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ISO/IEC 1st CD 29192-2

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Explanatory Report

Status	**SC 27 Decision**	**Reference documents**	
		Input	**Output**
Study Period on Low power encryption	18th SC 27 Plenary meeting, Apr. 2006, Resolution 31 (N5199).	20th JTC 1 Plenary, Nov. 2005, resolution 35 (N4891=JTC 1 N8010)	Call f. Contr. (N5245).
	33rd WG 2 meeting, Nov. 2006, resolutions 2, 5 (N5901).	JP[1] contr. (N5345)	Report (N5447) (N/A);
	34th WG 2 meeting, May 2007, resolutions 3, 12 & 31 (N5), May 2007; 19th Plenary meeting, May 2007, resolutions 1, 31 (N5939).		Extention by 6 months (WG2 resolution 31); Report (N5846); Call f. contr. (N5904).
Study Period on Light-weight cryptographic mechanisms ***(title changed)***	35th WG 2 meeting, Oct. 2007, resolutions 2, 23 (N6211).	JP[1] contr. (N6002); KR[1] contr. (N6115).	Report (N6199); Call f. contr. (N6201).
	36th WG 2 meeting, April 2008, resolutions 1, 12, 27 (N6793); 20th Plenary, Apr. 2008, resolutions 2, 20 (N6799).	SoContr. (N6480); JP[1] (N6597).	Extention by 6 months (WG 2 resolution 27); Report (N6709); Call f. contr. (N6715).
NWIP **1st WD**	37th WG 2 meeting, October 2008, resolutions 2, 3, 9 (NWIP), 15, 25 (N7303).	VISA contr. (N6860).	Termination of SP WG 2 resolution 25; Report (N7167); NWIP (N7276rev1); Text f. 1st WD (N7276).
NP 29192 **2nd WD 29192**	38th WG 2 meeting, May 2009 resolutions 1, 10 (N7718) & 21st Plenary, May 2009, resolution 2 (N7777).	SoCom. (N7413); JP[1] (N7526).	Report (N7716); Calls f. contr. (N7682, N7683); DoC (N7675); Text f. 2nd WD 29192 (N7688).
3rd WD 29192-1* * subject to JTC 1 endorsement on subdivision	39th WG 2 meeting, November 2009, resolutions 1, 2, 3, 8, 11 (subdivision) 12 (N8299).	SoCom (N7862).	Recommend on subdivisiion (N8202); Request / Conformation for / of endorsement/subdivision (N8313/N8888); DoC (N8200); Report (N8201); Call f. contr. (N8221); Text f. 1st WD (N8224).
1st CD 29192-1	40th WG 2 meeting, April 2010, resolutions 1, 12 (N8789); SC 27 resolution 1 (N8916).	SoCom (N8520); FR[1] com. (N8889).	DoC (N8754); Text f. 1st CD (N8755).

1st CD Registration and Consideration

In accordance with resolution 12 (in SC 27 N8789) of the 40th SC 27/WG 2 meeting held in Melaka (Malaysia), 19th – 23rd April 2010, the attached document SC 27 N8755 has been registered with the ISO Central Secretariat (ITTF) as a 1st Committee Draft (CD) and is hereby circulated for a 3-month 1st CD LB closing by

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[1)] **MB** = Member body (the ISO 3166 two-letter country code, e.g. CN for China)

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Secretariat: DIN

Information technology — Security techniques - Lightweight cryptography — Part 2: Block ciphers

Technologies de l'information — Techniques de sécurité - Cryptographie pour environnements constraints — Partie 2: Chiffrements par blocs

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Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work. In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1.

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ISO/IEC 29192-2 was prepared by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 27, *Security techniques*.

ISO/IEC 29192 consists of the following parts, under the general title *Information technology — Security techniques — Lightweight cryptography*:

— *Part 1: General*

— *Part 2: Block ciphers*

— *Part 3: Stream ciphers*

— *Part 4: Mechanisms using asymmetric techniques*

Further parts may follow.

Information technology — Security techniques - Lightweight cryptography — Part 2: Block ciphers

1 Scope

This part of ISO/IEC 29192 specifies block ciphers suitable for lightweight cryptography, which are tailored to be implemented in constrained environments. A block cipher maps blocks of *n* bits to blocks of *n* bits, under the control of a key of *k* bits. This part of ISO/IEC 29192 defines a lightweight block cipher with a block size of 64 bits in Clause 5 and a lightweight block cipher with a block size of 128 bits in Clause 6. Table 1 shows the lightweight block ciphers specified in this part of ISO/IEC 29192.

Table 1 — Lightweight block ciphers specified in this part of ISO/IEC 29192

Block length	Algorithm name (Subclause no.)	Key length
64 bits	PRESENT (5.1)	80 or 128 bits
128 bits	CLEFIA (6.1)	128, 192, or 256 bits

2 Normative references

There are no normative references for this part of ISO/IEC 29192.

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO/IEC 29192-1 and the following apply.

3.1
block
string of bits of defined length

[ISO/IEC 18033-1:2005]

3.2
block cipher
symmetric encipherment system with the property that the encryption algorithm operates on a block of plaintext, i.e. a string of bits of a defined length, to yield a block of ciphertext

[ISO/IEC 18033-1:2005]

3.3
ciphertext
data which has been transformed to hide its information content

[ISO/IEC 9798-1:1997]

3.4
key

sequence of symbols that controls the operation of a cryptographic transformation (e.g. encipherment, decipherment)

[ISO/IEC 11770-1:1996]

3.5
***n*-bit block cipher**
block cipher with the property that plaintext blocks and ciphertext blocks are *n* bits in length

[ISO/IEC 10116:2006]

3.6
plaintext
unenciphered information

[ISO/IEC 9797-1:1999]

4 Symbols and abbreviated terms

0x	A prefix for a binary string in a hexadecimal form
$a_{(b)}$	b denotes the bit length of a
$a \| b$	Concatenation of a and b
(a, b)	Vector style representation of $a \| b$
$a = b$	Updating a value of a by a value of b
$a \oplus b$	Bitwise exclusive-OR. Addition in GF(2^n)
$a \bullet b$	Multiplication in GF(2^n)
$a <<< b$	b-bit left cyclic shift operation
${}^t a$	Transposition of a vector or a matrix a
$\tilde{}\, a$	Logical negation

5 Lightweight block cipher with a block size of 64 bits

5.1 PRESENT

5.1.1 PRESENT algorithm

PRESENT algorithm [6] is a symmetric block cipher that can process data blocks of 64 bits, using cipher keys with lengths of 80 and 128 bits. These options are referred to as "PRESENT-80" and "PRESENT-128", respectively.

5.1.2 PRESENT encryption

Each of the 31 rounds consists of an exclusive-OR operation to introduce a round key K_i for $1 \leq i \leq 32$, where K_{32} is used for post-whitening (**addRoundKey**), a non-linear substitution layer (**sBoxLayer**) and a linear bitwise permutation (**pLayer**). The cipher is described in pseudo-code in Figure 1, and each stage is specified in 5.1.4. The intermediate values after each transformation of PRESENT are referred to as the *STATE* and the

KEY STATE, respectively. Throughout 5.1 bits are numbered from zero with bit zero on the right of a block, nibble or word. Two rounds of PRESENT are depicted in Figure 2.

generateRoundKeys()
for $i = 1$ to 31 **do**

  addRoundKey(STATE,K_i)
  sBoxLayer(STATE)
  pLayer(STATE)
end for
addRoundKey(STATE,K_{32})

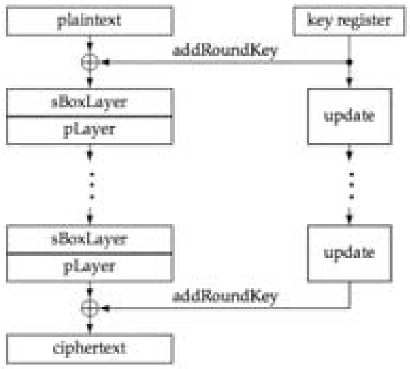


Figure 1 — The encryption procedure of PRESENT

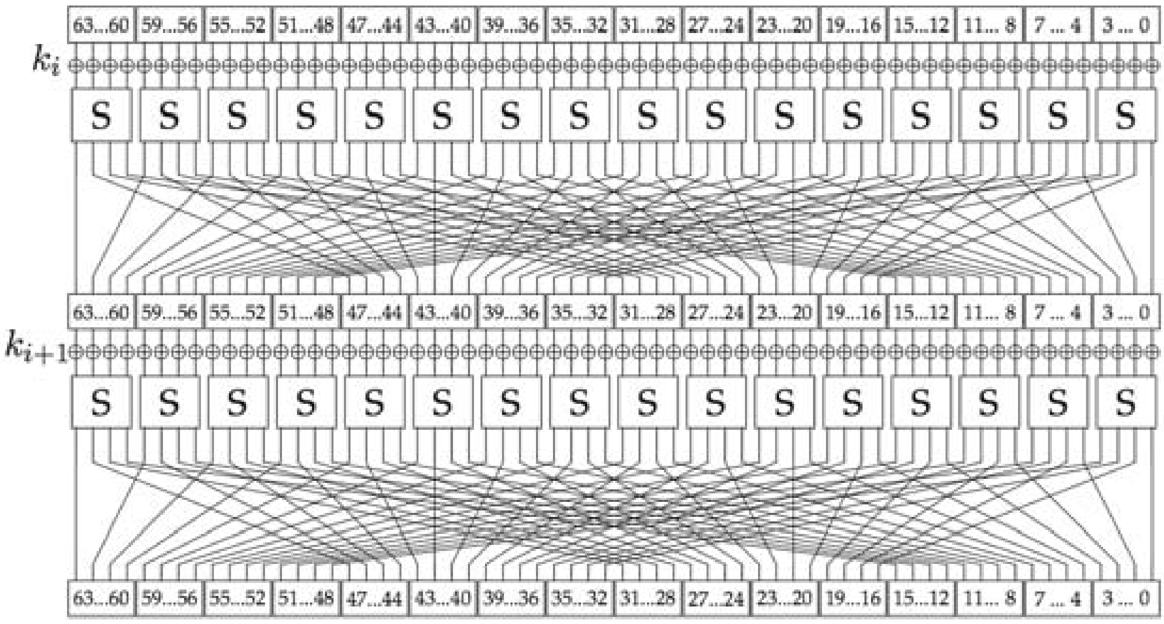


Figure 2 — Two rounds of PRESENT

5.1.3 PRESENT decryption

Figure 3 depicts a top-level algorithmic overview of the decryption routine of PRESENT. As can be seen it consists of the inverse operations applied in the reverse order of the encryption routine of PRESENT. Note that **addRoundKey** is an involution and thus there is used both for encryption and decryption.

```
generateRoundKeys()
addRoundKey(STATE,K32)
for i = 31 downto 1 do
   invPLayer(STATE)
   invSBoxLayer(STATE)

   addRoundKey(STATE,Ki)
end for
```

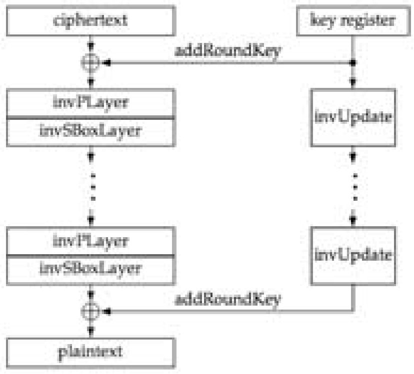


Figure 3 — The decryption procedure of PRESENT

5.1.4 PRESENT transformations

5.1.4.1 addRoundKey

Given round key $K_i = k^i_{63}\dots k^i_0$ for $1 \le i \le 32$ and current *STATE* $b_{63}\dots b_0$, **addRoundKe**y consists of the operation for $0 \le j \le 63$, $b_j \rightarrow b_j \oplus k^i_j$.

5.1.4.2 sBoxLayer

The non-linear **sBoxLayer** of the encryption process of PRESENT uses a single 4-bit to 4-bit S-box S which is applied 16 times in parallel in each round. The action of this S-box in hexadecimal notation is given by the following table.

Table 2 — PRESENT S-box

x	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
$S(x)$	C	5	6	B	9	0	A	D	3	E	F	8	4	7	1	2

For **sBoxLayer** the current *STATE* $b_{63}\dots b_0$ is considered as sixteen 4-bit words $w_{15}\dots w_0$ where $w_i = b_{4*i+3}||b_{4*i+2}||b_{4*i+1}||b_{4*i}$ for $0 \le i \le 15$ and the output nibble $S(w_i)$ provides the updated state values in the obvious way.

5.1.4.3 invsBoxLayer

The S-box used in the decryption procedure of PRESENT is the inverse of the 4-bit to 4-bit S-box S that was described in 5.1.4.2. The action of the inverse S-box in hexadecimal notation is given by the following table.

Table 3 — PRESENT inverse S-box

x	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
$S^{-1}(x)$	5	E	F	8	C	1	2	D	B	4	6	3	0	7	9	A

5.1.4.4 pLayer

The bit permutation **pLayer** used in the encryption routine of PRESENT is given by Table 4. Bit i of *STATE* is moved to bit position $P(i)$.

Table 4 — PRESENT permutation layer pLayer

i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$P(i)$	0	16	32	48	1	17	33	49	2	18	34	50	3	19	35	51

i	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
$P(i)$	4	20	36	52	5	21	37	53	6	22	38	54	7	23	39	55

i	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
P(i)	8	24	40	56	9	25	41	57	10	26	42	58	11	27	43	59

i	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
$P(i)$	12	28	44	60	13	29	45	61	14	30	46	62	15	31	47	63

5.1.4.5 invpLayer

The inverse permutation layer **invpLayer** used in the decryption routine of PRESENT is given by Table 5. Bit i of *STATE* is moved to bit position $P(i)$.

