

Klaus Finkenzeller

RFID Handbook

Fundamentals and Applications in Contactless
Smart Cards, Radio Frequency Identification
and Near-Field Communication

THIRD EDITION



 WILEY

RFID HANDBOOK

FUNDAMENTALS AND APPLICATIONS IN CONTACTLESS SMART CARDS, RADIO FREQUENCY IDENTIFICATION AND NEAR-FIELD COMMUNICATION, THIRD EDITION

Klaus Finkenzeller

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Preface to the Third Edition

This book is aimed at an extremely wide range of readers. First and foremost it is intended for engineers and students 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 each new edition of this book proves. This book therefore aims to fill a gap in the range of literature on the subject of RFID. The need for well-founded technical literature in this field is proven by the fortunate fact that this book has now already appeared in five languages. Editions in two further languages are currently being prepared. Further information on the German version of the RFID handbook and the translations can be found on the homepage of this book, <http://RFID-handbook.com>.

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 the physical principles of RFID, which is why the chapter on this subject is by far the most comprehensive of the book. However, great importance is also assigned to providing an understanding of the basic concepts, data carrier and reader, as well as of the relevant standards and radio-technology regulations.

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 and the latest standards and regulations. With the widespread use of RFID technology, it becomes also increasingly difficult not to lose track of applications. In ever-shorter intervals, the media provides information on new applications for RFID systems. 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.

A new addition to this third edition is Near-Field Communication (NFC) which has been introduced to several different chapters. Chapter 3 now includes the fundamentals of NFC; and Chapter 13 presents NFC interface components and describes the extension from NFC to secure-NFC.

Another addition is a complete wiring diagram and proposed circuit for an RFID reader according to ISO/IEC 14443. A layout and complete component kit of this wiring diagram and circuit is also available on the Internet.

It was a very special occasion when the Fraunhofer Smart Card Prize 2008 – which annually honors special contributions to smart-card technology – was awarded to the known smart-card

handbook of my two colleagues Rankl and Effing as well as to this RFID handbook. The prize-giving ceremony took place on the occasion of the 18th Smart-Card Workshop of the Fraunhofer Institute for Secure Information Technology (SIT) in Darmstadt on 5 February 2008.

In March 2008, we were able to look back on ten successful years of the RFID Handbook. The first German-language edition was published in March 1998 and comprised 280 pages. At that time, RFID was still a niche technology and hardly known to the public; this has completely changed. Today, RFID has become an established term; and due to applications such as the electronic passport and electronic product code (EPC), a broad public has become aware of this technology.

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

Klaus Finkenzeller

Munich, Autumn 2008

List of Abbreviations

μP	Microprocessor
μs	Microsecond (10^{-6} s)
ABS	Acrylnitrilbutadienstyrol
ACM	Access configuration matrix
AFC	Automatic fare collection
AFI	Application family identifier (see ISO 14443-3)
AI	Application identifier
AM	Amplitude modulation
APDU	Application data unit
ASCII	American Standard Code for Information Interchange
ASIC	Application specific integrated circuit
ASK	Amplitude shift keying
ATQ	Answer to request (ATQA, ATQB: see ISO 14443-3)
ATR	Answer to reset
AVI	Automatic vehicle identification (for railways)
BAC	Basic access control (ePassport)
BAPT	Bundesamt für Post und Telekommunikation (now the Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway)
Bd	Baud, transmission speed in bit/s
BGT	Block guard time
BKA	Germany's Federal Criminal Police Office
BMBF	Bundesministerium für Bildung und Forschung (Ministry for Education and Research, was BMFT)
BMI	German Federal Ministry of the Interior
BP	Bandpass filter
BSI	German Federal Office for Information Security
C	Capacitance (of a capacitor)
CCG	Centrale für Coorganisation GmbH (central allocation point for EAN codes in Germany)
CCITT	Comité Consultatif International Télégraphique et Téléphonique
CEN	Comité Européen de Normalisation
CEPT	Conférence Européenne des Postes et Télécommunications
CERP	Comité Européen de Règlementation Postale
CICC	Close coupling integrated circuit chip card
CIU	Contactless interface unit (transmission/receiving module for contactless microprocessor interfaces)
CLK	Clock (timing signal)
CRC	Cyclic redundancy checksum

