

Read-only UHF Radio Frequency Identification Device according to ISO IEC 18000-6

Description

The EM4223 chip is used in UHF passive read-only transponder applications. The chip derives its operating power from an RF beam transmitted by the reader, which is received and rectified by the chip. It transmits its factory-programmed code back to the reader by varying the amount of energy that is reflected from the chip antenna circuit (passive backscatter modulation).

The air interface communication protocol is implemented according to ISO18000-6 type A.

The code structure supports the effort of EPCglobal, Inc. as an industry accepted standard.

It additionally incorporates the Fast Counting Supertag™ protocol for applications where the fast counting of large tag populations is required.

The chip is frequency agile, and can be used in the range of 800 MHz to 2.5GHz for RF propagating field applications.

Features

- Air interface is ISO18000-6 type A compliant
- Supports EAN•UCC and EPC™ data structures as defined by the Auto-ID center
- Supports Fast Counting Supertag™ mode
- 128 bit user memory license plate Group select by means of 'Application Family Identifier' (AFI) according to ISO
- Fast reading of user data during arbitration (no need to first take an inventory)
- Specific command set for supply chain logistics support.
- Frequency independent: Typically used at 862 - 870 MHz, 902 - 950 MHz and 2.45 GHz
- Low voltage operation - down to 1.0 V
- Low power consumption
- Cost effective
- -40 to +85°C operating temperature range

Typical Applications

- Supply chain management (SCM)
- Tracking and tracing
- Asset control
- Licensing
- Auto-tolling

Key words

- ISO 18000-6A
- UHF
- EPC™ data structure
- Fast Supertag™

Benefits

- Numbering scheme according to international standards
- Operates worldwide according to the local radio regulation
- Ideal for applications where long range and high-speed item identification is required

Typical Operating Configuration

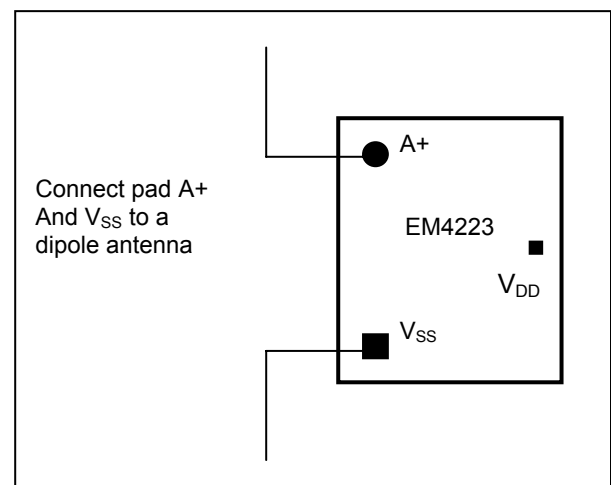


Fig. 1

Chip design is a joint development with RFIP Solutions Ltd

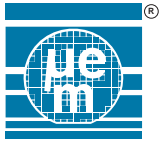


Table of contents

READ-ONLY UHF RADIO FREQUENCY IDENTIFICATION DEVICE ACCORDING TO ISO IEC 18000-6.....	1
Description	1
Typical Applications	1
Key words	1
Benefits	1
TABLE OF CONTENTS	2
Absolute Maximum Ratings	3
Handling Procedures	3
Operating Conditions	3
Block Diagram.....	3
Electrical Characteristics.....	4
Timing Characteristics	4
1. GENERAL DESCRIPTION.....	5
2. FUNCTIONAL DESCRIPTION	5
General Command Format	6
Supported Command set	6
3. BASIC COMMAND FORMATS.....	6
Short commands	6
Extended commands	6
Implied MUTE command (Fast Supertag Mode only) ..	7
Command state transitions	11
4. GENERAL REPLY FORMAT	14
5. FORWARD LINK ENCODING - READER TO TRANSPONDER	15
Carrier modulation pulses	15
Basic time interval – definition of “Tari”	15
Data coding	16
Data Frame format.....	16
Data decoding.....	17
Bits and byte ordering	17
Reader to Transponder 5 bit CRC (CRC-5)	17
Command Decoder	17
6. RETURN LINK DATA ENCODING - TRANSPORTER TO READER	18
Return link data encoding	18
Return link preamble	19
Cyclic Redundancy Check (CRC)	19
7. MEMORY ORGANISATION AND CONFIGURATION INFORMATION	19
Memory Map	19
Unambiguous User Data (UUD) & SUID.....	19
AFI	20
Personality Block	20
8. TRANSPONDER SELECTION OPERATION – INIT_ROUND AND BEGIN_ROUND COMMANDS.....	21
INIT_ROUND COMMAND SELECTION OPERATION	21
BEGIN_ROUND COMMAND SELECTION OPERATION	22
9. COMMANDS AND STATES.....	23
Commands.....	23
Tag States	23
Tag state storage	24
10. COLLISION ARBITRATION.....	25
General explanation of the collision arbitration mechanism	25
FST SYSTEMS	25
FST MODE OPTIONS.....	26
Use of the round_size function (ISO & FST modes) ..	27
Ordering Information	29
Versions	29

Absolute Maximum Ratings

Parameter	Symbol	Min	Max
Supply Voltage $V_{DD} - V_{SS}$ (V)	V_{DD}	-0.3	+3.6
Storage temperature (°C)	T_{store}	-50	+150
RMS supply current pad A (mA)			10

Table 1

Stresses above these listed maximum ratings may cause permanent damages to the device. Exposure beyond specified operating conditions may affect device reliability or cause malfunction.

Handling Procedures

This device has built-in protection against high static voltages or electric fields; however, anti-static precautions must be taken as for any other CMOS component. Unless otherwise specified, proper operation can only occur when all terminal voltages are kept within the voltage range. Unused inputs must always be tied to a defined logic voltage level.

Operating Conditions

Parameter	Symbol	Min	Max	Unit
Supply voltage	V_{DD}	1.0	3.5	V
Operating Temperature	T_A	-40	+85	°C

Table 2

Block Diagram

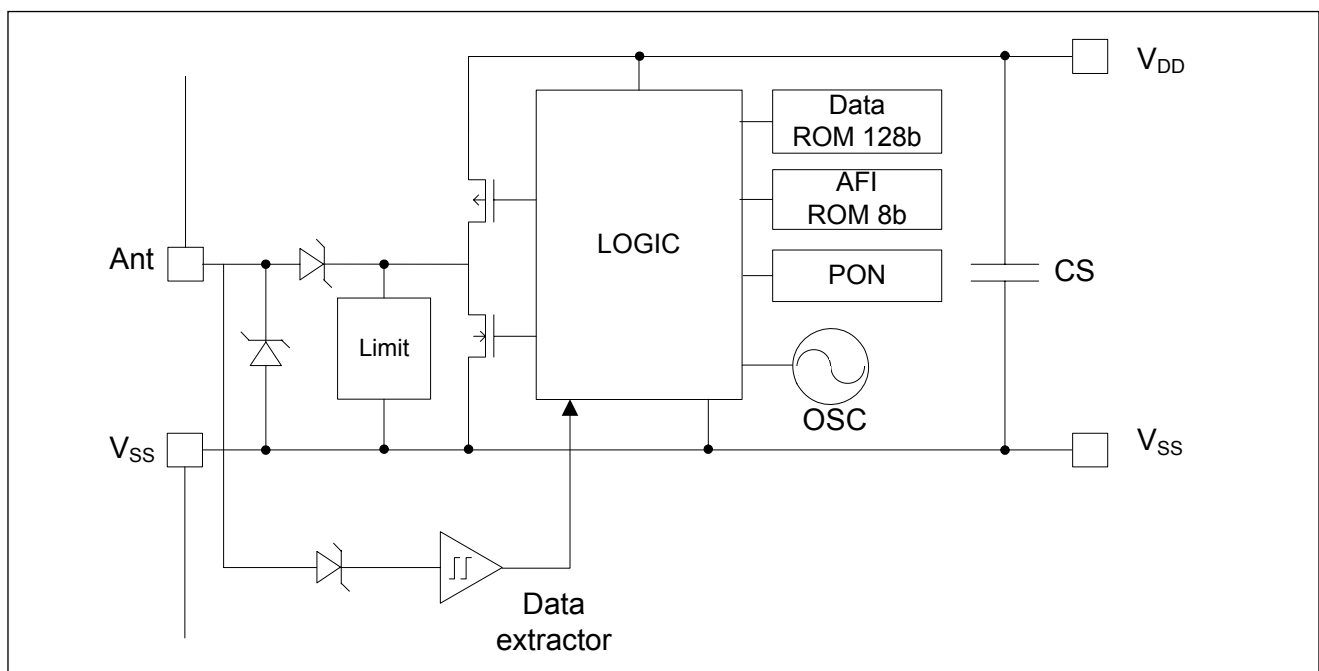
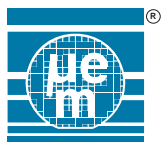


Fig. 2



Electrical Characteristics

$V_{DD} = 2.0V$, $T_A = +25^{\circ}C$, unless otherwise specified

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Operating voltage	$V_{DD} - V_{SS}$		V_{ponf}		3.5	V
Current consumption	I_S	$V_{DD} - V_{SS} = 1.5 V$		2.0	3.9	μA
Power On Reset Rising	V_{ponr}			1.2		V
Power On Reset Fall	V_{ponf}			1.0		V
Electrostatic discharge	HBM to MIL-STD-883 method 3015	V_{DD} and V_{SS} pad A+ pad	1.5 0.5			KV KV
Internal oscillator frequency	F_{osc}	Over full temperature range	192	320	448	KHz
Input series Impedance @900MHz	R_{in} C_{in}	$V_{DD} - V_{SS} < 1V$		19 0.620		Ω pF
Modulation depth decoding		At typical pulse width	27 %		100 %	%

Table 3

Timing Characteristics

Over full voltage and temperature range, unless otherwise specified

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Forward Link (Reader to Transponder)		average		33		kbps
Pulse width	T_{pw}	100% modulation depth	6	10	14	μS
Pulse interval Data 0	T_{pi0}	100% modulation depth	12	20	28	μS
Pulse interval Data 1	T_{pi1}	100% modulation depth	24	40	56	μS
Return Link (Transponder to Reader) (note 1)		nominal at $25^{\circ}C$ as selected by factory programmed Personality Bit		40 or 160		kbps
Bit rate accuracy short term (note 2)		During a message transmission			+/- 1	%
Bit rate accuracy long term @1.5V		of nominal 40kb/s			+/- 15	%
Reply to Receive turn-around time					2	Bit times
Receive to Reply turn-around time		Depends on Transponders chosen reply slot		150		μS
Tag Command window	T_{cw}	Opens at the start of the 3 rd bit clock period after the end of the last bit transmitted by the Transponder to the reader. Closes in the middle of the 5 th bit clock period.				

