Freescale Semiconductor
Application Note

AN2837
Rev. 0, 9/2004

KASUMI Block Cipher on the StarCore SC140 Core

by Mao Zeng

With the rapid growth of wireless services, security in wireless communications has become ever more crucial. Various security algorithms have been developed for wireless systems to provide users with effective and secure communications. The KASUMI block cipher is widely used for security in many synchronous wireless standards. For example, the A5/3 encryption algorithm used in GSM high-level protection against eavesdropping, the GEA3 algorithm adopted by GPRS for data confidentiality, and the ***f8*/*f9*** algorithms specified in 3GPP systems for confidentiality and data integrity are all algorithms based on the 64-bit KASUMI block cipher. The KASUMI is based on a previous block cipher known as MISTY1, which was chosen as the foundation for the 3GPP ciphering algorithm because of its proven security against the most advanced methods for breaking block ciphers, namely cryptanalysis techniques. *KASUMI* is the Japanese word for *misty.* This application note describes how to implement the KASUMI cipher on a Freescale StarCore™-based SC140 DSP.

CONTENTS

1 Basics of the KASUMI Block Cipher

The KASUMI is a Feistel cipher with eight rounds (see **Figure 1**). It operates on a 64-bit data block ***I*** using a 128-bit key ***K***. The 64-bit input string ***I*** is divided into two 32-bit strings L_0 and R_0, where $I = L_0 \| R_0$. For each integer i with $1 \le i \le 8$, the i^{th} round function of KASUMI is constituted as shown in **Equation 1**.

Equation 1

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

where ***fi*** denotes the round function with L_{i-1} and round key RK_i as inputs. The output result of the KASUMI is equal to the 64-bit string ($L_8 \| R_8$) offered at the end of the eighth round. The ***fi()*** function takes a 32-bit input and returns a 32-bit output 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 sub-functions:

- ***FL()***.Takes a 32-bit data input and a 32-bit subkey KL_i, and it returns a 32-bit output, as shown in **Figure 1**. The main operations of the ***FL*** function are 16-bit AND operations, 16-bit OR operations, and 1-bit left rotation operations.
- ***FO()***. Takes a 32-bit data input and two sets of subkeys, a 48-bit subkey KO_i and a 48-bit sub-key KI_i, and it generates a 32-bit data output. The ***FO*** function comprises three ***FI*** functions and six XOR operations.

The ***FI*** function takes a 16-bit data input and 16-bit sub-key $KI_{i,j}$. Two S-boxes are ***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, are used in the ***FI*** function to provide non-linearity to KASUMI. The details of the ***FI*** function and the S-boxes are defined in [2]. The *fi()* function has two different forms, depending on whether it is an even or odd round. For rounds 1, 3, 5, and 7, it is defined as shown in **Equation 2**.

Equation 2

$$f_i(I, RK_i) = FO(FL(I, LK_i)KO_iKI_i)$$

For rounds 2, 4, 6, and 8, it is defined as shown in **Equation 3**.

Equation 3

$$f_i(I, RK_i) = FL(FO(I, KO_i, \mathrm{KI}_i)KL_i)$$

See **Appendix A** for a detailed C implementation of the KASUMI cipher.

