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TECHNICAL REPORT

13.56 MHz ISM Band Class 1 Radio Frequency Identification Tag Interface Specification: Candidate Recommendation, Version 1.0.0

Auto-ID Center

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ABSTRACT

This document specifies the radio frequency communication interface and Reader commanded functionality requirements for an Auto-ID Center Class I radio frequency identification (RFID) Tag operating in the 13.56 MHz ISM frequency band. A Class I tag is designed to communicate only its unique identifier and other information required to obtain the unique identifier during the communication process.

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Contents

A. BACKGROUND

1. INTRODUCTION

This document provides both mandatory and optional specifications for a low cost electronic label, operating in the high frequency (13.56 MHz) ISM band, containing an Electronic Product Code™ (EPC™), and used for item identification.

The label contains an Electronic Product Code™ (EPC™) used for item identification, a cyclic redundancy check, and a destruct code. The identification of labels is performed using the first two elements, and label destruction is performed using all three.

2. DOCUMENT STRUCTURE

Although the sections are simply serially numbered, the document is divided into two major parts. Part A provides general background, and gives a description of the context within which the standard is intended to operate. Part B provides a definition of the **air interface** and **command set**; it covers signalling waveforms and extends to a description of detailed command structure and operation.

3. STATUS

Referring to the Auto-ID Center white paper "A Proposal for a Standard Process for the Auto-ID Center", May 1st 2002, this specification is in the status of a Candidate Recommendation. This document supersedes all former specifications for a HF EPC™ Label.

4. TERMINOLOGY

We take the opportunity here to clarify the terminology of this document.

We will not use the terms uplink, downlink, or forward link. Directions of communication will be described as **interrogator-to-label**, or **label-to-interrogator**.

Numbers, when they are written, have the most significant digit on the left and the least significant digit on the right.

In serial transmission, we will make no assumption as to whether the most significant bits or the least significant bits are transmitted first. We will make an **explicit statement** in every case.

We take the term **air interface** to mean the waveforms of the different **symbols** used in both the interrogator to label signaling and label to interrogator signaling, and the rules for **building commands**, but it does not include the commands themselves. It does include the coding of the label replies.

The term **command set** is taken to mean the set of label commands by means of which the label population may be explored or modified by the interrogator.

The term **operating procedure** refers to how we should use the command set to identify or modify labels.

The term **protocol** is intended to refer collectively to the elements **air interface**, **command set** and **operating procedure**.

5. ELECTRONIC PRODUCT CODE™

5.1. Introduction

This section describes the four varieties of Electronic Product Code™ so far defined, and acknowledges that further varieties will also be defined.

The label and reading system specification provided in this document is intended to apply to all of those varieties.

5.2. EPC™ Structure

In the Electronic Product Codes™ so far defined there are four fields, which are, in order: a **header**, defining the variety of EPC™ among a number of possible structures; a **domain manager number** which is effectively a manufacturer number; an **object class** which is equivalent to a product number; and a **serial number**.

The below table gives, for the four varieties of EPC™ so far defined, the size, in bits, of each field. The table also indicates, for each variety, the leading bits, i.e. the most significant bits, of the header.

Table 1: EPC-96 and EPC-64 structure.

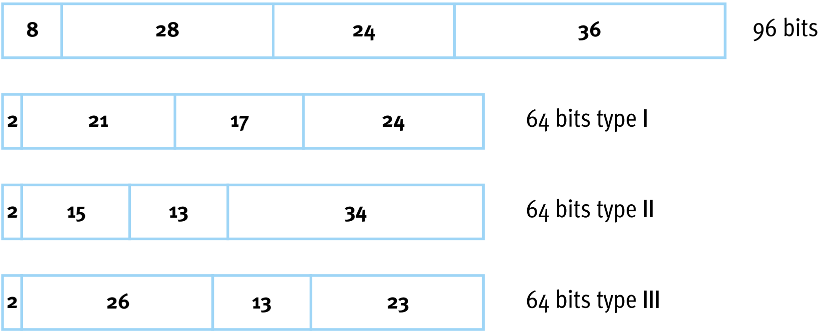
EPC™ TYPE	HEADER SIZE	FIRST BITS	DOMAIN MANAGER	OBJECT CLASS	SERIAL NUMBER	TOTAL
96 BIT	8	00	28	24	36	96
64 BIT TYPE I	2	01	21	17	24	64
64 BIT TYPE II	2	10	15	13	34	64
64 BIT TYPE III	2	11	26	13	23	64

5.3. Illustration

Figure 1 below provides an illustration of the Electronic Product Code™ just defined.

Figure 1: Illustration of the EPC-96 and EPC-64 structure.

ILLUSTRATION OF STRUCTURE OF SOME EPC™ CODES



5.4. Additional Information

- This does not preclude the definition of future versions of EPC™ code or designing labels for them.
- A 256-bit version is expected to be defined. No information is yet available on the structure of the header, but it is expected to be of length 8 bits.

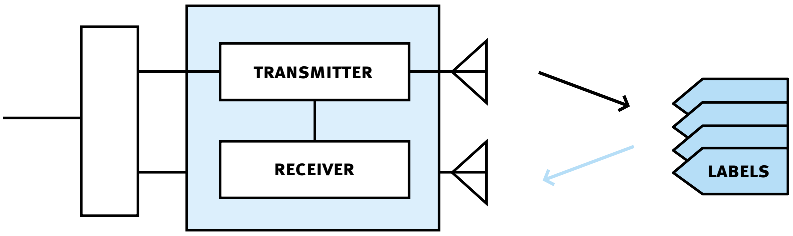
6. SYSTEM OUTLINE

6.1. Multiple Label Reading

Figure 2 below illustrates an example of a multiple electronic label reading system. It is assumed the labels are passive, i.e. they contain no internal energy source.

Figure 2: Illustration of multiple labels being read by an interrogator.

ILLUSTRATION OF A MULTIPLE LABEL READING SYSTEM



In the figure, a group of labels is interrogated by an **interrogator** containing a **transmitter** for generation of an interrogation signal which supplies power and information to the labels. The interrogator also contains a **receiver** for reception of a reply signal from the labels and for decoding that signal. The interrogator operates under control of a **controller** that supplies the decoded signal to external apparatus, and also manages the interrogation process.

6.2. Functions Required of the Label

The label must have the functions of:

- Being programmed with EPC™ and possibly other data.
- Being read by the interrogator.
- Being selected as part of a related group of labels.
- Being individually destroyed.

6.3. Factors Governing Performance

The performance of an HF EPC™ labelling system is influenced by the following factors:

- The nature of the interrogation field creation system. In this connection we note that label operation will generally be in the **near field**, but some regulations are enforced in **far field**.

- Electromagnetic compatibility regulations. Such regulations are considered in detail in **Section 7**. Their principal impact is on the choice of viable anti-collision algorithms that may be employed at HF, and on the operating range achievable in simple standardised field creation systems.

- Human exposure regulations for electromagnetic fields. Such regulations are considered in detail in **Section 8**.

- Label antenna size. The principal issues to consider are that smaller labels require higher fields for excitation and produce weaker replies, but are less prone to inter-label interference. An effort should be made to minimise label circuit operating power.

- Label quality factor. The principal issues to consider are that higher quality factor labels have greater sensitivity, i.e. greater operating range, but are more sensitive to environmental detuning and inter-label detuning.

- Reliability of programming, reading and destruction. The particular needs of EPC™ labels are not directly parallel to traditional RFID labels, and non-traditional approaches to reliability of communication in the EPC™ context can be considered. This matter will receive further consideration in **Section 10.4**, and later.

- Communication parameters of the air interface. The proposal below incorporates, for each direction of communication between interrogator and label, reasonably compact communication with an appropriate level of reliability for the EPC™ reading context.

- Anti-collision algorithms for multiple label reading. The principal impact is on the number of practicable label reads per second. This proposal will be based on an optimised version of the Slotted Terminating Adaptive Collection (STAC) algorithm, adapted to provide fast reading of selected groups of labels in an EPC™ context.

In the face of the complexity and inter-dependence of all of the above issues, we will propose what is believed, on the basis of experience, sensible and achievable label and system parameters.

6.4. Design Objectives

The design objectives pursued in producing the specification of this document are as follows.

- It must allow production of very low cost labels.
- The specification should apply to all varieties of HF EPC™ label.
- The signalling and label operation should support selection of groups of labels by a combination of code version, domain manager and object class.
- The signalling and system operation should allow high throughput in terms of label reads per second.
- Achieving a good (but necessarily label antenna size dependent) label operating range.
- Achieving tolerance of nearby similar label reading systems.
- Achieving non-interference between labels designed to this standard and labels designed to HF ISO standards.

