Part One

RFID: General Features, Basic Principles and Market

This first section will provide a quick introduction to radio frequency identification (RFID) with an orientation towards RFID at ultra high frequency (UHF) and super high frequency (SHF). This section will introduce a lot of vocabulary and numerous definitions of terms, concepts and principles relating to frequencies, operating modes, and the like. I have therefore divided it into three chapters, as follows:

- some introductory words, definitions and vocabulary;
- a description of the general operating principles of the 'base station–tag' pair;
- and finally the market and fields of application for contactless and RFID technology.

Note

I would ask the reader to be as careful as possible when using these terms, which are frequently used unwisely, owing to ignorance, abuse of language, journalistic distortions, supposedly technical articles that are excessively or badly popularized, etc., often causing great confusion. RFID professionals, working in the most reputable organizations concerned with ISO standardization, have courageously and painstakingly compiled and edited a definitive 'RFID Vocabulary' (ISO 19762) to help users to understand each other more easily – so, use it if you can!

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Introduction, Definitions and Vocabulary

In view of the imminent development of very many applications in the field of identification, systems of traceability and logistical monitoring, etc., using radio frequency identification (RFID), and having already written two books about some of these systems, operating mainly at frequencies below 135 kHz (mainly at 125 kHz) and 13.56 MHz (see References 1 and 2 mentioned in the Preface), I should now like to present this book, which is specifically concerned with RFID devices operating at ultra high frequency (UHF) and super high frequency (SHF). For various reasons (I will provide details of these subsequently), I preferred to wait until now to deal with this subject on a separate basis.

For the present, and for several years to come, this book will offer a wide-ranging theoretical, technical, technological and applications-related overview of RFID systems operating at UHF and SHF. I have also dealt in considerable detail with the themes of international standards (ISO, ETSI, FCC, etc.), the current regulations, the aspects of human exposure, etc., which cannot be ignored when working in this field.

The generic terms in the title of this book – identification, contactless tags and devices operating at UHF and SHF – cover a variety of different and controversial fields and subject areas. For example, while the words ‘identification’ and ‘tracking’ in relation to products will please a manufacturer wishing to monitor his output, the same words may also arouse fears of erosion of civil liberties and privacy. Similarly, the term ‘tag’ also suggests major benefits and ease of use for fast check-out procedures at large stores, flexibility for stocktaking, convenience for industrial and domestic supplies, opportunities for better protection against counterfeiting and the black market; however, the horrors of even more subtle market research may now lurk behind the purchase of any item!

That, then, is a very brief introduction to this vast, fascinating and contradictory world into which this book is designed to take you. It will deal with technical matters only, ‘from theory to practice’, as they say (see also References 1 and 2 mentioned in the Preface).

RFID at Ultra and Super High Frequencies: Theory and Application Dominique Paret

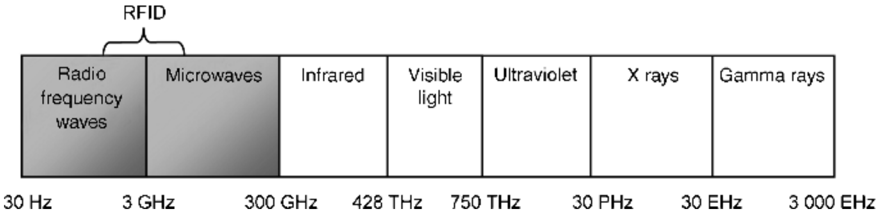

Figure 1.1 Electromagnetic spectrum of radio frequencies

1.1 To Understand Radio Frequency, We Must Know about Frequencies and Their Classification

We have arrived in the world of radio frequency identification (RFID). Let us start with frequencies, their definitions and their classifications.

1.1.1 General Classification of Radio Frequencies

To avoid any misunderstanding of terminology, and for simple practical reasons, the frequencies have been classified according to their values and/or related wavelengths. Figure 1.1 shows a summary of the international classification of frequencies.

