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Address: A1208, Overseas Decoration Building, #122 Zhenhua RD., Futian, Shenzhen, China

SL3ICS3001

UCODE HSL

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Product data sheet
COMPANY PUBLIC

1. General description

The UCODE HSL IC, SL3ICS3001 (UCODE High frequency Smart Label) is a dedicated chip for passive smart tags and labels, especially for supply chain management and logistics applications in the US, where operating distances of several meters can be realized. Further, the UCODE HSL technology platform is also designed for operation under European regulations.

This integrated circuit is the first member of a product family of smart label ICs targeted to be compliant with the future ISO standards 18000-4 and 18000-6 for item management.

The UCODE HSL system offers the possibility of operating labels simultaneously in the field of the interrogator antenna (Anticollision, Collision Arbitration).

The UCODE HSL family of ICs is especially designed for long range applications.

The tag requires no internal power supply. Its contactless interface generates the power supply via the antenna circuit by propagative energy transmission from the interrogator (read/write device), while the system clock is generated by an on-board oscillator. The contactless interface demodulates data transmitted from the interrogator to the UCODE HSL based tag, and further modulates the electromagnetic field provided by the interrogator for data transmission from the UCODE HSL based tag to the interrogator.

A generic RFID system consists of an interrogator (base station) that runs the RFID protocol, as well as one or more tags. The tag itself includes an SL3ICS3001 chip and an antenna tuned to the carrier frequency of the interrogator, and a package to hold the chip and antenna together.

When placed in the RF field of an interrogator, a SL3ICS3001 based tag will begin to power up. If the field is strong enough, the tag IC will execute a power-on reset and will be ready to receive commands. Each command begins with a preamble and start delimiter that, taken together, enable the tag to perform clock and data recovery on the incoming signal. Data to and from the tag is checked for errors using a CRC. Therefore, CRC fields are present in all interrogator commands and in all tag responses. Additional data protection is provided by Manchester encoding on the forward (interrogator to tag) link and FM0 encoding on the return (tag to interrogator) link.

The interrogator can perform a number of functions on tags in its field. For example, the interrogator can send a command sequence, which allows it to identify multiple tags in its RF field simultaneously. Alternatively, it can select a subset of the tags in the field based on tag memory contents. It can also read data stored on a tag in its field, as well as write data to such a tag. In addition, it can simultaneously write data to an arbitrary subset of the tags in the field.

Signals enter the chip through the RF front end, where both tag power and the modulation envelope are recovered. Tag power is regulated and bias voltages are generated in one part of the analog section. In another part of the analog section, the modulation envelope is applied to a clock and data recovery circuit. In the case of a valid command, the first part of the input signal is the preamble and start delimiter, which will be followed by a specific tag command and any additional fields that command may require. All valid digital data is processed in the digital section data path, which is controlled by the digital control module. If a read or write is to be executed, the EEPROM block will be accessed. If data is to be sent from the tag to the interrogator in response to the command, the digital section sends the output pattern back to the RF front end, where the impedance modulation that constitutes backscatter is executed.

2. Features and benefits

2.1 RF interface features

- Contactless transmission of data and supply energy (no battery needed)
- Operating distance, depending on antenna geometry and local regulations, up to 8.4 m for a single antenna
- Operating frequency within the released operating bands from 860 MHz to 960 MHz and from 2.4 GHz to 2.5 GHz
- High data integrity: 16 bit CRC, framing
- True anticollision for collision arbitration
- Write distance is 70% of reading distance

2.2 Memory features

- 2048 bits including lock bits
- 64 bits UID in memory bytes 0 to 7
- 216 bytes with user definable access conditions for memory bytes 8 to 223

2.3 Security features

- Unique serial number for each device
- Lock mechanism (write protection) for each byte

2.4 Operating distances features

RFID tags based on the SL3ICS3001 silicon may achieve operating distances according the following formula:

$$P_{tag} = EIRP \cdot G_{tag} \cdot \left(\frac{\lambda}{4\pi R}\right)^2$$

P_{TAG} ... minimum required RF power for the tag

G_{TAG} ... Gain of the tag antenna

EIRP ... Transmitted RF power

λ ... wavelength

$$R_{max} = \sqrt{\frac{EIRP \cdot G_{TAG} \cdot \lambda^2}{(4\pi)^2 \cdot P_{TAG}}}$$

R_{max} ... maximum achieved operating distance for a lossless, matched λ/2-dipole.

The maximum write distance is around 70% of the read distance.

Table 1. Operating distances for UCODE HSL based tags and labels in released frequency bands

Frequency range	Region	Available power	Calculated read distance single antenna[8][9]	Unit
868.4 to 868.65 MHz (UHF)	Europe [1]	0.5 W ERP	4.0	m
865.5 to 867.6 MHz (UHF)	Europe [2]	2 W ERP	8.0	m
902 to 928 MHz (UHF)	America [3]	4 W EIRP	8.4	m
860 to 930 MHz (UHF)	Others [4]			m
2.400 GHz to 2.4835 GHz	Europe [5]	0.5 W EIRP outdoor	0.6	m
2.400 GHz to 2.4835 GHz	Europe [5]	4 W EIRP indoor	1.8	m
2.400 GHz to 2.4835 GHz	America [6]	4 W EIRP	1.8	m
2.400 GHz to 2.4835 GHz	Others [7]			m

[1] Current CEPT/ETSI regulations [CEPT1], [ETSI1].

[2] Proposal for future CEPT/ETSI regulations.

[3] FCC regulation [FCC1].

[4] In many other countries regulations either similar to FCC or CEPT/ETSI may apply.

[5] Current CEPT/ETSI regulations [CEPT2], [ETSI2].

[6] FCC regulation [FCC1].

[7] In many other countries regulations either similar to FCC or CEPT/ETSI may apply.

[8] These distances are typical values for general tags and labels. A special tag antenna design or reflection could achieve higher values.

[9] Practical usable read distance values may be notable lower, strongly depending on application set-up, damping by environment materials and the quality of the matching between tag antenna and chip impedance.

The maximum write distance is around 70% of the read distance.