6.5. Anti-collision Method

As the proposal here presented for an HF EPC™ reading methodology differs from that currently embraced for UHF systems by the Auto-ID Center, some comment on the reasons for the difference is appropriate.

UHF EPC™ reading methodology can be described as a tree-walking algorithm with frequent and brief communications both from the interrogator to the labels and from the labels back to the interrogator.

In such a reading methodology, the speed of operation depends significantly upon turn-around times that can be achieved between interrogator signalling and label signalling. At UHF, large bandwidths are available from the interrogator and label antennas, and short turn-around times are achievable. In HF systems, which operate in the near field, and which employ high-quality factor tuned circuits for interrogator to label coupling, the communication bandwidths are significantly reduced, and turn-around times are in consequence extended. There are therefore advantages in speed of operation if the number of turn-arounds per label read are reduced, as they are in the algorithm adopted here.

6.6. Solution Features

The solution produced has the following features.

- It satisfies the design objectives identified above.
- It will cater for mixed label populations containing any of the so far defined varieties of EPC™, and expected future versions.
- It employs a special variant of the slotted adaptive round technology allowing high throughput in an EPC™ context.
- It incorporates label selection for any foreseeable distance along the EPC™ code.
- It achieves high reading throughput by employing truncated replies for selected labels.
- Labels may be destroyed, i.e. rendered unreadable, at close range, on a password protected interrogator command.
- It allows, as an option, the capacity for labels to retain short term memory of read status during field re-orientation.

7. ELECTROMAGNETIC COMPATIBILITY REGULATIONS

7.1. Summary

The regulatory situation worldwide can be summarised as providing an operating frequency of 13.56 MHz, a carrier tolerance of plus or minus 7 kHz, and is the following power level specifications:

– **Europe:** 42 dB µA/m at 10 m, quasi peak detector, and given spectral mask.
– **FCC:** 10,000 microvolt per m at 30 m, quasi peak detector, and different spectral mask.
– **Japan:** one W interrogator output power, antenna gain < or equal to –30 dBi.

It is believed that both Japan and the USA are moving rapidly to embrace European regulations.

7.2. A list of some Regulations

The most recent relevant European regulations appear to be:

– **ETSI EN 300 330-V1.3.1 (2001 – 06)**; Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment in the frequency range 9 kHz to 25 MHz and inductive loop systems in the frequency range 9 kHz to 30 MHz; Part 1: Technical characteristics and test methods.

– **ETSI EN 300 330-V1.1.1 (2001 – 06)**; Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment in the frequency range 9 kHz to 25 MHz and inductive loop systems in the frequency range 9 kHz to 30 MHz; Part 2: Harmonised EN under article 3.2 of the R&TTE Directive.

7.3. Assumption

Will make the assumption that the FCC either has or is about to grant the petition to harmonise its regulation with those in Europe, so we will not further consider the FCC regulations.

7.4. Assessment of Japanese Regulations

To compare the Japanese and European specifications, we notice that the magnetic field level of 42 dB µA/m is equivalent to 125.9 µA/m. Uniform radiation at this level on the surface of the sphere of radius 10 m would correspond to a radiated power of 7.509 milliwatts.

The Japanese regulations appear to allow an isotropically radiated power of one milliwatt. The ratio of the radiated powers allowed by the two regulations is therefore 7.509.

If we assume that the interrogator antenna produces a dipolar field, in which the reactive power density varies as the inverse sixth power of the distance from the antenna, we would conclude that the increase in energising distance available in Europe as compared with that available in Japan would be by a factor of the sixth root of 7.509, i.e. about 1.4.

The above analysis, although correct in early 2002, will become irrelevant if Japan embraces European regulations.

Recent information suggests that such harmonisation of Japanese regulations with European regulations will occur.

8. HUMAN EXPOSURE REGULATIONS

8.1. A List of some Standards

American National Standard
IDE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz, IEEE C95.1 – 1991, April 1992.

Europe
E. U. Council recommendation of 12 Jul 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz).

EN 50357 Evaluation of human exposure to electromagnetic fields from devices used in electronic article surveillance (EAS), radio frequency identification (RFID) and similar applications.

EN 50364 Limitation of human exposure to electromagnetic fields from devices operating in the frequency range 0 Hz to 10 GHz, used in electronic article surveillance (EAS), radio frequency identification (RFID) and similar applications.

The above two documents appear in the Cenelec index.

Australia
Interim Australian/New Zealand standard radio frequency field Part 1: Maximum exposure levels 3 kHz to 300 GHz; AS/NZS 2772.1 (int): 1998.

B. OPERATING CHARACTERISTICS

9. INTRODUCTION

This part B of the specification proposes an air interface and anti-collision method with the capability of an identification rate of 200 labels per second.

Features of the specification include:

a) it can apply to EPC™ labels of any length, including prospective 256 bit labels and beyond;
b) selection of labels for any conceivable distance along the EPC™ code is possible;
c) a full range of memory technologies is catered for;
d) label destruction has been made secure through the use of a destroy password of length 24 bits;
e) the use of round sizes of up to 512 slots in size ensures that large label populations can be handled efficiently.

10. PROTOCOL

The basic operating principle of this specification is what is known as the Slotted Terminating Adaptive Collection (STAC) protocol defined below.

10.1. Slotted Terminating Adaptive Collection Protocol

An illustration of the Slotted Terminating Adaptive Collection Protocol is provided in Figure 3.

In the Slotted Terminating Adaptive Collection Protocol, labels reply with randomly selected positions or time intervals referred to as **slots**, which have their beginning and end under interrogator control. An interrogator command signals both the end of the current and the beginning of the next slot. A number of slots form a **reply round**, and selected labels waiting to reply do so **once during each reply round**.

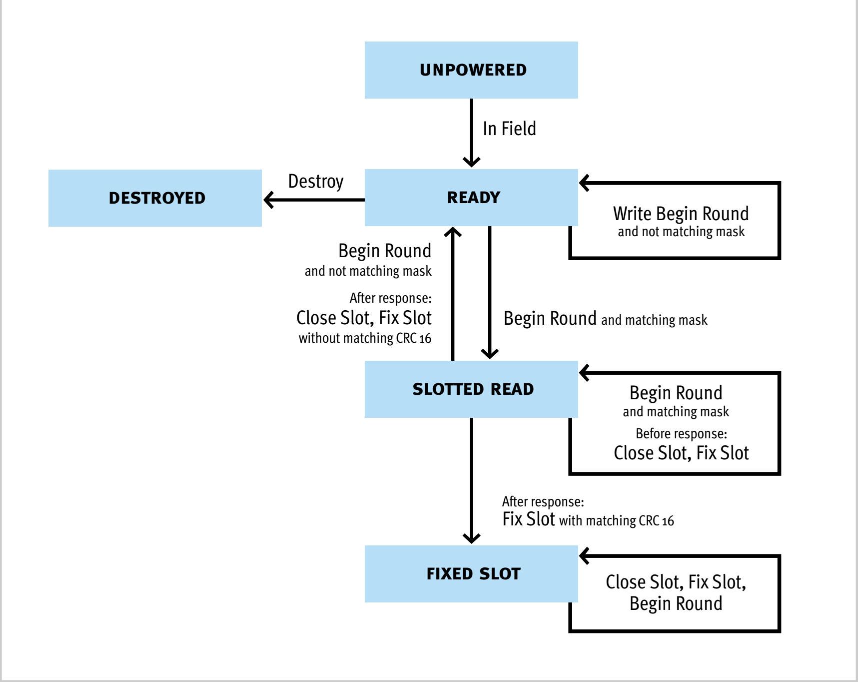
Labels which enter the energising or signalling field, when they have sufficient power for operation, wait before replying in a `READY` state for the reception of one of several commands. Such commands can be a **Write** command, by means of which a label may be programmed with its EPC™, a **Destroy** command by means of which a label may be permanently disabled, or a **Begin Round** command, by means of which an appropriate subset of the labels may offers their data for collection.

The **Begin Round** command contains several parameters. Some of these define the **number of slots** in the forthcoming round. Others of these define a **selection** from among the number of ready labels that will participate in the round. Another parameter is a **hash value** that may regulate the way in which label memory contents are used to generate reply positions within a round. It is intended that within each round, and between different rounds, label replies will occupy what are effectively random positions, so collisions between replies are neither frequent nor repeated.

Figure 3: "Slotted Terminating Adaptive Collection algorithm."

Remark: In the case when the label leaves the field and is not powered any more, the label moves from all states except the `DESTROYED` state into the `UNPOWERED` state.

