

Network Working Group  
Request for Comments: 3713  
Category: Informational

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April 2004

## A Description of the Camellia Encryption Algorithm

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### Abstract

This document describes the Camellia encryption algorithm. Camellia is a block cipher with 128-bit block size and 128-, 192-, and 256-bit keys. The algorithm description is presented together with key scheduling part and data randomizing part.

## 1. Introduction

### 1.1. Camellia

Camellia was jointly developed by Nippon Telegraph and Telephone Corporation and Mitsubishi Electric Corporation in 2000 [CamelliaSpec]. Camellia specifies the 128-bit block size and 128-, 192-, and 256-bit key sizes, the same interface as the Advanced Encryption Standard (AES). Camellia is characterized by its suitability for both software and hardware implementations as well as its high level of security. From a practical viewpoint, it is designed to enable flexibility in software and hardware implementations on 32-bit processors widely used over the Internet and many applications, 8-bit processors used in smart cards, cryptographic hardware, embedded systems, and so on [CamelliaTech]. Moreover, its key setup time is excellent, and its key agility is superior to that of AES.

Camellia has been scrutinized by the wide cryptographic community during several projects for evaluating crypto algorithms. In particular, Camellia was selected as a recommended cryptographic primitive by the EU NESSIE (New European Schemes for Signatures, Integrity and Encryption) project [NESSIE] and also included in the list of cryptographic techniques for Japanese e-Government systems which were selected by the Japan CRYPTREC (Cryptography Research and Evaluation Committees) [CRYPTREC].

## 2. Algorithm Description

Camellia can be divided into "key scheduling part" and "data randomizing part".

### 2.1. Terminology

The following operators are used in this document to describe the algorithm.

&     bitwise AND operation.  
|     bitwise OR operation.  
^     bitwise exclusive-OR operation.  
<<    logical left shift operation.  
>>    logical right shift operation.  
<<<   left rotation operation.  
~y     bitwise complement of y.  
0x     hexadecimal representation.

Note that the logical left shift operation is done with the infinite data width.

The constant values of MASK8, MASK32, MASK64, and MASK128 are defined as follows.

MASK8     = 0xff;  
MASK32    = 0xffffffff;  
MASK64    = 0xffffffffffffffff;  
MASK128   = 0xffffffffffffffffffffffffffffffff;

### 2.2. Key Scheduling Part

In the key schedule part of Camellia, the 128-bit variables of KL and KR are defined as follows. For 128-bit keys, the 128-bit key K is used as KL and KR is 0. For 192-bit keys, the leftmost 128-bits of key K are used as KL and the concatenation of the rightmost 64-bits of K and the complement of the rightmost 64-bits of K are used as KR. For 256-bit keys, the leftmost 128-bits of key K are used as KL and the rightmost 128-bits of K are used as KR.

128-bit key K:

```
KL = K;    KR = 0;
```

192-bit key K:

```
KL = K >> 64;
KR = ((K & MASK64) << 64) | (~ (K & MASK64));
```

256-bit key K:

```
KL = K >> 128;
KR = K & MASK128;
```

The 128-bit variables KA and KB are generated from KL and KR as follows. Note that KB is used only if the length of the secret key is 192 or 256 bits. D1 and D2 are 64-bit temporary variables. F-function is described in Section 2.4.

```
D1 = (KL ^ KR) >> 64;
D2 = (KL ^ KR) & MASK64;
D2 = D2 ^ F(D1, Sigma1);
D1 = D1 ^ F(D2, Sigma2);
D1 = D1 ^ (KL >> 64);
D2 = D2 ^ (KL & MASK64);
D2 = D2 ^ F(D1, Sigma3);
D1 = D1 ^ F(D2, Sigma4);
KA = (D1 << 64) | D2;
D1 = (KA ^ KR) >> 64;
D2 = (KA ^ KR) & MASK64;
D2 = D2 ^ F(D1, Sigma5);
D1 = D1 ^ F(D2, Sigma6);
KB = (D1 << 64) | D2;
```

The 64-bit constants Sigma1, Sigma2, ..., Sigma6 are used as "keys" in the F-function. These constant values are, in hexadecimal notation, as follows.

```
Sigma1 = 0xA09E667F3BCC908B;
Sigma2 = 0xB67AE8584CAA73B2;
Sigma3 = 0xC6EF372FE94F82BE;
Sigma4 = 0x54FF53A5F1D36F1C;
Sigma5 = 0x10E527FADE682D1D;
Sigma6 = 0xB05688C2B3E6C1FD;
```

64-bit subkeys are generated by rotating KL, KR, KA, and KB and taking the left- or right-half of them.

