Open Smart Card Infrastructure for Europe

V2

Volume 6: **Contactless Technology**

Part 1: **White paper on Requirements for the Interoperability of Contactless Cards**

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1. Introduction

The document is part of Since project which has three mains goals :

- Promote the proliferation of contactless technology
- Harmonise the contactless infrastructure and ensure the interoperability of systems
- Stimulate the use of contactless technology through education

The interoperability of contactless products and systems is essential if the market for this technology is to be expended. The technology is still in its infancy in terms of standardisation and industrialisation. Very recently, the ISO/IEC 14443 series of standards has become available. The next challenge is to ensure that different products/cards from different manufacturers with different applications on systems from different industrials are compatible, or at the very least not incompatible.

In this area, the first task is to evaluate all of layers and interfaces relevant to existing contactless technology. A map of the standards, which surround the technology, is needed. A report showing these layers will be produced and is the main deliverable of this subsection. Japan's "New Media Development Agency", has already been contacted so as to build a global collaboration towards Interoperability.

This document aim is to give to a general overview on standardized levels of contactless technology for smart card environment.

The first chapter describes contactless technology related to the integrated circuit cards and to give an overview of the others type of support (i.e. RF Tag, electronic tickets, paper).
Others chapters describe the product technology and a state of the art for standardization.

2. Description of Contactless technology

The contactless Radio Frequency technology exists since 1986. In the United States It was used to produced RFID fish tag for tracking salmons. In the 1991, La Régie Autonome des Transport Parisiens (RATP) and Innovatron decided to work together to produce the core of a contactless ticketing system for the metro, bus and regional railway system. In the 1993 a range of memory product operating at 6.78 MHz then at 13.57 MHz was developed and deployed on the RATP network.

The semiconductor manufacturers began to design a chip able to transmit and to receive data over the air, and able to receive enough power to drive the electronic circuitry on the card. This was first achieved with RF tags and memory devices. The need for more secure and more versatile products has driven contactless technology from a memory based product through a microprocessor based product which is able to give at the users more value added services.

2.1. Power Supply

Contactless devices are generally powered in two different way : by a RF field or by a battery embedded in the card. In the case of dual interface, the contactless device can also be powered by standard ISO/IEC 7816 contact pad.

2.1.1. RF Field

Contactless cards contain an electronic element that is called transponder. A transponder consists of an inductive antenna and a microchip connected to the ends of an antenna. For better protection of the microchip, it is usually packaged in a module and the antenna is then interconnected to the module.

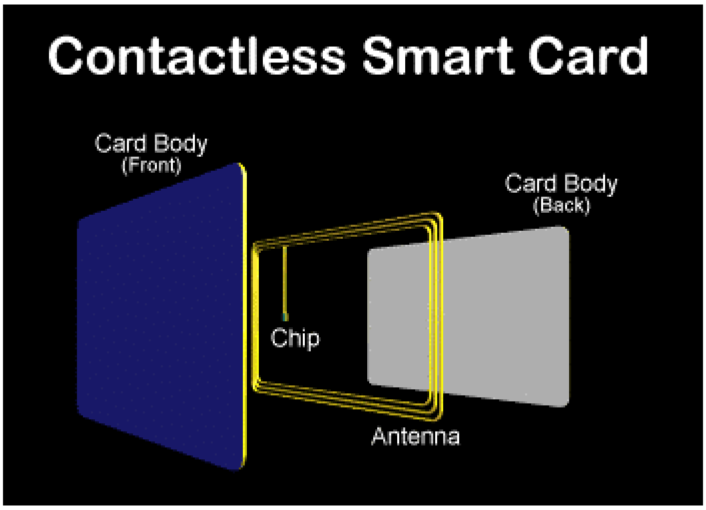


Figure 1 - Contactless card structure

In this case an inductive coupling will transmit both power and data through the air or a non metallic surface from the IFD (Interface Device) to the contactless card. The RF energy received by the contactless card antenna embedded in the card is converted in a DC voltage in order to power the card's internal circuits. Power conversion is done with a full bridge rectifier.

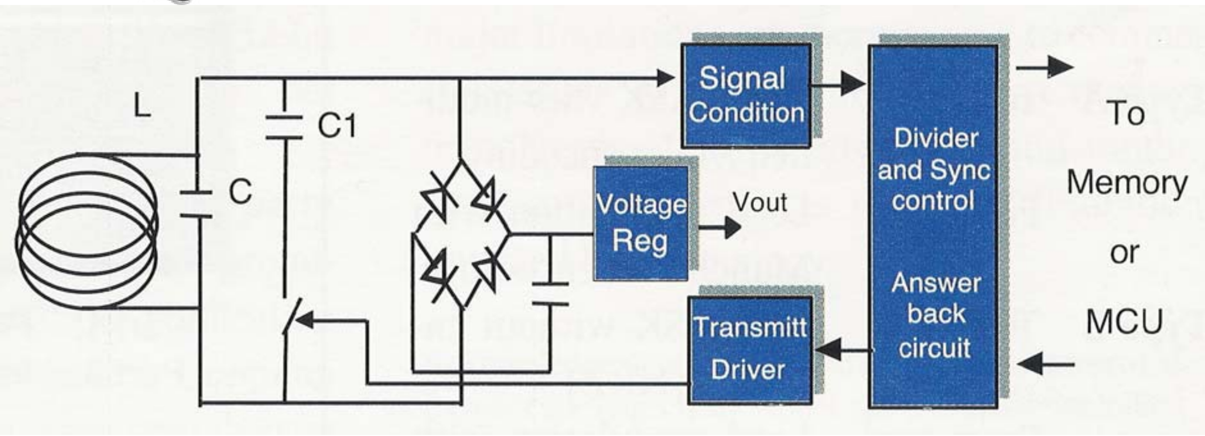


Figure 2 - Typical RF contactless receiver

Another way of looking at the power coupling is to view the card and the card reader antenna coils as component of a RF transformer. The transformer's primary coil is in the card reader, the secondary coil is in the card. The space between the coils is the transformer's air core. The card antenna may be parallel tuned to increase the coupling efficiency.

The diagram illustrates the RF energy coupling between a card and a reader. The card receives the signal, decodes it, and responds back to the reader.

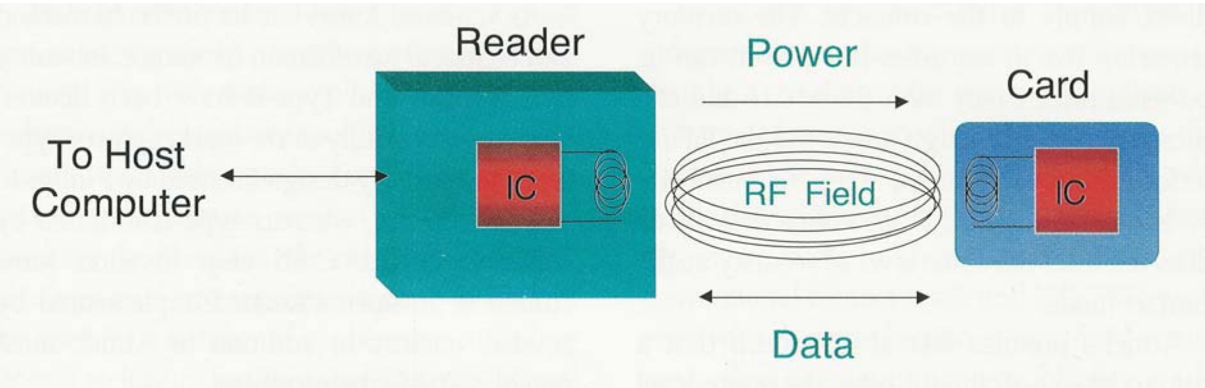


Figure 3 - Contactless card in a RF field

2.1.2. Battery

In this case a battery is incorporated in the card. This method is not widely used due to the difficulty of meeting the ISO standards for dimensions and for problems associated with flexing the card, moreover the battery causes a deeply cost increase of the contactless device.

To power smart card are used lithium batteries (the highest energy density batteries available today) which can supply the needed power for the life of the card. This kind of batteries have generally a thickness between 0,4 and 0,45 mm, an about 20 x 30 mm^2 surface area and they are able to provide about 30 mAh capacity.

2.2. Communication

There are two methods used to communicate with a contactless card : the first one, and also the most common, uses an RF interface between the IFD and the card ; the second one is the newest and exploits an acoustic interface called VocalID.

2.2.1. Radio Frequency

During the communication, contactless smart cards are placed in close proximity to a reader, from 0 to 10 centimetres. The clock may be internally derived and input/output is achieved by modulating the power signal.

RF systems are regarded as radio emitting devices and therefore the international an domestic radio regulations are relevant. This means that the frequency selection is restricted to a number of fixed frequency bands. The most common frequencies used are 0... 135kHz, 400kHz, 6.78MHz, 13.56MHz, 27.125MHz, 40.68MHz, 433.29MHz, 869MHz, 915MHz, 2.45GHz, 5.8GHz and 24.125GHz. Frequencies are divided in the following ranges:

Freq. Range [Hz]	Wavelength λ [m]	Name	Abbr.
3 ... 300	10^8 ... 10^6	extremely low freq.	ELF
300 ... 3k	10^6 ... 10^5	ultra low frequency	ULF
3k ... 30k	10^5 ... 10^4	very low frequency	VLF
30k ... 300k	10^4 ... 10^3	low frequency	LF
300k ... 3M	10^3 ... 10^2	medium frequency	MF
3M ... 30M	10^2 ... 10^1	high frequency	HF
30M ... 300M	10^1 ... 10^0	very high frequency	VHF
300M ... 3G	10^0 ... 10^{-1}	ultra high frequency	UHF
3G ... 30G	10^{-1} ... 10^{-2}	super high frequency	SHF
30G ... 3000G	10^{-2} ... 10^{-4}	extremely high freq.	EHF

Figure 4 - Normalized Frequency Ranges

In the US the 420MHz... 460MHz band was not favoured but therefore the 315MHz and 902MHz... 928MHz bands have been allocated. Due to the restricted use of this band for GSM mobile phones European regulations offered an appropriate frequency at 869MHz. The International Telecommunications Union (ITU) aims to harmonise these frequencies world-wide.

2.2.2. Inductive Coupling

Inductive coupling involves the use of two coils of wire - one acts as a primary coil and one acts as a secondary coil. An alternating current passes through a primary coil that creates an alternating magnetic field, which induces a flow of current in the secondary coil when they are in close proximity. Modulating the current at two different frequencies as it passes through the primary coil allows data to be transmitted to the secondary coil. When the card receives the current, it demodulates the signal and retrieves the data at the same time as it uses the transmitted power to activate its circuitry. Therefore, the advantage to this process is that it is able to transfer both information and power to a smart card.

Inductive coupling contactless cards can basically be divided into two groups ruled by the operating frequency they use to exchange data. The older of the two basic types operates at 125 kHz. These cards are mainly in use for access control to buildings and industrial applications. The inductance of these coils needs to be in the mH range, therefore a typical antenna in card format consist of 300 turns of thin insulated copper wire.

The second type operates at 13,56 MHz. The inductance of these antennas is in the µH range, therefore a few turns (three to eight) are sufficient. These coils are manufactured either by using a coil winding process or a wire embedding process.

These range of frequencies (50 kHz – 150 kHz low frequency induction and 2 MHz –20 MHz high frequency induction) give the following advantage/disadvantages:

- Advantages
  - Control of the communication area. It means you can shape the zone where a transaction will occur.
  - Little sensitivity to external interference.
  - Unaffected by the human body.
  - Good control of the communication area
  - Powering of the card through the RF field.
- Disadvantages
  - Low bit rate compared to microwave.
  - Range much smaller than microwave.