As we all know, an electromagnetic wave is identified by its frequency of oscillation f (and/or its period $T = 1/f$) and its related wavelength λ. The relation between f and λ in air or in a vacuum is well known (see Table 1.1):

$$\lambda = cT = c/f$$

Table 1.1 Frequencies and wavelengths used at radio frequency (RF)

Band number	Abbreviation of band name	Frequency bands (the upper and lower limits are exclusive)	Metric names	Metric abbreviations of the band	Wavelengths λ (the upper and lower limits are exclusive)
−1	ELF	0.03 to 0.3 Hz	Gigametre	Gm	1 to 10 Gm
0	ELF	0.3 to 3 Hz	Hectomegametre	hMm	100 to 1000 Mm
1	ELF	3 to 30 Hz	Decamegametre	daMm	10 to 100 Mm
2	ELF	30 to 300 Hz	Megametre	Mm	1 to 10 Mm
3	ULF	300 to 3000 Hz	Hectokilometre	hkm	100 to 1000 m
4	VLF	3 to 30 kHz	Myriametre	Mam	10 to 100 km
5	***LF***	***30 to 300 kHz***	***Kilometre***	***km***	***1 to 10 km***
6	MF	300 to 3000 kHz	Hectometre	hm	100 to 1000 m
7	***HF***	***3 to 30 MHz***	***Decametre***	***dam***	***10 to 100 m***
8	VHF	30 to 300 MHz	Metre	M	1 to 10 m
9	***UHF***	***300 to 3000 MHz***	***Decimetre***	***dm***	***10 to 100 cm***
10	***SHF***	***3 to 30 GHz***	***Centimetre***	***cm***	***1 to 10 cm***

The band number N is the value of the exponent (0.3×10^N to 3×10^N Hz).
The term ELF denotes the set of bands from −1 to 2.

where c is the speed of light, i.e. the velocity of propagation of light in a vacuum (or in air), λ is in metres and f is in hertz. Thus

$$\lambda = \frac{3 \times 10^8}{f}$$

Please note that I have shown the frequency bands used in RFID, i.e. LF, HF (VHF), UHF and SHF, in bold italics in Table 1.1.

1.1.1.1 Radio Frequencies Accepted and/or Authorized for RFID

Figure 1.2 and Table 1.2 show the ranges of radio frequencies, out of the frequency bands indicated above, that are accepted by national and international regulatory bodies for RFID applications, together with their relative positions in the RF spectrum.

