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Contents

Page

Foreword ..... **v**

Introduction ..... **vi**

1 Scope **1**

2 Normative references **1**

3 Terms, definitions, symbols and abbreviated terms **1**

3.1 Terms and definitions 1
3.2 Symbols 2
3.3 Abbreviated terms 3

4 Conformance **3**

4.1 Air interface protocol specific information 3
4.2 Interrogator conformance and obligations 3
4.3 Tag conformance and obligations 4

5 Introducing the SPECK cryptographic suite **4**

6 Parameter and variable definitions **4**

7 Crypto suite state diagram **5**

8 Initialization and resetting **6**

9 Authentication **6**

9.1 General 6
9.2 Message and response formatting 6
9.3 Tag authentication (AuthMethod “00”) 7
9.3.1 General 7
9.3.2 TAM1 message 7
9.3.3 Intermediate Tag processing 8
9.3.4 TAM1 response 8
9.3.5 Final Interrogator processing 8
9.4 Interrogator authentication (AuthMethod “01”) 9
9.4.1 General 9
9.4.2 IAM1 message 9
9.4.3 Intermediate Tag processing #1 10
9.4.4 IAM1 response 10
9.4.5 Intermediate Interrogator processing 10
9.4.6 IAM2 message 10
9.4.7 Intermediate Tag processing #2 11
9.4.8 IAM2 response 11
9.4.9 Final Interrogator processing 12
9.5 Mutual authentication (AuthMethod “10”) 12
9.5.1 General 12
9.5.2 MAM1 message 13
9.5.3 Intermediate Tag processing #1 13
9.5.4 MAM1 response 14
9.5.5 Intermediate Interrogator processing 14
9.5.6 MAM2 message 14
9.5.7 Intermediate Tag processing #2 15
9.5.8 MAM2 response 15
9.5.9 Final Interrogator processing 16

10 Communication **16**

10.1 General 16
10.2 Message and response formatting 17
10.3 Transforming a payload prior to encapsulation 17
10.3.1 General 17

10.3.2 Encapsulating an Interrogator command ... 19
10.3.3 Cryptographically protecting a Tag reply ... 20
10.4 Processing an encapsulated or cryptographically-protected reply ... 20
10.4.1 General ... 20
10.4.2 Recovering an encapsulated Interrogator command ... 21
10.4.3 Recovering a cryptographically-protected Tag response ... 22

11 Key table and key update ... 22

Annex A (normative) **Crypto suite state transition table ... 24**

Annex B (normative) **Errors and error handling ... 25**

Annex C (normative) **Description of SPECK and SILC v3 ... 26**

Annex D (informative) **Test vectors ... 30**

Annex E (normative) **Protocol specific information ... 42**

Bibliography ... 45

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee, SC 31 *Automatic identification and data capture techniques.*

A list of all the parts in the ISO/IEC 29167 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document specifies a variety of security services provided by the lightweight block cipher SPECK. While SPECK supports various key and block sizes, the cipher versions that are supported in this cryptographic suite take the following block/key sizes in bits: 64/96, 96/96, 64/128, 128/128, and 128/256.

The International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC) draw attention to the fact that it is claimed that compliance with this document may involve the use of patents concerning radio-frequency identification technology given in the clauses identified below.

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Information technology — Automatic identification and data capture techniques —

Part 22: Crypto suite SPECK security services for air interface communications

1 Scope

This document defines the crypto suite for SPECK for the ISO/IEC 18000 air interfaces standards for radio frequency identification (RFID) devices. Its purpose is to provide a common crypto suite for security for RFID devices that can be referred to by ISO committees for air interface standards and application standards. The crypto suite is defined in alignment with existing air interfaces.

SPECK is a symmetric block cipher that is parameterized in both its block length and key length. In this document, a variety of block/key length options are supported.

This document defines various methods of use for the cipher.

A Tag and an Interrogator can support one, a subset, or all of the specified options, clearly stating what is supported.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 18000-63, *Information technology — Radio frequency identification for item management — Part 63: Parameters for air interface communications at 860 MHz to 960 MHz Type C*

ISO/IEC 19762, *Information technology — Automatic identification and data capture (AIDC) techniques — Harmonized vocabulary*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 19762 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1.1
bit string
ordered sequence of 0s and 1s

3.1.2
block cipher
family of permutations that is parameterized by a cryptographic key and, optionally, the block size

3.1.3
block size
number of bits in a *data block* (3.1.6) that is an input (or output) of the *block cipher* (3.1.2)

3.1.4
cryptographic key
string of bits of length given by *key size* (3.1.7) that is used by the *block cipher* (3.1.2) to transform some *data block* (3.1.6)

3.1.5
command
<message> data that the Interrogator sends to the Tag with Message as parameter

3.1.6
data block
string of bits whose length is given by the *block size* (3.1.3) of the *block cipher* (3.1.2)

3.1.7
key size
length in bits of the *cryptographic key* (3.1.4) that is used by the *block cipher* (3.1.2)

3.1.8
message
part of the *command* (3.1.5) that is defined by the crypto suite

3.1.9
nonce
data block (3.1.6) that, within the parameters of typical use, can be assumed to be non-repeating

3.1.10
SPECK-b/k-ENC(key, data)
SPECK encryption of a *b*-bit *data block* (3.1.6) using a *k*-bit *cryptographic key* (3.1.4)

3.1.11
SPECK-b/k-DEC(key, data)
SPECK decryption of a *b*-bit *data block* (3.1.6) using a *k*-bit *cryptographic key* (3.1.4)

3.1.12
Reply
<response> data that the Tag returns to the Interrogator with *Response* (3.1.13) as parameter

3.1.13
Response
part of the *Reply* (3.1.12) (stored or sent) that is defined within the crypto suite

3.2 Symbols

$XXXX_2$	Binary notation
$XXXX_h$	Hexadecimal notation
$\|\|$	Concatenation of syntax elements, transmitted in the order written
∅	The empty string, typically used to indicate a deliberately empty input or omitted field
$\|A\|$	The bit-wise length of the string A expressed as an integer

	Example 1: $\lvert 0000_2 \rvert = 4$.
	Example 2: $\lvert 0000_h \rvert = 16$.
	Example 3: $\lvert \emptyset \rvert = 0$.
fix1(A)	The string obtained by fixing the first (leftmost) bit to 1_2
	Example 1: **fix**1(0000_2) = 1000_2.
	Example 2: **fix**1(0000_h) = 8000_h.
	Example 3: **fix**1(∅) = ∅.
msb$_n$ (A)	The *n*-bit binary string obtained by taking the first (leftmost) *n* bits of the binary representation of A
	Example 1: **msb**$_3$ (1010_2) = 101_2.
	Example 2: **msb**$_7$ ($ABCD_h$) = 1010101_2.
	Example 3: **msb**$_7$ (∅) = ∅.
Field [a:b]	Selection of bits from a string of bits denoted Field
	The selection ranges from bit "a" through to, and including, bit "b" where Field [0] represents the least significant or rightmost bit.
	Example 1: Field [2:0] represents the selection of the three least significant bits of Field.
	Example 2: Field, without a specified range, indicates the entirety of Field.
	Example 3: Field [-1:0] is an alternative representation of the empty string ∅.
Key.KeyID	The cryptographic key identified and indexed by the numerical value KeyID

3.3 Abbreviated terms

CS	Crypto Suite
CSI	Crypto Suite Indicator
RFU	Reserved for future use

4 Conformance

4.1 Air interface protocol specific information

An Interrogator or Tag shall comply with all relevant clauses of this document, except those marked as "optional".

4.2 Interrogator conformance and obligations

An Interrogator shall implement the mandatory commands defined in this document and conform to the relevant part of ISO/IEC 18000.

An Interrogator may implement any subset of the optional commands defined in this document.

The Interrogator shall not:

— implement any command that conflicts with this document; or

— require the use of an optional, proprietary or custom command to meet the requirements of this document.

4.3 Tag conformance and obligations

A Tag shall implement the mandatory commands defined in this document for the supported types and conform to the relevant part of ISO/IEC 18000.

A Tag may implement any subset of the optional commands defined in this document.

A Tag shall not:

— implement any command that conflicts with this document, or

— require the use of an optional, proprietary or custom command to meet the requirements of this document.

5 Introducing the SPECK cryptographic suite

SPECK is a lightweight Feistel block cipher that is suitable for extremely constrained environments such as RFID Tags. The details of the operation of the SPECK cipher are described in Annex C.

The background for the development of SPECK and its design principles are described in Reference [3].

SPECK is parameterized in terms of the block size, denoted *b*, and the key size denoted *k*. A particular variant of SPECK will be denoted SPECK-*b*/*k* throughout this document. While Reference [3] offers many different choices to the block and key size, this cryptographic suite only supports the five parameter combinations given in Table 1:

Table 1 — Variants of SPECK-*b*/*k* supported in this document

	SPECK-64/96	SPECK-64/128	SPECK-96/96	SPECK-128/128	SPECK-128/256
Block size (*b* bits)	64	64	96	128	128
Key size (*k* bits)	96	128	96	128	256

It is possible that not all variants of SPECK will be cryptographically suited to all applications. Guidance on the appropriate variant for a given application lies outside the scope of this document and a thorough security and risk assessment is advised before deployment.

Test vectors for the components of this document are provided in Annex D.

6 Parameter and variable definitions

Table 2 lists the variables and constants that are used in this document.

Table 2 — SPECK cryptographic suite variables and constants

Parameter	Description
IChallenge-*b*/*k*	A challenge generated at random by the Interrogator. The length of IChallenge-*b*/*k* depends on the values of *b* and *k*.
TChallenge-*b*/*k*	A challenge generated at random by the Tag. The length of TChallenge-*b*/*k* depends on the values of *b* and *k*.
TRnd-*b*/*k*	A salt value generated at random by the Tag. The length of TRnd-*b*/*k* depends on the values of *b* and *k*.
IRnd-*b*/*k*	A salt value generated at random by the Interrogator. The length of IRnd-*b*/*k* depends on the values of *b* and *k*.
C_TAM-*b*/*k*	A pre-defined constant. The length and value of C_TAM-*b*/*k* depends on the values of *b* and *k*.
C_IAM-*b*/*k*	A pre-defined constant. The length and value of C_IAM-*b*/*k* depends on the values of *b* and *k*.
C_MAM-*b*/*k*	A pre-defined constant. The length and value of C_MAM-*b*/*k* depends on the values of *b* and *k*.
Key.0 ... Key.255	A set of up to 256 keys Key.0 through to Key.255. Not all key values need to be specified. However Key.j shall not be specified when there remain unspecified Key.i with i<j.

