Universal Mobile Telecommunications System (UMTS);
LTE;
3G Security;
Specification of the 3GPP confidentiality and integrity algorithms;
Document 2: Kasumi specification
(3GPP TS 35.202 version 12.0.0 Release 12)
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Foreword

This Technical Specification (TS) has been produced by the 3rd Generation Partnership Project (3GPP).

The 3GPP Confidentiality and Integrity Algorithms $f_8$ & $f_9$ have been developed through the collaborative efforts of the European Telecommunications Standards Institute (ETSI), the Association of Radio Industries and Businesses (ARIB), the Telecommunications Technology Association (TTA), the T1 Committee.

The $f_8$ & $f_9$ Algorithms Specifications may be used only for the development and operation of 3G Mobile Communications and services. Every Beneficiary must sign a Restricted Usage Undertaking with the Custodian and demonstrate that he fulfills the approval criteria specified in the Restricted Usage Undertaking.

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x  the first digit:
   1  presented to TSG for information;
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   3  or greater indicates TSG approved document under change control.

y  the second digit is incremented for all changes of substance, i.e. technical enhancements, corrections, updates, etc.

z  the third digit is incremented when editorial only changes have been incorporated in the document.

Introduction

This specification has been prepared by the 3GPP Task Force, and gives a detailed specification of the 3GPP Algorithm KASUMI. KASUMI is a block cipher that forms the heart of the 3GPP confidentiality algorithm $f_8$, and the 3GPP integrity algorithm $f_9$.

This document is the second of four, which between them form the entire specification of the 3GPP Confidentiality and Integrity Algorithms:


The normative part of the specification of **KASUMI** is in the main body of this document. The annexes to this document are purely informative. Annex 1 contains illustrations of functional elements of the algorithm, while Annex 2 contains an implementation program listing of the cryptographic algorithm specified in the main body of this document, written in the programming language C.

Similarly the normative part of the specification of the \textit{f8} (confidentiality) and the \textit{f9} (integrity) algorithms is in the main body of Document 1. The annexes of those documents, and Documents 3 and 4 above, are purely informative.
0 Scope

This specification gives a detailed specification of the 3GPP Algorithm KASUMI. KASUMI is a block cipher that forms the heart of the 3GPP confidentiality algorithm $f_8$, and the 3GPP integrity algorithm $f_9$. 
This part of the document contains the normative specification of the KASUMI algorithm.
1 Outline of the normative part

Section 2 introduces the algorithm and describes the notation used in the subsequent sections.
Section 3 defines the algorithm structure and its operation.
Section 4 defines the basic components of the algorithm.

1.1 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document in the same Release as the present document.


2 Introductory information

2.1 Introduction

Within the security architecture of the 3GPP system there are two standardised algorithms: A confidentiality algorithm f8, and an integrity algorithm f9. These algorithms are fully specified in a companion document[3]. Each of these algorithms is based on the KASUMI algorithm that is specified here.

KASUMI is a block cipher that produces a 64-bit output from a 64-bit input under the control of a 128-bit key.
2.2 Notation

2.2.1 Radix

We use the prefix 0x to indicate hexadecimal numbers.

2.2.2 Bit/Byte ordering

All data variables in this specification are presented with the most significant bit (or byte) on the left hand side and the least significant bit (or byte) on the right hand side. Where a variable is broken down into a number of sub-strings, the left most (most significant) sub-string consists of the most significant part of the original string and so on through to the least significant.

For example if a 64-bit value \( X \) is subdivided into four 16-bit substrings \( P, Q, R, S \) we have:

\[
X = 0x0123456789ABCDEF
\]

we have:

\[
P = 0x0123, \quad Q = 0x4567, \quad R = 0x89AB, \quad S = 0xCDEF.
\]

In binary this would be:

\[
X = 00000001001000110100010101100111100010011010101111001101111101111
\]

with

\[
P = 0000000100100011
\quad Q = 0100010111001111
\quad R = 1000100110101011
\quad S = 1100110111101111
\]

2.2.3 Conventions

We use the assignment operator "=" as used in several programming languages. When we write

\[
<\text{variable}> = <\text{expression}>
\]

we mean that \(<\text{variable}>\) assumes the value that \(<\text{expression}>\) had before the assignment took place. For instance,

\[
x = x + y + 3
\]

means

(new value of \( x \)) becomes (old value of \( x \)) + (old value of \( y \)) + 3.

