Annex E
(informative)
Example of Tag inventory and access

E.1 Example inventory and access of a single Tag

Figure E.1 shows the steps by which an Interrogator inventories and accesses a single Tag.

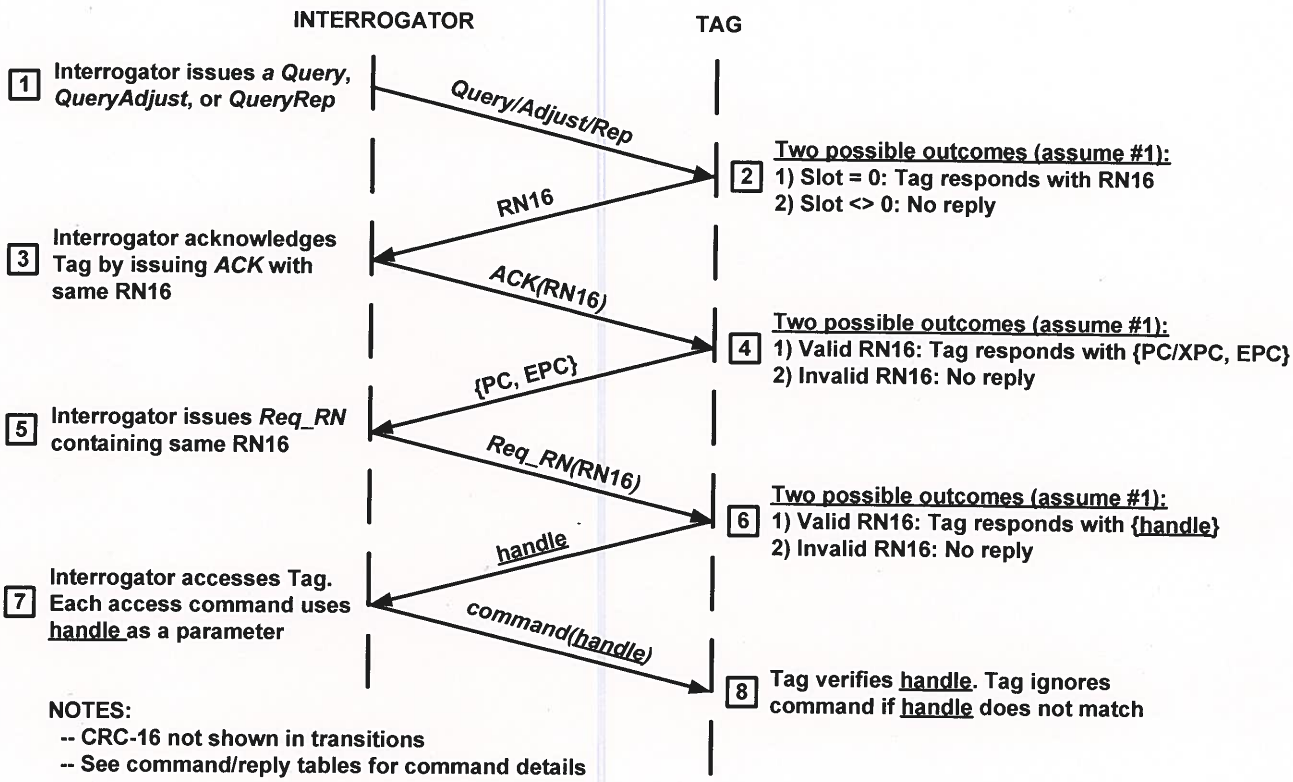


Figure E.1 – Example of Tag inventory and access

Annex F
(informative)
Calculation of 5-bit and 16-bit cyclic redundancy checks

F.1 Example CRC-5 encoder/decoder

An exemplary schematic diagram for a CRC-5 encoder/decoder is shown in Figure F.1, using the polynomial and preset defined in Table 6.12.

To calculate a CRC-5, first preload the entire CRC register (i.e. Q[4:0], Q4 being the MSB and Q0 the LSB) with the value 01001_2 (see Table F.1), then clock the data bits to be encoded into the input labeled DATA, MSB first. After clocking in all the data bits, Q[4:0] holds the CRC-5 value.

To check a CRC-5, first preload the entire CRC register (Q[4:0]) with the value 01001_2, then clock the received data and CRC-5 {data, CRC-5} bits into the input labeled DATA, MSB first. The CRC-5 check passes if the value in Q[4:0] = 00000_2.

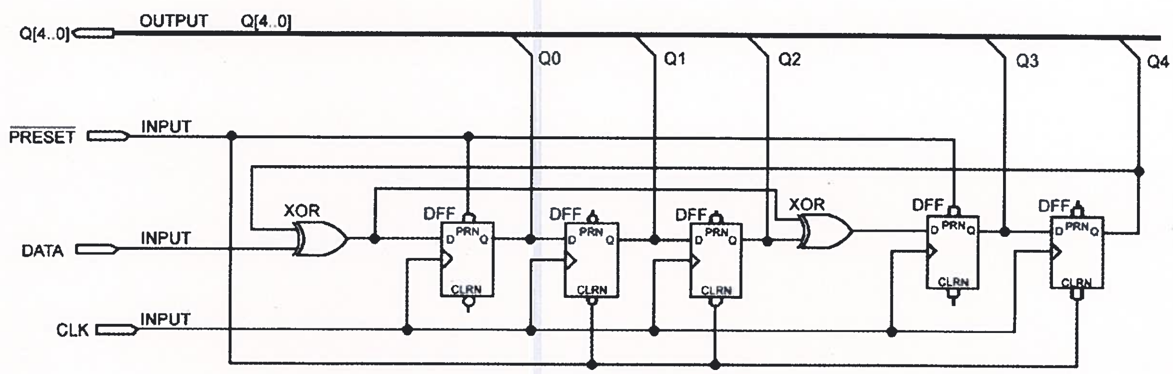


Figure F.1 – Example CRC-5 circuit

Table F.1 – CRC-5 register preload values

Register	Preload value
Q0	1
Q1	0
Q2	0
Q3	1
Q4	0

F.2 Example CRC-16 encoder/decoder

An exemplary schematic diagram for a CRC-16 encoder/decoder is shown in Figure F.2, using the polynomial and preset defined in Table 6.11 (the polynomial used to calculate the CRC-16, $x^{16} + x^{12} + x^5 + 1$, is the CRC-CCITT International Standard, ITU Recommendation X.25).

To calculate a CRC-16, first preload the entire CRC register (i.e. Q[15:0], Q15 being the MSB and Q0 the LSB) with the value $FFFF_h$. Second, clock the data bits to be encoded into the input labeled DATA, MSB first. After clocking in all the data bits, Q[15:0] holds the ones-complement of the CRC-16. Third, invert all the bits of Q[15:0] to produce the CRC-16.

There are two methods to check a CRC-16:

Method 1: First preload the entire CRC register (Q[15:0]) with the value $FFFF_h$, then clock the received data and CRC-16 {data, CRC-16} bits into the input labeled DATA, MSB first. The CRC-16 check passes if the value in Q[15:0]=$1D0F_h$.

Method 2: First preload the entire CRC register (Q[15:0]) with the value $FFFF_h$. Second, clock the received data bits into the input labeled DATA, MSB first. Third, invert all bits of the received CRC-16, and clock the inverted CRC-16 bits into the input labeled DATA, MSB first. The CRC-16 check passes if the value in $Q[15:0]=0000_h$.

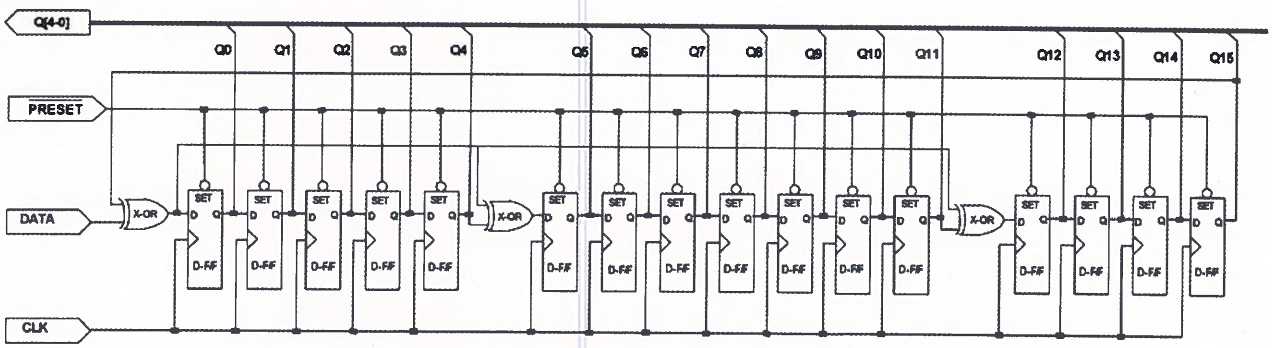


Figure F.2 – Example CRC-16 circuit

F.3 Example CRC-16 calculations

This example shows the StoredCRC (a CRC-16) that a Tag would calculate at power-up.

As shown in Figure 6.17, EPC memory contains a StoredCRC starting at address 00_h, a StoredPC starting at address 10_h, zero or more EPC words starting at address 20_h, an optional XPC_W1 starting at address 210_h, and an optional XPC_W2 starting at address 220_h. As described in 6.3.2.1.2.1, a Tag calculates its StoredCRC over its StoredPC and EPC, but omits the XPC_W1 and XPC_W2 from the calculation. Table F.2 shows the StoredCRC that a Tag would calculate and logically map into EPC memory at power-up, for the indicated example StoredPC and EPC word values. In each successive column, one more word of EPC memory is written, with the entire EPC memory written in the rightmost column. The indicated StoredPC values correspond to the number of EPC words written, with StoredPC bits 15_h–$1F_h$ set to zero. Entries marked N/A mean that that word of EPC memory is not included as part of the CRC calculation.

Table F.2 – EPC memory contents for an example Tag

EPC word starting address	EPC word contents	EPC word values						
00_h	StoredCRC	$E2F0_h$	$CCAE_h$	$968F_h$	$78F6_h$	$C241_h$	$2A91_h$	1835_h
10_h	StoredPC	0000_h	0800_h	1000_h	1800_h	2000_h	2800_h	3000_h
20_h	EPC word 1	N/A	1111_h	1111	1111_h	1111_h	1111_h	1111_h
30_h	EPC word 2	N/A	N/A	2222_h	2222_h	2222_h	2222_h	2222_h
20_h	EPC word 3	N/A	N/A	N/A	3333_h	3333_h	3333_h	3333_h
40_h	EPC word 4	N/A	N/A	N/A	N/A	4444_h	4444_h	4444_h
50_h	EPC word 5	N/A	N/A	N/A	N/A	N/A	5555_h	5555_h
60_h	EPC word 6	N/A	N/A	N/A	N/A	N/A	N/A	6666_h

Annex G
(Normative)
Multiple- and dense-Interrogator channelized signaling

This Annex describes channelized signaling in the optional multiple- and dense-Interrogator operating modes. It provides methods that Interrogators may use, as permitted by local authorities, to maximize the spectral efficiency and performance of RFID systems while minimizing the interference to non-RFID systems.

Because regulatory requirements vary worldwide, and even within a given regulatory region are prone to ongoing reinterpretation and revision, this Annex does not specify multiple- or dense-Interrogator operating requirements for any given regulatory region. Instead, this Annex merely outlines the goals of channelized signaling, and defers specification of the Interrogator operating requirements for each individual regulatory region to the channel plans located at www.epglobalinc.org/regulatorychannelplans.

When an Interrogator in a multiple- or dense-Interrogator environment instructs Tags to use subcarrier backscatter, the Interrogator shall adopt the channel plan found at the above-referenced link for the regulatory region in which it is operating. When an Interrogator in a multiple- and dense-Interrogator environment instructs Tags to use FM0 backscatter, the Interrogator shall adopt a channel plan in accordance with local regulations.

Regardless of the regulatory region and the choice of Tag backscatter data encoding,

- Interrogator signaling (both modulated and CW) shall be centered in a channel with the frequency accuracy specified in 6.3.1.2.1, unless local regulations specify tighter frequency accuracy, in which case the Interrogator shall meet the local regulations, and
- Interrogator transmissions shall satisfy the multiple- or dense-Interrogator transmit mask in 6.3.1.2.11 (as appropriate), unless local regulations specify a tighter mask, in which case the Interrogator shall meet the local regulations.

If an Interrogator uses SSB-ASK modulation, the transmit spectrum shall be centered in the channel during R=>T signaling, and the CW shall be centered in the channel during Tag backscatter.

G.1 Overview of dense-interrogator channelized signaling (informative)

In environments containing two or more Interrogators, the range and rate at which Interrogators singulate Tags can be improved by preventing Interrogator transmissions from colliding spectrally with Tag responses. This section describes three frequency-division multiplexing (FDM) methods that minimize such Interrogator-on-Tag collisions. In each of these methods, Interrogator transmissions and Tag responses are separated spectrally.

1. *Channel-boundary backscatter*: Interrogator transmissions are constrained to occupy only a small portion of the center of each channel, and Tag backscatter is situated at the channel boundaries.
2. *Alternative-channel backscatter*: Interrogator transmissions are located in a subset of the channels, and Tag backscatter is located in a different subset of the channels.
3. *In-channel backscatter*: Interrogator transmissions are constrained to occupy only a small portion of the center of each channel, and Tag backscatter is situated near but within the channel boundaries.

Figure G.1, shows examples of these FDM dense-Interrogator methods. For optimum performance, the operating requirements located at www.epglobalinc.org/regulatorychannelplans suggest (but do not require) choosing values for BLF and M that allow a guardband between Interrogator signaling and Tag responses.

Example 1: Channel-boundary backscatter

FCC 15.247, dated October 2000, authorizes frequency-hopping operation in the ISM band from 902–928 MHz with 500 kHz maximum channel width, and does not prohibit channel-boundary backscatter. In such an environment Interrogators will use 500 kHz channels with channel-boundary backscatter. Example 1 of Figure G.1 shows Interrogator transmissions using PR-ASK modulation with Tari = 25 µs, and 62.5 kbps Tag data backscatter on a 250 kHz subcarrier (BLF = 250 kHz; M = 4). Interrogators center their R=>T signaling in the channels, with transmissions unsynchronized in time, hopping among channels.

Example 2: Alternative-channel backscatter

ETSI Technical Group 34 has proposed an amendment to ERC REC 70-03E Annex 11 allocating four high-power 200 kHz channels, each spaced 600 kHz apart, in the 865–868 MHz frequency range. This amendment allows adjacent-channel Tag backscatter. In such an environment Interrogators will use alternative-channel backscatter. Example 2 of Figure G.1 shows Interrogator transmissions using SSB-ASK modulation with Tari = 25 µs, and 75 kbps Tag data backscatter on a 300 kHz subcarrier (BLF = 300 kHz, M = 4).

Example 3: FDM in-channel backscatter

A hypothetical regulatory region allocates four 500 kHz channels and disallows adjacent-channel and channel-boundary backscatter. In such an environment Interrogators will use in-channel backscatter. Example 3 of Figure G.1 shows Interrogator transmissions using PR-ASK modulation with Tari = 25 µs, and 25 kbps Tag data backscatter on a 200 kHz subcarrier (BLF = 200 kHz, M = 8).