For 128-bit keys, 64-bit subkeys  $kw_1, \dots, kw_4, k_1, \dots, k_{18}, ke_1, \dots, ke_4$  are generated as follows.

```

kw1 = (KL <<< 0) >> 64;
kw2 = (KL <<< 0) & MASK64;
k1  = (KA <<< 0) >> 64;
k2  = (KA <<< 0) & MASK64;
k3  = (KL <<< 15) >> 64;
k4  = (KL <<< 15) & MASK64;
k5  = (KA <<< 15) >> 64;
k6  = (KA <<< 15) & MASK64;
ke1 = (KA <<< 30) >> 64;
ke2 = (KA <<< 30) & MASK64;
k7  = (KL <<< 45) >> 64;
k8  = (KL <<< 45) & MASK64;
k9  = (KA <<< 45) >> 64;
k10 = (KL <<< 60) & MASK64;
k11 = (KA <<< 60) >> 64;
k12 = (KA <<< 60) & MASK64;
ke3 = (KL <<< 77) >> 64;
ke4 = (KL <<< 77) & MASK64;
k13 = (KL <<< 94) >> 64;
k14 = (KL <<< 94) & MASK64;
k15 = (KA <<< 94) >> 64;
k16 = (KA <<< 94) & MASK64;
k17 = (KL <<< 111) >> 64;
k18 = (KL <<< 111) & MASK64;
kw3 = (KA <<< 111) >> 64;
kw4 = (KA <<< 111) & MASK64;

```

For 192- and 256-bit keys, 64-bit subkeys  $kw_1, \dots, kw_4, k_1, \dots, k_{24}, ke_1, \dots, ke_6$  are generated as follows.

```

kw1 = (KL <<< 0) >> 64;
kw2 = (KL <<< 0) & MASK64;
k1  = (KB <<< 0) >> 64;
k2  = (KB <<< 0) & MASK64;
k3  = (KR <<< 15) >> 64;
k4  = (KR <<< 15) & MASK64;
k5  = (KA <<< 15) >> 64;
k6  = (KA <<< 15) & MASK64;
ke1 = (KR <<< 30) >> 64;
ke2 = (KR <<< 30) & MASK64;
k7  = (KB <<< 30) >> 64;
k8  = (KB <<< 30) & MASK64;
k9  = (KL <<< 45) >> 64;
k10 = (KL <<< 45) & MASK64;
k11 = (KA <<< 45) >> 64;

```

```

k12 = (KA <<< 45) & MASK64;
ke3 = (KL <<< 60) >> 64;
ke4 = (KL <<< 60) & MASK64;
k13 = (KR <<< 60) >> 64;
k14 = (KR <<< 60) & MASK64;
k15 = (KB <<< 60) >> 64;
k16 = (KB <<< 60) & MASK64;
k17 = (KL <<< 77) >> 64;
k18 = (KL <<< 77) & MASK64;
ke5 = (KA <<< 77) >> 64;
ke6 = (KA <<< 77) & MASK64;
k19 = (KR <<< 94) >> 64;
k20 = (KR <<< 94) & MASK64;
k21 = (KA <<< 94) >> 64;
k22 = (KA <<< 94) & MASK64;
k23 = (KL <<< 111) >> 64;
k24 = (KL <<< 111) & MASK64;
kw3 = (KB <<< 111) >> 64;
kw4 = (KB <<< 111) & MASK64;

```

### 2.3. Data Randomizing Part

#### 2.3.1. Encryption for 128-bit keys

128-bit plaintext  $M$  is divided into the left 64-bit  $D1$  and the right 64-bit  $D2$ .

```

D1 = M >> 64;
D2 = M & MASK64;

```

Encryption is performed using an 18-round Feistel structure with FL- and FLINV-functions inserted every 6 rounds. F-function, FL-function, and FLINV-function are described in Section 2.4.

```

D1 = D1 ^ kw1;           // Prewhitening
D2 = D2 ^ kw2;
D2 = D2 ^ F(D1, k1);    // Round 1
D1 = D1 ^ F(D2, k2);    // Round 2
D2 = D2 ^ F(D1, k3);    // Round 3
D1 = D1 ^ F(D2, k4);    // Round 4
D2 = D2 ^ F(D1, k5);    // Round 5
D1 = D1 ^ F(D2, k6);    // Round 6
D1 = FL (D1, ke1);      // FL
D2 = FLINV(D2, ke2);    // FLINV
D2 = D2 ^ F(D1, k7);    // Round 7
D1 = D1 ^ F(D2, k8);    // Round 8
D2 = D2 ^ F(D1, k9);    // Round 9
D1 = D1 ^ F(D2, k10);   // Round 10