2.2.4 Subfunctions

KASUMI decomposes into a number of subfunctions \((FL, FO, FI)\) which are used in conjunction with associated sub-keys \((KL, KO, KI)\) in a Feistel structure comprising a number of rounds (and rounds within rounds for some sub-functions). Specific instances of the function and/or keys are represented by \(XX_{ij}\) where \(i\) is the outer round number of KASUMI and \(j\) is the inner round number.

For example the function \(FO\) comprises three rounds of the function \(FI\), so we designate the third round of \(FI\) in the fifth round of KASUMI as \(FI_{5,3}\).
2.2.5 List of Symbols

- $=$ The assignment operator.
- $\oplus$ The bitwise exclusive-OR operation.
- $\|$ The concatenation of the two operands.
- $\ll<_{n}$ The left circular rotation of the operand by $n$ bits.
- ROL(...) The left circular rotation of the operand by one bit.
- $\cap$ The bitwise AND operation.
- $\cup$ The bitwise OR operation.

2.3 List of Functions and Variables

- $f_i()$ The round function for the $i^{th}$ round of KASUMI
- FI() A subfunction within KASUMI that translates a 16-bit input to a 16-bit output using a 16-bit subkey.
- FL() A subfunction within KASUMI that translates a 32-bit input to a 32-bit output using a 32-bit subkey.
- FO() A subfunction within KASUMI that translates a 32-bit input to a 32-bit output using two 48-bit subkeys.
- $K$ A 128-bit key.
- $KL_i, KO_i, KI_i$ subkeys used within the $i^{th}$ round of KASUMI.
- S7[] An S-Box translating a 7-bit input to a 7-bit output.
- S9[] An S-Box translating a 9-bit input to a 9-bit output.

3 KASUMI operation

3.1 Introduction

(See figure 1 in Annex 1)

KASUMI is a Feistel cipher with eight rounds. It operates on a 64-bit data block and uses a 128-bit key. In this section we define the basic eight-round operation. In section 4 we define in detail the make-up of the round function $f_i()$. 
3.2 Encryption

**KASUMI** operates on a 64-bit input \( I \) using a 128-bit key \( K \) to produce a 64-bit output \( \text{OUTPUT} \), as follows:

The input \( I \) is divided into two 32-bit strings \( L_0 \) and \( R_0 \), where

\[
I = L_0 \parallel R_0
\]

Then for each integer \( i \) with \( 1 \leq i \leq 8 \) we define:

\[
R_i = L_{i-1}, \quad L_i = R_{i-1} \oplus f_i(L_{i-1}, RK_i)
\]

This constitutes the \( i^{\text{th}} \) round function of **KASUMI**, where \( f_i \) denotes the round function with \( L_{i-1} \) and round key \( RK_i \) as inputs (see section 4 below).

The result \( \text{OUTPUT} \) is equal to the 64-bit string \( (L_8 \parallel R_8) \) offered at the end of the eighth round. See figure 1 of Annex 1.

In the specifications for the \( f8 \) and \( f9 \) functions we represent this transformation by the term:

\[
\text{OUTPUT} = \text{KASUMI}[I]_K
\]

### 4 Components of KASUMI

#### 4.1 Function \( f_i \)

(See figure 1 in Annex 1)

The function \( f_i() \) takes a 32-bit input \( I \) and returns a 32-bit output \( O \) under the control of a round key \( RK_i \), where the round key comprises the subkey triplet of \( (KL_i, KO_i, KL_i) \). The function itself is constructed from two subfunctions; \( FL \) and \( FO \) with associated subkeys \( KL_i \) (used with \( FL \)) and subkeys \( KO_i \) and \( KL_i \) (used with \( FO \)).

The \( f_i() \) function has two different forms depending on whether it is an even round or an odd round.

For rounds 1, 3, 5 and 7 we define:

\[
f_i(I, RK_i) = FO( FL( I, KL_i), KO_i, KL_i)
\]

and for rounds 2, 4, 6 and 8 we define:

\[
f_i(I, RK_i) = FL( FO( I, KO_i, KL_i), KL_i)
\]

i.e. For odd rounds the round data is passed through \( FL() \) and then \( FO() \), whilst for even rounds it is passed through \( FO() \) and then \( FL() \).