Table 5 — PRESENT inverse permutation Layer invpLayer

i	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
$P(i)$	0	4	8	12	16	20	24	28	32	36	40	44	48	52	56	60

i	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
$P(i)$	1	5	9	13	17	21	25	29	33	37	41	45	49	53	57	61

i	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
$P(i)$	2	6	10	14	18	22	26	30	34	38	42	46	50	54	58	62

i	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63
$P(i)$	3	7	11	15	19	23	27	31	35	39	43	47	51	55	59	63

5.1.5 PRESENT key schedule

5.1.5.1 PRESENT-80 and PRESENT-128

PRESENT can take keys of either 80 or 128 bits. In 5.1.5.2 the version with an 80-bit key (PRESENT-80) and in the following 5.1.5.3 the 128-bit version (PRESENT-128) is described.

5.1.5.2 80-bit key for PRESENT-80

The user-supplied key is stored in a key register K and represented as $k_{79}k_{78} \ldots k_0$. At round i the 64-bit round key $\boldsymbol{K_i} = \boldsymbol{k_{63}k_{62} \ldots k_0}$ consists of the 64 leftmost bits of the current contents of register K. Thus at round i we have that:

$$\boldsymbol{K_i} = \boldsymbol{k_{63}k_{62} \ldots k_0} = k_{79}k_{78} \ldots k_{16}.$$

After extracting the round key $\boldsymbol{K_i}$, the key register $K = k_{79}k_{78} \ldots k_0$ is updated as follows.

1) $k_{79}k_{78} \ldots k_1k_0 = k_{18}k_{17} \ldots k_{20}k_{19}$

2) $k_{79}k_{78}k_{77}k_{76} = S[k_{79}k_{78}k_{77}k_{76}]$

3) $k_{19}k_{18}k_{17}k_{16}k_{15} = k_{19}k_{18}k_{17}k_{16}k_{15} \oplus round\_counter$

Thus, the key register is rotated by 61 bit positions to the left, the left-most four bits are passed through the PRESENT S-box, and the $round\_counter$ value i is exclusive-ORed with bits $k_{19}k_{18}k_{17}k_{16}k_{15}$ of K with the least significant bit of $round\_counter$ on the right. Figure 4 depicts the key schedule for PRESENT-80 graphically.

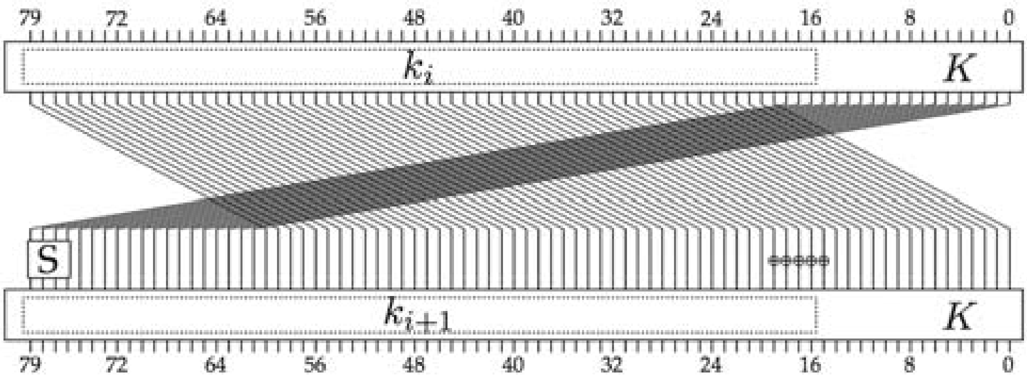


Figure 4 — PRESENT-80 key schedule

5.1.5.3 128-bit key for PRESENT-128

Similar to the 80-bit variant at the beginning the user-supplied key is stored in a key register K and is represented as $k_{127}k_{126} \ldots k_0$. At round *i* the 64-bit round key $\boldsymbol{K_i} = \boldsymbol{k_{63}k_{62} \ldots k_0}$ consists of the 64 leftmost bits of the current contents of register K. Thus at round i we have that:

$$\boldsymbol{K_i} = \boldsymbol{k_{63}k_{62} \ldots k_0} = k_{127}k_{126} \ldots k_{64}.$$

After extracting the round key $\boldsymbol{K_i}$, the key register $K = k_{127}k_{126} \ldots k_0$ is updated as follows.

1) $k_{127}k_{126} \ldots k_1k_0 = k_{66}k_{65} \ldots k_{68}k_{67}$

2) $k_{127}k_{126}k_{125}k_{124} = S[k_{127}k_{126}k_{125}k_{124}]$

3) $k_{123}k_{122}k_{121}k_{120} = S[k_{123}k_{122}k_{121}k_{120}]$

4) $k_{66}k_{65}k_{64}k_{63}k_{62} = k_{66}k_{65}k_{64}k_{63}k_{62} \oplus round\_counter$

Thus, the key register is rotated by 61 bit positions to the left, the left-most eight bits are passed through the PRESENT S-box, and the *round_counter* value i is exclusive-ORed with bits $k_{66}k_{65}k_{64}k_{63}k_{62}$ of K with the least significant bit of *round_counter* on the right. Figure 5 depicts the key schedule for PRESENT-128 graphically.

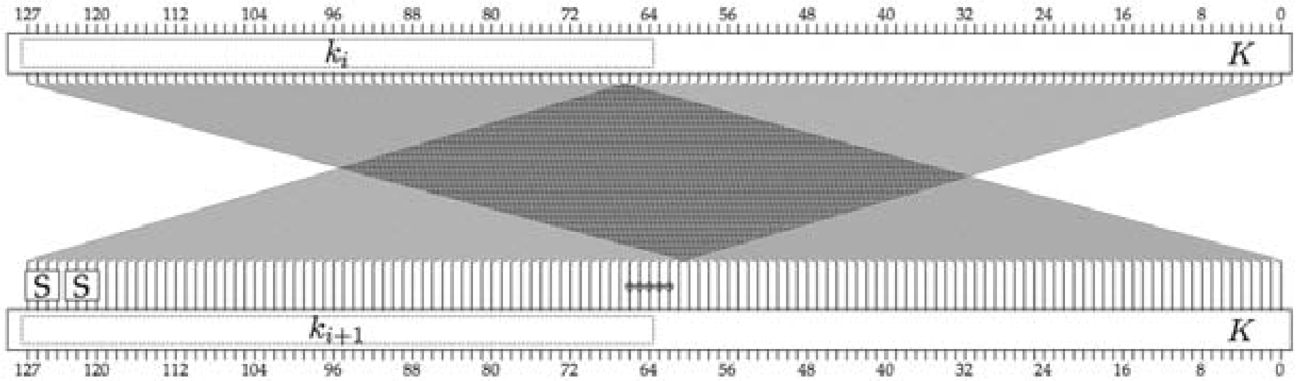


Figure 5 — PRESENT-128 key schedule

6 Lightweight block cipher with a block size of 128 bits

6.1 CLEFIA

6.1.1 CLEFIA encryption

The encryption process of CLEFIA [9] is based on the 4-branch r-round generalized Feistel structure $GFN_{4,r}$. Let P, $C \in \{0,1\}^{128}$ be a plaintext and a ciphertext, and let P_i, $C_i \in \{0,1\}^{32}$ $(0 \leq i < 4)$ be divided plaintexts and ciphertexts where $P = P_0 \parallel P_1 \parallel P_2 \parallel P_3$ and $C = C_0 \parallel C_1 \parallel C_2 \parallel C_3$, and let WK_0, WK_1, WK_2, $WK_3 \in \{0,1\}^{32}$ be whitening keys and $RK_i \in \{0,1\}^{32}$ $(0 \leq i < 2r)$ be round keys provided by the key scheduling part. Then, r-round encryption function ENC_r is defined as follows:

ENC_r :

1) $T_0 \parallel T_1 \parallel T_2 \parallel T_3 = P_0 \parallel (P_1 \oplus WK_0) \parallel P_2 \parallel (P_3 \oplus WK_1)$

2) $T_0 \parallel T_1 \parallel T_2 \parallel T_3 = GFN_{4,r}(RK_0, ..., RK_{2r-1}, T_0, T_1, T_2, T_3)$

3) $C_0 \parallel C_1 \parallel C_2 \parallel C_3 = T_0 \parallel (T_1 \oplus WK_2) \parallel T_2 \parallel (T_3 \oplus WK_3)$

6.1.2 CLEFIA decryption

The decryption function DEC_r is defined as follows:

DEC_r :

1) $T_0 \parallel T_1 \parallel T_2 \parallel T_3 = C_0 \parallel (C_1 \oplus WK_2) \parallel C_2 \parallel (C_3 \oplus WK_3)$

2) $T_0 \parallel T_1 \parallel T_2 \parallel T_3 = GFN_{4,r}^{-1}(RK_0, ..., RK_{2r-1}, T_0, T_1, T_2, T_3)$

3) $P_0 \parallel P_1 \parallel P_2 \parallel P_3 = T_0 \parallel (T_1 \oplus WK_0) \parallel T_2 \parallel (T_3 \oplus WK_1)$

Figure 6 illustrates both ENC_r and DEC_r.

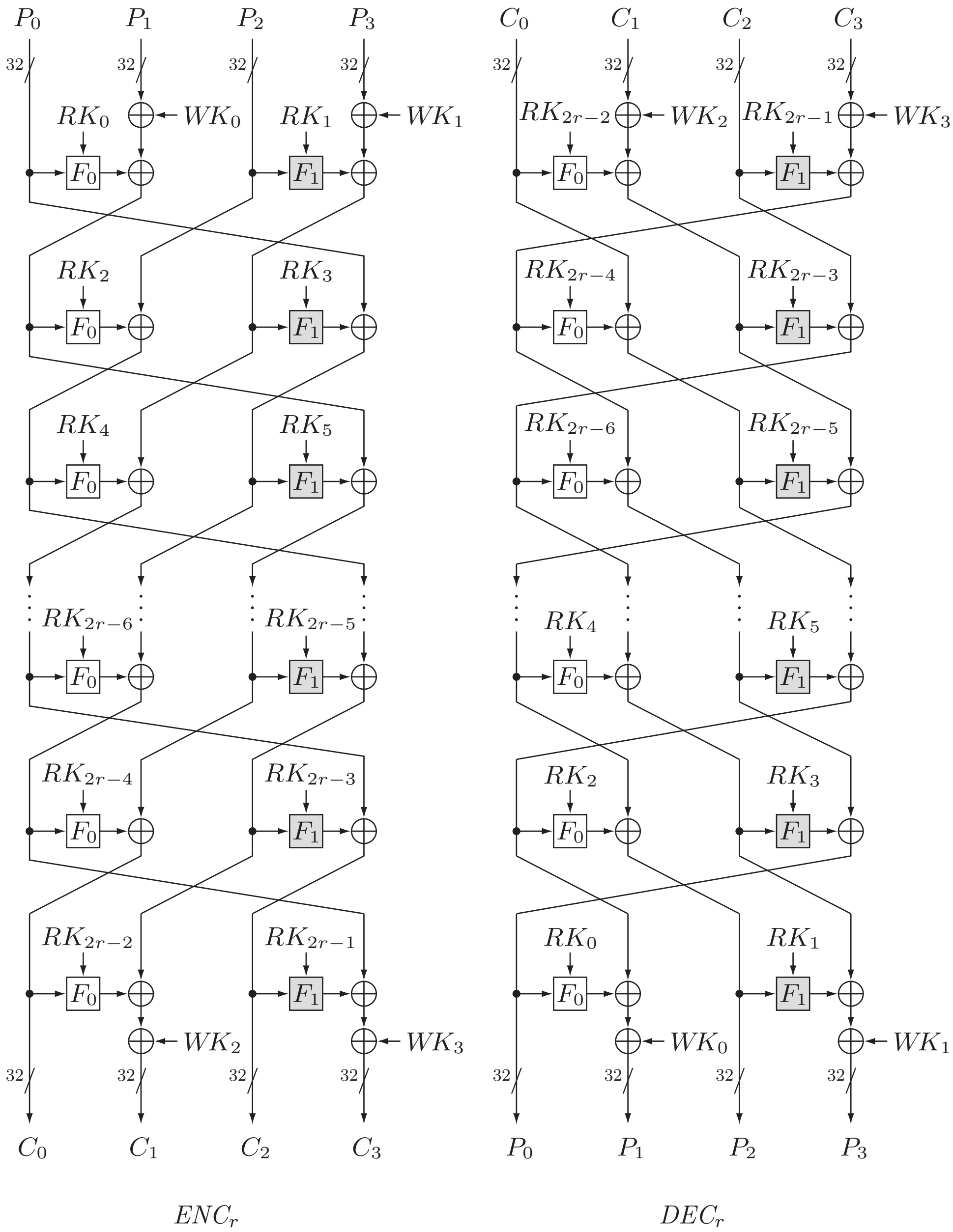


Figure 6 — The encryption procedure and the decryption procedure of CLEFIA

6.1.3 Number of rounds

The number of rounds, r, is 18, 22 and 26 for CLEFIA with 128-bit, 192-bit and 256-bit keys, respectively. The total number of round keys RK_i depends on the key length. The CLEFIA encryption and decryption function require 36, 44 and 52 round keys for 128-bit, 192-bit and 256-bit keys, respectively.

6.1.4 CLEFIA building blocks

6.1.4.1 $\mathbf{GFN_{d,r}}$

The fundamental structure of CLEFIA is a generalized Feistel structure. This structure is employed in both a data processing part and a key scheduling part.

CLEFIA uses a 4-branch and an 8-branch generalized Feistel network. The 4-branch generalized Feistel network is used in the data processing part and the key scheduling for a 128-bit key. The 8-branch generalized Feistel network is applied in the key scheduling for a 192-bit/256-bit key. We denote d-branch r-round generalized Feistel network employed in CLEFIA as $GFN_{d,r}$. $GFN_{d,r}$ uses two different 32-bit F-functions F_0 and F_1.

For d pairs of 32-bit input X_i and output Y_i $(0 \leq i < \mathrm{d})$, and $dr/2$ 32-bit round keys RK_i $(0 \leq i < dr/2)$, $GFN_{d,r}$ $(d = 4,8)$ and the inverse function $GFN_{d,r}^{-1}$ $(d = 4)$ are defined as follows.