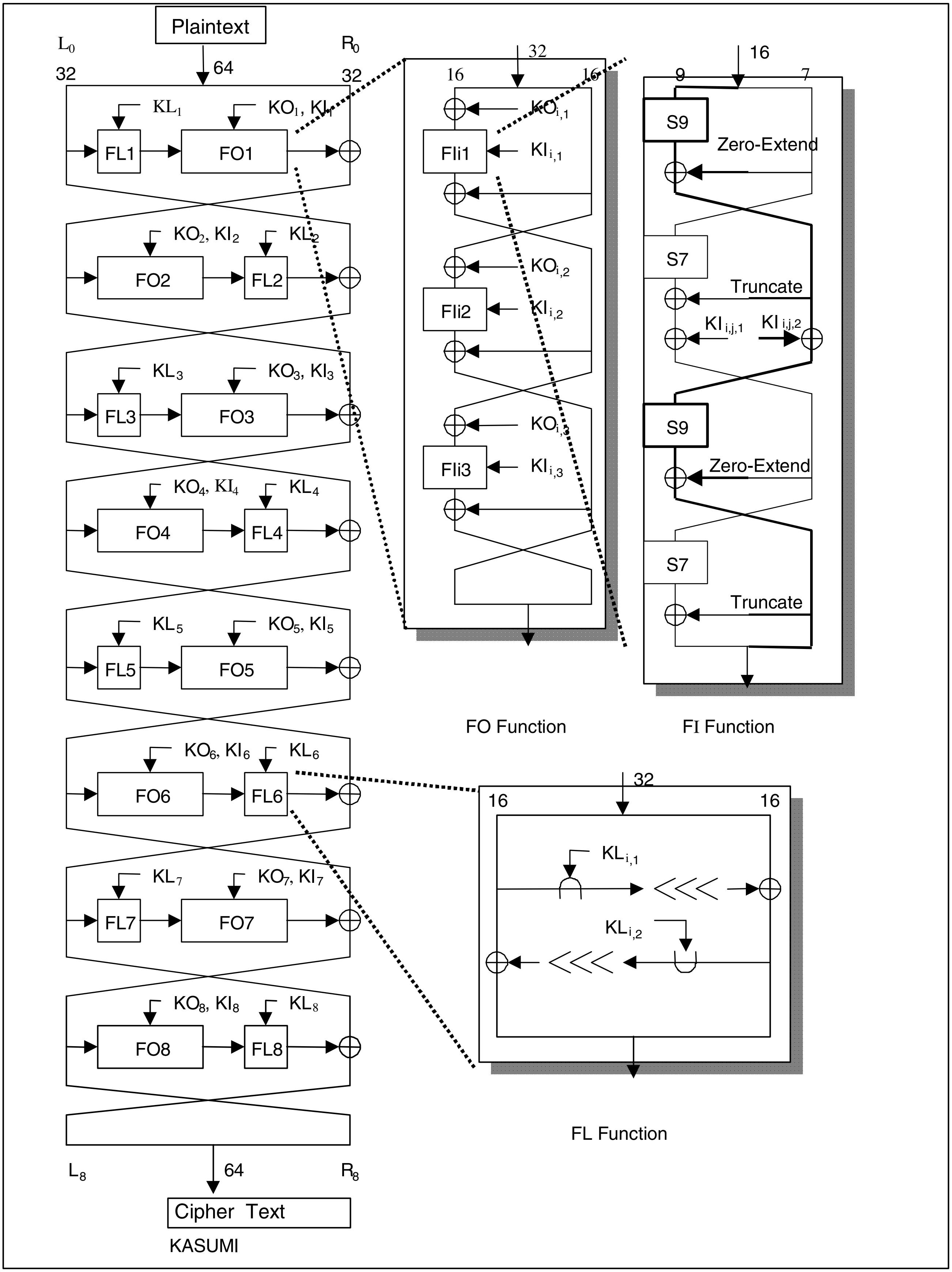

Figure 1. Components of the KASUMI Block Cipher

2 StarCore Implementation

The StarCore SC140 core is a flexible programmable DSP core that enables the emergence of computationally-intensive communications applications by providing exceptional performance, low power consumption, efficient compatibility, and compact code density. This core efficiently deploys a variable-length execution set (VLES) execution model that achieves maximum parallelism by allowing two address generation and four data arithmetic logic units to execute multiple instructions in a single clock cycle.[1] The SC140 core requires programmers to consider both data-level parallelism (DLP) and instruction-level parallelism (ILP). This section describes the implementation and optimization of the KASUMI cipher on the SC140 core.

2.1 Code Development

Writing functions directly in assembly usually offers the greatest flexibility in optimizing code. However, this method is a very challenging and time-consuming, and it makes debugging the code more difficult. Therefore, our code development and optimization processes are based on a C implementation. The main steps in this implementation process enable us to achieve high-performance code for the SC140 core in a reasonably short time:

1. Port the code to the SC140 core and profile it using the StarCore adaptations and optimization strategies.
2. Transform the algorithm using function-level C optimization techniques.
3. Implement selected functions in assembly for maximum code performance and minimum code size.

2.2 Optimization in C

To optimize the code, we first port the reference 3GPP C code to the SC140 core. 3GPP provides two set of test vectors for confidentiality algorithm ***f8*** and integrity algorithm ***f9***, respectively. We use the test data for ***f8*** for verification. The profiler information with the –O3 optimization option is listed in **Table 1**.

Table 1. Profiler Information of the 3GPP Reference Code

Functions	FI	FO	FL	KASUMI	Key Schedule
Cycle count	23	102	21	1092	220
Size	142	160	74	318	646

Based on the profiler information and the observations on the assembly code generated by the SC140 compiler, several optimization techniques, including function inlining, unique data typing, pipelining, and loop merging, are applied in the C implementation to improve the performance.

2.2.1 Function Inlining

Function inlining improves execution time by eliminating function-call overhead at the expense of larger code size. The KASUMI profiler information indicates that the overhead of a function-call is more than 20 percent for the ***FI*** and ***FL*** functions. Therefore, we inline these two functions to speed up execution.

---

[1] For details, refer to the S*C140 DSP Core Reference Manual*, which is available at the web site listed on the back cover of this document.

Functions can be inlined in one of three ways:

- Implicitly, allowing the compiler to select the functions to be inlined. This is done in the Enterprise C compiler by setting the `-Og` compiler option.
- Explicitly, using the `#pragma` inline C statement. To inline a function in several files, place the function in a head file and use the static keyword in each file to prevent the linker from generating duplicate global symbols.
- Manually replacing a function call within the body of the function.

We use the first and the third methods for ***FL*** and ***FI***, respectively. Because ***FO*** calls the ***FI*** function three times, as illustrated in **Figure 1**, inlining the ***FI*** function significantly increases code size. We modify the ***FO*** function by merging the three ***FI*** function calls into a DO-loop, as illustrated **Example 1**, to reduce code size without reducing efficiency.

Example 1. Modified C Code for the FO Function

```
/******************* Code Before modification *********************/
/* 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 );                                               */
/* }                                                              */
/******************************************************************/

static u32 FO( u32 in, int index )
{
      u16 x, y, temp;
      int i;
      /* Split the input into two 16-bit words */
      x  = (u16)(in>>16);
      y = (u16) in;

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

