ETSI TS 135 202 V5.0.0 (2002-06)

Technical Specification

Universal Mobile Telecommunications System (UMTS); Specification of the 3GPP confidentiality and integrity algorithms; Document 2: Kasumi algorithm specification (3GPP TS 35.202 version 5.0.0 Release 5)

Reference
RTS/TSGS-0335202v500

Keywords
UMTS

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00   Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Important notice

Individual copies of the present document can be downloaded from:
http://www.etsi.org

The present document may be made available in more than one electronic version or in print. In any case of existing or
perceived difference in contents between such versions, the reference version is the Portable Document Format (PDF).
In case of dispute, the reference shall be the printing on ETSI printers of the PDF version kept on a specific network drive
within ETSI Secretariat.

Users of the present document should be aware that the document may be subject to revision or change of status.
Information on the current status of this and other ETSI documents is available at
http://portal.etsi.org/tb/status/status.asp

If you find errors in the present document, send your comment to:
editor@etsi.fr

Copyright Notification

Intellectual Property Rights

IPRs essential or potentially essential to the present document may have been declared to ETSI. The information pertaining to these essential IPRs, if any, is publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (http://webapp.etsi.org/IPR/home.asp).

Pursuant to the ETSI IPR Policy, no investigation, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Foreword

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

The present document may refer to technical specifications or reports using their 3GPP identities, UMTS identities or GSM identities. These should be interpreted as being references to the corresponding ETSI deliverables.

The cross reference between GSM, UMTS, 3GPP and ETSI identities can be found under www.etsi.org/key .

Contents

Foreword

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

The present document may refer to technical specifications or reports using their 3GPP identities, UMTS identities or GSM identities. These should be interpreted as being references to the corresponding ETSI deliverables.

The cross reference between GSM, UMTS, 3GPP and ETSI identities can be found under www.etsi.org/key .

The 3GPP Confidentiality and Integrity Algorithms f8 & f9 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 f8 & f9 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.

Furthermore, Mitsubishi Electric Corporation holds essential patents on the Algorithms. The Beneficiary must get a separate IPR License Agreement from Mitsubishi Electronic Corporation Japan.

For details of licensing procedures, contact ETSI, ARIB, TTA or T1.

The contents of the present document are subject to continuing work within the TSG and may change following formal TSG approval. Should the TSG modify the contents of the present document, it will be re-released by the TSG with an identifying change of release date and an increase in version number as follows:

Version x.y.z

where:

    x   the first digit:

        1   presented to TSG for information;

        2   presented to TSG for approval;

        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 *f8*, and the 3GPP integrity algorithm *f9*.

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

-   3GPP TS 35.201: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the 3GPP Confidentiality and Integrity Algorithms; Document 1: *f8* and *f9* Specification".

-   **3GPP TS 35.202: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the 3GPP Confidentiality and Integrity Algorithms; Document 2: KASUMI Specification".**

- 3GPP TS 35.203: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the 3GPP Confidentiality and Integrity Algorithms; Document 3: Implementors' Test Data".

- 3GPP TS 35.204: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the 3GPP Confidentiality and Integrity Algorithms; Document 4: Design Conformance Test Data".

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 *f8* (confidentiality) and the *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 *f8*, and the 3GPP integrity algorithm *f9*.

NORMATIVE SECTION

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*.

[1]   3GPP TS 33.102 version 3.2.0: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Security Architecture".

[2]   3GPP TS 33.105 version 3.1.0: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Cryptographic Algorithm Requirements".

[3]   3GPP TS 35.201: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the 3GPP Confidentiality and Integrity Algorithms; Document 1: f8 and f9 Specification".

[4]   3GPP TS 35.202: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the 3GPP Confidentiality and Integrity Algorithms; Document 2: KASUMI Specification".

[5]   3GPP TS 35.203: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the 3GPP Confidentiality and Integrity Algorithms; Document 3: Implementors' Test Data".

[6]   3GPP TS 35.204: "3rd Generation Partnership Project; Technical Specification Group Services and System Aspects; 3G Security; Specification of the 3GPP Confidentiality and Integrity Algorithms; Document 4: Design Conformance Test Data".

[7]   ISO/IEC 9797-1:1999: "Information technology – Security techniques – Message Authentication Codes (MACs)".