```

```

D2 = D2 ^ F(D1, k11);    // Round 11
D1 = D1 ^ F(D2, k12);    // Round 12
D1 = FL    (D1, ke3);    // FL
D2 = FLINV(D2, ke4);    // FLINV
D2 = D2 ^ F(D1, k13);    // Round 13
D1 = D1 ^ F(D2, k14);    // Round 14
D2 = D2 ^ F(D1, k15);    // Round 15
D1 = D1 ^ F(D2, k16);    // Round 16
D2 = D2 ^ F(D1, k17);    // Round 17
D1 = D1 ^ F(D2, k18);    // Round 18
D2 = D2 ^ kw3;           // Postwhitening
D1 = D1 ^ kw4;

```

128-bit ciphertext C is constructed from D1 and D2 as follows.

```
C = (D2 << 64) | D1;
```

### 2.3.2. Encryption for 192- and 256-bit keys

128-bit plaintext M is divided into the left 64-bit D1 and the right 64-bit D2.

```

D1 = M >> 64;
D2 = M & MASK64;

```

Encryption is performed using a 24-round Feistel structure with FL- and FLINV-functions inserted every 6 rounds. F-function, FL-function, and FLINV-function are described in Section 2.4.

```

D1 = D1 ^ kw1;           // Prewhitening
D2 = D2 ^ kw2;
D2 = D2 ^ F(D1, k1);    // Round 1
D1 = D1 ^ F(D2, k2);    // Round 2
D2 = D2 ^ F(D1, k3);    // Round 3
D1 = D1 ^ F(D2, k4);    // Round 4
D2 = D2 ^ F(D1, k5);    // Round 5
D1 = D1 ^ F(D2, k6);    // Round 6
D1 = FL    (D1, ke1);    // FL
D2 = FLINV(D2, ke2);    // FLINV
D2 = D2 ^ F(D1, k7);    // Round 7
D1 = D1 ^ F(D2, k8);    // Round 8
D2 = D2 ^ F(D1, k9);    // Round 9
D1 = D1 ^ F(D2, k10);   // Round 10
D2 = D2 ^ F(D1, k11);   // Round 11
D1 = D1 ^ F(D2, k12);   // Round 12
D1 = FL    (D1, ke3);    // FL
D2 = FLINV(D2, ke4);    // FLINV
D2 = D2 ^ F(D1, k13);   // Round 13

```

```

D1 = D1 ^ F(D2, k14);    // Round 14
D2 = D2 ^ F(D1, k15);    // Round 15
D1 = D1 ^ F(D2, k16);    // Round 16
D2 = D2 ^ F(D1, k17);    // Round 17
D1 = D1 ^ F(D2, k18);    // Round 18
D1 = FL   (D1, ke5);      // FL
D2 = FLINV(D2, ke6);     // FLINV
D2 = D2 ^ F(D1, k19);    // Round 19
D1 = D1 ^ F(D2, k20);    // Round 20
D2 = D2 ^ F(D1, k21);    // Round 21
D1 = D1 ^ F(D2, k22);    // Round 22
D2 = D2 ^ F(D1, k23);    // Round 23
D1 = D1 ^ F(D2, k24);    // Round 24
D2 = D2 ^ kw3;           // Postwhitening
D1 = D1 ^ kw4;

```

128-bit ciphertext C is constructed from D1 and D2 as follows.

```
C = (D2 << 64) | D1;
```

### 2.3.3. Decryption

The decryption procedure of Camellia can be done in the same way as the encryption procedure by reversing the order of the subkeys.

That is to say:

128-bit key:

```

kw1 <-> kw3
kw2 <-> kw4
k1  <-> k18
k2  <-> k17
k3  <-> k16
k4  <-> k15
k5  <-> k14
k6  <-> k13
k7  <-> k12
k8  <-> k11
k9  <-> k10
ke1 <-> ke4
ke2 <-> ke3

```

192- or 256-bit key:

```

kw1 <-> kw3
kw2 <-> kw4
k1  <-> k24
k2  <-> k23
k3  <-> k22

```

```

k4  <-> k21
k5  <-> k20
k6  <-> k19
k7  <-> k18
k8  <-> k17
k9  <-> k16
k10 <-> k15
k11 <-> k14
k12 <-> k13
ke1 <-> ke6
ke2 <-> ke5
ke3 <-> ke4