ILLUSTRATION OF THE SLOTTED TERMINATING ADAPTIVE COLLECTION PROTOCOL

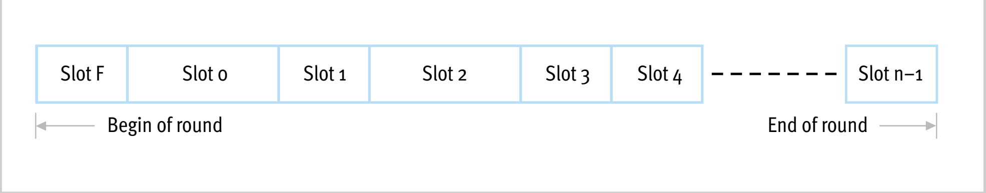


As no label replies without first receiving a **Begin Round** command the protocol is consistent with what is known in the electronic labelling industry as the **Reader Talks First** (RTF) operating mode.

In the STAC protocol the issuing by the interrogator of a **Begin Round** command causes the definition, within each of the selected labels, of a **round size parameter**, a **selected or not selected flag**, a **proposed reply slot position**, and sets to zero a **counter of reply slot positions**. Such reply slot positions are arranged as shown in Figure 4, about which a number points are made below.

Figure 4: Illustration of `STAC REPLY` round slots.

ILLUSTRATION OF SLOTS IN A REPLY ROUND



In relation to Figure 4, we should note that:

- The figure is not to scale, but does correctly indicate that slots are not of equal sizes.
- There is a special slot (slot F) at the beginning of a round. This slot is followed by n further slots to complete the round.
- The number n of further slots is a power of two and is regulated by the interrogator.
- Slot F is of a special and fixed size, but the duration of other slots is regulated by interrogator signalling.
- The longer slots are of duration sufficient for a label reply.

- The shorter slots, (other that slot F) are short because they contained no reply and were closed early by the interrogator.
- Slot F comes to an end automatically without an interrogator signal.
- All slots make an allowance for necessary interrogator signalling.

The issuing of a **Begin Round** command also causes a subset of the labels which were waiting in the READY state to enter the `SLOTTED READ` state. In this state the labels calculate for themselves a proposed reply slot and wait until their slot counter, which will advance each time the interrogator indicates the end of a slot and the beginning of a new one, reaches the **proposed reply slot position**, whereupon the label will reply during the slot.

If any labels in the `SLOTTED READ` state have at the conclusion of Slot F a proposed reply slot position of zero they will reply in slot position 0. The reply conditions within that slot can then be separated into three categories: no label reply present; one label reply present; and two or more label replies present.

The first case above is known to the interrogator through its waiting for the time in which a label reply should have commenced, and by its observing from an examination of the amplitude of signals in the receiver that no reply has in fact commenced.

If the interrogator detects that no label reply is present the interrogator may issue a **Close Slot Sequence** which signals to all labels in the `SLOTTED READ` state, to increment their current slot number. The waveform and timing of the Close Slot Sequence are defined, and with all other interrogator signalling, in **Section 11**.

In the second and third cases above it will be clear to the interrogator that one or more labels are replying, and the interrogator will continue to keep the slot open for a time sufficient for the reply or replies to conclude and be evaluated.

The evaluation may take several forms. One of these is based on a special feature of reply coding described in **Section 11.3**, and makes the detection of collisions, when they occur, highly probable.

Another of these is the checking of a CRC present in the reply, against an expected value that may be calculated from information present in the interrogator to label and label to interrogator signalling. More detail of the checking is provided in **Section 11.2.7**.

If there is evidence from these checks that the label data has not been correctly collected, the slot is closed by a **Close Slot Sequence** as already described for the case of an empty slot and the label returns to the `READY` state.

If however, it appears that the label information has been correctly collected, the slot is closed in another way, in particular by the issuing by the interrogator of a **Fix Slot** command, described along with other interrogator signalling in **Section 11**. The effect of this command, if it is correctly detected by the label, and a parameter of the command matches that expected by the label, is to move the label from the `SLOTTED READ` state to the `FIXED SLOT` state, in which state the label continues to reply once per round, but always in the fixed slot F. When a label replies in Slot F, its reply is truncated, as described in **Section 11.1.9**, so as always to fit into slot F, despite the small size of that slot.

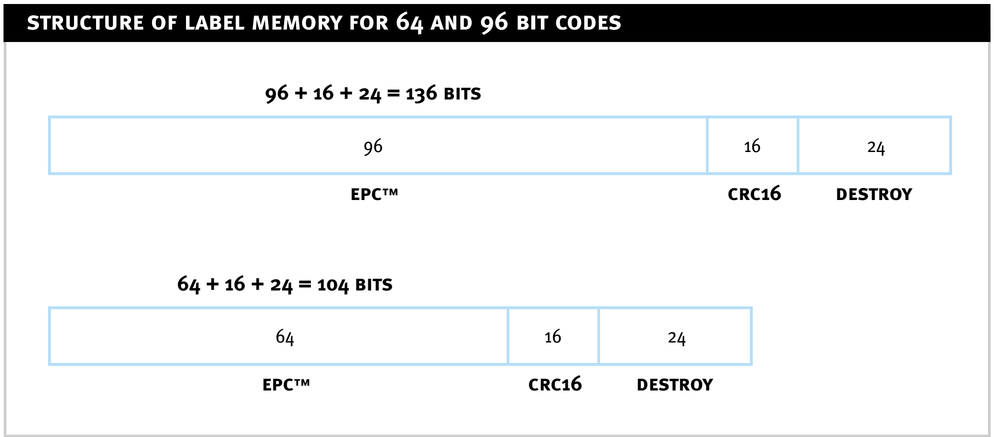
10.2. Memory Content

For the execution of the several functions described above, the label memory contains, as shown in Figure 5, the elements:

- The Electronic Product Code™ which can be of N bits in extent. Values of N are defined by the MIT Auto-ID Center. At present, values of 64 and 96, have been defined, and 256 is likely to be. Other values are also possible.
- A sixteen bit cyclic redundancy check;
- A twenty-four bit destroy code.

These elements are placed in order from left to right, as shown for the cases of 64 and 96 bits, in Figure 5 below. The same arrangement is used for the other length codes. For each, the most significant bit is on the left, and the least significant bit is on the right.

Figure 5: Label memory structure.



Use is made of the above memory structure in the process of label selection described below.

10.3. Label Selection

In this proposal, the labels have a **selection feature** in which groups of labels may be selected e.g. by header, domain manager, object class, or serial number. The interrogator therefore has a selection command which includes the selection data as **optional parameters of the command**.

While a selection command and its data are being processed within the label, the selection data is checked against memory contents on a bit by bit basis, Most Significant Bit (MSB) first. When the signalling of the number of selection bits stated within the command stops, labels in which the EPC™ matches each so far transmitted bit are **selected**. Labels which have a mis-match in one or more transmitted bits are **not selected**. Labels which are **selected** move from the READY state to the SLOTTED READ state shown in Figure 3.

When no effort is made to select labels, as a result of the Begin Round command not having a selection specification, all labels in a READY state when a Begin Round command is given are **automatically selected** and move from the READY state to the SLOTTED READ state shown in Figure 3.

10.4. Truncated Reply

A selected label which subsequently offers a reply will, as shown in Figure 6, reply with the remaining contents of its memory, rounded up to an integral number of bytes, omitting all or most that part which participated in the selection process, and a CRC that is calculated over the entire EPC™ data.

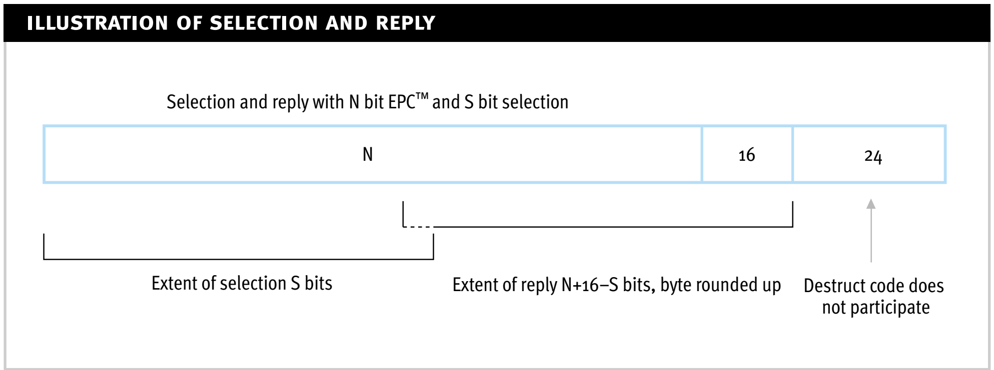


Figure 6: Illustration of label selection and its reply within a reply slot.

This CRC is stored within the label, and introduced therein when the label is first programmed. The reply stops at the end (LSB) of the CRC. It does not extend into the part of memory containing the destroy code.

The reply signal also contains **reply start of frame** and **reply end of frame** signals to be defined later.