Note 1: $V_{DD} = 2.0V$, $T_A = +25^{\circ}C$

Note 2: $V_{DD} = 2.0V$

Table 4



1. GENERAL DESCRIPTION

The EM4223 is a monolithic integrated circuit transponder for use in UHF passive backscatter RFID applications. Operating power for the transponder circuit is derived from the illuminating RF field of an RFID Reader by means of an on-chip virtual battery rectifier circuit.

A user specified license plate or tag identifier is factory programmed into the transponder by means of laser trimming. This data is communicated to the reader by means of backscatter modulation of the illuminating RF carrier wave.

The EM4223 supports both the ISO18000-6 type A and the Fast Supertag™ (FST) Protocols. The EM4223 may be configured to wake-up in either of these modes according to user requirements. Once active, the transponder will automatically respond to either protocol (and eventually switch modes) on receipt of the appropriate commands.

2. FUNCTIONAL DESCRIPTION

When a Transponder is placed in the RF energising field of a Reader it powers up. When the power supply has reached the correct operating voltage, the Configuration Register is loaded with the contents of the three pre-programmed personality flags. Depending on the state of these wake-up flags, the Transponder will be placed in either ISO 18000-6 Type A (ISO) or Fast Supertag (FST) mode and in one of three states: READY, ACTIVE or ROUND_STANDBY. After this process is complete the Transponder is able to receive commands and to transmit data to the Reader.

The Transponder is half-duplex and is thus in either receive mode (default) or transmit mode. When not actively transmitting messages to the Reader on the Return Link, the Transponder will wait for the start of a new command, which will be detected as a quiet period of specific duration, followed by a valid Start Of Frame (SOF) symbol (see Fig. 11). The Transponder requires the quiet period in order to ensure that it does not detect partial transmissions by a reader as a valid command. This can occur if a transponder enters the field of a reader and powers up part through a reader transmission. The received SOF symbol is used to calibrate the command decoder every time a command is received. This calibration is used to establish a pivot to distinguish between subsequent data '0' and data '1' symbols. Each time that a new command is received by the Transponder, the SOF re-calibrates the decode counter thereby compensating for any variation in the Transponder clock frequency due to changes in RF excitation levels or temperature variations. The circuit has been designed to accommodate a Transponder clock frequency variation of +/-40% from nominal. When the Transponder is transmitting the receive circuitry is disabled.

All commands received from the Reader will have an immediate effect on the Transponder. In addition, certain commands will have a persistent effect. The possible immediate effects are one or both of the following:

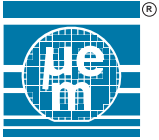
- A change of State (see Fig. 19)
- A Data Message sent to the Reader.

The possible persistent effects are:

- Data Messages to the Reader will contain SUID (as described later in this section) or Data Messages to the Reader will contain USER DATA of 128 bits,
- The Round Size (Number of Slots) over which all of the Transponders in the population will spread their Data Messages to the Reader will be configured.
- The Transponder will switch between ISO and FST modes of operation (as described below).
- A sub-population of Transponders will be enabled to send Data Messages to the Reader dependent on either the AFI or on all or a portion of the USER DATA of 128 bits.

The start of a command from the Reader has a special significance if a Transponder is operating in the FST mode and is in the ROUND_ACTIVE state. When the falling edge of the first symbol of a command (SOF) is received by a Transponder in the ROUND_ACTIVE state while in FST mode, it will immediately move to the ROUND_STANDBY state. If a command is successfully received, the Transponder will move back to the ROUND_ACTIVE state. If the Transponder does not receive a valid command it will remain in the ROUND_STANDBY state until a valid command has been received. This enables the Reader to silence all Transponders that have not already started sending their Data Messages to the Reader in compliance with the FST protocol. It is important to note that the Reader does not have to send a full command or indeed even a part of a command, as long as it sends a low going pulse of approximately $\frac{1}{2}$ Tari (Type A Reference Interval Time) duration.

An important feature of this transponder is its ability to switch seamlessly between ISO mode and FST mode whatever its "wake up" personality setting, depending only on the mode or characteristics of the controlling reader. A Transponder that "wakes up" in the ISO mode on power-up will switch to the FST mode if it receives a Wake_Up_FST command. Similarly, a Transponder that "wakes up" in the FST mode on power-up will switch to the ISO mode if it receives an INIT-ROUND, INIT-ROUND-ALL or BEGIN-ROUND command.



Transponders will only transmit Data Messages to the Reader while they are in the ROUND_ACTIVE state. When the CURRENT SLOT NUMBER and the SELECTED SLOT NUMBER values held by the Transponder match, the Transponder transmits its Data Message to the Reader. The Reply message will contain either the SUID (the Integrated Circuit Manufacturer code of 0x16 for MARIN and the lower 32 bits of the 128 bit User Data) or the 128 bit User Data .

In situations where different groups of transponders present in the reader field contain data having different owners, a reader may selectively wake up these different groups of transponders by means of the ISO compliant AFI parameter in the Init_Round command or by using the Mask parameter in the Begin_Round command. The Begin_Round command additionally supports selection of groups of transponders based on the user data content according to the EPC™ method.

General Command Format

All commands are transmitted from the Reader to the Transponder by means of pulse interval encoding as defined in chapter 5: *forward link encoding*, beginning with an SOF (Start Of Frame) and terminating in an EOF (End Of Frame). Commands are supported in accordance with the ISO 18000-6A specification which divides commands into the categories of MANDATORY, OPTIONAL, CUSTOM and PROPRIETARY. The EM4223 supports all of the ISO 18000-6A MANDATORY commands and 4 of the ISO 18000-6A OPTIONAL commands – Init_Round, Close_Slot, New_Round and Begin_Round. In addition, the EM4223 implements 1 PROPRIETARY command in accordance with the ISO 18000-6A specification – this is the Wake_Up_FST command which uses Op-Code 0x39.

Commands are divided into 2 basic types: Short Commands of a fixed 16 bit length and Extended commands which consist of a 16 bit section consistent with the Short Command format followed by a variable length extension containing various parameters and a second CRC of 16 bit length which covers the entire command, including the 1st 11 bits which will already have been covered by the 5 bit CRC and the 5 bit CRC itself.

Supported Command set

The EM4223 fully supports the four ISO MANDATORY commands: NEXT_SLOT, STANDBY_ROUND, RESET_TO_READY and INIT_ROUND_ALL.

The ISO OPTIONAL commands: INIT_ROUND, CLOSE_SLOT, and NEW_ROUND are also supported.

The BEGIN_ROUND command is included for Supply Chain Logistics support.

In addition to the above, the Fast Supertag™ commands: WAKE_UP_FST and MUTE are supported for compliance with the FST protocol. MUTE is interpreted as any partially decoded or invalid command as described in section 0.

3. BASIC COMMAND FORMATS

There are 7 short commands, 2 extended commands and 1 implied command.

Short commands

Short commands are a fixed length of 16 bits, which includes a 5 bit CRC. The commands comprise the following fields:

- Protocol extension – 1 bit.
- Command Op-code – 6 bits.
- Parameters – 4 bits (parameters could include flags).
- CRC – 5 Bits.

SOF	RFU (1 bit)	Command Code (6 bits)	Parameters & Flags (4 bits)	CRC-5 (5 bits)	EOF
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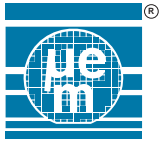
Fig. 3 General format, Short commands

Short commands are used for collision arbitration and other immediate functions.

Extended commands

The EM4223 supports 2 Extended commands (**Init_Round** and **Begin_Round**). They comprise a fixed length part of 16 bits, which is identical with the format of the 16 bit Short Commands described above, followed by an 8 bit fixed length parameter in the case of both of the Extended commands, followed by a 2nd parameter of variable length up to 136 bits and terminated with a 16 bit CRC. The Extended commands comprise the following fields:

- Protocol extension – 1 bit.
- Command Op-code – 6 bits.
- Parameters – 4 bits (parameters could include flags).
- CRC – 5 Bits.
- Extension of 8 bits (AFI) in the case of the INIT_ROUND command, or an 8 bit (MASK_LENGTH) parameter followed by a variable length (MASK) parameter in the case of the BEGIN_ROUND command
- CRC-16 :- 16 Bits (over full message from after the SOF to the last bit before the CRC16 itself).



SOF	RFU (1 bit)	Command Code (6 bits)	Parameters & Flags (4 bits)	CRC-5 (5 bits)	1 st Optional Parameter (8 bits)	2 nd Optional Parameter (0-136 bit)	CRC-16 16 bits	EOF
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Fig. 4 - General format, Extended commands

The 2 Extended commands supported by the EM4223 are used to all selected sub-populations of Tags to be introduced to the Arbitration process.

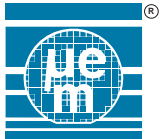
Implied MUTE command (Fast Supertag Mode only)

When operating in the Fast Supertag Mode and in the ACTIVE state, the reception of the first low-going pulse of any command causes the EM4223 to move to the ROUND_STANDBY state. This could be any single pulse or the first pulse of the SOF of a valid command. The Transponder will continue to decode the command. A known and valid command causes the Transponder to execute the command and to move to either the ROUND_ACTIVE or the READY state, depending on the command and its parameters (if any). An unknown command or a command having an error will cause the Transponder to remain in the ROUND_STANDBY state.

During reception of a command, and until the command has been correctly received, the Transponder will hold-off any attempt to reply until the command has been correctly received and executed. At the end of receiving a command, if it has not been correctly decoded, the Transponder will remain in the ROUND_STANDBY state until moved out of this state by the first correctly received and decoded command.

If the Tag is in the Fast Supertag Mode and in the TTF (Tag Talks First) sub-mode (Wake Up Status Flag = X00), the Tag will automatically leave the ROUND_STANDBY state after a timeout period of 2.5 X 176 tag bit periods has elapsed since the last MUTE command (176 bits = maximum Tag Data Message length). This timeout will be reset each time a new implied MUTE command is received.

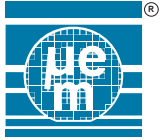
Command	Protocol Extension	Op- Code 6 bits	Parameter / flags 4 bits		CRC-5	Extended parameters		CRC-16	Comments
Init-Round	Always = 0	01	SUID 1 bit	Round Size 3 bits	5 bits	AFI 8 bits		16 bits	SUID = 0 tag responds with the 128 bits of user data. SUID = 1 tag responds with SUID. If AFI field = 00H, all tags respond, else if AFI is other value, only tags with matching AFI respond. Also moves tags already active in FST mode to ISO mode.
Next-Slot	Always = 0	02 *	Signature 4 bits		5 bits				The signature must match the signature value transmitted by the tag in its last reply to acknowledge the tag's reply. Advances the CURRENT SLOT COUNTER.
Close Slot	Always = 0	03	Ignored by EM4223		5 bits				Advances the CURRENT SLOT COUNTER.
Standby-Round	Always = 0	04 *	Ignored by EM4223		5 bits				The signature is not used in this implementation because the EM4223 has no select state. The EM4223 will always move to the ROUND_STANDBY state.
New-Round	Always = 0	05	SUID 1 bit	Round size 3 bits	5 bits				
Reset-To-Ready	Always = 0	06 *	Ignored by EM4223		5 bits				Moves Transponder from current state to READY state.
Init-Round-All	Always = 0	0A *	SUID 1 bit	Round size 3 bits	5 bits				SUID = 0 tag responds with the 128 bits of user data. SUID = 1 tag responds with SUID. Also moves tags already active in FST mode to ISO mode.