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:

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

In binary this would be:

$X = 0000000100100011010001010110011110001001101010111100110111101111$

with $P = 0000000100100011$
       $Q = 0100010101100111$
       $R = 1000100110101011$
       $S = 1100110111101111$

2.2.3 Conventions

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

$$<variable> = <expression>$$

we mean that $<variable>$ assumes the value that $<expression>$ 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 subfunctions). Specific instances of the function and/or keys are represented by $XX_{i,j}$ 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.
$\parallel$	The concatenation of the two operands.
<<<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 ith 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 ith 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 **OUTPUT**, as follows:

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

$$\mathbf{I = L_0 \| R_0}$$

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

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

This constitutes the ith 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 **OUTPUT** is equal to the 64-bit string $(L_8 \| R_8)$ 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:

$$\textbf{\textit{OUTPUT}} = \textbf{KASUMI}[\textbf{\textit{I}}]_K$$

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, KI_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 KI_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:

$$\mathbf{f_i(I,RK_i) = FO(\ FL(\ I, KL_i), KO_i, KI_i\ )}$$

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

$$\mathbf{f_i(I,K_i) = FL(\ FO(\ I, KO_i, KI_i\ ), KL_i\ )}$$

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

$$\mathbf{KL_i = KL_{i,1} \| KL_{i,2}.}$$

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

We define:

$$R' = R \oplus ROL(\ L \cap KL_{i,1})$$
$$L' = L \oplus ROL(\ R' \cup KL_{i,2})$$

The 32-bit output value is ($L' \| R'$).

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 $I = L_0 \parallel R_0$.

The 48-bit subkeys are subdivided into three 16-bit subkeys where

$$KO_i = KO_{i,1} \parallel KO_{i,2} \parallel KO_{i,3} \text{ and } KI_i = KI_{i,1} \parallel KI_{i,2} \parallel KI_{i,3}.$$

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 ($L_3 \parallel R_3$).

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 $I = L_0 \parallel R_0$.

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 $KI_{i,j} = KI_{i,j,1} \parallel KI_{i,j,2}$.

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*( ) and *TR*( ). 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:

$$L_1 = R_0 \qquad\qquad R_1 = S9[L_0] \oplus ZE(R_0)$$

$$L_2 = R_1 \oplus KI_{i,j,2} \qquad R_2 = S7[L_1] \oplus TR(R_1) \oplus KI_{i,j,1}$$

$$L_3 = R_2 \qquad\qquad R_3 = S9[L_2] \oplus ZE(R_2)$$

$$L_4 = S7[L_3] \oplus TR(R_3) \qquad R_4 = R_3$$

The function returns the 16-bit value ($L_4 \parallel R_4$).

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:

$$x = x8 \,\|\, x7 \,\|\, x6 \,\|\, x5 \,\|\, x4 \,\|\, x3 \,\|\, x2 \,\|\, x1 \,\|\, x0$$

and

$$y = y8 \,\|\, y7 \,\|\, y6 \,\|\, y5 \,\|\, y4 \,\|\, y3 \,\|\, y2 \,\|\, y1 \,\|\, y0$$

where the $x8, y8$ and $x7, y7$ bits only apply to **S9**, and the $x0$ and $y0$ bits are the least significant bits.

In the logic equations:

> **x0x1x2** implies $x0 \cap x1 \cap x2$ where $\cap$ 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 :

```
y0 =x1x3⊕x4⊕x0x1x4⊕x5⊕x2x5⊕x3x4x5⊕x6⊕x0x6⊕x1x6⊕x3x6⊕x2x4x6⊕x1x5x6
                                                        ⊕x4x5x6
y1 =x0x1⊕x0x4⊕x2x4⊕x5⊕x1x2x5⊕x0x3x5⊕x6⊕x0x2x6⊕x3x6⊕x4x5x6⊕1
y2 =x0⊕x0x3⊕x2x3⊕x1x2x4⊕x0x3x4⊕x1x5⊕x0x2x5⊕x0x6⊕x0x1x6⊕x2x6⊕x4x6⊕1
y3 =x1⊕x0x1x2⊕x1x4⊕x3x4⊕x0x5⊕x0x1x5⊕x2x3x5⊕x1x4x5⊕x2x6⊕x1x3x6
y4 =x0x2⊕x3⊕x1x3⊕x1x4⊕x0x1x4⊕x2x3x4⊕x0x5⊕x1x3x5⊕x0x4x5⊕x1x6⊕x3x6
                                                ⊕x0x3x6⊕x5x6⊕1
y5 =x2⊕x0x2⊕x0x3⊕x1x2x3⊕x0x2x4⊕x0x5⊕x2x5⊕x4x5⊕x1x6⊕x1x2x6⊕x0x3x6
                                                ⊕x3x4x6⊕x2x5x6⊕1
y6 =x1x2⊕x0x1x3⊕x0x4⊕x1x5⊕x3x5⊕x6⊕x0x1x6⊕x2x3x6⊕x1x4x6⊕x0x5x6
```