The high frequency induction has a higher bit rate than the low frequency induction.

2.2.2.1. Cards operate at 125 kHz

Devices which operate at 125 kHz are usually memory based integrated circuits without a micro controller support. At this frequency the power inducted to the contactless device is not enough in order to supply a MCU.

These kind of systems can be used in a wide range of access control applications including :

- Access control to and within public buildings (offices)
- Time and attendance systems
- Room Logistics at Hotels

Data encoding

These contactless devices operate up to 1 m from the reader with a communication speed of 4 baud/s. The most popular methods used to encode data are the following:

1. **NRZ (Non-Return to Zero) Direct.** In this method no data encoding is done at all; the 1's and 0's are clocked from the data array directly to the output transistor. A low in the peak-detected modulation is a '0' and a high is a '1'.

2. **Differential Biphasic.** Several different forms of differential biphasic are used, but in general the bit stream being clocked out of the data array is modified so that a transition always occurs on every clock edge, and 1's and 0's are distinguished by the transitions within the middle of the clock period. This method is used to embed clocking information to help synchronise the reader to the bit stream; and because it always has a transition at a clock edge, it inherently provides some error correction capability. Any clock edge that does not contain a transition in the data stream is in error and can be used to reconstruct the data.

3. **Biphase_L (Manchester).** This is a variation of biphasic encoding, in which there is not always a transition at the clock edge.

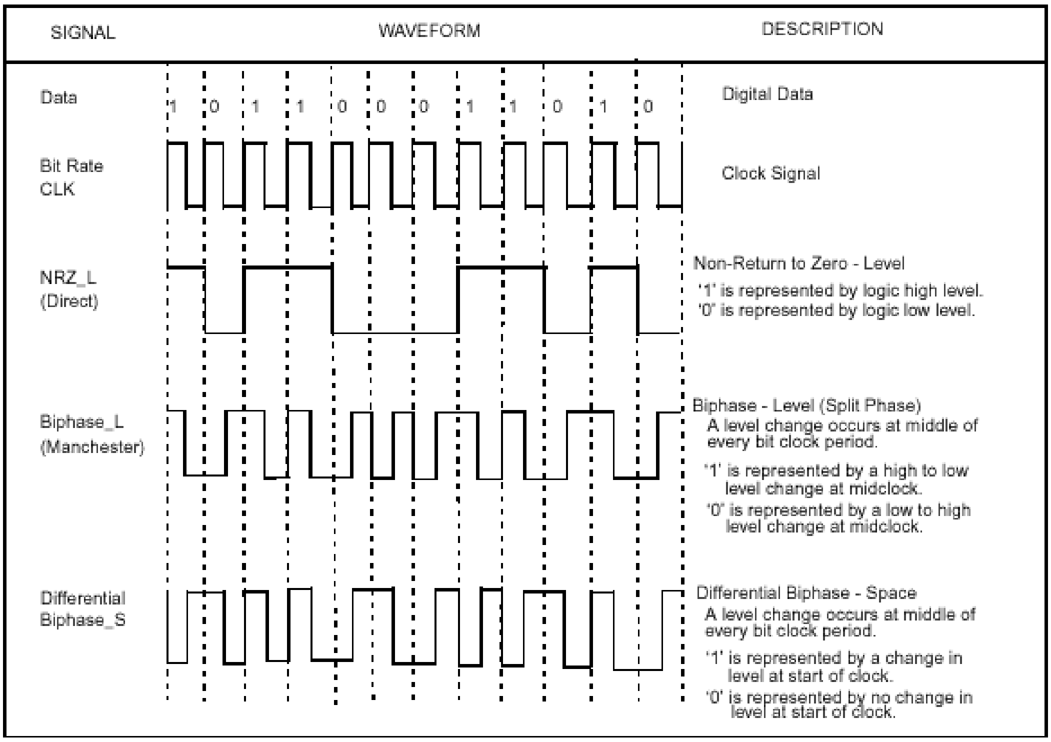


Figure 5 - Various data coding waveforms

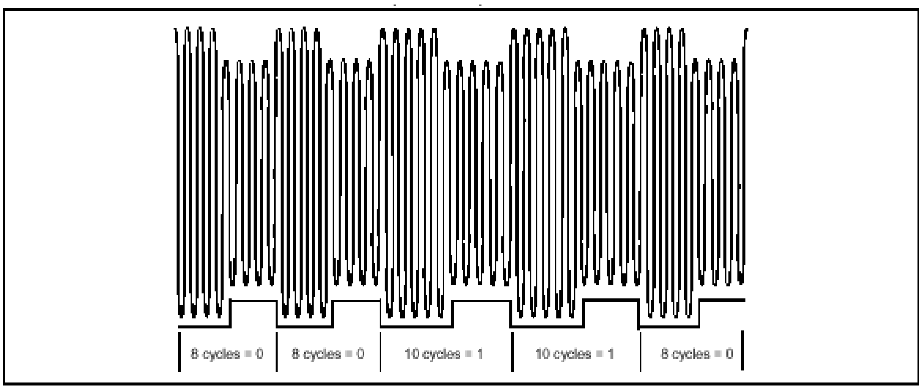
Modulation

Although all the data is transferred to the host by amplitude-modulating the carrier (backscatter modulation), the actual modulation of 1's and 0's is accomplished with three additional modulation methods:

1. **Direct.** In direct modulation, the Amplitude Modulation of the backscatter approach is the only modulation used. A high in the envelope is a '1' and a low is a '0'. Direct modulation can provide a high data rate but low noise immunity.

2. **FSK (Frequency Shift Keying)**

This form of modulation uses two different frequencies for data transfer; the most common FSK mode is Fc/8/10. A ‘0’ is transmitted as an amplitude-modulated clock cycle with period corresponding to the carrier frequency divided by 8, and a ‘1’ is transmitted as an amplitude-modulated clock cycle period corresponding to the carrier frequency divided by 10. The amplitude modulation of the carrier thus switches from Fc/8 to Fc/10 corresponding to 0's and 1's in the bit stream, and the reader has only to count cycles between the peak-detected clock edges to decode the data. FSK allows for a simple reader design, provides very strong noise immunity, but suffers from a lower data rate than some other forms of data modulation.

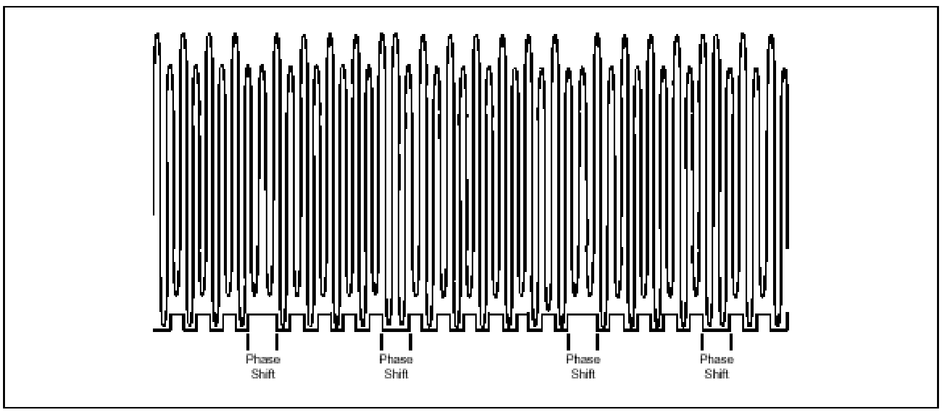


3. **PSK (Phase Shift Keying)**

This method of data modulation is similar to FSK, except only one frequency is used, and the shift between 1's and 0's is accomplished by shifting the phase of the backscatter clock by 180 degrees. Two common types of PSK are:

- ♦ Change phase at any ‘0’, or Change phase at any data change (0 to 1 or 1 to 0).

PSK provides fairly good noise immunity, a moderately simple reader design, and a faster data rate than FSK.



Anticollision

In many existing applications, a single contactless device is sufficient and even necessary: animal tagging and access control are examples. However, in a growing number of new applications, the simultaneous reading of several tags in the same RF field is absolutely critical: library books, airline baggage, garment, and retail applications are a few.

In order to read multiple transponder simultaneously, the contactless device and reader must be designed to detect the condition that more than one device is active. This is referred to as a collision. No data would be transferred to the reader. The RFID interface also requires arbitration so that only one contactless device transmits data at one time. A number of different methods are in use and in development today for preventing collisions and most of them are patented or patent pending.

2.2.2.2. Cards operate at 13,56 MHz

As already said inductive coupling contactless cards communicate with the IFD use a technique called load modulation where the card changes its load (for example a resistor), which is sensed by the reader. Contactless card which operate at 13,56 MHz use different type of modulation and different type of coding, but taking in to account only the modulation standardised by ISO/IEC we speak about the Proximity Integrated Circuit Cards (PICC) and Vicinity Integrated Circuit Card (VICC)

PICC are described by the ISO/IEC 14443 standard series. The standard defines two possible modulation called Type A and Type B. Both Type A and Type B use Amplitude Shift Key (ASK) modulation for communication between the reader, called Proximity Coupling Device (PCD), and the card.

PCD ➔ PICC Communication

Type A uses the modulation principle of ASK 100% of the RF operating field to create a "Pause". The bit coding is done with the Modified Miller code which permit to define three sequences used to code the following information:

- Logic "1"
- Logic "0"
- Start of communication
- End of communication
- No information

This allows Type A cards to count the bits of a frame and make possible identify an error in the frame also without any parity or CRC checking. Type B uses the modulation principle of ASK 10% of the operating field. The bit coding is done with a Non Return to Zero coding which doesn't offer different bit representations for logic "1", logic "0' and "No information".

PICC → PCD Communication

Both Type A and Type B cards are able to communicate with the PCD via an inductive coupling area where the carrier frequency (13,56 MHz) is loaded to generate a sub carrier with frequency of ~847 kHz. The sub carrier is obtained by switching a load in the PICC. Type A cards modulate the sub carrier using On-Off Keying[1] (OOK) modulation. The bit coding is done with the Manchester coding which permit to define three sequences used to code the following information :

- Logic “1”
- Logic “0”
- Start of communication
- End of communication
- No information

Type B cards modulate the sub carrier using Binary Phase Shift Keying (BPSK) modulation. The bit coding is done with a Non Return to Zero where the change of logic level is denoted by a phase shift (180°) of the sub carrier. Type A and Type B communicate in either direction (PCD to PICC and PICC to PCD) at the normalized rate of 106 Kbytes/s. If speed negotiation is already in the norm, the signal interface description is under normalisation to obtain higher rate of 212, 424 and 848 Kbytes/s.

Anticollision

To avoid interference between two or more contactless cards in the PCD range is necessary to define a protocol which manage the collision between them. This protocol is called Anticollision and is used to establish a link between the PCD and only a single card, within a short time.