```
            for(i=0; i<3; i++)
            {
                  x ^= KOi[i][index];
                  temp  = FI( x, Kli[i][index] );
                  x = y;
                  y ^= temp;
            }

            in = (((u32)x)<<16)+ y;

            return( in );
      }
```

2.2.2 Data Typing

Using unique data types for the intermediate local variables can prevent the compiler from generating unnecessary data transformation operations, such as sign extension, zero extension, and shift left or right by 16-bit, and so on. Using a 32-bit integer type for intermediate variables can reduce the critical path of computation and thus increase execution speed in some cases.

2.2.3 Pipelining

In the ***FO*** function, there are small data dependencies within two adjacent function calls of ***FI***. Software pipelining can be used to implement the three ***FI*** function calls in ***FO***, as illustrated in **Figure 2**. Pipelining allows us to take advantage of instruction-level parallelism of the SC140 core and thereby reduce the number of overall execution cycles.

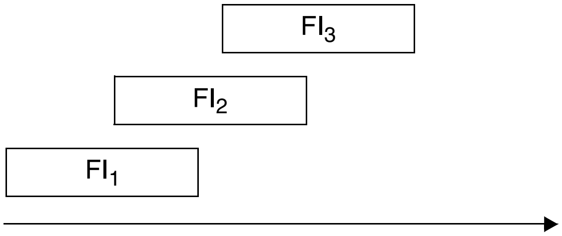

Figure 2. Pipelining of FI Function Calls

To assist the C compiler in software pipelining, the initial reference to the C code must be modified to eliminate variable dependencies by introducing more local variables for intermediate computational results. However, too many local variables may cause use of the stack for data passing, which costs extra execution cycles (two cycles for each stack access). Therefore, we take special care when introducing temporary variables. The modified C code for ***FI*** is shown in **Example 2**.

Example 2. Modified C Code for FI

```
// FI function
nine1  = x >> 7;
seven1 = x & 0x7F;

/* Now run the various operations */
nine1  = S9[nine1]  ^ seven1;
seven1 = S7[seven1] ^ (nine1 & 0x7F);
```

```
seven2 = seven1 ^ L_shr(subkey, 9);
nine2  = nine1  ^ (subkey&0x1FF);

nine2  = S9[nine2]  ^ seven2;
seven2 = S7[seven2] ^ (nine2 & 0x7F);

temp = (seven2<<9)  + nine2;
```

2.2.4 Loop Merging

Combining multiple loops into a single loop can reduce the size of the generated code and increase instruction-level parallelism, thus increasing speed. **Example 3** shows a section of code in KeySchedule() after loop merging.

Example 3. Loop Merging

```
/***************** Before loop merging ************************* */
/*     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]);                     */
/*                                                                  */
/*************************************************************** */

       /* Now build the K'[] keys */

       for( n=0; n<8; ++n )
       {
              key[n] = (u16)((k[2*n]<<8) + (k[2*n+1]));
              Kprime[n] = (u16)(key[n] ^ C[n]);
       }
```

2.3 Optimization in Assembly

Assembly-level code optimization can maximize execution speed and increase code density. We used the optimized C code and the following strategies to perform the assembly-level optimization:

- To reduce the data critical path and shorten execution time, use the special SC140 instruction ADDL1A to replace ASLA and ADDA in the table look-up operations.
- Shorten the initialization process by reducing data pointers.
- Use equivalent implementation transformations for data packing operations. For example, use the IMAC instruction to realize *(seven<<9)* + *nine* in the FI function.
- Use circular buffers to access data arrays of key[n] and Kprime[n] in sub-key constructions.
- To reduce code size, use the D[0–8] data registers and the R[0–8] address registers as long as possible.

When speed is of utmost concern, you can eliminate the overhead of function calls by inlining the ***FO*** functions. Most importantly, the redundant data packing/unpacking operations can also be eliminated after function inlining. Also, you can use hardware loops and loop nesting for efficient loop execution.

3 Performance Results

Table 2 summarizes the performance of the KASUMI cipher on the SC140 core at different optimization levels. The optimized assembly code is provided in **Appendix B**.

Table 2. Performance of the KASUMI Cipher on the SC140 Core

Optimization Level	Speed		Size	
	KASUMI	Key Schedule	Code	Data
Reference C (–O3)	1092	220	1350	1424
Optimized C (–O3)	576	203	1206	1296
Assembly (speed and size)	467	112	850	1296
Assembly (speed)	412	112	1042	1296

4 References

[1] 3GPP TS 35.202 V5.0.0, “Technical Specification Group Services and System Aspects, 3G Security,” *Specification of the 3GPP Confidentiality and Integrity Algorithms*, Document 1: f8 and f9 Specification. June, 2002.

[2] 3GPP TS 35.202 V5.0.0, “Technical Specification Group Services and System Aspects, 3G Security,” *Specification of the 3GPP Confidentiality and Integrity Algorithms*, Document 2: KASUMI Specification. June, 2002.

[3] 3GPP TS 35.202 V5.0.0, Technical Specification Group Services and System Aspects, 3G Security, *Specification of the 3GPP Confidentiality and Integrity Algorithms*, Document 4: Design Conformance Test Data. June, 2002.

[4] *SC140 DSP Core Reference Manual*, Freescale Semiconductor.

Appendix A:
Reference Code

```
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
 *---------------------------------------------------------------------*/
```

Appendix B:
Optimized Assembly code