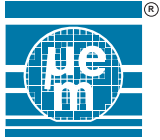
Begin-Round	Always = 0	OB	SUID 1 bit	Round size 3 bits	5 bits	Mask length 8 bits	Mask value 0-136 bits	16 bits	Tags that match the MASK value of MASK length will move to the ROUND_ACTIVE state from the ROUND_STANDBY or READY states or will remain in the ROUND_ACTIVE state if already there. Tags that do not match the Mask will move to the READY from either ROUND_ACTIVE or ROUND_STANDBY states. SUID = 0 tag responds with the 128 bits of user data. SUID = 1 tag responds with SUID, where the DSFID field is replaced by AFI field. Also moves Transponders already active in FST mode to ISO mode.
Wake-Up-FST	Always = 0	39	SUID 1 Bit	Round size 3 bits	5 bits				Wakes tag up in the Fast Supertag™ mode. Also moves tags already active in ISO mode to FST mode. SUID = 0 tag responds with the 128 bits of user data SUID = 1 tag responds with SUID.
Mute		Low Pulse							Implied command in FST mode. When tag receives an SOF it moves to the ROUND_STANDBY state. The tag returns to the active state on receipt of a next-slot or init-round or new-round command, or when a period of 2.5 X 176 tag bit periods has elapsed since the last Mute command (176 bits = maximum message length).

Table 5- Supported Commands

Mandatory ISO commands op-codes are marked with an * and command titles are in bold type face.

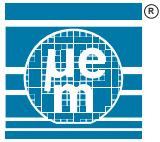


Reader Command	Transponder Operation in ISO Mode	Transponder Operation in Fast Supertag™ Mode
INIT_ROUND	Initialises the start of the arbitration sequence and tells the Transponder over how many slots to randomise the transmit slot selection. Configures the Transponder to transmit the SUID data or the full 128 bit User Data to the Reader dependent on the SUID parameter in the command. Moves the Transponder from the READY to the ROUND_ACTIVE states if the Transponders AFI matches the AFI in the command or if the AFI in the command = 0x00 . If the AFI in the command is non-zero and does not match the AFI in the Tag, causes the Tag to move from the ROUND_ACTIVE to the READY states.	Not supported in Fast Supertag™ Mode – causes the Transponder to immediately switch to ISO Mode .
BEGIN_ROUND	Initialises the start of the arbitration sequence and tells the Transponder over how many slots to randomise the transmit slot selection. Configures the transponder to transmit the SUID data where DSFID field is replaced by AFI field, or the full 128 bit User Data to the reader, depending in the SUID parameter in the command. Moves the Transponder from the READY to the ROUND_ACTIVE states if the number of bits of the Transponders User Data specified in the command is identical to the matching data in the command Mask parameter .	Not supported in Fast Supertag™ Mode – causes the Transponder to immediately switch to ISO Mode .
INIT_ROUND_ALL	Initialises the start of the arbitration sequence and tells the Transponder over how many slots to randomise the transmit slot selection. Configures the Transponder to transmit the SUID data or the full 128 bit User Data to the Reader dependent on the SUID parameter in the command. Moves the Transponder from the READY to the ROUND_ACTIVE states.	Not supported in Fast Supertag™ Mode – causes the Transponder to immediately switch to ISO Mode .
NEW_ROUND	Causes the EM4223 to enter a new Round and to change the number of pseudo-slots over which it randomises its transmissions. Tags in the READY state will ignore this command.	Causes the EM4223 to change the number of pseudo-slots over which it randomises its transmissions. Tags in the READY state will ignore this command.
WAKE_UP_FST	Not supported in ISO Mode – causes the Transponder to immediately switch to Fast Supertag™ Mode .	Initialises the start of the Fast Supertag™ arbitration sequence and tells the Transponder over how many slots to randomise the transmit slot selection. Configures the Transponder to transmit the full 128 bit User Data to the Reader irrespective of the SUID parameter in the command. Moves the Tag from the ROUND_STANDBY to the ROUND_ACTIVE states or from the READY to the ROUND_ACTIVE states if the Mask parameter matches, else moves Tag to the READY state.



NEXT_SLOT	<p>Acknowledges the successful reception of a Transponder transmission by the Reader when valid ie. when received by a Transponder which has just transmitted, and when the command is received in the timing window and when the Signature matches, causing the Transponder to move from the ROUND_ACTIVE to the QUIET states.</p> <p>Causes a Transponder in the ROUND_STANDBY state to move into the ROUND_ACTIVE state.</p> <p>Causes the Transponder Current Slot Counter to increment by one.</p> <p>Causes the Transponder to automatically start a new Round by resetting its Current Slot Counter and randomly selecting a new Reply Slot when the Current Slot Counter has reached the Round Size Value.</p>	<p>Acknowledges the successful reception of a Transponder transmission by the Reader when valid ie. when received by a Transponder which has just transmitted, and when the command is received in the timing window and when the Signature matches, causing the Transponder to move from the ROUND_ACTIVE to the QUIET states.</p> <p>Causes a Transponder in the ROUND_STANDBY state to move into the ROUND_ACTIVE state.</p>
CLOSE_SLOT	<p>Causes a Transponder in the ROUND_STANDBY state to move into the ROUND_ACTIVE state.</p> <p>Causes the Transponder slot counter to increment by one.</p> <p>Causes the Transponder to automatically start a new Round by resetting its Current Slot Counter and randomly selecting a new Reply Slot when the Current Slot Counter has reached the Round Size Value.</p>	<p>Causes a Transponder in the ROUND_STANDBY state to move into the ROUND_ACTIVE state.</p>
STANDBY_ROUND	<p>Causes the Transponder to move to the ROUND_STANDBY state, in which the Transponder does not transmit its identity or data.</p>	<p>Causes the Transponder to move to the ROUND_STANDBY state, in which the Transponder does not transmit its identity or data. While in the ROUND_STANDBY state, the random number generator for slot number choosing is running so that transponder slots are not synchronized and thus have maximum spread and randomisation in the Transmit times. When the Transponder exits the ROUND_STANDBY state, it will wait until the next internally generated slot time before re-enabling its data transmit circuitry.</p>
RESET_TO_READY	<p>Moves the Transponder from its current state to READY state.</p>	<p>Moves the Transponder from its current state to READY state.</p>
MUTE – this is not an actual command but is an implied command derived from the first low-going pulse of any command.	<p>Not used.</p>	<p>The Transponder will move to the ROUND_STANDBY state upon reception of the first low-going pulse of any command. This could be any single pulse or the first pulse of the SOF of a valid command. The Transponder will continue to decode the command and if the pulse turns out to be part of a valid command, the Transponder will move to either the READY or the ROUND_ACTIVE state depending on the actual command and the command parameters. If the WUS bit = 0 the Transponder will automatically leave the ROUND_STANDBY state after a timeout period of 2.5 X 176 tag bit periods has elapsed since the last MUTE command (176 bits = maximum Data Message length). This timeout will be reset each time a new implied MUTE command is received.</p>

Table 6– Command Operations



Command state transitions

The following tables show the state transitions for each of the commands supported by the EM4223 and should be read in conjunction with Fig. 19.

Command : Init_Round (Tag will be in ISO mode after this command)			
Initial State	Criteria	Action	New State
Ready	AFI in the command = 0 or tags AFI value matches the value in the command.	Tag chooses a random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active
	AFI in the command <> and Tags AFI value <> AFI value in the command.	None	Ready
Quiet	None	None	Quiet
Round_Active	AFI in the command = 0 or tags AFI value matches the value in the command.	Tag chooses a new random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active
	AFI in the command <> and Tags AFI value <> AFI value in the command.	None	Ready
Round_Standby	AFI in the command = 0 or tags AFI value matches the value in the command.	Tag chooses a new random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active
	AFI in the command <> and Tags AFI value <> AFI value in the command.	None	Ready

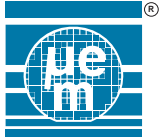
Table 7 – Tag state transitions for Init_Round

Command : New_Round			
Initial State	Criteria	Action	New State
Ready	None	None	Ready
Quiet	None	None	Quiet
Round_Active	None	Tag chooses a new random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active
Round_Standby	None	Tag chooses a new random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active

Table 8 – Tag state transitions for New_Round

Command : Init_Round_All (Tag will be in ISO mode after this command)			
Initial State	Criteria	Action	New State
Ready	None	Tag chooses a random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active
Quiet	None	None	Quiet
Round_Active	None	Tag chooses a new random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active
Round_Standby	None	Tag chooses a new random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active

Table 9 – Tag state transitions for Init_Round_All



Command : Begin_Round (Tag will be in ISO mode after this command)			
Initial State	Criteria	Action	New State
Ready	Number of bits of the MASK specified by MASK_LENGTH in the command matches the data in the Tag (AFI followed by USER DATA). If the 1 st 8 bits of the MASK = 0 they are not compared.	Tag chooses a random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active
	Number of bits of the MASK specified by MASK_LENGTH in the command does not match the data in the Tag.	None	Ready
Quiet	None	None	Quiet
Round_Active	Number of bits of the MASK specified by MASK_LENGTH in the command matches the data in the Tag (AFI followed by USER DATA). If the 1 st 8 bits of the MASK = 0 they are not compared.	Tag chooses a new random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active
	Number of bits of the MASK specified by MASK_LENGTH in the command does not match the data in the Tag.	None	Ready
Round_Standby	Number of bits of the MASK specified by MASK_LENGTH in the command matches the data in the Tag (AFI followed by USER DATA). If the 1 st 8 bits of the MASK = 0 they are not compared.	Tag chooses a new random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active
	Number of bits of the MASK specified by MASK_LENGTH in the command does not match the data in the Tag.	None	Ready

Table 10 – Tag state transitions for Begin_Round

Command : Wake_Up_FST (Tag will be in FST mode after this command)			
Initial State	Criteria	Action	New State
Ready	None	Tag chooses a random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active
Quiet	None	None	Quiet
Round_Active	None	Tag chooses a new random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active
Round_Standby	None	Tag chooses a new random slot in which it will send its response. Tag's Current Slot Counter is reset to first slot.	Round_Active