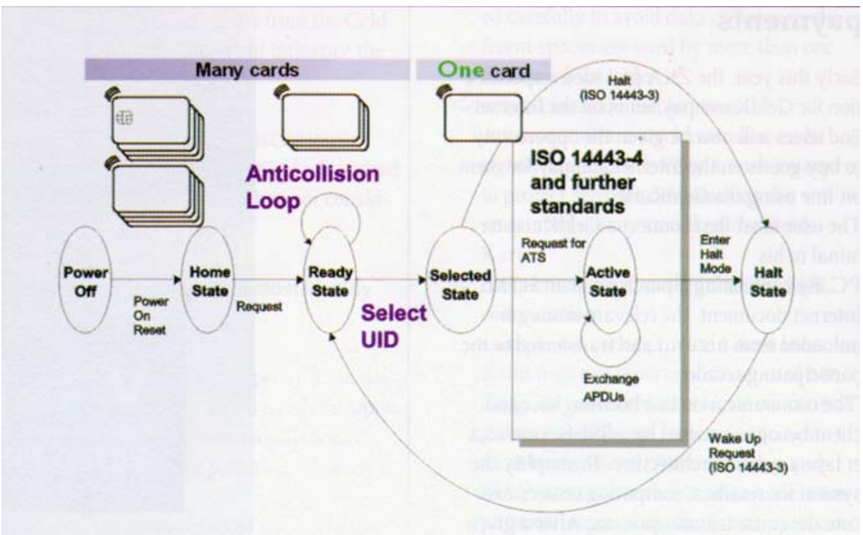


Figure 6 - State diagram for Type A cards

[1] *OOK modulation is a ASK particular case where the amplitude lessening is infinite.*

Home State: this state is entered after power on and left after a request

Ready State: this state is entered after a request and maintained; it is left when the PICC is selected with its serial number called Unique ID (UID).

Selected State: this state is entered by selecting the PICC with its complete serial number. From this state there are two possible state transitions:

Active State: in this state actions like PTS and exchange of APDU may performed.

Halt State: in this state PICC shall respond only to a wake-up request. There are two ways to enter this state:

1. Due to a transition from *Selected State* via the halt-command
2. Due to a transition from *Active State* via APDU

A wake-up request moves the PICC to *Ready State*.

PICCs that remain in *Halt State* will not participate in further anticollision loop when a standard request is applied. This reduce the number of cards in anticollision loop, increasing the anticollision procedure speed.

Type A cards use three types of frame in order to communicate with the PCD. The first one is the *Request and Wake-up Frame* which is used to initiate communication; these frame has a different structure from the other two, so a PICC can reliably identify a request. The second one are the *Standard Frame*, which is used for data exchange. The last one is the *Bit-oriented Anticollision Frame* which is used only during anticollision loop.

Thanks to Modified Miller coding and because card answer synchronously to request commands with Type A PCD it is possible to detect collision at bit level.

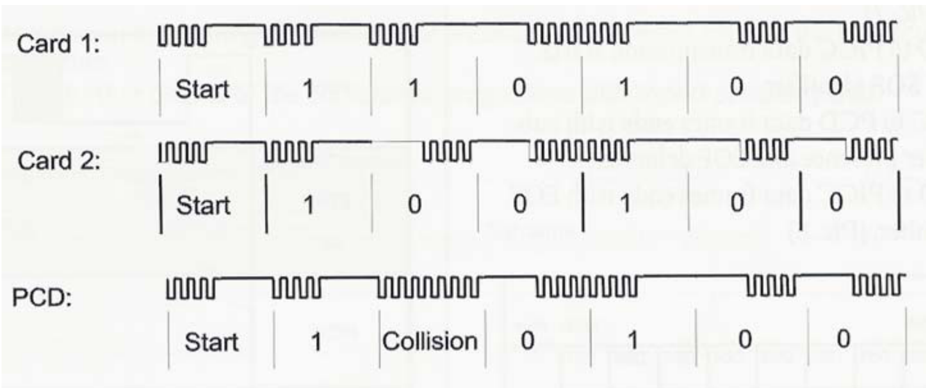


Figure 7 - Bit collision detection principle used by Type A cards

As the aim is to find a serial number as fast as possible and afterwards select the card, the following method is used to avoid collisions :

PCD **PICC**

Give me your UID →

← PICC1 send UID e.g. 01010111…

← PICC2 send UID e.g. 01110111…

← PICC3 send UID e.g. 01010100…

The PCD sees the following data stream (C=collision): 01C101CC…

The PCD knows that the first collision is at position 3: all others are ignored at this stage. The PCD sends a select command again requesting only cards which have a serial number starting with 01 plus, instead the first occurrence of a collision, a 1.

Select cards with serial number starting with 011
→

PICC with serial number starting with 011 will answer with the remaining bits of their serial number

PICC1 remains silent

← PICC2 send rest of UID 1011110…

The PCD knows the PICC2 serial number and sends a final Select command

Select card with UID 01110111… →

← PICC2 acknowledges selection

Type B cards uses NRZ coding where "no information" and "information" cannot be distinguished, further it is not bit synchronous, so it is impossible to detect collision at bit level. Collision detection is based on communication errors produced by multiple cards in the operating field and detecting such errors used Cyclic Redundancy Check (CRC) checking. To better understand the Type B anticollision procedure is important to define the character and the frame format used during communication between PICC and PCD.

Bytes are transmitted and received between PICCs and a PCD by characters, the format of which during the Anti-collision sequence is as follows :

- 1 start bit at logic "0" ;
- 8 data bits transmitted, LSB first ;
- 1 stop bit at logic "1".

PCDs and PICCs shall send characters as frames. The frame is normally delimited by Start Of Frame (SOF) and by End Of Frame (EOF). A frame shall only be considered correct if it is received with a valid CRC_B value. The frame CRC_B is a function of k data bits, which consist of all the data bits in the frame, excluding start bits, stop bits, delays between bytes, SOF and EOF, and the CRC_B itself. Since data is encoded in bytes, the number of bits k is a multiple of 8.

An anticollision sequence is managed by the PCD through a set of commands detailed in this section. The PCD is the master of the communication with one or more PICCs. It initiates PICC communication activity by issuing a Request Command to prompt for PICCs to respond.

During the anticollision sequence it may happen that two or more PICCs respond simultaneously : this is a collision. The command set allows the PCD to handle sequences to separate PICC transmissions in time. The PCD may repeat its anticollision procedure until it finds all PICCs in the operating volume.

Having completed the anticollision sequence, PICC communication will be under control of the PCD, allowing only one PICC to talk at a time.

The anticollision scheme is based on definition of timeslots in which PICCs are invited to answer with minimum identification data. The number of slots is parameterised in the Request Command and can vary from one to some integer number. PICC response probability in each timeslot is also controllable. PICCs are allowed to answer only once in the anticollision sequence.

Consequently, even in case of multiple PICCs present in the PCD field, there will probably be a slot in which only one PICC answers and where the PCD is able to capture the identification data. Based on the identification data the PCD is able to establish a communication channel with the identified PICC.

An anticollision sequence allows selection of one or more PICCs for further communication at any time. The set of commands allows implementation of different anticollision management strategies at the PCD level. This strategy is under the control of the application designer and can include :

- probabilistic (repetitive single slot prompt with response probability less than or equal to 1) ;
- pseudo-deterministic (multiple slots with scanning of them during the anticollision sequence to have the maximum probability that all present PICCs answer) ;
- any combination of these methods that can be conducted dynamically.

If more than one PICC are in the PCD RF field a first choice can be done by means of the Application Family Identifier (AFI). AFI represents the type of application targeted by the PCD and it is contained in the Request Command. Only PICCs with applications of the type indicated by the AFI may answer to a Request Command.

After receiving a valid Request Command a PICC shall respond according to the following rules, where the parameter N has been given in the Request Command :

- If N = 1 the PICC shall send an Answer To Request Command and is ready to start the communication
- If N > 1 the PICC shall internally generate a random number R which shall be evenly distributed between 1 to N
    - If R = 1 the PICC shall send an Answer To Request Command and is ready to start the communication.
    - If R > 1 the PICC can waiting for another Request Command or for A Slot Marker Command which define the time slot for its.

The following example may clarify the Type B anticollision procedure:

PCD	PICC
REQB (AFI=10 e N=1) →	
	← PICC 1 Matched AFI, N=1, transmit ATQB
	PICC2 Not matched AFI, wait for next REQB
	← PICC3 Matched AFI, N=1, transmit ATQB
Collision detected, REQB (AFI=10 e N=4) →	
	PICC1 randomly select R between 1 and N: R=2 so wait for slot marker for slot 2
	← PICC 3 randomly select R between 1 and N: R=1 so transmit in ATQB in slot 1
PCD has now a choice depending on its application: select the PICC3 and send no more slot marker, continue sending slot markers, or other possibilities.	
For this example the PCD will continue to send slot markers.	
Slot Marker for slot 2 →	
	← PICC1 R=2 transmit ATBQ in slot 2
Now the PCD has received two PICC response and can decide which card select in order to continue the communication.	

VICC are described by the ISO/IEC 15693 standard series. In order to meet different international radio regulations and different application requirements in the standard have been defined different mode and different data coding which can be combined with any modulation.

VCD ➔ VICC Communication

The communication between the Vicinity Coupling Device (VCD) and the VICC take place using the modulation principle of ASK. Two modulation indexes are used, 10% and 100% and the VICC shall able to decode both.

Data coding shall be implemented using pulse position modulation. Two data coding modes shall be supported by the VICC. The selection shall be made by the VCD and indicated to the VICC within the start of frame (SOF). The data coding modes are called “1 out 256” and “1 out 4”; the first one represents the value of one single byte with the position of 1 pause of 256 successive time period of $256/f_c$.

In the example of figure 8 data 'E1' = (11100001)b = (225) is sent by the VCD to the VICC

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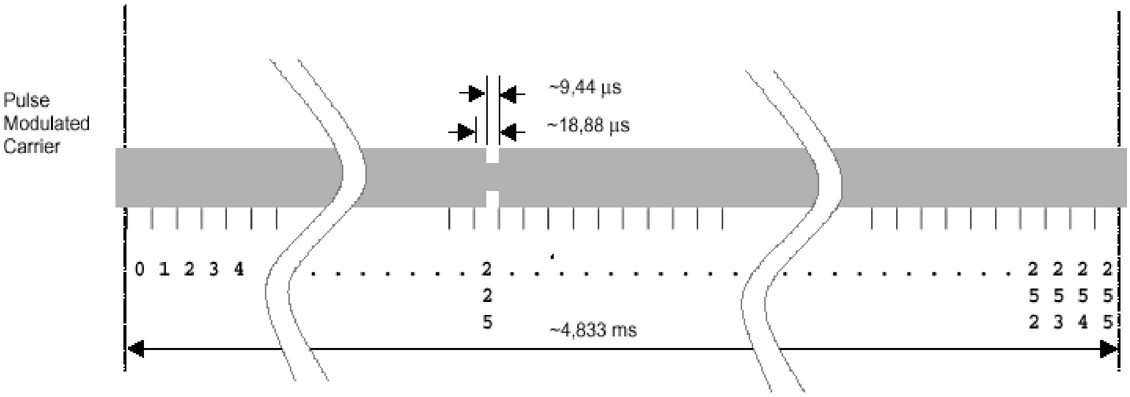


Figure 8 - 1 out of 256 coding mode

In the second mode the pulse position determines two bits at a time defining four different pulses associated to the bits pair “00”, “01”, “10” e “11” (see figure 9).