2.5 Air interface standards

The SL3ICS30 is fully supporting standardization on air interfaces. The SL3ICS30 is targeted to be compliant with the following air interfaces:

- ISO 18000-4
  - Information Technology - Radio Frequency Identification (RFID) for Item Management - Part 4: Parameters for Air Interface Communications at 2.45 GHz
- ISO 18000-6
  - Information Technology - Radio Frequency Identification (RFID) for Item Management - Part 6: Parameters for Air Interface Communications at 860 - 930 MHz
- ANSI/INCITS 256-2001
  - Radio Frequency Identification (RFID) Part 3 - 2.45 GHz
- ANSI/INCITS 256-2001
  - Radio Frequency Identification (RFID) Part 4 - UHF

2.6 Application standards

The SL3ICS30 is also fully supporting application standardization. The SL3ICS30 is targeted to be compliant with the following application standards:

- MH10.8.4
  - Radio Frequency Identification for Returnable Containers and Cable Reels
- AIAG B-11
  - Automotive Tire and Wheel Label Radio Frequency (RFID) Identification Standard
- EAN.UCC GTAG™
  - Global tag initiative
- ISO 18185
  - Freight Containers - Radio-frequency communication protocol for electronic seal

3. Applications

- Asset management
- Supply chain management
- Item level tagging
- Container identification
- Pallet and case tracking
- Product authentication
- Windshield tagging

4. Ordering information

Table 2. Ordering information

Type number	Package		
	Name	Description	Version
SL3ICS3001FW/V7	Wafer	Bumped die on sawn wafer	-

5. Block diagram

The SL3ICS3001 IC consists of three major blocks:

- Analog RF Interface
- Digital Controller
- EEPROM

The analog part provides stable supply voltage and demodulates data received from the interrogator for processing by the digital part. Further, the modulation transistor of the analog part transmits data back to the interrogator.

The digital section includes the state machines, processes the protocol and handles communication with the EEPROM, which contains a unique ID and user data.

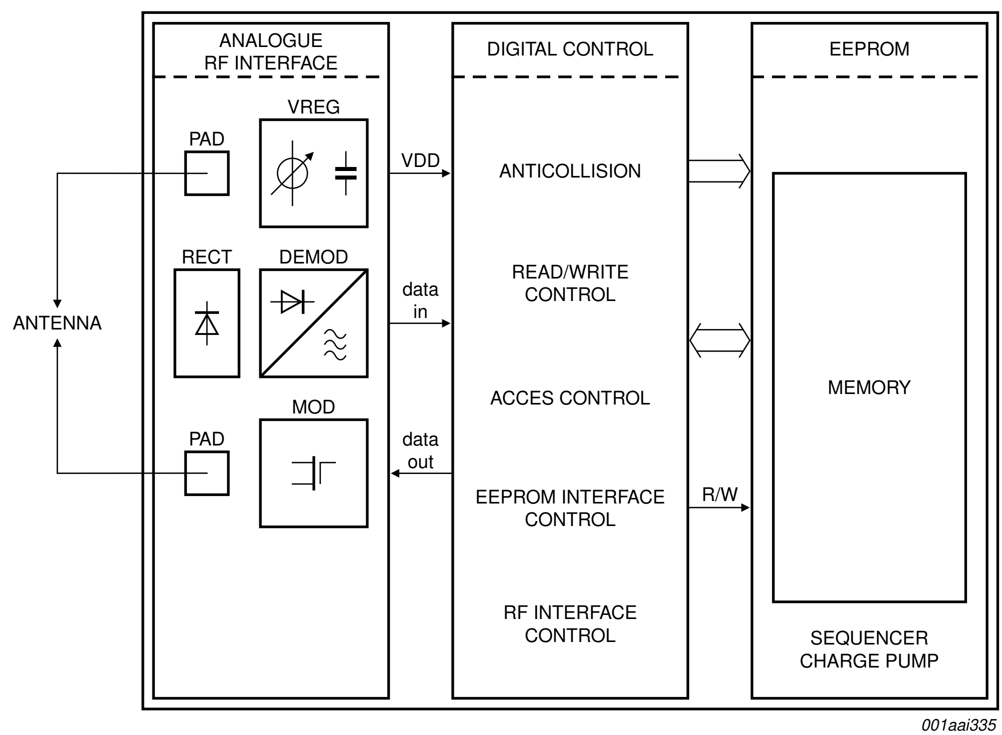


Fig 1. Block diagram

6. Pinning information

For pinning details please refer to Ref. 7 "Data sheet addendum".

7. Functional description

7.1 Power transfer

The interrogator provides a RF field that powers the tag containing the SL3ICS3001 and an antenna. The tag antenna transforms the impedance of free space to the chip input impedance in order to get the maximum possible power for the SL3ICS3001 on the tag.

The RF field, which is oscillating on the operating frequency provided by the interrogator, is rectified to provide smoothed DC voltage to the analog and digital modules of the IC.

The antenna that is attached to the chip has to support the rectifier structure on the chip by having no short circuit between the two antenna connectors (e.g. simple dipole structure). There will appear a DC voltage on the chip inputs during chip operation.

The RF field has to be turned on whenever the tag should operate. This also includes response time (backscatter) and the EEPROM programming process.

7.2 Operation frequency

The SL3ICS3001 supports global operation in different frequency bands. In principle, the SL3ICS3001 has no restriction on the operating frequency. Based on regulation requirements the SL3ICS3001 is released for the following frequency bands.

Table 3. Released operating frequency bands

Frequency band	Limit		Unit
	Lower	Upper	
UHF	860	960	MHz
2.45 GHz	2.4	2.5	GHz

7.3 Data transfer

7.3.1 Forward link

The SL3ICS3001 supports Manchester Code amplitude modulation. For data transmission, the interrogator switches between two values of emitted power.

Details are described in Section 9.

7.3.2 Return link

As the energy of the RF field is used and required for operation, the tag communicates back to the interrogator by changing its load to the RF field. For high frequencies, the behaviour of the RF field (electromagnetic field) may be described by travelling waves. Therefore, this method is called backscatter.

Details are described in Section 9.

8. Protocol

8.1 Major digital states

A powered IC can be in three major digital states:

- READY — the reset state when the tag is first powered up
- ID — the tag is trying to identify itself to the base station
- DATA EXCHANGE — the tag is known to the base station

In a typical application a tag will first be powered and set to the READY state. By a select command, the IC will participate in an anticollision sequence that will be processed in the ID state. If the tag gets identified a read command will typically move it to the DATA EXCHANGE state, where further read, write or lock commands can be performed.