An advantage of the above selection implementation is that label reply time is reduced as the number of bits transmitted is less than a full reply. The CRC provides protection against communication errors, either in the transmission by the interrogator of selection data, or by the label of the reply.

It is noted that during the label programming, the destroy code is stored in a dedicated portion of the memory. This destroy code portion of memory does not participate in normal selection or reply.

10.5. State Retention

As long as it is energised, the label keeps a record in a volatile memory of whether it should be in a `READY`, `SLOTTED READ` or `FIXED SLOT` state. It can, as described above, be moved between these states by interrogator command.

10.6. Optional Label Kernel

In normal labels, when energising power is lost, the information on whether a label was in an `READY`, `SLOTTED READ` or `FIXED SLOT` state may be lost.

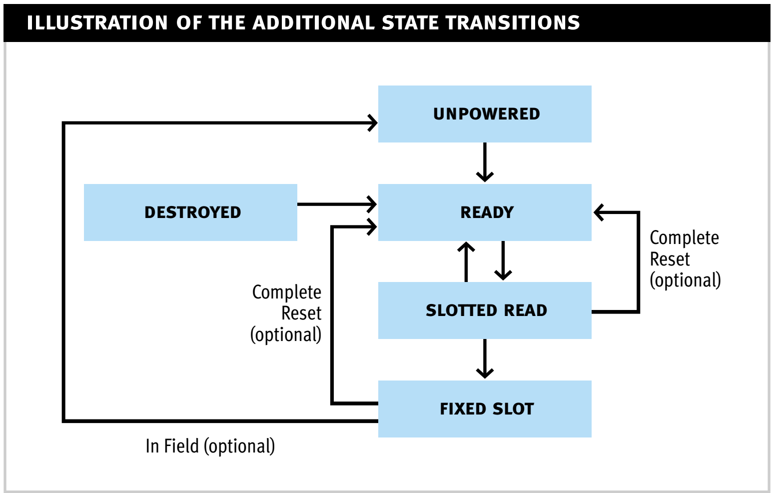


Figure 7: Illustration of the additional state transitions enabled by the optional label kernel.

Remark: In the case when the label was in the `FIXED SLOT` state before the label left the field, the label will return into the `FIXED SLOT` state by entering the field.

In a multiple read application, it can be desirable that such data be preserved for a short time during operations of label movement or necessary field re-orientation. For this purpose, as an option in this specification, a label may be fitted with controlled data retention memory, which will preserve the `FIXED SLOT` status when power is lost for a brief specified period, and move the label status to the `READY` state if energising power is restored after a greater period. That period shall be in the range between 100ms and 100s.

So that labels may, when it is desired, be guaranteed movement to a `READY` state even when the `FIXED SLOT` state has been preserved, the **Complete Reset** command described in **Section 11.1.11** has been provided as an option for those labels that have the capacity to remember to re-enter the `FIXED SLOT` state.

The additional state transitions enabled by this kernel feature and by the Complete Reset command are illustrated in **Figure 7**.

10.7. Label Programming

Before a label is placed into service, its entire memory contents are programmed and checked by the owner. This programming operation is intended to occur only once, after which the label memory contents should be **locked**. More detail on programming is given in **Section 11.1.11**.

10.8. Label Destruction

In a destruction operation the interrogator sends a **Destroy** command containing **selection data** that contains the entire memory contents consisting of the Electronic Product Code™, the CRC and the Destroy Code, as illustrated in **Figure 5**.

Provided the interrogation power experienced by the label reaches a specified threshold, and is present for a specified time following the reception of the destroy command, the selected label will be moved to the `DESTROYED` state.

In this state, the label will no longer modulate the interrogation carrier in any way.

No recovery from the `DESTROYED` state is possible.

The power level and dwell time for the destroy command to operate have not yet been specified.

11. AIR INTERFACE

Communication between the interrogator and the label is conducted via an air interface described in this section. The detailed operation of the anti-collision protocol is described in the preceding and following sections.

11.1. Communication Interrogator to Label

11.1.1. Operating frequency

The label receives its energising power, and also the instructions which regulate its behaviour, from a high frequency magnetic field produced by an interrogator.

The interrogator carrier frequency is required by EMC regulations to fall within 13.56 MHz ± 7 kHz.

When it is not modulated for the purpose of conveying commands or data, the interrogation carrier should maintain low phase noise.

During or between periods of interrogator command signalling, the interrogator may, for improved electromagnetic compatibility, employ a small amount of frequency modulation of limited frequency deviation, low sweep rate and low noise. Such modulation is unnoticed by the broadband amplitude detection circuits within the labels, and if confined to low frequencies, will not affect the spectrum of label reply signals.

11.1.2. Unitary pulse

All of the signalling from the interrogator to the label makes use of the unitary interrogation carrier signal amplitude dip of nominal width 9.44 µs, of which two instances are shown in Figure 7 below.

The pulse may be described in terms of the modulation index m, or the dip depth d, defined as:

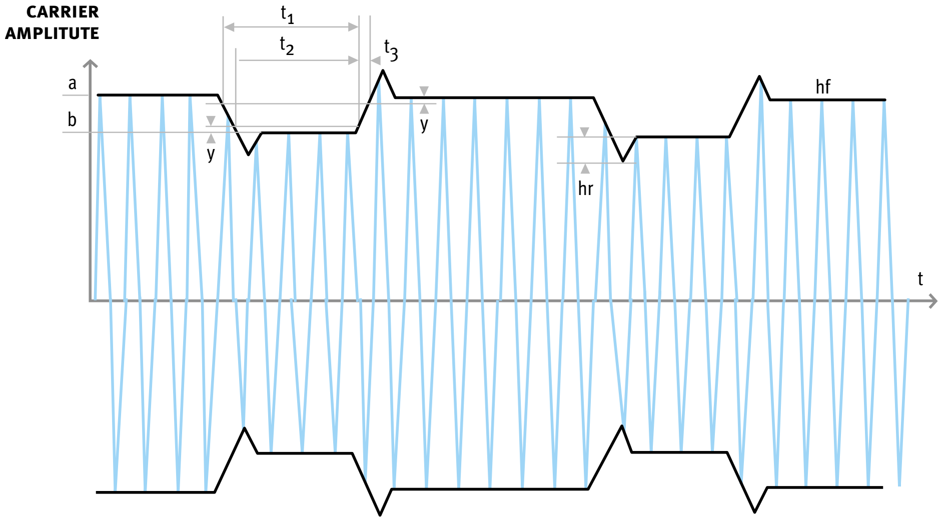
Modulation index	m	$(a - b) / (a + b)$
Dip depth	d	$(a - b) / a$

The relations between those parameters are:

$$m \qquad d / (2 - d)$$
$$d \qquad 2m / (m + 1)$$

Figure 8: Illustration of interrogator signalling parameters.

ILLUSTRATION OF INTERROGATOR SIGNAL DIP



	Min	Max
t_1	6,0 µs	9,44 µs
t_2	3,0 µs	t_1
t_3	0	9,44 µs
Modulation Index	10%	30%

y	0,005 (a–b)
hf, hr	0,1 (a–b) max

11.1.3. Important discussion

It is noted that the parameters in the tables appearing in **Figure 8** include the case of a rectangular dip of duration equal 9.44 µs, as well as smoother and shorter dips.

There are two points of view for which m (or d) and the other pulse parameters of **Figure 8** may be interpreted.

The first is the range of pulse amplitudes and waveforms to which the label should be capable of responding correctly. From this point of view, the table forming part of **Figure 8** indicates that the label should respond correctly with m from 10% to 30% (d from 18% to 46%).

The second point of view is what modulation depth is intended to be used in interrogators. There is an argument to say that in a well-designed interrogator such wide variation in m or d is not expected, and a lesser variation should be tolerated. This is particularly so since there are serious electromagnetic compatibility consequences to having the combination of long signalling strings, deep dip depths, dips of full area, full carrier operating power, and no interrogator carrier frequency modulation during signalling.

If for long range operations the maximum carrier level is used, designers of systems and interrogators should be aware that the just mentioned combination of signalling parameters should not be employed. The combination of signalling parameters must be chosen in a way that gives compliance to electromagnetic compatibility regulations.

It is therefore understood that while interrogator pulse parameters may not stray outside the limits specified in **Figure 8** above, the tolerances that will be applied by some manufacturers to interrogator pulses will sometimes be more strict than those appearing in **Figure 8** above.

11.1.4. Baud rate

The baud rate in the Interrogator to Label link is 26.48 kbit/sec (f_c/512).

11.1.5. General structure of interrogator signalling

All interrogator to label signalling is composed of **symbols** consisting of **patterns of single dips** of the type shown in **Figure 9**.