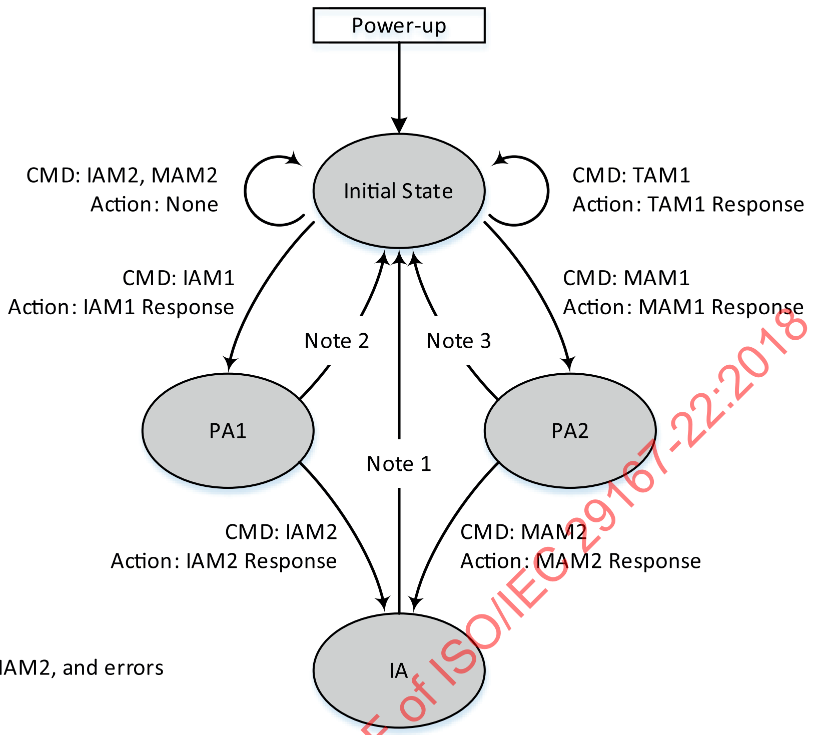
Table 3 gives the values of C_TAM-*b*/*k*, C_IAM-*b*/*k* and C_MAM-*b*/*k* that are used in this document. For a given choice of operational parameters, the length of these constants depends on the block size *b*.

Table 3 — Values of C_TAM-*b*/*k*, C_IAM-*b*/*k*, and C_MAM-*b*/*k* for different values of *b* and *k* and different parameter sets PS

b*/*k	**64/96**	**64/128**	**96/96**	**128/128**	**128/256**
C_TAM-*b*/*k*	11_2	11_2	FF_h	$FFFF_h$	$FFFF_h$
C_IAM-*b*/*k*	10_2	10_2	FE_h	$FFFE_h$	$FFFE_h$
C_MAM-*b*/*k* for PS=00_2	01_2	01_2	FD_h	$FFFD_h$	$FFFD_h$
C_MAM-*b*/*k* for PS=01_2	1_h	1_h	D_h	FD_h	FD_h

7 Crypto suite state diagram

After power-up and after a reset, the Cryptographic Suite shall transition into the **Initial** state, state transitions shall be defined by Annex A, and error handling shall be defined by Annex B. See Figure 1.



Note 1: For all of TAM1, IAM1, MAM1, IAM2, MAM2, and errors return to Initial State without action

Note 2: For all of TAM1, IAM1, MAM1, MAM2, and errors return to Initial State without action

Note 3: For all of TAM1, IAM1, MAM1, IAM2, and errors return to Initial State without action

Figure 1 — Crypto suite state diagram

8 Initialization and resetting

After power-up and after a reset the cryptographic state machine transitions into the **Initial** state.

Implementations of this suite shall ensure that all memory used for any intermediate results is cleared:

— after the completion of each cryptographic protocol,

— if some cryptographic protocol is abandoned or incomplete, and

— after reset.

9 Authentication

9.1 General

This document supports Tag authentication, Interrogator authentication and Mutual authentication.

This clause describes the details of the messages and responses that are exchanged between the Interrogator and Tag for each of the authentication methods.

9.2 Message and response formatting

Messages and responses are part of the security commands described in the air interface specification. The following subclauses of this document describe the formatting of message and response for a

Tag authentication method, an Interrogator authentication method and a Tag-Interrogator mutual authentication method.

9.3 Tag authentication (AuthMethod “00”)

9.3.1 General

Tag authentication uses a challenge-response protocol. See Figure 2.

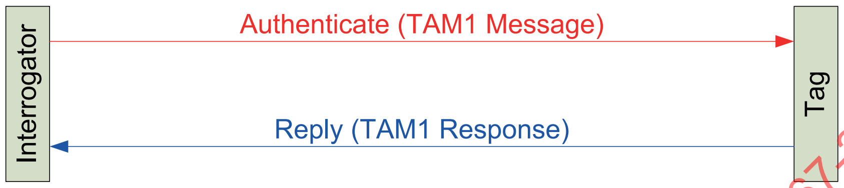


Figure 2 — Tag authentication via a challenge-response scheme

The parameter set PS defined in Table 4 gives the lengths of different fields for different block and key sizes.

NOTE The parameter set PS=00_2 closely matches other parts of the ISO/IEC 29167 series, most notably 29167-10. This provides some drop-in compatibility between SPECK-128/128 and AES-128.

Table 4 — Parameter set PS = 00_2 for Tag authentication

Parameter set PS= 00_2					
b/k	**64/96**	**64/128**	**96/96**	**128/128**	**128/256**
t **= │ IChallenge-*b/k* │**	42	42	56	80	80
r **= │ TRnd-*b/k* │**	20	20	32	32	32
c **= │ C_TAM-*b/k* │**	2	2	8	16	16

9.3.2 TAM1 message

The Interrogator shall generate a random Interrogator challenge (IChallenge-*b*/*k*) that is carried in the TAM1 message. The Interrogator shall also indicate the variant of SPECK to be used.

NOTE 1 The variant(s) of SPECK deployed on a device is (are) manufacturer dependent.

NOTE 2 Mechanisms to generate the random Interrogator challenge lie outside the scope of this document.

Table 5 — TAM1 message format

	Payload							
Field	**AuthMethod**	**Step**	**RFU**	**BlockSize**	**KeySize**	**KeyID**	**PS**	**Challenge**
Length (bits)	2	2	2	2	2	8	2	*t*
Value	00_2	00_2	00_2	00_2: *b*=64 01_2: *b*=96 10_2: *b*=128 11_2: RFU	00_2: *k*=96 01_2: *k*=128 10_2: *k*=256 11_2: RFU	variable	00_2	IChallenge-b/k

9.3.3 Intermediate Tag processing

The Tag shall accept the TAM1 message at any time (unless occupied by internal processing and not capable of receiving messages); *i.e.* upon receipt of the message with valid parameters, the Tag shall abort any cryptographic protocol that has not yet been completed and shall remain in the **Initial** state.

The Tag shall check if the Step is "00_2". If the value of Step is different, the Tag shall return a "Not Supported" error.

The Tag shall check if the RFU is "00_2". If the value of RFU is different, the Tag shall return a "Not Supported" error.

The Tag shall check whether the values of BlockSize and KeySize are supported by the Tag. If at least one of these checks is failed, the Tag shall return a "Not Supported" error.

The Tag shall check whether the values of BlockSize and KeySize are supported by Key.KeyID and that Key.KeyID is authorized for use in Tag authentication. If either (or both) of these checks is (are) failed, the Tag shall return a "Not Supported" error.

The Tag shall check whether the parameter set PS is supported. If the parameter set PS is not supported, the Tag shall return a "Not Supported" error.

Assuming that the TAM1 message is successfully parsed by the Tag, the Tag shall prepare the TAM1 response.

9.3.4 TAM1 response

The Tag shall generate a random salt TRnd-b/k of length r bits were r is given for the parameter set in Table 3.

The Tag shall use Key.KeyID and SPECK encryption to form a b-bit string TResponse such that:

TResponse = SPECK-b/k-ENC (Key.KeyID, C_TAM-b/k || TRnd-b/k || IChallenge-b/k).

The Tags shall return TResponse to the Interrogator.

NOTE 1 Only one input block of b bits is encrypted and so only one invocation of SPECK-b/k is required.

NOTE 2 Appropriate mechanisms to generate TRnd-b/k lie outside the scope of this document.

Table 6 — TAM1 response format

	Payload
Field	**Tag Response**
Length (bits)	b
Value	TResponse

9.3.5 Final Interrogator processing

After receiving TAM1 response the Interrogator shall use Key.KeyID to compute the b-bit string S where:

S = SPECK-b/k-DEC (Key.KeyID, TResponse).

1. The Interrogator shall check that S[t-1:0] = IChallenge-b/k.
2. The Interrogator may check that S[b-1:b-c] = C_TAM-b/k.

If these verification steps are successfully completed, the Interrogator may conclude that the Tag and Interrogator possess matching values of Key.KeyID. When combined with an appropriate key management scheme — the definition of which falls outside the scope of this document — the Interrogator may conclude that the Tag is authentic.

NOTE Determining Key.KeyID is a matter of key management and falls outside of the scope of this document.

9.4 Interrogator authentication (AuthMethod “01”)

9.4.1 General

Interrogator authentication uses a challenge-response protocol. See Figure 3.

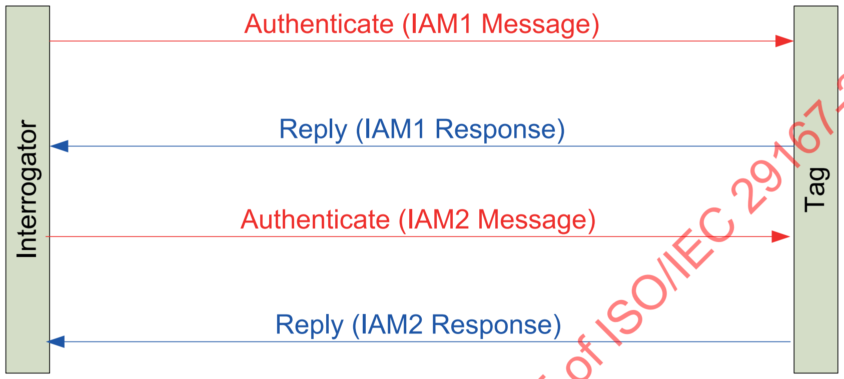


Figure 3 — Interrogator authentication via a challenge-response scheme

The parameter set in Table 7 gives the lengths of specific data fields for different choices of block and key size.

NOTE The parameter set PS=00_2 closely matches other parts of the ISO/IEC 29167 series, most notably 29167-10. This provides some drop-in compatibility between SPECK-128/128 and AES-128.

Table 7 — Parameter set PS = 00_2 for Interrogator authentication

Parameter set PS= 00_2					
b/*k*	64/96	64/128	96/96	128/128	128/256
$t = \lvert$ TChallenge-b/k $\rvert$	42	42	56	80	80
$r = \lvert$ IRnd-b/k $\rvert$	20	20	32	32	32
$c = \lvert$ I_MAM-b/k $\rvert$	2	2	8	16	16

9.4.2 IAM1 message

The Interrogator shall send an initial message IAM1 to the Tag prompting the Tag to start a challenge-response exchange.

The Interrogator shall also indicate the variant of SPECK to be used.

NOTE The variant(s) of SPECK deployed on a device is (are) manufacturer dependent.

Table 8 — IAM1 message format

	Payload						
Field	**AuthMethod**	**Step**	**RFU**	**BlockSize**	**KeySize**	**KeyID**	**PS**
Length (bits)	2	2	2	2	2	8	2
Value	01_2	00_2	00_2	00_2: b=64 01_2: b=96 10_2: b=128 11_2: RFU	00_2: k=96 01_2: k=128 10_2: k=256 11_2: RFU	variable	00_2

9.4.3 Intermediate Tag processing #1

The Tag shall accept this message at any time (unless occupied by internal processing and not capable of receiving messages); *i.e.* upon receipt of the message with valid parameters, the Tag shall abort any cryptographic protocol that has not yet been completed and shall remain in the **Initial** state.

If Interrogator authentication is not supported on the Tag, i.e. if "01_2" is not a valid value for AuthMethod, then the Tag shall return a "Not Supported" error condition.

The Tag shall check if the Step is "00_2". If the value of Step is different, the Tag shall return a "Not Supported" error.

The Tag shall check if the RFU is "00_2". If the value of RFU is different, the Tag shall return a "Not Supported" error.

The Tag shall check whether the values of BlockSize and KeySize are supported by the Tag. If at least one of these checks is failed, the Tag shall return a "Not Supported" error.