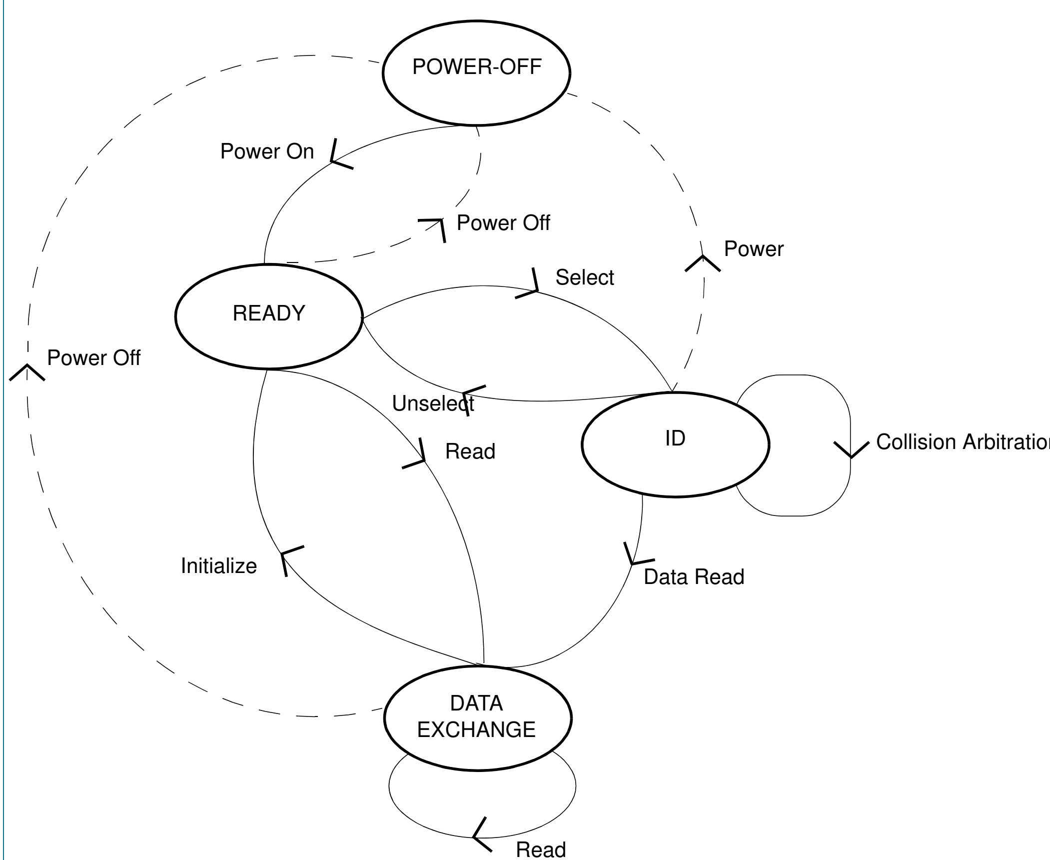


Fig 2. State diagram

State transition description

- Power-On
  - state change when interrogator field is turned on
- Power-Off
  - state change when interrogator field is turned off
- Select

  state change due to selection of tag by GROUP_SELECT commands
- Unselect
  - state change due to deselection of tag by GROUP_UNSELECT commands
- Data_Read
  - state change due to first read access in collision arbitration process
- Read
  - state change due to read access independent of collision arbitration process
- Initialize
  - state change due to deselection of all tags by the INITIALIZE command

As the state machine only supports 3 active states (READY, ID and DATA_EXCHANGE), only 3 opportunities of the tag status exist when the tag comes into the ready state after the power-off state.

1. The tag is new in this environment or was out of the field for a long while. In this case the tag should stay in the ready state until a new collision arbitration loop is initiated by a GROUP_SELECT command.
2. The tag has been participating in a collision arbitration and lost power through field nulls or just came out of the operating range. In this case, the tag has lost one or more collision arbitration commands and should therefore no longer participate in the active collision arbitration round. It should stay in the ready state until a new collision arbitration loop is initiated by a GROUP_SELECT command.
3. The tag had been selected already and was powered-down due to field nulls or short time being out of the operating range. In this case the tag no longer needs to be considered in the collision arbitration loops of this interrogator. Interrogators using the GROUP_SELECT_FLAG and GROUP_UNSELECT_ FLAG commands appropriately do not need to handle tags with DE_SB set and therefore limit the number of tags for the next collision arbitration loop to only those tags that have not been handled before.

By use of above mechanism each field null shorter than t_{DE_SB}, which is at least several seconds does not require a tag to be handled more than once in the collision arbitration. In general the use of the DE_SB bit improves the number of tags identified within a certain time especially for large tag numbers when field nulls exist.

The exact transition between these states is specified in Table 5.

8.2 Command overview

Table 4. Command Overview

Command name	State[1]			Description
	R	I	D	
GROUP_SELECT_xx [2]	x	x		group of commands that selects a class of tags in the field to participate in the identification process; selection criteria is the data at a specified address
GROUP_UNSELECT_xx [2]		x		group of commands that unselects a class of tags in the field; unselection criteria is the data at a specified address
GROUP_SELECT_yy_FLAGS [3]	x	x		group of commands that selects a class of tags in the field to participate in the identification process; selection criteria is the flag status of the IC
GROUP_UNSELECT_yy_FLAGS [3]		x		group of commands that unselects a class of tags in the field; unselection criteria is the flag status of the IC
MULTIPLE_UNSELECT		x		unselect tags from participating on the write_multiple process
FAIL		x		anticollision command after recognized collision
SUCCESS		x		anticollision command after recognized identification or no-response
RESEND		x		anticollision command after incorrect response
INITIALIZE	x	x	x	moves all tags in the READY state
READ	x	x	x	reads data of a defined tag from a special address
DATA_READ		x	x	reads data of a defined tag from a special address; typical after an identification process
READ_VERIFY	x	x	x	reads data of a defined tag from a special address; typical after a write process
WRITE	x	x	x	writes one byte to a special address of one tag
WRITE_MULTIPLE		x	x	writes one byte to a special address of all selected tags
WRITE4BYTE_MULTIPLE		x	x	writes four byte to a special address of all selected tags
WRITE4BYTE	x	x	x	writes four byte to a special address of one tag
LOCK			x	locks a special byte of one tag
QLOCK	x	x	x	queries the lock status of a special byte of one tag
READ_PORT	x	x	x	reads port data or defined tag port address
READ_VARIABLE	x	x	x	reads defined number of bytes from a certain memory address of a defined tag
READ_VERIFY	x	x	x	reads data of a defined tag from a special address; typical after a WRITE4BYTE command

[1] Commands active in state READY (R), ID (I) and DATA_EXCHANGE (D) if marked with “x” and ignored otherwise.