The leading edges of all such dips in a coherent signalling sequence are at a multiple of a basic time of exactly 128/f_c or approximately 9.44 µs from one another. By coherent signalling we mean a single symbol (such as the Close Slot Sequence defined in **Figure 9**), or a sequence of symbols making one of the commands defined in **Section 11.1.7**.

The duration of all symbols is one of T, 2T or 3T, where T is exactly 512/f_c, or approximately 37.76 µs.

Symbols are built up into **commands** as described in **Section 11.1.7**.

The symbols consist of:

- A **Long Start of Frame** that is used for beginning of some commands.
- A **Short Start of Frame** used for beginning of other commands.
- A common **End of Frame** used for ending of all commands.
- **Binary symbols** for zero and one used within commands.
- A special **Close Slot Sequence** that is used for closing slots from which no information was collected.

The full symbol set has been chosen to achieve a number of objectives.

- Neither of the Start of Frames will be accidentally mis-detected by a label that hears an incomplete portion of signalling.
- All symbols are sufficiently different from symbols used in 13.56 MHz standards for signals from an ISO interrogator not to be detected as a valid EPC™ label signalling string.

Framing has been chosen for ease of synchronization and independence of protocol.

The label shall be ready to receive a symbol within 1 ms of activation by the powering field.

The label shall be ready to receive a symbol from the interrogator within 300 µs after having sent a frame to the Interrogator. Framing of label reply signals is discussed in **Section 11.2.6**.

11.1.6. Illustration of symbol set

The symbol set used in signalling, including start and end of frames, is shown in the **Figure 9**. In that figure, all dips are of nominal width 9.44 µs, but may be shaped according to **Figure 8** in **Section 11.1.2**, and the discussion below it.

Binary symbols and the Common End of Frame have a duration of T = 512/f_c = 37.76 µs, the Short Start of Frame has a duration of 2T = 1024/f_c = 75.52 µs, and Long start of Frame and the Close Slot Sequence have a duration of 3T = 1536/f_c = 113.27 µs.

It should be noted that two of the possible short symbols which could have been generated is not allowed, and must not be employed by the interrogator. Such symbols, if detected by the label, are to be regarded as an error in signalling, and if they are so detected, the label should take no action in relation to the signalling string in which that symbol appears to have occurred.

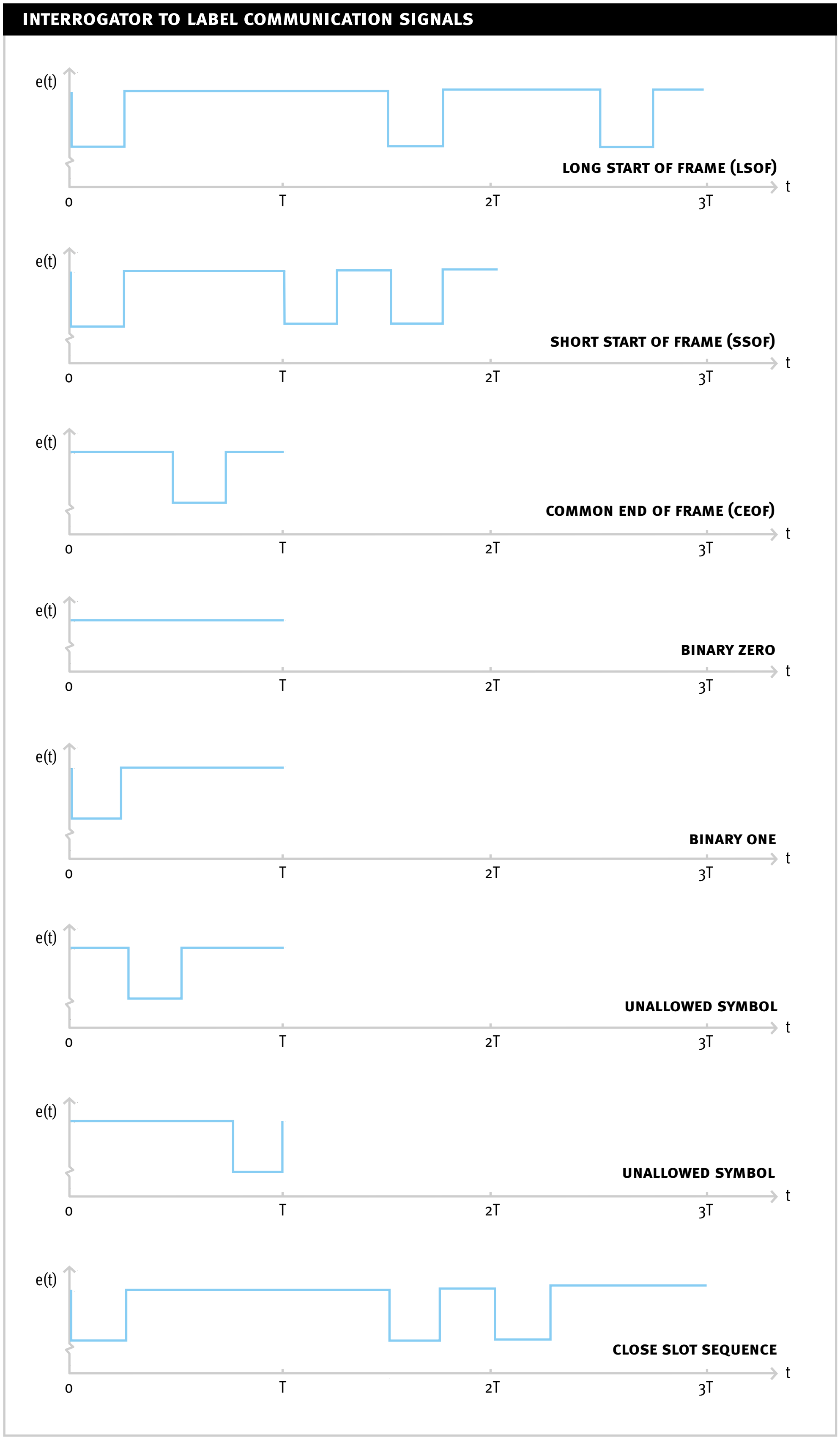


Figure 9: Interrogator to label communication signals.

11.1.7. Command set

The command set necessary to accomplish the slotted terminating adaptive collection algorithm is provided in the list below.

- A **Begin Round** command. This command necessarily carries a number of slots parameter, in the range 1 to 512, the Hash value and optionally carries a selection parameter.
- A **Complete Reset** command (optional).
- A family of **Write** Commands. This family, in catering for a range of memory technologies, includes a number of optional memory locking commands.
- A **Destroy** command.
- A **Close Slot Sequence**. This very simple command takes the form of the special sequence illustrated in **Figure 9**.
- A **Fix Slot** command. This command instructs a label that has just replied, and in which certain parameters of its memory match parameters found in the command, to move to a `FIXED SLOT` state. Other labels ignore this command, except that such other labels as are in the `SLOTTED READ` state will increment their count of slot number.

In this list, the **Begin Round** command contains a parameter describing round size. It may also contain a parameter that describes the extent of the label selection. It can move selected powered labels from the `READY` state to the `SLOTTED READ` state. It can also remove labels from the `SLOTTED READ` state and return them to the `READY` state.

If there is no selection parameter, all labels in the `READY` state are considered **selected**.

The **Complete Reset** command applies to all labels in the `FIXED SLOT` state with an implemented optional label kernel. It moves them all to the `READY` state.

The **Destroy** command applies to any label that has not been destroyed, that is in the `READY` state, has parameters in its memory matching those specified in the command, and for which the interrogation field reaches a specified threshold which may be higher than the normal interrogation threshold, and renders that label forever inoperable.

The **Write** commands apply to a label in the `READY` state, in which the part of memory sought to be written to has not been locked.

11.1.8. Begin round command

11.1.8.1. STRUCTURE

The structure and parameters of the Begin Round command are defined in Figure 10 below and the text which follows.

Figure 10: Begin round command structure.

BEGIN ROUND COMMAND

SSOF	COMMAND CODE	MASK LENGTH	SELECTION MASK	NUMBER OF SLOTS	CRC8	HASH VALUE	CEOF

The **Command code** has length 8 bits and value 30 hex.

The **Mask Length parameter** is always present, and is of length 8 bits or 24 bits. It specifies the number of bits included in the selection mask. If the value is zero, the selection mask is not present. If the value of the first byte is FFhex, the mask length is coded in three bytes, in the order FFhex, most significant byte of mask length, and least significant byte of mask length. These rules allow the number of bits in the mask to lie between 1 and 65535 inclusively. Labels need not provide for a mask length greater than their memory capacity.