#### 4.2 Function \( FL \)

(See figure 4 in Annex 1)

The input to the function \( FL \) comprises a 32-bit data input \( I \) and a 32-bit subkey \( KL_i \). The subkey is split into two 16-bit subkeys, \( KL_{i,1} \) and \( KL_{i,2} \) where

\[
KL_i = KL_{i,1} \parallel KL_{i,2}.
\]

The input data \( I \) is split into two 16-bit halves, \( L \) and \( R \) where \( I = L \parallel R \).

We define:

\[
R' = R \oplus ROL( L \cap KL_{i,1} )
\]

\[
L' = L \oplus ROL( R' \cap KL_{i,2} )
\]

The 32-bit output value is \( (L' \parallel R') \).
4.3 Function \( FO \)

(See figure 2 in Annex 1)

The input to the function \( FO \) comprises a 32-bit data input \( I \) and two sets of subkeys, a 48-bit subkey \( KO_i \) and 48-bit subkey \( KI_i \).

The 32-bit data input is split into two halves, \( L_0 \) and \( R_0 \) where \( I = L_0 \| R_0 \).

The 48-bit subkeys are subdivided into three 16-bit subkeys where \( KO_i = KO_{i,1} \| KO_{i,2} \| KO_{i,3} \) and \( KI_i = KI_{i,1} \| KI_{i,2} \| KI_{i,3} \).

Then for each integer \( j \) with \( 1 \leq j \leq 3 \) we define:

\[
R_j = FI(L_{j-1} \oplus KO_{i,j}, KI_{i,j}) \oplus R_{j-1} \\
L_j = R_{j-1}
\]

Finally we return the 32-bit value \( (L_3 \| R_3) \).

4.4 Function \( FI \)

(See figure 3 in Annex 1. The thick and thin lines in this diagram are used to emphasise the difference between the 9-bit and 7-bit data paths respectively).

The function \( FI \) takes a 16-bit data input \( I \) and 16-bit subkey \( KI_{i,j} \). The input \( I \) is split into two unequal components, a 9-bit left half \( L_0 \) and a 7-bit right half \( R_0 \) where \( I = L_0 \| R_0 \).

Similarly the key \( KI_{i,j} \) is split into a 7-bit component \( KI_{i,j,1} \) and a 9-bit component \( KI_{i,j,2} \) where \( KI_{i,j} = KI_{i,j,1} \| KI_{i,j,2} \).

The function uses two S-boxes, \( S7 \) which maps a 7-bit input to a 7-bit output, and \( S9 \) which maps a 9-bit input to a 9-bit output. These are fully defined in section 4.5. It also uses two additional functions which we designate \( ZE(\cdot) \) and \( TR(\cdot) \). We define these as:

\( ZE(x) \) takes the 7-bit value \( x \) and converts it to a 9-bit value by adding two zero bits to the most-significant end.

\( TR(x) \) takes the 9-bit value \( x \) and converts it to a 7-bit value by discarding the two most-significant bits.

We define the following series of operations:

\[
\begin{align*}
L_1 &= R_0 \\
R_1 &= S9[L_0] \oplus ZE(R_0) \\
L_2 &= R_1 \oplus KI_{i,j,2} \\
R_2 &= S7[L_1] \oplus TR(R_1) \oplus KI_{i,j,1} \\
L_3 &= R_2 \\
R_3 &= S9[L_2] \oplus ZE(R_2) \\
L_4 &= S7[L_3] \oplus TR(R_3) \\
R_4 &= R_3
\end{align*}
\]

The function returns the 16-bit value \( (L_4 \| R_4) \).
### 4.5 S-boxes

The two S-boxes have been designed so that they may be easily implemented in combinational logic as well as by a look-up table. Both forms are given for each table.

The input $x$ comprises either seven or nine bits with a corresponding number of bits in the output $y$. We therefore have:

$$ x = x_8 \ || \ x_7 \ || \ x_6 \ || \ x_5 \ || \ x_4 \ || \ x_3 \ || \ x_2 \ || \ x_1 \ || \ x_0 $$

and

$$ y = y_8 \ || \ y_7 \ || \ y_6 \ || \ y_5 \ || \ y_4 \ || \ y_3 \ || \ y_2 \ || \ y_1 \ || \ y_0 $$

where the $x_8$, $y_8$ and $x_7$, $y_7$ bits only apply to $S_9$, and the $x_0$ and $y_0$ bits are the least significant bits.