[2] xx can be “EQ”, “NE”, “GT” or “LT”.

[3] yy can be “EQ” or “NE”.

For details on each command see Section 11.

Table 5. State transition table

Initial state	Command name	Condition	Final state
READY	GROUP_SELECT_xx, GROUP_SELECT_yy_FLAGS	selection criteria does not match	READY
	GROUP_SELECT_xx, GROUP_SELECT_yy_FLAGS	selection criteria matches	ID
	INITIALIZE		READY
	READ, WRITE, WRITE4BYTE, QLOCK, READ_PORT, READ_VARABLE	UID matches	DATA EXCHANGE
	READ, WRITE, WRITE4BYTE, QLOCK, READ_PORT, READ_VARABLE	UID does not match	READY
	READ_VERIFY_4BYTE	UID matches and WRITE_OK [1]	DATA EXCHANGE
	READ_VERIFY_4BYTE	UID does not match or not WRITE_OK [1]	READY
ID	GROUP_SELECT_xx, GROUP_SELECT_yy_FLAGS		ID
	GROUP_UNSELECT_xx, GROUP_UNSELECT_yy_FLAGS	unselect criteria does not match	ID
	GROUP_UNSELECT_xx, GROUP_UNSELECT_yy_FLAGS	unselect criteria matches	READY
	MULTIPLE_UNSELECT	Data [2] incorrect or not WRITE_OK [1]	ID
	MULTIPLE_UNSELECT	Data[2] correct and WRITE_OK [1]	READY
	FAIL, SUCCESS, RESEND		ID
	INITIALIZE		READY
	READ, DATA_READ, WRITE, WRITE4BYTE, QLOCK, READ_PORT, READ_VARABLE	UID matches	DATA EXCHANGE
	READ, DATA_READ, WRITE, WRITE4BYTE, QLOCK, READ_PORT, READ_VARABLE	UID does not match	ID
	READ_VERIFY_4BYTE	UID does not match or not WRITE_OK [1]	ID
	READ_VERIFY_4BYTE	UID matches and WRITE_OK [1]	DATA EXCHANGE
	WRITE_MULTIPLE, WRITE4BYTE_MULTIPLE		ID
DATA_EXCHANGE	INITIALIZE		READY
	READ, DATA_READ, READ_VERIFY, READ_PORT, READ_VARABLE		DATA EXCHANGE
	WRITE, WRITE_MULTIPLE		DATA EXCHANGE
	WRITE4BYTE, WRITE4BYTE_MULTIPLE		DATA EXCHANGE
	LOCK, QLOCK		DATA EXCHANGE

[1] Flag that indicates a proper write process (see Section 8.3.2 “WRITE_OK”).

[2] Written data from a previous write command.

[3] Commands not listed at a certain initial state are ignored by a tag that is in this state.

8.3 Flags

The flag byte can be accessed by the GROUP_SELECT_yy_FLAGS and GROUP_UNSELECT_yy_FLAGS commands. In the BYTE_MASK (see Section 11.2.1.2) of those commands a matching criteria can be set. As only the two least significant bit of the flag byte are used in this IC all others are zero (logic 0).

The SL3ICS30 supports a field of 8 flags. This field is called FLAGS.

Table 6. Flags

Bit	Name
FLAG1 (LSB)	DE_SB (Data_Exchange Status Bit)
FLAG2	WRITE_OK
FLAG3	0 (RFU)
FLAG4	0 (RFU)
FLAG5	0 (RFU)
FLAG6	0 (RFU)
FLAG7	0 (RFU)
FLAG8 (MSB)	0 (RFU)

8.3.1 Data_Exchange status bit

The tag sets this bit when the tag goes into the DATA_EXCHANGE state and keeps it set unless it moves into the POWER-OFF state. When the DE_SB is set and the tag comes into the POWER-OFF state, then the tag triggers a timer that will reset the DE_SB bit after t_{DE_SB}.

When the tag goes into the READY state after POWER-OFF state and the DE_SB bit is still set, the timer is reset and DE_SB stays set.

When the tag receives the INITIALIZE command, then it reset the DE_SB bit immediately.

8.3.2 WRITE_OK

LSB+1 (Bit 1) of the flag byte. This bit indicates that a previous write operation was done without any problems. If WRITE_OK is set, the last programming cycle of the EEPROM was done properly.

The WRITE_OK bit is reset by any inadequate EEPROM write cycle or a voltage supply interruption (see Section 9.7). Further, it is reset latest at the begin of the second command following a write access to the EEPROM.

NOTE: To be absolute sure that the programming process was done correct, the data needs to be verified with an additional read command.

8.4 Lockable state machine

This state machine is used to control the possibility of locking bytes in the EEPROM.

The lockable state machine has 2 states, IDLE and LOCKABLE. Initially, the state is IDLE. After any valid READ, DATA_READ, WRITE and QLOCK commands to the tag, the state becomes LOCKABLE, and locks on that dedicated byte are allowed. The specified address (starting address) is saved.

If a LOCK command to the same address of the same tag is received and the state is LOCKABLE, the lock proceeds.

If any other command is received, including a command to another tags, or any command packet has an error, the state returns to IDLE and the lock is no longer allowed.

See also Section 10 and Section 11.

8.5 Collision arbitration, anticollision

The interrogator may use the GROUP_SELECT and GROUP_UNSELECT commands to define all or a subset of tags in the field to participate in the collision arbitration. It then may use the identification commands to run the collision arbitration algorithm.

For the collision arbitration, the tag supports two pieces of hardware on the tag:

- an 8-bit counter: COUNT
- a random ‘1’ or ‘0’ generator

In the beginning, a group of tags is moved to the ID state by GROUP_SELECT commands, and their internal counters are set to logic 0. Subsets of the group may be unselected by GROUP_UNSELECT commands back to the READY state. Other groups can be selected before the identification process begins. Simulation results show no advantage in identifying one large group or a few smaller groups.