The **Selection Mask parameter** is present if the mask length is non-zero; otherwise it is absent. When present, it specifies the number of bits to be compared with the EPC™ in the selection process. If all bits of the Selection Mask match, the label will be selected and will respond to a Begin Round command.
If the mask length exceeds the memory capacity of the chip, the label will remain unselected and shall not respond to a Begin Round command.

The Number of Slots parameter is always present, and is of length 8 bits. The coding of the number of slots is as follows:

Note: this coding allows an efficient implementation; two slots are not essential for applications.

1 slot : 00hex
4 slots : 01hex
8 slots : 03hex
6 slots : 07hex
32 slots : 0Fhex
4 slots : 1Fhex
28 slots : 3Fhex
256 slots : 7Fhex
512 slots : FFhex

The **CRC parameter** is of 8 bits and is described in **Section 11.1.13**.

The **hash value** is of length 8 bits and may be used by the label to generate from EPC™ data approximately random slot positions.

11.1.8.2. LABEL RESPONSE
All labels will calculate a response position in the range of the round size, excluding slot F, and when the slot count maintained within the label reaches that count, the label will reply with that part of the EPC™ which was not contained in the S bits of the selection data, but rounded up to an integral number of bytes, as illustrated in Figure 11 below.

Figure 11: Label response to the Begin Round command.

BEGIN ROUND COMMAND

RSOF	REMAINING PART (BYTE ROUNDED UP) OF N BIT EPC™	CRC16	REOF

The CRC 16 is stored in label memory, it is the CRC over all N bits of the EPC™. Further details of the reply CRC are given in **Section 12.2.7**.

Figure 6 has already shown how the label selection is integrated into the Begin Round command and its response. That information is re-asserted in Figure 10.

11.1.9. Close Slot Sequence

11.1.9.1. STRUCTURE

The form of the Close Slot Sequence has been defined in **Figure 9**.

11.1.9.2. LABEL RESPONSE

Upon receiving a Close Slot Sequence, a label that is in the `SLOTTED READ` state and has not replied, will advance its count of slot numbers, and then perform the actions described in **Section 10.1** for labels in the `SLOTTED READ` state that are carried out at the beginning of a slot.

Alternatively, upon receiving a Close Slot Sequence, a label that is in the `SLOTTED READ` state and has just replied will move to the `READY` state, and will be available for reading in another round.

All other labels will ignore the command.

11.1.10. Fix Slot command

If there is no evidence of a collision, either through failure of a CRC check or through the mechanisms of reply signal examination described in **Section 11.3**, it can be concluded that a successful collection of data has occurred and a Fix slot command may be issued.

11.1.10.1. STRUCTURE

The Fix Slot command is targeted at a label, and normally that is a label that has just replied. The Fix Slot command consists of a Long Start of Frame, sixteen binary digits that are the CRC16 of the label being targeted, and a common End of Frame, as shown in **Figure 12** below.

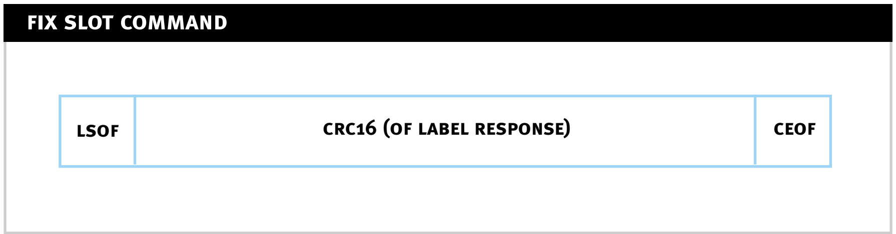


Figure 12: Structure of the Fix Slot command.

11.1.10.2. LABEL RESPONSE

Only the label that has just replied in the current slot, and has also a CRC matching the data sent in the command will move to the `FIXED SLOT` state.

A label that has just replied but has a CRC not matching the data sent in the command will move to the `READY` state.

All other labels will ignore this command except that such labels in the `SLOTTED READ` state will increment their count of slot number, and then perform the actions described in **Section 10.1** for labels in the `SLOTTED READ` state that are carried out at the beginning of a slot.

11.1.11. Reply Round timing

The following Figure shows the timing within a reply round. Note that the diagram is not to scale, but does show the elements that make up a slot.

Figure 13: Illustration of Reply Round timing.

FS – Fix Slot Command
CS – Close Slot Sequence
RSOF – Reply start of frame

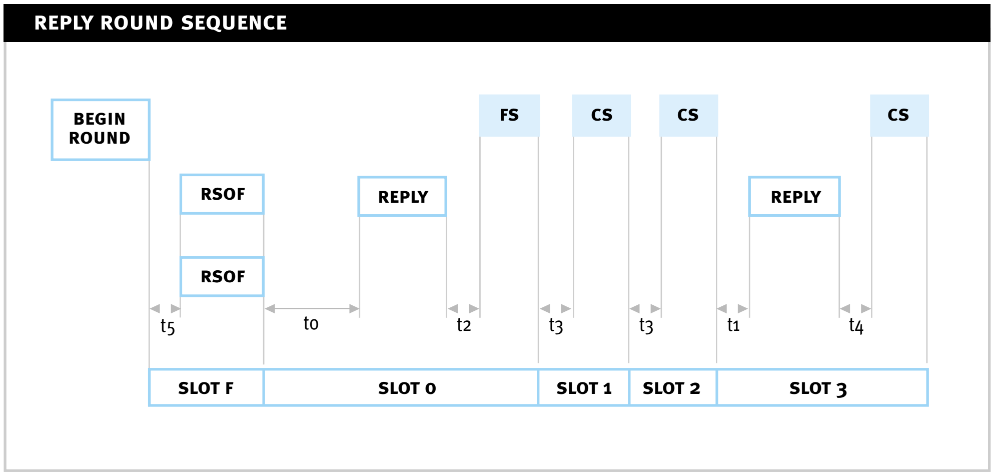


Table 2: Reply Round Timing.

Notes: All timings refer to the logical end of the preceding command or symbol.

	MINIMUM	MAXIMUM
t_0	113.27 µs – 2.36 µs	113.27 µs + 2.36 µs
t_1	302.06 µs – 2.36 µs	302.06 µs + 2.36 µs
t_2	302.06 µs – 2.36 µs	302.06 µs + 2.36 µs
t_3	$t_{1nominal} + t_{RSOF}$ + 37.76 µs	Infinite
t_4	302.06 µs – 2.36 µs	Infinite
t_5	151.03 µs – 2.36 µs	151.03 µs + 2.36 µs

The beginning of all interrogator signals must be synchronous with the interrogator bit grid which is at intervals of $256/f_c$ = 37.76 µs.

302.06 µsec is equal to $4096/f_c$
151.03 µsec is equal to $2048/f_c$
113.27 µsec is equal to $1536/f_c$
18.88 µsec is equal to $256/f_c$
2.36 µsec is equal to $32/f_c$

t_0: Time between the logical end of slot F and the reply of label replying in slot 0.

t_1: Time between the logical end of any slot except slot F and the reply of label replying in the following slot. The logical end of a slot is 18.88 µs after the first edge of the CEOF.

t_2: Time between the logical end of a reply of a correct identified label and the LSOF of a Fix Slot command. This command must be sent synchronous to the reader bit grid generated by the Begin Round command.

t_3: Time between the logical end of a slot where no label has replied and the Close Slot sequence. This command must be sent synchronous to the reader bit grid generated by the Begin Round command. $t_{RSOF} = 37.76\ \mu s$

t_4: Time between the logical end of a not correct received reply of one or more labels and the Close Slot sequence. This command must be sent synchronous to the reader bit grid generated by the Begin round command. It may also be issued if the reply of a label was correctly received.

t_5: Time between the logical end of the Begin round command and the RSOF of label replying in slot F.

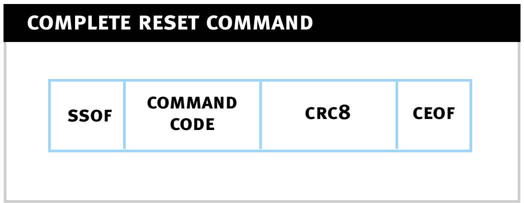
11.1.12. Complete Reset command (optional)

The function of the Complete Rest command is to get labels which have remained in the `FIXED SLOT` state as a result of implementing a persistent memory of this state and performing a field re-orientation back in to a condition in which their data may be collected.

11.1.12.1. STRUCTURE

The structure of the optional Complete Reset command is defined in **Figure 14** below and the text which follows. The command carries no parameters.

Figure 14: Structure of the Reset command.



The **Command code** has length 8bits and value 12 hex.

The **CRC parameter** is of 8 bits and is described in **Section 11.1.14**.

11.1.12.2. LABEL RESPONSE

The Complete Reset command is acted upon by all labels that have not been destroyed, and are powered.

It moves them all to the `READY` state.