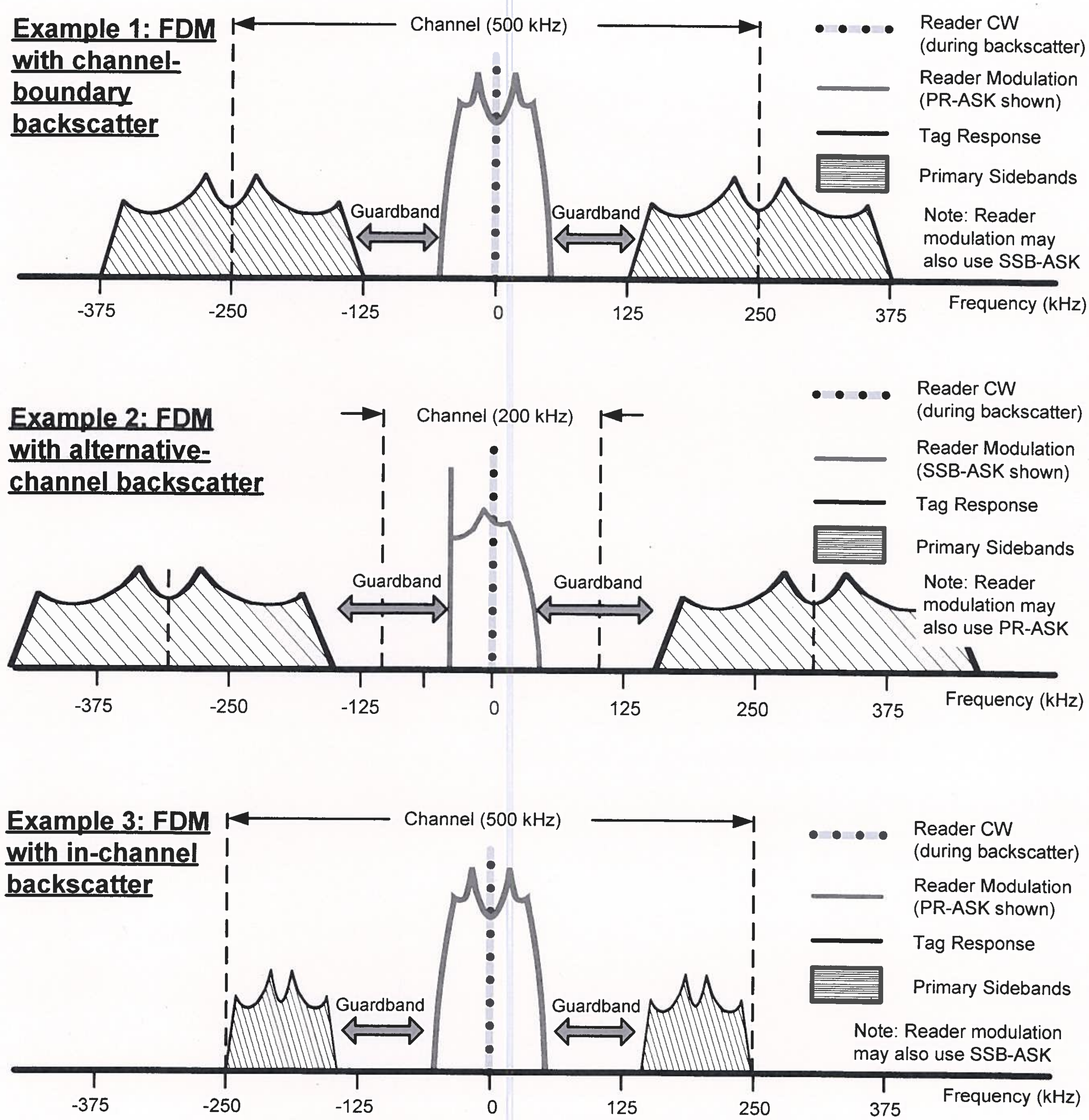


Figure G.1 – Examples of dense-Interrogator-mode operation

Annex H
(informative)
Interrogator-to-Tag link modulation

H.1 Baseband waveforms, modulated RF, and detected waveforms

Figure H.1 shows R=>T baseband and modulated waveforms as generated by an Interrogator, and the corresponding waveforms envelope-detected by a Tag, for DSB- or SSB-ASK modulation, and for PR-ASK modulation.

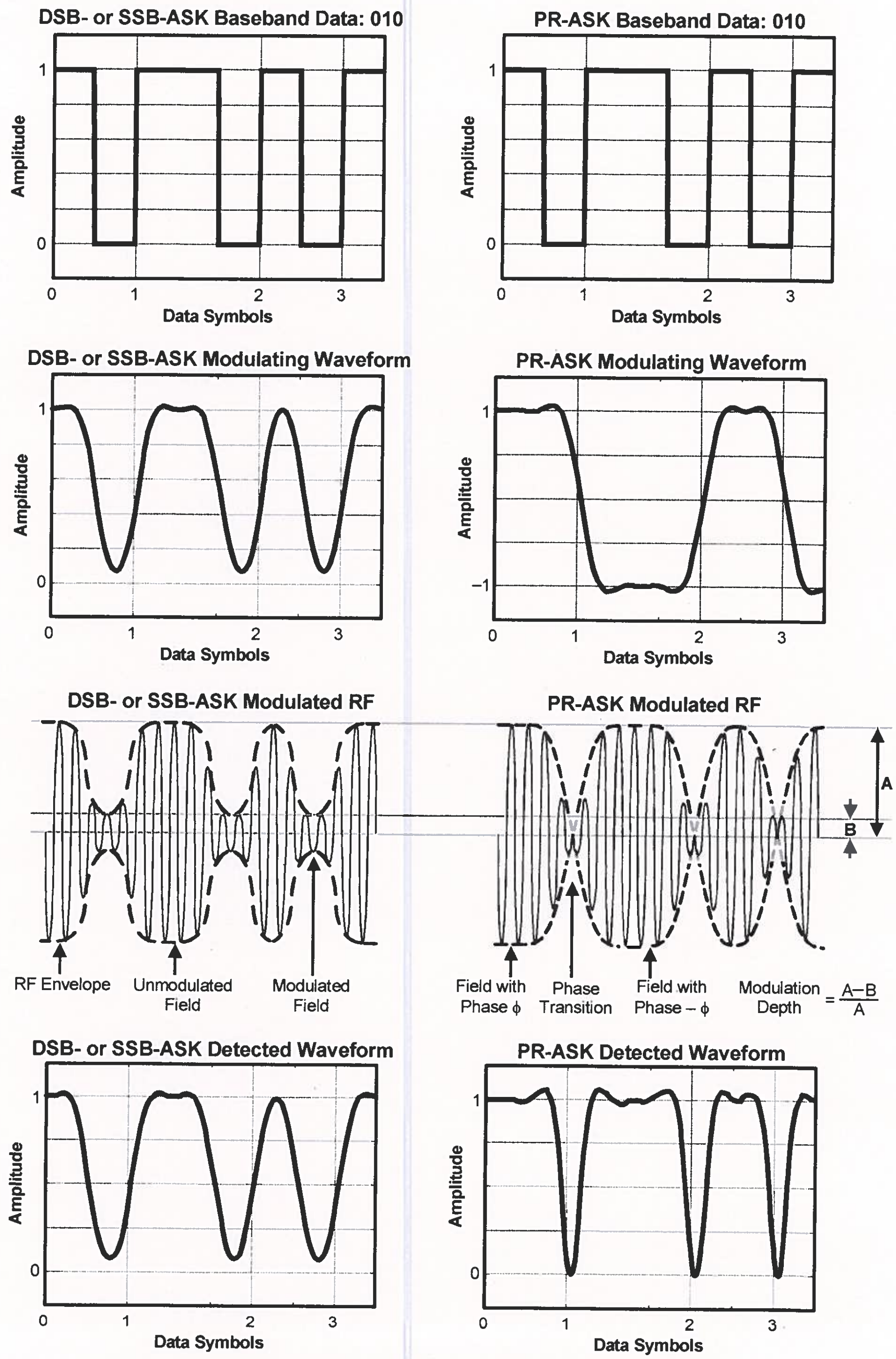


Figure H.1 – Interrogator-to-Tag modulation

Annex I
(Normative)
Error codes

I.1 Tag error codes and their usage

If a Tag encounters an error when executing an access command that reads from or writes to memory, and if the command is a handle-based command (i.e. *Read*, *Write*, *Kill*, *Lock*, *BlockWrite*, *BlockErase*, or *BlockPermalock*), then the Tag shall backscatter an error code as shown in Table I.1 instead of its normal reply.

- If the Tag supports error-specific codes, it shall use the error-specific codes shown in Table I.2.
- If the Tag does not support error-specific codes, it shall backscatter error code 00001111_2 (indicating a non-specific error) as shown in Table I.2.
- Tags shall backscatter error codes only from the **open** or **secured** states.
- A Tag shall not backscatter an error code if it receives an invalid access command; instead, it shall ignore the command.
- If an error is described by more than one error code, the more specific error code shall take precedence and shall be the code that the Tag backscatters.
- The header for an error code is a 1-bit, unlike the header for a normal Tag response, which is a 0-bit.

Table I.1 – Tag-error reply format

	Header	Error Code	RN	CRC-16
# of bits	1	8	16	16
description	1	Error code	handle	

Table I.2 – Tag error codes

Error-Code Support	Error Code	Error-Code Name	Error Description
Error-specific	00000000_2	Other error	Catch-all for errors not covered by other codes
	00000011_2	Memory overrun	The specified memory location does not exist or the EPC length field is not supported by the Tag
	00000100_2	Memory locked	The specified memory location is locked and/or permalocked and is either not writeable or not readable.
	00001011_2	Insufficient power	The Tag has insufficient power to perform the memory-write operation
Non-specific	00001111_2	Non-specific error	The Tag does not support error-specific codes

Annex J
(normative)
Slot counter

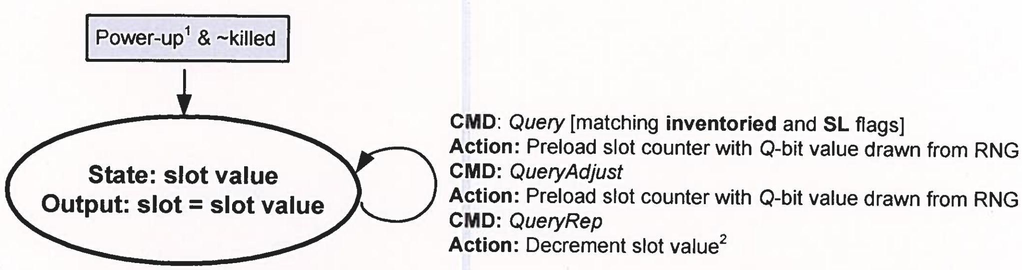
J.1 Slot-counter operation

As described in 6.3.2.4.8, Tags implement a 15-bit slot counter. As described in 6.3.2.8, Interrogators use the slot counter to regulate the probability of a Tag responding to a *Query*, *QueryAdjust*, or *QueryRep* command. Upon receiving a *Query* or *QueryAdjust* a Tag preloads a *Q*-bit value, drawn from the Tag's RNG (see 6.3.2.5), into its slot counter. *Q* is an integer in the range (0, 15). A *Query* specifies *Q*; a *QueryAdjust* may modify *Q* from the prior *Query*.

A Tag in the **arbitrate** state shall decrement its slot counter every time it receives a *QueryRep* command, transitioning to the **reply** state and backscattering an RN16 when its slot-counter value reaches 0000_h. A Tag whose slot-counter value reached 0000_h, who replied, and who was not acknowledged (including a Tag that responded to the original *Query* and was not acknowledged) returns to **arbitrate** with a slot-counter value of 0000_h.

A Tag that returns to **arbitrate** with a slot-counter value of 0000_h shall decrement its slot-counter from 0000_h to $7FFF_h$ (i.e. the slot counter rolls over) at the next *QueryRep* with matching session. Because the slot-counter value is now nonzero, the Tag remains in **arbitrate**. Slot counters implements continuous counting, meaning that, after a slot counter rolls over it begins counting down again from $7FFF_h$, effectively preventing subsequent Tag replies until the Tag receives either a *Query* or a *QueryAdjust* and loads a new random value into its slot counter.

Annex B and Annex C contain tables describing a Tag's response to Interrogator commands; "slot" is a parameter in these tables.



Notes
1. The slot counter may assume an arbitrary value at Tag power-up
2. If slot value = 0000_h, then decrementing the slot value causes it to roll over to $7FFF_h$

Figure J.1 – Slot-counter state diagram

Annex K
(informative)
Example data-flow exchange

K.1 Overview of the data-flow exchange

The following example describes a data exchange, between an Interrogator and a single Tag, during which the Interrogator reads the kill password stored in the Tag's Reserved memory. This example assumes that:

- The Tag has been singulated and is in the **acknowledged** state.
- The Tag's Reserved memory is locked but not permalocked, meaning that the Interrogator must issue the access password and transition the Tag to the **secured** state before performing the read operation.
- The random numbers the Tag generates (listed in sequence, and not random for reasons of clarity) are:
  - RN16_0 1600_h (the RN16 the Tag backscattered prior to entering **acknowledged**)
  - RN16_1 1601_h (will become the handle for the entire access sequence)
  - RN16_2 1602_h
  - RN16_3 1603_h
- The Tag's EPC is 64 bits in length.
- The Tag's access password is $ACCEC0DE_h$.
- The Tag's kill password is $DEADC0DE_h$.
- The 1st half of the access password EXORed with RN16_2 = $ACCE_h \otimes 1602_h = BACC_h$.
- The 2nd half of the access password EXORed with RN16_3 = $C0DE_h \otimes 1603_h = D6DD_h$.

K.2 Tag memory contents and lock-field values

Table K.1 and Table K.2 show the example Tag memory contents and lock-field values, respectively.

Table K.1 – Tag memory contents

Memory Bank	Memory Contents	Memory Addresses	Memory Values
TID	TID[15:0]	10_h–$1F_h$	$54E2_h$
	TID[31:16]	00_h–$0F_h$	$A986_h$
EPC	EPC[15:0]	50_h–$5F_h$	3210_h
	EPC[31:16]	40_h–$4F_h$	7654_h
	EPC[47:32]	30_h–$3F_h$	$BA98_h$
	EPC[63:48]	20_h–$2F_h$	$FEDC_h$
	StoredPC[15:0]	10_h–$1F_h$	2000_h
	StoredCRC[15:0]	00_h–$0F_h$	as calculated (see Annex F)
Reserved	access password[15:0]	30_h–$3F_h$	$C0DE_h$
	access password[31:16]	20_h–$2F_h$	$ACCE_h$
	kill password[15:0]	10_h–$1F_h$	$C0DE_h$
	kill password[31:16]	00_h–$0F_h$	$DEAD_h$

Table K.2 – Lock-field values

Kill Password		Access Password		EPC Memory		TID Memory		User Memory	
1	0	1	0	0	0	0	0	N/A	N/A

K.3 Data-flow exchange and command sequence

The data-flow exchange follows the *Access* procedure outlined in Figure 6.25 with a *Read* command added at the end. The sequence of Interrogator commands and Tag replies is:

Step 1: *Req_RN*[RN16_0, CRC-16]
Tag backscatters RN16_1, which becomes the handle for the entire access sequence

Step 2: *Req_RN*[handle, CRC-16]
Tag backscatters RN16_2

Step 3: *Access*[access password[31:16] EXORed with RN16_2, handle, CRC-16]
Tag backscatters handle

Step 4: *Req_RN*[handle, CRC-16]
Tag backscatters RN16_3

Step 5: *Access*[access password[15:0] EXORed with RN16_3, handle, CRC-16]
Tag backscatters handle

Step 6: *Read*[MemBank=Reserved, WordPtr=00_h, WordCount=2, handle, CRC-16]
Tag backscatters kill password

Table K.3 shows the detailed Interrogator commands and Tag replies. For reasons of clarity, the CRC-16 has been omitted from all commands and replies.

Table K.3 – Interrogator commands and Tag replies

Step	Data Flow	Command	Parameter and/or Data	Tag State
1a: *Req_RN* command	R => T	11000001	0001 0110 0000 0000 (RN16_0=1600_h)	**acknowledged → open**
1b: Tag response	T => R		0001 0110 0000 0001 (handle=1601_h)	
2a: *Req_RN* command	R => T	11000001	0001 0110 0000 0001 (handle=1601_h)	**open → open**
2b: Tag response	T => R		0001 0110 0000 0010 (RN16_2=1602_h)	
3a: *Access* command	R => T	11000110	1011 1010 1100 1100 ($BACC_h$) 0001 0110 0000 0001 (handle=1601_h)	**open → open**
3b: Tag response	T => R		0001 0110 0000 0001 (handle=1601_h)	
4a: *Req_RN* command	R => T	11000001	0001 0110 0000 0001 (handle=1601_h)	**open → open**
4b: Tag response	T => R		0001 0110 0000 0011 (RN16_2=1603_h)	
5a: *Access* command	R => T	11000110	1101 0110 1101 1101 ($D6DD_h$) 0001 0110 0000 0001 (handle=1601_h)	**open → secured**
5b: Tag response	T => R		0001 0110 0000 0001 (handle=1601_h)	
6a: *Read* command	R => T	11000010	00 (MemBank=Reserved) 00000000 (WordPtr=kill password) 00000010 (WordCount=2) 0001 0110 0000 0001 (handle=1601_h)	**secured → secured**
6b: Tag response	T => R		0 (header) 1101 1110 1010 1101 ($DEAD_h$) 1100 0000 1101 1110 ($C0DE_h$)	

Annex L
(informative)
Optional Tag Features

The following options are available to Tags certified to this protocol.