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,  0,125,118, 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 S7[38] = 58.

For the combinational logic we have:

$$38 = 0100110_2 \quad \Rightarrow \quad x6 = 0,\ x5{=}1,\ x4{=}0,\ x3{=}0,\ x2{=}1,\ x1{=}1,\ x0{=}0$$

which gives us:

$$y0 = 0\oplus0\oplus0\oplus1\oplus1\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0 \quad\quad = 0$$
$$y1 = 0\oplus0\oplus0\oplus1\oplus1\oplus0\oplus0\oplus0\oplus0\oplus0\oplus1 \quad\quad = 1$$
$$y2 = 0\oplus0\oplus0\oplus0\oplus0\oplus1\oplus0\oplus0\oplus0\oplus0\oplus0\oplus1 \quad\quad = 0$$
$$y3 = 1\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0 \quad\quad = 1$$
$$y4 = 0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus1 = 1$$
$$y5 = 1\oplus0\oplus0\oplus0\oplus0\oplus0\oplus1\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus1 = 1$$
$$y6 = 1\oplus0\oplus0\oplus1\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0\oplus0 \quad\quad = 0$$

Thus $y = 0111010_2 = 58$

4.5.2   S9

Gate Logic :

```
y0 = x0x2⊕x3⊕x2x5⊕x5x6⊕x0x7⊕x1x7⊕x2x7⊕x4x8⊕x5x8⊕x7x8⊕1
y1 = x1⊕x0x1⊕x2x3⊕x0x4⊕x1x4⊕x0x5⊕x3x5⊕x6⊕x1x7⊕x2x7⊕x5x8⊕1
y2 = x1⊕x0x3⊕x3x4⊕x0x5⊕x2x6⊕x3x6⊕x5x6⊕x4x7⊕x5x7⊕x6x7⊕x8⊕x0x8⊕1
y3 = x0⊕x1x2⊕x0x3⊕x2x4⊕x5⊕x0x6⊕x1x6⊕x4x7⊕x0x8⊕x1x8⊕x7x8
y4 = x0x1⊕x1x3⊕x4⊕x0x5⊕x3x6⊕x0x7⊕x6x7⊕x1x8⊕x2x8⊕x3x8
y5 = x2⊕x1x4⊕x4x5⊕x0x6⊕x1x6⊕x3x7⊕x4x7⊕x6x7⊕x5x8⊕x6x8⊕x7x8⊕1
y6 = x0⊕x2x3⊕x1x5⊕x2x5⊕x4x5⊕x3x6⊕x4x6⊕x5x6⊕x7⊕x1x8⊕x3x8⊕x5x8⊕x7x8
y7 = x0x1⊕x0x2⊕x1x2⊕x3⊕x0x3⊕x2x3⊕x4x5⊕x2x6⊕x3x6⊕x2x7⊕x5x7⊕x8⊕1
y8 = x0x1⊕x2⊕x1x2⊕x3x4⊕x1x5⊕x2x5⊕x1x6⊕x4x6⊕x7⊕x2x8⊕x3x8
```