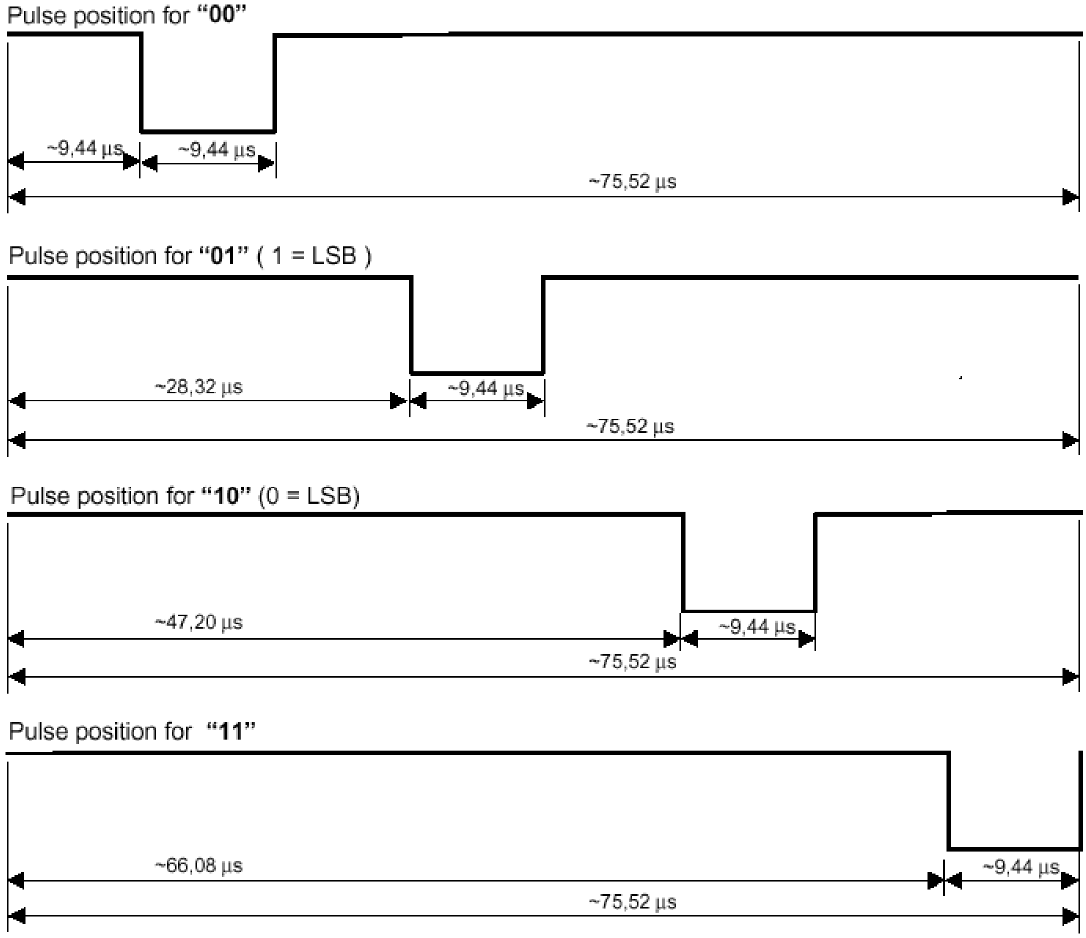


Figure 9 - 1 out of 4 coding mode

For example figure 10 shows the transmission of 'E1' = (11100001)b = 225 by the VCD.

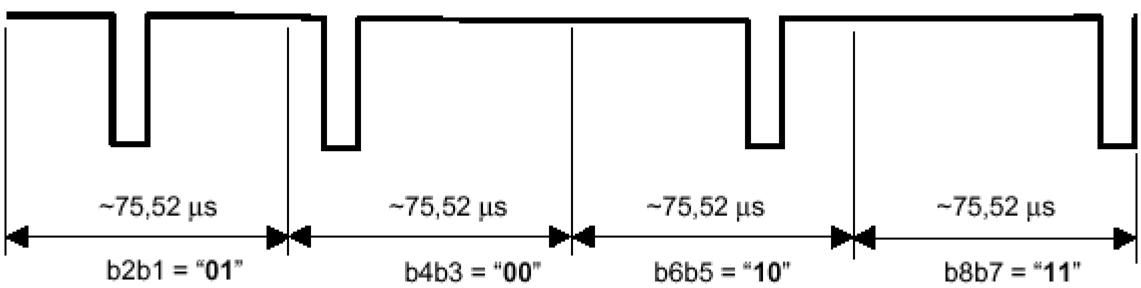


Figure 10 - 1 out of 4 coding example

To grant ease of synchronization and independence of protocol for the VCD to VICC communication has been chosen to use frame. Frames shall be delimited by a start of frame (SOF) and an end of frame (EOF) and are implemented using code violation.

VICC ➔ VCD Communication

The communication between VICC and VCD takes place using Load Modulation. The VICC shall be capable of communication to the VCD via an inductive coupling area whereby the carrier is loaded to generate a sub carrier with frequency f_s. The sub carrier shall be generated by switching a load in the VICC.

One or two sub carriers may be used as selected by the VCD. When one sub carrier is used, the frequency f_{s1} of the sub carrier load modulation shall be $f_c/32$ (423,75 kHz). When two sub carriers are used, the frequency f_{s1} shall be $f_c/32$ (423,75 kHz), and the frequency f_{s2} shall be $f_c/28$ (484,28 kHz).

The VCD can select a low or a high data rate (see table 1), but the VICC shall support both.

Table 1 - Data rates

Data Rate	Single Subcarrier	Dual Subcarrier
Low	6,62 kbits/s (f_c/2048)	6,67 kbits/s (f_c/2032)
High	26,48 kbits/s (f_c/512)	26,69 kbits/s (f_c/508)

Data shall be encoded using Manchester coding and, as in the communication from VCD to VICC, they are structured in frames delimited by a start of frame (SOF) and an end of frame (EOF) and are implemented using code violation.

Anticollision

The VICC are Uniquely Identified by a 64 bits unique identifier (UID). This is used for addressing each VICCs uniquely and individually, during the anticollision loop and for one-to-one exchange between a VCD and a VICC. Moreover the VICCs may also (optional) has an AFI (Application family identifier) which represents the type of application targeted by the VCD and is used to extract from all the VICCs present only the VICC meeting the required application criteria. The AFI coding is defined in the ISO/IEC 15693-3.

The purpose of the anticollision sequence is to make an inventory of the VICCs present in the VCD field by their unique ID (UID). The VCD is the master of the communication with one or multiple VICCs and thanks to an algorithm which manage different time slot is able to understand the UID and the AID of the VICCs within its field.

2.2.3. Capacitive Coupling

Capacitive coupling involves placing a pair of conductors below the surface of the smart card. When a voltage signal is placed across them, a charge separation occurs that generates an electric field. The electric field can extend beyond the surface and induce another charge separation on a second pair of conductors in the read/write unit, which transmits data between the card and the read/write unit. The advantages to this technique are that digital information can be transferred directly and no modulation is required

One example of this type of contactless card is the Contactless Integrated Circuit(s) Cards (CICC) standardised in the ISO/IEC 10536. The standard define either the inductive and the capacitive interface, but here it is described only the capacitive coupling.

The CICC has four coupling area, one pair is used for communication from CICC to the CCD and another pair is used for communication from CCD to CICC. The pairs of capacitive coupling area have a differential relationship, in fact their polarity shall alternate relative to their adjacent areas.

The communication between CDC and CICC takes place without modulation, so only data coding is necessary. The coding technique for capacitive data transfer shall be differential NRZ.

When the CICC is put in contact with the CDC, it shall send its answer to reset on one of two pairs of capacitive plate, in order to defines the communication channel for communication from CICC to the CDC. The answer to reset is also used to determine the orientation of the card, if necessary.

No anticollision technique is necessary since only one card at time can physically be in contact with the interface device.

This norm is discontinued and no known project is using it.

2.3. Vocal Transmission

Other than the more traditional RF interface, some manufacturer have tried to develop an acoustic interface between the IFD and the ICC, which is able to work anywhere there is a microphone (telephone, computer, etc.).

This kind of product implies taking a standard smart card and integrating it with an acoustic interface in order to permit to transmit identification data by emitting sound sequences. It is composed by the following component embedded in the ICC:

- Touch pad : integrated with the micro module. Simply touch it to trigger the emission of an authentication sound sequence.
- Extra flat battery : 0.3 mm thick providing the power required by the system. Typically the battery is non-rechargeable and lasts for 3000 uses, or 2 to 3 years depending on the associated application.

- Chip : dedicated ASIC
- Piezoelectric transducer : thin ceramic membrane driven by the chip, it generates the initial vibration and transmits it to the card body.

The identification data calculated in the chip are transmitted as sound sequences. These sequences are generated by vibration of the card. A touch sensitive area integrated with the chip activates the card when touched with a finger. The process is designed for use over a computer microphone or telephone handset, and does not require any special positioning or skills, as it is the entire card that vibrates and not a particular zone. The authentication sequence is transmitted as a loop in FSK format.

2.4. Medium

Contactless devices are mainly divided in two category: Integrated Circuit(s) Cards and Tag, other type of device exist (electronic tickets, paper) but are not largely used, so in this chapter are presented only them.

2.4.1. ID-1 Cards

Integrated Circuit(s) Card without contact are standardised by ISO/IEC which has defined three type of cards:

- Contactless Integrated Circuit(s) Cards (CICC)
- Proximity Integrated Circuit(s) Cards (PICC)
- Vicinity Integrated Circuit(s) Cards (VICC)

All the cards are based on the ID-1 format described in the ISO/IEC 7810 and contain an antenna embedded in the PVC layer which form the card. If the CICC is able to communicate in a capacitive way it contains also four capacitive plate used for data transmission and reception (see chapter 2.2.3).

Currently there are three basic antenna types on the market: wired, etched and printed. The first uses regular copper wire similar to 125 kHz antennae, only thicker. There are two manufacturing methods for wired antennae, the former is the same coil winding process as for 125 kHz the latter is a wire embedding process similar to a plotter, where the wire is essentially “written” into the plastic substrate.

Etched antennae are produced in the same way a regular PCB would be made. A layer of 35 m of copper is etched in the shape of the antenna. In recent years, the electrical parameters were inferior to wired antennae, but lately the parameters have come to competitive range. However, crossover are still awkward to manufacture at this time.

Printed antennae employ conductive ink, that is silkscreen printed on the sheets. The electrical parameters of those antennae are still inferior to wired antenna.

Another topic in the contactless card manufacturing process which is absent in the normal contact card manufacturing process is the interconnection between the chip module and the antenna.

Currently there are five principal interconnection methods a card manufacturer needs to understand and choose from:

- Thermal compression bonding
- Soldering
- Conductive gluing
- Crimping
- Ultrasonic welding

Thermal compression bonding employs temperature of 1500ºC and higher while simultaneously applying pressure to interconnect the wire with the chip module. this is a solid state interconnection, where free electrons from the wire migrate into the chip module substrate, and vice versa, to form a new crystal at the point of interconnection. The ohmic resistance is the lowest of all five interconnection methods.

There is no need to get rid of the isolation before the interconnection, which is an additional advantage of this process: it simply burnt away during the process. This is a true electrical interconnection and is mainly used for wired antennae.

In the Soldering a third material (tin) is introduced to mechanically interconnect the wire with the substrate. Even though, for flexible substrates like cards, the interconnection is likely to get damaged with continuous flex and torsion (card in wallet). This method is mainly used for etched antennae.

In the Conductive gluing method a conductive glue between the ends of the antenna to the chip module provides the electrical interconnection. This is the least effective of the described interconnection methods.

The Crimping forces a metal pin through the chip module and mechanical force is used to crimp the ends of the antenna to the chip module. This method is sometimes found with etched inlay. As is pure mechanical connection, corrosion of the etched antenna may destroy the interconnection after a while.

In the Ultrasonic welding an ultrasonic tool provides the heat and the pressure for this interconnection method. the temperature for this process is far less than the one used with thermal compression bonding. Therefore the solid state process does not take place. This is again a mechanical interconnection.

In summary, today the better technology choice for 13.56 MHz is wired embedded antennae interconnected to the chip module with the thermal compression bonding methods, in order to granted both performance as well as quality.