After above described selection, the following loop should be performed:

1. All tags in the ID state with the counter COUNT at ’0’ transmit their ID. This set initially includes all the selected tags.
2. If more than one tag transmits, the base station receives an erroneous response. The FAIL command shall be sent.
3. All tags receiving a FAIL command with COUNT not equal to logic 0 will increment COUNT. That is, they move further away from being able to transmit. All tags receiving FAIL, having a COUNT of ’0’ (those that just transmitted) will generate a random number. Those that roll a ’1’ will increment COUNT and will not transmit. Those that roll a zero will keep COUNT at zero and send their UID again. One of four possibilities now occurs:
4. If more than one tag transmits, the FAIL step 2 repeats. (Possibility 1)
5. If all tags roll a ’1’, none transmits. The interrogator receives nothing. It sends the SUCCESS command. All the counters decrement, and the tags with a count of ‘0’ transmit. Typically, this returns to step 2. (Possibility 2)

6. If only one tag transmits and the ID is received correctly, the base station shall send the DATA_READ command with the ID. If the DATA_READ command is received correctly, then that tag moves to the DATA_EXCHANGE state and will transmit its data. The base station shall sends SUCCESS. All tags in the ID state decrement COUNT.
7. If only one tag has a count of ‘1’ and transmits, step 5 or 6 repeats. If more than one tag transmits, step 2 repeats. (Possibility 3)
8. If only one tag transmits and the ID is received with an error, the base station shall send the RESEND command. If the ID is received correctly, step 5 repeats. If the ID is received again some variable number of times (this number can be set based on the level of error handling desired for the system), it is assumed that more than one tag is transmitting, and step 2 repeats. (Possibility 4)

8.6 Data exchange sequences

8.6.1 Forward link

Every command starts with a command header consisting of PREAMBLE_DETECT, PREAMBLE and START DELIMITER. In this document, the appearance of these sequences is given in NRZ format. A NRZ ‘1’ means maximum field strength and NRZ ‘0’ means lower or even zero field (see also Section 9.3). Compared to the Manchester coded data, these sequences are given in halfbits.

All other transmitted data will be defined Manchester coded. This means that the digital data will be defined by a falling or rising transition in the middle of the bit. Furthermore, this means that a Manchester coded bit can be defined by two halfbits of a NRZ code.

The forward link consists of the following sequences:

- PREAMBLE_DETECT

  no transition allowed during this time
- PREAMBLE

  tag calibrates onto forward data rate
- START DELIMITER (STDEL)

  tag verifies its calibration
- COMMAND (CMD)
- Address + Byte Mask + Data

  only if required by the command
- CRC - 16

  16 check bits, calculated from COMMAND + Address + Byte Mask + Data
- WAIT

  only if COMMAND was a WRITE, to power the tag during EEPROM write

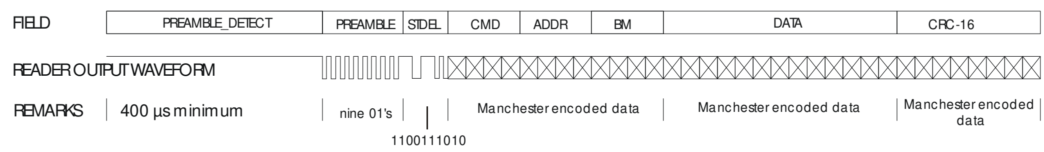


Fig 3. Example of a forward link sequence

8.6.1.1 Preamble

Table 7. Definition of forward PREAMBLE

	NRZ coded data stream
PREAMBLE	00 00 01 01 01 01 01 01 01 01 00 01 10 11 00 01

8.6.1.2 START DELIMITER

IC supports two Start Delimiters. See also Section 9.2.1 “Communication rate”.

Table 8. Definition of START DELIMITER

Type	NRZ coded data stream
STDEL1 (x1 return rate)	11 00 11 10 10
STDEL2 (x4 return rate)	11 01 11 00 10 1

8.6.2 Return link

A return link header consists of QUIET and RETURN_PREAMBLE. Just like the forward link header, this will be defined via NRZ coding. Here a NRZ ‘1’ means that the IC shortens the input pins. A NRZ ‘0’ does not affect the chip input impedance (see also Section 9.3).

Return data will be encoded in FM0. This means that on every edge of a bit a transition will occur. The digital data will be encoded by adding or non adding a transition in the middle of the bit. One FM0 bit is defined by 2 NRZ halfbits.

The return link consists of the following sequences, and starts immediately after the end of the forward link:

- QUIET
  – no transition allowed during this time
- RETURN PREAMBLE
  – interrogator may calibrate onto return data rate
- DATA
  – return data
- CRC - 16
  – 16 check bits, calculated from DATA

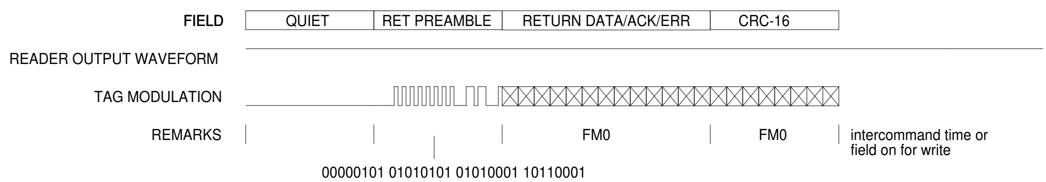


Fig 4. Example of a return link sequence

8.6.2.1 RETURN PREAMBLE

Table 9. Definition of forward RETURN PREAMBLE

	NRZ coded data stream
RETURN PREAMBLE	00 00 01 01 01 01 01 01 01 01 00 01 10 11 00 01

8.7 Bit and byte ordering

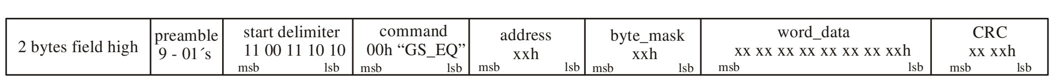
In all byte fields, the most significant bit (MSB) is transmitted first, proceeding to the least significant bit (LSB).

In all WORD_DATA (8 byte) or 4 BYTE_DATA (4 byte) data fields, the most significant byte is transmitted first. The most significant byte is the byte at the specified address. The least significant byte is the byte at the specified address plus 7 or plus 3. That is, bytes are transmitted in incrementing address order.

The byte significance is relevant to data transmission and the GROUP_SELECT and GROUP_UNSELECT greater than (“GT”) and less than (“LT”) comparisons.

The MSB of the byte mask corresponds to the most significant data byte, the byte at the specified address.