Decimal Table :

```
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,  0,333, 44,254,378, 58,143,220, 81,400,
 95,  3,315,245, 54,235,218,405,472,264,172,494,371,290,399, 76,
165,197,395,121,257,480,423,212,240, 28,462,176,406,507,288,223,
501,407,249,265, 89,186,221,428,164, 74,440,196,458,421,350,163,
232,158,134,354, 13,250,491,142,191, 69,193,425,152,227,366,135,
344,300,276,242,437,320,113,278, 11,243, 87,317, 36, 93,496, 27,
487,446,482, 41, 68,156,457,131,326,403,339, 20, 39,115,442,124,
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,
439,506,208,271,349,401,434,236, 16,209,359, 52, 56,120,199,277,
465,416,252,287,246,  6, 83,305,420,345,153,502, 65, 61,244,282,
173,222,418, 67,386,368,261,101,476,291,195,430, 49, 79,166,330,
280,383,373,128,382,408,155,495,367,388,274,107,459,417, 62,454,
132,225,203,316,234, 14,301, 91,503,286,424,211,347,307,140,374,
 35,103,125,427, 19,214,453,146,498,314,444,230,256,329,198,285,
 50,116, 78,410, 10,205,510,171,231, 45,139,467, 29, 86,505, 32,
 72, 26,342,150,313,490,431,238,411,325,149,473, 40,119,174,355,
185,233,389, 71,448,273,372, 55,110,178,322, 12,469,392,369,190,
  1,109,375,137,181, 88, 75,308,260,484, 98,272,370,275,412,111,
336,318,  4,504,492,259,304, 77,337,435, 21,357,303,332,483, 18,
 47, 85, 25,497,474,289,100,269,296,478,270,106, 31,104,433, 84,
414,486,394, 96, 99,154,511,148,413,361,409,255,162,215,302,201,
266,351,343,144,441,365,108,298,251, 34,182,509,138,210,335,133,
311,352,328,141,396,346,123,319,450,281,429,228,443,481, 92,404,
485,422,248,297, 23,213,130,466, 22,217,283, 70,294,360,419,127,
312,377,  7,468,194,  2,117,295,463,258,224,447,247,187, 80,398,
284,353,105,390,299,471,470,184, 57,200,348, 63,204,188, 33,451,
 97, 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, 59,461
```

Example:

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

For the combinational logic we have:

$$138 = 010001010_2 \quad \Rightarrow \quad x8 = 0, x7 = 1, x6 = 0, x5=0, x4=0, x3=1, x2=0, x1=1, x0=0$$

which gives us:

$$y0 = 0{\oplus}1{\oplus}0{\oplus}0{\oplus}0{\oplus}1{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}1 \qquad\qquad = 1$$

$$y1 = 1{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}1{\oplus}0{\oplus}0{\oplus}1 \qquad\qquad = 1$$

$$y2 = 1{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}1 \qquad\qquad = 0$$

$$y3 = 0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0 \qquad\qquad = 0$$

$$y4 = 0{\oplus}1{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0 \qquad\qquad = 1$$

$$y5 = 0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}1{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}1 \qquad\qquad = 0$$

$$y6 = 0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}1{\oplus}0{\oplus}0{\oplus}0{\oplus}0 \qquad\qquad = 1$$

$$y7 = 0{\oplus}0{\oplus}0{\oplus}1{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}1 \qquad\qquad = 0$$

$$y8 = 0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}0{\oplus}1{\oplus}0{\oplus}0 \qquad\qquad = 1$$

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 Kj and Kj' (j=1 to 8) are derived in the following manner:

The 128-bit key K is subdivided into eight 16-bit values $K1…K8$ where

$$K = K1 \parallel K2 \parallel K3 \parallel … \parallel K8.$$

A second array of subkeys, Kj' is derived from Kj by applying:

For each integer j with $1 \le j \le 8$

$$Kj' = Kj \oplus Cj$$

Where Cj is the constant value defined in table 2.

The round subkeys are then derived from Kj and Kj' in the manner defined in table 1.

Table 1: Round subkeys

	1	2	3	4	5	6	7	8
$KL_{i,1}$	K1<<<1	K2<<<1	K3<<<1	K4<<<1	K5<<<1	K6<<<1	K7<<<1	K8<<<1
$KL_{i,2}$	K3′	K4′	K5′	K6′	K7′	K8′	K1′	K2′
$KO_{i,1}$	K2<<<5	K3<<<5	K4<<<5	K5<<<5	K6<<<5	K7<<<5	K8<<<5	K1<<<5
$KO_{i,2}$	K6<<<8	K7<<<8	K8<<<8	K1<<<8	K2<<<8	K3<<<8	K4<<<8	K5<<<8
$KO_{i,3}$	K7<<<13	K8<<<13	K1<<<13	K2<<<13	K3<<<13	K4<<<13	K5<<<13	K6<<<13
$KI_{i,1}$	K5′	K6′	K7′	K8′	K1′	K2′	K3′	K4′
$KI_{i,2}$	K4′	K5′	K6′	K7′	K8′	K1′	K2′	K3′
$KI_{i,3}$	K8′	K1′	K2′	K3′	K4′	K5′	K6′	K7′