$GFN_{4,r}$:

1) $T_0 \| T_1 \| T_2 \| T_3 = X_0 \| X_1 \| X_2 \| X_3$

2) For $i = 0$ to $r - 1$ do the following:

   2.1) $T_1 = T_1 \oplus F_0(RK_{2i}, T_0)$,

   $T_3 = T_3 \oplus F_1(RK_{2i+1}, T_2)$

   2.2) $T_0 \| T_1 \| T_2 \| T_3 = T_1 \| T_2 \| T_3 \| T_0$

3) $Y_0 \| Y_1 \| Y_2 \| Y_3 = T_3 \| T_0 \| T_1 \| T_2$

$GFN_{8,r}$:

1) $T_0 \| T_1 \| ... \| T_7 = X_0 \| X_1 \| ... \| X_7$

2) For $i = 0$ to $r - 1$ do the following:

   2.1) $T_1 = T_1 \oplus \mathrm{F}_0(RK_{4i}, T_0)$,

   $T_3 = T_3 \oplus \mathrm{F}_1(RK_{4i+1}, T_2)$,

   $T_5 = T_5 \oplus \mathrm{F}_0(RK_{4i+2}, T_4)$,

   $T_7 = T_7 \oplus \mathrm{F}_1(RK_{4i+3}, T_6)$

   2.2) $T_0 \| T_1 \| ... \| T_6 \| T_7 = T_1 \| T_2 \| ... \| T_7 \| T_0$

3) $Y_0 \| Y_1 \| ... \| Y_6 \| Y_7 = T_7 \| T_0 \| ... \| T_5 \| T_6$

The inverse function $GFN_{4,r}^{-1}$ is obtained by changing the order of RK_i and the direction of word rotation at 2.2) and 3) in $GFN_{4,r}$.

$GFN_{4,r}^{-1}$:

1) $T_0 \| T_1 \| T_2 \| T_3 = X_0 \| X_1 \| X_2 \| X_3$

2) For $i = 0$ to $r - 1$ do the following:

   2.1) $T_1 = T_1 \oplus F_0(RK_{2(\mathrm{r}-i)-2}, T_0)$,

   $T_3 = T_3 \oplus F_1(RK_{2(\mathrm{r}-i)-1}, T_2)$

   2.2) $T_0 \| T_1 \| T_2 \| T_3 = T_3 \| T_0 \| T_1 \| T_2$

3) $Y_0 \| Y_1 \| Y_2 \| Y_3 = T_1 \| T_2 \| T_3 \| T_0$

6.1.4.2 F-functions

Two F-functions F_0 and F_1 used in $GFN_{d,r}$ are defined as follows:

F_0: $(RK_{(32)}, x_{(32)}) \mapsto y_{(32)}$

1) $T = RK \oplus x$

2) Let $T = T_0 \| T_1 \| T_2 \| T_3$, $T_i \in \{0,1\}^8$,

$T_0 = S_0(T_0)$,

$T_1 = S_1(T_1)$,

$T_2 = S_0(T_2)$,

$T_3 = S_1(T_3)$

3) Let $y = y_0 \| y_1 \| y_2 \| y_3$, $y_i \in \{0,1\}^8$,

${}^t(y_0, y_1, y_2, y_3) = M_0\, {}^t(T_0, T_1, T_2, T_3)$

F_1: $(RK_{(32)}, x_{(32)}) \mapsto y_{(32)}$

1) $T = RK \oplus x$

2) Let $T = T_0 \| T_1 \| T_2 \| T_3$, $T_i \in \{0,1\}^8$,

$T_0 = S_1(T_0)$,

$T_1 = S_0(T_1)$,

$T_2 = S_1(T_2)$,

$T_3 = S_0(T_3)$

3) Let $y = y_0 \| y_1 \| y_2 \| y_3$, $y_i \in \{0,1\}^8$,

${}^t(y_0, y_1, y_2, y_3) = M_1\, {}^t(T_0, T_1, T_2, T_3)$

S_0 and S_1 are nonlinear 8-bit S-boxes, and M_0 and M_1 are 4x4 diffusion matrices described in the following clause. In each F-function, two S-boxes are used in the different order, and a different matrix is used. Figure 7 shows the construction of the F-functions.

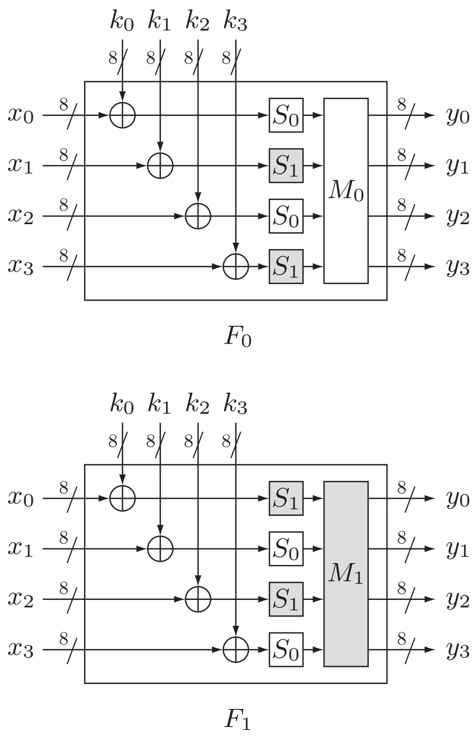


Figure 7 — F-functions

6.1.4.3 S-boxes

CLEFIA employs two different types of 8-bit S-boxes S_0 and S_1: S_0 is based on four 4-bit random S-boxes, and S_1 is based on the inverse function over GF(2^8).

Tables 6 and 7 show the output values of S_0 and S_1, respectively. In these tables all values are expressed in a hexadecimal form. For an 8-bit input of an S-box, the upper 4 bits indicate a row and the lower 4 bits indicate a column. For example, if a value 0xab is input, 0x7e is output by S_0 because it is on the cross line of the row indexed by 'a.' and the column indexed by '.b'.

Table 6 — S_0

	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	.a	.b	.c	.d	.e	.f
0.	57	49	d1	c6	2f	33	74	fb	95	6d	82	ea	0e	b0	a8	1c
1.	28	d0	4b	92	5c	ee	85	b1	c4	0a	76	3d	63	f9	17	af
2.	bf	a1	19	65	f7	7a	32	20	06	ce	e4	83	9d	5b	4c	d8
3.	42	5d	2e	e8	d4	9b	0f	13	3c	89	67	c0	71	aa	b6	f5
4.	a4	be	fd	8c	12	00	97	da	78	e1	cf	6b	39	43	55	26
5.	30	98	cc	dd	eb	54	b3	8f	4e	16	fa	22	a5	77	09	61
6.	d6	2a	53	37	45	c1	6c	ae	ef	70	08	99	8b	1d	f2	b4
7.	e9	c7	9f	4a	31	25	fe	7c	d3	a2	bd	56	14	88	60	0b
8.	cd	e2	34	50	9e	dc	11	05	2b	b7	a9	48	ff	66	8a	73
9.	03	75	86	f1	6a	a7	40	c2	b9	2c	db	1f	58	94	3e	ed
a.	fc	1b	a0	04	b8	8d	e6	59	62	93	35	7e	ca	21	df	47
b.	15	f3	ba	7f	a6	69	c8	4d	87	3b	9c	01	e0	de	24	52

c.	7b	0c	68	1e	80	b2	5a	e7	ad	d5	23	f4	46	3f	91	c9
d.	6e	84	72	bb	0d	18	d9	96	f0	5f	41	ac	27	c5	e3	3a
e.	81	6f	07	a3	79	f6	2d	38	1a	44	5e	b5	d2	ec	cb	90
f.	9a	36	e5	29	c3	4f	ab	64	51	f8	10	d7	bc	02	7d	8e

Table 7 — S_1

	.0	**.1**	**.2**	**.3**	**.4**	**.5**	**.6**	**.7**	**.8**	**.9**	**.a**	**.b**	**.c**	**.d**	**.e**	**.f**
0.	6c	da	c3	e9	4e	9d	0a	3d	b8	36	b4	38	13	34	0c	d9
1.	bf	74	94	8f	b7	9c	e5	dc	9e	07	49	4f	98	2c	b0	93
2.	12	eb	cd	b3	92	e7	41	60	e3	21	27	3b	e6	19	d2	0e
3.	91	11	c7	3f	2a	8e	a1	bc	2b	c8	c5	0f	5b	f3	87	8b
4.	fb	f5	de	20	c6	a7	84	ce	d8	65	51	c9	a4	ef	43	53
5.	25	5d	9b	31	e8	3e	0d	d7	80	ff	69	8a	ba	0b	73	5c
6.	6e	54	15	62	f6	35	30	52	a3	16	d3	28	32	fa	aa	5e
7.	cf	ea	ed	78	33	58	09	7b	63	c0	c1	46	1e	df	a9	99
8.	55	04	c4	86	39	77	82	ec	40	18	90	97	59	dd	83	1f
9.	9a	37	06	24	64	7c	a5	56	48	08	85	d0	61	26	ca	6f
a.	7e	6a	b6	71	a0	70	05	d1	45	8c	23	1c	f0	ee	89	ad
b.	7a	4b	c2	2f	db	5a	4d	76	67	17	2d	f4	cb	b1	4a	a8
c.	b5	22	47	3a	d5	10	4c	72	cc	00	f9	e0	fd	e2	fe	ae
d.	f8	5f	ab	f1	1b	42	81	d6	be	44	29	a6	57	b9	af	f2
e.	d4	75	66	bb	68	9f	50	02	01	3c	7f	8d	1a	88	bd	ac
f.	f7	e4	79	96	a2	fc	6d	b2	6b	03	e1	2e	7d	14	95	1d

a) S-box S_0

$S_0 : \{0,1\}^8 \to \{0,1\}^8 : x \mapsto y = S_0(x)$ is generated by combining four 4-bit S-boxes SS_0, SS_1, SS_2 and SS_3 in the following way. The values of these S-boxes are defined as Table 8.

1) $t_0 = SS_0(x_0),\ t_1 = SS_1(x_1),$ where $x = x_0|x_1,\ x_i \in \{0, 1\}^4$

2) $u_0 = t_0 \oplus \mathtt{0x2} \bullet t_1,\ u_1 = \mathtt{0x2} \bullet t_0 \oplus t_1$

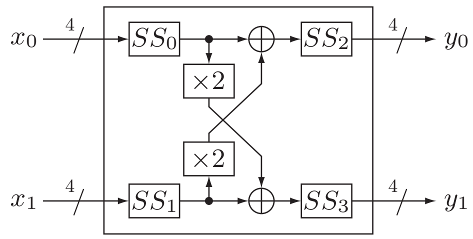
3) $y_0 = SS_2(u_0),\ y_1 = SS_3(u_1),$ where $y = y_0|y_1,\ y_i \in \{0, 1\}^4$

The multiplication in $\mathtt{0x2} \bullet t_i$ is performed in GF(2^4) defined by the lexicographically first primitive polynomial $z^4 + z + 1$. Figure 8 shows the construction of S_0.

Table 8 — SS_i ($0 \le i < 4$)

x	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
$SS_0(x)$	e	6	c	a	8	7	2	f	b	1	4	0	5	9	d	3
$SS_1(x)$	6	4	0	d	2	b	a	3	9	c	e	f	8	7	5	1
$SS_2(x)$	b	8	5	e	a	6	4	c	f	7	2	3	1	0	d	9
$SS_3(x)$	a	2	6	d	3	4	5	e	0	7	8	9	b	f	c	1

Figure 8 — S_0



b) S-box S_1

$S_1 : \{0,1\}^8 \to \{0,1\}^8 : x \mapsto y = S_1(x)$ is defined as follows:

$$y = \begin{cases} g(f(x)^{-1}) & \text{if} \quad f(x) \neq 0 \\ g(0) & \text{if} \quad f(x) = 0 \end{cases}$$

The inverse function is performed in GF(2^8) defined by a primitive polynomial $z^8 + z^4 + z^3 + z^2 + 1$. f and g are affine transformations over GF(2), which are defined as follows.

$f : \{0,1\}^8 \to \{0,1\}^8 : x \mapsto y = f(x)$,

$$\begin{pmatrix} y_0 \\ y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \\ y_7 \end{pmatrix} = \begin{pmatrix} 0&0&0&1&1&0&0&0 \\ 0&1&0&1&0&0&0&1 \\ 0&0&0&0&0&0&0&1 \\ 0&0&0&0&0&1&1&0 \\ 0&1&1&0&0&1&0&1 \\ 0&1&0&1&1&1&0&0 \\ 0&1&1&0&0&0&0&0 \\ 1&0&0&0&0&0&0&1 \end{pmatrix} \begin{pmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \end{pmatrix} \oplus \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \\ 1 \\ 1 \\ 1 \\ 0 \end{pmatrix}$$

$g : \{0,1\}^8 \to \{0,1\}^8 : x \mapsto y = g(x)$,

$$\begin{pmatrix} y_0 \\ y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \\ y_6 \\ y_7 \end{pmatrix} = \begin{pmatrix} 0&0&0&0&1&0&1&0 \\ 0&1&0&0&0&0&0&1 \\ 0&1&0&1&1&0&0&0 \\ 0&0&1&0&0&0&0&0 \\ 0&0&1&1&0&0&0&0 \\ 0&0&0&0&0&0&1&0 \\ 1&0&0&1&0&0&0&0 \\ 0&1&0&0&0&1&0&0 \end{pmatrix} \begin{pmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \end{pmatrix} \oplus \begin{pmatrix} 0 \\ 1 \\ 1 \\ 0 \\ 1 \\ 0 \\ 0 \\ 1 \end{pmatrix}$$

Here, $x = x_0|x_1|x_2|x_3|x_4|x_5|x_6|x_7$ and $y = y_0|y_1|y_2|y_3|y_4|y_5|y_6|y_7$, x_i, $y_i \in \{0,1\}$. The constants in f and g can be represented as `0x1e` and `0x69`, respectively.