The Tag shall check whether the values of BlockSize and KeySize are supported by Key.KeyID and that Key.KeyID is authorized for use in Interrogator authentication. If at least one of these checks is failed, the Tag shall return a "Not Supported" error.

The Tag shall check whether the value of parameter set PS is supported by the Tag. If not, the Tag shall return a "Not Supported" error.

If the IAM1 message is successfully parsed by the Tag, the Tag shall calculate the IAM1 response.

9.4.4 IAM1 response

The Tag shall generate a random challenge TChallenge-b/k of length t bits, where t is determined by the parameter set, and shall send this to the Interrogator.

Table 9 — IAM1 response format

	Payload
Field	**Challenge**
Length (bits)	t
Value	TChallenge-b/k

9.4.5 Intermediate Interrogator processing

The Interrogator shall construct the IAM2 message.

9.4.6 IAM2 message

The Interrogator shall form a b-bit string IResponse such that:

$$\text{IResponse} = \text{SPECK-}b/k\text{-DEC (Key.KeyID, C\_IAM-}b/k \parallel \text{IRnd-}b/k \parallel \text{TChallenge-}b/k).$$

The Interrogator shall send IResponse to the Tag as part of the IAM2 message; see Table 10.

NOTE Determining Key.KeyID is a matter of key management and falls outside of the scope of this document.

Table 10 — IAM2 message format

	Payload			
Field	**AuthMethod**	**Step**	**RFU**	**InterrogatorResponse**
Length (bits)	2	2	4	*b*
Value	01_2	01_2	0000_2	IResponse

9.4.7 Intermediate Tag processing #2

The Tag shall only accept the IAM2 message when the cryptographic engine is in state **PA1** (see Clause 7).

If Interrogator authentication is not supported on the Tag, i.e. if "01_2" is not a valid value for AuthMethod, then the Tag shall return a "Not Supported" error condition.

The Tag shall check if the Step is "01_2". If the value of Step is different, the Tag shall return a "Not Supported" error.

The Tag shall check if the RFU is "0000_2". If the value of RFU is different, the Tag shall return a "Not Supported" error.

If the IAM2 Message is successfully parsed by the Tag, the Tag shall check the returned value of IResponse in the following manner.

The Tag shall use Key.KeyID to compute the *b*-bit string S where:

$$S = \text{SPECK-}b/k\text{-ENC (Key.KeyID, IResponse).}$$

1. The Tag shall check that $S[t\text{-}1{:}0]$ = TChallenge-b/k.

2. The Tag may check that $S[b\text{-}1{:}b\text{-}c]$ = C_IAM-b/k.

If the checks performed by the Tag are successful then the Tag may conclude that the Tag and Interrogator possess matching values of Key.KeyID. When combined with an appropriate key management scheme — the definition of which falls outside the scope of this document — the Tag may conclude that the Interrogator is authentic and TStatus is set to 1_2. Otherwise TStatus is set to 0_2.

The Tag shall prepare IAM2 response.

9.4.8 IAM2 response

The Tag shall return the value of TStatus to the Interrogator. If TStatus = 1_2 , then the cryptographic state machine moves to state **IA** (see Clause 7).

Table 11 — IAM2 response format

	Payload
Field	**Status**
Length (bits)	1
Value	TStatus

9.4.9 Final Interrogator processing

The Interrogator receives IAM2 Response.

If the value of TStatus is 1_2 then the Interrogator may assume that the Tag is in the state **IA** (see Clause 7).

If, under conditions laid out in the over-the-air protocol, there is no response from the Tag or if the returned value of TStatus is 0_2 then the Interrogator shall abandon the cryptographic protocol.

9.5 Mutual authentication (AuthMethod "10")

9.5.1 General

Mutual Interrogator-Tag authentication uses an interleaved challenge-response protocol.

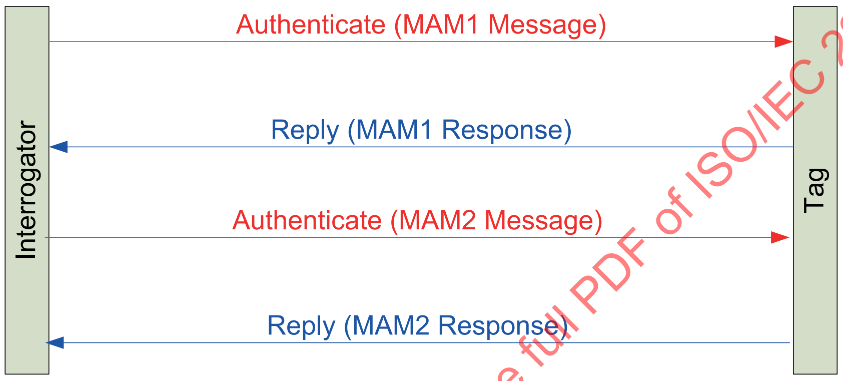


Figure 4 — Interrogator-Tag mutual authentication via an interleaved challenge-response scheme

The parameter set in Table 12 gives the lengths of specific data fields for different choices of block and key size.

NOTE 1 The parameter set PS=00_2 closely matches other parts of the ISO/IEC 29167 series, most notably 29167-10. This provides some drop-in compatibility between SPECK-128/128 and AES-128.

NOTE 2 The parameter set PS=01_2 allows a more efficient mutual authentication protocol than PS=00_2. In particular, the length of the Tag and Interrogator challenges are chosen so that both can fit within a single *b*-bit block.

Table 12 — Parameter sets for mutual Tag-Interrogator authentication

Parameter set PS= 00_2					
b*/*k	**64/96**	**64/128**	**96/96**	**128/128**	**128/256**
$t = \lvert$ **TChallenge-*b*/*k*** $\rvert$	42	42	56	80	80
$t = \lvert$ **IChallenge-*b*/*k*** $\rvert$	42	42	56	80	80
$c = \lvert$ **C_MAM-*b*/*k*** $\rvert$	2	2	8	16	16
Parameter set PS= 01_2					
b*/*k	**64/96**	**64/128**	**96/96**	**128/128**	**128/256**
$t = \lvert$ **TChallenge-*b*/*k*** $\rvert$	30	30	46	60	60
$t = \lvert$ **IChallenge-*b*/*k*** $\rvert$	30	30	46	60	60
$c = \lvert$ **C_MAM-*b*/*k*** $\rvert$	4	4	4	8	8

9.5.2 MAM1 message

The Interrogator shall generate a random Interrogator challenge (IChallenge-b/k) that is carried in the MAM1 message. The length of IChallenge-b/k is denoted t and specified in Table 12.

The Interrogator shall also indicate the variant of SPECK to be used.

NOTE The variant(s) of SPECK deployed on a device is (are) manufacturer dependent.

Table 13 — MAM1 message format

	Payload							
Fields	**AuthMethod**	**Step**	**RFU**	**BlockSize**	**KeySize**	**KeyID**	**PS**	**Challenge**
Length (bits)	2	2	2	2	2	8	2	t
Value	10_2	00_2	00_2	00_2: b=64 01_2: b=96 10_2: b=128 11_2: RFU	00_2: k=96 01_2: k=128 10_2: k=256 11_2: RFU	variable	variable	IChallenge-b/k

9.5.3 Intermediate Tag processing #1

The Tag shall accept MAM1 message at any time (unless occupied by internal processing and not capable of receiving messages); *i.e.* upon receipt of the message with valid parameters, the Tag shall abort any cryptographic protocol that has not yet been completed and shall remain in the **Initial** state.

If Mutual authentication is not supported on the Tag, i.e. if "10_2" is not a valid value for AuthMethod, then the Tag shall return a "Not Supported" error condition.

The Tag shall check if the Step is "00_2". If the value of Step is different, the Tag shall return a "Not Supported" error.

The Tag shall check if the RFU is "00_2". If the value of RFU is different, the Tag shall return a "Not Supported" error.

The Tag shall check whether the values of BlockSize and KeySize are supported by the Tag. If at least one of these checks is failed, the Tag shall return a "Not Supported" error.

The Tag shall check whether the values of BlockSize and KeySize are supported by Key.KeyID and that Key.KeyID is authorized for use in Interrogator-Tag mutual authentication. If at least one of these checks is failed, the Tag shall return a "Not Supported" error.

The Tag shall check whether the value of parameter set PS is supported by the Tag. If not, the Tag shall return a "Not Supported" error.

Assuming the MAM1 message is successfully parsed by the Tag, the Tag shall calculate its response accordingly.

The Tag shall generate a random challenge TChallenge-b/k of length t bits.

The Tag shall construct a b-bit string by concatenating C_MAM-b/k with the (b-t-c) most significant bits of TChallenge-b/k and the entirety of IChallenge-b/k.

The Tag shall use Key.KeyID to compute the b-bit string S where:

$$S = \text{SPECK-}b/k\text{-ENC}(\text{Key.KeyID}, \text{C\_MAM-}b/k \,||\, \text{TChallenge-}b/k\,[t\text{-}1{:}2t\text{-}b\text{+}c] \,||\, \text{IChallenge-}b/k).$$

TResponse is a string that consists of S concatenated with the remainder (if any) of TChallenge-b/k

$$\text{TResponse} = \text{TChallenge-}b/k\,[2t\text{-}b\text{+}c\text{-}1{:}0] \,||\, \text{S}.$$

NOTE 1 Only one input block of *b* bits is encrypted and so only one invocation of SPECK-*b*/*k* is required.

NOTE 2 Parameter set PS=01_2 is constructed so that TResponse is exactly *b* bits long; *i.e.* TResponse = S.

9.5.4 MAM1 response

The Tag returns the value of TResponse to the Interrogator.

Table 14 — MAM1 response format

	Payload
Field	**Tag Response**
Length (bits)	$2t + c$
Value	TResponse

9.5.5 Intermediate Interrogator processing

After receiving MAM1 Response, the Interrogator shall use Key.KeyID to compute the *b*-bit string T where:

T = SPECK-*b*/*k*-DEC (Key.KeyID, TResponse[*b*-*1*:*0*]).

1. The Interrogator shall check that T[*t*-1:0] = IChallenge-*b*/*k*.
2. The Interrogator may check that T[*b*-1:*b*-*c*] = C_TAM-*b*/*k*.

If these verification steps are not successful, the Interrogator shall abandon the cryptographic protocol. Otherwise, the Interrogator may conclude that the Tag and Interrogator possess matching values of Key.KeyID. When combined with an appropriate key management scheme — the definition of which falls outside the scope of this document — the Interrogator may conclude that the Tag is authentic.

NOTE Determining Key.KeyID is a matter of key management and falls outside of the scope of this document.

9.5.6 MAM2 message

If the cryptographic protocol has not been abandoned, the Interrogator shall form a *b*-bit string IResponse depending on the parameter set PS as follows:

1. If PS = 00_2 then IResponse is equal to

   SPECK-b/k-DEC (Key.KeyID, C_MAM-*b*/*k* || T[*b*-*t*-*c*-1:0] || T[*b*-*c*-1:*t*] || TResponse[*2t*+*c*-1:*b*]).
2. If PS = 01_2 then IResponse is equal to T[*b*-*c*:*t*].

The Interrogator shall set SecureComm = 0001_2 if secure communications as described in Clause 10 will be used after mutual authentication is completed. Otherwise the Interrogator shall set SecureComm = 0000_2.

The Interrogator shall send IResponse and the value of SecureComm to the Tag as part of the MAM2 message, see Table 15.

Table 15 — MAM2 message format

	Payload				
Field	**AuthMethod**	**Step**	**RFU**	**SecureComm**	**Interrogator Response**
Length (bits)	2	2	4	4	variable
Value	10_2	01_2	0000_2	variable	IResponse

9.5.7 Intermediate Tag processing #2

The Tag shall only accept this message when the cryptographic engine is in the state **PA2**; see Clause 7.