Table 2: Constants

C1	0x0123
C2	0x4567
C3	0x89AB
C4	0xCDEF
C5	0xFEDC
C6	0xBA98
C7	0x7654
C8	0x3210

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
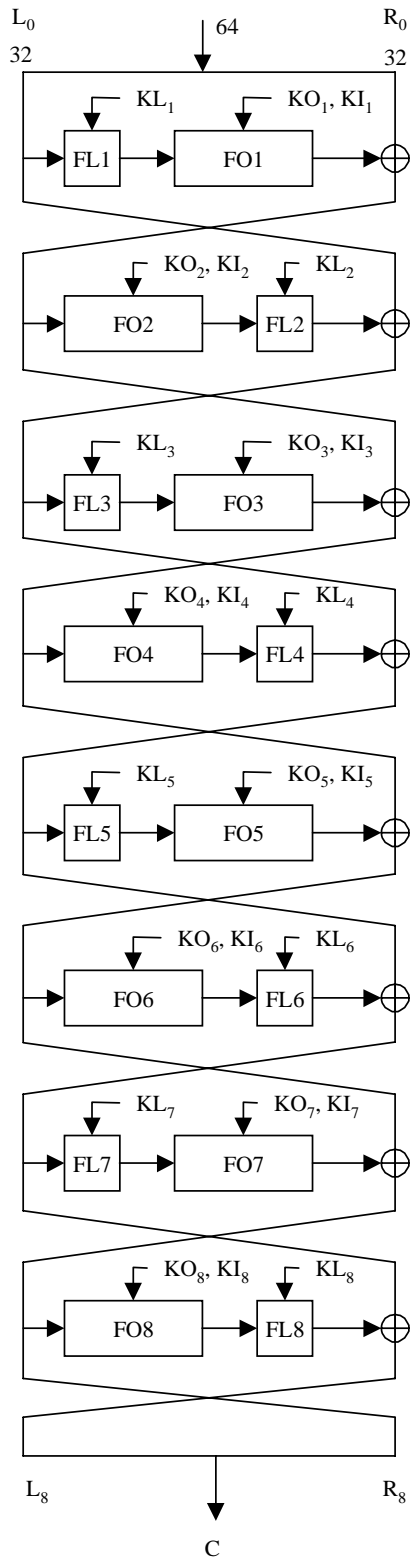
Fig. 1: KASUMI
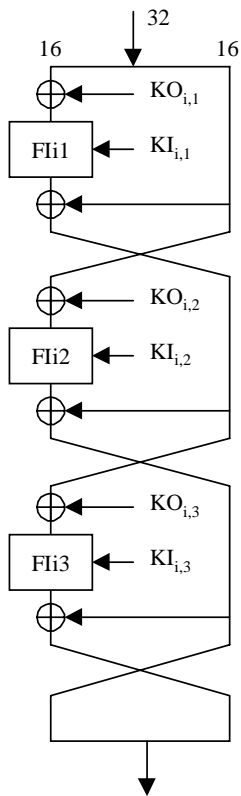
Fig.2: FO Function
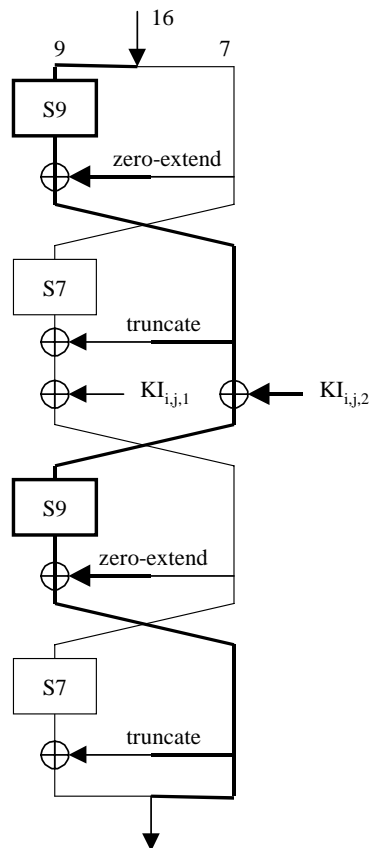
Fig.3: FI Function
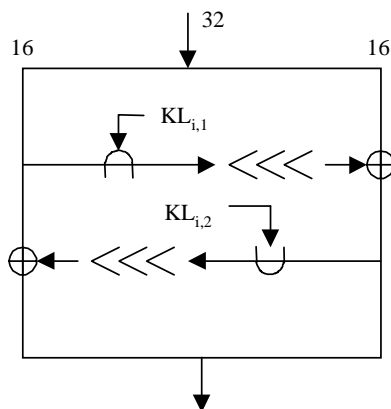
Fig.4: FL Function