6.1.4.4 Diffusion matrices

Two matrices M_0 and M_1 are defined as follows.

$$M_0 = \begin{pmatrix} 01 & 02 & 04 & 06 \\ 02 & 01 & 06 & 04 \\ 04 & 06 & 01 & 02 \\ 06 & 04 & 02 & 01 \end{pmatrix}, \quad M_1 = \begin{pmatrix} 01 & 08 & 02 & 0a \\ 08 & 01 & 0a & 02 \\ 02 & 0a & 01 & 08 \\ 0a & 02 & 08 & 01 \end{pmatrix}.$$

The multiplications of a matrix and a vector are performed in GF(2^8) defined by the lexicographically first primitive polynomial $z^8 + z^4 + z^3 + z^2 + 1$.

6.1.5 CLEFIA key scheduling part

6.1.5.1 Overall structure

The key scheduling part of CLEFIA supports 128, 192 and 256-bit keys and outputs whitening keys WK_i $(0 \leq i < 4)$ and round keys RK_j $(0 \leq j < 2r)$ for the data processing part. Let K be the key and L be an intermediate key, and the key scheduling part consists of the following two steps.

1) Generating L from K.

2) Expanding K and L (Generating WK_i and RK_j).

To generate L from K, the key schedule for a 128-bit key uses a 128-bit permutation $GFN_{4,12}$, while the key schedules for 192/256-bit keys use a 256-bit permutation $GFN_{8,10}$.

6.1.5.2 Key scheduling for a 128-bit key

The 128-bit intermediate key L is generated

by applying $GFN_{4,12}$ which takes twenty-four 32-bit constant values $CON_i^{(128)}$ $(0 \leq i < 24)$ as round keys and $K = K_0 \parallel K_1 \parallel K_2 \parallel K_3$ as an input. Then K and L are used to generate WK_i $(0 \leq i < 4)$ and RK_j $(0 \leq j < 36)$ in the following steps. In the latter part, thirty-six 32-bit constant values $CON_i^{(128)}$ $(24 \leq i < 60)$ are used. The generation steps of $CON_i^{(128)}$ are explained in 6.1.5.6. Σ is the DoubleSwap function. The definition of Σ is mentioned in 6.1.5.5.

(Generating L from K)

1) $L = GFN_{4,12}(CON_0^{(128)}, ..., CON_{23}^{(128)}, K_0, ..., K_3)$

(Expanding K and L)

2) $WK_0 \parallel WK_1 \parallel WK_2 \parallel WK_3 = K$

3) For $i = 0$ to 8 do the following:

$T = L \oplus (CON_{24+4i}^{(128)} \parallel CON_{24+4i+1}^{(128)} \parallel CON_{24+4i+2}^{(128)} \parallel CON_{24+4i+3}^{(128)})$

$L = \Sigma(L)$

if i is odd: $T = T \oplus K$

$RK_{4i} \| RK_{4i+1} \| RK_{4i+2} \| RK_{4i+3} = T$

Table 9 shows the relationship between generated round keys and related data.

Table 9 — Expanding K and L (128-bit key)

WK_0 WK_1 WK_2 WK_3	K
RK_0 RK_1 RK_2 RK_3	$L \oplus (CON_{24}^{(128)} \| CON_{25}^{(128)} \| CON_{26}^{(128)} \| CON_{27}^{(128)})$
RK_4 RK_5 RK_6 RK_7	$\Sigma(L) \oplus K \oplus (CON_{28}^{(128)} \| CON_{29}^{(128)} \| CON_{30}^{(128)} \| CON_{31}^{(128)})$
RK_8 RK_9 RK_{10} RK_{11}	$\Sigma^2(\mathrm{L}) \oplus (CON_{32}^{(128)} \| CON_{33}^{(128)} \| CON_{34}^{(128)} \| CON_{35}^{(128)})$
RK_{12} RK_{13} RK_{14} RK_{15}	$\Sigma^3(L) \oplus K \oplus (CON_{36}^{(128)} \| CON_{37}^{(128)} \| CON_{38}^{(128)} \| CON_{39}^{(128)})$
RK_{16} RK_{17} RK_{18} RK_{19}	$\Sigma^4(L) \oplus (CON_{40}^{(128)} \| CON_{41}^{(128)} \| CON_{42}^{(128)} \| CON_{43}^{(128)})$
RK_{20} RK_{21} RK_{22} RK_{23}	$\Sigma^5(L) \oplus K \oplus (CON_{44}^{(128)} \| CON_{45}^{(128)} \| CON_{46}^{(128)} \| CON_{47}^{(128)})$
RK_{24} RK_{25} RK_{26} RK_{27}	$\Sigma^6(L) \oplus (CON_{48}^{(128)} \| CON_{49}^{(128)} \| CON_{50}^{(128)} \| CON_{51}^{(128)})$
RK_{28} RK_{29} RK_{30} RK_{31}	$\Sigma^7(L) \oplus K \oplus (CON_{52}^{(128)} \| CON_{53}^{(128)} \| CON_{54}^{(128)} \| CON_{55}^{(128)})$
RK_{32} RK_{33} RK_{34} RK_{35}	$\Sigma^8(L) \oplus (CON_{56}^{(128)} \| CON_{57}^{(128)} \| CON_{58}^{(128)} \| CON_{59}^{(128)})$

6.1.5.3 Key scheduling for a 192-bit key

Two 128-bit values K_L and K_R are generated from a 192-bit key $K = K_0 \| K_1 \| K_2 \| K_3 \| K_4 \| K_5$, where $K_i \in \{0,1\}^{32}$. Then two 128-bit values L_L and L_R are generated by applying $GFN_{8,10}$ which takes $CON_i^{(192)}$ $(0 \le i < 40)$ as round keys and $K_L \| K_R$ as a 256-bit input. Figure 9 shows the construction of $GFN_{8,10}$.

Then K_L, K_R and L_L, L_R are used to generate WK_i $(0 \le i < 4)$ and RK_j $(0 \le j < 44)$ in the following steps. In the latter part, forty-four 32-bit constant values $CON_i^{(192)}$ $(40 \le i < 84)$ are used.

The following steps show the 192-bit/256-bit key scheduling. For the 192-bit key scheduling, the value of k is set as 192.

(Generating L_L,L_R from K_L,K_R for a k-bit key)

1) Set $k = 192$ or $k = 256$

2) If $k = 192$: $K_L = K_0 \| K_1 \| K_2 \| K_3$, $K_R = K_4 \| K_5 \| {}^{\sim}K_0 \| {}^{\sim}K_1$

   else if $k = 256$: $K_L = K_0 \| K_1 \| K_2 \| K_3$, $K_R = K_4 \| K_5 \| K_6 \| K_7$

3) Let $K_L = K_{L0} \| K_{L1} \| K_{L2} \| K_{L3}$, $K_R = K_{R0} \| K_{R1} \| K_{R2} \| K_{R3}$

   $L_L \| L_R = GFN_{8,10}(CON_0^{(k)}, ..., CON_{39}^{(k)}, K_{L0}, ..., K_{L3}, K_{R0}, ..., K_{R3})$

(Expanding K_L,K_R and L_L,L_R for a k-bit key)

4) $WK_0 \| WK_1 \| WK_2 \| WK_3 = K_L \oplus K_R$

5) For $i = 0$ to 10 (if $k = 192$), or 12 (if $k = 256$) do the following:

   If (i mod 4) = 0 or 1:

$T = L_L \oplus (CON_{40+4i}^{(k)} \| CON_{40+4i+1}^{(k)} \| CON_{40+4i+2}^{(k)} \| CON_{40+4i+3}^{(k)})$

$L_L = \Sigma(L_L)$

if i is odd: $T = T \oplus K_R$

else:

$T = L_R \oplus (CON_{40+4i}^{(k)} \| CON_{40+4i+1}^{(k)} \| CON_{40+4i+2}^{(k)} \| CON_{40+4i+3}^{(k)})$

$L_R = \Sigma(L_R)$

if i is odd: $T = T \oplus K_L$

$RK_{4i} \| RK_{4i+1} \| RK_{4i+2} \| RK_{4i+3} = T$

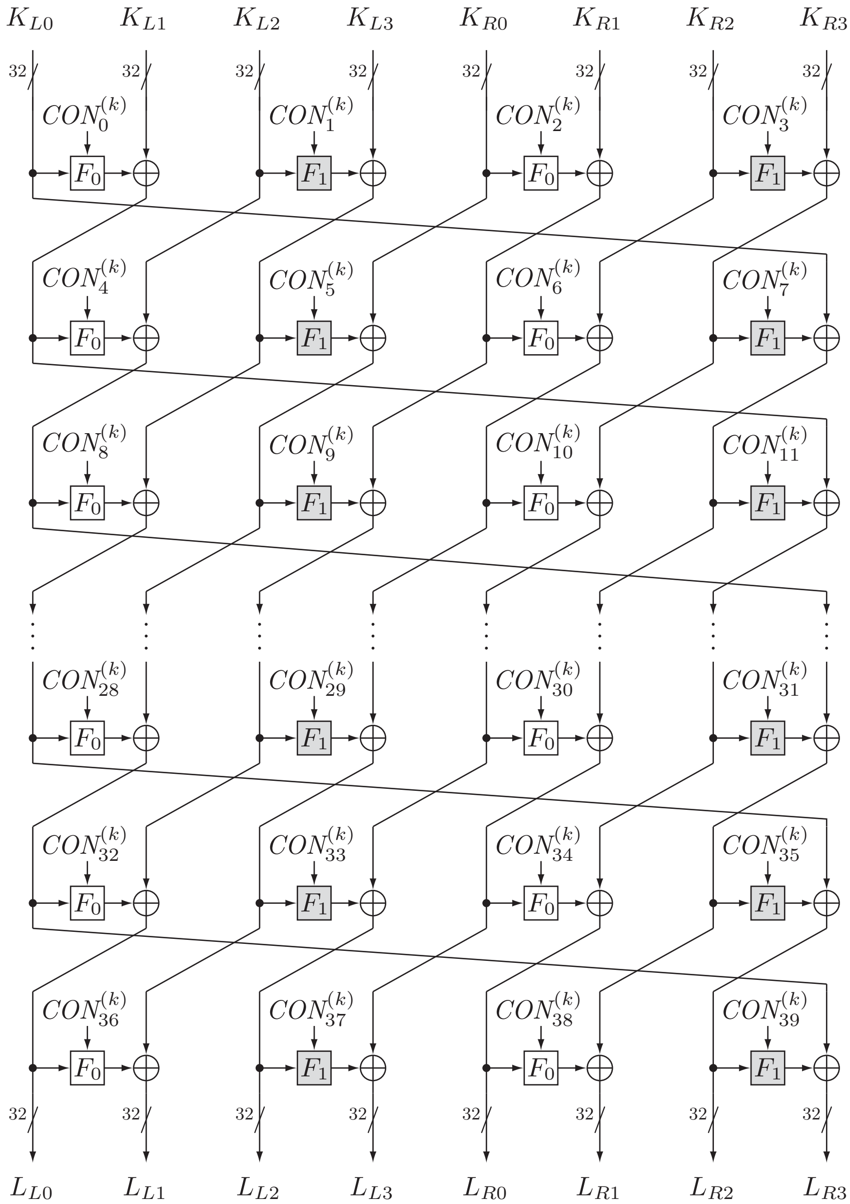


Figure 9 — Structure of $GFN_{8,10}$

Table 10 shows the relationship between generated round keys and related data.

Table 10 — Expanding K_L, K_R, L_L and L_R (192-bit key)

WK_0 WK_1 WK_2 WK_3	$K_L \oplus K_R$
RK_0 RK_1 RK_2 RK_3	$L_L \oplus (CON_{40}^{(192)} \parallel CON_{41}^{(192)} \parallel CON_{42}^{(192)} \parallel CON_{43}^{(192)})$
RK_4 RK_5 RK_6 RK_7	$\Sigma(L_L) \oplus K_R \oplus (CON_{44}^{(192)} \parallel CON_{45}^{(192)} \parallel CON_{46}^{(192)} \parallel CON_{47}^{(192)})$
RK_8 RK_9 RK_{10} RK_{11}	$L_R \oplus (CON_{48}^{(192)} \parallel CON_{49}^{(192)} \parallel CON_{50}^{(192)} \parallel CON_{51}^{(192)})$
RK_{12} RK_{13} RK_{14} RK_{15}	$\Sigma(L_R) \oplus K_L \oplus (CON_{52}^{(192)} \parallel CON_{53}^{(192)} \parallel CON_{54}^{(192)} \parallel CON_{55}^{(192)})$
RK_{16} RK_{17} RK_{18} RK_{19}	$\Sigma^2(L_L) \oplus (CON_{56}^{(192)} \parallel CON_{57}^{(192)} \parallel CON_{58}^{(192)} \parallel CON_{59}^{(192)})$
RK_{20} RK_{21} RK_{22} RK_{23}	$\Sigma^3(L_L) \oplus K_R \oplus (CON_{60}^{(192)} \parallel CON_{61}^{(192)} \parallel CON_{62}^{(192)} \parallel CON_{63}^{(192)})$
RK_{24} RK_{25} RK_{26} RK_{27}	$\Sigma^2(L_R) \oplus (CON_{64}^{(192)} \parallel CON_{65}^{(192)} \parallel CON_{66}^{(192)} \parallel CON_{67}^{(192)})$
RK_{28} RK_{29} RK_{30} RK_{31}	$\Sigma^3(L_R) \oplus K_L \oplus (CON_{68}^{(192)} \parallel CON_{69}^{(192)} \parallel CON_{70}^{(192)} \parallel CON_{71}^{(192)})$
RK_{32} RK_{33} RK_{34} RK_{35}	$\Sigma^4(L_L) \oplus (CON_{72}^{(192)} \parallel CON_{73}^{(192)} \parallel CON_{74}^{(192)} \parallel CON_{75}^{(192)})$
RK_{36} RK_{37} RK_{38} RK_{39}	$\Sigma^5(L_L) \oplus K_R \oplus (CON_{76}^{(192)} \parallel CON_{77}^{(192)} \parallel CON_{78}^{(192)} \parallel CON_{79}^{(192)})$
RK_{40} RK_{41} RK_{42} RK_{43}	$\Sigma^4(L_R) \oplus (CON_{80}^{(192)} \parallel CON_{81}^{(192)} \parallel CON_{82}^{(192)} \parallel CON_{83}^{(192)})$

6.1.5.4 Key scheduling for a 256-bit key

The key scheduling for a 256-bit key is almost the same as that for 192-bit key, except for constant values, the required number of RK_i, and the initialization of K_R.