If Mutual authentication is not supported on the Tag, i.e. if "10_2" is not a valid value for AuthMethod, then the Tag shall return a "Not Supported" error condition.

The Tag shall check if the Step is "01_2". If the value of Step is different, the Tag shall return a "Not Supported" error.

The Tag shall check if the RFU is "0000_2". If the value of RFU is different, the Tag shall return a "Not Supported" error.

Assuming that the MAM2 Message is successfully parsed by the Tag, the Tag shall check the returned value of IResponse in the following manner.

1. If PS = 00_2 then the Tag computes the *b*-bit string S = SPECK-*b*/*k*-ENC (Key.KeyID, IResponse).

SPECK-b/k-DEC (Key.KeyID, C_MAM-*b*/*k* || T[*b*-*t*-*c*-1:0] || T[*b*-*c*-1:*t*] || TResponse[*2t*+*c*-*b*-1:0]).

The Tag shall check if S[*t*-1:0] = TChallenge-*b*/*k*.

The Tag may check if S[*b*-*c*-1:*t*] = IChallenge-*b*/*k* [*b*-*t*-*c*-1:0]

The Tag may check if S[*b*-1:*b*-*c*] = C_MAM-*b*/*k*.

2. If PS = 01_2 then the Tag shall check whether S = TChallenge-*b*/*k*.

NOTE No encryption operation is required in the case of PS = 01_2.

If the checks performed by the Tag are successful then the Tag may conclude that the Tag and Interrogator possess matching values of Key.KeyID. When combined with an appropriate key management scheme — the definition of which falls outside the scope of this document — the Tag may conclude that the Interrogator is authentic and TStatus is set to 1_2. Otherwise TStatus is set to 0_2.

If TStatus = 0_2, the Tag sets $N_T = \emptyset$.

If TStatus = 1_2 and SecureComm = 0_2, the Tag sets $N_T = \emptyset$.

If TStatus = 1_2 and SecureComm = 1_h, the Tag shall generate a random string N_T of the length shown in Table 16. The Tag shall further indicate using $KeyID_2$ which key shall be used for the subsequent secure communication session.

Table 16 — Length of N_T for different values of *b* and *k*

b/*k*	64/96	64/128	96/96	128/128	128/256
$\|N_T\|$ for PS = 00_2	6	6	24	32	32
$\|N_T\|$ for PS = 01_2	18	18	34	52	52

9.5.8 MAM2 response

The Tag shall prepare and send a MAM2 response as specified in Table 17.

If TStatus = 1_2 then the cryptographic state machine moves to state **IA** (see Clause 7).

Table 17 — MAM2 response format

	Payload		
Field	**Status**	**KeyID**	**Pre-IV**
Length (bits)	1	8	variable
Description	TStatus	$KeyID_2$	N_T

9.5.9 Final Interrogator processing

The Interrogator receives MAM2 response.

If the value of TStatus is 1_2 then the Interrogator may assume that the Tag is in the state **IA** (see Clause 7).

If, under conditions laid out in the over-the-air protocol, there is no response from the Tag or if the returned value of TStatus is 0_2 then the Interrogator shall abandon the cryptographic protocol.

If the value of TStatus is 1_2, the Interrogator may subsequently invoke secure communication (see Clause 10) using the key identified by $KeyID_2$ and the Pre-IV N_T.

10 Communication

10.1 General

This document supports a method for secure communication between the tag and the reader. It permits the secure encapsulation of messages, as envisaged in ISO/IEC 18000-63, as a way of encrypting and authenticating communications between Interrogator and Tag.

In this document, one option for encapsulating communications is provided by the SILC mechanism for authenticated encryption. The full definition of the SILC mechanism, along with information on its design and analysis, is provided in Reference [4]. Implementation shall be as described in Annex C. The SILC mechanism is invoked when the SecureComm field in MAM2 message takes the value 0001_2. Future versions of this document may support additional mechanisms.

SILC is built around the use of a block cipher and is notable for an accompanying proof-of-security. The fundamental approach to SILC was published in 2014 and, since then, the scheme has been both open to public cryptanalysis and widely promoted within the global cryptographic CAESAR initiative. The design of SILC is optimized for implementation efficiency in constrained hardware.

SILC consists of two transformations. The first, denoted SILC-E_k, is for encrypting and generating a message authentication code or authentication token T on an input P. The second, denoted SILC-D_k, is for decrypting a ciphertext C and verifying an accompanying message authentication code or authentication token T. SILC requires the use of a constant that provides separation between different block ciphers and different lengths to the authentication token T. The values of `param` are provided in Reference [4] and in Annex C and this document reflects the fact that there is a family of SILC transformations using the notation $SILC^{\texttt{param}}$.

With this slight change of notation, the SILC transformations[4] can be referred to as:

$SILC^{\texttt{param}}\text{-}E_k$ (N, A, P,) → (A, C, T):	Input a nonce N, auxiliary data A that is to be authenticated but not encrypted, and plaintext P that it is to be authenticated and encrypted. Compute, using the key *k*, the ciphertext C and authentication token T and append these to the auxiliary data A.
$SILC^{\texttt{param}}\text{-}D_k$ (N, A, C, T) → (A, P):	Input a nonce N, auxiliary data A, ciphertext C, and authentication token T. Compute, using the key *k*, the message P provided the authentication token T is correct and append this to the auxiliary data A.

This subclause describes how these transformations are used in the context of this document.

NOTE 1 Throughout, the Tag only needs to support the encryption direction of the block cipher.

NOTE 2 Throughout, the Interrogator only needs to support the encryption direction of the block cipher.

NOTE 3 During secure communication, a value N is incremented by one using integer addition for each message exchanged. Any upper bound to the number of messages that can be exchanged, any policy on the potential roll-over of N, and the tag behaviour in such situations will be implementation dependent.”

Secure communication can only be provided after successful mutual authentication. A Tag response to an encapsulated command may be encapsulated. If the response is encapsulated, then it shall be encapsulated as described in this crypto suite. A Tag shall only encapsulate the response to an encapsulated command.

10.2 Message and response formatting

The air interface specification provides definitions of the commands and responses that can be sent over the air. In the case of an *encapsulating* command, the air interface standard specifies the data fields and permissible payloads for the encapsulating command.

The following subclauses of this document describe how the payloads for the commands and responses should be processed using SILC to provide an authenticated encryption of that payload.

If a secure communication session is required, the session shall be launched by the Interrogator after a successful mutual authentication.

All secure sessions are initialized by a choice of key and a value to the nonce N.

1. The key to be used is chosen by the Interrogator and indicated using KeyID_2. The variable KeyID_2 may be the same as KeyID used for the authentication session or it may be different.

   NOTE Determining Key.KeyID_2 and managing the deployed choices for KeyID and KeyID_2 are matters of security architecture and key management that fall outside the scope of this document.

2. The initial value to the nonce N is derived from information exchanged during the mutual authentication process. After successful mutual authentication the value N is available to both the Interrogator and Tag.

10.3 Transforming a payload prior to encapsulation

10.3.1 General

This subclause specifies how to authenticate and/or encrypt a payload P that is to be encapsulated. This is achieved via a transformation SEC. The transformation SEC is best viewed as a wrapper around $\text{SILC}^{\texttt{param}}\text{-E}_k$ that provides the interface between the over-the-air command and $\text{SILC}^{\texttt{param}}\text{-E}_k$.

There are four inputs to SEC in addition to the payload P that is to be encapsulated.

1. A b-bit key Key.KeyID_2 that is passed on to the instantiation of $\text{SILC}^{\texttt{param}}\text{-E}_k$ where it is referred to as k.

2. A nonce N that is passed to the instantiation of $\text{SILC}^{\texttt{param}}\text{-E}_k$.

3. The 8-bit value of `param` which is used in the $\text{SILC}^{\texttt{param}}\text{-E}_k$ computation.

   For each variant of SPECK-b/k and each permitted size of authentication tag T, an input `param` is defined to take a specific value. These values are specified in the description of SILC v3 and Table 18.

Table 18 — Values of `param` for different variants of SPECK-*b*/*k* and different lengths of authentication tag T

b/*k*	64/96	64/128	96/96	128/128	128/256
|T| = 32	$B0_h$	$B1_h$	$B2_h$	$B3_h$	$B4_h$
|T| = 48	$B5_h$	$B6_h$	$B7_h$	$B8_h$	$B9_h$
|T| = 64	BA_h	BB_h	BC_h	BD_h	BE_h

4. A one-bit parameter Enc that indicates whether the payload P is to be authenticated (Enc = 0_2) or encrypted and authenticated (Enc = 1_2).

SEC may be used by the Interrogator, *e.g.* to protect an over-the-air command. SEC may also be used by the Tag to protect a response.

SEC shall only be used after mutual authentication has been established and it guarantees the confidentiality and/or authenticity of the payload P being encapsulated.

SEC takes Key.KeyID$_2$, N, `param`, Enc, and P as five inputs and interfaces to the SILC transformations in the following way, where C is the encryption of P:

$$\text{SEC (Key.KeyID}_2\text{, N, param, 0, P)} = \text{SILC}^{\text{param}}\text{-E}_{\text{Key.KeyID2}}\text{ (N, P, Ø)} = \text{P} \parallel \text{Ø} \parallel \text{T.}$$

$$\text{SEC (Key.KeyID}_2\text{, N, param, 1, P)} = \text{SILC}^{\text{param}}\text{-E}_{\text{Key.KeyID2}}\text{ (N, Ø, P)} = \text{Ø} \parallel \text{C} \parallel \text{T.}$$

NOTE In the first case, the encapsulated command is authenticated. In the second case, the encapsulated command is encrypted and authenticated.

This process is illustrated in Figure 5.

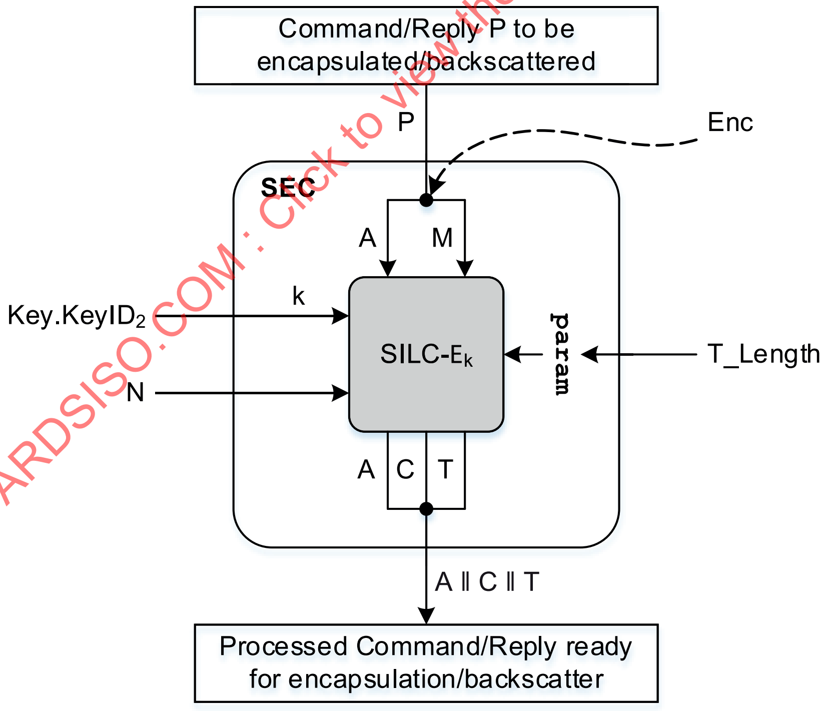

Command/Reply P to be encapsulated/backscattered
P
Enc
SEC
A
M
k
Key.KeyID2
SILC-Ek
param
T_Length
N
A
C
T
A ‖ C ‖ T
Processed Command/Reply ready for encapsulation/backscatter

Figure 5 — Interface between SEC and SILC$^{\text{param}}$-E$_k$

10.3.2 Encapsulating an Interrogator command

Optionally, an Interrogator may wish to cryptographically protect an over-the-air command. To send a command as an encapsulated payload P, the Interrogator shall perform the following steps:

1. The Interrogator shall verify that TStatus is 1_2. If not, the Interrogator shall abandon the encapsulation process.

   SEC shall only be used after mutual authentication has been established.