dBm	Logarithmic measure of power, related to 1 mW HF-power (0 dBm = 1 mW, 30 dBm = 1 W)
DBP	Differential bi-phase encoding
DIN	Deutsche Industrienorm (German industrial standard)
DoD	Department of Defense (USA)
DS	Discovery services (EPC)
DWD	German Weather Service
EAN	European Article Number (barcode on groceries and goods)
EAS	Electronic article surveillance
EC	Eurocheque or electronic cash
ECC	European Communications Committee
ECTRA	European Committee for Regulatory Telecommunications Affairs
EDI	Electronic document interchange
EEPROM	Electric erasable and programmable read-only memory
EIRP	Equivalent isotropic radiated power
EMC	Electromagnetic compatibility
EOF	End of frame
EPC	Electronic product code
EPCIS	EPC Information Services
ERC	European Radiocommunications Committee
ERM	Electromagnetic compatibility and radio spectrum matters
ERO	European Radiocommunications Office
ERO	European Radio Office
ERP	Equivalent radiated power
ETCS	European Train Control System
ETS	European Telecommunication Standard
ETSI	European Telecommunication Standards Institute
EVC	European Vital Computer (part of ETCS)
FCC	Federal Commission of Communication
FDX	Full-duplex
FHSS	Frequency hopping spread spectrum
FM	Frequency modulation
FRAM	Ferroelectric random access memory
FSK	Frequency shift keying
GIAI	Global individual asset identifier (EPC)
GID	General identifier (EPC)
GRAI	Global returnable asset identifier (EPC)
GSM	Global System for Mobile Communication (was Groupe Spécial Mobile)
GTAG	Global-tag (RFID Initiative of EAN and the UCC)
HDX	Half-duplex
HF	High frequency (3–30 MHz)
I ² C	Inter-IC-bus
ICAO	International Civil Aviation Organization
ICC	Integrated chip card
ID	Identification
ISM	Industrial scientific medical (frequency range)
ISO	International Organization for Standardization
ITU	International Telecommunication Union
L	Loop (inductance of a coil)
LAN	Local area network

LBT	Listen before talk
LF	Low frequency (30–300 kHz)
LPD	Low-power device (low-power radio system for the transmission of data or speech over a few hundred metres)
LRC	Longitudinal redundancy check
LSB	Least significant bit
MAD	MIFARE® Application Directory
MRZ	Machine readable zone (ePassport)
MSB	Most significant bit
NAD	Node address
NFC	Near field communication
nomL	Nonpublic mobile land radio (industrial radio, transport companies, taxi radio, etc.)
NRZ	Non-return-to-zero encoding
NTC	Negative temperature coefficient (thermal resistor)
NTWC	New Technologies Working Group (ICAO)
NVB	Number of valid bits (see ISO 14443-3)
OCR	Optical character recognition
OEM	Original equipment manufacturer
ONS	Object naming server (EPC)
OTA	Over the air (possibility to program a SIM card or a secure element via the GPRS/UMTS interface of a mobile phone)
OTP	One time programmable
PC	Personal computer
PCD	Proximity card device (see ISO 14443)
PICC	Proximity integrated contactless chip card (see ISO 14443)
PIN	Personal identification number
PKI	Public key infrastructure
PMU	Power management unit
POS	Point of sale
PP	Plastic package
PPS	Polyphenylensulfide
PSK	Phase shift keying
PUPI	Pseudo-unique PICC identifier (see ISO 14443-3)
PVC	Polyvinylchloride
R&TTE	Radio and Telecommunication Terminal Equipment (The Radio Equipment and Telecommunications Terminal Equipment Directive (1999/5/EC))
RADAR	Radio detecting and ranging
RAM	Random access memory
RCS	Radar cross-section
REQ	Request
RFID	Radio frequency identification
RFU	Reserved for future use
RTI	Returnable trade items
RTI	Road transport information system
RTTT	Road transport and traffic telematics
RWD	Read–write device
SAM	Security authentication module
SAW	Surface acoustic wave
SCL	Serial clock (I ² C bus interface)
SDA	Serial data address input–output (I ² C bus interface)