The byte mask for WRITE4BYTES and WRITE4BYTES_MULTIPLE uses only 4 bits. The MSB corresponds to the most significant byte that should be written. The 4 unused LSB´s in the byte mask are ignored.



Data is transmitted from the left to the right.

Fig 5. Example for bit and byte ordering for the GROUP_SELECT command

8.8 Data integrity

There are two types of transmission errors: modulation coding errors (detectable per bit) and CRC errors (detectable per command). Both errors cause any command to be aborted. The tag does not respond. For all CRC errors, the tag returns to the READY state. For all coding errors, the tag returns to the READY state if a valid start delimiter had been detected. Otherwise, it maintains in its current state.

8.9 CRC definition

The CRC-16 is calculated according the CRC-CCITT standard polynom $X^{16}+X^{12}+X^5+1$. The Cyclic Redundancy Check (CRC) is calculated on all data contained in a message, from the start of the command through to the end of data. This CRC is used from interrogator to tag and from tag to interrogator.

On receiving a command from the interrogator, the tag verifies if the checksum or the CRC value is valid. If it is invalid, it discards the frame and does neither respond, nor take any other action.

Table 10. CRC definition

CRC type	Length	Polynomial	Direction	Preset	Residue
CRC-CCITT	16 bits	$X^{16} + X^{12} + X^5 + 1$	forward and return link	'FFFF'	'0'

8.9.1 CRC algorithm

For computing the CRC:

- initialize the CRC accumulator to all ones - FFFFh
- accumulate data using the polynomial $X^{16} + X^{12} + X^5 + 1$
- invert the resulting CRC value
- attach the inverted CRC-16 to the end of the packet and transmit it MSB first

For checking the CRC:

- compute the CRC on the incoming packet
- accumulate the inverted CRC in the CRC registers
- verify that the accumulator is all zeroes

An example for the CRC calculation is given in the following section.

8.9.2 CRC calculation example

This example refers to a SUCCESS command.

SUCCESS command code: '09 hex or 00001001b'.

The packet sent from the interrogator to the tag consists of the following blocks, but only the SUCCESS command (09h), is used in the CRC calculation.

PREAMBLE_ DETECT	PREAMBLE	START DELIMITER	SUCCESS command - 09h	CRC-16

The CRC is calculated on the SUCCESS command as the field is transmitted MSB first.

The following example shows the values of the 16 CRC registers as the data is shifted through the CRC registers.

Table 11. Practical example of CRC calculation for a 'SUCCESS' command in the Interrogator

Step	Input (SUCCESS Cmd)	Calculated CRC in interrogator
1	0	'EFDF'
2	0	'CF9F'
3	0	'8F1F'
4	0	'0E1F'
5	1	'0C1F'
6	0	'183E'
7	0	'307C'
8	1	'70D9'

Table 12. Practical example of CRC checking for a 'SUCCESS' command in the Tag

Step	Input (Sent CRC-16)	Calculated CRC in interrogator
0		'70D9'
1	0	'E1B2'
2	1	'C364'
3	1	'86C8'
4	1	'0D90'
5	0	'1B20'
6	0	'3640'
7	0	'6C80'
8	0	'D900'
9	1	'B200'
10	1	'6400'
11	0	'C800'
12	1	'9000'
13	1	'2000'
14	0	'4000'
15	0	'8000'
16	1	'0000'

9. Communication timing and waveforms

9.1 Forward link

The tag front end effectively filters out short power interruption. Longer power interruptions will be detected and are interpreted as communication, tag writing, or, if exceeding a certain criteria in duration, may generate a tag reset (see Section 9.7).

If tag power is to be maintained between commands, the interrogator field must be kept on. If power is interrupted within t_{SD} (as if might happen during interrogator frequency hops from one channel to another), the tag may interpret the hop event as the beginning of the PREAMBLE field. The tag will not succeed to decode the first command that follows the hop. If a data stream with 10 closely-spaced rising edges (i.e. 10 Manchester 0's) is sent to the tag immediately after a known brief power interruption event, however, the first command following the event will be decoded (that command must start with the PREAMBLE_DETECT field). The sequence that provides the ten rising edges to the tag is called TAG RESYNC.

Table 13. Definition of TAG RESYNC

	NRZ coded data stream
TAG RESYNC	01 01 01 01 01 01 01 01 01 01

In order for a write to be successful, tag power must be maintained throughout the $t_{EEwrite}$ execution time. Furthermore, the on-chip supply voltage required for a successful write is higher than that required for a successful read (this asymmetry causes the asymmetry between tag read and write ranges). Power interruptions during the write cycle may be unavoidable, however, resulting in corrupted or unreliable data. The commands READ_VERIFY, MULTIPLE_UNSELECT, GROUP_ SELECT_ FLAGS, and GROUP_ UNSELECT_ FLAGS are used to identify bad data immediately after the WRITE, WRITE4BYTE, WRITE_MULTIPLE, WRITE4BYTE_ MULTIPLE or LOCK process so that it can be rewritten. Please see Section 11. for details regarding those commands.

9.1.1 Communication rate

As the chip supports two different values of modulation index (see Table 15) in the forward link, there are also different limits for the communication rate.

Table 14. Forward data rate

Modulation index		Forward data rate
Type 18% [1]	18%	8 to 40 kBits/s
Type 100% [2]	100%	30 to 40 kBits/s

[1] Type 18 % is intended to be used to fit into CEPT/ETSI and FCC regulations (for details see Section 16 “References”).

[2] Type 100% is intended to be used for FCC regulations only (for details see Section Section 16 “References”).

9.1.2 Modulation Waveform of Interrogator Modulation

The rectifier and demodulator of the IC is built in such a way that a command is recognized when transmitted as defined in Figure 6 and Table 15.