Table 11 – Tag state transitions for Wake_Up_FST

Command : Next_Slot			
Initial State	Criteria	Action	New State
Ready	None	None	Ready
Quiet	None	None	Quiet
Round_Active	Tag has answered in previous slot, AND Signature matches AND 1 st low pulse of Next_Slot command was received in the acknowledgement time window.	None	Quiet
	Tag is in ISO Mode and has NOT answered in previous slot, OR Signature does not match OR 1 st low pulse of Next_Slot command was not received in the acknowledgement time window.	The tag shall increment its slot counter and send its response if slot counter matches the chosen slot.	Round_Active
	Tag is in FST Mode and has NOT answered in previous slot, OR Signature does not match OR 1 st low pulse of Next_Slot command was not received in the acknowledgement time window.	The tag will automatically increment is Current Slot Counter at internally determined times and send its response if the its Current Slot Counter matches its Selected Slot Register.	Round_Active
Round_Standby	ISO Mode	The tag shall increment its slot counter and send its response if slot counter matches the chosen slot.	Round_active
	FST Mode	The tag resumes the FST Arbitration process and will automatically increment is Current Slot Counter at internally determined times and send its response if the its Current Slot Counter matches its Selected Slot Register.	Round_active

Table 12 - Tag state transitions for Next_Slot

Command : Close_slot			
Initial State	Criteria	Action	New State
Ready	None	None	Ready
Quiet	None	None	Quiet
Round_Active	ISO Mode	The tag shall increment its slot counter and send its response if slot counter matches the chosen slot.	Round_Active
	FST Mode	The tag will automatically increment is Current Slot Counter at internally determined times and send its response if the its Current Slot Counter matches its Selected Slot Register.	Round_Active
Round_Standby	ISO Mode	The tag shall increment its slot counter and send its response if slot counter matches the chosen slot.	Round_active
	FST Mode	The tag resumes the FST Arbitration process and will automatically increment is Current Slot Counter at internally determined times and send its response if the its Current Slot Counter matches its Selected Slot Register.	Round_active

Table 13 - Tag state transitions for Close_Slot

Command : Reset_To_Ready			
Initial State	Criteria	Action	New State
Ready	None	None	Ready
Quiet	None	None	Ready
Round_Active	None	None	Ready
Round_Standby	None	None	Ready

Table 14 - Tag state transitions for Reset_To_Ready

Command : Standby_Round			
Initial State	Criteria	Action	New State
Ready	None	None	Ready
Quiet	None	None	Quiet
Round_Active	None	None	Round_Standby
Round_Standby	None	None	Round_Standby

Table 15 – Tag state transitions for Standby_Round

4. GENERAL REPLY FORMAT

The Transponder will reply to a successful arbitration sequence by sending a message having the following format:

- Preamble – see description of the Return Link.
- Flags – 2 bits (Preset)
- Parameters as follows:
 - Transponder type – 1 bit (Always = 0)
 - Battery status – 1 bit (Always = 0)
 - Signature – 4 bits (last 4 bits of the clock counter).
- Data – 136 bits if the SUID bit = 0 as follows:
 - AFI of 8 bits.
 - User Data of 128 bits.
- Data – 48 bits if the SUID bit = 1 as follows:
 - DSFID of 8 bits.
 - SUID of 40 bits (lower 32 bits of User Data + IC Manufacturer code).
- CRC – 16 bits

Preamble	Flags	Parameters	Data	CRC
----------	-------	------------	------	-----

Fig. 5- Transponder Reply, general format

Preamble	Flags	Trans. Type	Battery Status	Signature	AFI	USER DATA	CRC16
	2 bits	Always = 0	Always = 0	4 bits	8 bits	128 bits	16 bits

Fig. 6 – Transponder Reply to commands with the SUID flag = 0.

The above reply will be received after a successful arbitration sequence that was initiated by the Init-Round, Init-Round-All, Begin_Round and Wake-Up_FST commands with the SUID flag = 0.

Preamble	Flags	Trans. Type	Battery Status	Signature	DSFID	SUID	CRC 16
	2 bits	Always = 0	Always = 0	4 bits	Always = 0x00	40 bits	16 bits

Fig. 7 – Transponder Reply commands with the SUID flag = 1.

The above reply will be received after a successful arbitration sequence that was initiated by the Init_Round, Init_Round_All and Wake_Up_FST commands with the SUID flag = 1.

Preamble	Flags	Trans. Type	Battery Status	Signature	AFI	SUID	CRC 16
	2 bits	Always = 0	Always = 0	4 bits	8 bits	40 bits	16 bits

Fig. 8 – Transponder Reply to Begin_Round command with the SUID flag = 1.

The above reply will be received after a successful arbitration sequence that was initiated by the Begin_Round command with the SUID flag = 1.

5. FORWARD LINK ENCODING - READER TO TRANSPONDER

Commands and data are received from the Reader, encoded by means of Pulse Interval Encoding. The Reader transmits pulses in the form of dips in its carrier wave. The intervals between dips convey information in accordance with the following description.

The Transponder responds to transmissions by the Reader as described herein.

Carrier modulation pulses

The data transmission from the Reader to the Transponder is achieved by modulating the carrier amplitude (ASK). The data coding is performed by generating pulses at variable time intervals. The duration of the interval between two successive pulses carries the data coding information. This is known as Pulse Interval Encoding, (PIE). The Transponder measures the inter-pulse time on the high to low transitions (falling) edges of the pulse as shown in Fig. 9

Basic time interval – definition of “Tari”

The time “Tari” specifies the period in microseconds between two falling edges representing the symbol “0”. The word “Tari” is an acronym for “Type A Reference Interval Time” as defined in the ISO18000-6 Type A specification. The period between the two falling edges defining each of the other symbols is based on a multiple of the basic Tari period. The SOF symbol (Start of Frame) consists of 2 periods, the 1st of which is equal to

One Tari, while the 2nd period of the SOF symbol is equal to 3 Tari. The first part of the SOF symbol is provided to allow detector circuitry to settle (should this be necessary). The second part of the SOF symbol is used as a Calibration period. The received SOF symbol is used to calibrate the command decoder every time a command is received. This calibration is used to establish a pivot to distinguish between subsequent data ‘0’ and data ‘1’ symbols. The pivot point has a value of 1.5Tari and is derived from the 3Tari interval contained in the 2nd part of the SOF symbol. The binary data ‘0’ and ‘1’ are extracted from the incoming data stream by comparing the inter-pulse interval with a pivot point. If the interval is less than the pivot, then the binary value is ‘0’ and if it is greater than the pivot then the binary value is ‘1’ (See clause 0). Each time that a new command is received by the Transponder, the SOF re-calibrates the decode counter thereby compensating for any variation in the Transponder clock frequency due to changes in RF excitation levels or temperature variations. The circuit has been designed to accommodate a Transponder clock frequency variation of $\pm 40\%$ from nominal. The basic Tari period as transmitted by the Reader is specified in Table 16 and illustrated in Fig. 9.

Tari	Tolerance
20 μ s	± 100 ppm

Table 16 - Reference interval timing

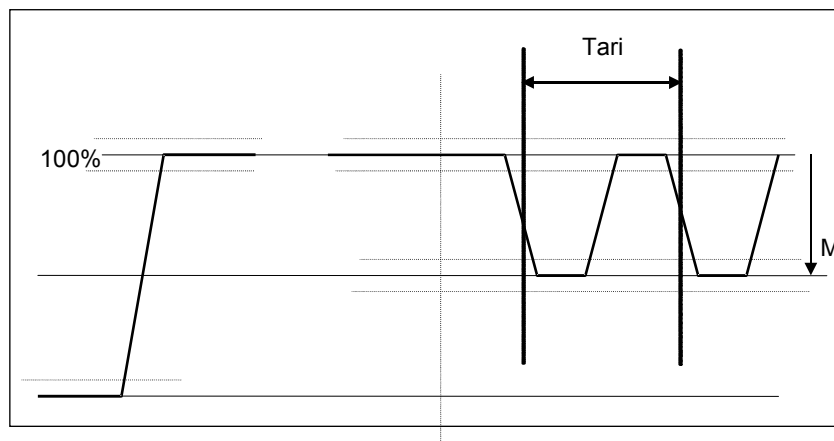


Fig. 9 - Inter-pulse mechanism

Data coding

Data transmitted by the Reader to the Tag is encoded in PIE format as described in 0 and 0 above. Four symbols are encoded; '0', '1', SOF and EOF. The Transponder is able to decode symbols having values as shown in Fig. 10 below.

Symbol	Mean duration	Limits
0	1 Tari	$\frac{1}{2} \text{ Tari} < '0' \leq \frac{3}{2} \text{ Tari}$
1	2 Tari	$\frac{3}{2} \text{ Tari} < '1' < 3 \text{ Tari}$
SOF	1 Tari followed by 3 Tari	Calibration sequence
EOF	4 Tari	$\geq 4 \text{ Tari}$

Table 17 - PIE symbols

Values falling outside of the limits in Table 17 will cause the received data to be rejected and the EM4223 to wait for an unmodulated carrier of EOF duration or greater before being ready to receive a new command.

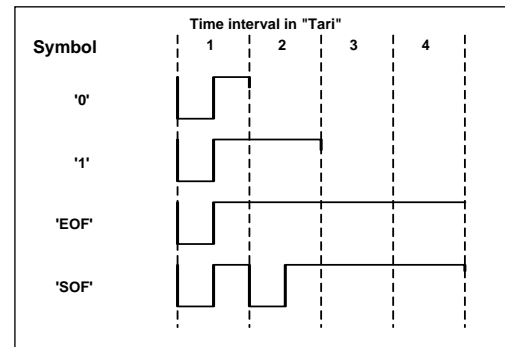


Fig. 10 - PIE symbols

Data Frame format

The bits transmitted by the Reader to the Transponder are embedded in a frame as specified in Fig. 11. Before sending the frame, the Reader ensures that it has established an unmodulated carrier for duration of at least T_{aq} (Quiet time) of 300 μ s.

The frame consists of a Start-Of-Frame (SOF), immediately followed by the data bits and terminated by an End-Of-Frame (EOF). After sending the EOF the Reader maintains a steady carrier for sufficient time to allow all Transponders present to be powered so that they may send their **Reply**.

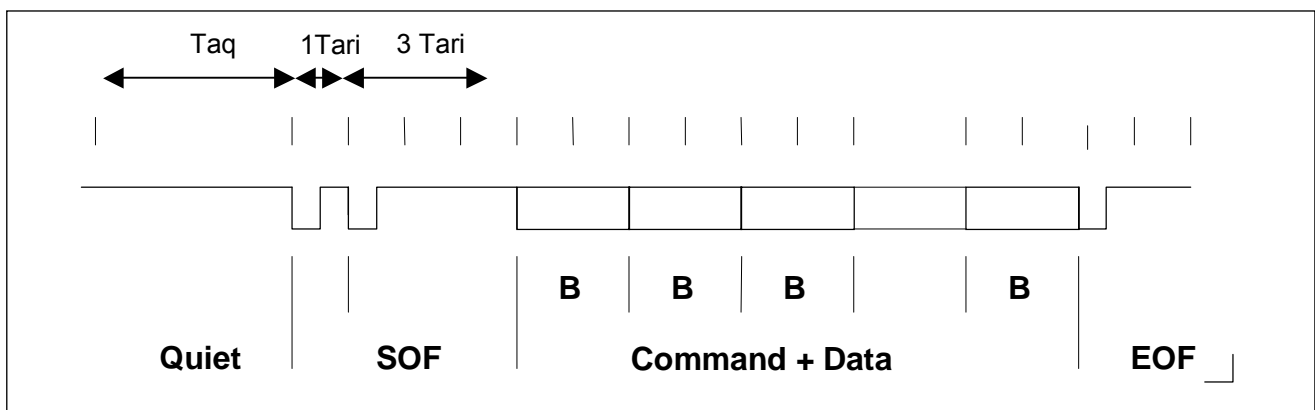


Fig. 11 - Forward link frame format

Data decoding

The binary data '0' and '1' are extracted from the incoming data stream by comparing the inter-pulse interval with a pivot point. The pivot point has a value of 1.5Tari and is derived from the 3Tari interval contained in the 2nd part of the SOF symbol. If the interval is less than the pivot, then the binary value is '0' and if it is greater than the pivot then the binary value is '1'.