2.4.2. Tag

RFID tags come in a wide variety of shapes and sizes. Animal tracking tags, inserted beneath the skin, can be as small as a pencil lead in diameter and one-half inch in length. Tags can be screw-shaped to identify trees or wooden items, or credit-card shaped for use in access applications. The anti-theft hard plastic tags attached to merchandise in stores are RFID tags. In addition, heavy-duty 5- by 4- by 2-inch rectangular transponders used to track intermodal containers or heavy machinery, trucks, and railroad cars for maintenance and tracking applications are RFID tags.

RFID tags are categorized as either active or passive. Active RFID tags are powered by an internal battery and are typically read/write, i.e., tag data can be rewritten and/or modified. An active tag's memory size varies according to application requirements; some systems operate with up to 1MB of memory. In a typical read/write RFID work-in-process system, a tag might give a machine a set of instructions, and the machine would then report its performance to the tag. This encoded data would then become part of the tagged part's history. The battery-supplied power of an active tag generally gives it a longer read range. The trade off is greater size, greater cost, and a limited operational life (which may yield a maximum of 10 years, depending upon operating temperatures and battery type).

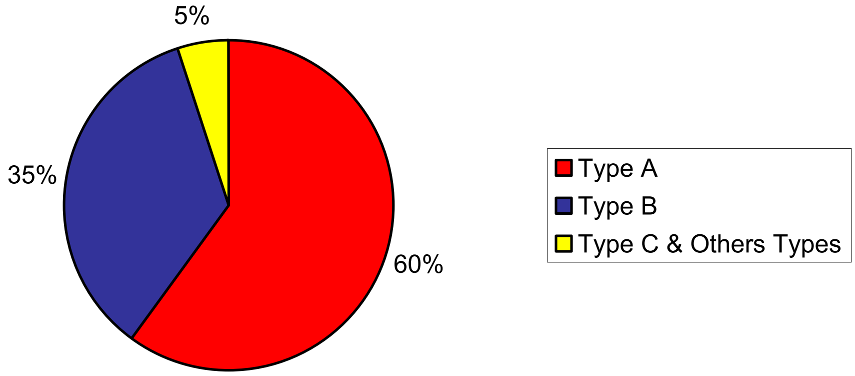
Passive RFID tags operate without a separate external power source and obtain operating power generated from the reader. Passive tags are consequently much lighter than active tags, less expensive, and offer a virtually unlimited operational lifetime. The trade off is that they have shorter read ranges than active tags and require a higher-powered reader. Read-only tags are typically passive and are programmed with a unique set of data (usually 32 to 128 bits) that cannot be modified. Read-only tags most often operate as a license plate into a database, in the same way as linear barcodes reference a database containing modifiable product-specific information.

3. Market

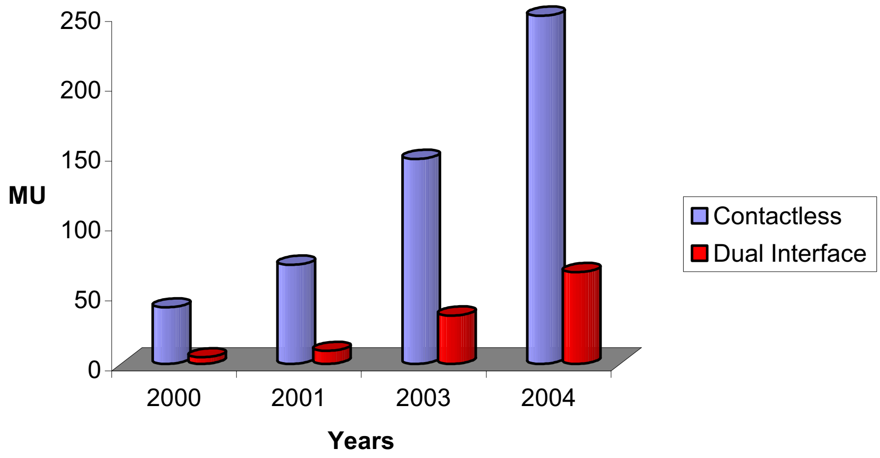
The contactless market is split between three types of products, contactless only, hybrid and dual interface. There are no real statistics on the split, the share of contactless only (including hybrid) is certrainely over 90%.

Contactless-only has been the first generation of products, it has been on the market for over five years and was based on memory cards.
The main application for contactless smart card are ticketing, road tolling, access control and loyalty. Some new markets such as proximity payment appear.

The most famous technology is Mifare and represents about 60 % of market share. Type B and Type A are part of ISO 14443. Some other types (C to G) are also on the market but not part of ISO 14443.



Here are some market view, average of Gartner and Eurosmart figures (hybrid cards are included in contactless figures)



4. Description of product technology

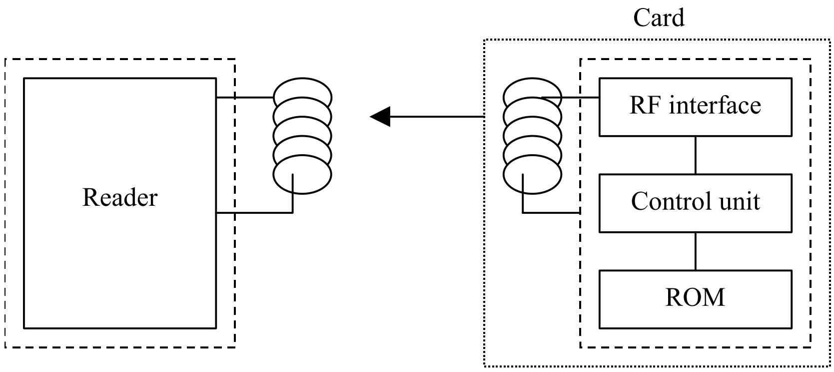
This chapter describes the product technology for smartcards and gives an overview of industrial process issues.

4.1. ID-1 Card

Read only cards

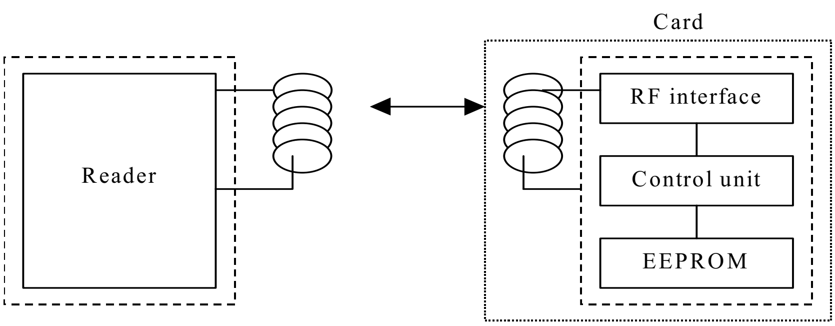
These cards "talk" first in presence of magnetic field. The reader is not sending data.

As they are not defined in the standard and are mainly proprietary products, interoperability cannot be managed. The ISO standard specify that these cards are not allowed in the system.



4.1.1. Memory cards

Memory cards are used when cost is an issue for a system. The interface is mainly pure contactless and the communication protocol (including chip commands) doesn't refer to a standard.
The security management is also proprietary and not defined in a standard. For example, the Mifare product claimed to be ISO 14443-A but as the security is proprietary to Philips, other company are not able to build an interoperable product.



4.1.2. Hybrid cards

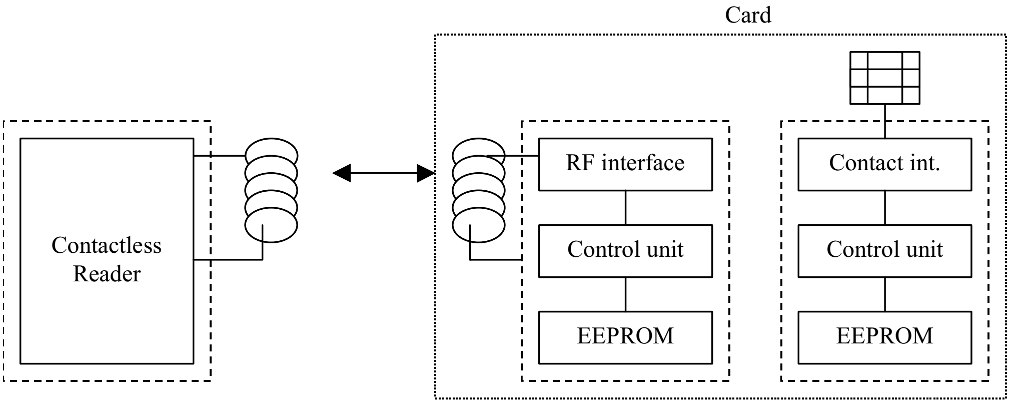
Hybrid cards are used where a contact card application is already running and a contactless application has to be added. The contactless chip is mainly a memory card (microprocessor cards got a dual interface and then its not interesting to build a Hybrid card with it)

There is 2 types of Hybrid cards :

- Separated chips
- Both chips are connected together through I/Os

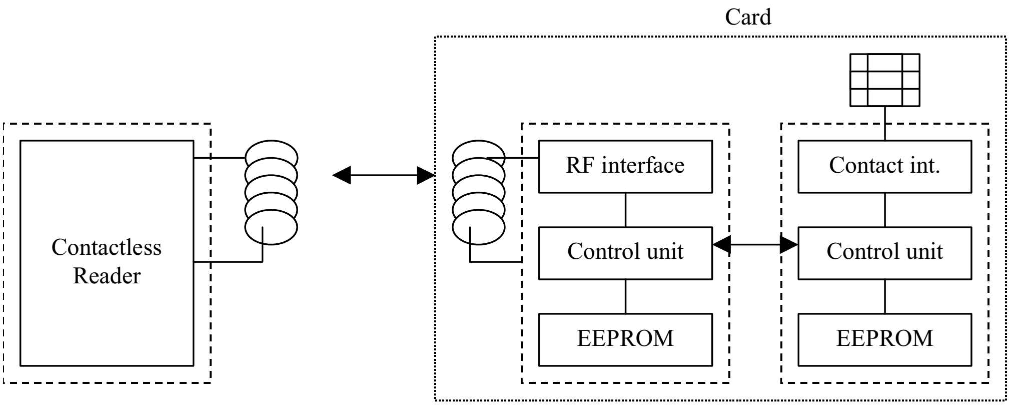
4.1.2.1. Unconnected chips

Both chips are totally independent. The communication between chips is done through the readers.



4.1.2.2. Connected chips

Both chips are connected through an or several I/O. The contact interface is the master device which drive the contactless interface.



4.1.3. Dual interface cards

It allow to use new contactless applications while keeping the interface with the existing contact applications.

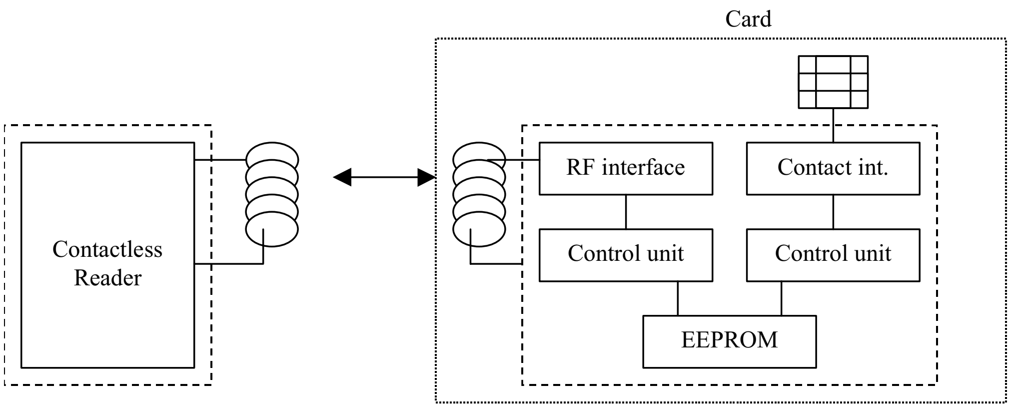
There is 2 configurations :

- Shared memory (old design method)
- Same memory

Dual interface cards are the preferred solution if the customer wants to keep interoperability with its existing application (contact mode) and want to migrate to a full contactless operation.