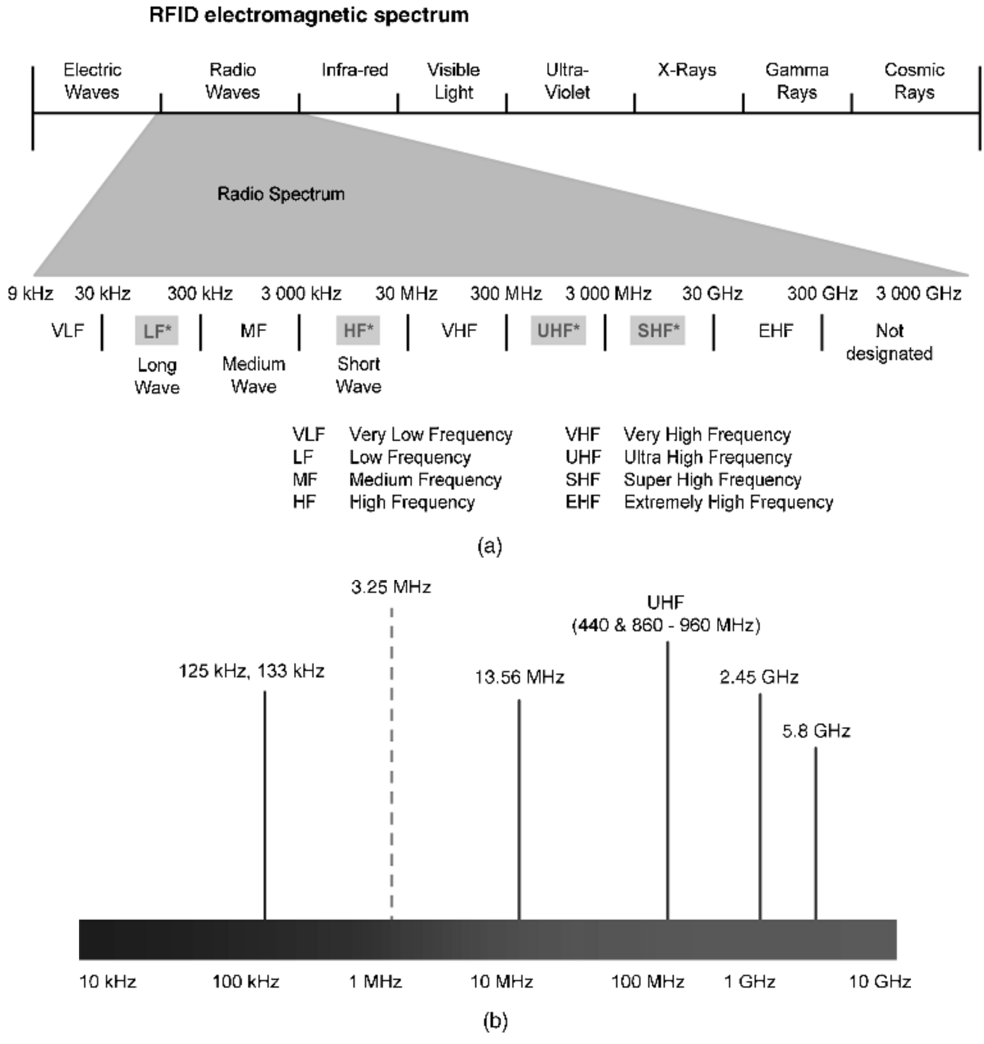

Figure 1.2 (a) RF and RFID electromagnetic spectrum. (b) Frequencies authorized/accepted for RFID applications

Table 1.2

Radio frequency bands		Radio frequencies accepted and/or authorized for RFID	
From 30 to 300 kHz	LF	Low frequencies	<135 kHz
From 3 to 30 MHz	HF	High frequencies	13.56 MHz
From 300 to 3000 MHz	UHF	Ultra high frequencies	433 and from 860 to 960 MHz 2.45 GHz
From 3 to 30 GHz	SHF	Super high frequencies	5.8 GHz

Notes
Because of the closeness of its value and its physical properties, the 2.45 GHz frequency at the top of the UHF band is very often included in SHF band – and I will do this as well.

In my first two books (References 1 and 2 mentioned in the Preface), I have provided full details of applications using LF and HF; the present book will only be concerned with UHF and SHF applications.

For the time being, we have finished with the definitions of frequencies. Let us now look at the way they are used.

1.2 RFID: Who Uses It and What For?

Until recent times, the identification of objects and persons was practically always based on paper, card and other media, using written or printed codes and data processing, requiring either contact with the identifier (for writing) or direct visibility of it (for reading). For some years now, as the performance of radio frequency links and the associated electronic components has improved, research and development has been directed towards the possibility of replacing and enhancing the former identification methods with methods called *radio frequency identification* (RFID) or *contactless identification.* These new methods have been restricted for a long time by the impossibility of providing a remote power supply to the identifier, mainly because of its power consumption, which required the provision of a local power source (a battery or accumulator). However, with the tremendous advances in integrated circuit technology over the last decade, the dream of true contactless systems (using no batteries) has become a reality.

In Chapter 3, I will consider what this is used for (i.e. the applications) and who benefits (i.e. the market).