If the Transponder detects an invalid code it discards the frame and waits for an unmodulated carrier of EOF duration. No Error Messages are sent to the Reader.

Bits and byte ordering

Coding of data into symbols is MSB first. The coding for the 8 bits of hex byte 'B1' is shown in Fig. 12.

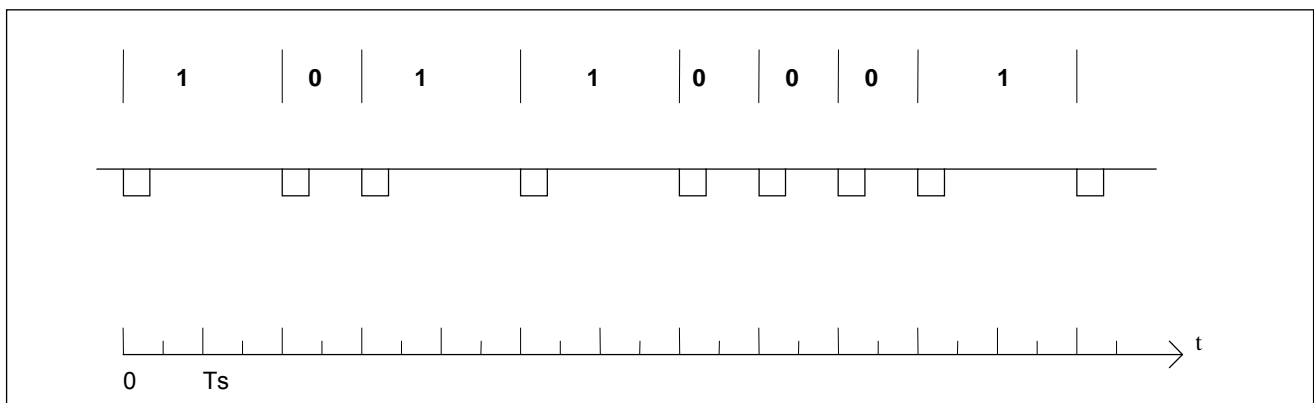


Fig. 12 - Example of PIE byte encoding for 'B1'

Reader to Transponder 5 bit CRC (CRC-5)

The CRC-5 is used only for commands from the Reader to the Transponder. All commands have a CRC-5 as the last 5 bits of the first 16 bit part of an Extended command or as the last 5 bits of a Short Command. The CRC-5 is calculated on all the command bits after the SOF up to the end of the Extended Parameters (11 bits in total – see Fig. 3).

The polynomial used to calculate the CRC-5 is $x^5 + x^3 + 1$. The CRC-5 register is pre-loaded with '01001' (MSB (C4) to LSB (C0)) prior to commencing a CRC-5 calculation in both the case of a Reader to Transponder command transmission and the case of a Transponder initializing its CRC-5 register prior to receiving a command from the Reader.

The 5 bits of the CRC-5 embedded in the command are received MSB first by the Transponder. The Transponder will clock the first 16 bits of an Extended command or a complete Short Command through its CRC-5 register as it is receiving the command from the Reader and if these 16 bits were received without error, the Transponder's CRC-5 register will contain all zeros after the last bit has been clocked through.

Command Decoder

The Transponder can receive commands from a Reader at any time other than the time that it is transmitting a

Reply to the Reader and during the 2 Transponder bit periods following a **Reply** transmission.

In the case of the Next_Slot command the command is interpreted by the Transponder in one of two ways.

- If a Next_Slot command is received such that the first pulse of the command is received during the active command window of the Transponder, which follows a transmission by the Transponder and this Next_Slot command contains a signature parameter that matches that sent by the Transponder in its last transmission, then the command will be interpreted as an instruction for that Transponder to move to the quiet state
- Fig. 13 and below show the timing of the Transponder command window.
- If a Next_Slot command is received at any time other than coincident with an active command window (opened by the Transponder following a transmission) or if the Transponder had not transmitted a **Reply** immediately prior to receiving the NEXT_SLOT command or if the Next_Slot command does not contain a signature parameter that matches that sent by the Transponder in its last transmission then the command is interpreted as an instruction to step the current slot counter value in ISO mode or as a command to exit the ROUND_STANDBY state in either ISO or FST modes.

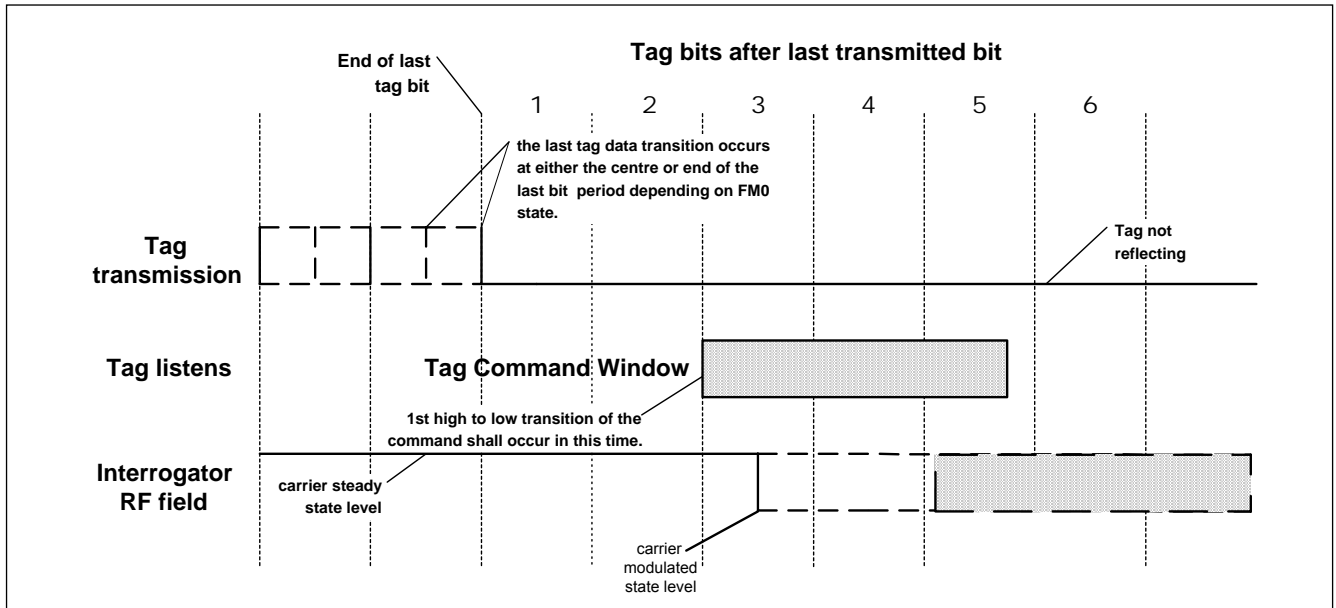


Fig. 13 - Command Window Timing

6. RETURN LINK DATA ENCODING - TRANSPORTER TO READER

The return link data is modulated onto the impinging illuminating RF carrier using varying impedance modulation.

Return link data encoding

Data is encoded using Bi-phase space (FM0).

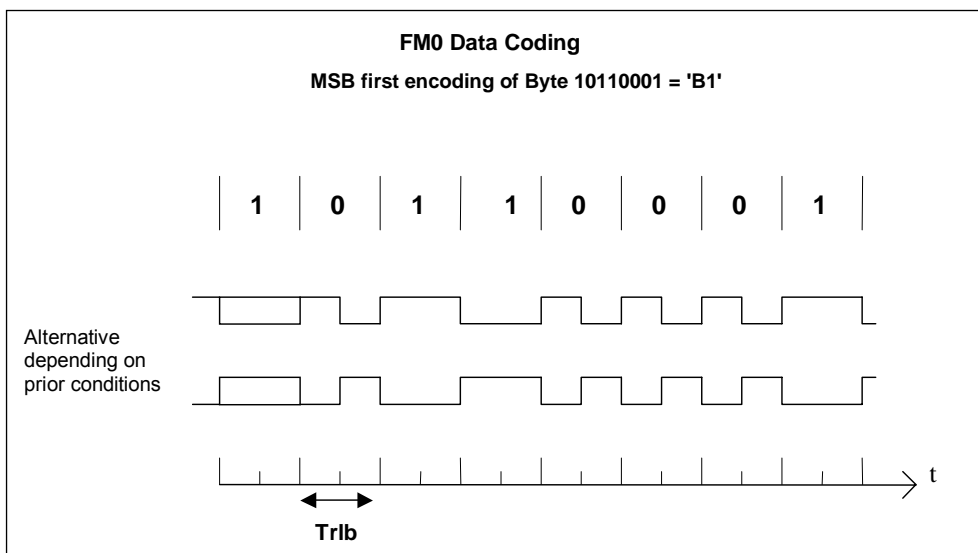


Fig. 14 - Return link – data encoding

Return link preamble

The **FM0** return link preamble has the bit pattern described in **Error! Reference source not found.**

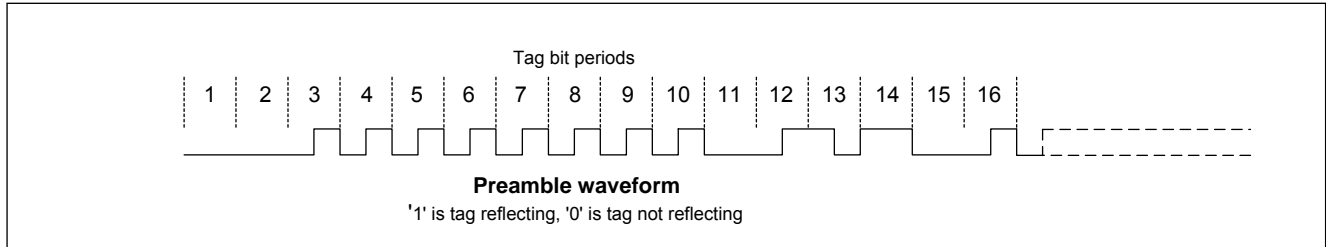


Fig. 15 - FM0 Return link preamble

Cyclic Redundancy Check (CRC)

The 16 bit CRC is calculated on all data bits up to, but not including, the first CRC bit.