L.1 Optional Tag passwords

Kill password: A Tag may optionally implement a kill password. A Tag that does not implement a kill password operates as if it has a zero-valued kill password that is permanently read/write locked. See 6.3.2.1.1.1.

Access password: A Tag may optionally implement an access password. A Tag that does not implement an access password operates as if it has a zero-valued access password that is permanently read/write locked. See 6.3.2.1.1.2.

L.2 Optional Tag memory banks and memory-bank sizes

Reserved memory: Reserved memory is optional. If a Tag does not implement either a kill password or an access password then the Tag need not physically implement Reserved memory. Because a Tag with non-implemented passwords operates as if it has zero-valued password(s) that are permanently read/write locked, these passwords must still be logically addressable in Reserved memory at the memory locations specified in 6.3.2.1.1.1 and 6.3.2.1.1.2.

EPC memory: EPC memory is required, but its size is vendor-defined. The minimum size is 32 bits, to contain a 16-bit StoredCRC and a 16-bit StoredPC. EPC memory may be larger than 32 bits, to contain an EPC whose vendor-specified length may be 16 to 496 bits (if a Tag does not support XPC functionality) or to 464 bits (if a Tag supports XPC functionality) in 16-bit increments, as well as an optional XPC word or words. See 6.3.2.1.2.

TID memory: TID memory is required, but its size is vendor-defined. The minimum-size TID memory contains an 8-bit ISO/IEC 15963 allocation class identifier, as well as sufficient identifying information for an Interrogator to uniquely identify the custom commands and/or optional features that a Tag supports. TID memory may optionally contain vendor-specific data. See 6.3.2.1.3.

User memory: User memory is optional. See 6.3.2.1.4, 6.3.2.1.4.1, and 6.3.2.1.4.2.

L.3 Optional Tag commands

Proprietary**:** A Tag may support proprietary commands. See 2.3.3.

Custom**:** A Tag may support custom commands. See 2.3.4.

Access**:** A Tag may support the *Access* command. See 6.3.2.11.3.6.

BlockWrite**:** A Tag may support the *BlockWrite* command. See 6.3.2.11.3.7.

BlockErase**:** A Tag may support the *BlockErase* command. See 6.3.2.11.3.8.

BlockPermalock**:** A Tag may support the *BlockPermalock* command. See 6.3.2.11.3.9.

L.4 Optional Tag error-code reporting format

A Tag may support error-specific or non-error-specific error-code reporting. See Annex I.

L.5 Optional Tag backscatter modulation format

A Tag may support ASK and/or PSK backscatter modulation. See 6.3.1.3.1.

L.6 Optional Tag functionality

A Tag may implement the UMI by one of two methods. See 6.3.2.1.2.2.

A Tag may implement an XPC_W1, XPC_W2, XI, and XEB. See 6.3.2.1.2.2 and 6.3.2.1.2.5.

A Tag may implement recommissioning. See 6.3.2.1.2.5, 6.3.2.10, and 6.3.2.11.3.4.

Annex M
(informative)
Revision History

Table M.1 – Revision history

Date & Version Number	Section(s)	Change	Approved by
Sept 8, 2004 Version 1.0.4	All	Modified Chicago protocol V1.0.3 as per August 17, 2004 “combo” CRC change template.	
Sept 14, 2004 Version 1.0.5	All	Modified Gen2 protocol V1.0.4 as per September 10, 2004 CRC review.	
Sept 17, 2004 Version 1.0.6	All	Modified Gen2 protocol V1.0.5 as per September 17, 2004 HAG review.	
Sept 24, 2004 Version 1.0.7	All	Modified Gen2 protocol V1.0.6 as per September 21, 2004 CRC review to fix errata. Changed OID to EPC.	
Dec 11, 2004 Version 1.0.8	Multiple	Modified Gen2 protocol V1.0.7 as per the V1.0.7 errata.	
Jan 26, 2005 Version 1.0.9	Multiple	Modified Gen2 protocol V1.0.8 as per the V1.0.8 errata and AFI enhancement requests.	
Dec 1, 2005 Version 1.1.0	Multiple	Harmonized Gen2 protocol V1.0.9 with the ISO 18000-6 Type C amendment.	
May 11, 2008 Version 1.2.0	Multiple	Modified Gen2 protocol V1.1.0 to satisfy the ILT JRG requirements V1.2.3.	

E

INTECH
open science | open minds

OPEN ACCESS
ARTICLE

International Journal of Engineering Business Management

A Framework for the Implementation of RFID Systems

Invited Paper

S. L. Ting[1,*], Albert H. C. Tsang[1] and Y. K. Tse[2]

1 Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
2 The York Management School, University of York, Freboys Lane, Heslington, York, UK

Received 1 March 2013; Accepted 27 March 2013

DOI: 10.5772/56511

Abstract There are an increasing number of organizations planning to implement Radio Frequency Identification (RFID) systems to enhance their competitiveness. Due to the novelty of the technology, many managerial challenges exist in determining and planning for the implementation of such systems. These challenges often lead to wasted efforts and resources, as well as to failed implementations. This paper presents a systematic and holistic RFID implementation framework which has been validated by both users and experts. The framework outlines the important tasks to be performed in each step of the implementation process. To enable practitioners to make informed go/no-go decisions, essential considerations of implementation are also discussed in this paper. Furthermore, the critical success factors for the deployment of such systems are also elaborated.

Keywords RFID, RFID Implementation, Critical Success Factors, Implementation Framework, Deployment And Management Issues

1. Introduction

Radio Frequency Identification (RFID) - a cutting-edge technology in the Auto-ID industry - has been around for more than 50 years. It was first used in military applications for identifying enemy aircraft (Fanberg, 2004). Nowadays, RFID has become one of our partners in daily-life (Smart 2004; Garter, 2005; Stuart 2006). In many industries, a growing number of organizations around the world are considering introducing RFID systems as a means to improve their business and operational processes. RFID has revealed its potential to revolutionize existing systems, and it is undoubtedly a highly versatile technology that can serve the needs of diverse industries.

RFID is a technology that uses radio waves to transmit information. This kind of system usually consists of tags, readers and a data processing system. Such a system allows computers to acquire information about the identities of physical objects. It is more than a substitute technology of barcode systems. An RFID tag can hold much more information than a barcode, to the extent that it is possible to identify individual tagged items in a supply chain. RFID is superior to a barcode as it does not require line of sight for automatic data capturing, which is a definite advantage in numerous applications (Chowdhury et al., 2007). It also has a faster response time and process time when it is used to identify objects remotely.

An important application of RFID is its use as a tool to enhance the visibility of objects in a supply chain. This allows the organization to achieve better material management so as to improve a supply chain's efficiency and effectiveness. It enables organizations to track product information, allowing for greater control and flexibility in managing goods as they move through the supply chain. It will also significantly reduce the manpower needed and minimize human errors when compared with the existing technology. More importantly, the use of RFID technology improves supply chain efficiency by streamlining the stocktaking operations. As a result, it strengthens customer relationships by providing better services, facilitating promotional activities and allowing retailers to allocate resources more effectively (Angeles, 2005).

Although RFID is recognized as a revolutionary innovation that has the potential to change the way of managing businesses and supply chains, and even though it has captured the attention of many organizations, the adoption of RFID solutions in businesses has been slow (Wu et al., 2006). Many organizations are only "interested" in this technology, waiting for others to take the plunge and see if it bears fruit. Due to the lack of standards in relation to the technology and uncertainties about the return on investment (ROI), organizations usually take the wait-and-see approach in taking a decision to adopt it (Reyes, 2007).

It has been mentioned that implementing RFID brings about lot of potential benefits. In order to convert these potential benefits of RFID into positive ROI, it is very important for the organization using it to pay attention to the pitfalls of RFID's implementation.

A lack of worldwide standards for RFID tags, the security of the data stored in the RFID tags, as well as the costs and risks of the early implementation of RFID technology comprise the major concerns of managers (Paul, 2007). Somehow, the largest difficulty confronting managers is the huge amount of investment required for the implementation of RFID systems together with the unpredictable payback period and the time needed to break even. The pace of implementing RFID from its introduction to a project's completion is determined by the perceived potential and limitations of the RFID system, as well as the way in which they are managed and exploited. The speed of adoption will then affect the benefits that the organization will receive and the risks to which it will be exposed.

Many RFID implementation and evaluation frameworks for various industries have been suggested (Soylemezoglu, 2006; Reyes and Jaska, 2007; Ngai et al., 2010). Kim and Garrison (2010) have introduced the key organizational characteristics that drive the evaluation of RFID, whereas Angeles (2009) has investigated the ability of the components of IT infrastructure integration and supply chain process integration in predicting RFID deployment outcomes. With the process of technological innovation, Matta et al. (2012) examined the key antecedents that may influence the initiation, experimentation and implementation stages of a RFID system. However, a systematic framework that helps managers to understand how RFID should be implemented along with the activities and issues that need to be considered in implementing RFID solutions in specific business and operational settings is yet to be developed. Without such a framework, managers will need to spend a lot of time looking for useful references.

Managers find it difficult to make decisions on the implementation of RFID systems due to a lack of knowledge about RFID technology. Unfamiliarity with the system leads to myth creation and an erroneous perception about the benefits that an RFID system can produce. In such a situation, managers will have improper perceptions and expectations of RFID technology. They are curious about when the right time to adopt an RFID solution might be. Although there are lots of successful cases, they remain doubtful about the benefits and the ROI of such costly investments. This is particularly true in relation to the high initial investment costs for realizing the potential benefits, in which there is no concrete resource commitment to pilot studies or implementation (Brown and Russell, 2007). As discussed in Leimeister et al. (2009), many IT decision-makers have heard about and taken an interest in RFID, but are still far from considering implementation. They need clear guidance that will help them to analyse and identify the benefits and pitfalls of any system's deployment.

This paper presents a methodology to address the above mentioned issues in deciding RFID's implementation. Suggestions on how and when to implement an RFID system that will bring benefits to the whole company will be offered. The critical success factors for RFID's implementation will also be discussed.

2. Current Expectations Towards RFID Deployment

Figures 1 and 2 show the major reasons against deploying an RFID system and those in favour of deploying one in an organization, respectively (Osyk et al., 2012).

A common expectation as to RFID deployment is the enhanced visibility of the supply chain (Angeles, 2005). Improved efficiency in item-tracking and reduced item location uncertainty can result in cost reductions after the deployment of RFID systems (Lee et al., 2008). The real-time exchange of data provides logistics networks with a better and more accurate information flow (Saygin et al., 2007). Information on locations, inventory levels and demands can be easily collected from a more transparent network - this facilitates managers' decision-making and it can assist the implementation of new business processes (Saygin et al., 2007). When a rewriteable tag is attached to an object, transactional data stored in the tag can be updated as it moves along the supply chain (Mills-Harris et al., 2006). By enhancing the visibility of the supply chain, stock uncertainty can be reduced and operational efficiency can be improved, thereby achieving the overall goal of cost reduction upon successful implementation of the system (Lee et al., 2008).

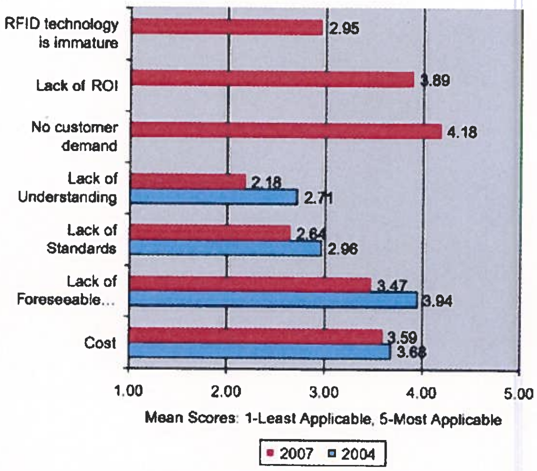


Figure 1. Reasons for not implementing RFID (Osyk et al., 2012)

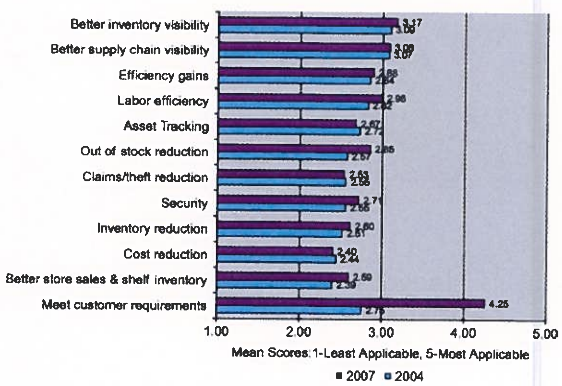


Figure 2. Reasons for deploying RFID (Osyk et al., 2012)

Another expectation is the more effective use of labour. After the implementation of an RFID system, an organization will expect that all the repetitive tasks will be performed by the system, releasing labour to do other tasks that can be more knowledge-based (Harvey et al., 1997; Mills-Harris et al., 2006). Since all data entries are instantaneous and operator-free, supply chain transactions that used to be labour-intensive can be automated to increase the efficiency of the whole supply chain. This can also help to automate workflow and avoid the business's interruption in the manufacturing process (Chowdhury et al., 2008). Thus, RFID systems are a breakthrough for business in relation to automation (Cheong and Kim, 2005). With information being more readily available, the picking and put-away accuracy of warehouse operators can be enhanced (Bhuptani and Moradpour, 2005).

Since RFID technology can help to provide information about the object being tagged, organizations could make use of this to minimize inventories by deciding upon the right time to place the right product at the right place so as to maximize sales and profits (Chowdhury et al., 2008). As businesses could obtain more accurate and timely information about their products, the product inventory across the supply chain can be managed better, such as by reducing the inventory turns and the risk of stock-out (Cheong and Kim, 2005; Doerr et al., 2006).

It is also claimed that RFID systems can produce higher quality and more information (Bergeron et al., 2005). Information is collected automatically without human intervention. Thus, the gathered information is more precise and free of human errors that often exist in data collected manually. Since data entry is no longer needed and labour is saved, the automation could result in the reduced cost of data collection, improved data quality and providing for the easier manipulation of information (Joglekar and Rosenthal, 2005). Moreover, information is validated and transmitted to other operational systems without delay, thereby enhancing the timeliness of information that might facilitate contact with customers (Lee et al., 2008). With higher quality information that is easily accessible, RFID systems can assist in various management tasks, such as event management, business action management, task management and scheduling, exception handling, interface management, authentication and authorization (Chen, 2005). It is also thought that it can help organizations to learn more about customer behaviour (Wang et al., 2006).

The other expected benefits of RFID technology are the reduced risk of counterfeiting (Lee et al., 2008) and theft prevention (Chowdhury et al., 2008). These benefits can be realized because of the technology's ability to authenticate and track products. This can lead to increased customer satisfaction and loyalty, contributing to revenue growth and increased profits, as the products are more reliable and customers will receive better service (Heskett et al., 1994; Lee et al., 2008). As RFID systems will also enable the identification of items, it could enhance the security of organizations (Bhuptani and Moradpour, 2005) and might improve patient safety in healthcare services (Ting et al., 2011).

3. Methods

Figure 3 depicts the research methodology of this study. A search of English language articles published in major electronic databases from Jan 1, 2000, to Dec 31, 2010, was conducted. As the research on this topic is relatively recent, the scope of this investigation is limited to the timeframe 2000 to 2010; nonetheless, this 10-year period is deemed to be representative of the application of RFID. The six international electronic databases listed below were interrogated:

1. Science Direct;
2. IEEE Xplore;
3. InformaworldTM;
4. Emerald;
5. Inderscience;
6. ABI/INFORM

The search was conducted using the keywords "RFID", "RFID implementation", and "RFID application". The authors and ten other RFID experts reviewed each article collected from the search to determine whether it was related to the scope of this study. The review exercise was conducted by the authors and experts individually in the first instance and then collectively. The search focused upon articles that discuss the common and critical procedures of RFID implementation (e.g., the steps for implementing RFID in a medical organization, from the point of a project's initiation to its end). For this reason, numerous articles that discuss the integration of RFID with other technologies (such as barcodes and sensors) were considered to be outside the scope of this review, and they were eliminated from further consideration. The shortlisted articles were classified into various critical procedures on the basis of their contents. Differences in the classifications made by members of the review team were discussed collectively until an agreement was reached. The essential steps of different deployment methods and the critical success factors for implementing RFID solutions were identified from the results of this classification exercise.