1.3 History

Identification has existed in numerous forms for many years. Looking at just the last few decades, it is clear that there has been an explosion in the growth of labelling for identifying many articles, with the appearance of paper bar code labels and their readers. At the same time, many industrial experiments and applications using electronic tags were developed, mainly concerned with monitoring industrial processes and animal identification (for sheep, pigs, cattle, horses, domestic pets, etc.), using implants, or monitoring individuals by access control systems (for buildings, transport, etc.). This concept of electronic tagging is now moving out of its industrial setting towards the field of high-level identification systems incorporating all the provision for confidentiality and secrecy that may be required.

These specialist subjects have been studied for many years, and we can now say that their application on a massive scale is imminent, if not already present. In addition to the widespread and well-known systems of electronic immobilizer devices for motor vehicles (more than 700 million fitted over a few years) operating on this secure contactless principle and transport smart cards (close to 2 billion operating at present, mainly in Asia, Europe and South America), there are also many experiments, pilot studies and major projects currently under way in the field of electronic tags.

Clearly, this has been a great stimulus to users of 'contact' devices, particularly users of tracking systems.

1.4 Radio Frequency (or Contactless) Identification and Its Range of Applications

Here is a brief outline of the range of applications of contactless electronic identification, or RFID, at the present time.

1.4.1 Contactless RFID

The term *radio frequency identification* (RFID) denotes any identification system operating by means of radio frequency waves. The term *contactless* is also frequently used, but it does not specify the kind of transmission (RF, IR, etc.). The field of contactless identification can be broken down into various subfields, the main ones being as follows.

Optical Vision

This requires the presence of a detector operating with direct vision of the identifier, using either the human eye, a reading device (laser, etc.) or a CCD (charge coupled device) camera. The most widespread example is that of standard printed labels, or bar code and 2D (two-dimensional) code labels.

The greatest problem (if it really is a problem) of these systems is the fact that direct vision is essential for reading and that it is dependent on the cleanness of the label (which may be stained or torn, for example). A second problem generally arises from the impossibility of updating the labels in a straightforward way – other than by simply replacing the labels. Nevertheless, we must not forget their greatest advantage, namely their very low cost!

LF and HF Link

By using radio frequency communication between the identifiers and the readers, it is possible to read at longer distances (not dependent on the resolution of the human eye or of an optoelectronic reader), without the need for direct physical optical vision of the identifier. This also makes it possible to propose 'bulk' reading systems, which can handle a large number of identifiers simultaneously in the radio frequency field of the reader, without the need to view them optically. With the aid of electronic systems, it is also possible to provide protection, security, etc., for the information on or in the identifier. This often leads to the development of identifiers, which are frequently referred to as *intelligent bar codes* or *intelligent labelling*; these will be described more fully below.

As I have mentioned, the frequencies used under the name of 'LF and HF radio frequencies' extend from a few kilohertz to several tens of megahertz.

Links at Ultra High Frequencies (UHF) and Super High Frequencies (SHF)

The carrier frequencies for the operation of these devices at UHF are 433 and 860/960 MHz. For SHF, the most common applications are at 2.45–5.8 and sometimes 24 GHz. Although some of these identifiers have incorporated batteries (in which case they are called *battery assisted*, see below), these systems are to be classed as 'passive' devices, since they do not transmit any electromagnetic radiation (the fact that they have incorporated batteries does not in any way make them 'active'!). In fact, as will be described in detail in this book, these identifiers modulate their degrees or rates of reflection of the incident radiation (known as the 'mirror' effect) in order to enable the transmitter to interpret them. The transmitting source, which also receives the reflected radiation, can then interpret the modulation created by the identifier.

Because of the level of these carrier frequencies, high communication speeds are possible, resulting in short transaction times, of the order of tens of milliseconds. This also makes it possible to identify rapidly moving objects 'on the fly' (as in the case of trains, or cars at motorway toll booths, for example, bearing in mind that a speed of 10 m/s is equivalent to 36 km/h, or alternatively 144 km/h is equivalent to 40 m/s and therefore a vehicle covers 1 m in 25 ms).

The well-known technical problem of UHF and SHF applications is their very modest (or downright poor) ability to pass through most liquids and the human body (which is 80% water!), as well as their generally rather directional propagation – although this may sometimes be an advantage!