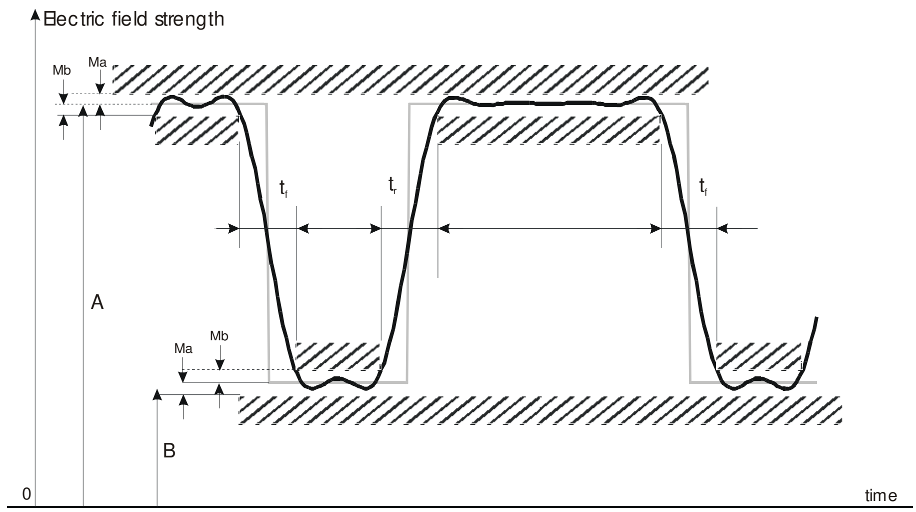


Fig 6. Definition of the RF envelope in the forward link

“A” in Figure 6 is the maximum amplitude of the RF field envelope. “B” is always smaller than “A”

$$\text{modulation index (m)} = \frac{A - B}{A + B} \quad (1)$$

The IC supports two values of modulation index: 18% and 100% as typical values.

Table 15. Modulation Type 18 % - Parameters for the RF envelop shape

Parameter	Min	Typ	Max	Unit
m	15	18	20	%
Ma = Mb	0	-	0.05 × (A-B)	-
$t_{r,10\text{-}90\% (A\text{-}B)}$	0	-	0.17 × $T_{bitrate}$	s
$t_{f,90\text{-}10\% (A\text{-}B)}$	0	-	0.17 × $T_{bitrate}$	s

[1] $T_{bitrate}$ is the bit period of the forward link bitrate.

[2] All values are valid for matched RF operation only.

Table 16. Modulation Type 100% - Parameters for the RF envelop shape

Parameter	Min	Typ	Max	Unit
m	90	100	100	%
Ma = Mb	0	-	0.03 × (A-B)	-
$t_{r,10\text{-}90\% (A\text{-}B)}$	0	-	0.1 × $T_{bitrate}$	s
$t_{f,90\text{-}10\% (A\text{-}B)}$	0	-	0.1 × $T_{bitrate}$	s

[1] $T_{bitrate}$ is the bit period of the forward link bitrate.

Table 17. Bit duty cycle tolerance

	Min	Typ	Max	Unit
forward duty cycle	45	50	55	%

9.1.3 RF envelope of data streams

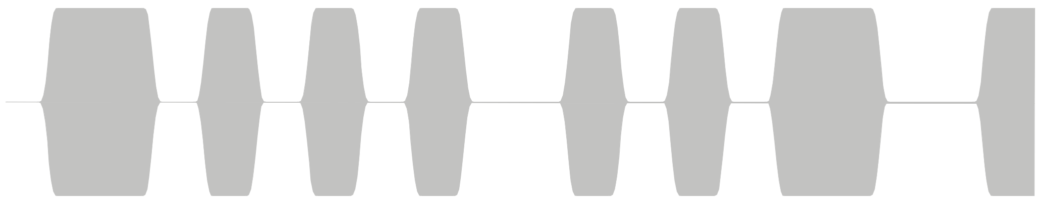


Fig 7. Example of a 100% modulation.

Fig 8. Example of a 15% modulation.

9.2 Return link

9.2.1 Communication rate

The chip supports two different kinds of return link data rates. The START DELIMITER (see Section 8.6.1.2.) of the command generating the response defines the data rate for the return link.

Table 18. Return data rate

Start delimiter	Return data rate	Tolerance
11 00 11 10 10	1 x forward data rate	± 15%
11 01 11 00 10 1	4 x forward data rate	± 15%

9.2.2 Modulation Waveform of Transponder Modulation

A modulation transistor operating right behind the rectifier is used to minimize the tag antenna impedance (ideally a short between the IC input pins) during back modulation.

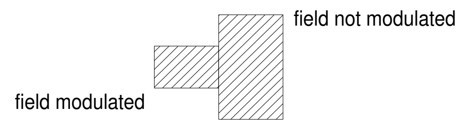
Table 19. Bit duty cycle tolerance

	Min	Typ	Max	Unit
return bit duty cycle	40	50	60	%

9.3 Bit Coding

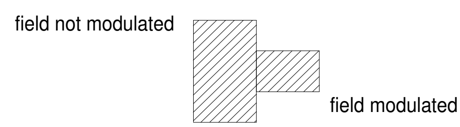
9.3.1 Forward Link

Maximum RF field is a NRZ ‘1’ (“A” in Figure 6), modulated RF field level equals NRZ ‘0’ (“B” in Figure 6).



Therefore a Manchester’0’ is “01” in NRZ.

Fig 9. Definition of a Manchester ‘0’



Therefore a Manchester’0’ is “01” in NRZ.

Fig 10. Definition of a Manchester ‘1’.

9.3.2 Return Link

NRZ ‘0’ is no modulation, that means a high chip input impedance.

NRZ ‘1’ is a modulation (modulation transistor turned on), that means a very low chip input impedance.

Within the FM0 encoded data patterns, a logical ‘0’ is transmitted, if there is transition at the midbit. A logical ‘1’ is transmitted if no transition occurs at the midbit. Note: in FM0 encoding a transition occurs additionally at all bit boundaries.

9.4 Response Time

The tag immediately starts sending back the return sequence after a correct command was received. As this sequence starts with a QUIET field (see Section 8.6.2) the interrogator may use the time for that field for settling its receiver section.

Table 20. Maximum interrogator settling time

QUIET field length	$16 \times T_{return\ bit\ rate} - 0.75 \times T_{forward\ bit\ rate}$

9.5 Regeneration Time

After a response of the tag or the end of a WAIT field, the tag is immediately able to receive a new command sequence from the interrogator. This sequence will again start with a PREAMBLE DETECT field.

9.6 Start-up Time

In general no special rise time is required. However, before starting data transmission to the tag, the interrogator has to establish a permanent carrier. If one uses the begin of ramp up of the field as starting time of a new command (as may desired after a frequency hop, to shorten the communication time) the values defined in Figure 11 and Table 21 hold.