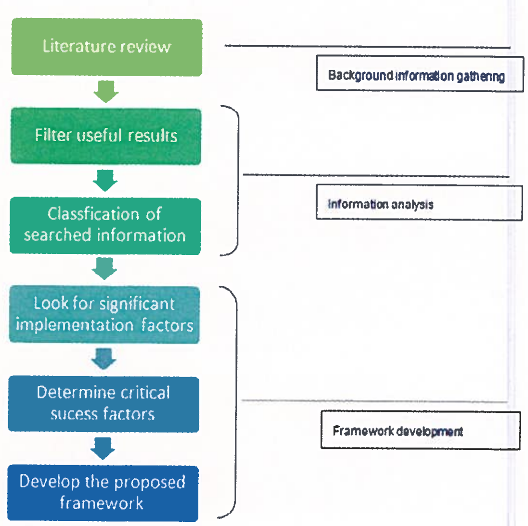


Figure 3. Research Methodology

4. Proposed Implementation Framework

Table 1 summarizes the proposed 6-step generic framework for the implementation of an RFID system. The implementation of RFID solutions is a complex task that involves both technical and human factors. The proposed framework is based upon a synthesis of existing frameworks published in the literature that will make it applicable to most industrial settings.

Steps	Description	Reference(s)
Project Scoping	• Understand the potential and limitations of RFID technology • Define the project objectives	Angeles (2005); Vijayaraman and Osyk (2006); Wu et al. (2006); Attaran (2007); Reyes and Jaska (2007); Sellitto et al. (2007); Ngai et al. (2010)
Analysis of the Existing System	• Collect information • Information analysis	Soylemezoglu et al. (2006); Attaran (2007); Jaska (2007); Pålsson (2007); Huang and Tang (2008); Hellström (2009); Kim and Garrison (2010); Ngai et al. (2010)
System Design	• Requirement analysis • Hardware/ software selection • Develop a new process	Soylemezoglu et al. (2006); Reyes and Jaska (2007); Huang and Tang (2008); Hellström (2009); Ngai et al. (2010)
Prototype Testing	• Debug • System Adaptation	Reyes and Jaska (2007); Soylemezoglu et al. (2006); Ngai et al. (2010)
Implementation	• System deployment • Training	Soylemezoglu et al. (2006); Spekman and Sweeney II (2006); Attaran (2007); Reyes and Jaska (2007); Ngai et al. (2010)
Continuous Improvement	• Monitoring • Collect feedback from users	Ngai et al. (2010)

Table 1. Proposed Framework for RFID Implementation

4.1 Step 1: Project Scoping

The typical tasks in this step are to understand the potential and the limitations of RFID systems and to define a given project's objectives. These are critical tasks that need to be completed during the planning stage. Understanding the potential and limitations of an RFID system can help to avoid unrealistic expectations towards RFID's deployment. Defining the project objectives can give a clear direction to the implementation team.

4.1.1 *Understand the Potential and the Limitations of RFID Technology*

RFID technology will bring a lot of benefits when it is successfully implemented, but this does not mean that it is a perfect solution that does not have limitations. Organizations should understand what RFID both can and cannot do before the making the decision to implement a system. As discussed by Hardgrave and Miller (2006), organizations tend to create unrealistic expectations and have incorrect perceptions towards the system. Misunderstandings and false expectations about the technology could lead to the formulation of unachievable goals or else the premature rejection of a project. Grasping the technology's limitations would also allow managers to reflect upon the suitability of implementing the solution in their own organizations. For example, data accuracy is one of the common false expectations encountered by the public. Indeed, RFID cannot work properly with metals and liquids; thus, in the case on placing RFID tags directly on a metal surface (such as a truck) for vehicle in under the container terminal environment, managers need to be aware of the risk of getting poor readability results, as metal will reflect radio waves (Ting et al., 2012). To avoid poor reading performance, managers are required to take into consideration the limitations of RFID; they will ultimately adjust the tag's location by placing it away from metal surfaces (i.e., affixing the tag on a windshield). As a result, a better understanding of the technology could assist in formulating a clearer goal and gaining most of the potential benefits.

4.1.2 *Define the Project Objectives*

After gaining a clear picture about what RFID technology can bring to an organization, it should attempt to identify the areas that need to be improved in the current process. It is essential for the organization to know the reasons and expected outcomes of the implementation. A clear scope and objectives in implementing the system will guide the organization towards a productive programme (Ngai et al., 2010). Establishing the scope of the project could assist decision makers to develop well-defined boundaries for the implementation of the project. The project objectives to be established must be achievable and sensible, and sometimes short-term goals may also be set at this stage. Take a wine cellar as an example - the objectives of its RFID system are identified as functions with regard to: (i) the prevention of counterfeiting, (ii) avoiding the mixing of customer's wines, (iii) enhancing the stock-take accuracy and process, (iv) avoiding theft in shops, and (v) mapping wine products with location information automatically (RFID News, 2011; Swedberg, 2012). Concerning the scope of the work for these objectives, wine cellar managers should divide the project into different phases (i.e., objectives (ii), (iii) and (v) are achieved in first phase, whereas objectives (i) and (iv) are achieved in the second phase). In this way, achievable goals and objectives will encourage an organization to improve the system continuously and to gain the most benefits from the project. Furthermore, these objectives should also align with the organization's strategies. To earn the support of all stakeholders, the project objectives should be communicated across the whole organization.

The organization should focus on those RFID solutions that will have a significant impact upon the business performance of the company. Setting long-term goals and major milestones is also important. Members of the project team will have a sense of fulfilment when the milestones are met, one by one.

4.2 *Step 2: Analysis of the Existing System*

During this step, various methods are used to collect information on the existing system which is analysed to evaluate the current system. This helps to identify the vital procedures in the process – i.e., the vital inputs to the subsequent redesign stage.

4.2.1 *Collect information*

The details of the current process will be collected by various methods, such as conducting interviews with the key individuals and front-line staff who use the present system, collecting comments from stakeholders, and eliciting experts' opinions. Observations should also be made through site visits in order to understand the physical flow of items that may be tagged in the new process. Information about the current process that needs to be collected would include data on the operation, equipment, related documents and forms, as well as the activities performed in the process. It is stressed that only information relevant to the RFID implementation process should be collected. Making reference to the project's scope will help to achieve this. Apart from the physical flow of the process, the information flow of the process should also be studied. It is important to collect information about the daily decision-making processes. For example, Sonoco - a global manufacturer of packaging products - invested in a RFID system upon their customers' request (RFID News, 2008). Sonoco's customers requested better visibility into the company's supply chain. Sonoco and its customers were able to improve inventory management and track their goods in real-time. The company tagged the goods when they were manufactured. Thus, the traceability of product quality could be improved, as the source of defects could be precisely identified. This could help Sonoco to reduce the frequency of lost shipments and reduce waste. More importantly, it increases customers' satisfaction. This example illustrates the implications of collecting information from different kinds of people.

4.2.2 Information Analysis

After collecting information about the operation process, the analysis and evaluation of the current process will follow. This could be performed by using the diagramming techniques and tools that have been agreed upon by the key individuals who are currently using the system. By examining the current process with the aid of workflow diagrams, areas for improvement can be identified. When multiple candidates for improvement exist, they should be prioritized according to their impact upon the organization's business performance. Those candidates that will bring about more potential benefits to the organization will be given higher priority in implementation. For example, in the case of the wine cellar again, the stock-take accuracy and process can be significantly improved, with a 60% time reduction (when compared with manual operation). Therefore, managers will decide to develop the system with this objective first, as it is the most direct and worthwhile benefits of RFID implementation.

4.3 Step 3: System Design

After analysing the current situation and the operation process, the organization should design a new process that is most suitable to matching its needs and requirements. The system design stage should include requirement analysis, hardware and software selection, and the development of the new process.

4.3.1 Requirement Analysis

This task is the follow-up step of information analysis. Upon the completion of information analysis, the major problems and potential steps that need to be modified are identified. The purpose of performing requirement analysis is to thoroughly understand the ways in which RFID technology can address the problems identified. Sometimes, this may suggest a complete redesign of the process in order to optimize the process flow. However, a complete redesign is not always necessary; very often, minor modifications that meet the system's requirements can remarkably improve the process flow. For example, in the case of warehouse operations, the company has developed its own Enterprise Resources Planning (ERP) system to enhance day-to-day management (Ting and Tsang, 2012); however, the company would like to adopt RFID technology in its forklift for automating the product flow within the warehouse (e.g., from Location A in G/F to Location C in 1/F). Therefore, it is suggested that the operator drive slowly when passing through the RFID gate door for the better capture of RFID signals; this is constitutes a minor change of operation. However, according to the findings of the detailed analysis of twenty-four businesses conducted by the Grocery Manufacturers of America (GMA), one of the major issues of RFID deployment lies in defining the process that requires changes (Roberti, 2004). Such an analysis can help to pin-point the specific supply chain management issues that need to be addressed.

4.3.2 Hardware/Software Selection

The performance of an RFID system is easily influenced by the operating environment. Therefore, the careful selection and testing of hardware and software is crucial to the successful implementation of the system. An RFID system comprises hardware items such as RFID tags, antenna and readers; these hardware items should be selected by taking into consideration the environmental factors which are identified in the requirement analysis step. One of the factors to be considered is the material of the tagged object, because it will have a significant effect on the performance of the RFID system. For example, metal absorbs and degrades radio frequency signals; to avoid such problems, the RFID tag attached to such objects should be coated with an insulator (Ngai, et al., 2010). In developing the software, one should study the radio frequency signals that might exist in the environment in which the system is going to be deployed; such signals may have the potential to interfere with the RFID system. Therefore, a suitable radio frequency should be selected to avoid the interference problem. The organization should design the way in which the readers are connected to the network and the software architecture, including the RFID middleware and the application level software.

The selection of hardware and software also involves the process of testing them; this is to understand the characteristics of each element of hardware and software and to decide which option is more suitable for the current environment. The testing of the hardware would give decision-makers a clearer picture of how the hardware and software items function in an integrated system, as well as providing data for measuring the reliability of the system. One should also select the appropriate means of mounting the antenna and the orientation of the tags so as to optimize the readability of the tags. The proper selection of the software could also assist in meeting the data requirements - some software might perform better in handling a special kind of data and some might not; therefore, an organization should select the software that meets its requirements.

4.3.3 Develop the New Process

After information and requirement analysis, the organization should be familiar with the process's needs and the improvements that need to be made. At this stage, the organization should be able to modify the existing process or else develop a brand new one to enhance its performance and meet any project objectives. The new process should be designed based upon the knowledge of the current process and any potential changes so as to avoid surprises when the system is implemented.

Apart from designing the hardware and software systems, the decision-making and operation processes may also need to be redesigned. The RFID system's implementation may involve the simplification or elimination of existing procedures. For example, the stock in and out process can be automated by capturing the RFID signals when the RFID-tagged objects passed through the reading device (e.g., a RFID gate way). As a result, one should ensure that the decision-making process and the operation process are aligned with the new procedures to be implemented. It could avoid tag collisions and the duplication of efforts, thereby reducing confusions in the early stage of system implementation.

4.4 Step 4: Prototype Testing

Before the actual implementation of the RFID system, it is very important to conduct demo testing so as to ensure that the workflow developed together with the RFID technology will work and that it is ready for deployment. This will also help users to understand the systems. On the successful completion of prototype testing, the implementation of the system in the actual environment can start. Prototype testing may be conducted in the laboratory or in the actual environment. Conducting on-site testing is more reliable, because all the environmental factors can be considered and tested. When it is impossible to conduct the test in the actual environment, demo testing in the laboratory could be an alternative. The simulated environment should be as similar to the actual environment as possible, to ensure that the test results will be useful. Apart from debugging the technical system and eliminating the mistakes in the analyses, this step also includes collecting feedback from users after the demo testing. This is designed as such in order to elicit comments on the various user interfaces and in order to fine tune their design.

4.4.1 Debug

The prototype testing covers both software and hardware tests. Thus, bugs and the collision of systems may be detected. Technical staff should be involved so as to support the testing and in order to resolve (debug) any technical problems detected in the test. Tests under different foreseeable scenarios are conducted to assess the flexibility and capability of the system. For example, proof-of-concept testing on several scenarios is conducted to simulate all the situations to be encountered by the RFID system. As with the case of vehicle tracking, tests on various speed levels (e.g., normal speeds, fast speeds, and over the limit speeds) should be taken into consideration to capture the reading performance of different levels so as to see how to debug the system and help it fit with all situations (Ting et al., 2012).

4.4.2 System Adaptation

The adaptation of processes may be necessary to ensure that the RFID system will deliver the expected performance results. Problems found during the demo testing should be recorded and reviewed so as to fine-tune the system and resolve these problems. Consider the case of Mississippi Blood Services, a non-profit organization that collects more than 60,000 units of blood annually. It faced problems in managing the inventory of blood products that have a short shelf life (Greengard, 2006). The organization would like to know if RFID would help to solve this problem. After consulting some experts, the organization conducted a pilot test on 1,000 units of blood products. The process being tested involved transferring specific blood products from the tray to the cooler. Problems of interference caused by the metal trays and other electronic devices in the operating environment are yet to be addressed. However, after the pilot test, it was found that the high water contents of the blood products together with the metal tray exacerbated the readability problem presented to the auto-identification system. This case shows that, without the actual on-site testing of the system, it would be difficult to identify the full extent of potential problems in a given environment. Therefore, prototype testing is an essential step of any RFID implementation project.

4.5 Step 5: Implementation

Implementation follows the adaptation of the system; it is more than just the installation and commissioning of hardware and software systems. Typically, it also involves change management, training and system deployment. All if the tasks in the implementation step are vital, as they will affect the success of the implementation. Sometimes, implementation might not involve a clean changeover to the new system; the new RFID system may run side-by-side with the original system, and the latter will phase out only when the performance of the new system is assured.

4.5.1 System Deployment

System deployment will include installation and commissioning of hardware and software systems, as well as developing the new procedures. During the process of installing hardware items, care must be given to the placement of the antenna as well as that of the tag on the object to be tracked, because such factors will affect the readability of the tags. The placement of hardware items should have been tested earlier - what needs to be done at this stage is to install these items according to the optimal design determined during the earlier test. Software configuration is the other issue that goes hand-in-hand with hardware installation.

Software configuration involves middleware configuration and deployment. Middleware is used to control the readers' ability to read from and write to the tags; it also filters the tags' data and forwards useful information to other functional applications. It is important to configure the middleware properly to achieve the seamless integration of the current applications and database with the new RFID system. For example, a data interface layer for an application may need to be developed - the database may need to be modified in order to make it possible to accept data collected from the new system. A security system should be set up at this stage as well. RFID applications can be high risk systems when there is no control to protect their security. Therefore, at this stage, it is important to establish control measures for assuring the security of the system, such as formulation and enforcement of access controls that apply to data collected by the system.

In addition, policies and procedures that support the implementation of the new system would be established at this stage. Current policies and procedures may need to be modified to facilitate the adoption of the new system. Sometimes, management practices may need to be changed. However, people tend to resist change because familiar practices will become obsolete - there is anxiety about unknown factors such as the impact of the new system. Management should be sensitive to those problems that threaten the successful implementation of the new system. Myths should be broken before they become perceived truths. New management practices that accompany the implementation of the RFID system may involve new divisions of labour or coordination and communication with multiple stakeholders.

4.5.2 Training

Users need to receive training on technical operations of the system and basic information about the system. The training should include courses that introduce the system and basic knowledge of its operation and shatter the myths about it.

It is also essential to provide users with practical training so that they will have hands-on experience in using the new system and the changed process (Ting, et al., 2011). This will also provide users with opportunities to understand the guidelines and precautions as to system usage. At the same time, the organization should listen to users' comments on the changes, as well as their acceptance of these changes. This will reduce conflicts between users and managers and speed up implementation, thereby turning successful deployment into a reality.

4.6 Step 6: Continuous Improvement

The last step for implementation is continuous improvement. Since no system is perfect upon its introduction, there is always room for improvement. The organization should continuously evaluate the system's performance and compare it with the preset objectives, enhance the system with emergent technologies, or else adapt it to match the changing needs of the market. This step includes the tasks of system monitoring and the collection of user feedback.

4.6.1 Monitoring

After system deployment, the performance of the RFID solution needs to be closely monitored - especially in the early stage of implementation - so that the project team can quickly respond to the problems encountered. The actual performance of the system should be compared with the targets set during the system design stage. For example, a multi-frequency tag readability test was conducted at United Airline's ticket counter in Tokyo (O'Connor, 2005). In that test, an average of fifteen pieces of dummy baggage per day were tagged with randomly generated numbers that simulated passenger names. The dummy bags would then be dispatched to flights for different destinations via different routes and then sent back to Tokyo flights in the reverse direction. The readability of the tags on these bags was recorded and the results were analysed to monitor the performance of the baggage tagging system.