The polynomial used to calculate the CRC is $x^{16} + x^{12} + x^5 + 1$.

The 16-bit register is preloaded with 'FFFF'. The resulting CRC value is inverted, attached to the end of the packet and transmitted.

The most significant byte shall be transmitted first. The most significant bit of each byte shall be transmitted first.

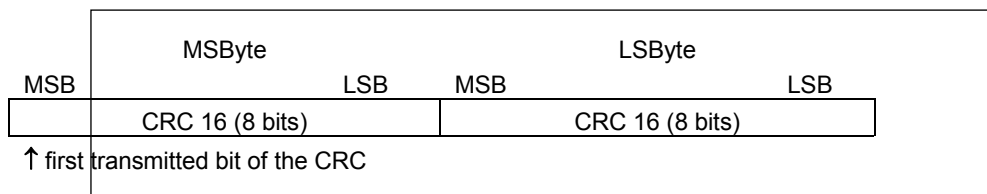


Fig. 16- CRC format

7. MEMORY ORGANISATION AND CONFIGURATION INFORMATION

Memory Map

The physical memory comprises 128 bits of user memory, 8 bits AFI and 3 personality bits. In addition, the IC Manufacturer Code as specified in ISO7816-6/AM1 is hard-wired into the Transponder.

128 bits UUD memory	8 bit AFI	3 bits Personality
---------------------	-----------	--------------------

Fig. 17- Memory map

Unambiguous User Data (UUD) & SUID

The user memory on the Transponder comprises 128 bits of user specified data. This data is known as Unambiguous User Data UUD, because it is expected that this data be unique and unambiguous. The UUD is a license plate defined by the user and may be an EPC™, GTAG™ or other user defined number.

The Transponder will return a Sub-UID (SUID) as defined in ISO 18000-6 when the SUID flag is =1 in the arbitration initiation commands. The SUID in this Transponder is derived from the least significant 32 bits of the UUD as described below. The SUID consists of 40 bits: the 8 bit manufacturer code followed by the least significant 32 bits of the UUD.

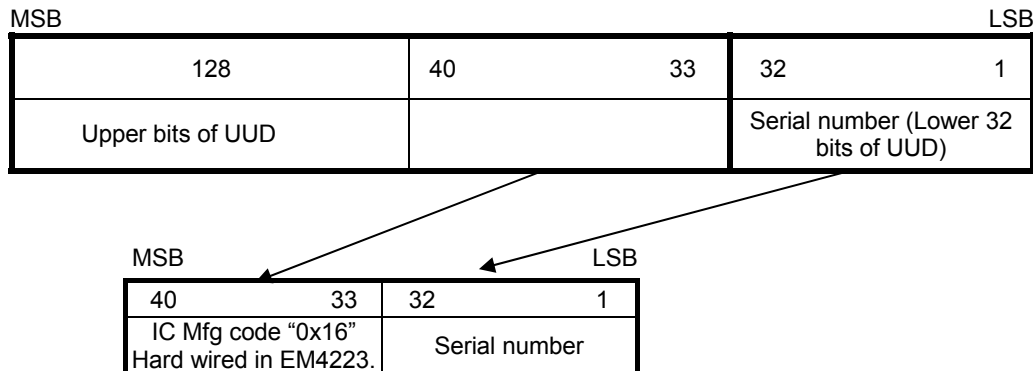


Fig. 18- UUD/SUID mapping

Transponder Unique Identifier (UID) & SUID

An ISO 18000-6A Transponder does not transmit the UID except in response to the optional ISO Get_System_Information command which is not supported in the EM4223. All other transactions are conducted using the SUID (which is supported).

The Interrogator derives the Transponder 64 bit UID from the SUID and it is made up as follows:

- Bits 57 → 64 are always set to Hex 'E0'.
- Bits 49 → 56 carry the Integrated Circuit Manufacturers Code
- Bits 33 → 48 are always set to Hex '0000'
- Bits 1 → 32 carry the 32 bit Serial number.

AFI

Application Family Identifier - 8 bits per ISO 18000-6 clause 7.2.3. If the AFI byte is set with all 00 the tag will respond, or if the AFI in the tag matches the AFI byte in the init-round command the tag will respond, otherwise the tag will remain quiet.

Personality Block

The personality block contains 3 control bits. The default state of these bits is programmed during manufacture. These bits control the Wake Up Status flag (WUS), the power up selection of FST or ISO mode of operation and the Return Link Bit Rate.

Transponders will power up in the default mode set by the bits programmed during manufacture. Only the FST/ISO mode flag can be changed by Reader commands. Transponders will be switched to FST mode by the WAKE_UP_FST command. INIT_ROUND, INIT_ROUND_ALL and BEGIN_ROUND commands will switch Transponders to the ISO mode of operation.

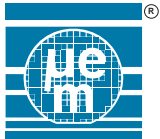
The state of the WUS bit cannot be changed from the value set during manufacture. Transponders will operate in ISO or MOD_ISO mode depending on the factory programmed state of the WUS bit. Similarly, Transponders will operate as TTF or as RTF in FST mode depending on the factory programmed state of the WUS bit. It is important to note that tags can only switch between MOD_ISO and FST (TTF) or between ISO and FST (RTF) modes.

FST/ISO Flag (pbit 1)	Wake Up Status Flag (pbit 0)	Tag State	Transponder SUID and Roundsize Initialize Conditions	Mode
Power Up Condition				
1	1	READY – Transponder replies in its selected slot in each round.	Don't care	ISO
1	0	READY - Transponder replies in both the first slot and its selected slot in every round	Don't care	MOD_ISO
0	1	ROUND_STANDBY state, Reader Talks First mode	SUID flag = 0 Roundsize = 16	FST (RTF)
0	0	ROUND_ACTIVE –Tag Talks First mode	SUID flag = 0 Roundsize = 16	FST (TTF)

Table18 - Transponder Operational Modes

Personality Block 0- Bit 2 determines the Transponder Reply data rate:

- 0 = 40 kb/s
- 1 = 160 kb/s



8. TRANSPONDER SELECTION OPERATION – INIT_ROUND AND BEGIN_ROUND COMMANDS

The INIT_ROUND and BEGIN_ROUND commands have the ability to move only a selected sub-set of the Transponder population from the READY to the ROUND_ACTIVE states. Transponders that are already in the ROUND_ACTIVE or ROUND_STANDBY states will be removed from the active Transponder population and moved to the READY state if they do not match the selection parameters sent with the INIT_ROUND or BEGIN_ROUND command.

This allows the population to be “thinned”, thus increasing the effective read rate achieved.

Because only transponders of interest to the application will be selected any other Transponders in the Reader field will not degrade Reader performance by needing to be read and acknowledge to send them to the QUIET state – they virtually do not exist if they have not been selected.

The selection capabilities also allow the Transponder population to be “Tree-Walked” allowing fully “Deterministic” arbitration of a Transponder population. By adding more and more bits to the selection criteria, the population can be resolved down to a single Transponder. (See the explanatory note below).

EXPLANATION OF “DETERMINISTIC” OPERATION BASED ON “TREE-WALKING”

Transponders that use randomly selected reply slots in order to transmit their data to a Reader have a very small risk of more than one Transponder selecting the same slot several times, which could mean that such tags may not be read before they move out of the active population. This is known as “Probabilistic” operation and must be balanced against the many advantages of this mode of operation. “Tree Walking” is a method of resolving Transponder populations by effectively issuing a series of “tests” or “challenges” in which the Reader would request a response from all tags containing say “0” in the 1st bit position of the Transponder data (or in an encrypted version of the data). If the Reader received a non-clashing response (only 1 transponder responding) it could request that Transponder to send its full data. If the Reader received a clashing response (more than 1 transponder responding) it would know that it had identified a productive “branch” and would extend its test by requesting a response from all tags containing say “00” in the 1st two bit positions of the Transponder data. It would continue testing and requesting responses until it had resolved the entire tag population in this manner. If the Reader received no response it would know that it had identified an unproductive “branch” and would temporarily abandon further testing for Transponders with “0” in the 1st bit position. The Reader would then test for Transponders with “1” in the first bit position. This would continue until all Transponders had been identified, or moved out of the Reader’s RF field.

INIT_ROUND COMMAND SELECTION OPERATION (see Fig. 19)

The INIT_ROUND command contains a single fixed length (8 bit) selection parameter. This parameter represents the AFI (Application Family Identifier according to ISO18000-6A) value which will be matched with the AFI value contained in the Transponders memory. Transponders with a matching AFI value will move from the ROUND_ACTIVE or ROUND_STANDBY or READY states to the ROUND_ACTIVE state and commence participation in the Arbitration process. Transponders that do not match the AFI value sent in the command will remain in the READY state or they will move to the READY state if they are already in the ROUND_ACTIVE or ROUND_STANDBY states.

If the AFI value contained in the INIT_ROUND command is 0x00, the Transponders will ignore the parameter in the command and all Transponders will move to the ROUND_ACTIVE state from the ROUND_ACTIVE or ROUND_STANDBY or READY states. With an AFI parameter of 0x00, the command will perform identically to an INIT_ROUND_ALL command.

Tags in the QUIET state will ignore the INIT_ROUND command.



BEGIN_ROUND COMMAND SELECTION OPERATION (see Fig. 19)

The BEGIN_ROUND command contains 2 selection parameters. The 1st parameter, called MASK_LENGTH, consists of a fixed length (8 bit) value, which specifies how many bits will be sent in the following parameter, called the MASK. This MASK_LENGTH will be between 0 and 136 for the EM4223. The MASK value will be compared to the number of bits of the tags data memory specified in the MASK_LENGTH parameter. Transponders with data matching the MASK in the command will move from the ROUND_ACTIVE or ROUND_STANDBY or READY states to the ROUND_ACTIVE state and commence participation in the Arbitration process. Transponders whose data does not match the MASK value sent in the command will remain in the READY state or they will move to the READY state if they are already in the ROUND_ACTIVE or ROUND_STANDBY states.

The MASK value is transmitted MSB 1st. The 1st bit of the MASK is compared to the MSB of the Transponders AFI, the 2nd bit of the MASK is compared to the 2nd most significant bit of the Transponders AFI and so on, up to the 8th bit of the MASK, which is compared to the AFI. If the 1st 8 bits of the MASK contain the value B00000000, the result of the comparison of the 1st 8 bits of the MASK to the AFI is forced to a Match result. If the MASK_LENGTH is less than 8 bits, then the number of bits of the Transponder's AFI compared to the MASK is determined by the MASK_LENGTH parameter.

The 9th to the 136th bits of the MASK is compared to the 128 bit USER DATA in the Transponder – in other words, bit 9 of the MASK is compared to the MSB of the USER DATA and so on down to bit 136 of the MASK being compared to the LSB of the USER DATA. The number of bits of the USER DATA compared to the MASK is equal to MASK_LENGTH – 8 if MASK_LENGTH > 8. If MASK_LENGTH ≤ 8 no USER DATA bits will be compared to the MASK.

Tags in the QUIET state will ignore the BEGIN_ROUND command.