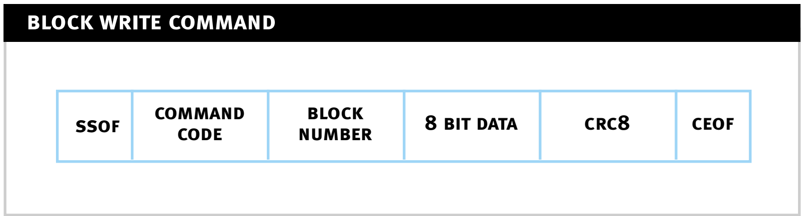
They will not then be participating in a round, but will be ready to receive a Begin Round command.

11.1.13. Write commands

11.1.13.1. BLOCK WRITE COMMAND

The block write commands write data into the label memory in eight bit blocks. The structure of the block write command is as shown in Figure 15 below.

Figure 15: Structure of the Block Write command.



Writing may occur to any part of memory including in the EPC™ data, the 16 bit reply CRC and the destroy password.

The parameters of the write command are defined as follows:

- The **command code** is of length 8 bits and has the value 01hex.
- The **block number parameter** takes the values:

  00hex (MSByte of EPC™), 01hex, … XXhex (LSByte of EPC™);
  (XX+1)hex (MSByte of CRC16);
  (XX+2)hex (LSByte of CRC16);
  (XX+3)hex … (XX+5)hex 24 bit password starting with MSByte.

XX is the hexadecimal representation of the EPC™ length in bytes minus one.

The **8 bit data parameter** is the eight bits of data to be written, MSB on the left.
The **CRC8 parameter** is calculated over the Command- code, Block number, and 8 bit data as described in **Section 11.1.14**.

There is no reply response from the label.

As options available to the chip manufacturer, the block written to may
a) for the case when the memory has been programmed at mask level, the label may ignore the command
b) for the case when the memory is one time writeable, the block may be automatically locked by the command, or
c) for the case when the chip has memory which may be several times written, the block may remain writeable after the command.

11.1.13.2. LOCK BLOCK COMMAND (OPTIONAL)
The optional Lock Block commands lock eight bit blocks of data into the label memory.
The structure of the Lock Block commands is as shown in **Figure 16** below.

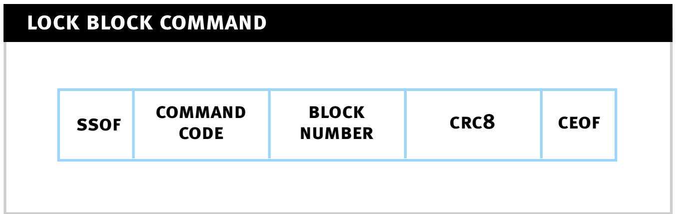


Figure 16: Structure of the Lock Block command.

Locking of any part of memory may be performed.

The parameters of the Lock Block command are defined as follows:

- The **command code** is of length 8 bits, and has the value 20 hex.
- The **block number parameter** takes the values defined for the Block Write command.
- The **CRC8 parameter** is calculated over the Command code and Block number as described in **Section 11.1.14**.

There is no reply response from the label.

As options available to the chip manufacturer:
a) for the case when the label has been programmed at mask level, the chip will take no further action;
b) for the case when the label has one time writeable memory which becomes automatically locked on writing, the chip may take no action on this command;
c) for the case when the chip has memory which may be several times written, the addressed block may become locked by this command.

As locking is in eight bit segments, and some EPC™ fields transcend 8 bit boundaries, locking will need to be carefully organised.

11.1.13.3. LOCK WHOLE MEMORY (OPTIONAL)

The optional Lock Whole Memory command locks all blocks of data in the label memory.

The structure of the Lock whole Memory command is as shown in **Figure 17** below.

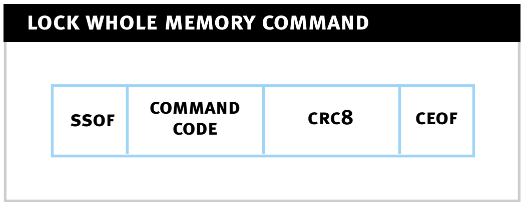


Figure 17: Structure of the Lock Whole Memory command.

The parameters of the Lock Whole Memory command are defined as follows:

- The **command code** is of length 8 bits, and has the value 21 hex.
- The **CRC8 parameter** is calculated over the Command-code as described in **Section 11.1.14**.
- There is no reply response from the label.

As options available to the chip manufacturer:
a) for the case when the label has been programmed at mask level, the chip will take no further action;
b) for the case when the label has one time writeable memory which becomes automatically locked on writing, the chip may take no action on this command;
c) for the case when the chip has memory which may be several times written, the whole memory may become locked by this command.

11.1.13.4. DESTROY COMMAND

The destroy command will render the label permanently unable to give any replies.

The structure of the Destroy command is as shown in **Figure 18** below.

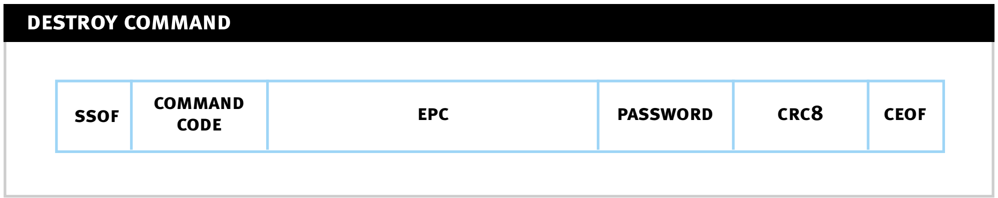


Figure 18: Structure of the Destroy command.

The parameters of the Destroy command are defined as follows:

- The **command code** is of length 8bits, and has the value 02hex.
- The **EPC™ parameter** includes the entire N bits of the EPC™.
- The **password parameter** is of length 24 bits, and can have any content previously written into the relevant section of memory.
- The **CRC8 parameter** is calculated over the Command-code, the EPC™, and password as described in **Section 11.1.14**.
- There is no reply response from the label.

11.1.13.5. LOCKING AFTER WRITING

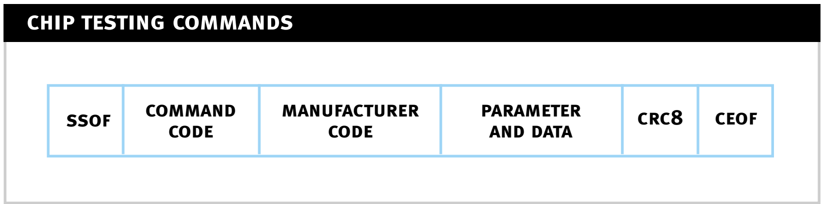
After the EPC™ and destroy password have been programmed into the label, the label memory is to be locked so that change of these parameters cannot occur.

11.1.13.6. CHIP TESTING COMMANDS

The op-code-range from “F8” to “FF” may be used for manufacturer specific chip testing commands.

The structure of manufacturer specific chip testing commands should be as follows:

Figure 19: Structure of the Chip Testing commands.



CHIP TESTING COMMANDS

SSOF	COMMAND CODE	MANUFACTURER CODE	PARAMETER AND DATA	CRC8	CEOF

Any manufacturer specific command contains as its first parameter a single byte manufacturer code. This allows manufacturers to implement custom chip testing commands without risking duplication of such command codes and thus misinterpretation. The manufacturer codes will be issued by the Auto-ID Center upon application.

The Auto-ID Center will reserve the zero manufacturer code for itself.

If the label does not support a manufacturer specific chip testing command, it must remain silent.

The manufacturer specific chip testing commands must not introduce additional chip functions not performing the objective of chip testing.

11.1.14. Reserved commands

All command operation codes not specifically defined in the specification are reserved by the Auto-ID Center for future use.

11.1.15. CRC in interrogator to label link

In the interrogator to label link an 8 bit CRC is used.

8 bits is seen as a good compromise between required data integrity and chip area. It is noted that the interrogator to label signalling has a much higher S/N ratio than the label to interrogator link.

The generator Polynomial is $x^8+x^4+x^3+x^2+1$, the preset value is FFhex, and no inversion of the CRC is done before transmission.

If the label detects a CRC error it shall not execute the command.