4.6.2 Collecting Feedback from Users

Feedback from the different stakeholders of the RFID system should be collected and analysed so as to spot potential problems and issues in the newly deployed system. Both technical and operational issues should be covered when comments from users are elicited through interviews.

Apart from monitoring system performance and collecting user feedback, the project team should also keep track of the development of new technology and be sensitive to potential any problems revealed by the findings of the interviews.

4.7 Implementation Considerations

A systematic and holistic framework for the implementation of RFID systems has been proposed above. Specific issues that need to be considered before and during the implementation of RFID have also been discussed briefly and they are further elaborated upon below.

4.7.1 Scoping

Fontanella (2004) states that there are four types of RFID implementation, namely discrete processes, intra-company processes, inter-company processes and information synchronization. They represent different scales of implementation scenarios. Some might only involve the entities of a company; others may need to create links across the whole supply chain. Before launching the implementation project, the organization should decide upon the boundaries of it so that appropriate objectives and performance targets can be established for the project. For any type of RFID project, consultation and assistance from internal or external RFID experts will be crucial.

4.7.2 Privacy and Security

One of the factors that needs to be considered is privacy, while the security issues associated with the deployment of RFID technology are another important factor to be considered (Stuart and Liu, 2006). Concern has been raised about access rights to information and the related privacy problems across the supply chain. Unauthorized users may intercept communications between the tags and RFID readers in order to capture private or sensitive information that is not supposed to be made available to a third party (Chowdhury, et al., 2008). For example, there is concern about tagging items or patients who do not wish to share their personal information without their prior consent. There are a number of ways to address these problems, including "kill tags", password locks, a cage approach and active-jamming (Boulard, 2005). This is a very important issue that organizations must address so as to ensure that the information written on the tags are securely protected.

4.7.3 Lack of Standards

Unlike barcodes, RFID technology is still evolving. Thus, the standards related to the technology are not yet well-developed, presenting a major obstacle to the implementation of the technology. According to Saygin et al. (2007), there is no standard related to RFID technology that meets the needs of all users. The development of standards has progressed through the formation of the Electronic Product Code (EPC) network, while EPC's operation itself must be backed up by the International Organization of Standards (ISO) to develop a widely accepted standard. Since common standards for the radio frequency and other technical aspects are yet to emerge, it is difficult to develop RFID solutions that will cover the whole supply chain. People tend to stick to the existing barcode system and refuse to get involved in deploying RFID systems. Therefore, the lack of clear standards and policies for RFID technology is an intangible barrier to the deployment of such systems (Floerkemeier and Lampe, 2004).

4.7.4 Interference Issues

RFID technology uses radio frequencies to transmit data. This creates interference problems in a number of environments. It is common to encounter objects and equipment that are covered with metal or have liquid contents in a supply chain. These items will adversely affect the readability performance of the RFID tags; they will disrupt the RFID signals generated, making it challenging to track the tagged objects. Electronic devices will also affect the read rate of RFID signals (Greengard, 2006). Therefore, RFID readers are not always 100% successful in reading all the tagged items (Lee, 2005). Objects with metal components, glass fibres or nylon may also create noise in the RFID signal, creating an environment that is unfriendly to RF. It is challenging to implement RFID systems in an RF-unfriendly environment, even with precise prototype testing, because the interference problem cannot be completely eliminated in such an environment.

4.7.5 Cost Control

Deploying an RFID system to enhance the performance of a process involves significant investment. This constitutes the common roadblock to the implementation of the technology (Paul, 2007). Investment includes the costs of tagging objects, acquiring and installing hardware devices and application software, system integration, staff training and other expenses, all of which must be taken into consideration before making the decision to implement the technology across the system. During the initial stage of deployment, the cost of infrastructure is high because, given the current state of technology, RFID tags are much more expensive than barcodes and the testing of the new system requires a considerable amount of time. Thus, before the adoption of any new technology, the organization should determine the ROI. The ROI of deploying RFID technology is often slow - being aware of the slow return rate will help organizations to be realistic in estimating the benefits of deploying such systems. For example, a book store that has implemented RFID system will result in savings from faster and more accurate stock receiving operations and better inventory management (Bansode and Desale, 2009). The system also reduced the out-of-stock rate and improved re-ordering effectiveness, producing the potential for increasing sales by five percent.

4.7.6 Motivation of Adoption

The organization should have the appropriate motivation and expectations of RFID systems. As RFID technology is still evolving, it is not as powerful as commonly perceived; decision-makers should gain more knowledge about RFID technology so that they will not have excessive expectations about it. It is advisable to consult the experts to acquire knowledge about the technical issues. If the organization wishes to apply the technology to streamline an inter-company process or to achieve data synchronization, it should note that many supply chain players may be reluctant to invest in RFID (Chowdhury et al., 2008). Moreover, front-line users of the system usually tend to resist changing their practices when necessitated by the deployment of new technology. This is a critical issue because the success of the implementation will depend upon acceptance of users. The organization should make efforts to eliminate users' concerns and earn their support. It is important not to have unrealistic expectations, because in the end it will lead to disappointment.

5. Critical Success Factors for the Implementation of RFID Systems

The critical success factors for a system's implementation as gleaned from the literature are discussed in this section. These factors are classified according to technological, managerial and social dimensions (Table 2). In addition, each of these factors is associated with a specific step in the implementation framework (Table 3).

Classification	Critical success factors	Reference(s)
Technological Dimension	• Selection of appropriate hardware and software	Angeles (2005); Soylemezoglu et al. (2006); Huang and Tang (2008); Yue et al. (2008); Kwok et al. (2010)
	• Effective testing	Spekman and Sweeney II (2006); Soylemezoglu (2006); Reyes and Jaska (2007); Ngai et al. (2010)
	• Sufficient technical support	Attaran (2007)
	• Clear process, data routing	Yue et al. (2008)
	• Clear performance measures	Kwok et al. (2010)
Managerial Dimension	• Clear vision	Zailani et al. (2010)
	• Good project management skills	Wang et al. (2006); Ngai et al. (2010)
	• Good risk management skills	Luo et al. (2007); Lim and Koh (2009)
Social Dimension	• Teamwork	Ngai et al. (2010)
	• Effective communication	Wang et al. (2006); Ngai et al. (2007); Wang et al. (2010)

Table 2. Classification of Critical Success Factors

5.1 Technological Dimension

Since RFID technology is still evolving, technical knowledge is vital for successful system implementation.

5.1.1 Selection of appropriate hardware and software

To succeed in deploying RFID systems, the organization needs to select the appropriate hardware and software that it purchases or develops. Selecting suitable hardware devices for the system will reduce the chance of system collision and interference (Ngai et al., 2010). Various types of RFID hardware and software are available for selection, but each type may only be suitable for specific applications. Therefore, the careful evaluation of these items must be made. In many circumstances, price does not reflect suitability (Ting et al., 2011). In selecting the hardware and software to acquire, and apart from the product itself, the vendor should also be evaluated, taking into consideration its attitude towards partnering with customers. Sometimes, it may be more appropriate for the organization to develop its own application software that will be most suitable and fit for use.

Steps	Critical success factors
Project scoping	Clear vision Good project management skills
Analysis of the existing system	Teamwork Support across the organization
System design	Selection of appropriate hardware and software Clear process, data routing
Prototype testing	Effective testing Sufficient technical support
Implementation	Good risk management skills Suitable training
Continuous improvement	Clear performance measures Effective communication

Table 3. Corresponding Critical Success Factors in Each Step

5.1.2 Effective Testing

Since prototype testing is used to assess the availability performance of the system, it is important that effective and reliable testing be conducted so as to expose potential problems in the new process (Saygin et al., 2007). The project team should review and modify, if necessary, the system design in light of the exposed problems.

5.1.3 Sufficient technical support

Since RFID is an evolving technology, it would be very helpful if an expert or technician in that field could support the deployment of the system (Ngai et al., 2010). Organizations typically encounter many technical problems at the early stage of implementation and misunderstand the technology (Smart, 2004) Adequate support from technical staff will effectively assist the whole implementation process, especially during the step of prototype testing. Technical support staff can give objective opinions and comments about the testing results. They can also give constructive advice on the adjustments that need to be made. Inadequate technical support will lead to faults in system design and unrealistic expectations as to performance results. This could also drive up implementation costs and times, as debugging and mistake detection are performed by inexperienced staff.

5.1.4 Clear Process, Data Routing

A clear process of the RFID system and the data routes should be mapped, as such a system is often deployed to deal with complex tasks and complicated data transfer routes. Well-defined process and data routes will help technical staff to understand and build the system. Furthermore, such information will also facilitate users and operators in appreciating the design of the system. The process and information data routes can be represented by using graphical tools; visualizing the data routes could make profound impressions upon users, thereby enhancing the effectiveness of the process (Fuhrer, et al., 2006). Clear process and data routing is of critical importance during the system design stage because this could enhance the development of the new system so that it will be both efficient and effective. During the system design stage, when processes are developed and designed, a well-defined process flow could also facilitate the subsequent implementation process, as it will make it unnecessary to give a lot of explanations during prototype-testing and the actual implementation of the system.

5.1.5 Clear Performance Measures

During the continuous improvement stage, the organization should measure the achieved performance and compare it with the target to evaluate the effectiveness of the new solution. In order to track performance of the RFID system, it is critical to develop well-defined performance indicators for the system so that users and the project team can closely monitor the progress made and work hard to meet the target. Performance targets must be concrete and specific. For example, the performance target for the read rate of the RFID tags should be an exact percentage - such as 95% - rather than "most of the tags should be read".

5.2 Managerial Dimension

Apart from technical contents, good management will also contribute to success of RFID system implementation. Management plays an important role in coordinating the whole implementation process. The critical success factors in the managerial dimension are discussed in the following section.

5.2.1 Clear vision

As an RFID system could be implemented in a variety of areas in an organization, complex objectives and visions may give rise to confusion. A clear vision can keep a project in focus in order to align with the organization's business goals. This ensures that proper priority will be set while the RFID system is being developed. Resources will be allocated according to the importance of the area, and only those areas that have a leverage effect on the implementation results will be given the required resources (Rao, 2004). A clear vision will also help to set the appropriate project scope. With a clear focus on the aim of a deployment, the pre-set goals can be achieved more easily. This will make the whole development process more focused. Since money, labour and time are limited in a new technology development project, a clear vision will provide managers with guidelines for making informed decisions on the utilization of limited resources that will produce optimal benefits for the project.

5.2.2 Good Project Management Skills

RFID implementation typically constitutes a huge project, involving a lot of stakeholders. Introducing it into a business also involves huge amounts of money. Good project management skills will streamline integration across the stakeholders and achieve better project cost control. This ensures that the deployment project will be completed within budget and on schedule. The project team should concentrate on results, keep track of the progress made, and review the schedules and budget periodically. To manage a large project, the schedule and milestones of the deployment should be set clearly before implementation so as to provide users, as well as members of the operation and project teams, with a comprehensive roadmap to the project (Saygin, 2007). As such, these stakeholders will have realistic expectations about the timing when the benefits will be realized. A clear schedule will also ensure that adequate levels of appropriate resources are available before the required action takes place.

5.2.3 Good Risk Management Skills

As the standards of RFID technology are not yet established, a certain degree of risk exists when the technology is deployed in an organization. The project team should have good risk management skills to deal with various types of problems and issues that may arise during the implementation process. Contingency plans should be developed and tested in advance so that unforeseen incidents that may emerge can be addressed promptly and efficiently (Bhattacharya et al., 2008).

5.3 Social Dimension

Apart from technological and managerial issues, the organization should also be sensitive to the social issues of a change initiative, such as the introduction of RFID technology. The deployment of RFID systems involves a lot of individuals and the behaviour of these individuals will have various degrees of impact upon the performance of an RFID deployment project.

5.3.1 Teamwork

During the process of developing the RFID system, the success of the project is determined to a significant extent by the level of teamwork within the whole organization. During the analysis stage, data on the current system needs to be collected; members of frontline staff should be interviewed or onsite observations be conducted.

These activities will require the support of the whole organization in order to collect appropriate and accurate information. Moreover, as the implementation of RFID systems involves many individuals, they must share the vision and objectives of the project so that the whole process will be finished effectively. "Islands of RFID applications" developed within departments, and a lack of integration and cooperation inside the company will lead to the waste of resources (Saygin, 2007).

5.3.2 Effective Communication

As a lot of people are involved in the development process, communication is very important for information transfers within an organization. During the stage of continuous improvement, feedback and comments are given by the frontline users, and their opinions should be effectively communicated to the management level so that proper adjustments are made in a responsive manner (Ngai et al., 2010). This could improve the performance of the RFID system and might increase the effectiveness of it. To deal with the fears of staff towards the implementation, it requires the coordination of both stakeholders and users. To resolve fears within the operation team, communication with all the people concerned is substantial and at the same time supporting evidence should be provided to prove its truthfulness.

5.3.3 Suitable Training

As a new technology, implementing adequate and suitable training could provide front-line staff with precise knowledge about the system and break the myths discussed among them. Appropriate training can not only provide theoretical knowledge, but so too should practical things be taught - this could reduce the opposition towards the transition time of the early deployment stage. The newly implemented technology could be rather daunting and difficult; training should be provided to explain the benefits of the system and the changes involved. To gain the buy-in of the users and the operation team, a demonstration of the system and an explanation of its benefits and the changes it would bring about should be done during the training (Ngai et al., 2010).

5.3.4 Support Across the Organization

Gaining support across the organization could ensure that the system is operating in the desired way - if there are staff who do not support the development of the system, they may refuse to use it and stick to the original one. By launching a reward scheme for improvements in process or productivity due to the implementation of the system, the upper management can show their support and confidence towards the implementation. Management support could also convince any lower level staff or users that the RFID technology could help the organization. Without that buy-in from the management team, it will be difficult to carry out the project within the organization (Ngai et al., 2010). An appropriate culture within an organization could hasten the implementation process, since a good organizational culture will increase staff loyalty and they will be more willing to share their opinions towards the newly developed system. Good staff morale will also increase the level of acceptance from the staff during the implementation process because they will unintentionally believe that the organization only aims at release their burdens from work and doing this kind of automation will not affect their employment.

6. Validation of the Proposed Framework

6.1 Evaluation Methods

In order to validate the usefulness of the proposed implementation methodology, a questionnaire was developed in the spring of 2011. It consisted of the significant procedures and critical elements of success (identified by the authors and RFID experts) and was administrated to a number of RFID practitioners, including representatives from manufacturing, garments, food, retailing, logistics, library services and healthcare, in order to gather a number of different perspectives. The responses to each of the steps and the criteria are provided on a 5-point Likert scale, ranging from highly insignificant (1) to highly significant (5) (i.e., 1 = highly insignificant, 2 = insignificant, 3 = no strong view, 4 = significant, 5 = highly significant). The questionnaires were distributed to selected respondents by standard mail in mid-June. A pre-paid, pre-addressed envelope was included to facilitate the return of the completed questionnaires. The anonymity of the respondents was assured by using a unique control number to which only the author had access. The recipients of the questionnaires who did not respond after two weeks were contacted by a follow-up letter. The data collected from the returned questionnaires was analysed using SPSS software.

6.2 Participants

The evaluation included 300 participants, ranging from system specialists to presidents of organizations. All of the participants were at the management level or above (in which they were the target group significantly influencing and participating in the RFID implementation). In order to ascertain the validation results, responses from those who had had 1-3 experiences of the implementation RFID systems were considered in the survey. Of 300 questionnaires distributed in the first instance, 201 valid responses (16% were presidents, 17% were vice-presidents, 20% were directors, 21% were managers, 16% were senior architects and 10% were senior systems specialists) were returned. This represented a response rate of 67%.

Regarding the variety of industries involving in the evaluation, the majority of these responses were from logistics (30%), followed by retailing (20%), manufacturing (19%), healthcare (15%), garments (10%), food (3%) and libraries (2%). This was to be expected, given that most of the applications of RFID are in the logistics/supply chains and manufacturing industries.