```

## 2.4. Components of Camellia

### 2.4.1. F-function

F-function takes two parameters. One is 64-bit input data F\_IN. The other is 64-bit subkey KE. F-function returns 64-bit data F\_OUT.

```
F(F_IN, KE)
```

```
begin
```

```

var x as 64-bit unsigned integer;
var t1, t2, t3, t4, t5, t6, t7, t8 as 8-bit unsigned integer;
var y1, y2, y3, y4, y5, y6, y7, y8 as 8-bit unsigned integer;
x = F_IN ^ KE;
t1 = x >> 56;
t2 = (x >> 48) & MASK8;
t3 = (x >> 40) & MASK8;
t4 = (x >> 32) & MASK8;
t5 = (x >> 24) & MASK8;
t6 = (x >> 16) & MASK8;
t7 = (x >> 8) & MASK8;
t8 = x & MASK8;
t1 = SBOX1[t1];
t2 = SBOX2[t2];
t3 = SBOX3[t3];
t4 = SBOX4[t4];
t5 = SBOX2[t5];
t6 = SBOX3[t6];
t7 = SBOX4[t7];
t8 = SBOX1[t8];
y1 = t1 ^ t3 ^ t4 ^ t6 ^ t7 ^ t8;
y2 = t1 ^ t2 ^ t4 ^ t5 ^ t7 ^ t8;
y3 = t1 ^ t2 ^ t3 ^ t5 ^ t6 ^ t8;
y4 = t2 ^ t3 ^ t4 ^ t5 ^ t6 ^ t7;
y5 = t1 ^ t2 ^ t6 ^ t7 ^ t8;
y6 = t2 ^ t3 ^ t5 ^ t7 ^ t8;

```

```

y7 = t3 ^ t4 ^ t5 ^ t6 ^ t8;
y8 = t1 ^ t4 ^ t5 ^ t6 ^ t7;
F_OUT = (y1 << 56) | (y2 << 48) | (y3 << 40) | (y4 << 32)
| (y5 << 24) | (y6 << 16) | (y7 << 8) | y8;
return FO_OUT;
end.

```

SBOX1, SBOX2, SBOX3, and SBOX4 are lookup tables with 8-bit input/output data. SBOX2, SBOX3, and SBOX4 are defined using SBOX1 as follows:

```

SBOX2[x] = SBOX1[x] <<< 1;
SBOX3[x] = SBOX1[x] <<< 7;
SBOX4[x] = SBOX1[x <<< 1];

```

SBOX1 is defined by the following table. For example, SBOX1[0x3d] equals 86.

```

SBOX1:
  0   1   2   3   4   5   6   7   8   9   a   b   c   d   e   f
00: 112 130  44 236 179  39 192 229 228 133  87  53 234  12 174  65
10:  35 239 107 147  69  25 165  33 237  14  79  78  29 101 146 189
20: 134 184 175 143 124 235  31 206  62 48 220  95  94 197  11  26
30: 166 225  57 202 213  71  93  61 217  1  90 214  81  86 108  77
40: 139  13 154 102 251 204 176  45 116  18  43  32 240 177 132 153
50: 223  76 203 194  52 126 118  5 109 183 169  49 209  23  4 215
60:  20  88  58  97 222  27  17  28  50  15 156  22  83  24 242  34
70: 254  68 207 178 195 181 122 145  36  8 232 168  96 252 105  80
80: 170 208 160 125 161 137  98 151  84  91  30 149 224 255 100 210
90:  16 196  0  72 163 247 117 219 138  3 230 218  9  63 221 148
a0: 135  92 131  2 205  74 144  51 115 103 246 243 157 127 191 226
b0:  82 155 216  38 200  55 198  59 129 150 111  75  19 190  99  46
c0: 233 121 167 140 159 110 188 142  41 245 249 182  47 253 180  89
d0: 120 152  6 106 231  70 113 186 212  37 171  66 136 162 141 250
e0: 114  7 185  85 248 238 172  10  54  73  42 104  60  56 241 164
f0:  64  40 211 123 187 201  67 193  21 227 173 244 119 199 128 158

```

#### 2.4.2. FL- and FLINV-functions

FL-function takes two parameters. One is 64-bit input data FL\_IN. The other is 64-bit subkey KE. FL-function returns 64-bit data FL\_OUT.

```

FL(FL_IN, KE)
begin
  var x1, x2 as 32-bit unsigned integer;
  var k1, k2 as 32-bit unsigned integer;
  x1 = FL_IN >> 32;

```

```

x2 = FL_IN & MASK32;
k1 = KE >> 32;
k2 = KE & MASK32;
x2 = x2 ^ ((x1 & k1) <<< 1);
x1 = x1 ^ (x2 | k2);
FL_OUT = (x1 << 32) | x2;
end.