In the logic equations:

$$ x_0x_1x_2 \ \text{implies} \ x_0 \ \text{AND} \ x_1 \ \text{AND} \ x_2 $$

where $\text{AND}$ is the AND operator.

$$ \oplus $$

is the exclusive-OR operator.

Following the presentation of the logic equations and the equivalent look-up table an example is given of the use of each.

#### 4.5.1 S7

**Gate Logic :**

- $y_0 = x_1x_3@[x_4 \oplus x_0 \times x_1 \times x_2 \times x_5 \times x_3 \times x_4] \oplus x_6$ \oplus x_1 \times x_5 \times x_6$
- $y_1 = x_0 x_3 \oplus x_2 x_4 \oplus x_0 x_1 \times x_2 x_5 \oplus x_0 x_3 \times x_5 \times x_6 \oplus x_0 x_2 \times x_6 \oplus x_3 \times x_6 \oplus x_6 \oplus 1$
- $y_2 = x_0 x_3 \oplus x_2 x_3 \oplus x_0 x_4 \oplus x_1 x_3 \oplus x_0 x_5 \times x_0 x_6 \oplus x_0 x_1 \times x_6 \oplus 1$
- $y_3 = x_0 x_1 \times x_2 x_3 \times x_4 \times x_5 \times x_0 x_1 \times x_2 x_3 \times x_5 \times x_1 x_4 \times x_5 \times x_2 x_6 \times x_6 \times x_1 x_3 \times x_6$
- $y_4 = x_0 x_2 \times x_3 \times x_1 x_3 \times x_1 x_4 \times x_0 x_4 \times x_0 x_5 \times x_1 x_3 \times x_5 \times x_0 x_4 \times x_5 \times x_1 x_6 \times x_6 \times x_3 \times x_6 \oplus 1$
- $y_5 = x_2 x_0 x_2 \times x_0 x_3 \times x_1 x_2 x_3 \times x_0 x_2 x_4 \times x_0 x_5 \times x_2 x_5 \times x_4 x_5 \times x_1 x_6 \times x_2 x_6 \times x_0 x_3 \times x_6 \oplus x_3 \times x_4 \times x_2 x_5 \times x_6 \oplus 1$
- $y_6 = x_1 x_2 \times x_0 x_1 x_3 \times x_0 x_4 \times x_1 x_5 \times x_3 x_5 \times x_6 \times x_0 x_1 x_6 \times x_2 x_3 \times x_6 \times x_1 x_4 \times x_6 \times x_0 x_5 \times x_6$

**Decimal Table :**

54, 50, 62, 56, 22, 34, 94, 96, 38, 6, 63, 93, 2, 18, 123, 33, 55, 113, 39, 114, 21, 67, 65, 12, 47, 73, 46, 27, 25, 111, 124, 81, 53, 9, 121, 79, 52, 60, 58, 48, 101, 127, 40, 120, 104, 70, 71, 43, 20, 122, 72, 61, 23, 109, 13, 100, 77, 1, 16, 7, 82, 10, 105, 98, 117, 116, 76, 11, 89, 106, 6, 125, 118, 99, 86, 69, 30, 57, 126, 87, 112, 51, 17, 5, 95, 14, 90, 84, 91, 8, 35, 103, 32, 97, 28, 66, 102, 31, 26, 45, 75, 4, 85, 92, 37, 74, 80, 49, 68, 29, 115, 44, 64, 107, 108, 24, 110, 83, 36, 78, 42, 19, 15, 41, 88, 119, 59, 3

**Example:**

If we have an input value = 38, then using the decimal table $S_7[38] = 58$.