6.3 Results

The outcome of the evaluation indicated a medium to high level of user satisfaction with the proposed RFID implementation framework. In particular, 70% of the respondents gave a mean score of at least 3.5 on the five-point scale of all the major steps. This indicates that the steps of the proposed framework identified from the literature match with the prevailing reality. Such a satisfactory result validates the view that the steps in the proposed framework are applicable to most industrial settings (when applying RFID in business). Furthermore, the respondents gave high ratings on both the project scoping step and the implementation step, with a mean score of at least 4.1 on the five-point scale. These results highlight that it is important to identify and inform users' of the limitations of the project during the preparation stage. In addition, training is also an important factor in driving successful implementation. With regard to the critical success factors, most of them have mean scores ranging from 3.8 to 3.9; a few of the respondents suggested that a more in-depth discussion on technical issues would help them to understand the implementation better. To confirm that the mean scores of the system evaluation are significantly different from the neutral values of the scale (i.e., 3 = no strong view), a sample t-test using 3 as the test value was conducted. The results showed that the mean values of all the questionnaire items were significantly larger than the neutral values of the scale at a 5% significance level. This suggests that the proposed RFID implementation framework is able to support a system implementation that starts from the preparation stage and ends at the delivery stage (See Tables 4 and 5 for details).

6.4 Limitations of the Study

The methodology employed in this study has a number of limitations. First, this literature review is based on the results of a keyword search of selected international, refereed academic journals. Thus, only publications registered in the selected databases are considered. Second, non-academic publications, such as news and practical reports, are not included in this study. Third, non-English publications are also not taken into account in this study. As a result, the effects of different cultures on the implementation of RFID and sensor integration systems are not studied. Notwithstanding these limitations, the journals covered in this review are highly regarded internationally. The fourth possible limitation is the time period, whereby a 10-year time frame was taken to develop the implementation framework in the study. It is assumed to be representative of the RFID research over the past few years because it is believed that a more recent coverage of the major journals would be more appropriate for this analysis. As such, we believe that the results of this review adequately reflect the recent trend of RFID development and implementation.

Steps	Description	Mean Rating	Standard Deviation
Project Scoping	● Understand the potential and limitations of RFID technology ● Define the project objectives	4.5 4.1	0.5 0.2
Analysis of the Existing System	● Collect information ● Information analysis	3.6 3.9	0.4 0.7
System Design	● Requirements analysis ● Hardware/software selection ● Develop the new process	3.9 4.5 3.8	0.3 0.2 0.3
Prototype Testing	● Debug ● System adaptation	4.0 3.7	0.5 0.2
Implementation	● System deployment ● Training	4.5 4.8	0.3 0.4
Continuous Improvement	● Monitoring ● Collect feedback from users	3.8 4.0	0.5 0.2

Table 4. Mean Values to the Significant RFID Implementation Steps by the Respondents (n = 201)

Classification	Critical success factors	Mean Rating	Standard Deviation
Technological Dimension	● Selection of appropriate hardware and software	3.9	0.3
	● Effective testing	4.1	0.4
	● Sufficient technical support	3.7	0.3
	● Clear process, data routing	3.9	0.2
	● Clear performance measures	3.8	0.4
Managerial Dimension	● Clear vision	3.9	0.5
	● Good project management skills	3.9	0.3
	● Good risk management skills	4.1	0.2
Social Dimension	● Teamwork	3.9	0.5
	● Effective communication	4.1	0.2

Table 5. Mean Values to the Critical Success Factors by the Respondents (n = 201)

7. Conclusions

A comprehensive implementation framework for the management level is presented in this paper. It provides decision-makers with a clear roadmap for the deployment of RFID technology in an organization. This simple, step-by-step approach to system implementation is generally applicable to all industries. It has been noted that many organizations have not considered implementing RFID technology yet. The authors hope that the findings of the study reported in this paper will arouse organizations' interest in considering the introduction of RFID technology. By synthesizing the implementation issues across various industries, the proposed framework gives managers a holistic perspective of the implementation RFID solutions in an organization. This can allow organizations to develop better implementation strategies by considering different methods of deployment. With the proper adaptations to different types of industry, the framework can achieve a better appreciation and execution of any project activities. Apart from presenting the general implementation framework, the discussion on the considerations of implementation also identified potential pitfalls that the project team should be aware of before the implementation of the system. It is important for the organization to consider both the pros and cons of implementation; most implementation approaches only focus on the benefits of deploying the technology while the potential problems are seldom highlighted. The part of this study that discusses project considerations provides decision-makers with a balanced view of the change initiative.

8. Acknowledgment

The authors would like to express their sincere thanks to the Research Committee of The Hong Kong Polytechnic University for providing this research work with financial support.

9. References

[1] Angeles, R., RFID Technologies: Supply-chain Applications and Implementation Issues. *Information System Management. Volume 22, No. 1, pp51-65.* Taylor & Francis. UK (2005).

[2] Angeles, R. Anticipated IT infrastructure and supply chain integration capabilities for RFID and their associated deployment outcomes. *International Journal of Information Management. Volume 29, No. 3, pp219-231.* (2009).

[3] Attaran, M. RFID: An Enabler of Supply Chain Operations. *Supply Chain Management: An International Journal.* Volume 12, No. 4, pp249- 257. Emerald Group Publishing. UK (2007).

[4] Bansode, S.Y., Desale, S.K. Implementation of RFID Technology in University of Pune Library. *Program: Electronic Library and Information Systems,* Volume 43, No. 2, pp202-214. Emerald Group Publishing. UK (2009).

[5] Bergeron, F., Gingras, L. and Hadaya, P. A Framework for Evaluating Strategic Location-based Applications in Business. *Proceedings of the 38th Hawaii International Conference on System Science. pp*1-8. IEEE Computer Society. USA (2005).

[6] Bhattacharya, M., Chu, C.H. and Mullen, T. A Comparative Analysis of RFID Adoption in Retail and Manufacturing Sectors. *IEEE International Conference on RFID, pp*241-249. IEEE Computer Society. USA (2008).

[7] Bhuptani, M. and Moradpour, S. *Field Guide Deploying Radio Frequency Identification Systems.* Upper Saddle River, N.J.: Prentice Hall PTR (2005).

[8] Boulard, G. RFID: Promise or Perils? *State Legislatures Magazine.* pp22-40. The National Conference of State Legislatures. USA (2005).

[9] Brown, I. and Russell, J. Radio frequency identification technology: An exploratory study on adoption in the South African retail sector. *International Journal of Information Management.* Volume 27, No. 4, pp250-265. (2007).

[10] Chen, J. W. A Ubiquitous Information Technology Framework using RFID to Support Students' Learning. *The Fifth IEEE International Conference on Advanced Learning Technologies.* IEEE Computer Society. USA (2005).

[11] Cheong, T. and Kim, Y. RFID Data Management and RFID Information Value Chain Support with RFID Middleware Platform Implementation. *Lecture Notes Computer Science. Volume 3760, pp*557–575. Springer. Germany (2005).

[12] Chowdhury, B. and Khosla, R. RFID-based Real-time Hospital Patient Management System. Proceedings of the 6th IEEE/ACIS International Conference on Computer and Information Science, and International Workshop on e-Activity 2007, July 11-13,2007. IEEE Computer Society. USA (2007).

[13] Chowdhury, B., Chowdhury, M.U. and D'souza, C. Challenges Relating to RFID Implementation within the Electronic Supply Chain Management – A Practical Approach. *Studies in Computational Intelligence.* Volume 149, pp49–59. Springer. Germany (2008).

[14] Doerr, K.H., Gates, W.R., Mutty, J.E. and Caron, C.A Hybrid Approach to the Valuation of RFID/MEMS Technology Applied to Ordnance Inventory. *International Journal of Production Economics. Volume 103, No. 2,* pp726-741. Elsevier. Netherlands (2006).

[15] Fanberg, H. The RFID Revolution – Healthcare is Ready to Embrace the New Technologies. *Marketing Health Services Fall.* pp43-44. American Marketing Association. USA (2004).

[16] Floerkemier, C. and Lampe, M. Issues with RFID Usage in Ubiquitous Computing Applications.

Proceedings of Second International Conference, Linz/Vienna, Austria, April 21-23. Springer. Germany (2004).

[17] Fontanella, J. Finding the ROI in RFID. *Supply Chain Management Review. Volume 8, No.* 1, pp13-14. Peerless Media Network. USA (2004).

[18] Fuhrer, P., Guinard, D. and Liechti, O. *RFID: From Concepts to Concrete Implementation.* Retrieved December, 2010, available at: http://www.guinard.org/unifr/docs/rfid_internal.pdf (2006).

[19] Greengard, S. Mississippi Blood Services Banks on RFID. Retrieved Dec, 2010, available at: http://www.rfidjournal.com/article/articleview/2472/1/4/ (2006).

[20] Hardgrave, B. and Miller, R. The Myths and Realities of RFID. *International Journal of Global Logistics & Supply Chain Management. Volume 1, No.* 1, pp1-16. (2006).

[21] Harvey, J., Lefebvre, L.A. and Lefebvre, E. Flexibility and Technology in Services: A Conceptual Model. *International Journal of Operation and Production Management. Volume 17, No.* 1, pp29-45. Elsevier. Netherlands (1997).

[22] Hellström, D. The Cost and Process of Implementing RFID Technology. *International Journal of Logistics Research and Applications*. Volume 12, No. 1, pp1-12. Taylor & Francis. UK (2009).

[23] Heskett, J.L., Jones, T.O., Loveman, G.W., Sasser, W.E. and Schlesinger, L.A. Putting the Service Profit Chain to Work. *Harvard Business Review. Volume 72, No.* 2, pp164-174. Harvard Business Publishing. USA (1994).

[24] Huang, K.S. and Tang, S.M. RFID Applications Strategy and Deployment in Bike Renting system. *10th International Conference on Advanced Communication Technology*. pp660-663. Institute of Electrical and Electronics Engineers (IEEE). USA (2008).

[25] Joglekar, N. and Rosenthal, S. Experimentation with RFID Usage in Supply Chains. *POMS Chronicle. Volume 12, No.* 1, pp10-11. Production and Operations Management Society. USA (2005).

[26] Kim, S. and Garrison, G. Understanding Users' Behaviors Regarding Supply Chain Technology: Determinants Impacting the Adoption and Implementation of RFID technology in South Korea. *International Journal of Information Management*. Volume 30, pp388-398. Elsevier. Netherlands (2010).

[27] Kwok, S.K., Ting, J.S.L., Tsang, A.H.C., Lee, W.B. and Cheung, B.C.F. Design and Development of a Mobile EPC-RFID Based Self-validation System (MESS) for Product Authentication. *Computers In Industry*. Volume 61, No. 7, pp624-635. Elsevier. Netherlands (2010).

[28] Lee, S. Mutual Authentication of RFID System using Synchronized Information. *M.Sc. Thesis. School of Engineering, Information and Communications University*, South Korea (2005).

[29] Lee, L.S., Fiedlera, K.D. and Smith, J.S. Radio Frequency Identification (RFID) Implementation in the Service Sector: A customer-facing Diffusion Model. *International Journal of Production Economics. Volume 112, pp*587-600. Elsevier. Netherlands (2008).

[30] Leimeister, S., Leimeister, J.M., Knebel, U. and Krcmar, H. A cross-national comparison of perceived strategic importance of RFID for CIOs in Germany and Italy. *International Journal of Information Management. Volume 29, No. 1, pp*37-47. Elsevier. Netherlands (2009).

[31] Lim, S.H. and Koh, C.E. RFID Implementation Strategy: Perceived Risks and Organizational Fits. *Industrial Management & Data Systems*. Volume 109, No. 8, pp1017-1036. Emerald Group Publishing. UK (2009).

[32] Luo, Z., Wang, E.C., Tan, C.J. and Chow, K.K. Apply Model Integration in RFID Technology Adoption Analysis. *2007 IEEE International Conference on Automation and Logistics*, 18-21 Aug. 2007, pp2931-2935. IEEE Computer Society. USA (2007).

[33] Matta, V., Koonce, D. and Jeyaraj, A. Initiation, Experimentation, Implementation of innovations: The case for Radio Frequency Identification Systems. *International Journal of Information Management*. Volume 32, No. 2, pp164-174. (2012).

[34] Michael, K. and Mccathie, L. The Pros and Cons of RFID in Supply Chain Management. *Proceedings of the International Conference on Mobile Business. pp*623-629. IEEE Computer Society. USA (2005).

[35] Mills-Harris, M., Soylemezoglu, A. and Saygin, C. Adaptive Inventory Management Using RFID Data. *International Journal of Advanced Manufacturing Technology*. Volume 32, No. 9-10, pp1045-1051. Springer. Germany (2006).

[36] Ngai, E.W.T., To, C.K.M., Moon, K.K.L., Chan, L.K., Yeung, P.K.W. and Lee, M.C.M. RFID Systems Implementation: A Comprehensive Framework and A Case Study. *International Journal of Production Research*. Volume 48, No. 9, pp2583- 2612. Taylor & Francis. UK (2010).

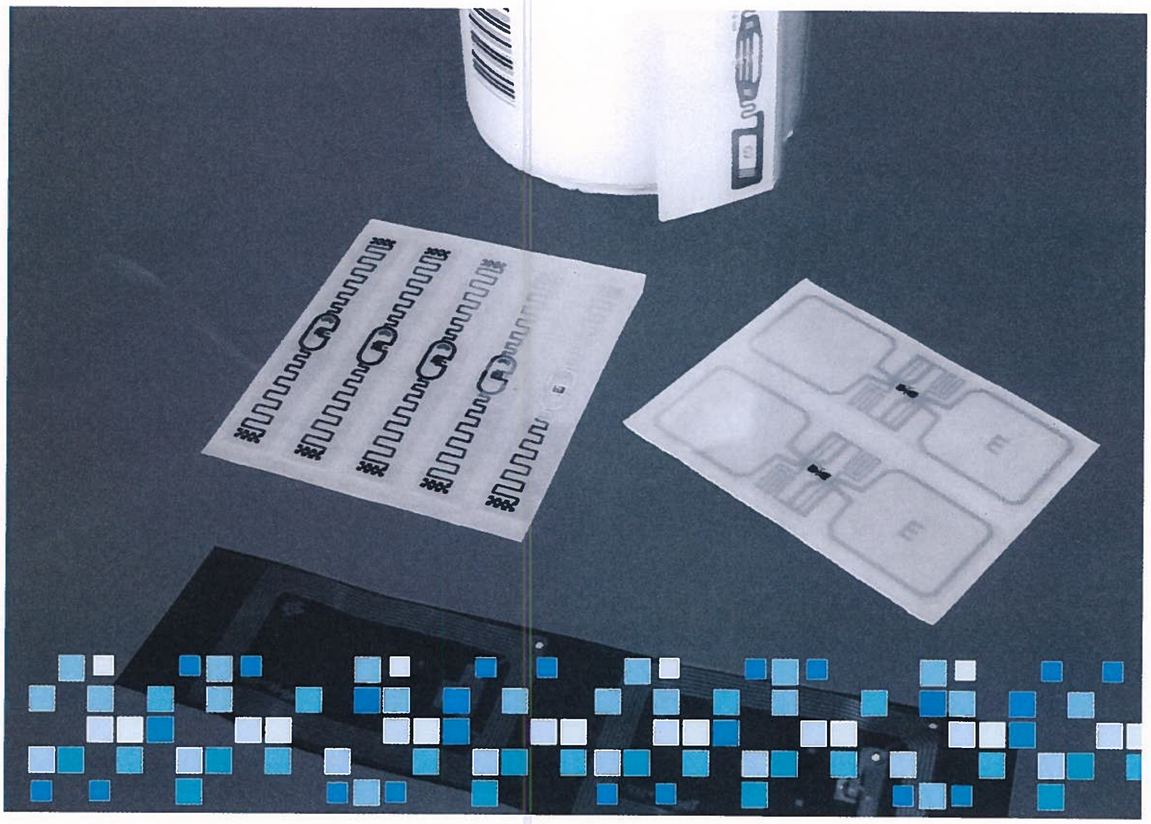
[37] Ngai, E.W.T., Cheng, T.C.E., Lai, K. Development of an RFID-based Traceability System: Experiences and Lessons Learned from an Aircraft Engineering Company. *Production and operations management*. Volume 16, No. 5, pp554–568. Production and Operations Management Society. USA (2007).

[38] O'Connor, M.C. EPC bag tagging takes wings in *RFID Journal*. Retrieved Dec, 2010, available at: http://www.rfidjournal.com/article/articleview/2024/ (2005).

[39] Osyk, B.A., Vijayaraman, B.S., Srinivasan, M., Dey, A. RFID adoption and implementation in warehousing. *Management Research Review*. Volume 135, No. 10, pp904-926. Emerald Group Publishing. UK (2012).