For a 256-bit key, the value of k is set as 256, and the steps are almost the same as in the 192-bit key case. The difference is that we use $CON_i^{(256)} (0 \le i < 40)$ as round keys to generate L_L and L_R, and then to generate RK_j $(0 \le j < 52)$, we use fifty-two 32-bit constant values $CON_i^{(256)} (40 \le i < 92)$.

Table 11 shows the relationship between generated round keys and related data.

Table 11 — Expanding K_L, K_R, L_L and L_R (256-bit key)

WK_0 WK_1 WK_2 WK_3	$K_L \oplus K_R$
RK_0 RK_1 RK_2 RK_3	$L_L \oplus (CON_{40}^{(256)} \parallel CON_{41}^{(256)} \parallel CON_{42}^{(256)} \parallel CON_{43}^{(256)})$
RK_4 RK_5 RK_6 RK_7	$\Sigma(L_L) \oplus K_R \oplus (CON_{44}^{(256)} \parallel CON_{45}^{(256)} \parallel CON_{46}^{(256)} \parallel CON_{47}^{(256)})$
RK_8 RK_9 RK_{10} RK_{11}	$L_R \oplus (CON_{48}^{(256)} \parallel CON_{49}^{(256)} \parallel CON_{50}^{(256)} \parallel CON_{51}^{(256)})$
RK_{12} RK_{13} RK_{14} RK_{15}	$\Sigma(L_R) \oplus K_L \oplus (CON_{52}^{(256)} \parallel CON_{53}^{(256)} \parallel CON_{54}^{(256)} \parallel CON_{55}^{(256)})$
RK_{16} RK_{17} RK_{18} RK_{19}	$\Sigma^2(L_L) \oplus (CON_{56}^{(256)} \parallel CON_{57}^{(256)} \parallel CON_{58}^{(256)} \parallel CON_{59}^{(256)})$
RK_{20} RK_{21} RK_{22} RK_{23}	$\Sigma^3(L_L) \oplus K_R \oplus (CON_{60}^{(256)} \parallel CON_{61}^{(256)} \parallel CON_{62}^{(256)} \parallel CON_{63}^{(256)})$
RK_{24} RK_{25} RK_{26} RK_{27}	$\Sigma^2(L_R) \oplus (CON_{64}^{(256)} \parallel CON_{65}^{(256)} \parallel CON_{66}^{(256)} \parallel CON_{67}^{(256)})$
RK_{28} RK_{29} RK_{30} RK_{31}	$\Sigma^3(L_R) \oplus K_L \oplus (CON_{68}^{(256)} \parallel CON_{69}^{(256)} \parallel CON_{70}^{(256)} \parallel CON_{71}^{(256)})$
RK_{32} RK_{33} RK_{34} RK_{35}	$\Sigma^4(L_L) \oplus (CON_{72}^{(256)} \parallel CON_{73}^{(256)} \parallel CON_{74}^{(256)} \parallel CON_{75}^{(256)})$

$RK_{36}\ RK_{37}\ RK_{38}\ RK_{39}$	$\Sigma^{5}(L_L) \oplus K_R \oplus (CON_{76}^{(256)} \parallel CON_{77}^{(256)} \parallel CON_{78}^{(256)} \parallel CON_{79}^{(256)})$
$RK_{40}\ RK_{41}\ RK_{42}\ RK_{43}$	$\Sigma^{4}(L_R) \oplus (CON_{80}^{(256)} \parallel CON_{81}^{(256)} \parallel CON_{82}^{(256)} \parallel CON_{83}^{(256)})$
$RK_{44}\ RK_{45}\ RK_{46}\ RK_{47}$	$\Sigma^{5}(L_R) \oplus K_L \oplus (CON_{84}^{(256)} \parallel CON_{85}^{(256)} \parallel CON_{86}^{(256)} \parallel CON_{87}^{(256)})$
$RK_{48}\ RK_{49}\ RK_{50}\ RK_{51}$	$\Sigma^{6}(L_L) \oplus (CON_{88}^{(256)} \parallel CON_{89}^{(256)} \parallel CON_{90}^{(256)} \parallel CON_{91}^{(256)})$

6.1.5.5 DoubleSwap function

The DoubleSwap function $\Sigma : \{0,1\}^{128} \rightarrow \{0,1\}^{128}$ is defined as follows:

$$X_{(128)} \mapsto Y_{(128)}$$

$$Y = X[7\text{-}63] \parallel X[121\text{-}127] \parallel X[0\text{-}6] \parallel X[64\text{-}120],$$

where X[a-b] denotes a bit string cut from the a-th bit to the b-th bit of X. Bit 0 is the most significant bit.

The DoubleSwap function is illustrated in Figure 10.

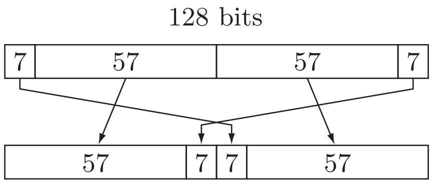


Figure 10 — DoubleSwap Function Σ

6.1.5.6 Constant values

32-bit constant values $CON_i^{(k)}$ are used in the key scheduling algorithm. We need 60, 84 and 92 constant values for 128, 192 and 256-bit keys, respectively. Let $P_{(16)}$ = `0xb7e1` (= (e-2) 2^{16}) and $Q_{(16)}$ = `0x243f` (= (π -3) 2^{16}), where e is the base of the natural logarithm (2.71828...) and π is the circle ratio (3.14159...). $CON_i^{(k)}$, for k = 128,192,256 are generated by the following way (See Table 11 for the repetition numbers $l^{(k)}$ and the initial values $IV^{(k)}$).

1) $T_0 = IV^{(k)}$

2) For i = 0 to $l^{(k)}$ - 1 do the following:

   2.1) $CON_{2i}^{(k)} = (T_i \oplus P) \parallel (\tilde{}T_i <<< 1)$

   2.2) $CON_{2i+1}^{(k)} = (\tilde{}T_i \oplus Q) \parallel (T_i <<< 8)$

   2.3) $T_{i+1} = T_i \bullet \mathtt{0x0002}^{-1}$

In 2.3), the multiplication are performed in the field GF(2^{16}) defined by a primitive polynomial $z^{16} + z^{15} + z^{13} + z^{11} + z^{5} + z^{4} + 1$ (= `0x1a831`). $\mathtt{0x0002}^{-1}$ denotes the multiplicative inverse of finite field element z. The selection criteria of $IV^{(k)}$ and the primitive polynomial are shown in [4].

Table 12 — Required numbers of constant values

k	# of $CON_i^{(k)}$	$l^{(k)}$	$IV^{(k)}$
128	60	30	`0x428a`
192	84	42	`0x7137`
256	92	46	`0xb5c0`

Tables 13-15 show the values of T_i and Tables 16-18 show the values of $CON_i^{(k)}$.

Table 13 — $T_i^{(128)}$

i	0	1	2	3	4	5	6	7
$T_i^{(128)}$	428a	2145	c4ba	625d	e536	729b	ed55	a2b2
i	8	9	10	11	12	13	14	15
$T_i^{(128)}$	5159	fcb4	7e5a	3f2d	cb8e	65c7	e6fb	a765
i	16	17	18	19	20	21	22	23
$T_i^{(128)}$	87aa	43d5	f5f2	7af9	e964	74b2	3a59	c934
i	24	25	26	27	28	29		
$T_i^{(192)}$	649a	324d	cd3e	669f	e757	a7b3		

Table 14 — $T_i^{(192)}$

i	0	1	2	3	4	5	6	7
$T_i^{(192)}$	7137	ec83	a259	8534	429a	214d	c4be	625f
i	8	9	10	11	12	13	14	15
$T_i^{(192)}$	e537	a683	8759	97b4	4bda	25ed	c6ee	6377
i	16	17	18	19	20	21	22	23
$T_i^{(192)}$	e5a3	a6c9	877c	43be	21df	c4f7	b663	8f29
i	24	25	26	27	28	29	30	31
$T_i^{(192)}$	938c	49c6	24e3	c669	b72c	5b96	2dcb	c2fd
i	32	33	34	35	36	37	38	39
$T_i^{(192)}$	b566	5ab3	f941	a8b8	545c	2a2e	1517	de93
i	40	41						
$T_i^{(192)}$	bb51	89b0						

Table 15 — $T_i^{(256)}$

i	0	1	2	3	4	5	6	7
$T_i^{(256)}$	b5c0	5ae0	2d70	16b8	0b5c	05ae	02d7	d573
i	8	9	10	11	12	13	14	15
$T_i^{(256)}$	bea1	8b48	45a4	22d2	1169	dcac	6e56	372b
i	16	17	18	19	20	21	22	23
$T_i^{(256)}$	cf8d	b3de	59ef	f8ef	a86f	802f	940f	9e1f
i	24	25	26	27	28	29	30	31
$T_i^{(256)}$	9b17	9993	98d1	9870	4c38	261c	130e	0987
i	32	33	34	35	36	37	38	39
$T_i^{(256)}$	d0db	bc75	8a22	4511	f690	7b48	3da4	1ed2
i	40	41	42	43	44	45		
$T_i^{(256)}$	0f69	d3ac	69d6	34eb	ce6d	b32e		

Table 16 — $CON_i^{(128)}$

i	0	1	2	3
$CON_i^{(128)}$	f56b7aeb	994a8a42	96a4bd75	fa854521
i	4	5	6	7
$CON_i^{(128)}$	735b768a	1f7abac4	d5bc3b45	b99d5d62
i	8	9	10	11
$CON_i^{(128)}$	52d73592	3ef636e5	c57a1ac9	a95b9b72
i	12	13	14	15
$CON_i^{(128)}$	5ab42554	369555ed	1553ba9a	7972b2a2
i	16	17	18	19
$CON_i^{(128)}$	e6b85d4d	8a995951	4b550696	2774b4fc
i	20	21	22	23
$CON_i^{(128)}$	c9bb034b	a59a5a7e	88cc81a5	e4ed2d3f
i	24	25	26	27
$CON_i^{(128)}$	7c6f68e2	104e8ecb	d2263471	be07c765
i	28	29	30	31
$CON_i^{(128)}$	511a3208	3d3bfbe6	1084b134	7ca565a7
i	32	33	34	35
$CON_i^{(128)}$	304bf0aa	5c6aaa87	f4347855	9815d543
i	36	37	38	39
$CON_i^{(128)}$	4213141a	2e32f2f5	cd180a0d	a139f97a
i	40	41	42	43
$CON_i^{(128)}$	5e852d36	32a464e9	c353169b	af72b274
i	44	45	46	47
$CON_i^{(128)}$	8db88b4d	e199593a	7ed56d96	12f434c9
i	48	49	50	51
$CON_i^{(128)}$	d37b36cb	bf5a9a64	85ac9b65	e98d4d32
i	52	53	54	55
$CON_i^{(128)}$	7adf6582	16fe3ecd	d17e32c1	bd5f9f66
i	56	57	58	59
$CON_i^{(128)}$	50b63150	3c9757e7	1052b098	7c73b3a7

Table 17 — $CON_i^{(192)}$

i	0	1	2	3
$CON_i^{(192)}$	c6d61d91	aaf73771	5b6226f8	374383ec
i	4	5	6	7
$CON_i^{(192)}$	15b8bb4c	799959a2	32d5f596	5ef43485
i	8	9	10	11
$CON_i^{(192)}$	f57b7acb	995a9a42	96acbd65	fa8d4d21
i	12	13	14	15
$CON_i^{(192)}$	735f7682	1f7ebec4	d5be3b41	b99f5f62
i	16	17	18	19
$CON_i^{(192)}$	52d63590	3ef737e5	1162b2f8	7d4383a6
i	20	21	22	23
$CON_i^{(192)}$	30b8f14c	5c995987	2055d096	4c74b497
i	24	25	26	27
$CON_i^{(192)}$	fc3b684b	901ada4b	920cb425	fe2ded25
i	28	29	30	31
$CON_i^{(192)}$	710f7222	1d2eeec6	d4963911	b8b77763
i	32	33	34	35
$CON_i^{(192)}$	524234b8	3e63a3e5	1128b26c	7d09c9a6
i	36	37	38	39
$CON_i^{(192)}$	309df106	5cbc7c87	f45f7883	987ebe43

i	40	41	42	43
$CON_i^{(192)}$	963ebc41	fa1fdf21	73167610	1f37f7c4
i	44	45	46	47
$CON_i^{(192)}$	01829338	6da363b6	38c8e1ac	54e9298f
i	48	49	50	51
$CON_i^{(192)}$	246dd8e6	484c8c93	fe276c73	9206c649
i	52	53	54	55
$CON_i^{(192)}$	9302b639	ff23e324	7188732c	1da969c6
i	56	57	58	59
$CON_i^{(192)}$	00cd91a6	6cec2cb7	ec7748d3	8056965b
i	60	61	62	63
$CON_i^{(192)}$	9a2aa469	f60bcb2d	751c7a04	193dfdc2
i	64	65	66	67
$CON_i^{(192)}$	02879532	6ea666b5	ed524a99	8173b35a
i	68	69	70	71
$CON_i^{(192)}$	4ea00d7c	228141f9	1f59ae8e	7378b8a8
i	72	73	74	75
$CON_i^{(192)}$	e3bd5747	8f9c5c54	9dcfaba3	f1ee2e2a
i	76	77	78	79
$CON_i^{(192)}$	a2f6d5d1	ced71715	697242d8	055393de
i	80	81	82	83
$CON_i^{(192)}$	0cb0895c	609151bb	3e51ec9e	5270b089