4.1.3.1. Shared memory

This is a old design method which allows to share a part of the global memory between the contact and the contactless interface.
The main advantage is to reduce the power consumption of the chip during contactless operations

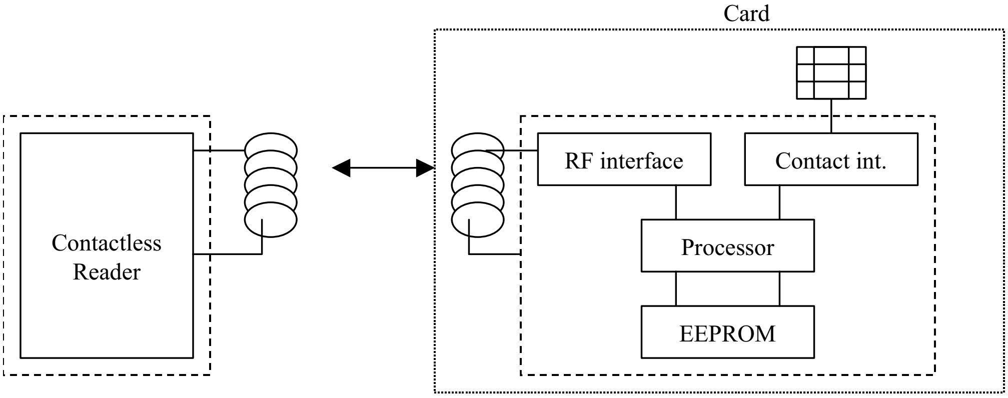


There is 2 mode of operation :

- Whole EEPROM memory is shared
- Only a part of the EEPROM is shared for the contactless operation

4.1.3.2. Single memory

All new design are based on this architecture which bring the better flexibility to the developer and the lowest cost for the end user. The main issue with this architecture is to reduce the power consumption in order to obtain the best communication distance without limiting the speed of operation.

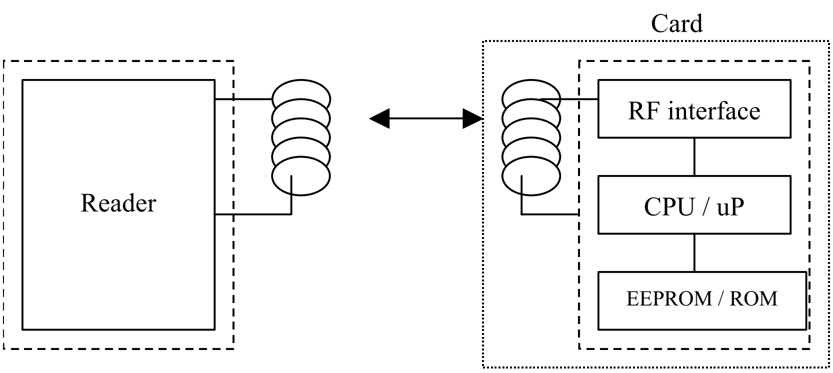


4.1.4. Full contactless cards

These cards are used for new contactless applications where the contact interface is not already used for another purpose or for application which can use a different package from ISO cards (tokens, coins, passports …).

This approach is the best to lower the package cost and bring a higher reliability to the system (no more contacts and connectors in the reader)

For interoperability purpose, this solution is preferred for new systems implementation.



4.2. Other packaging formats

For pure contactless systems, the ISO card format is not mandatory, as the card is not inserted into a slot. In this case, the chip package can be strictly adapted to the application needs:

- ID card: Contactless passport
- Transport / Ski pass: Paper ticket
- Access control: Key fob
- Secured identification: Printed label
- …

These new packages can help the market development for contactless technology.

Packaging format doesn't limit interoperability between systems as a paper ticket can be used on the same reader than a Key fob

4.3. Proximity coupling devices (readers)

Today, interoperability is solved through the reader when several cards (not interoperable and often not 100% in the standard) has to be used in the same application.

4.3.1. Compatibility with the standards

Standards are defined to avoid interoperability problems. However, the standard is not defining a reference implementation that could impact on execution speed. For this reason, standard should be completed with application constraints to allow interoperability.

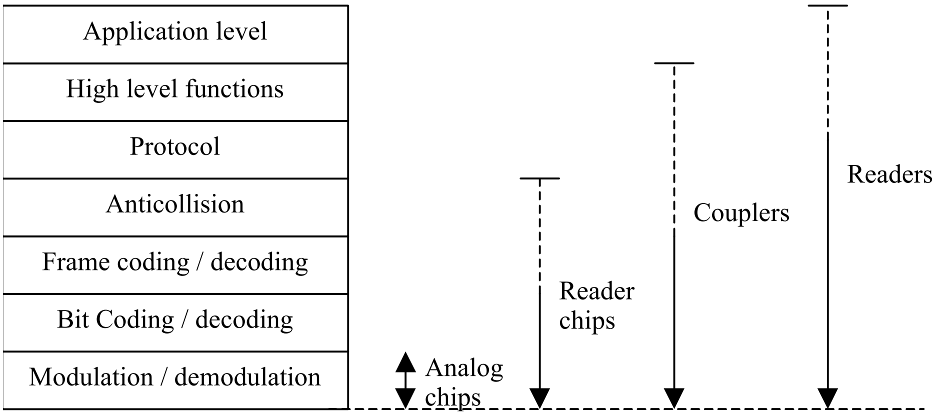
Even if today few chips and readers are fully compliant with the standard, the final target is to provide interoperable readers for an application.

For example, it is necessary to have reader that pool both type A and type B chips during the anticollision sequence.

4.3.2. Compatibility with the software / hardware

Within an application, software / hardware compliance could be reach between several device. However, between applications, the compliance is not necessary especially if reader cost is important.

Depending on the reader manufacturer, the contactless function can be split at any point in this stack :



Depending where the reader is split, the software/hardware interface with the host cannot be compatible between readers.
Most of the host interfaces are proprietary today but a good idea can be to define a standard host interface as it has been done for the PC/SC standard. A draft is underway to integrate contactless in the future PC/SC standard.

4.4. Industrial Process

Depending on chip packaging and antenna material, communication distance and packaging resistance can be affected.

Overview of common packaging offers (contactless only)

Chip connection / **Antenna type**	Module	Direct bonding	Flip Chip
Copper wire	x		
Copper		x	x
Aluminium			x
Conductive ink			x

Low power chips combined with low cost package (bad quality) can then compensate the communication distance problem.

5. State of the Art for Standardisation

5.1. Standardisation Committee

Standardisation for contactless is performed by an international standardisation committee:
ISO/IEC JTC1/SC17/WG8 "Contactless Integrated Circuit(s) Cards"
Convener is Michael Hegenbarth /Germany

WG8 has delegated its projects to three subgroups to achieve efficient and dedicated developments of the standards.

- For the development of the standard series ISO/IEC 14443 the subgroup WG8/TF2, or shorter just TF2, standing for Task Force 2, was established in 1994.
- For the development of the standard series ISO/IEC 15693 the subgroup WG8/TF3, or shorter just TF3, was established in 1996.
- There is one more Task Force, namely TF1, which was established in 1990 and was originally developing the standard ISO/IEC 10536. It still exists, but has presently no specific development task.

5.2. Basic Standardisation on Smart cards:

ISO/IEC 7810 Identification Cards - Physical Characteristics
International Standard, published in 1985

This standard describes major characteristics for different sizes (ID-1, ID-2, ID-3). ID-1 is the standard size for proximity and vicinity smart cards with dimensions of: 54 mm x 85.6 mm x 0.76 mm.

ISO/IEC 7816-2 Identification Cards - Integrated circuit(s) cards with contacts
Part 2: Dimensions and location of the contacts
International Standard, published in 1996

For dual interface cards which cover both, a contact interface and a contactless interface, the location of contact pads is described in this standard.

5.3. Overview over Contactless Standards:

There are two major groups of standards which differ in range of operating distance.
ISO/IEC 14443, so-called "Proximity Systems" with an operating range of up to 10 cm and
ISO/IEC 15693, so-called "Vicinity Systems" with an operating range of up to 1 m
ISO/IEC 10536 type of inductive or capacitive coupled contactless cards with an operating range of few millimetres are not more relevant to the market due to technical advantage of magnetic coupled cards described in ISO/IEC-Standards 14443 and 15693 which will be covered afterwards more detailed.

5.4. Identification Cards - Contactless integrated circuit(s) cards Close-coupled cards :

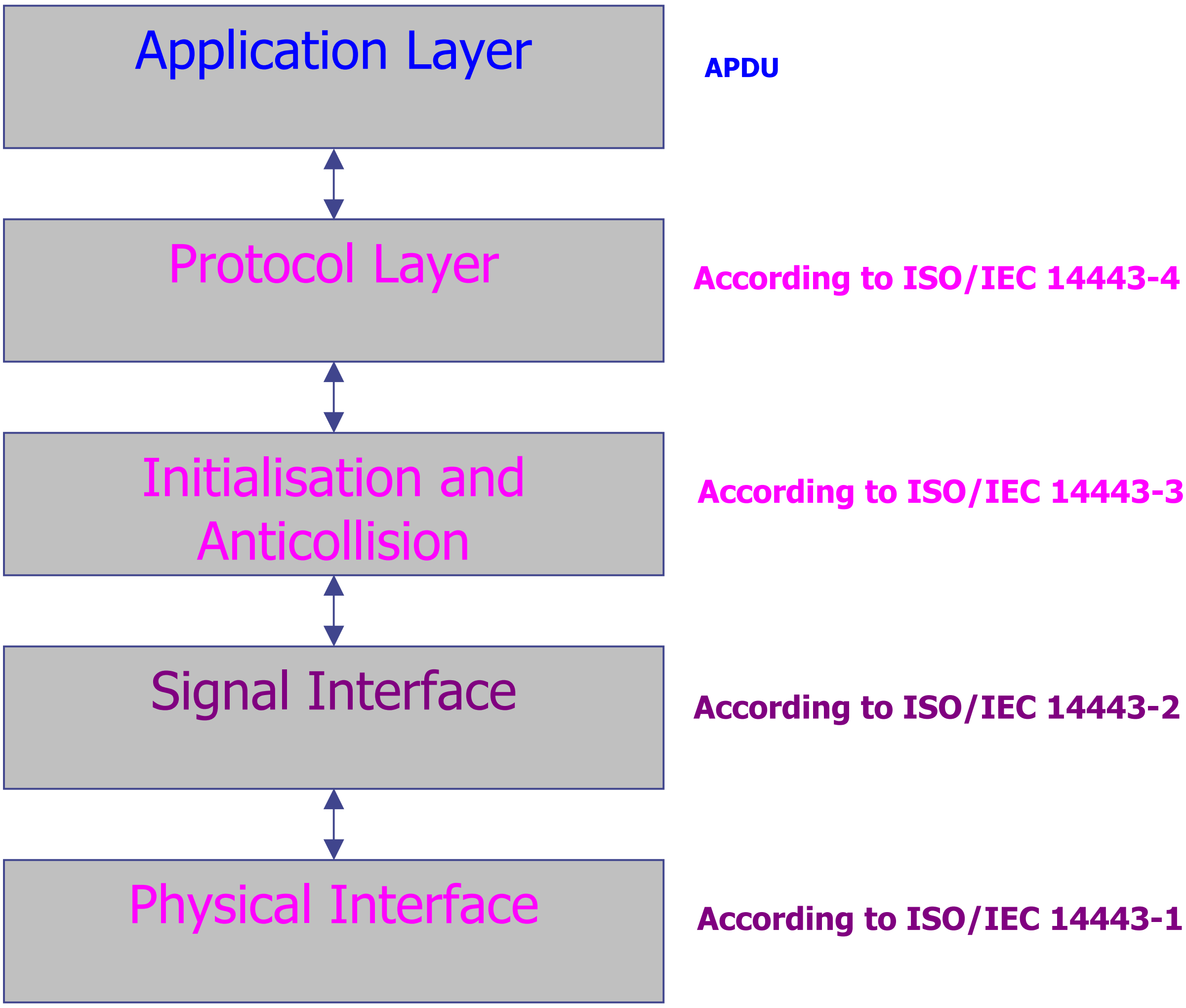
ISO/IEC 10536-1 Physical characteristics
International Standard, published on 15th April 2000