[40] Pålsson, H. Participant Observation in Logistics Research: Experiences from an RFID Implementation Study. I*nternational Journal of Physical Distribution & Logistics Management*. Volume 37, No. 2, pp148-163. Emerald Group Publishing. UK (2007).
[41] Paul, R.A. High Cost slows RFID implementation. Retrieved Dec 2010, available at: http://www.drugtopics.com/drugtopics/article/articleDetail.jsp?id=429850 (2007).
[42] Rao, S. *Supply Chain Management: Strengthening the Weakest Link! in Team Leader for Industrial Automation*. Retrieved January, 2011, available at: http://hosteddocs.ittoolbox.com/SR032604.pdf (2004).
[43] Reyes, P.M. and Jaska, P. RFID Right for Your Organization or Application?. *Management Research News. Volume 30, pp*570-580. Emerald Group Publishing. UK (2007).
[44] RFID News. Sonoco takes RFID into the core. Retrieved March 2011, available at: http://www.rfidnews.org/2008/07/22/sonoco-takes-rfid-into-the-core?tag=Logistics (2008).
[45] RFID News. RFID solution introduced to manage wine cellars. Retrieved December 2012, available at: http://www.rfidnews.org/2011/01/24/rfid-solution-introduced-to-manage-wine-cellars (2011).
[46] Roberti, M. GMA: Business Case for EPC mixed in *RFID Journal*. Retrieved December, 2010, available at: http://www.rifdjournal.com/article/articleview/1250/1/1 (2004).
[47] Saygin, C., Sarangapani, J. and Grasman, S.E. A Systems Approach to Viable RFID Implementation in the Supply Chain. *Springer Series in Advanced Manufacturing. Volume 1, pp*3-27. Springer. Germany (2007).
[48] Sellitto, C., Burgess, S. and Hawking, P. Information Quality Attributes Associated with RFID-derived Benefits in the Retail Supply Chain. *International Journal of Retail & Distribution Management*. Volume 35, No. 1, pp69 – 87. Emerald Group Publishing. UK (2007).
[49] Smart, L. Making Sense of RFID. *Library Journal. Volume 129*, pp4-11. Media Source Inc. USA (2004).
[50] Soylemezoglu, A., Zawodniok, M.J., Cha, K., Hall, D., Birt, J. and Sarangapani, J. (2006). A Testbed Architecture for Auto-ID Technologies. *Assembly Automation. Volume 26, No.* 2, pp127-136. Emerald Group Publishing. UK (2006).
[51] Spekman, R.E. and Sweeney II, P.J. RFID: From Concept to Implementation, *International Journal of Physical Distribution & Logistics Management*. Volume 36, No. 1, pp736-754. Emerald Group Publishing. UK (2006).
[52] Stuart, C.K. and Liu, J.J. Securing RFID Application: Issues, Methods, and Controls. *Telecommunication and Network Security*. Volume 15, No. 4, pp43-50. (2006).
[53] Swedberg, C. GS1 Pilot Program Shows How RFID Can Track International Wine Shipments. Retrieved December 2012, available at: http://www.rfidjournal.com/article/print/9665 (2012).
[54] Ting, S.L., Kwok, S.K., Tsang, A.H.C. and Lee, W.B. Critical Elements and Lessons Learnt from the Implementation of an RFID-enabled Healthcare Management System in a Medical Organization. *Journal of Medical Systems*. Volume 35, No. 4, pp657-669. Springer. Germany (2011).
[55] Ting, J.S.L. and Tsang, A.H.C. Design of an RFID-based Inventory Control and Management System: A Case Study. *The West Indian Journal of Engineering*. Volume 34, No. 1/2, pp70-79 (2012).
[56] Ting, S.L., Wang, L.X. and Ip, W.H. A Study on RFID Adoption for Vehicle Tracking in a Container Terminal. *Journal of Industrial Engineering and Management*. Volume 5, No. 1, pp22-52. (2012).
[57] Vijayaraman, B.S. and Osyk, B.A. An Empirical Study of RFID Implementation in the Warehouse Industry. *The International Journal of Logistics Management*. Volume 17, No. 1, pp6-20. Emerald Group Publishing. UK (2006).
[58] Wang, S.W., Chen, W.H., Ong, C.S., Liu, L. and Chuang, Y.W. RFID Applications in Hospitals: A Case Study on a Demonstration RFID Project in a Taiwan Hospital. *39th Hawaii International Conference on System Sciences,(Honolulu, USA); New York, IEEE (May 2006), pp*1-10. IEEE Computer Society. USA (2006).
[59] Wang, Y.M. and Wang, Y.S. Understanding the Determinants of RFID Adoption in the Manufacturing Industry. *Technological Forecasting and Social Change*. Volume 77, No. 5, pp803-815. Elsevier. Netherlands (2010).
[60] Wu, N.C., Nystrom, M.A., Lin, T.R. and Yu, H.C. Challenges to Global RFID Adoption. *Technovation*. Volume 26, No. 12, pp1317-1323. Elsevier. Netherlands (2006).
[61] Yue, D., Wu, X. and Bai, J. RFID Application Framework for Pharmaceutical Supply Chain. *2008 IEEE International Conference on Service Operations and Logistics, and Informatics*, pp1125–1130. IEEE Computer Society. USA (2008).
[62] Zailani, S., Fernando, Y. and Zakaria, H. Determinants of RFID Adoption among Logistics Service Providers in Malaysia: A Discriminant Analysis. *International Journal of Logistics Systems and Management*. Volume 7, No. 3, pp345-367. Inderscience Publishers. Switzerland (2010).

La tecnología RFID: Usos y oportunidades



AETIC
Asociación de Empresas de Electrónica, Tecnologías de la Información y Telecomunicaciones de España

GOBIERNO DE ESPAÑA
MINISTERIO DE INDUSTRIA, TURISMO Y COMERCIO

La tecnología RFID:
Usos y oportunidades

La tecnología RFID:
Usos y oportunidades

En la realización de este trabajo han intervenido:

- Área de Estudios del Observatorio Nacional de las Telecomunicaciones y de la Sociedad de la Información (ONTSI), órgano adscrito a la Entidad Pública Empresarial red.es.
  - Alberto Urueña (Coordinación)
  - Annie Ferrari
  - Elena Valdecasa
- AETIC, Asociación de Empresas de Electrónica, Tecnologías de la Información y Telecomunicaciones de España.
  - Antonio Cimorra
  - Albert Sitjà (Comisión RFID AETIC)
  - María del Mar Duque
  - Comisión RFID de AETIC
- Asistencia Técnica: AT4 wireless S.A. Empresa tecnológica española con sede en el Parque Tecnológico de Andalucía en Málaga.
  - Francisco Cañas
  - Rosario Trapero
  - Antonio Jiménez
  - Miguel Ángel Guijarro

EDITA:
©red.es
Edificio Bronce
Plaza Manuel Gómez Moreno, s/n.
28020 Madrid

Depósito Legal: M-11526-2009

Maquetación y Producción: Scan96, s.l.

Fotografías:
AT4 wireless, S.A.
Fabricantes o distribuidores de equipos de RFID.

Índice

Prólogo

La realización de este libro divulgativo de la tecnología RFID y sus aplicaciones por parte del Observatorio Nacional de las Telecomunicaciones y de la Sociedad de la Información (ONTSI) de red.es, se ha efectuado conjuntamente con la Asociación de Empresas de Electrónica, Tecnologías de la Información y Telecomunicaciones de España (AETIC) y en concreto, con la comisión de desarrollo de mercado y su grupo de trabajo de RFID.

Esta iniciativa, sin duda alguna, facilitará el desarrollo de la tecnología RFID en España, contribuyendo al crecimiento y al empleo del sector. Se espera que el RFID no sólo genere nuevos modelos de negocio, sino que además se conviertan en la piedra angular de la nueva etapa de desarrollo de la Sociedad de la Información, denominada "Internet de los Objetos", en la que la Red potencialmente conectará a cualquier objeto entre sí, a sistemas de datos o procesos de negocio. La

Comisión Europea está interesada así mismo en promover este avance, como pone de manifiesto la celebración de las conferencias "On RFID: The next step to the Internet of Things", celebradas en Noviembre 2007.

En cualquier caso, el desarrollo de RFID permitirá que nuestras empresas sean más competitivas en un mundo global favoreciendo sobre todo, el desarrollo avanzado de soluciones de localización e identificación de los objetos. Estas soluciones nos proporcionarán, sin duda alguna, junto a Internet y a las soluciones de movilidad, la entrada a la gran revolución de la sociedad en el futuro.

Desde AETIC se promueven y desarrollan las actividades de RFID desde su inicio, además de contribuir con aportaciones a las líneas de actuación sobre RFID en las diferentes plataformas tecnológicas que pueden tener relación más directa con la tecnología, como pueden ser eMOV, eNEM, eISI, eVIA e Internet del futuro.

También desde AETIC, como miembros de pleno derecho en EICTA (European Information & Communications Technology Industry Association), se siguen y promueven las actuaciones que sobre RFID se vienen efectuando a nivel europeo, y que han contribuido, algunas de ellas, a la realización de consultas públicas por parte de la Comisión Europea.

Por otro lado, ONTSI realiza un seguimiento proactivo de la evolución de la Sociedad de la Información a través de sus publicaciones referentes a empresas, hogares y Administración Pública, con el fin de ofrecer un instrumento de referencia a nivel nacional y de comparativa europea. En el marco de los objetivos de ONTSI, de máxima colaboración con instituciones y entidades públicas y privadas del sector TIC, y de fomentar las nuevas tecnologías de alto potencial social y económico, surge la necesidad del presente libro.

Por último, queremos agradecer a los expertos, instituciones y empresas que intervinieron de distinto modo en la elaboración de esta guía.

02 Introducción

La identificación por radiofrecuencia (RFID) es una tecnología de captura e identificación automática de información contenida en etiquetas electrónicas (tags). Cuando estas etiquetas entran en el área de cobertura de un lector RFID, éste envía una señal para que la etiqueta le transmita la información almacenada en su memoria, habitualmente un código de identificación. Una de las claves de esta tecnología es que la recuperación de la información contenida en la etiqueta se realiza vía radiofrecuencia y sin necesidad de que exista contacto físico o visual (línea de vista) entre el dispositivo lector y las etiquetas, aunque en muchos casos se exige una cierta proximidad de esos elementos. Se prevé que el uso de la tecnología RFID tenga un impacto importante sobre la actividad diaria de empresas, instituciones y ciudadanos cuando cada vez más productos sean etiquetados y lleguen a los clientes finales propiciando la aparición de nuevas aplicaciones y servicios basados en RFID.

La tecnología RFID: Usos y oportunidades

Las tecnologías de identificación por radiofrecuencia no son nuevas, llevan funcionando desde hace muchos años, sin embargo es recientemente cuando están teniendo una mayor aplicación y con mayor diversidad sectorial. En los últimos años las tecnologías RFID se han desarrollado y perfeccionado técnicamente, disponiendo actualmente de estándares internacionalmente aceptados para las bandas de frecuencia de trabajo más habituales con mayor número de aplicaciones, y con la aceptación de las Administraciones Públicas responsables de la asignación de frecuencias, que entienden que deben liberar recursos suficientes que permitan el desarrollo de las tecnologías RFID, pensando además en que los recursos (por ejemplo las bandas de frecuencia) deben ser compatibles para el uso de la tecnología a nivel internacional, punto imprescindible para que se produzca el uso masivo de la tecnología considerando la globalización de productos que existe en la actualidad.

Esta evolución de la tecnología RFID también ha supuesto un avance en las aplicaciones que se derivan de su uso. Si inicialmente el funcionamiento estaba limitado a distancias cortas por el uso de las tecnologías HF, más maduras tecnológicamente, actualmente los nuevos estándares en UHF permiten lecturas a varios metros con gran fiabilidad. Este aumento en el rango de lectura supone para las soluciones basadas en RFID un gran avance en los procesos de identificación, máxime si lo comparamos con las tecnologías más usadas en la actualidad, como el código de barras, que necesita visión directa y por tanto distancias muy cortas entre lector y código.

El despliegue e implantación de la tecnología RFID esta siendo apoyado por algunas de las empresas internacionales de distribución más grandes (Wal-Mart, Metro,...), por lo que se prevé una adopción global en la cadena de suministro en los próximos años atendiendo al efecto de tracción que ejercen estas empresas fomentando el uso de la tecnología RFID entre sus proveedores.

Entre los factores más influyentes en la propagación del uso de RFID figuran aspectos relacionados con la seguridad y privacidad, los costes iniciales de despliegue, precio actual de las etiquetas RFID y las inercias para acometer y gestionar procesos de cambio en muchas empresas. Hasta hace poco, las experiencias de implantación de la tecnología tenían como actores principales a los llamados "early adopters", empresas con perfil innovador que esperan

Para el desarrollo del RFID es fundamental la existencia de estándares internacionales que recojan los protocolos de comunicación y los modos de operación para conseguir un funcionamiento global.

tomar ventaja de su experiencia frente a competidores y obtener beneficios comerciales. De los datos recogidos en encuestas recientes se desprende un cambio en esa tendencia y el número de empresas acometiendo proyectos con esta tecnología está creciendo cada año, esperándose un número muy importante de implantaciones antes del año 2012.

Como cualquier tecnología que tiene una gran aplicación a nivel comercial, para el desarrollo del RFID es fundamental la existencia de estándares internacionales que recojan los protocolos de comunicación y los modos de operación para conseguir un funcionamiento global. A su vez, por ser una tecnología basada en la radiofrecuencia, necesita que se controlen y regulen las emisiones radioeléctricas y el uso del espectro mediante normativas. La variedad de bandas de frecuencias en las que RFID puede trabajar ha generado a su vez una gran variedad de estándares y normativas que se corresponden con cada una de las posibles bandas de trabajo.

Aunque inicialmente los sistemas RFID se están aplicando principalmente en soluciones internas o de "ciclo cerrado", se prevé una migración a situación de "ciclo abierto" en donde sistemas de información independientes comparten información mediante servicios de red seguros tanto en control de acceso como integridad de datos, dotando así de toda su funcionalidad a las aplicaciones de la tecnología RFID y por lo tanto promoviendo su implantación en todas las empresas.

03

Qué es RFID y cómo funciona

La tecnología de identificación por radio frecuencia, conocida por sus siglas en inglés RFID (Radio Frequency Identification), no es una tecnología nueva, lleva conviviendo entre nosotros desde hace ya muchos años, aunque es recientemente cuando ha cobrado mayor relevancia y presencia especialmente debido al desarrollo tecnológico (miniaturización) y el descenso de los costes de fabricación de los componentes electrónicos, factores que están permitiendo orientar el uso de esta tecnología de identificación hacia sectores tan amplios como la logística y la cadena de suministro, entre otros. La tecnología RFID se usó por primera vez en la segunda guerra mundial, por la armada británica, con el fin de identificar aviones amigos. Actualmente podemos encontrar sistemas que usan la tecnología RFID en gran variedad de servicios del ámbito civil y militar, públicos y privados, tales como la identificación de pacientes en hospitales, el pago automático en autopistas, identificación de animales, etc.

La característica principal que dota a este sistema de identificación de un gran valor añadido, es que el chip de RFID permite almacenar en su interior información de identificación que confiere a cada uno de los elementos etiquetados de un carácter único.

En un sistema RFID, el elemento a identificar (puede ser un objeto, animal o persona) se etiqueta con un pequeño chip de silicio unido a una antena de radiofrecuencia (conocido como 'tag' o etiqueta) de modo que pueda comunicarse y ser identificado, a través de ondas de radiofrecuencia, por un dispositivo transmisor/receptor (conocido como 'reader') diseñado para ese propósito. La característica principal que dota a este sistema de identificación de un gran valor añadido, es que el chip de RFID permite almacenar en su interior información de identificación que confiere a cada uno de los elementos etiquetados de un carácter único.

Los fundamentos físicos en los que se basa la tecnología RFID, implican la aparición de varios modelos de comunicación entre los dispositivos básicos del sistema. La comunicación por radiofrecuencia, requiere la incorporación de una antena RF en cada uno de los dispositivos implicados en la comunicación cuya forma y características depende de la banda de frecuencia en la que funcionen.