```
;*******************************************************************************
; COPYRIGHT © 2004  FreeScale Semiconductor INC.
; FreeScale  Semiconductor
; DSPP, Austin
;*******************************************************************************
;
; FILE NAME: Kasumi.asm
; LANGUAGE (optional): Assembly
; TARGET PROCESSOR: Star*Core 140
;
;*************************** PURPOSE *******************************************
;
; DESCRIPTION : Implementation of Kasumi cipher defined by 3GPP TS 35.202
;
; REFERENCES (optional): None.
;
;*************************** INPUT AND OUTPUT **********************************
;
; INPUT: pointer to data --- R0
;
; OUTPUT: none
;
; SCRATCH VARIABLES:
;
; IMPORTED REFERENCES: None.
;
; EXPORTED REFERENCES: None.
;
;***************************** RESOURCES ***************************************
;
; REGISTERS USED:  d0 - d7, d14, d15, r0 - r12, m0 - m2, n0 - n3
;
; REGISTERS CHANGED: all above registers except d6, d7, r6, r7.
;
; CYCLE COUNT:
;   Typical = 412
;
; SIZE: 1042 bytes (code) + 1296 bytes (data)
;
;*************************** REVISION HISTORY **********************************
;
; MM/DD/YYYY   Author        CR Number        Brief Description
; ----------- -------------- ---------------- ----------------------------------
; 07/01/2004  Mao Zeng                         created the code - optimized for
;                                              for speed
;
;************************** ASSEMBLY CODE *************************************

      SECTIONKasumi_dataLOCAL
      SECFLAGS ALLOC,WRITE,NOEXECINSTR
      ALIGN  8
```

```
             SECTYPE PROGBITS
      __C    TYPE VARIABLE
             SIZE __C,16,8
          DCW      291,17767,35243,52719,65244,47768,30292,12816  ; offset = 0
      _S9    TYPE VARIABLE
             SIZE _S9,1024,2
          DCW      167,239,161,379,391,334,9,338,38,226,48,358,452,385  ; offset = 16
          DCW      90,397,183,253,147,331,415,340,51,362,306,500,262,82,216
          DCW      159,356,177,175,241,489,37,206,17,0,333,44,254,378,58
          DCW      143,220,81,400,95,3,315,245,54,235,218,405,472,264,172
          DCW      494,371,290,399,76,165,197,395,121,257,480,423,212,240,28
          DCW      462,176,406,507,288,223,501,407,249,265,89,186,221,428,164
          DCW      74,440,196,458,421,350,163,232,158,134,354,13,250,491,142
          DCW      191,69,193,425,152,227,366,135,344,300,276,242,437,320,113
          DCW      278,11,243,87,317,36,93,496,27,487,446,482,41,68,156
          DCW      457,131,326,403,339,20,39,115,442,124,475,384,508,53,112
          DCW      170,479,151,126,169,73,268,279,321,168,364,363,292,46,499
          DCW      393,327,324,24,456,267,157,460,488,426,309,229,439,506,208
          DCW      271,349,401,434,236,16,209,359,52,56,120,199,277,465,416
          DCW      252,287,246,6,83,305,420,345,153,502,65,61,244,282,173
          DCW      222,418,67,386,368,261,101,476,291,195,430,49,79,166,330
          DCW      280,383,373,128,382,408,155,495,367,388,274,107,459,417,62
          DCW      454,132,225,203,316,234,14,301,91,503,286,424,211,347,307
          DCW      140,374,35,103,125,427,19,214,453,146,498,314,444,230,256
          DCW      329,198,285,50,116,78,410,10,205,510,171,231,45,139,467
          DCW      29,86,505,32,72,26,342,150,313,490,431,238,411,325,149
          DCW      473,40,119,174,355,185,233,389,71,448,273,372,55,110,178
          DCW      322,12,469,392,369,190,1,109,375,137,181,88,75,308,260
          DCW      484,98,272,370,275,412,111,336,318,4,504,492,259,304,77
          DCW      337,435,21,357,303,332,483,18,47,85,25,497,474,289,100
          DCW      269,296,478,270,106,31,104,433,84,414,486,394,96,99,154
          DCW      511,148,413,361,409,255,162,215,302,201,266,351,343,144,441
          DCW      365,108,298,251,34,182,509,138,210,335,133,311,352,328,141
          DCW      396,346,123,319,450,281,429,228,443,481,92,404,485,422,248
          DCW      297,23,213,130,466,22,217,283,70,294,360,419,127,312,377
          DCW      7,468,194,2,117,295,463,258,224,447,247,187,80,398,284
          DCW      353,105,390,299,471,470,184,57,200,348,63,204,188,33,451
          DCW      97,30,310,219,94,160,129,493,64,179,263,102,189,207,114
          DCW      402,438,477,387,122,192,42,381,5,145,118,180,449,293,323
          DCW      136,380,43,66,60,455,341,445,202,432,8,237,15,376,436
          DCW      464,59,461
      _KOIi  TYPE VARIABLE
             SIZE _KOIi,96,2
          DS       96                   ; offset = 1040
      _KLi   TYPE VARIABLE
             SIZE _KLi,32,2
          DS       32                   ; offset = 1136
      _S7    TYPE VARIABLE
             SIZE _S7,128,1
          DCB
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
; offset = 1168
          DCB
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
```

```
          DCB
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
          DCB
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
          DCB      41,88,119,59,3

             ENDSEC


             SECTION Kasumi_code LOCAL
             SECFLAGS ALLOC,NOWRITE,EXECINSTR
             SECTYPE PROGBITS
      TextStart_Kasumi


      ;*********************************************************************
      ;
      ; Function _Kasumi, ; Stack frame size: 0
      ;
      ; Calling Convention: 1
      ;
      ; Parameter data   passed in register r0
      ;
      ; Returned value  ret__Kasumi_1_FL   optimized out
      ;
      ;*********************************************************************