ISO/IEC 10536-2 Dimensions and location of coupling areas
International Standard, published in December 1995, Revision published in October 2001

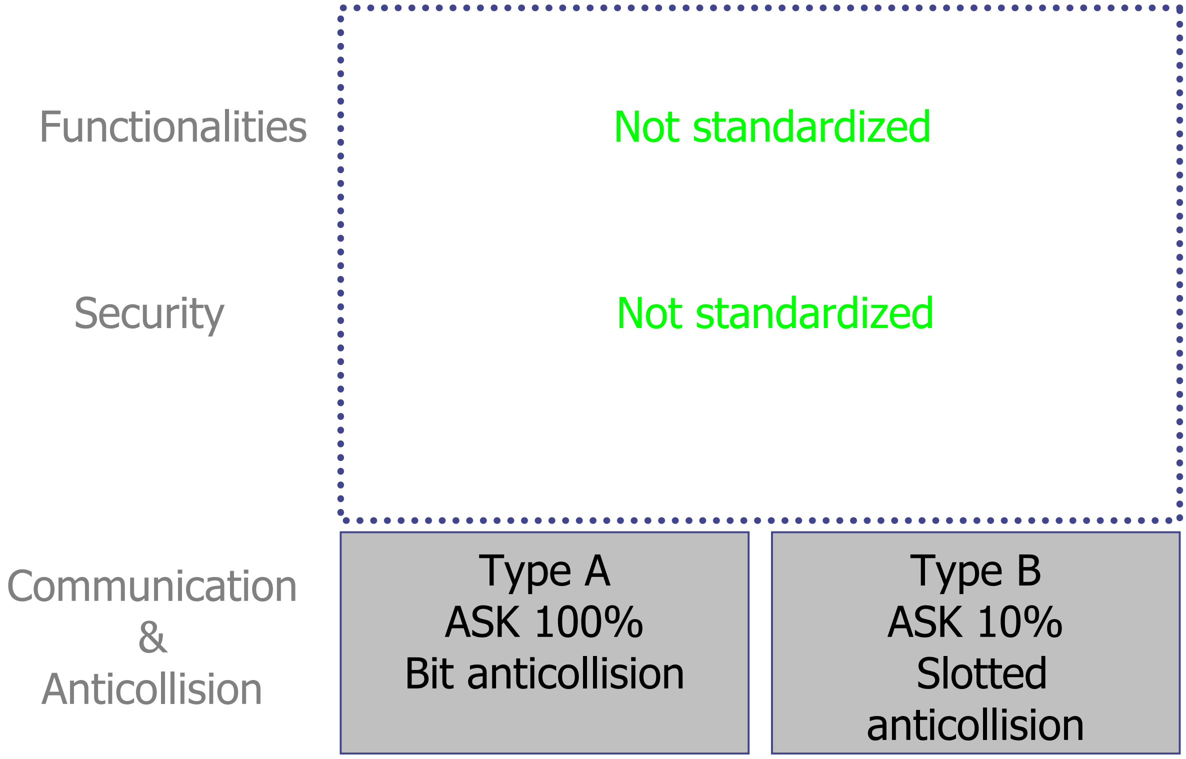
ISO/IEC 10536-3 Electronic signals and reset procedures
International Standard, published in December 1996

5.5. Identification Cards - Contactless integrated circuit(s) cards Proximity Cards :

A data transfer structure from application down to physical layer similar to the OSI-layer structure is shown here for PICC and PCD.



The standardization level is given here:



5.5.1. ISO/IEC 14443-1 Physical characteristics
International Standard, published on 15th April 2000

Physical characteristics

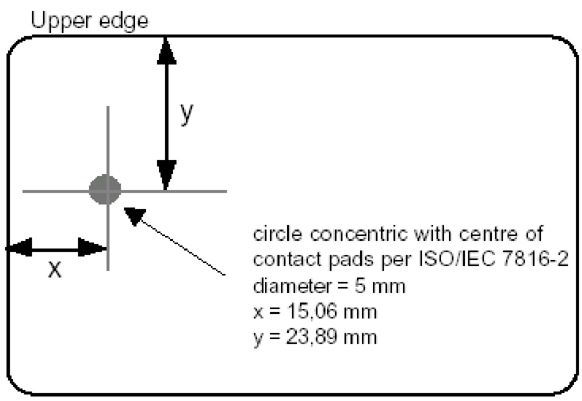
Dimensions compliant to ID-1 ISO/IEC 7810
Bending and other stress defined in ISO/IEC 10373
Alternating magnetic and electric fields
Static magnetic and electric fields
Operating temperature (0 to 50 degree Celsius)
Surface quality printing
Restrictions may apply to embossing of the PICC

5.5.2. ISO/IEC 14443-2 Radio frequency power and signal interface
International Standard, published on 1st July 2001

This part of ISO/IEC 14443 describes:
- Power transfer at 13.56 Mhz
- Communication between PICC and PCD with two different types of communication signal interfaces are specified, Type A and Type B:

Card type			PICC to PCD	
	Modulation	Coding	Modulation	Coding
A	ASK 100%	Modified Miller	Load m. / OOK	Manchester
B	ASK 10%	NRZ-L	Load m. / BPSK	NRZ-L

Then, minimal coupling zone is given:



5.5.3. ISO/IEC 14443-3 Initialisation and anticollision

International Standard, published on 1st February 2001

This part of ISO/IEC 14443 describes:
- polling for PICCs entering the field of a PCD
- byte format, frames and timings
- Request (REQ) and Answer to request (ATQ) commands
- Anticollision methods to detect and communicate with one card among several cards

Polling methods: Terminal talks first
PICC should be able to accept a request within 5 ms after exposure to a non-modulated operating field according to ISO/IEC 14443-2.

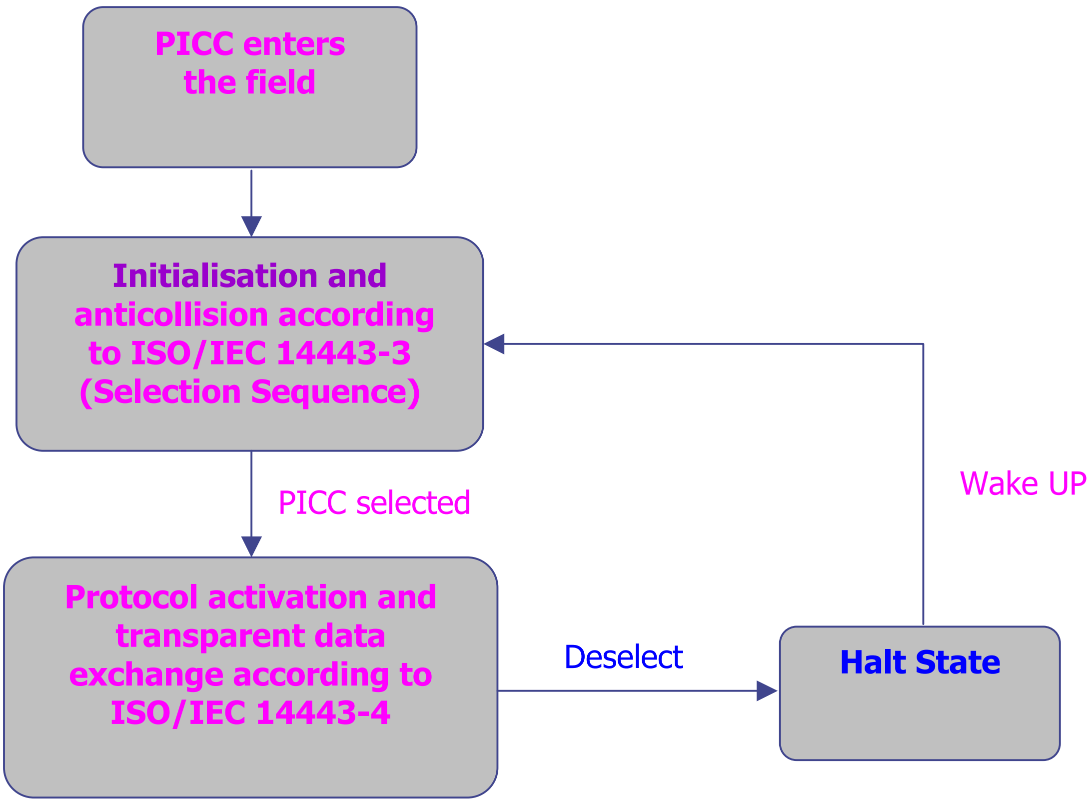
Anticollision methods:
Type A: Binary search method referring to the Unique Identifier (UID) of the card
Type B: Slotted Aloha method

5.5.4. ISO/IEC 14443-4 Transmission protocol

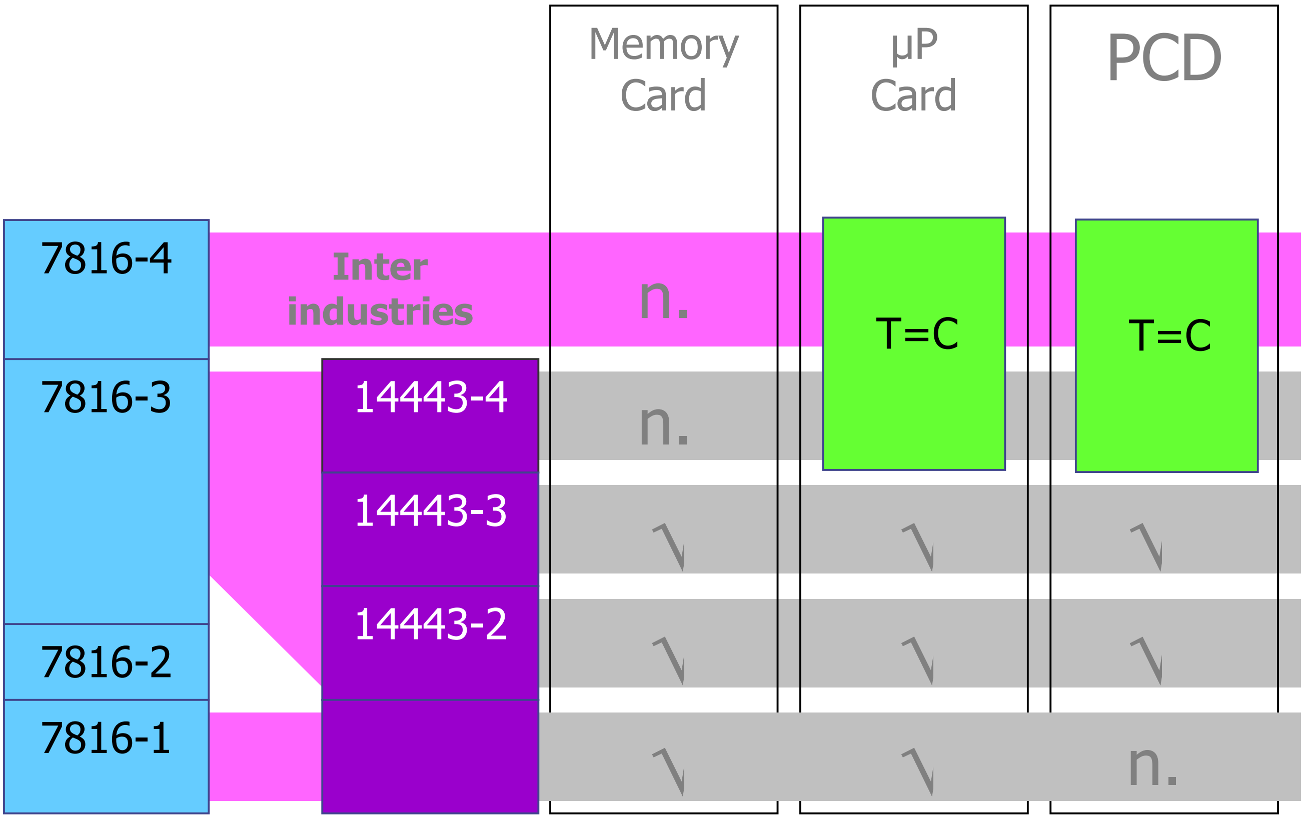
International Standard, published on 1st February 2001