∩   bitwise AND operation

∪   bitwise OR operation

<<<   one bit left rotation

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 $FI_{i,1}$ and $FI_{i,2}$ operations may be carried out in parallel (see alternative presentation in figure 6).
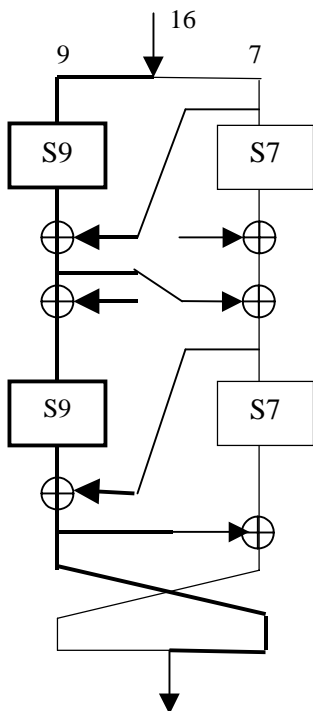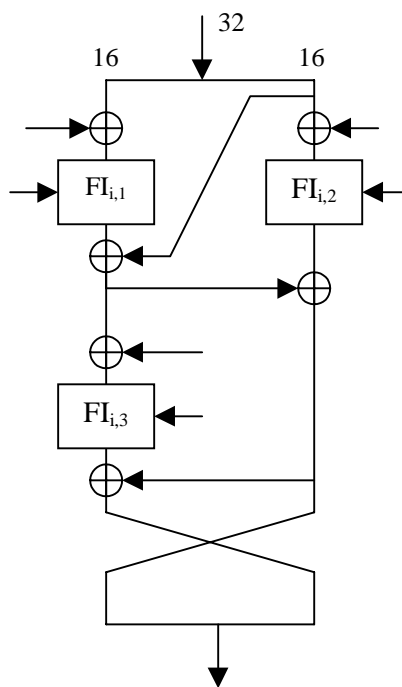
Fig.5: FI Function   Fig.6: FO Function

Annex 2 (informative): Simulation Program Listing

Header file

```
/*----------------------------------------------------------
 *                    Kasumi.h
 *--------------------------------------------------------*/

typedef unsigned  char   u8;
typedef unsigned short   u16;
typedef unsigned  long   u32;

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

C Code

```
/*---------------------------------------------------------------------
 *                      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 KLi1[8], KLi2[8];
static u16 KOi1[8], KOi2[8], KOi3[8];
static u16 KIi1[8], KIi2[8], KIi3[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 )
{
    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,
```