SEQ	Sequential system
SGLN	Serialised global location number (EPC)
SMD	Surface-mounted devices
SNR	Serial number
SOF	Start of frame
SRAM	Static random access memory
SRD	Short-range devices (low-power radio systems for the transmission of data or voice over short distances, typically a few hundred metres)
SSCC	Serial shipping container code (EPC)
TR	Technical Regulation
UART	Universal asynchronous receiver–transmitter (transmission/receiving module for computer interfaces)
UCC	Universal Code Council (American standard for barcodes on groceries and goods)
UHF	Ultra-high frequency (300 Mhz to 3 GHz)
UN	United Nations
UPC	Universal Product Code
UPU	Universal Postal Union
VCD	Vicinity card device (see ISO 15693)
VDE	Verein Deutscher Elektrotechniker (German Association of Electrical Engineers)
VHE	Very high frequency (30 MHz to 300 MHz)
VICC	Vicinity integrated contactless chip card (see ISO 15693)
VSWR	Voltage standing wave ratio
XOR	Exclusive OR
ZV	Zulassungsvorschrift (Licensing Regulation)

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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 devices 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 actively involved in the development and sale of RFID systems indicates that this is a market that should be taken seriously. Whereas global sales of RFID systems were approximately 900 million \$US in the year 2000 it is estimated that this figure will reach 2650 million \$US in 2005 (Krebs, n.d.). The *RFID market* therefore belongs to the fastest growing sector of the radio technology industry, including mobile phones and cordless telephones (Figure 1.1).

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

As an introduction, the following section gives a brief overview of different automatic ID systems that perform similar functions to RFID (Figure 1.2).

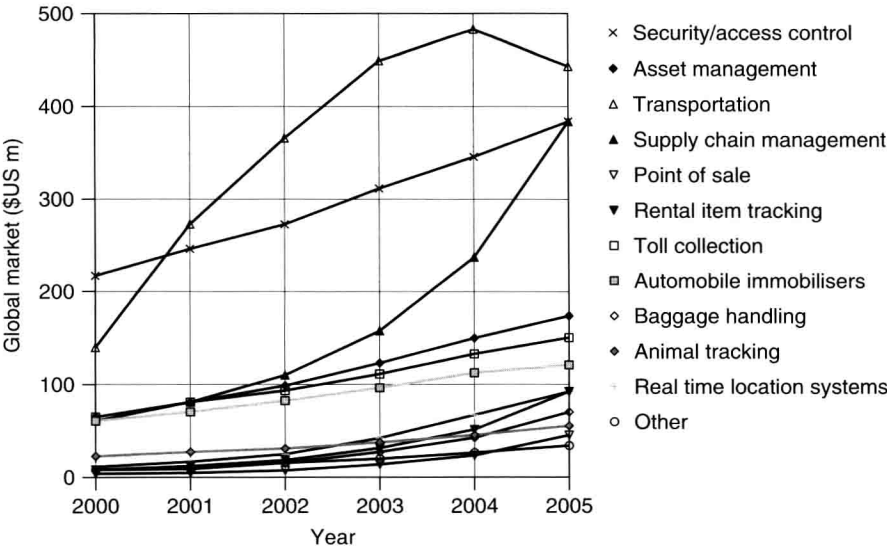


Figure 1.1 The estimated growth of the global market for RFID systems between 2000 and 2005 in million \$US, classified by application (Krebs, n.d.)

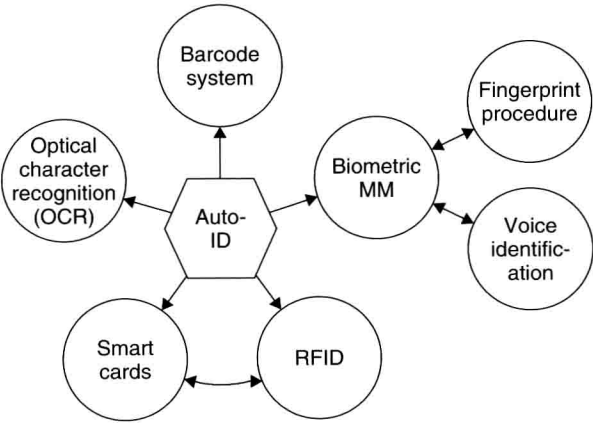


Figure 1.2 Overview of the most important auto-ID procedures

1.1 Automatic Identification Systems

1.1.1 Barcode Systems

Barcodes have successfully held their own against other identification systems over the past 20 years. According to experts, the turnover volume for barcode systems totalled around 3 billion DM in Western Europe at the beginning of the 1990s (Virnich and Posten, 1992).