Another problem of links operating at these frequencies is the limitation on remote power supply to the identifier, since the ability to use a small antenna, because of the wavelengths associated with the frequencies concerned, means that energy recovery is rather limited, and therefore it is sometimes necessary to use a local power supply.

Infrared Links

Like super high frequency links, optical links of the infrared type (with wavelengths of around 800 nm) are often used in support of contactless identification devices (at motorway tolls, for example) to provide a higher data rate and greater directionality of the communication beam. In this case also, operating distances are generally high and the transponders are often supplied autonomously.

1.5 The Concept of Contactless Communication

I will now provide a brief interpretation of the concept of contactless communication. This will include a basic introduction to:

- the concept of contactless communication distances;
- the concept of power supply and power supply mode;

- communication and the communication model (ISO/OSI);
- the concept of the operating mode.

1.5.1 The Concept of Contactless Communication Distances

Please note that the term ‘distance’ refers to the total/maximum distance that can be covered by a transmission, while ‘range’ refers to the interval between two distances or limits.

Since this book is concerned with RFID and ‘contactless’ applications, it will now be useful to define the mechanical concept implied by ‘contactless’, in other words the concept of communication distances and consequently the applications envisaged by users of ‘contactless’ technology. First of all, however, in order to avoid needless debate, you should know that, surprising though it may seem, there is no ISO standard that defines the operating distance (in terms of metres) of RFID devices in the strict sense of the term.

Very Short Distance, i.e. from Contactless to Contact!

Surprisingly, there are many ‘contactless’ applications in which the operating distance between the base station and the identifier must be, or can be, virtually zero (in ‘touch’ systems); the essential point is that electrical insulation must be present for the purposes of the application.

Short Distance

‘Short distance’ applications (such as those operating at 13.56 MHz according to ISO 10536) generally operate over distances of the order of a few millimetres or tens of millimetres. These are contactless applications that ‘make contact’.

Proximity

The same applies to the concept of ‘proximity’ contactless systems (e.g. ISO 14443), which use distances of the order of tens of centimetres. This family of applications includes contactless smart cards requiring ‘voluntary action’ for their presentation for applications in banking, payment, transport, access control, etc.

Vicinity

The same advantages and drawbacks are found in ‘vicinity’ contactless systems (see, for example, ISO 15693/ISO 18000-x). The distances required are of the order of 50 cm to 1 m and support ‘hands-free’ applications including access control, baggage recognition and monitoring at airports, movement of trolleys, etc.

Long Distance

This term is generally used for applications operating over distances of the order of 1 to 5–10 m. Examples are applications at the gates of super- and hypermarkets or reading from pallets. Beyond these distances, we speak of ‘very long distance’.

Very Long Distance

In very long distance applications (over more than tens or even hundreds of metres) we tend to leave the field of remotely powered tags or transponders, which will be described

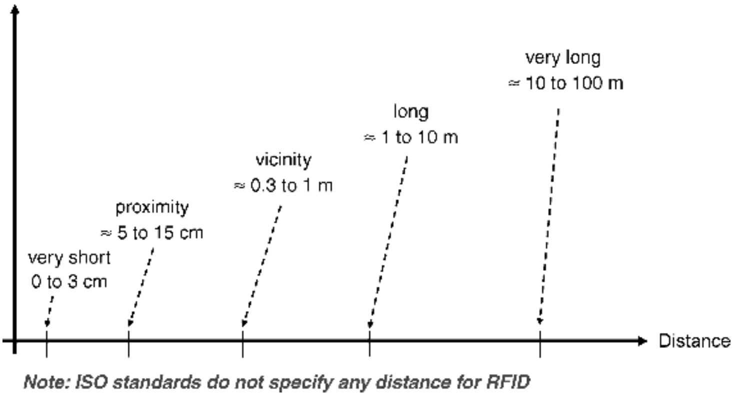

Figure 1.3 Operating distances in RFID

subsequently, and enter the world of systems using radio frequency links in which the identifiers have their own incorporated power supplies and operate on conventional 'radio' principles, using transmitters and receivers on each side (i.e. on the fixed and remote elements).

