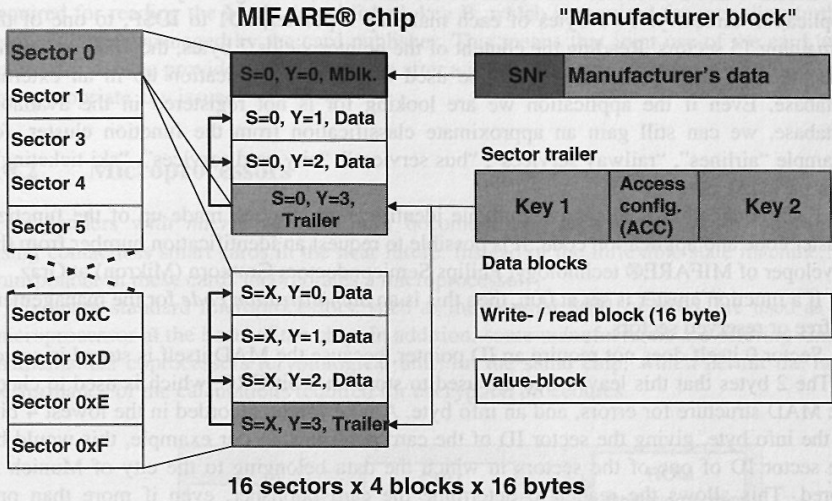


Figure 10.14: Memory configuration of a MIFARE® data carrier [koo]. The entire memory is divided into 16 independent sectors. Thus a maximum of separate 16 applications can be loaded onto a MIFARE® card

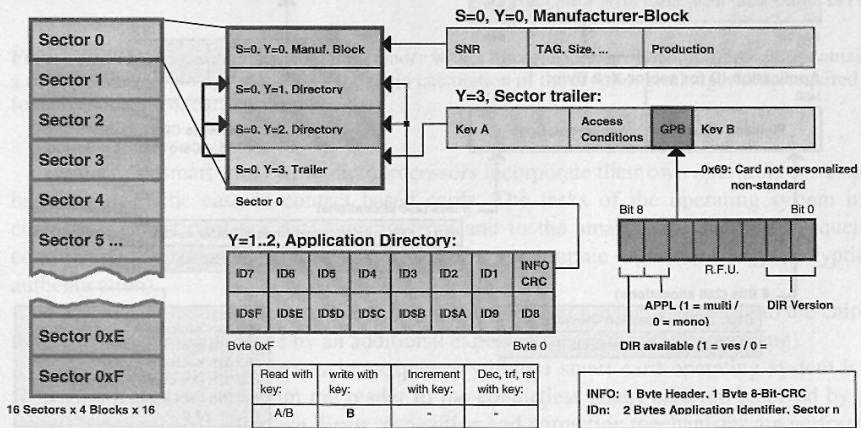


Figure 10.15: The data structure of the MIFARE® application directory consists of an arrangement of 15 pointers (ID1 to IDSF), which point to the subsequent sectors

Table 14.1 continued: Overview of RFID systems on the market

System manufacturer:	Coupling, operating method, energy, distance:	Memory: gross / net:	Security logic	Downlink reader → transponder:	Uplink transponder → reader:
SLE44R42S (MIFARE® plus)	“-“	14 k Mask ROM 4 k EEPROM 7816 contacts	“-“ + 8 bit,	“-“	“-“
MOBY-F	125 kHz, ind., 0 – 7 cm	240 Byte EEPROM	n.i.	n.i.	n.i.
MOBY-L	4 MHz, ind., 0 – 5 cm	512 Byte EEPROM	n.i.	0.1 kbyte/s	n.i.
MOBY-I	1.81 MHz, ind., 0 – 1 m	128 Byte EEPROM, 32 k RAM	n.i.	n.i.	n.i.
MOBY-E	13.56 MHz, ind., 0 – 10 cm	752 Byte EEPROM	n.i.	n.i.	n.i.
MOBY-V	433 MHz, em., battery, 0 – 80 cm	32 k RAM	n.i.	>1 kbyte/s	n.i.
SOFIS	2.45 GHz, em., 0 – 1.3 m	20 bit fix. SAW	n.i.	(read only)	surface wave
Sokymat Titan 4000	125 kHz, ind.	128 Byte EEPROM	password	ASK	load modulation
Unique 1200	125 kHz, ind., 0 – 20 cm	8 Byte, OTP Laser-ROM	n.i.	ASK	load modulation
Sony, FeliCa	13.56 MHz, ind., 0 – 10 cm	1 kByte	authentication encryption	modified ASK 250 kbit/s	n.i.
TagMaster AB, Confident S1251, S1255	2.45 Ghz, em., 0–4 m (read) 0–0.5m (write), Li battery	8 – 75 Byte	anticollision	(random interval mode) 4 kBit/s	backscatter, 16 kBit/s
Temic, TK 5530	125 kHz, ind.	16 Byte PROM (Laser cutting)	n.i.	read-only	load modulation FSK, PSK, / Manchester, bi-phase, max. 15 kbit/s

- Code
 - DBP, 126
 - differential, 126
 - differential bi-phase, 126
 - EAN, 2
 - Manchester, 126, 145
 - Miller, 126
 - modified Miller, 127
 - NRZ, 126, 145, 165
 - pulse-pause, 126
 - unipolar RZ, 126
- Coding
 - bit, 145
 - in the baseband, 125
- Collar transponder, 245
- Collision, 142
- Combicard, 187
- Communication system, 125
- Configuration register, 177
- Contactless clock, 19
- Container, 167
- Container identification, 167, 258
- Coupling
 - capacitive, 44
 - close, 21, 43, 163
 - inductive, 22, 116, 275
 - transformer, 36, 37
 - vicinity, 166
- Coupling coefficient, 62
- Coupling element, 9
 - capacitive, 164
 - inductive, 164
- Coupling loss, 203
- CRC, 139
- Cryptological key, 151
- Cryptological unit, 174
- DASA, 279
- Data carrier, 9
 - electronic, 171
- Data transfer, 125
- Deactivation device, 26, 170
- Deactivation rate, 170
- Deciphering, 155
- Decryption, 155
- Deister electronic, 279
- Demodulation, 125, 128, 172
- Demodulator, 125
- Detection rate, 26, 168
- Die, 220
- Diehl Ident, 279
- Dimple, 28
- Diode
 - capacitance, 29
 - low barrier Schottky, 42
- Dip, 27
- Dipole, 30
- Directed beam, 277
- Directional coupler, 42, 203
- Directivity, 204
- Disk, 13
- Dopant profile, 29
- Doppler effect, 195
- Driver, 208
- Dual interface card, 187
- Duplex
 - full, 11, 34
 - half, 11, 34
- Duty factor, 129
- Ear tag, 247
- EAS, 26, 27
- Eddy current, 64
- EEPROM, 191
 - lifetime, 192
- Effective area, 108
- Effective length, 109
- Electric rotational field, 64
- Electromagnetic interference field, 276
- Electromagnetic procedure, 32
- Electromagnetic wave, 105, 211
- Electronic article surveillance, 11, 26
- Electronic immobilisation system, 15
- EM microelectronic-Marin, 279
- EN 300220, 122
- EN 300330, 117, 120
- EN 300440, 123
- Encrypted data transmission, 155
- Encryption, 155, 277
- Encryption function, 157
- End of burst detector, 47
- Endrich, 279