             GLOBAL _Kasumi
             ALIGN  16
      _KasumiTYPE   func OPT_SPEED
             SIZE _Kasumi,F_Kasumi_end-_Kasumi,16
       [
          tfr      d6,d14            ;save d6,d7
          tfr      d7,d15            ;
          adda     #>4,r0,r11        ;r11 = &data[4]
          tfra     r0,r10            ;r10 = &data[0]
       ]
       [
          dosetup2 L3
          doen2  #4
       ]
       [
          moveu.b  (r10)+,d7         ; data[0]
          moveu.b  (r11)+,d6         ; data[4]
       ]
       [
          asll     #<24,d7           ; data[0]<<24
          asll     #<24,d6           ; data[4]<<24
          moveu.b  (r10)+,d1         ; data[1]
          moveu.b  (r11)+,d2         ; data[5]
       ]
       [
          aslw     d1,d3             ; data[1]<<16
```

```
         aslw     d2,d4             ; data[5]<<16
         moveu.b  (r10)+,d1         ; data[2]
         moveu.b  (r11)+,d2         ; data[6]
      ]
      [
         asll     #8,d1             ; data[2]<<16
         asll     #8,d2             ; data[6]<<16
         or       d3,d7
         or       d4,d6
         tfra     r7,r9             ;save r7
         moveu.b  (r11),d4          ; data[7]
      ]
      [
         or       d1,d7
         or       d2,d6
         moveu.b  (r10),d3          ; data[3]
         move.l   #_KLi,r7          ; r7 = &KLi
      ]
      [
         or       d3,d7     ; d7 = left
         or       d4,d6     ; d6 = right
         tfra     r6,r8             ; save r6
         move.l   #_KLi+16,r12      ; r12 = &KLi + 8
      ]
      [
           tfr      d4,d4             ; loop alignment
           tfr      d5,d5             ; loop alignment
         move.l   #_KOIi,r6         ;
      ]

         FALIGN
         LOOPSTART2
     L3
     ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
     ;;  inline FL(left, n)
     ;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
      [
         extractu #<16,#<16,d7,d1   ; l = (u16)(in>>16)
         zxt.w    d7,d3             ; r = (u16)in
         moveu.w  (r7)+,d4          ; KLi1[index]
         moveu.w  (r12)+,d5         ; KLi2[index]
      ]
      [
         and      d1,d4             ; a = i&KLi1[index]
         tfra     r6,r1             ;
      ]
      [
         extractu #<1,#<15,d4,d0    ; for ROL16(a,1)
         asll     #<1,d4            ; for ROL16(a,1)
      ]
      [
         eor      d3,d0             ; for r^=ROL16(a,1)
         zxt.w    d4,d2
         adda     #<2,r6
      ]
```

```
    eor      d2,d0             ; d0 = r^=ROL16(a,1)
    or       d0,d5             ; b = r|KLi2[index]
 [
    extractu #<1,#<15,d5,d4    ; for ROL16(b,1)
    asll     #<1,d5            ; for ROL16(b,1)
 ]
 [
    eor      d1,d4             ; for l^= ROL16(b,1)
    zxt.w    d5,d3             ;
 ]
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;  inline FO(temp,n++)
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
 [
    eor      d3,d4             ; d4 = left, d0 = right
    move.w   #8,n3
    moveu.w  (r1),d3   ; d3 = KOi[index]
 ]
 [
    eor      d3,d4             ; x^KOi[index]
    move.l   #_S9,r0           ; r0 = S9
      adda     #16,r1
 ]
 [
    extractu #<16,#<7,d4,d1    ; nine1 = x>>7
    and      #127,d4,d5        ; seven1 = x & 0x7F
    moveu.w  (r1)+n3,d2        ; d2 = subkey
    doen3    #2                ;
 ]
 [
    and      #511,d2,d4        ; d4 = subkey&0x1FF
    asrr     #<9,d2            ; d2 = subkey>>9
    move.l   d1,r3             ; r3 = nine1
    move.l   d5,r5             ; r5 = seven1
 ]
 [
    tfra     r0,r4             ; r4 = S9
    move.l   #_S7,r2
 ]
 [
    dosetup3 L22A
      addl1a   r3,r4         ; &S9[nine1]
 ]
 [
    moveu.w  (r4),d3           ; d6 = S9[nine1]
    adda     r2,r5             ; &S7[seven1]
 ]
 [
    eor      d3,d5             ; nine1=S9[nine1]^seven1
    push     d6
    push     d7
 ]
 [
    eor      d5,d4             ; nine2 = nine1^(subkey&0x1FF)
    and      #127,d5,d6        ; nine1&0x7F
```

```
    moveu.b  (r5),d1           ; d1 = S7[seven1]
 ]
 [
    eor      d1,d6             ; seven1 = S7[seven1]^(nine1&0x7F)
    tfr      d0,d4             ; d4 = x = y
    move.l   d4,r3             ; r3 = nine2
    tfra     r0,r4
 ]