2. The Interrogator shall identify the key Key.KeyID$_2$ to be used.

3. The Interrogator shall construct the initial value of the (b-16)-bit string N as N = N_T || TChallenge.

   NOTE TChallenge is generated by the Tag and returned to the Interrogator in the MAM1 response while N_T is generated by the Tag and returned to the Interrogator in the MAM2 response.

4. The Interrogator shall choose the length T_Length for the authentication token T.

5. The Interrogator shall specify if the payload is authenticated or both encrypted and authenticated.

   If authentication without encryption is required, then the Interrogator shall set Enc = 0. If both encryption and authentication are required, then the Interrogator shall set Enc = 1.

   NOTE If the encapsulating over-the-air command only supports authentication then Enc = 0.

6. The Interrogator shall specify if the payload parameters should be protected.

   If parameter protection is required then the Interrogator shall set Protect = 1. If parameter protection is not required then the Interrogator shall set Protect = 0.

7. The Interrogator shall specify whether the Tag response is to be in the clear, authenticated, or encrypted and authenticated. These different options are represented by the following values to the Response field in Table 19:

0_x: Clear	1_x: Authenticated only	2_x: Encrypted and authenticated	3_x – F_x: RFU

8. The Interrogator shall construct a string X where |X| = 0 or |X| = 8.

   If Protect = 0 then X = ∅. If Protect = 1 then X = Response || Enc || Protect || 00_2.

9. The Interrogator shall compute SEC (Key.KeyID$_2$, N, `param`, Enc, X || P). The output is denoted Q || T.

   NOTE Depending on the value of Enc, Q will either be equal to X || P or equal to the encryption of X || P. In both cases, an authentication token T will be included.

10. The Interrogator shall encapsulate the payload defined in Table 19 and send this to the Tag using an encapsulating over-the-air command.

11. After a successful invocation of SEC, the value of N shall be incremented by 1 using integer addition.

Table 19 — Secured payload for transport by an encapsulating command

	Payload						
Field	**KeyID**	**Param**	**Response**	**Enc**	**Protect**	**RFU**	**Processed Command/ Reply**
Length (bits)	8	8	4	1	1	2	*variable*
Description	KeyID$_2$	`param`	*variable*	*variable*	*variable*	00_2	Q || T

10.3.3 Cryptographically protecting a Tag reply

Depending on the value of Response, a Tag may be required to cryptographically protect the reply to an encapsulated over-the-air command. To protect the reply to an encapsulated command, the Tag shall perform the following steps:

1. If the Tag is not in the state IA then the Tag shall return a "Cryptographic Suite Error" and abandon the communication session.

   NOTE 1 A Tag can only react to an encapsulated command after mutual authentication has been established.

2. The Tag shall process the encapsulating command as described in 10.4.1. Unless an error has been encountered, this will reveal the encapsulated command and, optionally, the values of Response, Enc and Protect.

   NOTE 2 The value of the Nonce N is always incremented after an invocation of SEC or CES.

   NOTE 3 The values of Response, Enc and Protect are carried as headers to the encapsulated payload (see Table 19). When carried as headers, these values are not cryptographically protected. Optionally, Response, Enc and Protect can be included as part of the cryptographic computation invoked by SEC. In this latter case, the values of Response, Enc and Protect are cryptographically protected.

3. If Protect = 1_2 the Interrogator has used parameter protection. Provided the encapsulated command was processed without error (10.4.1), the values of Response, Enc and Protect in Table 19 shall be recovered from the output of CES in 10.4.1.

   If Protect = 0_2 the Interrogator has not used parameter protection. The values of Response, Enc and Protect shall be recovered from the payload in Table 19.

4. If Response = 0000_2, the Tag shall respond without encapsulation.

5. Otherwise, the Tag shall execute the encapsulated command and construct the reply R.

   NOTE 4 An encapsulated reply can only be formed by the tag on receipt of a correctly-received encapsulated command.

6. If Response = 1_x or 2_x, the Tag shall compute SEC (Key.KeyID$_2$, N, `param`, Enc, R) with the reply R. The value of Enc will be 0 if Response = 1_x and Enc = 1 if Response = 2_x. The output is denoted Q || T.

   NOTE 5 Depending on the value of Enc, Q will either be equal to R or equal to the encryption of R. In both cases, an authentication tag T will be included.

7. The Tag shall return Q || T to the Interrogator instead of the unprotected reply R.

8. After a successful invocation of SEC, the value of N shall be incremented by 1 using integer addition.

10.4 Processing an encapsulated or cryptographically-protected reply

10.4.1 General

This subclause specifies how to process an encapsulated, *i.e.* cryptographically protected, payload P. This is achieved via a transformation CES. CES can be viewed as a wrapper around SILC$^{\texttt{param}}$-D$_k$ that provides the interface between the over-the-air command and SILC$^{\texttt{param}}$-D$_k$.

NOTE With the same Key.KeyID$_2$, nonce N, `param`, and value to Enc the transformation CES can be viewed as providing the reverse functionality of SEC.

CES has four inputs in addition to Q || T which is either an encapsulated command or a protected reply.

1. A *b*-bit key Key.KeyID$_2$ that is passed on to the instantiation of SILC$^{\texttt{param}}$-D$_k$ where it is referred to as k.

2. A nonce N that is passed on to the instantiation of SILC$^{\texttt{param}}$-D$_k$.

3. The 8-bit `param` used in the SILC$^{\texttt{param}}$-D$_k$ computation. The values of `param` are given in Table 18.

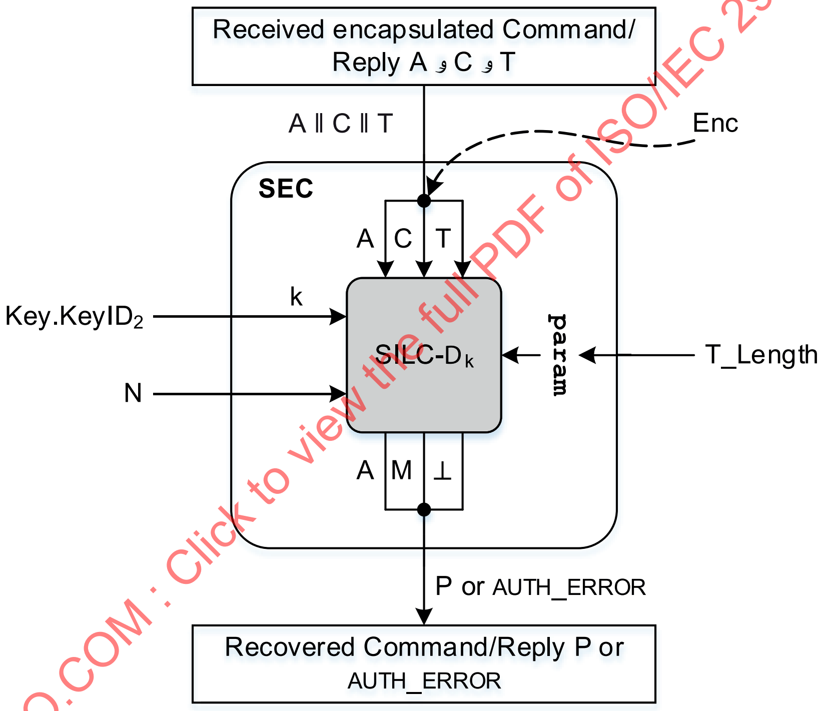
4. A one-bit parameter Enc indicating whether authentication or both encryption and authentication were used. In both cases, an authentication tag T is verified.

CES may be used by (a) the Tag for processing an encapsulated air interface command or (b) the Interrogator for processing a cryptographically-protected response. This process is illustrated in Figure 6.

CES takes Key.KeyID$_2$, N, `param`, Enc, and Q || T as five inputs and interfaces to SILC$^{\texttt{param}}$-D$_k$ in the following way, where P is the decryption of Q:

CES (Key.KeyID$_2$, N, `param`, 0, Q || T) = SILC$^{\texttt{param}}$-D$_{\text{Key.KeyID2}}$ (N, Q, Ø, T) = Q or AUTH_ERROR (⊥).

CES (Key.KeyID$_2$, N, `param`, 1, Q || T) = SILC$^{\texttt{param}}$-D$_{\text{Key.KeyID2}}$ (N, Ø, Q, T) = P or AUTH_ERROR (⊥).



Received encapsulated Command/ Reply A و C و T
A ‖ C ‖ T
Enc
SEC
A
C
T
k
Key.KeyID2
SILC-Dk
param
T_Length
N
A
M
⊥
P or AUTH_ERROR
Recovered Command/Reply P or AUTH_ERROR

Figure 6 — Interface between CES and SILC$^{\texttt{param}}$-D$_k$ where an authentication error is denoted ⊥

10.4.2 Recovering an encapsulated Interrogator command

On receiving an encapsulating command with payload Q || T, the Tag shall perform the following steps to process the payload Q || T.

1. If the Tag is not in the state IA then the encapsulating command shall be ignored and the Tag shall return a “Cryptographic Suite Error” and abandon the communication session.

   CES shall only be used after mutual authentication has been established.

2. The Tag shall check whether Key.KeyID$_2$ is authorized for use with secure communication. If not, the Tag shall return a "Not Supported" error.

3. The Tag shall check if `param` is supported by the Tag. If not, the Tag shall return a "Not Supported" error condition.

4. The Tag shall check if the value of Enc is supported by the Tag. If not, the Tag shall return a "Not Supported" error condition.

5. The Tag shall check if the RFU is "00_2". If the value of RFU is different, the Tag shall return a "Not Supported" error.

6. The Tag shall construct the initial value of N as N = N_T || TChallenge.

7. Assuming that the encapsulating command is successfully parsed by the Tag, the Tag shall recover Q || T from the encapsulating command and compute CES (Key.$KeyID_2$, N, param, Enc, Q || T).

8. If the output from CES (Key.$KeyID_2$, N, T_Length, Enc, Q || T) is AUTH_ERROR, the Tag shall return a "Cryptographic Suite Error" and abandon the communication session.

9. If the output from CES (Key.$KeyID_2$, N, T_Length, Enc, Q || T) is not AUTH_ERROR, the Tag shall consider the output to be the intended encapsulated command.

10. After a successful invocation of CES, the value of N shall be incremented by 1 using integer addition.

10.4.3 Recovering a cryptographically-protected Tag response

To recover the original response from a cryptographically-protected Tag response, the Interrogator shall perform the following steps:

1. The Interrogator shall verify that the Tag response was received in response to an encapsulated command issued by the Interrogator. If not, the Interrogator shall abandon the secure communication process.

   NOTE SEC can only be used by a Tag to cryptographically protect the response to an encapsulated Interrogator command.

2. The Interrogator shall recover the cryptographically-protected reply Q || T from the over-the-air Tag response.

3. The Interrogator shall compute CES (Key.$KeyID_2$, N, param, Enc, Q || T).

   If the output is AUTH_ERROR, the Interrogator shall abandon the communication session. Otherwise the output is the originally constructed Tag reply R.