Table 18 — $CON_i^{(256)}$

i	0	1	2	3
$CON_i^{(256)}$	0221947e	6e00c0b5	ed014a3f	8120e05a
i	4	5	6	7
$CON_i^{(256)}$	9a91a51f	f6b0702d	a159d28f	cd78b816
i	8	9	10	11
$CON_i^{(256)}$	bcbde947	d09c5c0b	b24ff4a3	de6eae05
i	12	13	14	15
$CON_i^{(256)}$	b536fa51	d917d702	62925518	0eb373d5
i	16	17	18	19
$CON_i^{(256)}$	094082bc	6561a1be	3ca9e96e	5088488b
i	20	21	22	23
$CON_i^{(256)}$	f24574b7	9e64a445	9533ba5b	f912d222
i	24	25	26	27
$CON_i^{(256)}$	a688dd2d	caa96911	6b4d46a6	076cacdc
i	28	29	30	31
$CON_i^{(256)}$	d9b72353	b596566e	80ca91a9	eceb2b37
i	32	33	34	35
$CON_i^{(256)}$	786c60e4	144d8dcf	043f9842	681edeb3
i	36	37	38	39
$CON_i^{(256)}$	ee0e4c21	822fef59	4f0e0e20	232feff8
i	40	41	42	43
$CON_i^{(256)}$	1f8eaf20	73af6fa8	37ceffa0	5bef2f80
i	44	45	46	47
$CON_i^{(256)}$	23eed7e0	4fcf0f94	29fec3c0	45df1f9e
i	48	49	50	51
$CON_i^{(256)}$	2cf6c9d0	40d7179b	2e72ccd8	42539399
i	52	53	54	55
$CON_i^{(256)}$	2f30ce5c	4311d198	2f91cf1e	43b07098
i	56	57	58	59

$CON_i^{(256)}$	fbd9678f	97f8384c	91fdb3c7	fddc1c26
i	60	61	62	63
$CON_i^{(256)}$	a4efd9e3	c8ce0e13	be66ecf1	d2478709
i	64	65	66	67
$CON_i^{(256)}$	673a5e48	0b1bdbd0	0b948714	67b575bc
i	68	69	70	71
$CON_i^{(256)}$	3dc3ebba	51e2228a	f2f075dd	9ed11145
i	72	73	74	75
$CON_i^{(256)}$	417112de	2d5090f6	cca9096f	a088487b
i	76	77	78	79
$CON_i^{(256)}$	8a4584b7	e664a43d	a933c25b	c512d21e
i	80	81	82	83
$CON_i^{(256)}$	b888e12d	d4a9690f	644d58a6	086cacd3
i	84	85	86	87
$CON_i^{(256)}$	de372c53	b216d669	830a9629	ef2beb34
i	88	89	90	91
$CON_i^{(256)}$	798c6324	15ad6dce	04cf99a2	68ee2eb3

Annex A
(normative)

ASN.1 module

This annex lists the object identifiers assigned to algorithms specified in this part of ISO/IEC 29192.

```
--
-- ISO/IEC 29192-2 ASN.1 Module
--

LightweightCryptography-2 {
   iso(1) standard(0) lightweight-cryptography(29192) part2(2)
      asn1-module(0) algorithm-object-identifiers(0) }
   DEFINITIONS EXPLICIT TAGS ::= BEGIN

-- EXPORTS All; --

-- IMPORTS None; --

OID ::= OBJECT IDENTIFIER – Alias

-- Synonyms --
is29192-2  OID ::= { iso(1) standard(0) is29192(29192) part2(2) }

id-lbc64  OID ::= { is29192-2 cipher-64-bit(1)  }
id-lbc128 OID ::= { is29192-2 cipher-128-bit(2) }

-- Assignments --

id-bc64-present     OID ::= {id-lbc64 present(1)}
id-bc128-clefia     OID ::= {id-lbc128 clefia(1)}

LightweightCryptographyIdentifier ::= SEQUENCE {
   Algorithm    ALGORITHM.&id({BlockAlgorithms}),
   parameters   ALGORITHM.&Type({BlockAlgorithms}{@algorithm}) OPTIONAL
}

BlockAlgorithms ALGORITHM ::= {

    { OID id-bc64-present     PARMS KeyLengthID } |
    { OID id-bc128-clefia     PARMS KeyLengthID } |

   ...   -- Except additional algorithms --
}

KeyLength ::= INTEGER

KeyLengthID ::= CHOICE {
   int    KeyLength,
   oid    OID
}

-- Cryptographic algorithm identification --

ALGORITHM ::= CLASS {
   &id    OBJECT IDENTIFIER   UNIQUE,
```

```
    &Type  OPTIONAL
}
    WITH SYNTAX {OID &id [PARMS &TYPE] }

END  -- LightweightCryptography-2 --
```

Annex B
(informative)

Test vectors

This annex provides test vectors for PRESENT and CLEFIA for each key length in hexadecimal notation.

B.1 PRESENT test vectors

B.1.1 PRESENT-80

	Plaintext	**0123456789abcdef**		
	Key	**0123456789abcdef**	**0123**	
	Ciphertext	**f8dd50531d973bde**		
Round	**Round Key Value**	**After addRoundKey**	**After sLayer**	**After pLayer**
1	0123456789abcdef	0000000000000000	cccccccccccccccc	ffffffff00000000
2	1024602468acf135	efdb9fdb68acf135	1278e278a3f425b0	19a22a346eeaa266
3	8f37a2048c048d14	96958830e2ee2f72	eae033bc161162d6	e302a14bee4d0eb2
4	e3c4d1e6f4409181	00c670ad1a0d9f33	cc4adcf75fc7e2bb	de6beff8135f0bd3
5	62345c789a3cde8a	bc5fb3808963d559	84028b3c3eab700e	8d71414916f90698
6	92460c468b8f1345	1f374d0f9d7615dd	52bd97c2e7da5077	3ab096eb65d3bc6b
7	f37a3248c188d172	c9caa4a3a45b6d19	4e4ff9fbf908a75e	5fd9fa875b8d1fc6
8	0c4d1e6f46491832	5394e4e81dc407f4	0be919135749cd29	741d20ec61425fd5
9	0345c189a3cde8cd	7758e165c28fb718	dd0315a046328d53	c20cc4c61271dc27
10	f460c068b831347d	366c04aeaa40e85a	baa4c9f1ff9c130f	eef11ad1e2c587ed
11	f7a33e8c180d1703	1952245dfac890ee	5e0669072f43ec11	444cd96c59d88553
12	a4d1fef467d18304	e09d27983e090657	1ce76de3b1ceca0d	66bd7e393b9495c1
13	345c149a3fde8cfc	52e16aa3044a193d	0615affbc99f5eb7	0ff6569d4f17377b
14	360c068b829347fd	39fa5016cd847086	be2f0c5a4739dc3a	d51d56ccf163927a
15	fa33e6c180d17055	2f2eb00d71b2e22f	62618cc7d5861662	0ea0a7d6e11711c8
16	fd1fff467cd8301d	f3bf58909dcf21d5	2b8203ece7426570	638003eed6da4446
17	85c15fa3ffe8cf93	e6415c4d29328bd5	1a9504976eb63870	626415d241fab32a
18	a0c070b82bf47ff5	c2a4656a6a0eccdf	46f9a0afafc14472	3be0e16e6bc33152
19	833e54180e170577	b8deb57665d43425	837180daa079b960	8b9c222261aa723c
20	21ffd067ca8301cb	aa63f245ab2973f7	ffab2690f86edb2d	f2ddc4b9fcb6d28d
21	ac15c43ffa0cf95a	5ec8008606ba2bd7	0143cc3aca8f687d	0df52c9b135a5213
22	9c073582b887ff4b	91f21919abddad58	e5265e5ef877f703	85c8dfbcb5bd4abd
23	a3e57380e6b0571b	262dac3c530d1da6	6a67f4b40bc757fa	4a63bd3efa571a5e
24	dffd347cae701cdd	959e894254270683	e0e13e96096dca3b	a65da538ad271a53
25	815c7bffa68f95c2	2701dec70ba88f91	6dc5714dc8f332e5	61e2fba3883e5d39
26	9073702b8f7ff4dd	f1918b880741a9e4	25e53833cd95fe19	24ed70dcab0c5b7b
27	fe57120e6e0571e2	daba62d2c5092a99	7f8fa67640ce6fee	7837d7bfdf1fd204
28	0fd37fcae241cdcd	77e4a8753d5e1fc9	dd19f3d0b701524e	da81ca4b0cc5fed8
29	f5c781fa6ff95c46	2f464bb1633ca29e	629a9885abb4f6e1	3eea811ed0ee2969
30	47373eb8f03f4df1	79ddbfa620d16498	de7782fa6c75a9e3	cb4ef2f277abb235
31	b57108e6e7d71e08	7e3ffa14907cac3d	d1b22f59ecd4f4b7	a5ea86fd3c8be72b
32	5d37d6ae211cdcf5	f8dd50531d973bde		

B.1.2 PRESENT-128

	Plaintext	**0123456789abcdef**		
	Key	**0011223344556677**	**8899aabbccddeeff**	
	Ciphertext	**88728500054418de**		
Round	**Round Key Value**	**After addRoundKey**	**After sLayer**	**After pLayer**
1	0011223344556677	01326754cdfeab98	c5b6ad094721f8e3	ad0ed4ca386b6559
2	25133557799bbddf	881de19d41f0d886	335715e7952c733a	02913758d32ffdce
3	29004488cd115599	2b9173d01e3ea857	68e5db7c51b1f30d	6d29bb89a62c1efd
4	63944cd55de66ef7	0ebdf75cfbca700a	c1872d04284fdccf	a45f953f18915419
5	29a4011223344557	8dfb942d3ba5114e	3728e967b8f05591	1ce24b2ceba0c5af
6	178e5133557799ba	0b6c1a1fbed75c15	c8a45f52817d0450	e4909e3625200e72
7	0ca69004488cd114	e8360e326dacdf66	13bac1b6a7f472aa	3aa3097873efe668
8	e35e3944cd55de67	d9fd303cbeba380f	7e27bcb4818fb3c2	4ebad512fa1d9a5c
9	19329a4011223346	57884f52eb3fa91a	0d33920618b2fe5f	486d410f353d78ab
10	488d78e51335577b	00e039ea26082fd0	cc1cbe1f6ac3627c	dd61d5ab0dde2b12
11	d364ca69004488cf	0e051fc20d9aa3dd	c1c05246c7effb77	a0bcabfb057f485f
12	252235e3944cd55f	859e9e1891339d00	30e1e153e5bbe7cc	28bb2acfa9bc9774
13	1d4d9329a4011220	35f6b9e60dbd8554	b02a8e1ac7873009	9da104d0b5588259
14	c99488d78e513356	54358c073b09b10f	09b034cdb8ce85c2	63fa073628916984
15	4975364ca690044b	2a8f317a8e016dcf	6f32b5df31c5a742	4b28c736f98d6fd4
16	ab2652235e3944ce	e00e9515a7b42b1a	1cc1e050fd89685f	68f56acb088992d3
17	7525d4d9329a4015	1dd0be123a13d2c6	577c8156bf5b764a	18d1f36e61dde6f8
18	faac99488d78e517	e27d6a26eca503ef	16d7af6a14f0cb12	2d2c76685f25b4a6
19	17d4975364ca6904	3af8e13b3befdda2	bf2315b8b81277f6	c3c2440ff29fdeae
20	e8eab2652235e390	2b28f66ad0aa3d3e	68632aaf7cffb7b1	477aa1f4bfbe11bf
21	5c5f525d4d9329a1	1b25f3a9f22d381e	58602bfe2667b351	4708a3722ffc861f
22	6ba3aac99488d78b	2cab09bbbb745194	64f8ce8888d905e9	3ff3ec26a4022035
23	a5717d4975364ca3	9a82916fd1346c96	ef36e5a275b9a4ea	ca3bdcc6fbab64f0
24	a5ae8eab2652235b	6f95526dddf947ab	a2e006a7772e9df8	a21f25d6e7f201ce
25	d195c5f525d4d934	738ae023c226d8fa	db3f1c6b466a732f	d51196e9737ff90d
26	e696ba3aac99488b	33872cd3dfe6b186	bb3d647b721a853a	d1191e84ebd3f3a6
27	ad465717d4975362	7c5f49933f44a0c4	d4029eebb299fc49	8fbdc60e17c889b9
28	989a5ae8eab26524	17279ce6fd7aec9d	5d6de41a27df14e7	5932fc7729d3d279
29	e1b5195c5f525d4a	b887e52b76818f33	833d1068da3532bb	91c31290626f78bb
30	0662696ba3aac993	97a17bfbc1c5b128	edf5d82845408563	ed08f8e6a2037845
31	d886d465717d4972	358e2c83d37e3137	b031643b7bd1b5bd	816b0ca5abcab3ff
32	091989a5ae8eab21	88728500054418de		