9. COMMANDS AND STATES

Commands

The EM4223 supports the commands as specified in Table 5- Supported Commands and as set out in ISO/IEC CD 18000-6A clause 7.6 and clause 7.7.

Tag States

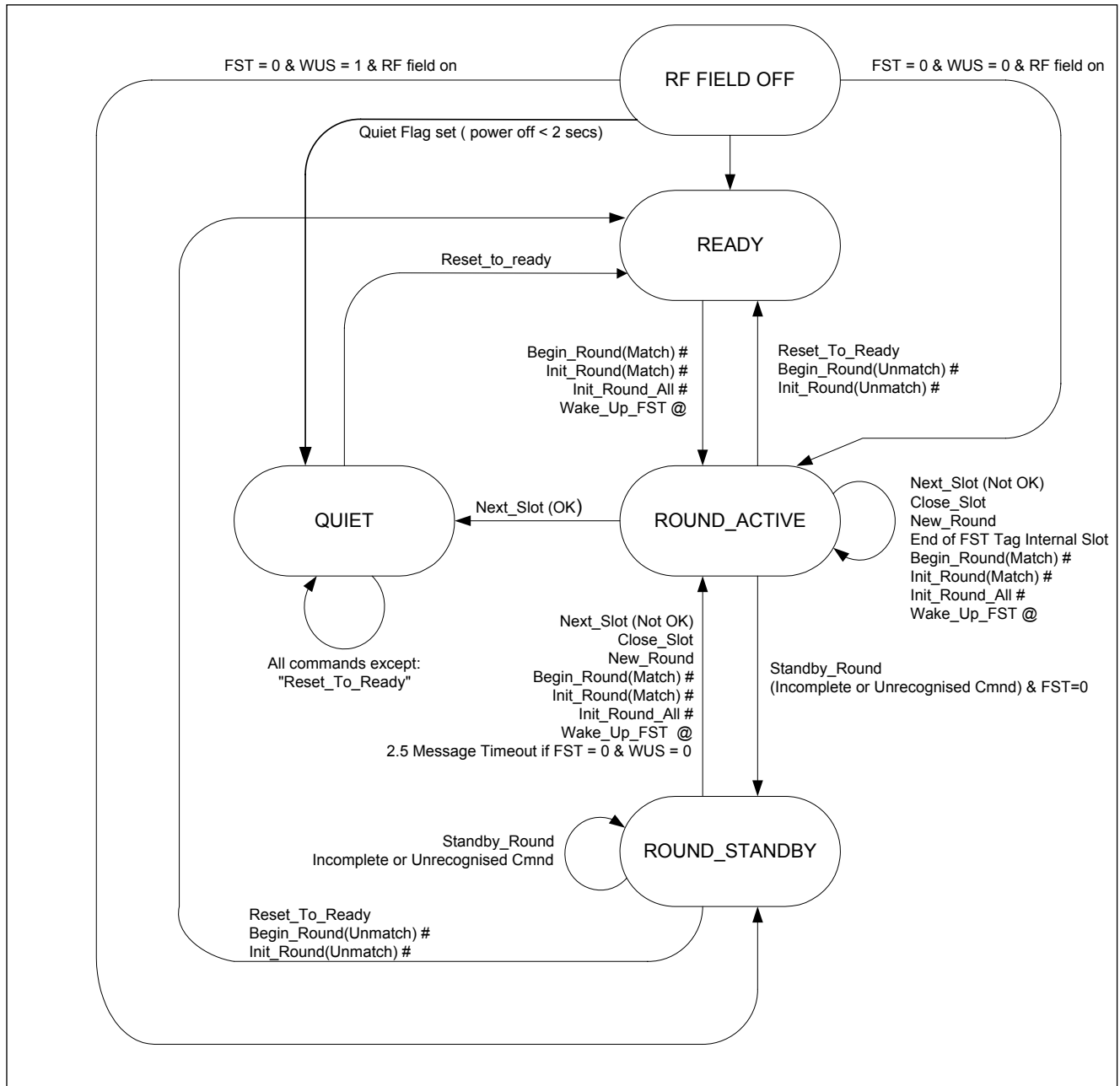
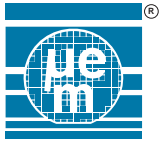


Fig. 19– State transition diagram showing commands.



NOTES:

- Commands marked with the "#" character will place tags in the "ISO" mode of operation. These are the "Begin_Round", "Init_Round" & "Init_Round_All" commands.
- The "Wake_Up_FST" command marked with the "@" character will place tags in the "FST" mode of operation.
- The last Mask selection made in the "ISO" mode will be retained when switching from the "ISO" to the "FST" mode.
- "Next_Slot(OK)" will only occur when the tag receiving the "Next_Slot" command receives the command in the command window immediately following its transmission to the Reader and if the "Next_Slot" command contained the same

SIGNATURE value as sent by the tag to the Reader as part of its transmission. In all other cases the "Next_Slot" command will be accepted as "Next_Slot (Not OK)".

- Tags will automatically start a new round without a "Begin_Round", "New_Round", "Init_Round" or "Init_Round_All" command when they receive a "Next_Slot" or "Close_Slot" command while their internal "Current Slot Counter" indicates the last slot in the current round. This will also apply to tags being moved from the ROUND_STANDBY state to the ROUND_ACTIVE state by a "Next_Slot" or "Close_Slot" command.

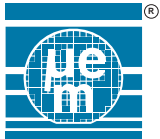
Tag state storage

In the case where the Transponder loses the energizing field for short periods of time (eg. when moving), the Transponder retains its state for at least 300µs. In addition, if the Transponder is in the Quiet state, it retains its Quiet state for at least 2s.

Note: Implementation of the Quiet state storage may imply that the Transponder will retain this condition during a time greater than 2s, up to several minutes in low temperature conditions. The Reset_to_Ready command overrides the Quiet state under these circumstances.

State	Description	Commands to which responsive
RF field off	The Transponder is out of the RF field or the Reader Tx Carrier is switched off.	None.
READY	The Transponder is in an RF field, its clock is running and it is waiting for a command.	Wake-Up_FST, Init-Round-All, Init-Round, Begin-Round
ROUND_ACTIVE	The Transponder steps through the hold-off loop and will transmit if it has reached its turn to transmit	None required, responsive to all commands according to the collision arbitration loop. Standby_Round will move the Transponder to the ROUND_STANDBY state.
ROUND_STANDBY	ROUND_ACTIVE state is suspended	Next-Slot, Close-Slot, New-round, Init-Round, Init-Round-All, Begin-Round, Reset-To-Ready, Wake-Up-FST & Time-Out
QUIET (Persistent Sleep)	The Transponder is unresponsive to commands and the hold-off loop has been suspended. It will only respond to a Reset-To-Ready command or will reset when removed from the RF field for an extended period of time typically greater than 2 seconds.	Reset-To-Ready

Table19 - Transponder States



10. COLLISION ARBITRATION

The EM4223 implements the ISO 18000-6 Type A anti-collision scheme as described in CD ISO-IEC 18000 part 6 Type A. Additionally, the EM4223 implements the Fast Supertag™ anti-collision protocol.

The basic collision arbitration scheme is based on slots. The ISO implementation uses regimented slots that are controlled by the Reader. Fast Supertag™ uses pseudo-slots (non-synchronised slots) by virtue of the fact that transmissions are initiated in integer multiples of a slot time. However because Transponder clocks will not be identical and because the Reader does not synchronize slots at the start of each slot, there will be a natural drift and the timing of slots between individual Transponders will diverge.

Refer to the state diagram, Fig. 19.

General explanation of the collision arbitration mechanism

The collision arbitration uses a mechanism, which allocates Transponder transmissions into rounds and slots. A round consists of a number of slots. A Transponder will only transmit once in a round unless the Transponder is in ISO mode and the WUS bit= 0, in which case the Transponder will reply in the first slot as well as in its chosen slot, or only in the first slot if the first slot was selected as the **Reply** slot by the Transponder. The time position where it transmits in a round is determined randomly.

ISO COMPLIANT SYSTEMS

Each slot has a duration at least as long as a Transponder transmission or as long as the Reader requires to identify an unproductive (empty) slot and send the CLOSE_SLOT command to the Transponder population. The Reader determines the duration of the slot by closing slots with CLOSE_SLOT or NEXT_SLOT commands in response to successful data replies from Transponders or clashing replies from Transponders or in response to identifying an empty slot.

On receiving an Init_round command, Transponders randomly select a slot in which to respond. If a Transponder has selected the first slot it will transmit its **Reply**. The Transponder includes its four-bit Transponder signature in its **Reply**. If the Transponder has selected a slot number greater than one, it will retain its slot number and wait for a further command.

After the Reader has sent the Init_round command there are three possible outcomes:

1. The Reader does not receive a Reply because either no Transponder has selected slot one or the Reader has not detected a Transponder Reply. The Reader then issues a Close_Slot command because it has not received a Reply.

2. The Reader detects a collision between two or more Transponder replies. Collisions may be detected either as contention from the multiple transmissions or by detecting an invalid CRC. After waiting until the channel is clear, the Reader sends a Close_Slot command to increment the Transponder slot counter.
3. The Reader receives a Transponder Reply without error, i.e. with a valid CRC. The Reader sends a Next_slot command synchronized to the Transponder timing window, containing the signature of the Transponder just received.

When Transponders in the ROUND_ACTIVE state that have not transmitted in the current slot receive a Next_slot command or a Close_Slot command, they increment their slot counters by one. When the slot counter equals the slot number previously selected by the Transponder, the Transponder transmits according to the rules above otherwise the Transponder waits for another command.

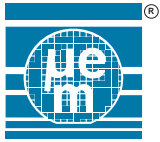
The Reader keeps track of the slot count each time it issues a Next_slot command or Close_Slot command. When the number of slots used equals the round_size issued in the Init_round command, the round has completed and the Reader may issue a round initializing command. (Note: A Reader may issue a round initializing command at any time).

Transponders that have not been acknowledged (by a synchronous Next_Slot command with a valid signature) during the current round, will enter a new round on determining the end of the current round or at any time on receiving a round initializing command. The Transponders will select a slot at random and transmit in the new round when the slot counter value and the slot selected are equal.

If at any time the Transponder receives a wake_up (FST) command whether in the READY state or in the ISO ROUND_ACTIVE or ROUND_STANDBY states, it will immediately switch to the FST mode of operation.

FST SYSTEMS

In the absence of an RF field, the Transponders are in the RF_field_off state. When the Transponders enter the energizing field of a Reader, they go through a power on reset sequence. If the FST bit = 0 and the WUS bit = 0, then the Transponder moves to the ROUND_ACTIVE State it is therefore in a Tag Talks First mode and commences a Fast Supertag™ collision arbitration sequence. If the FST bit = 0 and the WUS bit = 1, then the Transponder moves to the ROUND_STANDBY state until it receives a Next_Slot, Close_Slot, New_Round or Wake_up_FST command, at which time it commences a Fast Supertag™ collision arbitration sequence.