4. After a successful invocation of CES, the value of N shall be incremented by 1 using integer addition.

11 Key table and key update

Since this cipher suite provides a method of secure encapsulation, key update can be naturally and transparently supported via command encapsulation.

Optionally, the Tag manufacturer may support a Key Table. If a Key Table is supported then it may store up to 256 keys (Key.0 through to Key.255) and it may take the form shown in Table 20. Not all key values need to be specified. However Key.j shall not be specified when there remain unspecified Key.i with i<j.

The field RFU may be used to define properties that should be associated with a given Key.i. Any use of such values is manufacturer dependent.

Table 20 — Optional Key Table for 29167-21

Field	**KeyID**	**Key**	**RFU**
Length (bits)	8	*b*	8
	00000000_2	Key.0	00_h
	00000001_2	Key.1	00_h
	etc.	*etc.*	*etc.*

Optionally, the Key Table may be updated using a key update command. If so, the payload to the key update command may have the form given in Table 21.

Table 21 — Optional payload format for a key update

	Payload		
Field	**KeyID**	Key	**RFU**
Length (bits)	8	*b*	8
Description	KeyID	Key.KeyID	00_h

If a Tag is unable to act on the key update command, the Tag shall return a "Not Supported" error. The success or otherwise of a key update command may be indicated using a single bit in a reply while any response field to a key update command may be empty.

Annex A
(normative)

Crypto suite state transition table

Table A.1 — Crypto suite state transition table

Start state	Transition	End state	Action
Initial	TAM1	**Initial**	Send TAM1 Response
Initial	IAM2, MAM2, improper, or faulty command	**Initial**	Cryptographic Suite Error
Initial	IAM1	**PA1**	Send IAM1 Response
Initial	MAM1	**PA2**	Send MAM1 Response
PA1	TAM1, IAM1, MAM1, MAM2, improper, or faulty command	**Initial**	Cryptographic Suite Error
PA1	IAM2	**IA**	Send IAM2 Response
PA2	TAM1, IAM1, MAM1, IAM2, improper, or faulty command	**Initial**	Cryptographic Suite Error
PA2	MAM2	**IA**	Send MAM2 Response
IA	TAM1, IAM1, MAM1, IAM2, MAM2, improper, or faulty command	**Initial**	Cryptographic Suite Error

Annex B
(normative)

Errors and error handling

A Tag that encounters an error during the execution of a cryptographic suite operation may send an error reply to the Interrogator. The details of these error replies are defined in the respective air interface standards.

This annex contains a listing of the errors that can result from the operation of this cryptographic suite. These errors shall be translated into an error code for the air interface in accordance with Annex E.

Table B.1 — Error conditions

Error	Error condition
Not Supported	Supplied parameter values are either not supported by this cryptographic suite or not supported by this implementation.
Cryptographic Suite Error	A conflict in the protocol flow has been detected.

Annex C
(normative)

Description of SPECK and SILC v3

C.1 SPECK

SPECK-*b*/*k* is a block cipher that is parameterized to use a range of block and key sizes denoted by *b* and *k*. SPECK-*b*/*k* uses the repeated application of a round function and SPECK-b/k is defined by its round function and associated key schedule. With a block size *b*, the basic operational unit is an *n*-bit word where $b=2n$. The key length *k* will be an integral multiple of *n* with the multiple depending on the variant used.

For $k \in GF(2)^n$, the key-dependent SPECK-b/k round function is the map $R_k : GF(2)^n \times GF(2)^n \rightarrow GF(2)^n \times GF(2)^n$ defined by:

$$R_k\,(x, y) = (S^{-\alpha}x + y) \oplus k, S^{\beta}y \oplus (S^{-\alpha}x + y) \oplus k$$

where *k* is the round key. Here "+" denotes integer addition modulo 2^n, "$\oplus$" denotes bitwise XOR, and $S^t x$ denotes the leftward rotate of the *n*-bit word *x* by (*t* modulo *n*) bit positions. The SPECK-*b*/*k* key schedule takes a *k*-bit key and generates *T* key words $k_0 \dots k_{T-1}$, where *T* is the number of rounds. A pseudo-code description of encryption using SPECK-b/k is given below for the values of *b*/*k* supported by this document. More details can be found in Reference [3].

```
---------------------------- definitions ----------------------------
n = word size (32, 48, or 64)                (Note: block size b = 2n)

m = number of key words = 3 or 4 if n = 32,
                        = 2 if n = 48,
                        = 2 or 4 if n = 64

T = number of rounds    = 26 or 27 if n = 32, m = 3 or 4
                        = 28 if n = 48, m = 2
                        = 32 or 34 if n = 64, m = 2 or 4

(α,β) = (8,3)
x,y = plaintext words                   (Note: plaintext input = x ‖ y)
λ[m-2]..λ [0],k[0] = key words
---------------------------- key expansion ----------------------------
for i = 0..T-2
    λ[i+m-1] ← (k[i] + $S^{-α}$λ[i])⊕ i
    k[i+1] ← $S^{β}$(k[i]) ⊕ λ[i+m-1]
end for
----------------------------- encryption -----------------------------
for i = 0..T-1
    x ← ($S^{-α}$x + y) ⊕ k[i]
    y ←   $S^{β}$y ⊕ x
end for                                (Note: ciphertext output = x ‖ y)
------------------------------ end -----------------------------------
```

C.2 SILC v3

Some additional parameters and definitions are required for a description of the authenticated-encryption mode SILC v3.

For each variant of SPECK-b/k, the size of the nonce N is fixed according to the block size *b*.

b/k	**64/96**	**64/128**	**96/96**	**128/128**	**128/256**
|N|	48	48	72	96	96

For each variant of SPECK-b/k and each permitted size of authentication tag T, an input **`param`** is defined to take a specific value. These values are specified in the description of SILC v3 and repeated here.

b/k	**64/96**	**64/128**	**96/96**	**128/128**	**128/256**
|T| = 32	$B0_h$	$B1_h$	$B2_h$	$B3_h$	$B4_h$
|T| = 48	$B5_h$	$B6_h$	$B7_h$	$B8_h$	$B9_h$
|T| = 64	BA_h	BB_h	BC_h	BD_h	BE_h

Some addition definitions for the following material in Annex C are provided here.

$\mathtt{len}_b(A)$	The b-bit binary representation of the integer length of the bit string A.
	Example 1: $\mathtt{len}_8(01111_2) = 00000101_2$.
	Example 2: $\mathtt{len}_{16}(FFFF_h) = 0000000000010000_2$.
	Example 3: $\mathtt{len}_{16}(\emptyset) = 0000000000000000_2$.
$\mathtt{zpp}_b(A)$	Bit-wise padding to the left of the n-bit string A with 0_2 giving a b-bit result for $n < b$.
	Example 1: $\mathtt{zpp}_8(1111_2) = 00001111_2$.
	Example 2: $\mathtt{zpp}_{16}(FFFF_h) = FFFF_h$.
$\mathtt{zap}_b(A)$	Bit-wise padding to the right of the n-bit string A with 0_2 giving a b-bit result for $n < b$.
	Example 1: $\mathtt{zap}_8(1111_2) = 11110000_2$.
	Example 2: $\mathtt{zap}_{16}(FFFF_h) = FFFF_h$.
$\mathbf{g}(A)$	A byte-wise operation on the b-bit input A, represented as bytes $A[1] \parallel \ldots \parallel A[b/8]$, and defined as follows.

For b=64:	$\mathbf{g}(X) = \mathbf{g}(A[1] \parallel \ldots \parallel A[7] \parallel A[8])$	$= A[2] \parallel \ldots \parallel A[8] \parallel (A[1] \oplus A[2])$
For b=96:	$\mathbf{g}(A) = \mathbf{g}(A[1] \parallel \ldots \parallel A[11] \parallel A[12])$	$= A[2] \parallel \ldots \parallel A[12] \parallel (A[1] \oplus A[2])$
For b=128:	$\mathbf{g}(A) = \mathbf{g}(A[1] \parallel \ldots \parallel A[15] \parallel A[16])$	$= A[2] \parallel \ldots \parallel A[16] \parallel (A[1] \oplus A[2])$

SILC-E$_K$ (N, A, M)	**SILC-D$_K$ (N, A, *C*, *T*)**
1. Set V = HASH$_K$(N,A)	1. Set V = HASH$_K$(*N*,*A*)
2. Set C = ENC$_K$(V,M)	2. Set T* = PRF$_K$(*V*,*C*)
3. Set T = PRF$_K$(V,C)	3. **if** T* ≠ T **then return** AUTH_ERROR
4. **return** (C ‖ T)	4. Set M = DEC$_K$(*V*,*C*)
	5. **return** M

```
Algorithm HASH_K (N, A)
1. Set $S_H[0]$ = SPECK-$b/k$-ENC (K, $\mathtt{zpp}_b$ (param ‖ N) )
2. if $A = \emptyset$ then
    Set $V = \mathbf{g}(S_H[0])$
3. else
    Write A as $w$ $b$-bit blocks $A[1] \parallel \ldots \parallel A[w]$
    for $i = 1$ to $w - 1$ do
        Set $S_H[i]$ = SPECK-$b/k$-ENC (K, $S_H[i-1] \oplus A[i]$)
    Set $S_H[w]$ = SPECK-$b/k$-ENC ($K$, $S_H[w-1] \oplus \mathtt{zap}_b(A[a])$ )
    Set $V = \mathbf{g}(S_H[w] \oplus \mathtt{len}_b(A))$
4. return $V$
```

```
Algorithm ENC_K (V, M)
1. if M = ∅ then
     Set C = ∅
2. else
     Write M as d b-bit blocks M[1] ‖ … ‖ M[d]
     Set S_E[1] = SPECK-b/k-ENC (K, V)
     for i = 1 to d−1 do
          Set C[i] = S_E[i] ⊕ M[i]
          Set S_E[i+1] = SPECK-b/k-ENC (K, fix1(C[i]))
     Set C[d] = msb_|M[d]| (S_E[d]) ⊕ M[d]
     Set C = C[1] ‖ … ‖ C[x]
3. return C
```

```
Algorithm DEC_K (V, C)
1. if C = ∅ then
     Set M = ∅
2. else
     Write C as d b-bit blocks C[1] ‖ … ‖ C[d]
     Set S_D[1] = SPECK-b/k-ENC (K, V)
     for i = 1 to d−1 do
          Set M[i] = S_D[i] ⊕ M[i]
          Set S_D[i+1] = SPECK-b/k-ENC (K, fix1(C[i]))
     Set M[d] = msb_|C[d]| (S_D[d]) ⊕ C[d]
     Set M = M[1] ‖ … ‖ M[d]
3. return M
```

```
Algorithm PRF_K (V, C)
1. Set S_P[0] = SPECK-b/k-ENC (K, g(V))
2. if |C| = 0 then
     Set U = g(S_P[0])
     Set T = msb_τ (SPECK-b/k-ENC (K, U))
3. else
     Write C as d b-bit blocks C[1] ‖ … ‖ C[d]
     for i = 1 to d−1 do
          Set S_P[i] = SPECK-b/k-ENC (K, S_P[i − 1] ⊕ C[i])
     Set S_P[d] = SPECK-b/k-ENC (K, S_P[d− 1] ⊕ zap_b (C[m]))
     Set U = g(S_P[d] ⊕ len_b (C))
     Set T = msb_|T|(SPECK-b/k-ENC (K, U))
4. return T
```

Annex D
(informative)

Test vectors

Table D.1 provides test vectors for encrypting plaintext messages using the SPECK block cipher with *b*-bit blocks and *k*-bit keys.