For the combinational logic we have:

$$ 38 = 0100110_2 \ \Rightarrow \ x_6 = 0, x_5 = 1, x_4 = 0, x_3 = 0, x_2 = 1, x_1 = 1, x_0 = 0 $$
which gives us:

\[
y_0 = \overline{0000001100000000000} = 0
\]

\[
y_1 = \overline{0000001100000000000} = 1
\]

\[
y_2 = \overline{0000000000000000001} = 0
\]

\[
y_3 = \overline{0000000000000000001} = 1
\]

\[
y_4 = \overline{0000000000000000001} = 1
\]

\[
y_5 = \overline{0000000000000000001} = 1
\]

\[
y_6 = \overline{0000000000000000001} = 0
\]

\[
y_7 = \overline{0000000000000000001} = 0
\]

Thus \( y = 01110102 = 58 \)

### 4.5.2 S9

**Gate Logic:**

\[
y_0 = \overline{x_0x_2x_3x_4x_5x_6x_7} \oplus \overline{x_0x_1x_2x_3x_4x_5x_6x_7} = 0
\]

\[
y_1 = \overline{x_0x_2x_3x_4x_5x_6x_7} \oplus \overline{x_0x_2x_3x_4x_5x_6x_7} = 1
\]

\[
y_2 = \overline{x_0x_2x_3x_4x_5x_6x_7} \oplus \overline{x_0x_2x_3x_4x_5x_6x_7} = 0
\]

\[
y_3 = \overline{x_0x_2x_3x_4x_5x_6x_7} \oplus \overline{x_0x_2x_3x_4x_5x_6x_7} = 1
\]

\[
y_4 = \overline{x_0x_2x_3x_4x_5x_6x_7} \oplus \overline{x_0x_2x_3x_4x_5x_6x_7} = 1
\]

\[
y_5 = \overline{x_0x_2x_3x_4x_5x_6x_7} \oplus \overline{x_0x_2x_3x_4x_5x_6x_7} = 0
\]

\[
y_6 = \overline{x_0x_2x_3x_4x_5x_6x_7} \oplus \overline{x_0x_2x_3x_4x_5x_6x_7} = 0
\]

\[
y_7 = \overline{x_0x_2x_3x_4x_5x_6x_7} \oplus \overline{x_0x_2x_3x_4x_5x_6x_7} = 0
\]

\[
y_8 = \overline{x_0x_2x_3x_4x_5x_6x_7} \oplus \overline{x_0x_2x_3x_4x_5x_6x_7} = 0
\]

### Decimal Table:

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<th>Binary (8bit)</th>
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</table>

---

**ETSI**
Example:

If we have an input value = 138, then using the decimal table S9[138] = 339.

For the combinational logic we have:
\[ 138 = 010001010_2 \Rightarrow x_8 = 0, x_7 = 1, x_6 = 0, x_5 = 0, x_4 = 0, x_3 = 1, x_2 = 0, x_1 = 1, x_0 = 0 \]

which gives us:
\[
\begin{align*}
y_0 &= 0\oplus 1\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0 = 1 \\
y_1 &= 1\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0 = 1 \\
y_2 &= 1\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0 = 0 \\
y_3 &= 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0 = 0 \\
y_4 &= 0\oplus 1\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0 = 1 \\
y_5 &= 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0 = 0 \\
y_6 &= 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0 = 1 \\
y_7 &= 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0 = 0 \\
y_8 &= 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0\oplus 0 = 1 \\
\end{align*}
\]

Thus \( y = 101010011_2 = 339 \)

4.6 Key Schedule

KASUMI has a 128-bit key \( K \). Each round of KASUMI uses 128 bits of key that are derived from \( K \). Before the round keys can be calculated two 16-bit arrays \( K_j \) and \( K_j' \) \((j=1 \text{ to } 8)\) are derived in the following manner:

The 128-bit key \( K \) is subdivided into eight 16-bit values \( K_1 \ldots K_8 \) where

\[
K = K_1 \parallel K_2 \parallel K_3 \parallel \ldots \parallel K_8.
\]

A second array of subkeys, \( K_j' \) is derived from \( K_j \) by applying:

For each integer \( j \) with \( 1 \leq j \leq 8 \)

\[
K_j' = K_j \oplus C_j
\]

Where \( C_j \) is the constant value defined in table 2.

The round subkeys are then derived from \( K_j \) and \( K_j' \) in the manner defined in table 1.