B.2 CLEFIA test vectors

B.2.1 CLEFIA with a 128-bit key

key	`ffeeddcc bbaa9988 77665544 33221100`
plaintext	`00010203 04050607 08090a0b 0c0d0e0f`
ciphertext	`de2bf2fd 9b74aacd f1298555 459494fd`
L	`8f89a61b 9db9d0f3 93e65627 da0d027e`
$WK_{0,1,2,3}$	`ffeeddcc bbaa9988 77665544 33221100`
$RK_{0,1,2,3}$	`f3e6cef9 8df75e38 41c06256 640ac51b`
$RK_{4,5,6,7}$	`6a27e20a 5a791b90 e8c528dc 00336ea3`
$RK_{8,9,10,11}$	`59cd17c4 28565583 312a37cc c08abd77`
$RK_{12,13,14,15}$	`7e8e7eec 8be7e949 d3f463d6 a0aad6aa`
$RK_{16,17,18,19}$	`e75eb039 0d657eb9 018002e2 9117d009`
$RK_{20,21,22,23}$	`9f98d11e babee8cf b0369efa d3aaef0d`
$RK_{24,25,26,27}$	`3438f93b f9cea4a0 68df9029 b869b4a7`
$RK_{28,29,30,31}$	`24d6406d e74bc550 41c28193 16de4795`
$RK_{32,33,34,35}$	`a34a20f5 33265d14 b19d0554 5142f434`

plaintext		00010203	04050607	08090a0b	0c0d0e0f
initial whitening key			ffeeddcc		bbaa9988
after whitening		00010203	fbebdbcb	08090a0b	b7a79787
Round 1	input	00010203	fbebdbcb	08090a0b	b7a79787
	F-function	F_0		F_1	
	input	00010203		08090a0b	
	round key	f3e6cef9		8df75e38	
	after key add	f3e7ccfa		85fe5433	
	after S	290246e1		777de8e8	
	after M	547a3193		abf12070	
Round 2	input	af91ea58	08090a0b	1c56b7f7	00010203
	F-function	F_0		F_1	
	input	af91ea58		1c56b7f7	
	round key	41c06256		640ac51b	
	after key add	ee51880e		785c72ec	
	after S	cb5d2b0c		63a5edd2	
	after M	f51cebb3		82dfe347	
Round 3	input	fd15e1b8	1c56b7f7	82dee144	af91ea58
	F-function	F_0		F_1	
	input	fd15e1b8		82dee144	
	round key	6a27e20a		5a791b90	
	after key add	973203b2		d8a7fad4	
	after S	c2c7c6c2		be59e10d	
	after M	d8dfd8de		e15ea81c	
Round 4	input	c4896f29	82dee144	4ecf4244	fd15e1b8
	F-function	F_0		F_1	
	input	c4896f29		4ecf4244	
	round key	e8c528dc		00336ea3	
	after key add	2c4c47f5		4efc2ce7	
	after S	9da4dafc		43bce638	

	after M	b5b28e96		b65c519a	
Round 5	input	376c6fd2	4ecf4244	4b49b022	c4896f29
	F-function	F_0		F_1	
	input	376c6fd2		4b49b022	
	round key	59cd17c4		28565583	
	after key add	6ea17816		631fe5a1	
	after S	f26ad3e5		62af9f1b	
	after M	29f08afd		be01d127	
Round 6	input	673fc8b9	4b49b022	7a88be0e	376c6fd2
	F-function	F_0		F_1	
	input	673fc8b9		7a88be0e	
	round key	312a37cc		c08abd77	
	after key add	5615ff75		ba020379	
	after S	b39c8e58		2dd1e9a2	
	after M	5999a79e		0429b329	
Round 7	input	12d017bc	7a88be0e	3345dcfb	673fc8b9
	F-function	F_0		F_1	
	input	12d017bc		3345dcfb	
	round key	7e8e7eec		8be7e949	
	after key add	6c5e6950		b8a235b2	
	after S	8b737025		67a08eba	
	after M	6ed11b09		dfd3cd32	
Round 8	input	1459a507	3345dcfb	b8ec058b	12d017bc
	F-function	F_0		F_1	
	input	1459a507		b8ec058b	
	round key	d3f463d6		a0aad6aa	
	after key add	c7adc6d1		1846d321	
	after S	e7ee5a5f		9e97f1a1	
	after M	8c9d011c		93684eec	
Round 9	input	bfd8dde7	b8ec058b	81b85950	1459a507
	F-function	F_0		F_1	
	input	bfd8dde7		81b85950	
	round key	e75eb039		0d657eb9	
	after key add	58866dde		8cdd27e9	
	after S	4e821daf		59c56044	
	after M	e6d6501e		6d5839b4	
Round 10	input	5e3a5595	81b85950	79019cb3	bfd8dde7
	F-function	F_0		F_1	
	input	5e3a5595		79019cb3	
	round key	018002e2		9117d009	
	after key add	5fba5777		e8164cba	
	after S	612d8f7b		0185a49c	
	after M	3a1b0e97		b9b479c8	
Round 11	input	bba357c7	79019cb3	066ca42f	5e3a5595
	F-function	F_0		F_1	
	input	bba357c7		066ca42f	
	round key	9f98d11e		babee8cf	
	after key add	243b86d9		bcd24ce0	
	after S	f70f1144		cb72a481	
	after M	28974052		4a6700b1	
Round 12	input	5196dce1	066ca42f	145d5524	bba357c7
	F-function	F_0		F_1	
	input	5196dce1		145d5524	
	round key	b0369efa		d3aaef0d	
	after key add	e1a0421b		c7f7ba29	

	after S	6f7efd4f	72642dce
	after M	ffb5db32	907d3820
Round 13	input	f9d97f1d 145d5524	2bde6fe7 5196dce1
	F-function	F_0	F_1
	input	f9d97f1d	2bde6fe7
	round key	3438f93b	f9cea4a0
	after key add	cde18626	d210cb47
	after S	3f751141	ab28e0da
	after M	0a744c28	1c3e38a3
Round 14	input	1e29190c 2bde6fe7	4da8e442 f9d97f1d
	F-function	F_0	F_1
	input	1e29190c	4da8e442
	round key	68df9029	b869b4a7
	after key add	76f68925	f5c150e5
	after S	fe6db7e7	fc0c25f6
	after M	aaa2c803	c4315b8d
Round 15	input	817ca7e4 4da8e442	3de82490 1e29190c
	F-function	F_0	F_1
	input	817ca7e4	3de82490
	round key	24d6406d	e74bc550
	after key add	a5aae789	daa3e1c0
	after S	8d233818	2904757b
	after M	7bd4cced	eac2f0fb
Round 16	input	367c28af 3de82490	f4ebe9f7 817ca7e4
	F-function	F_0	F_1
	input	367c28af	f4ebe9f7
	round key	41c28193	16de4795
	after key add	77bea93c	e235ae62
	after S	7c4a935b	669b8953
	after M	598e6940	c119609f
Round 17	input	64664dd0 f4ebe9f7	4065c77b 367c28af
	F-function	F_0	F_1
	input	64664dd0	4065c77b
	round key	a34a20f5	33265d14
	after key add	c72c6d25	73439a6f
	after S	e7e61de7	788c85b4
	after M	2ac01b0a	c755adfa
Round 18	input	de2bf2fd 4065c77b	f1298555 64664dd0
	F-function	F_0	F_1
	input	de2bf2fd	f1298555
	round key	b19d0554	5142f434
	after key add	6fb6f7a9	a06b7161
	after S	b44d648c	7e99ea2a
	after M	ac7738f2	12d0c82d
output		de2bf2fd ec12ff89	f1298555 76b685fd
final whitening key		77665544	33221100
after whitening		de2bf2fd 9b74aacd	f1298555 459494fd
ciphertext		de2bf2fd 9b74aacd	f1298555 459494fd

B.2.2 CLEFIA with a 192-bit key

key	ffeeddcc bbaa9988 77665544 33221100 f0e0d0c0 b0a09080
plaintext	00010203 04050607 08090a0b 0c0d0e0f

ciphertext	e2482f64	9f028dc4	80dda184	fde181ad
L_L	db05415a	800082db	7cb8186c	d788c5f3
L_R	1ca9b2e1	b4606829	c92dd35e	2258a432
$WK_{0,1,2,3}$	0f0e0d0c	0b0a0908	77777777	77777777
$RK_{0,1,2,3}$	4d3bfd1b	7a1f5dfa	0fae6e7c	c8bf3237
$RK_{4,5,6,7}$	73c2eeb8	dd429ec5	e220b3af	c9135e73
$RK_{8,9,10,11}$	38c46a07	fc2ce4ba	370abf2d	b05e627b
$RK_{12,13,14,15}$	38351b2f	74bd6e1e	1b7c7dce	92cfc98e
$RK_{16,17,18,19}$	509b31a6	4c5ad53c	6fc2ba33	e1e5c878
$RK_{20,21,22,23}$	419a74b9	1dd79e0e	240a33d2	9dabfd09
$RK_{24,25,26,27}$	6e3ff82a	74ac3ffd	b9696e2e	cc0b3a38
$RK_{28,29,30,31}$	ed785cbd	9c077c13	04978d83	2ec058ba
$RK_{32,33,34,35}$	4bbd5f6a	31fe8de8	b76da574	3a6fa8e7
$RK_{36,37,38,39}$	521213ce	4f1f59d8	c13624f6	ee91f6a4
$RK_{40,41,42,43}$	17f68fde	f6c360a9	6288bc72	c0ad856b

plaintext		00010203	04050607	08090a0b	0c0d0e0f
initial whitening key			0f0e0d0c		0b0a0908
after whitening		00010203	0b0b0b0b	08090a0b	07070707
Round 1	input	00010203	0b0b0b0b	08090a0b	07070707
	F-function	F_0		F_1	
	input	00010203		08090a0b	
	round key	4d3bfd1b		7a1f5dfa	
	after key add	4d3aff18		721657f1	
	after S	43c58e9e		ed85d736	
	after M	b5021a3b		c397f62b	
Round 2	input	be091130	08090a0b	c490f12c	00010203
	F-function	F_0		F_1	
	input	be091130		c490f12c	
	round key	0fae6e7c		c8bf3237	
	after key add	b1a77f4c		0c2fc31b	
	after S	f3d10ba4		13d83a3d	
	after M	9fba69c1		6683cae3	
Round 3	input	97b363ca	c490f12c	6682c8e0	be091130
	F-function	F_0		F_1	
	input	97b363ca		6682c8e0	
	round key	73c2eeb8		dd429ec5	
	after key add	e4718d72		bbc05625	
	after S	79ea66ed		f47b0d7a	
	after M	61c21ea5		120e06e2	
Round 4	input	a552ef89	6682c8e0	ac0717d2	97b363ca
	F-function	F_0		F_1	
	input	a552ef89		ac0717d2	
	round key	e220b3af		c9135e73	
	after key add	47725c26		651449a1	
	after S	daeda541		355c651b	
	after M	28a43c63		cb1ab573	
Round 5	input	4e26f483	ac0717d2	5ca9d6b9	a552ef89
	F-function	F_0		F_1	
	input	4e26f483		5ca9d6b9	
	round key	38c46a07		fc2ce4ba	
	after key add	76e29e84		a0853203	
	after S	fe663e39		7edcc7c6	
	after M	5ce7dafe		ac7f4e3e	

Round 6	input	f0e0cd2c 5ca9d6b9	092da1b7 4e26f483
	F-function	F_0	F_1
	input	f0e0cd2c	092da1b7
	round key	370abf2d	b05e627b
	after key add	c7ea7201	b973c3cc
	after S	e77f9fda	174a3a46
	after M	b9869270	8fc7e089
Round 7	input	e52f44c9 092da1b7	c1e1140a f0e0cd2c
	F-function	F_0	F_1
	input	e52f44c9	c1e1140a
	round key	38351b2f	74bd6e1e
	after key add	dd1a5fe6	b55c7a14
	after S	c5496150	5aa5c15c
	after M	33d8590f	e62eb913
Round 8	input	3af5f8b8 c1e1140a	16ce743f e52f44c9
	F-function	F_0	F_1
	input	3af5f8b8	16ce743f
	round key	1b7c7dce	92cfc98e
	after key add	21898576	8401bdb1
	after S	a118dc09	3949b1f3
	after M	f091202d	04f9e827
Round 9	input	31703427 16ce743f	e1d6acee 3af5f8b8
	F-function	F_0	F_1
	input	31703427	e1d6acee
	round key	509b31a6	4c5ad53c
	after key add	61eb0581	ad8c79d2
	after S	2a8d3304	eeffc072
	after M	f9639a90	8bebfe3d
Round 10	input	efadeeaf e1d6acee	b11e0685 31703427
	F-function	F_0	F_1
	input	efadeeaf	b11e0685
	round key	6fc2ba33	e1e5c878
	after key add	806f549c	50fbcefd
	after S	cd5eeb61	25d7fe02
	after M	a100e35b	26a4e16d
Round 11	input	40d64fb5 b11e0685	17d4d54a efadeeaf
	F-function	F_0	F_1
	input	40d64fb5	17d4d54a
	round key	419a74b9	1dd79e0e
	after key add	014c3b0c	0a034b44
	after S	49a4c013	b4c6c912
	after M	51c0208f	f1a2c339
Round 12	input	e0de260a 17d4d54a	1e0f2d96 40d64fb5
	F-function	F_0	F_1
	input	e0de260a	1e0f2d96
	round key	240a33d2	9dabfd09
	after key add	c4d415d8	83a4d09f
	after S	801beebe	86b8f8ed
	after M	8a9aef34	3e451646
Round 13	input	9d4e3a7e 1e0f2d96	7e9359f3 e0de260a
	F-function	F_0	F_1
	input	9d4e3a7e	7e9359f3
	round key	6e3ff82a	74ac3ffd
	after key add	f371c254	0a3f660e
	after S	29ea68e8	b4f530a8

	after M	17524741		4b8c607e	
Round 14	input	095d6ad7	7e9359f3	ab524674	9d4e3a7e
	F-function	F_0		F_1	
	input round key after key add after S after M	095d6ad7 b9696e2e b03404f9 152a2f03 f7ee818b		ab524674 cc0b3a38 67597c4c 52161e39 7902f3eb	
Round 15	input	897dd878	ab524674	e44cc995	095d6ad7
	F-function	F_0		F_1	
	input round key after key add after S after M	897dd878 ed785cbd 640584c5 459d9e10 4034defc		e44cc995 9c077c13 784bb586 636b5a11 0228bdd4	
Round 16	input	eb669888	e44cc995	0b75d703	897dd878
	F-function	F_0		F_1	
	input round key after key add after S after M	eb669888 04978d83 eff1150b 90e4ee38 4a678609		0b75d703 2ec058ba 25b58fb9 e7691f3b 05b2b4a9	
Round 17	input	ae2b4f9c	0b75d703	8ccf6cd1	eb669888
	F-function	F_0		F_1	
	input round key after key add after S after M	ae2b4f9c 4bbd5f6a e59610f6 f6a5286d 720df49d		8ccf6cd1 31fe8de8 bd31e139 b15d7589 bad65e22	
Round 18	input	7978239e	8ccf6cd1	51b0c6aa	ae2b4f9c
	F-function	F_0		F_1	
	input round key after key add after S after M	7978239e b76da574 ce1586ea 919c117f ef24fe56		51b0c6aa 3a6fa8e7 6bdf6e4d 283aaa43 08916103	
Round 19	input	63eb9287	51b0c6aa	a6ba2e9f	7978239e
	F-function	F_0		F_1	
	input round key after key add after S after M	63eb9287 521213ce 31f98149 5d03e265 b7464b63		a6ba2e9f 4f1f59d8 e9a57747 3c8d7bda e1d086a7	
Round 20	input	e6f68dc9	a6ba2e9f	98a8a539	63eb9287
	F-function	F_0		F_1	
	input round key after key add after S after M	e6f68dc9 c13624f6 27c0a93f 20b5938b 3cae819e		98a8a539 ee91f6a4 7639539d 09893194 b603c454	
Round 21	input	9a14af01	98a8a539	d5e856d3	e6f68dc9
	F-function	F_0		F_1	
	input round key after key add	9a14af01 17f68fde 8de220df		d5e856d3 f6c360a9 232b367a	

	after S	6666bff2		b383a1bd	
	after M	7ae08a5d		662b2c4d	
Round 22	input	e2482f64	d5e856d3	80dda184	9a14af01
	F-function	F_0		F_1	
	input	e2482f64		80dda184	
	round key	6288bc72		c0ad856b	
	after key add	80c09316		407024ef	
	after S	cdb5f1e5		fbe99290	
	after M	3d9dac60		108259db	
output		e2482f64	e875fab3	80dda184	8a96f6da
final whitening key			77777777		77777777
after whitening		e2482f64	9f028dc4	80dda184	fde181ad
ciphertext		e2482f64	9f028dc4	80dda184	fde181ad