Each slot has a duration at least as long as the duration of a Transponder preamble. The actual duration of the slot is determined by the Transponder and is equal to 16 Transponder bit times. If a Transponder has selected the current slot in which to transmit its reply, the Slot length is increased for that Transponder to the duration of a message length so that the Transponder can send its complete message. In order to prevent other tags (those that have not yet started their replies) from transmitting during the first tag's reply slot the Reader issues a MUTE command to place the tags into the ROUND_STANDBY state. After the active Transponder has finished transmitting its message, and if the Reader has successfully read the Transponder it issues a Next_Slot command synchronously with the tag's signature. If the Transponder message was not successfully read then the Reader issues a Close_Slot command, which will cause all the tags currently in the ROUND_STANDBY state to re-enter the ROUND_ACTIVE state.

The number of slots in a round, referred to as round size, is determined by the Reader and is signaled to the Transponder in the Wake_Up_FST or New_Round command. In the FST mode the tag elects a default roundsize of 16, which may be overridden by a Reader command, however the FST mode is able to operate without any round initializing command. During the subsequent collision arbitration process the Reader dynamically chooses an optimum round size for the following rounds based on the number of collisions and/or unproductive time in a round. The number of collisions is a function of the number of Transponders in the ROUND_ACTIVE state present in the Reader field and the current round size. The Reader signals a change in round size to Transponders by sending a New_Round command containing the required round size.

The Transponder on entering the ROUND_ACTIVE State or on re-entering the ROUND_ACTIVE state having completed a round, selects a pseudo slot at random in which to reply. Pseudo slots are equal to Transponder preamble in duration. If the Transponder has selected the first pseudo slot, it will transmit immediately, if not it will hold off until it has reached the selected pseudo-slot and then transmit.

On receiving and recognizing a valid Transponder transmission preamble, the Reader sends a MUTE command (SOF), which tells all Transponders that have not yet started transmitting, to move to the ROUND_STANDBY state. When the Reader receives the Transponder **Reply** without error, it sends a Next_Slot command containing the signature of the Transponder that it has just received.

Transponders in the ROUND_STANDBY state will go through an internal time-out sequence and will return to the ROUND_ACTIVE state after a period equal to 2.5 X 176 tag bit periods has elapsed since the last MUTE command if the WUS bit = 0 (this time-out may be overridden by the Transponder receiving further Standby_Round or MUTE commands from the Reader which keep the Transponder in the ROUND_STANDBY state). The Transponder will move to the ROUND_ACTIVE state before the end of time-out period if it receives a Next_Slot, Close_Slot, New_Round or Wake_Up_FST command.

When the Transponder has reached the end of a round, it will self-trigger a new round, randomly select a new slot in which to transmit and it will transmit its identity or data when it reaches the selected slot. The process continues until the Transponder has been successfully read and acknowledged by a valid Next_Slot command or removed from the RF energizing field.

If at any time the Transponder receives an Init_Round, Init_Round_All or Begin_Round command whether in the READY, ROUND_ACTIVE or ROUND_STANDBY states, it will immediately switch to the ISO mode of operation.

BOTH TYPES – READ ACKNOWLEDGE

When a Transponder which has transmitted its data in the current slot, receives a Next_slot command, it:

- Verifies that the signature in the command matches the signature it sent in its last **Reply**
- Verifies that the Next_Slot command has been received within the timing window.

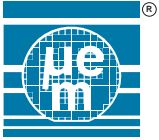
If the Transponder has met these acknowledge conditions it enters the Quiet state. Otherwise, it remains in the ROUND_ACTIVE state.

A Transponder in the Quiet state can only be returned to the active population by means of a Reset_To_Ready command followed by the appropriate round initializing command or by removing it from the RF energizing field for longer than the persistent sleep time.

FST MODE OPTIONS

If the FST = 0 set and the WUS = 1, the Transponder will wake up in Tag Talks First mode but muted. The first Next_Slot command will move the Transponder to the ROUND_ACTIVE state and it will enter a round as if it had received a Wake_Up command.

If both the WUS = 0 and FST = 0 the Transponder will move directly to the ROUND_ACTIVE state as if it had received a Wake_Up command.



Use of the round_size function (ISO & FST modes)

To optimized the system for the Transponder population size, the Reader is able to send round size commands to the Transponder by way of INIT_ROUND, INIT_ROUND_ALL, BEGIN_ROUND, NEW_ROUND and WAKE_UP_FST commands. The Reader needs to determine the proportion of collisions occurring and the amount of white space occurring and accordingly adjust the round size. As collisions increase proportional to the

number of successful reads, the round size should be increased. As the proportion of white space increases in proportion to the number of successful reads the round size should be decreased.

The round size is coded in the INIT_ROUND, INIT_ROUND_ALL, BEGIN_ROUND, NEW_ROUND and WAKE_UP_FST commands using 3 bits according to Table20.

Value	Bit coding		Round Size
	MSB	LSB	
'0'	0	0 0	1
'1'	0	0 1	8
'2'	0	1 0	16
'3'	0	1 1	32
'4'	1	0 0	64
'5'	1	0 1	128
'6'	1	1 0	256
'7'	1	1 1	RFU

Table20 - Round size coding

Pad Location Diagram

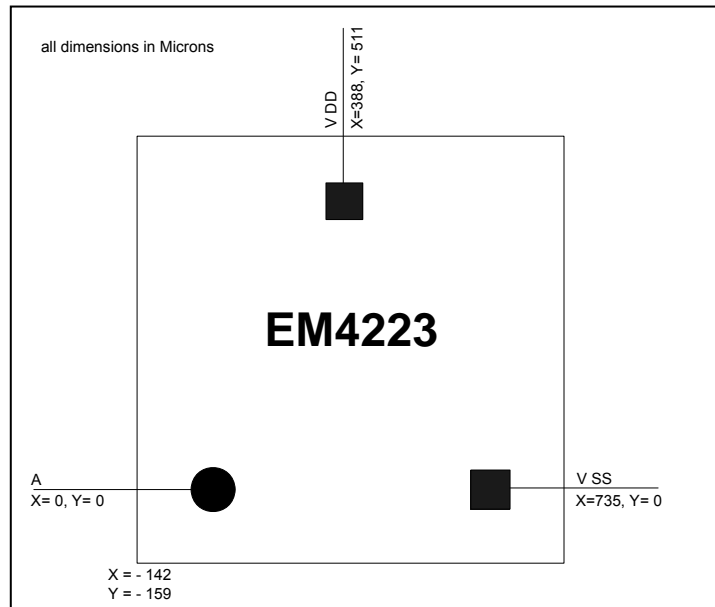


Fig. 20

Chip size is X= 1012 by Y= 830 microns

Note: The origin (0,0) is the lower left coordinate of center pads

The lower left corner of the chip shows distances of origin

Pin #	Name	Position x	Position y
1	A+	200	120
2	V _{SS}	700	120
3	V _{DD}	450	550

Table 21 - Connection Pad Positioning

Position is given in μm from the Seal Ring.

SOT 23 package outline

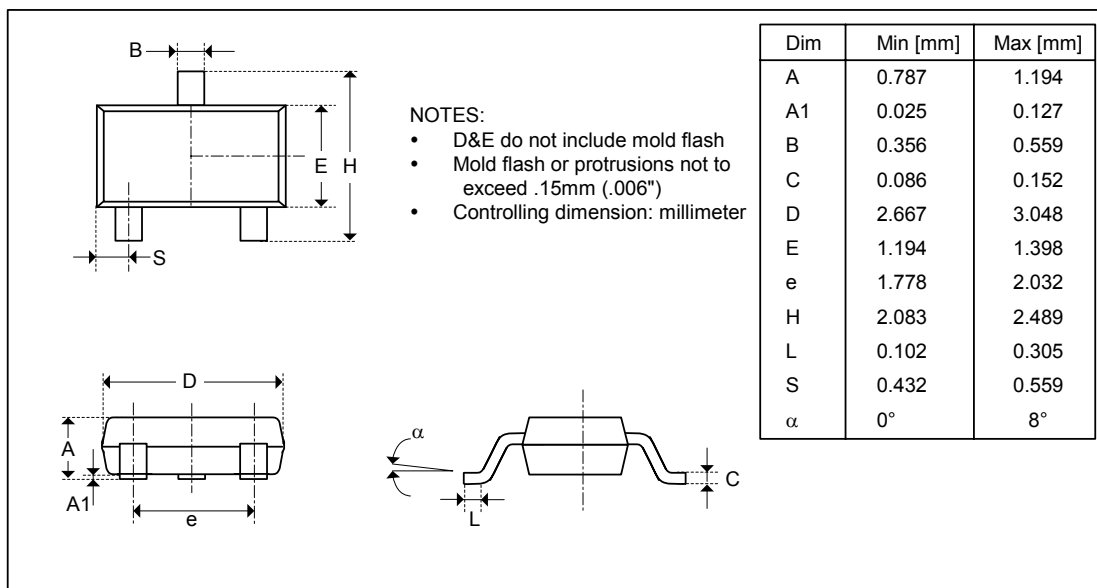


Fig. 21

SOT 23 pinout

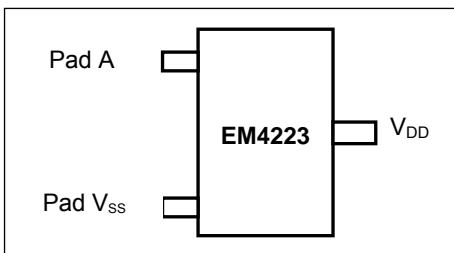


Fig. 22

Ordering Information

Packaged Device:

EM4223	V%	SP3B
Version "Personality word" Check table below		
Package SP3B = 3-pin SOT23, in Tape&Reel of 3000 pieces		

Device in DIE Form:

EM4223	V%	WS	11
Version "Personality word" Check table below			
Die form WW = Wafer WS = Sawn Wafer/Frame			
Thickness 7 = 7 mils (158um) 11 = 11 mils (280um)			
Bumping " " (blank) = no bump E = with gold bumps			

Versions (Personality word)

Personality word	Return link data rate	FST / ISO Flag	Wake Up Status Flag
V8	160 Kbps	ISO	
V7	160 Kbps	ISO	ISO_MOD
V6	160 Kbps	FST	RTF
V5	160 Kbps	FST	TTF
V4	40 Kbps	ISO	
V3	40 Kbps	ISO	ISO_MOD
V2	40 Kbps	FST	RTF
V1	40 Kbps	FST	TTF

Table 22

Standard Versions:

The versions below are considered standards and should be readily available. For the other delivery form, please contact EM Microelectronic-Marín S.A. Please make sure to give the complete part number when ordering.

Part Number	Package/Die Form	Delivery form/Bumping
EM4223V2SP3B	SOT 23	Tape & reel
EM4223V3SP3B	SOT 23	Tape & reel
EM4223V2WS11E	Die 11 mils	Sawn on frame / Bump
EM4223V3WS11E	Die 11 mils	Sawn on frame / Bump

Table 23

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