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Table 2: Constants

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<td>0x89AB</td>
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<td>C4</td>
<td>0xCDEF</td>
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<td>C6</td>
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<td>0x7654</td>
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<td>C8</td>
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</table>
INFORMATIVE SECTION

This part of the document is purely informative and does not form part of the normative specification of KASUMI.
Annex 1 (informative):
Figures of the KASUMI Algorithm

Fig. 1: KASUMI

Fig. 2: FO Function

Fig. 3: FI Function

Fig. 4: FL Function
KASUMI has a number of characteristics that may be exploited in a hardware implementation and these are highlighted here.

- The simple key schedule is easy to implement in hardware.
- The S-Boxes have been designed so that they may be implemented by a small amount of combinational logic rather than by large look-up tables.
- The S7-Box and S9-Box operations in the FI function may be carried out in parallel (see alternative presentation in figure 5).
- The FI\textsubscript{i,1} and FI\textsubscript{i,2} operations may be carried out in parallel (see alternative presentation in figure 6).
Annex 2 (informative):
Simulation Program Listing

Header file

```c
/*-----------------------------------------------*/
/* Kasumi.h                                          */
/*-----------------------------------------------*/
typedef unsigned char u8;
typedef unsigned short u16;
typedef unsigned long u32;

void KeySchedule( u8 *key );
void Kasumi( u8 *data );
```

C Code

```c
/*-----------------------------------------------*/
/* Kasumi.c                                          */
/*-----------------------------------------------*/
/* A sample implementation of KASUMI, the core algorithm for the */
/* 3GPP Confidentiality and Integrity algorithms. */
/* This has been coded for clarity, not necessarily for efficiency. */
/* This will compile and run correctly on both Intel (little endian) */
/* and Sparc (big endian) machines. (Compilers used supported 32-bit ints). */
/* Version 1.1  08 May 2000 */
/*-----------------------------------------------*/
#include "Kasumi.h"

/*----------------------------------------------------------------------------*/
/* 16 bit rotate left --------------------------------------------------*/
#define ROL16(a,b) (u16)((a<<b)|(a>>(16-b))

/*----------------------------------------------------------------------------*/
/* unions: used to remove *endian* issues ----------------*/
typedef union {
    u32 b32;
    u16 b16[2];
    u8  b8[4];
} DWORD;

typedef union {
    u16 b16;
    u8  b8[2];
} WORD;

/*----------------------------------------------------------------------------*/
/* globals: The subkey arrays */
static u16 KL11[8], KL12[8];
static u16 KO11[8], KO12[8], KO13[8];
static u16 KI11[8], KI12[8], KI13[8];

/*----------------------------------------------------------------------------*/
/* FI() */
/* The FI function (fig 3). It includes the S7 and S9 tables. */
/* Transforms a 16-bit value. */
static u16 FI( u16 in, u16 subkey ) {
    static u16 nine, seven;
    static u16 S7[] = {
        54, 50, 62, 56, 22, 34, 94, 96, 38, 6, 63, 93, 2, 18, 123, 33,
        55, 113, 39, 114, 21, 67, 65, 12, 47, 73, 46, 27, 25, 111, 124, 81,
        53, 9, 121, 79, 52, 60, 58, 48, 101, 127, 40, 120, 104, 70, 71, 43,
        20, 122, 72, 61, 23, 109, 13, 100, 77, 1, 16, 7, 82, 10, 105, 98,
    };

```
static u16 S9[ ] = {
167,239,161,379,391,334,9,338,38,226,48,358,452,385,90,397,
183,253,147,331,415,340,51,362,306,500,262,82,216,159,356,177,
175,241,489,37,206,17,303,44,254,378,58,143,220,81,400,95,
5,215,245,54,235,218,405,472,264,172,494,371,290,399,76,
165,395,121,257,480,423,212,240,28,462,176,406,507,288,223,
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475,384,508,53,112,170,479,151,126,169,73,268,279,321,168,364,
363,292,46,499,393,327,324,24,456,267,157,460,488,426,309,229,
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30,310,219,94,160,129,493,64,179,263,102,189,207,114,402,
438,477,387,122,192,42,381,5,145,118,180,449,293,323,136,380,
43,66,60,455,341,445,202,432,8,237,15,376,436,464,59,4611;

/* The sixteen bit input is split into two unequal halves, */
/* nine bits and seven bits – as is the subkey */

nine = (u16)(in>>7);
seven = (u16)(in&0x7F);