```
        117,116, 76, 11, 89,106, 0,125,118, 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};
    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,  0,333, 44,254,378, 58,143,220, 81,400,
         95,  3,315,245, 54,235,218,405,472,264,172,494,371,290,399, 76,
        165,197,395,121,257,480,423,212,240, 28,462,176,406,507,288,223,
        501,407,249,265, 89,186,221,428,164, 74,440,196,458,421,350,163,
        232,158,134,354, 13,250,491,142,191, 69,193,425,152,227,366,135,
        344,300,276,242,437,320,113,278, 11,243, 87,317, 36, 93,496, 27,
        487,446,482, 41, 68,156,457,131,326,403,339, 20, 39,115,442,124,
        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,
        439,506,208,271,349,401,434,236, 16,209,359, 52, 56,120,199,277,
        465,416,252,287,246,  6, 83,305,420,345,153,502, 65, 61,244,282,
        173,222,418, 67,386,368,261,101,476,291,195,430, 49, 79,166,330,
        280,383,373,128,382,408,155,495,367,388,274,107,459,417, 62,454,
        132,225,203,316,234, 14,301, 91,503,286,424,211,347,307,140,374,
         35,103,125,427, 19,214,453,146,498,314,444,230,256,329,198,285,
         50,116, 78,410, 10,205,510,171,231, 45,139,467, 29, 86,505, 32,
         72, 26,342,150,313,490,431,238,411,325,149,473, 40,119,174,355,
        185,233,389, 71,448,273,372, 55,110,178,322, 12,469,392,369,190,
          1,109,375,137,181, 88, 75,308,260,484, 98,272,370,275,412,111,
        336,318,  4,504,492,259,304, 77,337,435, 21,357,303,332,483, 18,
         47, 85, 25,497,474,289,100,269,296,478,270,106, 31,104,433, 84,
        414,486,394, 96, 99,154,511,148,413,361,409,255,162,215,302,201,
        266,351,343,144,441,365,108,298,251, 34,182,509,138,210,335,133,
        311,352,328,141,396,346,123,319,450,281,429,228,443,481, 92,404,
        485,422,248,297, 23,213,130,466, 22,217,283, 70,294,360,419,127,
        312,377,  7,468,194,  2,117,295,463,258,224,447,247,187, 80,398,
        284,353,105,390,299,471,470,184, 57,200,348, 63,204,188, 33,451,
         97, 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, 59,461};

    /* 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 );
}


/*---------------------------------------------------------------------
 * FO()
 *      The FO() function.
 *      Transforms a 32-bit value.  Uses <index> to identify the
 *      appropriate subkeys to use.
 *-------------------------------------------------------------------*/
static u32 FO( u32 in, int index )
{
    u16 left, right;

    /* Split the input into two 16-bit words */

    left  = (u16)(in>>16);
    right = (u16) in;

    /* Now apply the same basic transformation three times        */
```

```
    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 (endian corect) */

    d = (DWORD*)data;
    left  = (((u32)d[0].b8[0])<<24)+(((u32)d[0].b8[1])<<16)
+(d[0].b8[2]<<8)+(d[0].b8[3]);
    right = (((u32)d[1].b8[0])<<24)+(((u32)d[1].b8[1])<<16)
+(d[1].b8[2]<<8)+(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);
```

```
    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);
}

/*----------------------------------------------------------------------
 * KeySchedule()
 *      Build the key schedule.  Most "key" operations use 16-bit
 *      subkeys so we build u16-sized arrays that are "endian" correct.
 *----------------------------------------------------------------------*/
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);
        KIi1[n] = Kprime[(n+4)&0x7];
        KIi2[n] = Kprime[(n+3)&0x7];
        KIi3[n] = Kprime[(n+7)&0x7];
    }
}
/*----------------------------------------------------------------------
 *            e n d   o f   k a s u m i . c
 *----------------------------------------------------------------------*/
```

Annex 3 (informative):
Change history

Change history								
Date	TSG #	TSG Doc.	CR	Rev	Subject/Comment		Old	New
12-1999	-	-	-	-	ETSI SAGE Publication (restricted)		-	SAGE v1.0
05-2000	-	-	-	-	ETSI SAGE update: Small change to sample code (portability issue)		SAGE v1.0	SAGE v1.1
09-2000	SA_07				Approved by TSG SA and placed under change control		SAGE v1.1	3.1.0
07-2001	-	-	-	-	Word version received: Re-formatted into 3GPP TS format (MCC) No technical change from version 3.1.0.		3.1.0	3.1.1
08-2001	-				Addition of Mitsubishi IPR information in Foreword and correction of reference titles. No technical change from version 3.1.0.		3.1.1	3.1.2
08-2001	-	-	-	-	Release 4 version created.		3.1.2	4.0.0
06-2002	-	-	-	-	Release 5 version created.		4.0.0	5.0.0

History

Document history		
V5.0.0	June 2002	Publication