Table D.1 — Test vectors for SPECK-b/k

Variant *b*/*k*	Plaintext	Key	Ciphertext
64/96	6F722067$_h$ ‖ 6E696C63$_h$	13121110$_h$ ‖ 0B0A0908$_h$ ‖ 03020100$_h$	863376EF$_h$ ‖ 7295059B$_h$
64/128	656B696C$_h$ ‖ 20646E75$_h$	1B1A1918$_h$ ‖ 13121110$_h$ ‖ 0B0A0908$_h$ ‖ 03020100$_h$	DA0A71CB$_h$ ‖ D5FAA975$_h$
96/96	2072616C$_h$ ‖ 6C697020$_h$ ‖ 65687420$_h$	0D0C0B0A$_h$ ‖ 09080504$_h$ ‖ 03020100$_h$	4701A708$_h$ ‖ 73FA91E3$_h$ ‖ D885E712$_h$
128/128	63736564$_h$ ‖ 20737265$_h$ ‖ 6C6C6576$_h$ ‖ 61727420$_h$	0F0E0D0C$_h$ ‖ 0B0A0908$_h$ ‖ 07060504$_h$ ‖ 03020100$_h$	90AA5135$_h$ ‖ BC6624EB$_h$ ‖ FE3CBBDF$_h$ ‖ 66914001$_h$
128/256	74206E69$_h$ ‖ 206D6F6F$_h$ ‖ 6D697320$_h$ ‖ 61207369$_h$	1F1E1D1C$_h$ ‖ 1B1A1918$_h$ ‖ 17161514$_h$ ‖ 13121110$_h$ ‖ 0F0E0D0C$_h$ ‖ 0B0A0908$_h$ ‖ 07060504$_h$ ‖ 03020100h	BBD10D45$_h$ ‖ D675C5F9$_h$ ‖ D0EC6494$_h$ ‖ 05B3AA29$_h$

Table D.2 provides test vectors for Tag authentication using SPECK with *b*-bit blocks and *k*-bit keys. The value of the key used for each example in Table D.2 corresponds to the key used for each *b*/*k* value in Table D.1. The value of KeyID is set to 0$_h$. See the text for the bit length of parameters; values are written here by filling 32-bit words starting from the right-most bit.

Table D.2 — Test vectors for Tag authentication using SPECK-b/k

Variant *b*/*k*	IChallenge-b/k	TAM1 Message	TRnd-b/k	TResponse
64/96	2F7$_h$ ‖ 220676E6$_h$	000002F7$_h$ ‖ 220676E6$_h$	ABCDE$_h$	EBAA6EF3$_h$ ‖ 3B790E37$_h$
64/128	2F7$_h$ ‖ 220676E6$_h$	002002F7$_h$ ‖ 220676E6$_h$	ABCDE$_h$	D457AC8F$_h$ ‖ B72682B4$_h$
96/96	6F7220$_h$ ‖ 676E696C$_h$	010$_h$ ‖ 006F7220$_h$ ‖ 676E696C$_h$	321ABCDE$_h$	1262579b$_h$ ‖ 203A135D$_h$ ‖ CE0D62C2$_h$
128/128	6F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$	0$_h$ ‖ 24006F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$	321ABCDE$_h$	4DE73016$_h$ ‖ 78A507E1$_h$ ‖ 7A372149$_h$ ‖ B3CA54B3$_h$
128/256	6F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$	0$_h$ ‖ 28006F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$	321ABCDE$_h$	4A2FA6A7$_h$ ‖ DE46B48E$_h$ ‖ 67090611$_h$ ‖ 1628C941$_h$

Table D.3 provides test vectors for Interrogator authentication using SPECK with *b*-bit blocks and *k*-bit keys. The value of the key used for each example in Table D.3 corresponds to the key used for each *b*/*k* value in Table D.1. The value of KeyID is set to 0$_h$. See the text for the bit length of parameters; values are written here by filling 32-bit words starting from the right-most bit.

Table D.3 — Test vectors for Interrogator authentication using SPECK-b/k

Variant *b*/*k*	IAM1 Message	TChallenge-b/k	IRnd-b/k	IAM2 Message
64/96	40000$_h$	2F7$_h$ ‖ 220676E6$_h$	ABCDE$_h$	50$_h$ ‖ 99B9D02C$_h$ ‖ 060F6268$_h$
64/128	40400$_h$	2F7$_h$ ‖ 220676E6$_h$	ABCDE$_h$	50$_h$ ‖ 875C87C4$_h$ ‖ BCFE0A84$_h$
96/96	41000$_h$	6F7220$_h$ ‖ 676E696C$_h$	321ABCDE$_h$	50$_h$ ‖ 47FA85B4$_h$ ‖ 7E838977$_h$ ‖ F67C3D04$_h$
128/128	42000$_h$	6F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$	321ABCDE$_h$	50$_h$ ‖ 6A7B3E27$_h$ ‖ AE319BD6$_h$ ‖ 97A8C2DD$_h$ ‖ AF002949$_h$
128/256	42800$_h$	6F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$	321ABCDE$_h$	50$_h$ ‖ 3CE936AF$_h$ ‖ 20F5DBC5$_h$ ‖ 72257DDE$_h$ ‖ E0B049AE$_h$

Tables D.4 to D.13 provide test vectors for Mutual authentication using SPECK with *b*-bit blocks and *k*-bit keys. Tables D.14 to D.23 provide test vectors for authenticated command encapsulation using SPECK with b-bit blocks and k-bit keys. The value of the key used for each example corresponds to the key used for each *b*/*k* value in Table D.1. The value of KeyID is set to 0$_h$. See the text for the bit length of parameters; values are written here by filling 32-bit words starting from the right-most bit.

Table D.4 — Test vectors for Mutual authentication using SPECK-64/96 and PS= 00_2

SPECK-64/96	Bits	Value
Key	96	13121110$_h$ ‖ 0B0A0908$_h$ ‖ 03020100$_h$
IChallenge-64/96	42	2F7$_h$ ‖ 220676E6$_h$
MAM1 Message	64	200002F7$_h$ ‖ 220676E6$_h$
TChallenge-64/96	42	2F7$_h$ ‖ 220676E6$_h$
Input to ENC	64	6F7222F7$_h$ ‖ 220676E6$_h$
S	64	50D07AF7$_h$ ‖ 535618D1$_h$
TResponse	86	0676E6$_h$ ‖ 50D07AF7$_h$ ‖ 535618D1$_h$
Input to DEC for MAM2	64	59DB9AF7$_h$ ‖ 220676E6$_h$
IResponse	64	883D72B6$_h$ ‖ 7B67A756$_h$
MAM2 Message (SecureComm = 0)	76	900$_h$ ‖ 883D72B6$_h$ ‖ 7B67A756$_h$
MAM2 Message (SecureComm = 1)	76	901$_h$ ‖ 883D72B6$_h$ ‖ 7B67A756$_h$

Table D.5 — Test vectors for Mutual authentication using SPECK-64/128 with PS=00_2

SPECK-64/128	Bits	Value
Key	128	1B1A1918$_h$ ‖ 13121110$_h$ ‖ 0B0A0908$_h$ ‖ 03020100$_h$
IChallenge-64/96	42	2F7$_h$ ‖ 220676E6$_h$
MAM1 Message	64	201002F7$_h$ ‖ 220676E6$_h$
TChallenge-64/96	42	2F7$_h$ ‖ 220676E6$_h$
Input to ENC	64	6F7222F7$_h$ ‖ 220676E6$_h$
S	64	EA391A0A$_h$ ‖ 23CFF898$_h$
TResponse	86	0676E6$_h$ ‖ EA391A0A$_h$ ‖ 23CFF898$_h$
Input to DEC for MAM2	64	59DB9AF7$_h$ ‖ 220676E6$_h$
IResponse	64	4E03BE13$_h$ ‖ D3D19E52$_h$
MAM2 Message (SecureComm = 0)	76	900$_h$ ‖ 4E03BE13$_h$ ‖ D3D19E52$_h$
MAM2 Message (SecureComm = 1)	76	901$_h$ ‖ 4E03BE13$_h$ ‖ D3D19E52$_h$

Table D.6 — Test vectors for Mutual authentication using SPECK-96/96 with PS=00$_2$

SPECK-96/96	Bits	Value
Key	96	0D0C0B0A$_h$ ‖ 09080504$_h$ ‖ 03020100$_h$
IChallenge-64/96	56	6F7220$_h$ ‖ 676E696C$_h$
MAM1 Message	76	810$_h$ ‖ 006F7220$_h$ ‖ 676E696C$_h$
TChallenge-64/96	56	6F7220$_h$ ‖ 676E696C$_h$
Input to ENC	96	FD676E69$_h$ ‖ 6C6F7220$_h$ ‖ 676E696C$_h$
S	96	E430A59E$_h$ ‖ 64A2A4AB$_h$ ‖ 5574F3CB$_h$
TResponse	120	6F7220$_h$ ‖ E430A59E$_h$ ‖ 64A2A4AB$_h$ ‖ 5574F3CB$_h$
Input to DEC for MAM2	96	FD676E69$_h$ ‖ 6C6F7220$_h$ ‖ 676E696C$_h$
IResponse	96	098601D6$_h$ ‖ 8602BCCC$_h$ ‖ BE7EE9B1$_h$
MAM2 Message (SecureComm = 0)	108	900$_h$ ‖ 098601D6$_h$ ‖ 8602BCCC$_h$ ‖ BE7EE9B1$_h$
MAM2 Message (SecureComm = 1)	108	901$_h$ ‖ 098601D6$_h$ ‖ 8602BCCC$_h$ ‖ BE7EE9B1$_h$

Table D.7 — Test vectors for Mutual authentication using SPECK-128/128 with PS=00$_2$

SPECK-128/128	Bits	Value
Key	128	0F0E0D0C$_h$ ‖ 0B0A0908$_h$ ‖ 07060504$_h$ ‖ 03020100$_h$
IChallenge-128/128	80	6F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$
MAM1 Message	100	8$_h$ ‖ 24006F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$
TChallenge-128/128	80	6F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$
Input to ENC	128	FFFD6F72$_h$ ‖ 20676F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$
S	128	B77119B3$_h$ ‖ 621328E8$_h$ ‖ 616bA064$_h$ ‖ F01FE70C$_h$
TResponse	176	6E69$_h$ ‖ 6C636C6C$_h$ ‖ B77119B3$_h$ ‖ 621328E8$_h$ ‖ 616bA064$_h$ ‖ F01FE70C$_h$
Input to DEC for MAM2	128	FFFD6F72$_h$ ‖ 20676F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$
IResponse	128	BAFD52B9$_h$ ‖ 9E1334FF$_h$ ‖ F26A7C2A$_h$ ‖ CA1E08E7$_h$
MAM2 Message (SecureComm = 0)	140	900$_h$ ‖ BAFD52B9$_h$ ‖ 9E1334FF$_h$ ‖ F26A7C2A$_h$ ‖ CA1E08E7$_h$
MAM2 Message (SecureComm = 1)	140	901$_h$ ‖ BAFD52B9$_h$ ‖ 9E1334FF$_h$ ‖ F26A7C2A$_h$ ‖ CA1E08E7$_h$

Table D.8 — Test vectors for Mutual authentication using SPECK-128/256 with PS=00$_2$