This type of system, known as 'active', is outside the scope of this book, and you should consult the excellent monograph by François de Dieuleveult, *Electronique Appliquée aux Hautes Fréquences* (Dunod, Paris, 2007), for assistance in developing projects of this type.

Figure 1.3 summarizes these classes of operating distances.

1.6 The Elements, Terms and Vocabulary of RFID

Figure 1.4 and Table 1.3 show the various elements of a contactless application, in the form of a block diagram and the layers of the OSI/ISO model.

Here is a rapid survey of the building blocks of an RFID system.

Remote Element

Let us start with the remote element, which has a memory (WORM, E2PROM, FLASH, etc.) for storing the data forming part of the application concerned and which provides control of the communication and finally the part providing RF transmission.

Table 1.3

	Remote element	Fixed element
Layer 7	Application	Application
Layer 2	Communication protocol	Communication protocol
Layer 1	Analogue part	Analogue part
	Antenna	Antenna
Medium	Electromagnetic radiation	Air coupling

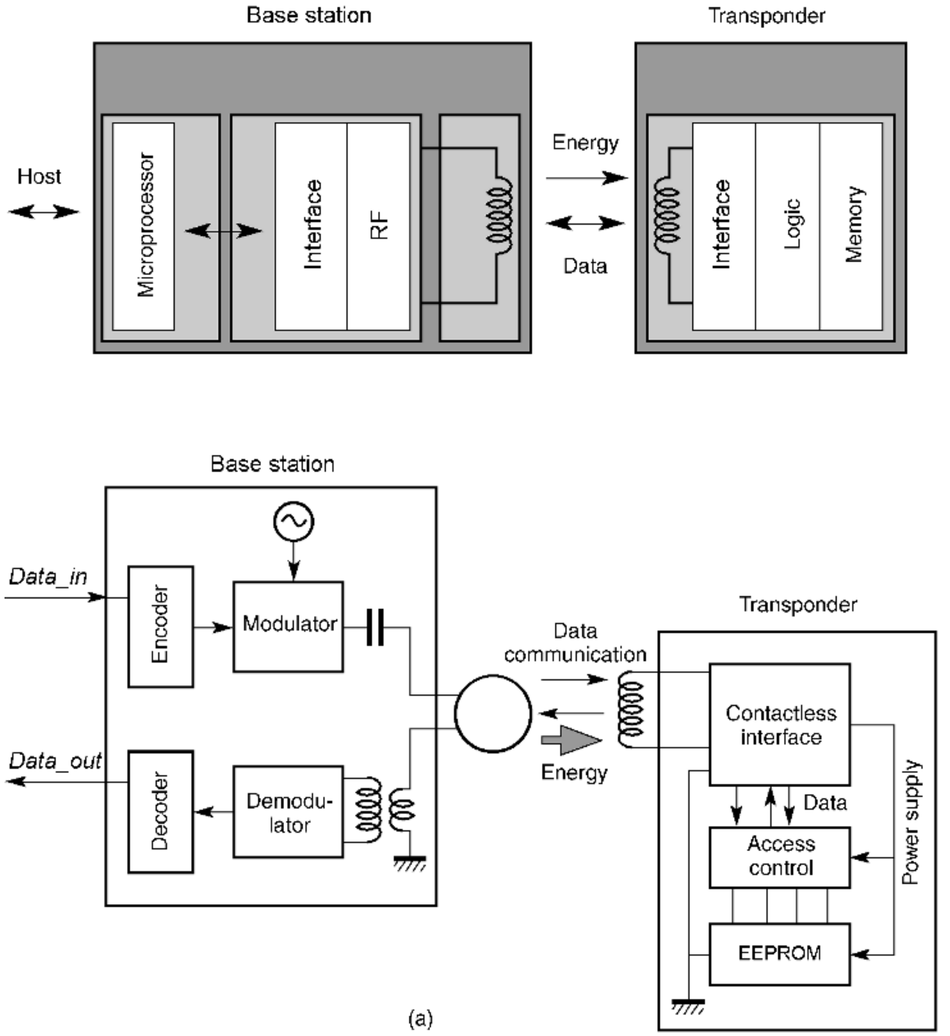

Figure 1.4 (a) Block diagram of the elements of a contactless application. (b) The OSI structure of an RFID application