Las siguientes bandas de frecuencia son las que utilizan los diferentes sistemas de RFID que actualmente están presentes en el mercado:

Tabla 1. Bandas de frecuencia utilizadas en RFID

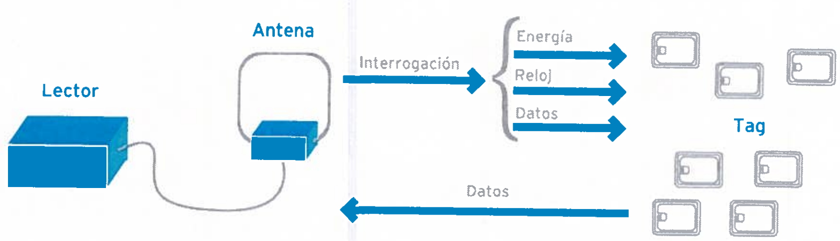
Banda de Frecuencias	Descripción	Rango
125 kHz - 134 kHz	LF (Baja Frecuencia)	Hasta 45 cm.
13,553 MHz - 13,567 MHz	HF (Alta Frecuencia)	De 1 a 3 m.
400 MHz - 1.000 MHz	UHF (Ultra Alta Frecuencia)	De 3 a 10 m.
2,45 GHz - 5,4 GHz	Microondas	Más de 10 m.

Fuente: Elaboración propia

Cada una de estas bandas de frecuencia tiene unas características específicas que confieren elementos diferenciales a la funcionalidad de los dispositivos RFID, por lo tanto elegir la frecuencia de trabajo es un punto fundamental al diseñar una solución RFID. Dependiendo de los requisitos funcionales de la aplicación final, la identificación automática puede requerir o no, una mayor o menor distancia de identificación, generar la menor interferencia radioeléctrica posible, estabilidad de la señal frente a entornos hostiles o una alta capacidad de penetración en los materiales. Según sean los requisitos, así se seleccionará la frecuencia de trabajo del sistema.

Los componentes básicos de un sistema RFID son: tag, lector, antena RF y sistema gestor de información. Un sistema RFID no está completo si carece de alguno de estos cuatro elementos. El modo de operación de un sistema RFID básico consiste en la identificación localizada y automática de objetos etiquetados. Dentro de este objetivo final, cada uno de los componentes del sistema tiene su función particular que permite que, de forma secuencial, se lleve a cabo el proceso de identificación.

Figura 1. Esquema general de funcionamiento de un sistema RFID



Fuente: Elaboración propia

a) El **tag o etiqueta RFID**, o en ámbito de electrónica "transpondedor", es el componente estrella del sistema RFID. Se denomina dispositivo "transpondedor" por su modo de operación básico, tiene capacidad de recibir y transmitir señales, pero sólo transmitirá a modo de respuesta ante una posible petición de un dispositivo "transceptor" o lector RFID. El tag es un pequeño chip, o circuito integrado, adaptado a una antena de radiofrecuencia (RF) que permite la comunicación vía radio. Estos dos elementos integrados sobre un substrato, forman lo que se conoce como tag. Dependiendo de la aplicación final del sistema de identificación, el substrato donde se encapsula el chip y la antena RF será diferente permitiendo la adaptación de sus características a los requisitos de la aplicación, por ejemplo hay tags especiales para textil, líquidos, metales, libros, etc.

Los tags son fabricados en una amplia variedad de formatos. El proceso básico de montaje consta en primer lugar de una base de material de substrato (papel, PVC, PET, etc.), sobre ésta una antena hecha de diferentes materiales conductivos, tipo aluminio, cobre, etc. A continuación el chip del tag es conectado a la antena.

Finalmente, se reviste con una capa protectora realizada en diferentes tipos de materiales tales como PVC laminado, resina epóxica o papel adhesivo, según requerimientos que se necesiten por las distintas condiciones finales del entorno.

Los tags tienen características o capacidades muy diferentes, por lo que podemos realizar múltiples clasificaciones que nos ayuden a entender como afectan a su comportamiento o modo de trabajo. Podríamos clasificar tags según su tipología (activo, pasivo y

Se denominа dispositivo "transpondedor"
por su modo de operación básico,
tiene capacidad de recibir y transmitir señales, pero sólo
transmitirá a modo de respuesta ante una posible petición

Los tags tienen características o capacidades muy diferentes, por lo que podemos realizar múltiples clasificaciones que nos ayuden a entender como afectan a su comportamiento o modo de trabajo.

semiactivo), por su tipo de memoria, capacidad de almacenamiento, origen de alimentación, frecuencias de trabajo, características físicas, protocolo de interfaz aérea (cómo se comunica con el equipo lector) y así sucesivamente con casi todas las características. Clasificar los tags según todas estas características, nos permite obtener una guía para encontrar el mejor tipo de tag para cada una de las aplicaciones o proyectos. La elección de la etiqueta o "tag" adecuado es un factor clave para garantizar el éxito de la aplicación RFID y su aportación a los procesos productivos.

Hay muchas características básicas que pueden modificar el comportamiento de un tag RFID, algunas comunes a todos los tags (requerimientos mínimos que todos deben cumplir) y otras que sólo se encuentran según modelo.

- **Adhesión del tag:** cualquier tipo de tag debe tener un mecanismo adhesivo o mecánico para adjuntarlo al objeto.
- **Lectura del tag:** Cualquier tag debe poder comunicar la información mediante la radiofrecuencia.
- **Kill/Disable** (inhabilitación): Algunos tags permiten al lector enviar un comando (orden) para que deje de funcionar permanentemente, siempre y cuando reciba el correcto "Kill code". Esto provoca que no responda nunca más.
- **Write Once** (una sola escritura): A muchos tags se les introduce la identificación en la propia fabricación, pero los que contienen la característica write-once permiten al usuario configurar o escribir su valor una sola vez; después de modificar el inicial, es imposible cambiarlo.
- **Write many** (varias escrituras): Algunos tags tienen la capacidad de poder escribir y reescribir tantas veces como se desee (normalmente hay un límite de

ciclos muy elevado, como por ejemplo 100.000 escrituras) el campo de datos del identificador.

- **Anticolisión:** Cuando hay muchos tags próximos a un lector, éste puede tener la dificultad de "hablar" o comunicarse con ellos a la vez. La característica anticolisión permite al tag conocer cuando debe transmitir para no entorpecer o molestar otras lecturas. Esta característica se realiza mediante protocolos que permiten controlar las comunicaciones entre tag y lector.
- **Seguridad y encriptación:** Algunos tags permiten encriptar la información en la comunicación, además existe la posibilidad en varios tipos de estos tags de responder sólo a lectores que les proporciona un password secreto.
- **Estándares soportados (conformidad):** Los tags pueden cumplir con uno o más estándares, permitiendo comunicarse con los lectores que los cumplen.

Los tags RFID toman multitud de formas y tamaños según los diferentes entornos donde deben utilizarse, esta característica de adaptación proporciona un elevado surtido de tags. Además estos tags pueden estar encapsulados en diferentes tipos de material. Hay tags que se encapsulan en plástico (normalmente PVC), o botones para obtener mayor durabilidad, sobre todo en aplicaciones de ciclo cerrado donde se tiene que reutilizar o en ambientes hostiles. Si por el contrario el objetivo final es identificar objetos, como podrían ser cajas y paletas dentro y fuera de un almacén, la solución más común es utilizar un substrato de plástico con forma de etiqueta que se adhiera a la superficie del objeto a identificar.

También pueden estar insertadas en tarjetas de plástico como las de crédito, este tipo se denominan "contactless smart cards", o láminas de papel (similar a los códigos de barras), que reciben el nombre de "smart labels". Por último, destacamos los encapsulados de cristal o cerámica especialmente idóneos en entornos corrosivos, líquidos o para incrementar la protección del tag, por ejemplo, su utilización en la trazabilidad animal. Si el objetivo final de la aplicación es la identificación de animales, suele usarse el método de insertar el tag debajo de la piel del animal o bien en el estómago. Para hacer esto posible, el chip y la antena se encapsulan en substratos no

Figura 2. Ejemplos de tags de diferentes formas y tamaños

Fuente: Documentación comercial de los fabricantes

tóxicos a modo de cápsula o bolo rumial. Entre estos dos casos extremos, se encuentran otras aplicaciones como las llaves de seguridad del automóvil, o las tarjetas de control de acceso a zonas restringidas y/o edificios.

Figura 3. Ejemplos de impresoras de etiquetas RFID

Fuente: Documentación comercial de los fabricantes

Los tags pasivos obtienen la energía de la transmisión del lector, los activos utilizan una batería propia y los semi activos o semi pasivos utilizan una batería para activar los circuitos del chip pero la energía para generar la comunicación es la que recoge de las ondas radio del lector (como en los pasivos).

Otra característica importante a considerar a la hora de seleccionar tags para una aplicación concreta, es el modo de alimentación. Esta característica es uno de los principales factores que determina el coste y vida del tag. Los tags pasivos obtienen la energía de la transmisión del lector, los activos utilizan una batería propia y los semi activos o semi pasivos utilizan una batería para activar los circuitos del chip pero la energía para generar la comunicación es la que recoge de las ondas radio del lector (como en los pasivos).

Los más comunes son los tags pasivos, ya que permiten al dispositivo transpondedor trabajar sin necesidad de fuente de alimentación propia, lo que lo hace más económico, de menor tamaño, y con un ciclo de vida ilimitado. Como desventaja está la dependencia con el campo electromagnético generado por el dispositivo lector y por tanto la correspondiente limitación de la distancia de identificación. Los tags semipasivos, tienen su propia batería, lo que le permite aumentar la distancia de identificación, pero siguen dependiendo de la señal proveniente del dispositivo lector, ya que la necesitan para generar la señal de respuesta. En este caso, el ciclo de vida del tag aparece limitado por el ciclo de vida de su batería. El caso más extremo es el de los tags activos. Tienen su propia batería y su propio transmisor, lo que los hace totalmente independientes a la señal transmitida por el dispositivo lector. La distancia de identificación se incrementa muchísimo con respecto de los tags pasivos. El ciclo de vida estará limitado al ciclo de vida de su propia batería.

A continuación se puede ver una tabla comparativa entre los dos extremos, tags pasivos y tags activos:

Tabla 2. Comparativa entre características de tags pasivos y tags activos

Tag Pasivo	Tag Activo
Funciona sin batería	Funciona con batería
Relativamente económico	Relativamente costoso
Ciclo de vida ilimitado	Ciclo de vida limitado por la batería
Poco peso	Mayor peso
Alcance limitado (3 - 5m)	Mayor alcance (100 m)
Sensible al ruido	Mayor inmunidad ante presencia de ruido
Dependencia de la señal del dispositivo lector	Trasmisor propio
Requiere dispositivos lectores potentes	Relaja el requisito de potencia de los lectores
Velocidad de transmisión baja	Velocidad de transmisión alta
Lectura simultánea baja	Lectura simultánea alta
Alta sensibilidad de orientación	Menor sensibilidad de orientación

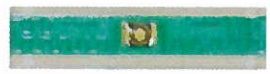
Fuente: Elaboración propia

La capacidad de almacenamiento de información y su capacidad de procesamiento son también importantes a la hora de escoger la utilidad del tag, además de las otras características descritas anteriormente. Los tags RFID existentes en el mercado nos permiten elegir una amplia variedad de capacidades. De los más simples con sólo un bit de almacenamiento (utilizado para soluciones antihurto) hasta kilobytes de datos para almacenar identificadores y datos complementarios.

Finalmente se muestran diversos ejemplos de tags de diferentes fabricantes, con distintas formas y tamaños, y características específicas según su aplicación:

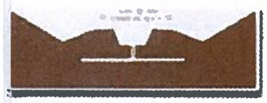
Figura 4. Ejemplos de tags de diferentes fabricantes

Tag rígido para superficies metálicas y resistente a entornos agresivos



Tag flexible diseñado para los neumáticos, cumple el estándar AIAG B-11 de la automoción

Tag Alien Technology flexible de UHF Gen1 de alto rendimiento

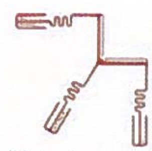


Tag Alien Technology flexible de UHF Gen1 de alto rendimiento y etiquetajes difíciles

Tag Alien Technology flexible de UHF Gen1 de reducido tamaño

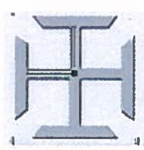
Tag Alien Technology flexible de UHF Gen1 de buen rendimiento y etiquetajes difíciles

Tag Alien Technology flexible de UHF diseñado para aplicaciones farmacéuticas

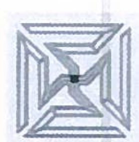


Tag Alien Technology flexible de UHF Gen2 de alto rendimiento y solución omnidireccional

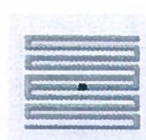
Tag Alien Technology flexible de UHF Gen1 de bajo coste



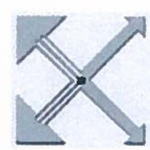
Symbol



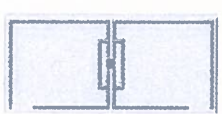
Symbol



Symbol



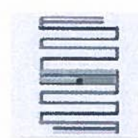
Symbol



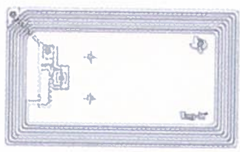
Symbol

Symbol

Symbol

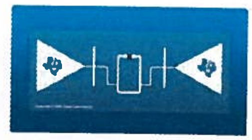


Symbol



Tag HF (13,56 MHz)
de Texas Instruments

Tag HF (13,56 MHz) de Texas Instruments
en forma redonda para CD o DVD

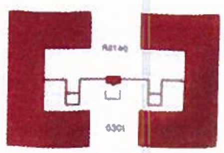


Tag UHFGen2 de Texas Instruments

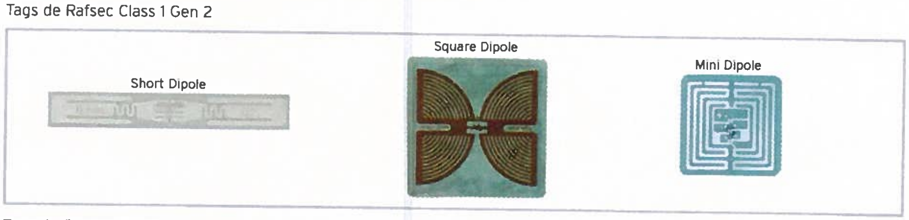
Tag rígido UHF de Caen RFID
con sensor de temperatura

Tag de Astag en forma de
pulseras para HF

Tag de Astag en HF para
etiquetar objetos de cristal



Tags de Rafsec Class 1 Gen 2



Tags de Omron Class1

b) **El dispositivo lector,** o en ámbito de electrónica "transceptor", actúa como estación de identificación transmitiendo señales de petición hacia los tags y recibiendo las respuestas a estas peticiones. Es un dispositivo receptor/transmisor radio, que incorpora además de los subsistemas de transmisión y recepción, un procesador de señales digitales que lo dota de mayor funcionalidad y complejidad en sus operaciones. Un dispositivo lector, necesitará de una o varias antenas RF para transmitir la señal generada y recibir la respuesta del tag. Es posible encontrar lectores con la antena RF integrada en su propio hardware y lectores con conectores de antena RF externos. Según el ámbito de la aplicación final, será necesario disponer de una configuración u otra. En el caso de la identificación de animales o incluso pacientes en un hospital, lo más usual es disponer de dispositivos lectores de mano, tipo PDA, en los que la antena aparece integrada en el propio lector. En el caso de un centro de distribución o almacén, en el que la identificación está localizada en una zona de paso o comprobación, se utilizan dispositivos lectores con varias antenas externas que posibilitan una configuración de arco de identificación acotando una determinada área de lectura.

La funcionalidad y/o complejidad de cálculo y operaciones de un dispositivo lector, es totalmente proporcional al tamaño del hardware. La capacidad de proceso, memoria y velocidad requiere hardware adicional y por tanto el tamaño del dispositivo va en aumento. Podemos encontrar desde lectores del tamaño de una tarjeta PCMCIA para acoplarlos a una PDA, hasta lectores robustos para entornos hostiles que requieren protección física, mayor velocidad de lectura y multiplexación entre antenas y procesado de información, cuyo tamaño aumenta considerablemente respecto a los primeros. De forma similar al caso de las antenas de los tags, las antenas RF conectadas al dispositivo lector, variarán de forma y de tamaño según la frecuencia de operación del sistema. La figura siguiente muestra algunos lectores ejemplo de entre los citados.

Figura 5. Ejemplos de lectores RFID de diferentes fabricantes

Fuente: Documentación comercial de los fabricantes