/* Now run the various operations */
nine = (u16)(S9[nine] ^ seven);
seven = (u16)(S7[seven] ^ (nine & 0x7F));
seven ^= (subkey>>9);
nine ^= (subkey&0x1FF);
nine = (u16)(S9[nine] ^ seven);
seven = (u16)(S7[seven] ^ (nine & 0x7F));
in = (u16)((seven<<9) + nine);
return( in );
}
left ^= KOi1[index];
left = FI(left, KIi1[index]);
left ^= right;

right ^= KOi2[index];
right = FI(right, KIi2[index]);
right ^= left;

left ^= KOi3[index];
left = FI(left, KIi3[index]);
left ^= right;

in = (((u32)right)<<16)+left;
return( in );

/*---------------------------------------------------------------------
* FL()
* The FL() function.
* Transforms a 32-bit value. Uses <index> to identify the
* appropriate subkeys to use.
*---------------------------------------------------------------------*/
static u32 FL( u32 in, int index )
{
  u16 l, r, a, b;
  /* split out the left and right halves */
  l = (u16)(in>>16);
  r = (u16)(in);
  /* do the FL() operations */
  a = (u16) (l & KLi1[index]);
  r ^= ROL16(a,1);
  b = (u16)(r | KLi2[index]);
  l ^= ROL16(b,1);
  /* put the two halves back together */
  in = (((u32)l)<<16) + r;
  return( in );
}

/*---------------------------------------------------------------------
* Kasumi()
* the Main algorithm (fig 1). Apply the same pair of operations
* four times. Transforms the 64-bit input.
*---------------------------------------------------------------------*/
void Kasumi( u8 *data )
{
  u32 left, right, temp;
  DWORD *d;
  int n;
  /* Start by getting the data into two 32-bit words (endianness correct) */
  d = (DWORD*)data;
  left  = (((u32)d[0].b8[0])<<24)+(((u32)d[0].b8[1])<<16)+
         (((u32)d[0].b8[2])<<8)+((u32)d[0].b8[3]);
  right = (((u32)d[1].b8[0])<<24)+(((u32)d[1].b8[1])<<16)+
         (((u32)d[1].b8[2])<<8)+((u32)d[1].b8[3]);
  n = 0;
  do{
    temp = FL(left, n );
    temp = FO( temp, n++ );
    right ^= temp;
    temp = FO( right, n );
    temp = FL( temp, n++ );
    left ^= temp;
  }while( n<=7 );
  /* return the correct endian result */
  d[0].b8[0] = (u8)(left>>24);
  d[1].b8[0] = (u8)(right>>24);
  d[0].b8[1] = (u8)(left>>16);
  d[1].b8[1] = (u8)(right>>16);
```c

d[0].b8[2] = (u8)(left>>8);  d[1].b8[2] = (u8)(right>>8);
d[0].b8[3] = (u8)(left);   d[1].b8[3] = (u8)(right);

void KeySchedule(u8 *k)
{
  static u16 C[] = {
    0x0123,0x4567,0x89AB,0xCDEF, 0xFEDC,0xBA98,0x7654,0x3210
  };
  u16 key[8], Kprime[8];
  WORD *k16;
  int n;

  /* Start by ensuring the subkeys are endian correct on a 16-bit basis */
  k16 = (WORD *)k;
  for( n=0; n<8; ++n )
    key[n] = (u16)((k16[n].b8[0]<<8) + (k16[n].b8[1]));

  /* Now build the K'[] keys */
  for( n=0; n<8; ++n )
    Kprime[n] = (u16)(key[n] ^ C[n]);

  /* Finally construct the various sub keys */
  for( n=0; n<8; ++n )
  {
    KLi1[n] = ROL16(key[n],1);
    KLi2[n] = Kprime[(n+2)&0x7];
    KOi1[n] = ROL16(key[(n+1)&0x7],5);
    KOi2[n] = ROL16(key[(n+5)&0x7],8);
    KOi3[n] = ROL16(key[(n+6)&0x7],13);
    KLi1[n] = Kprime[(n+4)&0x7];
    KLi2[n] = Kprime[(n+3)&0x7];
    KLi3[n] = Kprime[(n+7)&0x7];
  }
}
```
## Annex 3 (informative):
### Change history

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