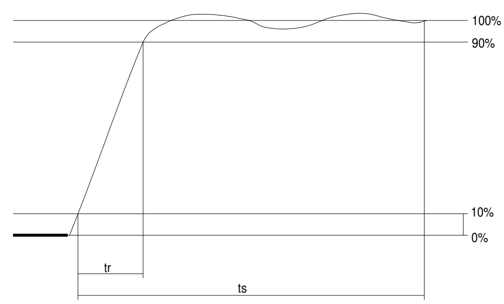


Fig 11. RF envelope - power up waveform

Table 21. Timing limits

Symbol	Min	Typ	Max	Unit
t_r	0		30	µs
t_s	400			µs

Note: Respecting above values, the power up process can be used for the PREAMBLE_DETECT field. If the power interruption for the tag was in the range of $t_{NN} < t \leq t_{SD}$, a TAG RESYNC has to be used before the next command (see Section 9.7).

9.7 Power interruptions

Power interruptions of different times will lead to the following consequences:

Table 22. Tag reaction on power interruptions

Power interruption time: $T_{interrupt}$		Consequences
FROM	**TO**	
0	t_{NN}	No notice of interruption by the tag
t_{NN}	t_{SD}	Start of demodulation by the tag due to the interrupt may happen, if the tag is not reset due to power shortage.
t_{SD}	t_{DE_SB}	Date exchange status bit stays valid, despite that the digital state information is lost.
t_{DE_SB}		Tag looses all internal state information and the data exchange status bit is reset.

10. Memory

- Tag memory size:
  - 2048 bits
- ID memory size:
  - 8 bytes
- User memory size:
  - 216 bytes

All transmitted ADDRESS fields in the forward link has to be within the range of 0 to 223 (‘0h’ to ‘DFh’), as this address refers to byte units. If an ADDRESS field is received that exceeds ‘DFh’, the command is ignored.

Each byte has an associated lock bit. If this lock bit is set to ‘1’ the data of the byte cannot be changed anymore. This means that no more write commands can be processed on that byte.

Note: In case a read command uses a valid value for ADDRESS, but the number of bytes read by the command exceed ‘DFh’ is not defined.

10.1 Memory organization

The memory is organized byte-wise. Each byte has a dedicated lock bit.

Writing with the commands WRITE4BYTE and WRITE4BYTE_MULTIPLE is only possible on a 4 byte boundary: 0, 4, 8, …

10.2 Definition of block contents

10.2.1 UID

The Unique ID (UID) is a 64 bit number, and is located in the bytes from 0 to 7. The most significant byte is stored on byte location 0. The bytes associated with the UID have to be locked latest after final label test.

10.3 Configuration of delivered ICs

Table 23. Configuration of delivered ICs

Memory Address	Memory Content	Lock Status	Comment
Byte 0, 1	E0, 04 hex	locked	unique serial number
Byte 2 - 7	xx hex	locked	unique serial number
Byte 8 - 10	00 hex	unlocked	user memory
Byte 11	02 hex	unlocked	user memory
Byte 12 - 17	FF hex	unlocked	user memory
Byte 18 - 219	00 hex	unlocked	user memory
Byte 220 - 223	57 5F 4F 4B hex	unlocked	“w_ok” in ASCII, user memory

11. Commands

11.1 Definitions

Table 24. Command codes and format

Command name	Code	Parameters			
GROUP_SELECT_EQ	00h	ADDRESS	BYTE_MASK	WORD_DATA	
GROUP_SELECT_NE	01h	ADDRESS	BYTE_MASK	WORD_DATA	
GROUP_SELECT_GT	02h	ADDRESS	BYTE_MASK	WORD_DATA	
GROUP_SELECT_LT	03h	ADDRESS	BYTE_MASK	WORD_DATA	
GROUP_UNSELECT_EQ	04h	ADDRESS	BYTE_MASK	WORD_DATA	
GROUP_UNSELECT_NE	05h	ADDRESS	BYTE_MASK	WORD_DATA	
GROUP_UNSELECT_GT	06h	ADDRESS	BYTE_MASK	WORD_DATA	
GROUP_UNSELECT_LT	07h	ADDRESS	BYTE_MASK	WORD_DATA	
FAIL	08h	none			
SUCCESS	09h	none			
INITIALIZE	0Ah	none			
DATA_READ	0Bh	ID	ADDRESS		
READ	0Ch	ID	ADDRESS		
WRITE	0Dh	ID	ADDRESS	BYTE_DATA	
WRITE_MULTIPLE	0Eh	ADDRESS	BYTE_DATA		
LOCK	0Fh	ID	ADDRESS		
QUERY_LOCK	11h	ID	ADDRESS		
READ_VERIFY	12h	ID	ADDRESS		
MULTIPLE_UNSELECT	13h	ADDRESS	BYTE_DATA		
RESEND	15h	none			
CALIBRATE	16h	none			
GROUP_SELECT_EQ_FLAGS	17h	BYTE_MASK	BYTE_DATA		
GROUP_SELECT_NE_FLAGS	18h	BYTE_MASK	BYTE_DATA		
GROUP_UNSELECT_EQ_FLAGS	19h	BYTE_MASK	BYTE_DATA		
GROUP_UNSELECT_NE_FLAGS	1Ah	BYTE_MASK	BYTE_DATA		
WRITE4BYTE	1Bh	ID	ADDRESS	BYTE_MASK	4BYTE_DATA
WRITE4BYTE_MULTIPLE	1Ch	ADDRESS	BYTE_MASK	4BYTE_DATA	
READ_VERIFY_4BYTE	1Dh	ID	ADDRESS		
READ_VARIABLE	51h	ID	ADDRESS	LENGTH	
READ_PORT	52h	ID	ADDRESS		

Table 25. Command fields

Field name	Field size
COMMAND	1 byte
ADDRESS	1 byte
BYTE_MASK	1 byte
ID	8 bytes
WORD_DATA	8 bytes
BYTE_DATA	1 byte
4BYTE_DATA	4 bytes
LENGTH	1 byte

Table 26. Tag response

Response name	Response size	Value
ACKNOWLEDGE	1 byte	00
ACKNOWLEDGE_NOK	1 byte	00
ACKNOWLEDGE_OK	1 byte	01
ERROR_NOK	1 byte	FE
ERROR	1 byte	FF
ERROR_OK	1 byte	FF
ID	8 bytes	n/a
WORD_DATA	8 bytes	n/a
BYTE_DATA	1 byte	n/a
CRC	2 bytes	n/a
VARIABLE_DATA	LENGTH bytes	n/a