```

FLINV-function is the inverse function of the FL-function.

```

FLINV(FLINV_IN, KE)
begin
  var y1, y2 as 32-bit unsigned integer;
  var k1, k2 as 32-bit unsigned integer;
  y1 = FLINV_IN >> 32;
  y2 = FLINV_IN & MASK32;
  k1 = KE >> 32;
  k2 = KE & MASK32;
  y1 = y1 ^ (y2 | k2);
  y2 = y2 ^ ((y1 & k1) <<< 1);
  FLINV_OUT = (y1 << 32) | y2;
end.

```

### 3. Object Identifiers

The Object Identifier for Camellia with 128-bit key in Cipher Block Chaining (CBC) mode is as follows:

```

id-camellia128-cbc OBJECT IDENTIFIER ::=
  { iso(1) member-body(2) 392 200011 61 security(1)
    algorithm(1) symmetric-encryption-algorithm(1)
      camellia128-cbc(2) }

```

The Object Identifier for Camellia with 192-bit key in Cipher Block Chaining (CBC) mode is as follows:

```

id-camellia192-cbc OBJECT IDENTIFIER ::=
  { iso(1) member-body(2) 392 200011 61 security(1)
    algorithm(1) symmetric-encryption-algorithm(1)
      camellia192-cbc(3) }

```

The Object Identifier for Camellia with 256-bit key in Cipher Block Chaining (CBC) mode is as follows:

```

id-camellia256-cbc OBJECT IDENTIFIER ::=
  { iso(1) member-body(2) 392 200011 61 security(1)
    algorithm(1) symmetric-encryption-algorithm(1)
      camellia256-cbc(4) }

```

The above algorithms need Initialization Vector (IV). To determine the value of IV, the above algorithms take parameters as follows:

```
CamelliaCBCParameter ::= CamelliaIV -- Initialization Vector  
CamelliaIV ::= OCTET STRING (SIZE(16))
```

When these object identifiers are used, plaintext is padded before encryption according to RFC2315 [RFC2315].

#### 4. Security Considerations

The recent advances in cryptanalytic techniques are remarkable. A quantitative evaluation of security against powerful cryptanalytic techniques such as differential cryptanalysis and linear cryptanalysis is considered to be essential in designing any new block cipher. We evaluated the security of Camellia by utilizing state-of-the-art cryptanalytic techniques. We confirmed that Camellia has no differential and linear characteristics that hold with probability more than  $2^{-128}$ , which means that it is extremely unlikely that differential and linear attacks will succeed against the full 18-round Camellia. Moreover, Camellia was designed to offer security against other advanced cryptanalytic attacks including higher order differential attacks, interpolation attacks, related-key attacks, truncated differential attacks, and so on [Camellia].

#### 5. Informative References

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[http://www.soumu.go.jp/joho\\_tsusin/security/cryptrec.html](http://www.soumu.go.jp/joho_tsusin/security/cryptrec.html),  
CRYPTREC home page by Information-technology Promotion Agency, Japan (IPA)  
<http://www.ipa.go.jp/security/enc/CRYPTREC/index-e.html>
- [NESSIE] New European Schemes for Signatures, Integrity and Encryption (NESSIE) project.  
<http://www.cryptonessie.org>
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## Appendix A. Example Data of Camellia

Here are test data for Camellia in hexadecimal form.

## 128-bit key

```
Key       : 01 23 45 67 89 ab cd ef fe dc ba 98 76 54 32 10
Plaintext : 01 23 45 67 89 ab cd ef fe dc ba 98 76 54 32 10
Ciphertext: 67 67 31 38 54 96 69 73 08 57 06 56 48 ea be 43
```

## 192-bit key

```
Key       : 01 23 45 67 89 ab cd ef fe dc ba 98 76 54 32 10
           : 00 11 22 33 44 55 66 77
Plaintext : 01 23 45 67 89 ab cd ef fe dc ba 98 76 54 32 10
Ciphertext: b4 99 34 01 b3 e9 96 f8 4e e5 ce e7 d7 9b 09 b9
```

## 256-bit key

```
Key       : 01 23 45 67 89 ab cd ef fe dc ba 98 76 54 32 10
           : 00 11 22 33 44 55 66 77 88 99 aa bb cc dd ee ff
Plaintext : 01 23 45 67 89 ab cd ef fe dc ba 98 76 54 32 10
Ciphertext: 9a cc 23 7d ff 16 d7 6c 20 ef 7c 91 9e 3a 75 09
```

## Acknowledgements

Shiho Moriai worked for NTT when this document was developed.

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## Acknowledgement

Funding for the RFC Editor function is currently provided by the Internet Society.