This standard specifies :

- Protocol activation for type A
- A half duplex block transmission protocol (T=CL). Several protocol scenarios in Appendix B of this standard show, how this common transmission protocol can be used.
- Protocol deactivation of the card



The connection between ISO/IEC 14443 and ISO/IEC 7816 is shown here for PICC (memory card and microprocessor card) and PCD (reader) :



The block format related to T=CL protocol is shown here:

Block format

Prologue field			Information field	Epilogue field
PCB	[CID]	[NAD]	[INF]	[EDC]
1 byte	1 byte	1 byte		2 bytes

The items in bracket are optional

PCB Protocol Control Byte
CID Card IDentifier
NAD Node ADdress

→ I-block information for the application
R-block positive or negative ack
S-block control information:
Waiting time extension
Deselect command

5.6. Identification Cards - Contactless integrated circuit(s) cards Vicinity Cards:

5.6.1. ISO/IEC 15693-1 Physical characteristics

International Standard, published on 15th July 2000

Refers to ISO/IEC 7810 for dimensions and introduces specific terms:
VICC: Vicinity Integrated Circuit(s) card
VCD: Vicinity coupling device
Also definitions are made for behaviour of the card exposed to static and alternating electric and magnetic fields.

5.6.2. ISO/IEC 15693-2 Air interface and initialisation

International Standard, published on 1st May 2000

This part of ISO/IEC 15693 describes characteristics of power-transfer and communication between VICC and VCD. Several different modes must be supported by the VICC.

Abbreviations:
ASK Amplitude shift keying
PPM Pulse positioning modulation

Common parameters:
Power transfer: 13,56 MHz +/- 7 kHz,
Inductive coupling
Magnetic field strength: 0,15 .. 5 A/m

Modes:
VCD to VICC: (Downlink)
Modulation: 10% ASK or 100% ASK
Coding: Pulse positioning modulation
"1 out of 256" (long distance mode)
"1 out of 4" (fast mode)
Baud rate: 1,65 kBit/s (long distance mode)
26,48 kBit/s (fast mode)
VICC to VCD: (Uplink)
Modulation: Load modulation with one or two sub carriers
one sub carrier: 432,75 kHz
two sub carriers: 432,75 kHz and 484,28 kHz
Coding: Manchester Coding
Baud rate: depending on Number of sub carriers

	One sub carrier:	Two sub carriers
Low Data Rate	6,62 Kbit/s	6,67 Kbit/s
High Data Rate	26,48Kbit/s	26,69 Kbit/s

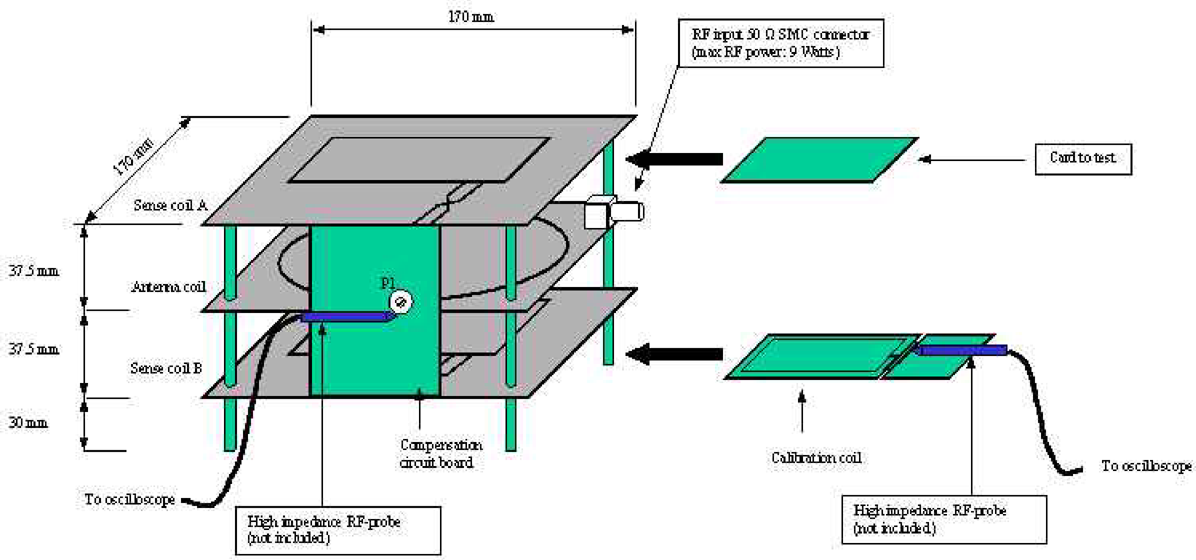
5.6.3. ISO/IEC 15693-3 Anticollision and transmission protocol
International Standard, published on 1st April 2001

This part of ISO/IEC 15693 describes:
- protocol and commands
- other parameters required to initialise communication between a VICC and a VCD
- methods to detect and communicate with one card among several cards (anticollision)
- Data elements like Unique identifier (UID) and Application family identifier (AFI)
- Memory organisation
- Behaviour of VICCs described in state machine diagrams
- Set of commands (mandatory, optional, custom and proprietary)

5.7. Identification Cards - Test Methods

5.7.1. ISO/IEC 10373-6 Proximity cards
International Standard, published on 15th May 2001

Different apparatus and test items are specified to tests PICCs:
- Calibration Coil
- Test PCD assembly
- Reference PICCs



Following test methods are described in ISO/IEC 10373-6:
- Static electricity test (discharge with an ESD-gun)

- Load modulation test
- Maximum field strength test
- Minimum field strength test
- Power transfer PCD to PICC test
- Modulation index and waveform test
- Load modulation reception (informative only, test for PCD)

Tuned and ready to use Test PCD and PICC assemblies are available at company like Arsenal Research, Micropross and SmartWare.

ISO/IEC 10373-7 Vicinity cards

International Standard, published on 15th May 2001

Different apparatus and test items are specified to tests PICCs:

- Calibration Coil
- Test VCD assembly (different from Test PCD assembly in ISO/IEC 10373-6)
- Reference VICCs (for VCD power and load modulation test)

Following test methods are described in ISO/IEC 10373-6:

- Static electricity test (discharge with an ESD-gun)
- Load modulation test
- Maximum field strength test
- Minimum field strength test
- Modulation index and waveform test
- Load modulation reception (informative only, test for VCD)

Tuned and ready to use Test PCD and VCD assemblies are available at company like Arsenal Research, Micropross and SmartWare.

6. Conclusion

6.1. Interoperability

Technically contactless solutions exist and work together. Some standards are already in use and are known today as proven solutions.

NDMA (New Development Media Association), a Japanese association, formed by the Ministry of economy, International trade and Industry has worked on the « project on Cities Equipped with information technologies ».
This project deals with the deployment of 1,2 million contactless smart card for public application such as residential services and healthcare and have been deployed in 21 areas in Japan. Objective of this project was the establishment of implementation standard to improve interoperability between cards and terminal manufacturers .

A software PC tool was specified and developed to verify the functional cross test between different vendors.
Five types of cards and 7 types of readers have been tested method and the interoperability results show a good compatibility for all combinations of the various type of smart card and reader.

6.2. Interoperability between ISO 14443 type A and type B.

To provide Interoperability between proximity systems of type A and type B means, that proximity terminals will have to handle cards of both types. That means, terminal software has to contribute something like a appropriate hardware abstraction layer to provide a type independent application platform.
Vice versa, vicinity cards have to integrate an abstraction layer to cover Interoperability for different modes of vicinity systems.

In principles there is also no barrier for use of proximity and vicinity cards in one application due to similarity in terminal front-end.
Present standardisation for contactless is mainly card related and describes behaviour and functionality for cards as there is no standardisation for terminals.

In standards for test methods (ISO/IEC 10373-6 and ISO/IEC 10373-7) some aspects for characterisation of terminals are already described.

There is a user demand for continuing standardisation for contactless covering normative description of behaviour and functionality for terminals. An improvement of standards for test methods (ISO/IEC 10373-6 and ISO/IEC 10373-7) by implementing test plans and further methods might cover this demand for better specification and real interoperability in the future.

6.3. Interoperability between ISO 14443 and ISO 15693

For some application requirements, the final customer can require a dual protocol communication between the two ISO 14443 protocols or between the ISO 14443 and ISO 15693.

One example is to use the ISO 14443 for payment in a transport application and the ISO 15693 to gather marketing information in the subway. People can be identified with the long range communication using the ISO 15693 and thanks to the chip serial number, the customer can define where the people enter the subway and where he/she left it.

Interoperability can be handled in the chip itself if both protocols are implemented. Depending on the reader the chip will answer with the requested protocol. This mean that interoperability between short range and long range applications can be easily managed.

7. Abbreviations and Symbols

ACK	positive Acknowledgement
ASK	Amplitude Shift Keying
ATS	Answer To Select
ATQ	Answer To Request
BPSK	Binary Phase Shift Keying
CID	Card Identifier
CRC	Cyclic Redundancy Check error detection
EDC	Error Detection Code
EOF	End Of Frame
FSC	Frame Size for proximity Card
FSD	Frame Size for proximity coupling Device
HLT	Halt Command
I-Block	Information Block
ID	Identification number
INF	INFormation field
LSB	Least Significant Bit
MSB	Most Significant Bit
NAD	Node Address
NAK	Negative AcKnowledgement
NRZ-L	Non-Return to Zero, Level
OSI	Open Systems Interconnection
PCB	Protocol Control Byte
PCD	Proximity Coupling Device
PICC	Proximity Card
PPS	Protocol and Parameter Selection
R-Block	Receive ready Block
R(ACK)	R-block containing a positive acknowledgement
R(NAK)	R-block containing a negative acknowledgement
RATS	Request for Answer To Select
REQ	Request Command
RF	Radio Frequency
RFU	Reserved for Future Use
S-Block	Supervisory Block
SAK	Select AcKnowledge
SOF	Start Of Frame
UID	Unique Identifier
WTX	Waiting Time eXtension
WUP	Wake-UP Command
ETU	Elementary Time Unit
FC	Frequency of operating field (carrier frequency)
FS	Frequency of sub carrier modulation

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