Medium
The communication medium between the antennae of the remote element and the fixed part is usually air. The electromagnetic RF radiation carries the data.

Fixed Element
The fixed element comprises an analogue part, used for transmitting and receiving RF signals, the circuits for managing the protocol for communication with the identifier, the communication management system (collision management, authentication, encryption, etc.) and finally an interface for dialogue with the host system.

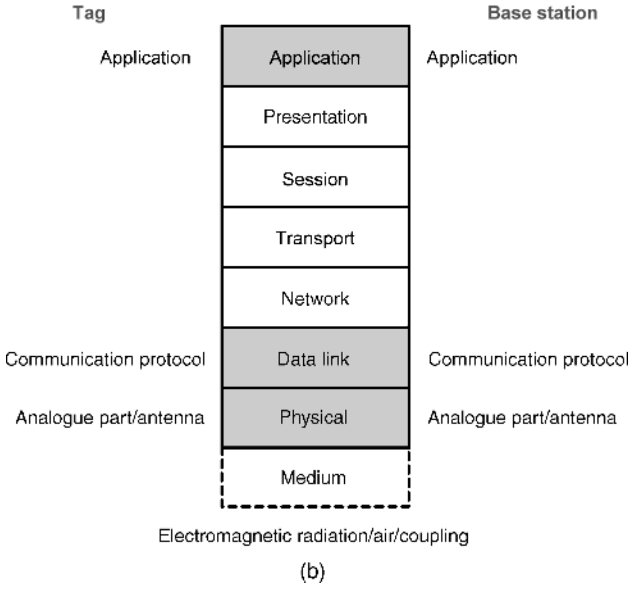

Figure 1.4 (*Continued*)

Host System

To complete this brief survey of an RFID system, we have the host system, which manages the application at the highest level.

Now that the general picture is in place, we can go on to examine each of these blocks more closely, but first of all it is time to learn some vocabulary, to avoid any misunderstandings.

1.7 Vocabulary: The Many Terms Used for the Elements of RFID

Instead of attaching specific names to the 'remote elements' and 'fixed elements' in the preceding section, I have rather avoided the issue! In fact, my profession is extravagant with its naming of the various elements used in contactless applications. It is therefore necessary to carry out a little pruning on this large stock of names given to the main components of contactless RFID applications.

1.7.1 Remote Element

Let us start with the remote element. We often encounter the following terms.

Identifier

I have chosen to use this term so far in my introduction to the subject, because it is sufficiently descriptive . . . for now.

Tag
From the noun ‘tag’ meaning a label, and the verb ‘to tag’, i.e. to check or mark.

Pit
A more powerful term. PIT stands for *programmable identification tag*, which is used to identify an ‘object’. Strictly speaking, a ‘tag’ is not (re)programmable – only a PIT is!

Data Carrier
This generic term (not restricted to contactless systems) denotes the carrier in the sense of the element that includes or contains the data, which is obviously the tag or the PIT.

Label, Smart Label
These are other names for ‘tag’.

Transponder
The technology used for contactless applications is practically always based on an electronic device composed of an interrogating transmitter (fixed element) and responder (remote element), i.e. a transmitter/responder pair, abbreviated to ‘transponder’, meaning an object that can respond to commands sent by a ‘transmitter’ using a radio signal. This is one of the generic terms that will be used frequently in this book to avoid repetition.