    FALIGN
    LOOPSTART3
L22A

 [
    eor      d6,d2             ; seven2 = seven1^(subkey>>9)
    moveu.w  (r1)+n3,d3        ; KOi[index]
 ]
 [
    addl1a   r3,r4             ; &S9[nine2]
    move.l   d2,r5             ; r5 = seven2
 ]
 [
    eor      d3,d4             ; x^KOi[index]
    moveu.w  (r4),d6           ; S9[nine2]
 ]
 [
    extractu #<16,#<7,d4,d7    ; nine1 = x>>7
    eor      d6,d2             ; nine2 = S9[nine2]^seven2
    and      #127,d4,d1        ; seven1 = x&0x7F
    adda     r2,r5             ; &S7[seven2]
    moveu.w  (r1)+n3,d5        ; subkey = KIi[index]
 ]
 [
    and      #127,d2,d4        ; nine2&0x7F
    and      #511,d5,d3        ; subkey & 0x1FF
    move.l   d7,r3             ; r3 = nine1
    moveu.b  (r5),d6           ; d6 = S7[seven2]
 ]
 [
    eor      d6,d4             ; seven2 = S7[seven2]^(nine2&0x7F)
       tfra     r0,r4
       move.w   #512,d6
 ]
 [
    imac d6,d4,d2      ; temp = (seven2<<9)+nine2
    move.l   d1,r5             ; r5 = seven1
    addl1a   r3,r4     ; &S9[nine1]
 ]
 [
    eor      d2,d0             ; y^=temp
    tfr      d5,d2             ; subkey
    moveu.w  (r4),d6           ; S9[nine1]
 ]
 [
    eor      d6,d1             ; nine1=S9[nine1]^seven1
```

```
    asrr     #<9,d2             ; subkey >> 9
    tfr      d0,d4              ; x = y
    adda     r2,r5     ; &S7[seven1]
 ]
 [
    eor      d1,d3              ; nine2=nine1^(subkey&0x1FF)
    and      #127,d1,d6         ; nine1&0x7F
    moveu.b  (r5),d7            ; S7[seven1]
 ]
 [
    eor      d7,d6              ; seven1 = S7[seven1]^(nine1&0x7F)
    move.l   d3,r3              ; r3 = nine2
       tfra     r0,r4
 ]
    LOOPEND3

    eor      d6,d2              ; seven2 = seven1^(subkey>>9)
 [
    move.l   d2,r5              ; r5 = seven2
    addl1a   r3,r4              ; &S9[nine2]
 ]
 [
    aslw     d4,d4              ; x<<16
    moveu.w  (r4),d7            ; S9[nine2]
 ]
 [
    eor      d7,d2              ; nine2 = S9[nine2]^seven2
    adda     r2,r5              ; &S7[seven2]
    move.w   #512,d3
 ]
 [
    and      #127,d2,d5         ; nine2&0x7F
       zxt.l    d4
    moveu.b  (r5),d6            ; S7[seven2]
 ]
 [
    eor      d6,d5              ; seven2 =S7[seven2]^(nine2&0x7F)
    pop      d6
    pop      d7
 ]
 [
    imac     d3,d5,d2   ; temp =(seven2<<9)+nine2
    or     d4,d0                ; in = (u32)((x<<16)+y)
 ]
    eor      d2,d0              ; y^=temp
 [
    eor      d0,d6              ; right^=temp
    tfra     r6,r1              ;
 ]
    zxt.l    d6                 ;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;  inline FO(right,n)
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
 [
    lsrw     d6,d4              ; (u16)(in>>16)
```

```
    zxt.w    d6,d0             ; (u16)in
    move.w   #8,n3             ;
    moveu.w  (r1),d3   ; d3 = KOi[index]
 ]
 [
    eor      d3,d4             ; x^KOi[index]
    move.l   #_S9,r0           ; r0 = S9
       adda     #16,r1
 ]
 [
    extractu #<16,#<7,d4,d1    ; nine1 = x>>7
    and      #127,d4,d5        ; seven1 = x & 0x7F
    moveu.w  (r1)+n3,d2        ; d2 = subkey
    doen3    #2                ;
 ]
 [
    and      #511,d2,d4        ; d4 = subkey&0x1FF
    asrr     #<9,d2            ; d2 = subkey>>9
    move.l   d1,r3             ; r3 = nine1
    move.l   d5,r5             ; r5 = seven1
 ]
 [
    tfra     r0,r4             ; r4 = S9
    move.l   #_S7,r2
 ]
 [
    dosetup3 L22B
       addl1a   r3,r4        ; &S9[nine1]
 ]
 [
    moveu.w  (r4),d3           ; d6 = S9[nine1]
    adda     r2,r5             ; &S7[seven1]
 ]
 [
    eor      d3,d5             ; nine1=S9[nine1]^seven1
    push     d6
    push     d7
 ]
 [
    eor      d5,d4             ; nine2 = nine1^(subkey&0x1FF)
    and      #127,d5,d6        ; nine1&0x7F
    moveu.b  (r5),d1           ; d1 = S7[seven1]
 ]
 [
    eor      d1,d6             ; seven1 = S7[seven1]^(nine1&0x7F)
    tfr      d0,d4             ; d4 = x = y
    move.l   d4,r3             ; r3 = nine2
    tfra     r0,r4
 ]