SPECK-128/256	Bits	Value
Key	256	1F1E1D1C$_h$ ‖ 1B1A1918$_h$ ‖ 17161514$_h$ ‖ 13121110$_h$ ‖ 0F0E0D0C$_h$ ‖ 0B0A0908$_h$ ‖ 07060504$_h$ ‖ 03020100$_h$
IChallenge-128/256	80	6F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$
MAM1 Message	100	8$_h$ ‖ 28006F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$
TChallenge-128/256	80	6F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$
Input to ENC	128	FFFD6F72$_h$ ‖ 20676F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$
S	128	B433F966$_h$ ‖ A69C8BE3$_h$ ‖ 64A4375A$_h$ ‖ A74f4065$_h$
TResponse	176	6E69$_h$ ‖ 6C636C6C$_h$ ‖ B433F966$_h$ ‖ A69C8BE3$_h$ ‖ 64A4375A$_h$ ‖ A74F4065$_h$
Input to DEC for MAM2	128	FFFD6F72$_h$ ‖ 20676F72$_h$ ‖ 20676E69$_h$ ‖ 6C636C6C$_h$

Table D.8 *(continued)*

SPECK-128/256	Bits	Value
IResponse	128	DAB64659$_h$ ‖ C89CCDC6$_h$ ‖ 98021898$_h$ ‖ EC68D9E2$_h$
MAM2 Message (SecureComm = 0)	140	900$_h$ ‖ DAB64659$_h$ ‖ C89CCDC6$_h$ ‖ 98021898$_h$ ‖ EC68D9E2$_h$
MAM2 Message (SecureComm = 1)	140	901$_h$ ‖ DAB64659$_h$ ‖ C89CCDC6$_h$ ‖ 98021898$_h$ ‖ EC68D9E2$_h$

Table D.9 — Test vectors for Mutual authentication using SPECK-64/96 with PS=01$_2$

SPECK-64/96	Bits	Value
Key	96	13121110$_h$ ‖ 0B0A0908$_h$ ‖ 03020100$_h$
IChallenge-64/96	30	220676E6$_h$
MAM1 Message	50	20000$_h$ ‖ 620676E6$_h$
TChallenge-64/96	30	220676E6$_h$
Input to ENC	64	18819DB9$_h$ ‖ A20676E6$_h$
S	64	6019E12A$_h$ ‖ 37B18C74$_h$
TResponse	64	6019E12A$_h$ ‖ 37B18C74$_h$
Input to DEC for MAM2	—	—
IResponse	30	220676E6$_h$
MAM2 Message (SecureComm = 0)	42	240$_h$ ‖ 220676E6$_h$
MAM2 Message (SecureComm = 1)	42	240$_h$ ‖ 620676E6$_h$

Table D.10 — Test vectors for Mutual authentication using SPECK-64/128 with PS=01$_2$

SPECK-64/128	Bits	Value
Key	128	1B1A1918$_h$ ‖ 13121110$_h$ ‖ 0B0A0908$_h$ ‖ 03020100$_h$
IChallenge-64/128	30	220676E6$_h$
MAM1 Message	50	20100$_h$ ‖ 620676E6$_h$
TChallenge-64/128	30	220676E6$_h$
Input to ENC	64	18819DB9$_h$ ‖ A20676E6$_h$
S	64	B8FFDF48$_h$ ‖ 05A9F7F4$_h$
TResponse	64	B8FFDF48$_h$ ‖ 05A9F7F4$_h$
Input to DEC for MAM2	—	—
IResponse	30	220676E6$_h$
MAM2 Message (SecureComm = 0)	42	240$_h$ ‖ 220676E6$_h$
MAM2 Message (SecureComm = 1)	42	240$_h$ ‖ 620676E6$_h$

Table D.11 — Test vectors for Mutual authentication using SPECK-96/96 with PS=01$_2$

SPECK-96/96	Bits	Value
Key	96	0D0C0B0A$_h$ ‖ 09080504$_h$ ‖ 03020100$_h$
IChallenge-96/96	46	3220$_h$ ‖ 676E696C$_h$
MAM1 Message	62	20400620$_h$‖ 676E696C$_h$
TChallenge-96/96	46	3220$_h$ ‖ 676E696C$_h$
Input to ENC	96	DC8819DB$_h$ ‖ 9A5B3220$_h$ ‖ 676E696C$_h$
S	96	5ACE71E2$_h$ ‖ 5B151445$_h$ ‖ B1E5BA1B$_h$
TResponse	96	5ACE71E2$_h$ ‖ 5B151445$_h$ ‖ B1E5BA1B$_h$
Input to DEC for MAM2	—	—

Table D.11 *(continued)*

SPECK-96/96	Bits	Value
IResponse	46	3220$_h$ ‖ 676E696C$_h$
MAM2 Message (SecureComm = 0)	58	2403220$_h$ ‖ 676E696C$_h$
MAM2 Message (SecureComm = 1)	58	2407220$_h$ ‖ 676E696C$_h$

Table D.12 — Test vectors for Mutual authentication using SPECK-128/128 with PS=01$_2$

SPECK-128/128	Bits	Value
Key	128	0F0E0D0C$_h$ ‖ 0B0A0908$_h$ ‖ 07060504$_h$ ‖ 03020100$_h$
IChallenge-128/128	60	0676E69$_h$ ‖ 6C636C6C$_h$
MAM1 Message	80	8240$_h$ ‖ 10676E69$_h$ ‖ 6C636C6C$_h$
TChallenge-128/128	60	0676E69$_h$ ‖ 6C636C6C$_h$
Input to ENC	128	FD0676E6$_h$ ‖ 96C636C6$_h$ ‖ C0676E69$_h$ ‖ 6C636C6C$_h$
S	128	9F682F58$_h$ ‖ 42357D82$_h$ ‖ 4381FCE6$_h$ ‖ FABADB08$_h$
TResponse	128	9F682F58$_h$ ‖ 42357D82$_h$ ‖ 4381FCE6$_h$ ‖ FABADB08$_h$
Input to DEC for MAM2	—	—
IResponse	60	0676E69$_h$ ‖ 6C636C6C$_h$
MAM2 Message (SecureComm = 0)	72	90$_h$ ‖ 00676E69$_h$ ‖ 6C636C6C$_h$
MAM2 Message (SecureComm = 1)	72	90$_h$ ‖ 10676E69$_h$ ‖ 6C636C6C$_h$

Table D.13 — Test vectors for Mutual authentication using SPECK-128/256 with PS=01$_2$

SPECK-128/256	Bits	Value
Key	256	1F1E1D1C$_h$ ‖ 1B1A1918$_h$ ‖ 17161514$_h$ ‖ 13121110$_h$ ‖ 0F0E0D0C$_h$ ‖ 0B0A0908$_h$ ‖ 07060504$_h$ ‖ 03020100$_h$
IChallenge-64/96	60	0676E69$_h$ ‖ 6C636C6C$_h$
MAM1 Message	80	8280$_h$ ‖ 10676E69$_h$ ‖ 6C636C6C$_h$
TChallenge-64/96	60	0676E69$_h$ ‖ 6C636C6C$_h$
Input to ENC	128	FD0676E6$_h$ ‖ 96C636C6$_h$ ‖ C0676E69$_h$ ‖ 6C636C6C$_h$
S	128	E98081D8$_h$ ‖ 32E85407$_h$ ‖ 921DBF44$_h$ ‖ 429960A6$_h$
TResponse	128	E98081D8$_h$ ‖ 32E85407$_h$ ‖ 921DBF44$_h$ ‖ 429960A6$_h$
Input to DEC for MAM2	—	—
IResponse	60	0676E69$_h$ ‖ 6C636C6C$_h$
MAM2 Message (SecureComm = 0)	72	90$_h$ ‖ 00676E69$_h$ ‖ 6C636C6C$_h$
MAM2 Message (SecureComm = 1)	72	90$_h$ ‖ 10676E69$_h$ ‖ 6C636C6C$_h$

Table D.14 — Test vectors for authenticated command encapsulation using SPECK-64/96 with PS=00$_2$

SPECK-64/96 (PS= 00$_2$)	Bits	Value
Key.00	96	13121110$_h$ ‖ 0B0A0908$_h$ ‖ 03020100$_h$
TChallenge-64/96	42	2F7$_h$ ‖ 220676E6$_h$
MAM2 Message (SecureComm = 1$_h$)	76	901$_h$ ‖ 883D72B6$_h$ ‖ 7B67A756$_h$
MAM2 Response (KeyID$_2$ = 01$_h$)	15	406D$_h$
Nonce N = N$_T$ ‖ TChallenge	48	B4F7$_h$ ‖ 220676E6$_h$
Key.01	96	03020100$_h$ ‖ 1B1A1918$_h$ ‖ 13121110$_h$
READ first four rows of user memory	26	30B0004$_h$

Table D.14 *(continued)*

SPECK-64/96 (PS= 00_2)	Bits	Value
SEC (Key.01, B0$_h$, 0$_b$ 30B0004$_h$) **<start>**	Add 32-bit authentication tag	
Get V **<start>**		
$S_H[0]$	64	156253CA$_h$ ‖ 551BA0A5$_h$
$S_H[1]$	64	B32C498D$_h$ ‖ 91016779$_h$
V **<end>**	64	g(B32c498D$_h$ ‖ 91016763$_h$) = 2C498D91$_h$ ‖ 0167639F$_h$
Get C	-	-
Get T **<start>**		
$S_P[0]$	64	73AEB17f$_h$ ‖ DE10A390$_h$
$S_P[1]$	—	—
U	64	AEB17FDE$_h$ ‖ 10A390DD$_h$
T **<end>**	32	F78F1D92$_h$
SEC (Key.01, B0$_h$, 0$_b$, 30B0004$_h$) **<end>**	58	30B0004$_h$ ‖ F78F1D92$_h$
Secured payload	82	006C0$_h$ ‖ 030B0004$_h$ ‖ F78F1D92$_h$

Table D.15 — Test vectors for authenticated and encrypted command encapsulation using SPECK-64/96 with PS=00_2

SPECK-64/96 (PS= 00_2)	Bits	Value
Key.00	96	13121110$_h$ ‖ 0B0A0908$_h$ ‖ 03020100$_h$
TChallenge-64/96	42	2F7$_h$ ‖ 220676E6$_h$
MAM2 Message (SecureComm = 1)	76	901$_h$ ‖ 883D72B6$_h$ ‖ 7B67A756$_h$
MAM2 Response (KeyID$_2$ = 01$_h$)	15	406D$_h$
Nonce N = N_T ‖ Tchallenge	48	B4F7$_h$ ‖ 220676E6$_h$
Key.01	96	03020100$_h$ ‖ 1B1A1918$_h$ ‖ 13121110$_h$
READ first four rows of user memory	26	30B0004$_h$
SEC (Key.01, B0$_h$, 0$_b$, 30B0004$_h$) **<start>**	Encrypt and add 32-bit authentication tag	
Get V **<start>**		
$S_H[0]$	64	156253CA$_h$ ‖ 551BA0A5$_h$
$S_H[1]$	—	—
V **<end>**	64	g(156253CA$_h$ ‖ 551BA0A5$_h$) = 6253CA55$_h$ ‖ 1BA0A577$_h$
Get C **<start>**		
$S_E[1]$	64	51C82AAE$_h$ ‖ 66C0C68C$_h$
C **<end>**	26	24C20AE$_h$
Get T **<start>**		
$S_P[0]$		9780c47e$_h$ ‖ 91724240$_h$
$S_P[1]$		6930BEA5$_h$ ‖ 5C4D7DA2$_h$
U	64	g(6930BEA5$_h$ ‖ 5C4D7DB8$_h$) = 30BEA55C$_h$ ‖ 4D7DB859$_h$
T **<end>**	32	4B81178D$_h$
SEC (Key.01, B0$_h$, 0$_b$ 30B0004$_h$) **<end>**	58	24C20AE$_h$ ‖ 4B81178D$_h$
Secured payload	82	006C0$_h$ ‖ 224C20AE$_h$ ‖ 4B81178D$_h$