B.2.3 CLEFIA with a 256-bit key

key	ffeeddcc	bbaa9988	77665544	33221100
	f0e0d0c0	b0a09080	70605040	30201000
plaintext	00010203	04050607	08090a0b	0c0d0e0f
ciphertext	a1397814	289de80c	10da46d1	fa48b38a

L_L	477e8f09	66ee5378	2cc2be04	bf55e28f
L_R	d6c10b89	4eeab575	84bd5663	cc933940

$WK_{0,1,2,3}$	0f0e0d0c	0b0a0908	07060504	03020100
$RK_{0,1,2,3}$	58f02029	15413cd0	1b0c41a4	e4bacd0f
$RK_{4,5,6,7}$	6c498393	8846231b	1fc716fc	7c81a45b
$RK_{8,9,10,11}$	fa37c259	0e3da2ee	aacf9abb	8ec0aad9
$RK_{12,13,14,15}$	b05bd737	8de1f2d0	8ffee0f6	b70b47ea
$RK_{16,17,18,19}$	581b3e34	03263f89	2f7100cd	05cee171
$RK_{20,21,22,23}$	b523d4e9	176d7c44	6d7ba5d7	f797b2f3
$RK_{24,25,26,27}$	25d80df2	a646bba2	6a3a95e1	3e3a47f0
$RK_{28,29,30,31}$	b304eb20	44f8824e	c7557cbc	47401e21
$RK_{32,33,34,35}$	d71ff7e9	aca1fb0c	2deff35d	6ca3a830
$RK_{36,37,38,39}$	4dd7cfb7	ae71c9f6	4e911fef	90aa95de
$RK_{40,41,42,43}$	2c664a7a	8cb5cf6b	14c8de1e	43b9caef
$RK_{44,45,46,47}$	568c5a33	07ef7ddd	608dc860	ac9e50f8
$RK_{48,49,50,51}$	c0c18358	4f53c80e	33e01cb9	80251e1c

plaintext		00010203	04050607	08090a0b	0c0d0e0f
initial whitening key			0f0e0d0c		0b0a0908
after whitening		00010203	0b0b0b0b	08090a0b	07070707
Round 1	input	00010203	0b0b0b0b	08090a0b	07070707
	F-function	F_0		F_1	
	input	00010203		08090a0b	
	round key	58f02029		15413cd0	
	after key add	58f1222a		1d4836db	
	after S	4ee41927		2c78a1ac	
	after M	2db2101b		d87ee718	
Round 2	input	26b91b10	08090a0b	df79e01f	00010203
	F-function	F_0		F_1	
	input	26b91b10		df79e01f	

	round key	1b0c41a4		e4bacd0f	
	after key add	3db55ab4		3bc32d10	
	after S	aa5afadb		0f1e1928	
	after M	317e029c		c0cc96ba	
Round 3	input	39770897	df79e01f	c0cd94b9	26b91b10
	F-function	F_0		F_1	
	input	39770897		c0cd94b9	
	round key	6c498393		8846231b	
	after key add	553e8b04		488bb7a2	
	after S	5487484e		d84876a0	
	after M	c3a7ac1d		7ae05884	
Round 4	input	1cde4c02	c0cd94b9	5c594394	39770897
	F-function	F_0		F_1	
	input	1cde4c02		5c594394	
	round key	1fc716fc		7c81a45b	
	after key add	03195afe		20d8e7cf	
	after S	c607fa95		12f002c9	
	after M	5edee0ce		4cfb0e90	
Round 5	input	9e137477	5c594394	758c0607	1cde4c02
	F-function	F_0		F_1	
	input	9e137477		758c0607	
	round key	fa37c259		0e3da2ee	
	after key add	6424b62e		7bb1a4e9	
	after S	4592c8d2		46f3a044	
	after M	adfd33ae		42450650	
Round 6	input	f1a4703a	758c0607	5e9b4a52	9e137477
	F-function	F_0		F_1	
	input	f1a4703a		5e9b4a52	
	round key	aacf9abb		8ec0aad9	
	after key add	5b6bea81		d05be08b	
	after S	22285e04		f822d448	
	after M	0fa52ed4		aa7a0a9c	
Round 7	input	7a2928d3	5e9b4a52	34697eeb	f1a4703a
	F-function	F_0		F_1	
	input	7a2928d3		34697eeb	
	round key	b05bd737		8de1f2d0	
	after key add	ca72ffe4		b9888c3b	
	after S	23ed8e68		172b59c0	
	after M	8b158630		334e2af2	
Round 8	input	d58ecc62	34697eeb	c2ea5ac8	7a2928d3
	F-function	F_0		F_1	
	input	d58ecc62		c2ea5ac8	
	round key	8ffee0f6		b70b47ea	
	after key add	5a702c94		75e11d22	
	after S	facf9d64		586f2c19	
	after M	72c2027e		a582d5f0	
Round 9	input	46ab7c95	c2ea5ac8	dfabfd23	d58ecc62
	F-function	F_0		F_1	
	input	46ab7c95		dfabfd23	
	round key	581b3e34		03263f89	
	after key add	1eb042a1		dc8dc2aa	
	after S	177afd6a		57664735	
	after M	51d5740a		110287d7	
Round 10	input	933f2ec2	dfabfd23	c48c4bb5	46ab7c95
	F-function	F_0		F_1	

	input	933f2ec2	c48c4bb5
	round key	2f7100cd	05cee171
	after key add	bc4e2e0f	c142aac4
	after S	e0434cd9	22fd2380
	after M	a768d32a	b6ae4f2b
Round 11	input	78c32e09 c48c4bb5	f00533be 933f2ec2
	F-function	F_0	F_1
	input	78c32e09	f00533be
	round key	b523d4e9	176d7c44
	after key add	cde0fae0	e7684ffa
	after S	3fd410d4	02ef5310
	after M	08bd9b01	2fdb3f65
Round 12	input	cc31d0b4 f00533be	bce411a7 78c32e09
	F-function	F_0	F_1
	input	cc31d0b4	bce411a7
	round key	6d7ba5d7	f797b2f3
	after key add	a14a7563	4b73a354
	after S	1b512562	c94a71eb
	after M	7c2c762b	81ca0b59
Round 13	input	8c294595 bce411a7	f9092550 cc31d0b4
	F-function	F_0	F_1
	input	8c294595	f9092550
	round key	25d80df2	a646bba2
	after key add	a9f14867	5f4f9ef2
	after S	93e47852	5c26cae5
	after M	4a87c858	54bc68d5
Round 14	input	f663d9ff f9092550	988db861 8c294595
	F-function	F_0	F_1
	input	f663d9ff	988db861
	round key	6a3a95e1	3e3a47f0
	after key add	9c594c1e	a6b7ff91
	after S	58ff39b0	054d1d75
	after M	d82301d4	085d5025
Round 15	input	212a2484 988db861	847415b0 f663d9ff
	F-function	F_0	F_1
	input	212a2484	847415b0
	round key	b304eb20	44f8824e
	after key add	922ecfa4	c08c97fe
	after S	86d2c9a0	b5ff567d
	after M	dbf56073	87e2a6a2
Round 16	input	4378d812 847415b0	71817f5d 212a2484
	F-function	F_0	F_1
	input	4378d812	71817f5d
	round key	c7557cbc	47401e21
	after key add	842da4ae	36c1617c
	after S	9e19b889	a10c5414
	after M	6791a3e3	e177d3a8
Round 17	input	e3e5b653 71817f5d	c05df72c 4378d812
	F-function	F_0	F_1
	input	e3e5b653	c05df72c
	round key	d71ff7e9	aca1fb0c
	after key add	34fa41ba	6cfc0c20
	after S	d4e1be2d	32bc13bf
	after M	2743ef2d	6fec0aab
Round 18	input	56c29070 c05df72c	2c94d2b9 e3e5b653

	F-function	F_0		F_1	
	input	56c29070		2c94d2b9	
	round key	2deff35d		6ca3a830	
	after key add	7b2d632d		40377a89	
	after S	56193719		fb13c1b7	
	after M	ee6316fa		5e3245b7	
Round 19	input	2e3ee1d6	2c94d2b9	bdd7f3e4	56c29070
	F-function	F_0		F_1	
	input	2e3ee1d6		bdd7f3e4	
	round key	4dd7cfb7		ae71c9f6	
	after key add	63e92e61		13a63a12	
	after S	373c4c54		8fe6c54b	
	after M	87aab08e		8f8d16f3	
Round 20	input	ab3e6237	bdd7f3e4	d94f8683	2e3ee1d6
	F-function	F_0		F_1	
	input	ab3e6237		d94f8683	
	round key	4e911fef		90aa95de	
	after key add	e5af7dd8		49e5135d	
	after S	f6ad88be		65f68f77	
	after M	0889df33		f418c84f	
Round 21	input	b55e2cd7	d94f8683	da262999	ab3e6237
	F-function	F_0		F_1	
	input	b55e2cd7		da262999	
	round key	2c664a7a		8cb5cf6b	
	after key add	993866ad		5693e6f2	
	after S	2c2b6cee		0df150e5	
	after M	8999e772		da5415d2	
Round 22	input	50d661f1	da262999	716a77e5	b55e2cd7
	F-function	F_0		F_1	
	input	50d661f1		716a77e5	
	round key	14c8de1e		43b9caef	
	after key add	441ebfef		32d3bd0a	
	after S	12b052ac		c7bbb182	
	after M	f5efd89e		744a9ced	
Round 23	input	2fc9f107	716a77e5	c114b03a	50d661f1
	F-function	F_0		F_1	
	input	2fc9f107		c114b03a	
	round key	568c5a33		07ef7ddd	
	after key add	7945ab34		c6fbcde7	
	after S	a2a77e2a		4cd7e238	
	after M	e84f6d9b		ce67e20a	
Round 24	input	99251a7e	c114b03a	9eb183fb	2fc9f107
	F-function	F_0		F_1	
	input	99251a7e		9eb183fb	
	round key	608dc860		ac9e50f8	
	after key add	f9a8d21e		322fd303	
	after S	f84572b0		c7d8f1c6	
	after M	20634b77		591b3f55	
Round 25	input	e177fb4d	9eb183fb	76d2ce52	99251a7e
	F-function	F_0		F_1	
	input	e177fb4d		76d2ce52	
	round key	c0c18358		4f53c80e	
	after key add	21b67815		3981065c	
	after S	a14dd39c		c8e20aa5	
	after M	3f88fbef		89ff5caf	

Round 26	input	a1397814	76d2ce52	10da46d1	e177fb4d
	F-function	F_0		F_1	
	input	a1397814		10da46d1	
	round key	33e01cb9		80251e1c	
	after key add	92d964ad		90ff58cd	
	after S	864445ee		9a8e803f	
	after M	5949235a		183d49c7	
output		a1397814	2f9bed08	10da46d1	f94ab28a
final whitening key			07060504		03020100
after whitening		a1397814	289de80c	10da46d1	fa48b38a
ciphertext		a1397814	289de80c	10da46d1	fa48b38a

Annex C
(informative)

Feature Table

This annex shows lightweight properties of the cryptographic algorithms described in this document. ISO/IEC 29192-1 Annex C.1 gives hardware metrics for lightweight block ciphers. Based on the metrics, the lightweight properties of PRESENT and CLEFIA are summarized as follows.

	Algorithm name					
	PRESENT [6][7][8]				CLEFIA [9]	
Key size [bits]	80	128	80	128	128	128
Block size [bits]	64	64	64	64	128	128
Area [GE]	1 570	1 884	1 075	1 391	4 950	5 979
Cycles [CLK]	32	32	547	559	36	18
Bits per cycles [bits/CLK]	2	2	0,18	0,11	3,56	7,11
Power[a] [GE]	1 570	1 884	1 075	1 391	4 950	5 979
Energy[a] [GE*CLK]	50 240	60 288	588 025	777 569	178 200	107 622
Energy per bit[a] [GE*CLK/bits]	785	942	9188	12 150	1 392	841
Technology [µm]	0,18		0,18		0,09	0,09
Support of decryption	NO		NO		YES	YES
Features	Small area and low energy (round-based)		Smallest area (serialized)		Small area (round-based)	Low energy and high efficiency (round-based)

[a] Estimated using hardware metrics for lightweight cryptography in ISO/IEC 29192-1 Annex C.1.

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