    FALIGN
    LOOPSTART3
L22B

 [
```

```
          eor       d6,d2               ; seven2 = seven1^(subkey>>9)
          moveu.w   (r1)+n3,d3          ; KOi[index]
       ]
       [
          addl1a    r3,r4               ; &S9[nine2]
          move.l    d2,r5               ; r5 = seven2
       ]
       [
          eor       d3,d4               ; x^KOi[index]
          moveu.w   (r4),d6             ; S9[nine2]
       ]
       [
          extractu #<16,#<7,d4,d7       ; nine1 = x>>7
          eor       d6,d2               ; nine2 = S9[nine2]^seven2
          and       #127,d4,d1          ; seven1 = x&0x7F
          adda      r2,r5               ; &S7[seven2]
          moveu.w   (r1)+n3,d5          ; subkey = KIi[index]
       ]
       [
          and       #127,d2,d4          ; nine2&0x7F
          and       #511,d5,d3          ; subkey & 0x1FF
          move.l    d7,r3               ; r3 = nine1
          moveu.b   (r5),d6             ; d6 = S7[seven2]
       ]
       [
          eor       d6,d4               ; seven2 = S7[seven2]^(nine2&0x7F)
             tfra      r0,r4
             move.w    #512,d6
       ]
       [
          imac d6,d4,d2         ; temp = (seven2<<9)+nine2
          move.l    d1,r5               ; r5 = seven1
          addl1a    r3,r4       ; &S9[nine1]
       ]
       [
          eor       d2,d0               ; y^=temp
          tfr       d5,d2               ; subkey
          moveu.w   (r4),d6             ; S9[nine1]
       ]
       [
          eor       d6,d1               ; nine1=S9[nine1]^seven1
          asrr      #<9,d2              ; subkey >> 9
          tfr       d0,d4               ; x = y
          adda      r2,r5       ; &S7[seven1]
       ]
       [
          eor       d1,d3               ; nine2=nine1^(subkey&0x1FF)
          and       #127,d1,d6          ; nine1&0x7F
          moveu.b   (r5),d7             ; S7[seven1]
       ]
       [
          eor       d7,d6               ; seven1 = S7[seven1]^(nine1&0x7F)
          move.l    d3,r3               ; r3 = nine2
             tfra      r0,r4
       ]
```

```
    LOOPEND3

    eor      d6,d2             ; seven2 = seven1^(subkey>>9)
 [
    move.l   d2,r5             ; r5 = seven2
    addl1a   r3,r4             ; &S9[nine2]
 ]
 [
       zxt.w    d4,d4             ; d4 = x
    moveu.w  (r4),d7           ; S9[nine2]
 ]
 [
    eor      d7,d2             ; nine2 = S9[nine2]^seven2
    adda     r2,r5             ; &S7[seven2]
    move.w   #512,d3
 ]
 [
    and      #127,d2,d5        ; nine2&0x7F
    moveu.b  (r5),d6           ; S7[seven2]
    moveu.w  (r7)+,d1          ; KLi1[index]
 ]
 [
    eor      d6,d5             ; seven2 =S7[seven2]^(nine2&0x7F)
    pop      d6
    pop      d7
 ]
;;; end of inline FO
 [
    and      d4,d1             ; I & KLi1[index]
    adda     #<2,r6            ;
    imac     d3,d5,d2   ; temp =(seven2<<9)+nine2 (FO)
 ]
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;; inline FL(temp, n++)
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
 [
    extractu #<1,#<15,d1,d3    ; for ROL16(a,1)
    asll     #<1,d1            ; for ROL16(a,1)
    eor      d0,d2             ; r = y^=temp (FO)
    moveu.w  (r12)+,d5         ; Kli2[index]
 ]
 [
    eor      d2,d3             ; for r^ROL16(a,1)
    zxt.w    d1,d1             ;
 ]
    eor      d1,d3             ; r^=ROL16(a,1)
    or       d3,d5             ; b = r|KLi2[index]
 [
    extractu #<1,#<15,d5,d2    ; for ROL16(b,1)
    asll     #<1,d5            ; for ROL16(b,1)
 ]
 [
    eor      d4,d2             ; for I^ROL16(b,1)
    zxt.w    d5,d4             ; for ROL16(b,1)
 ]
```

```
    eor      d4,d2             ; l^=ROL16(b,1)
    aslw     d2,d1             ;
    or       d1,d3             ; temp = in = (((u32)l)<<16) + r
    eor      d3,d7             ; left^=temp
    LOOPEND2

 [
      asrr     #8,d7
      asrr     #8,d6
    move.b   d7,(r10)-         ; save data[3]
    move.b   d6,(r11)-         ; save data[7]
 ]
 [
      asrr     #8,d7
      asrr     #8,d6
    move.b   d7,(r10)-         ; save data[2]
    move.b   d6,(r11)-         ; save save[6]
 ]
 [
      asrr     #8,d7
      asrr     #8,d6
    move.b   d7,(r10)-         ; save data[1]
    move.b   d6,(r11)-         ; save data[5]
 ]
 [
    tfra     r9,r7
    tfra     r8,r6             ;restore r6,r7
 ]
    rtsd
 [
    tfr      d15,d7
    tfr      d14,d6    ; restore d7,d6
    move.b   d7,(r10)          ; save data[0]
    move.b   d6,(r11)          ; save data[4]
 ]

      GLOBAL F_Kasumi_end
F_Kasumi_end
FuncEnd_Kasumi


;***********************************************************************
;
; Function _KeySchedule, ; Stack frame size: 40
;
; Calling Convention: 1
;
; Parameter k   passed in register r0
;
;***********************************************************************

      GLOBAL _KeySchedule
      ALIGN  16
_KeyScheduleTYPEfunc OPT_SPEED
      SIZE _KeySchedule,F_KeySchedule_end-_KeySchedule,16
```

```
 [
    adda     #32,sp,r3
    doen3    #<4
 ]
 [
    dosetup3 L18
    tfra     r3,sp
 ]
 [
    adda     #>2,r0,r1                ; r0 = &k[0], r1= &k[2]
    move.l   d6,m0                    ; save d6
 ]
 [
    move.l   d7,m1                    ; save d7
    move.l   #__C,r3                ; r3 = C
 ]
 [
    adda     #>-32,sp,r5              ; r5 = Kprime
    adda     #>-16,sp,r4              ; r4 = Key
 ]
    move.2w  (r3)+,d0:d1              ; d0:d1 =C[2n]:C[2n+1]