ICC, PICC, VICC
You should note that ISO standards relating to contactless smart card applications often refer to the terms ICC, PICC and VICC, which stand for *integrated circuit card*, *proximity integrated circuit card* and *vicinity integrated circuit card* respectively. Although smart card applications appear to be outside the scope of this book, it is always possible that UHF or SHF tags may be produced in smart card format one day . . . or maybe smart cards operating at UHF and SHF!

Now let us look at the other end of the system.

1.7.2 Fixed Element

The fixed element, or what is called the fixed element (in fact, it may be a handheld or pistol-type reader), can also have many different names.

Base Station
The term ‘base station’ denotes the (generally fixed) command unit, which can request the reading, writing, management, etc., of the tag, using radio frequency communication.

Reader
This frequently used (and overused) term is illogical since, in most applications, the ‘reader’ can also transmit writing commands to the tag. Can we really call this unit a ‘reader’ if it can also ‘write’? Preferably, we should restrict this term to its original meaning, to avoid confusion between pure readers, which can only read, and those that can both read and write. Thanks in advance!

Interrogator
Frequently used in the USA, this term, recognized by the ISO, is rather closer to the reality, since the base station does indeed give orders and/or commands to the transponder to tell it

what to do. When the transponder is requested to dump or return its contents, then clearly this could be considered as an interrogation from the viewpoint of the base station, but when the base station sends data to be written to the transponder, is the base station really an ‘interrogator’?

Initiator
Some radio frequency communication systems such as NFC (near field communication) use the term ‘initiator’, since there is always one element or base station that initializes the communication.

Now let us look at some other terms.

Modem
If we respect the derivation of the term ‘modem’ from ‘MODulator/DEModulator’, we should use it only to denote the electronic components responsible for modulating and demodulating the signals of transponders and base stations. The term should be avoided if possible in order to avoid confusion.

CD, PCD, VCD, etc
These terms, also used by the ISO, are some of the least misleading terms, since they denote coupling devices, proximity coupling devices and vicinity coupling devices, in other words the elements for coupling (in which direction(s)?) between the transponder(s) and base station(s).

In short, to avoid any confusion, I shall use the generic terms ‘tag’ or ‘transponder’ and ‘base station’ as far as possible, as in my opinion they are the most accurate (or least misleading!) descriptive names for these elements. Now let us look at the operating principle of this system.

1.8 Appendix: Units and Constants

Quantity	Symbol	Unit	Dimension
Current density	J	Ampere per square metre	$\mathrm{A\,m^{-2}}$
Electric field strength	E	Volts per metre	$\mathrm{V\,m^{-1}}$
Electric displacement	D	Coulomb per square metre	$\mathrm{C\,m^{-2}}$
Conductivity	σ	Siemens per metre	$\mathrm{S\,m^{-1}}$
Frequency	f	Hertz	Hz
Magnetic field	H	Ampere per metre	$\mathrm{A\,m^{-1}}$
Magnetic induction (flux density)	B	Tesla ($\mathrm{V\,s\,m^{-2}}$)	T
Density	ρ	Kilogram per cubic metre	$\mathrm{kg\,m^{-3}}$
Permeability	μ	Henry per metre	$\mathrm{H\,m^{-1}}$
Permittivity	ε	Farad per metre	$\mathrm{F\,m^{-1}}$
Power flux density	S	Watt per square metre	$\mathrm{W\,m^{-2}}$
Specific absorption rate	SAR	Watt per kilogram	$\mathrm{W\,kg^{-1}}$
Wavelength	λ	Metre	m
Temperature	T	Kelvin	K

Physical constant	Symbol	Value	Dimension
Speed of light	c	2.997×10^{8}	$\mathrm{m\,s^{-1}}$
Permittivity of free space	$\varepsilon\varepsilon_0$	$10^{-9}/36\pi = 8.854 \times 10^{-12}$	$\mathrm{F\,m^{-1}}$
Permeability of vacuum/air	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\,m^{-1}}$
Impedance of free space	Z_0	120π (or 377)	Ω