11.2. Communication Label to Interrogator

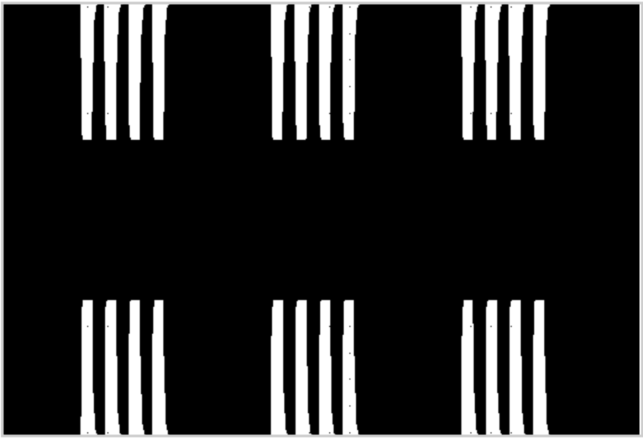
11.2.1. Generation of reply

The label shall be capable of communication to the interrogator via inductive coupling from its antenna coil. The label reply is generated through amplitude modulation of the oscillation in the tuned circuit containing the label antenna coil, wherein the tuned circuit load is switched by a sub-carrier with frequency f_s. The sub-carrier is generated by dividing the 13.56 MHz clock frequency f_c. The frequency f_s of the sub-carrier is $f_c/32$ (423,75 kHz).

11.2.2. Illustration of reply modulation

The principle of load modulation is shown in **Figure 20**, which illustrates the label tuned circuit voltage during modulation. The black regions indicate regions of interrogator carrier wave oscillations of period too small to be resolved.

Figure 20: Label antenna voltage during load modulation.



11.2.3. Reply signal content

As already partly explained in the **Section 10.4**, the reply signal consists of a **reply start of frame** signal as defined in **Section 11.2.6**, that portion of the Electronic Product Code™ of which was not used in the label selection by means of which the label became active, followed by a 16-bit cyclic redundancy check drawn from the label memory, and terminated by the **reply end of frame** signal defined in **Section 11.2.6**.

11.2.4. Reply data coding

A logic 0 starts with 4 pulses of $f_c/32$ (~423,75 kHz) sub-carrier, followed by an un-modulated time of $128/f_c$ (~9.94 µs), as shown in **Figure 21**.

The waveforms in **Figure 21**, and similar diagrams to follow, represent logic states illustrating the periods of high damping and low damping of the antenna tuned circuit. They are not amplitudes of signals, but high oscillation amplitude will in fact occur during the high parts of the waveforms.

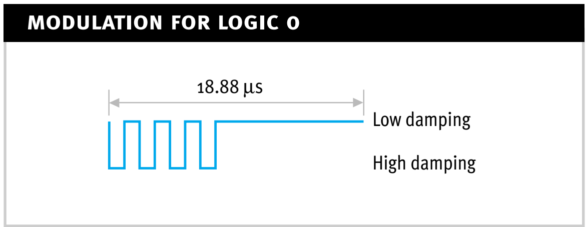


Figure 21: Modulation for logic 0.

A logic 1 starts with an un-modulated time of $128/f_c$ (~9.94 µs) followed by 4 pulses of $f_c/32$ (~423,75 kHz) sub-carrier, as shown in **Figure 22**.

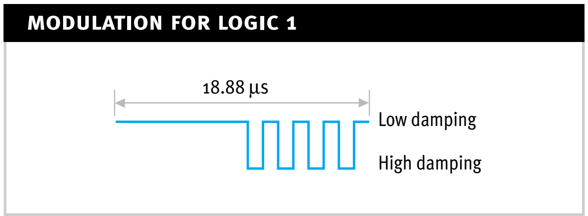


Figure 22: Modulation for logic 1.

11.2.5. Reply baud rate

The baud rate in the label to interrogator link is 52.969 kbit/s ($f_c/256$).

11.2.6. Reply framing

The **reply start of frame** (RSOF) starts with 12 pulses of sub-carrier of $f_c/32$ (~423,75 kHz), followed by an un-modulated time of $128/f_c$(~9.94 µs) as shown in **Figure 23**. The significance of high levels and low levels in the diagram are the same as for **Figures 21** and **22**.

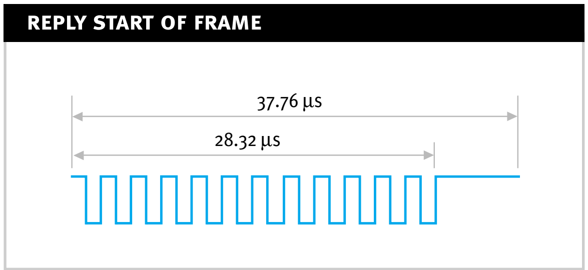


Figure 23: Modulation for reply start of frame.

The **reply end of frame** (REOF) shown in **Figure 24** starts with an un-modulated time of $128/f_c$ (~9.94 µs), followed by 12 pulses of sub-carrier of $f_c/32$ (~423,75 kHz).

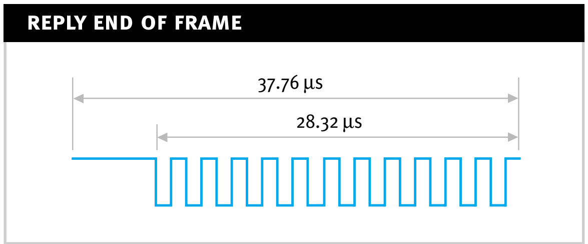


Figure 24: Modulation for reply end of frame.

11.2.7. Reply CRC

The interrogator to label link uses a 16 bit CRC which is defined in **Figure 25** and following text, and is stored in the label.

Figure 25: CRC 16 definition.

CRC DEFINITION				
CRC Type	Length	Polynomial	Preset	Residue
ISO/IEC 13239	16 bits	X16 + X12 + X5 + 1	0xFFFF	0x1D0F

The Cyclic Redundancy Check (CRC) is calculated on all N bits of the EPC™ starting with the MSByte MSbit thereof.

A further transformation on the calculated CRC is made. The value stored in the label and which is attached to the message for transmission is the One's Complement of the CRC calculated as in Figure 23. For ease of checking of received messages, the two CRC bytes are often also included in the re-calculation. In this case, the expected value for the residue of the CRC generated in the receiver is 0x1D0F.

11.3. Anti-collision

The anti-collision process is linked to the physical air interface because:

- regulatory requirements limit the amount of interrogator signalling that may be employed;
- recovery times of receivers are related to the ratio: (bit-duration) / (sub-carrier frequency).

Good performance may be achieved using a synchronous, pulse slot-based reply system, in which the labels respond in self-chosen slots, whose timing is initiated at first by a command from the interrogator, but is later maintained by next slot signals signalled by the interrogator.

Use is also made of the uniqueness of the EPC™ codes in the detection of collisions.

The operation of the collision detection methodology is explained in the sections below.

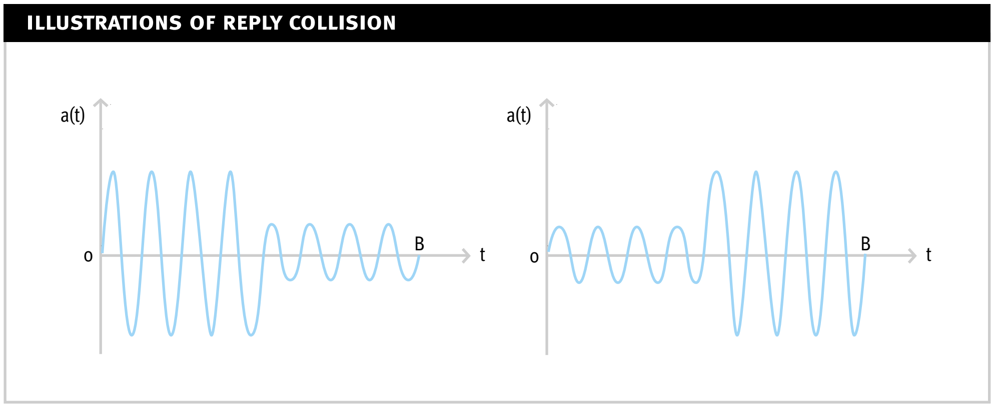
11.3.1. Concept

The collision detection methodology present in this proposal depends upon the facts that:

- The data content of all replying labels will be different.
- The bit boundaries in the reply signals from all simultaneously replying labels will be closely aligned.
- Each bit period contains a period of no modulation, positioned in a data dependent way.

In consequence, two simultaneously replying labels will, even if replying with different signal strengths, exhibit in the receiver of the interrogator the interference pattern as illustrated in the Figure 26 below.

11.3.2. Illustration



ILLUSTRATIONS OF REPLY COLLISION

Figure 26: Illustrations of reply collisions.

The presence of modulation in both halves of the reply period can be detected by the interrogator. The dynamic range of reliable detection is suitably large when the four cycles of sub-carrier occupy each half of the bit period B = 256/f_c (~18.88 µs).

11.3.3. Interrogator response to collision

In response to detection of a collision as described above, or to a failure of the CRC check as described in **Section 11.2.7** the interrogator will close the current slot through the issuing of the Close Slot Sequence described in **Section 11.1.9**.

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