    FALIGN
    LOOPSTART3
L18
 [
    zxt.w    d0,d0
    zxt.w    d1,d1
    moveu.b  (r0)+,d2                 ; k[4n]
    moveu.b  (r1)+,d4                 ; k[4n+2]
 ]
 [
    asll     #<8,d2
    asll     #<8,d4
    moveu.b  (r0)+,d7                 ;k[4n+1]
    moveu.b  (r1)+,d5                 ;k[4n+3]
 ]
 [
    add      d2,d7,d2                 ; d2 = key[2n]
    add      d4,d5,d3                 ; d3 = key[2n+1]
    adda     #<2,r0                   ; point to next words
    adda     #<2,r1                   ;
 ]
 [
    eor      d2,d0                    ; key[2n  ]^C[2n  ]
    eor      d3,d1                    ; key[2n+1]^C[2n+1]
    move.2w  d2:d3,(r4)+              ; save key[2n],key[2n+1]
 ]
 [
    move.2w  d0:d1,(r5)+              ; save Kprime[2n],Kprime[2n+1]
    move.2w  (r3)+,d0:d1              ; load C[] for next
 ]
    LOOPEND3

 [
```

```
            adda     #>-16,sp,r0               ; Key
            adda     #>-32,sp,r1               ; Kprime
         ]
         [
            move.l   #_KLi,r2
            tfra r1,r9
         ]
         [
            move.l   #_KOIi,r3
            adda     #4,r1
         ]
         [
            move.w   #16,m2
            move.w   #<3,n0
         ]
         [
            tfra r0,r8
            move.l   #$000000AA,mctl   ; R0,R1 use module address
         ]
         [
            doen3    #<8                       ; for(n=0; n<8; n++)
            dosetup3 L19
         ]
         [
            move.w   #<4,n1
            move.w   #<8,n2
         ]
         [
            move.w   #-39,n3
            moveu.w (r0)+,d0          ; d0 = key[n]
         ]

            FALIGN
            LOOPSTART3
        L19
         [
            asrr     #15,d0
            asl      d0,d2
            moveu.w  (r0)+n1,d1                ; d1=key[n+1]
            moveu.w  (r1)+,d4                  ; d4=Kprime[(n+2)&7]
         ]
         [
            or       d2,d0               ; d0 = ROL16(key[n],1)
            extractu #5,#11,d1,d3
            asll     #5,d1
            moveu.w  (r0)+,d2                  ; d2=key[(n+5)&7]
            moveu.w  (r1)+,d5                  ; d5=Kprime[(n+3)&7]
         ]
         [
            or       d3,d1                 ; d1 = ROL16(key[(n+1)&7],5)
            extractu #8,#8,d2,d0
            asll     #8,d2
            moveu.w  (r0)+n0,d3                ; d3=key[(n+6)&7]
            move.w   d0,(r2)+n2                ; save KLi1[n]
         ]
```

```
    [
       or       d0,d2                  ; d2 = ROL16(key[(n+5)&7],8)
       extractu #13,#3,d3,d1
       asll     #13,d3
       moveu.w  (r1)+n0,d6                ; d6=Kprime[(n+4)&7]
       move.w   d1,(r3)+n2                ; save KOi1[n]
    ]
    [
       or       d1,d3                  ; d3 = ROL16(key[(n+6)&7],13)
       move.w   d4,(r2)                   ; save KLi2[n]
       move.w   d6,(r3)+n2                ; save KIi1[n]
    ]
    [
       move.w   d2,(r3)+n2                ; save KOi2[n]
       moveu.w  (r1)+n1,d6                ; d6=Kprime[(n+7)&7]
    ]
    [
       move.w   d5,(r3)+n2                ; save KIi2[n]
       moveu.w (r0)+,d0         ; d0 = key[n]
    ]
    [
       move.w   d3,(r3)+n2                ; save KOi3[n]
       adda     #-14,r2,r2
    ]
       move.w   d6,(r3)+n3                ; save KIi3[n]

       LOOPEND3

       move.l #0,mctl
    [
       adda     #-32,sp,r4                ;
       move.l   m1,d7                     ;restore d7
    ]
    [
       tfra     r4,sp                     ;
       move.l   m0,d6                     ;restore d6
    ]
       rts

          GLOBAL F_KeySchedule_end
F_KeySchedule_end
FuncEnd_KeySchedule

TextEnd_Kasumi
          ENDSEC
```

How to Reach Us:

Home Page:
www.freescale.com

E-mail:
support@freescale.com

USA/Europe or Locations not listed:
Freescale Semiconductor
Technical Information Center, CH370
1300 N. Alma School Road
Chandler, Arizona 85224
+1-800-521-6274 or +1-480-768-2130
support@freescale.com

Europe, Middle East, and Africa:
Freescale Halbleiter Deutschland GMBH
Technical Information Center
Schatzbogen 7
81829 München, Germany
+44 1296 380 456 (English)
+46 8 52200080 (English)
+49 89 92103 559 (German)
+33 1 69 35 48 48 (French)
support@freescale.com

Japan:
Freescale Semiconductor Japan Ltd.
Technical Information Center
3-20-1, Minami-Azabu. Minato-ku
Tokyo 106-8573, Japan
0120 191014 or +81-3-3440-3569
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Asia/Pacific:
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Technical Information Center
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Tai Po Industrial Estate
Tai Po, N.T. Hong Kong
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AN2837
Rev. 0
9/2004

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