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The SEED Encryption Algorithm

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Abstract

This document describes the SEED encryption algorithm, which has been adopted by most of the security systems in the Republic of Korea. Included are a description of the encryption and the key scheduling algorithm ([Section 2](#)), the S-boxes (Appendix A), and a set of test vectors (Appendix B).

This document obsoletes [RFC 4009](#).

1. Introduction

1.1. Changes from RFC 4009

This specification obsoletes [RFC 4009](#), because [RFC 4009](#) had ambiguous function and SS-boxes definitions cryptographically. Thus, some definitions have been changed, and for better understanding, the SEED pseudo codes have been modified. This update is to provide clarity and facilitate the development of interoperable implementations. The SEED algorithm itself has not been changed.

This specification updates [RFC 4009](#) in the following areas:

- Pseudo code changes. The pseudo code in [Section 2 of RFC 4009](#) is insufficient for the explanation of the structure of SEED. Thus, detailed pseudo code is introduced.
- Some corrections of errata, which are the definitions of $R1'$, Z , X , and SS-boxes.

1.2. SEED Overview

SEED is a 128-bit symmetric key block cipher that has been developed by KISA (Korea Information Security Agency) since 1998. SEED is a national standard encryption algorithm in the Republic of Korea [[TTASSEED](#)] and is designed to use the S-boxes and permutations that balance with the current computing technology. It has the Feistel structure with 16-round and is strong against DC (Differential Cryptanalysis), LC (Linear Cryptanalysis), and related key attacks, balanced with security/efficiency trade-off.

The features of SEED are outlined as follows:

- The Feistel structure with 16-round
- 128-bit input/output data block size
- 128-bit key length
- A round function that is strong against known attacks
- Two 8x8 S-boxes
- Mixed operations of XOR and modular addition

SEED has been widely used in the Republic of Korea for confidential services such as electronic commerce; e.g., financial services provided in wired and wireless communication.

1.3. Notation

The following notation is used in the description of the SEED encryption algorithm:

&	bitwise AND
^	bitwise exclusive OR
+	addition in modular 2^{32}
-	subtraction in modular 2^{32}
	concatenation
<< n	left circular rotation by n bits
>> n	right circular rotation by n bits
0x	hexadecimal representation

2. The Structure of SEED

The input/output block size of SEED is 128 bits, and the key length is also 128 bits. SEED has the 16-round Feistel structure. A 128-bit input is divided into two 64-bit blocks (L, R), and the right 64-bit block is an input to the round function F, with a 64-bit subkey K_i generated from the key schedule. L is the most significant 64 bits of 128-bit input, and R is the least significant 64 bits.

A pseudo code for the structure of SEED is as follows:

```
Input : (L, R)

for i = 1 to 15

    T = R;
    R = L ^ F(Ki, R);
    L = T;

L = L ^ F(K16, R), R=R

Output : (L, R)
```

Where T is a temporary.

2.1. The Round Function F

SEED uses two 8x8 S-boxes, permutations, rotations, and basic modular operations such as exclusive OR (XOR) and additions to provide strong security, high speed, and simplicity in its implementation.

A 64-bit input block of the round function F is divided into two 32-bit blocks (R₀, R₁) and wrapped with 4 phases:

- A mixing phase of two 32-bit subkey blocks (K_{i0} , K_{i1})
- 3 layers of function G (see [Section 2.2](#)), with additions for mixing two 32-bit blocks

Where R_0 is the most significant 32 bits of R , and R_1 is the least significant 32 bits.

The outputs (R_0' , R_1') of function F are as follows:

$$R_0' = G[G[G[(R_0 \wedge K_{i0}) \wedge (R_1 \wedge K_{i1})] + (R_0 \wedge K_{i0})] + G[(R_0 \wedge K_{i0}) \wedge (R_1 \wedge K_{i1})]] + G[G[(R_0 \wedge K_{i0}) \wedge (R_1 \wedge K_{i1})] + (R_0 \wedge K_{i0})]$$

$$R_1' = G[G[G[(R_0 \wedge K_{i0}) \wedge (R_1 \wedge K_{i1})] + (R_0 \wedge K_{i0})] + G[(R_0 \wedge K_{i0}) \wedge (R_1 \wedge K_{i1})]]$$

2.2. The Function G

The function G has two layers: a layer of two 8x8 S-boxes and a layer of block permutation of sixteen 8-bit sub-blocks. The outputs Z ($= Z_3 || Z_2 || Z_1 || Z_0$) of the function G with four 8-bit inputs X ($= X_3 || X_2 || X_1 || X_0$) are as follows:

$$\begin{aligned} Z_0 &= \{S_0(X_0) \& m_0\} \wedge \{S_1(X_1) \& m_1\} \wedge \{S_0(X_2) \& m_2\} \wedge \{S_1(X_3) \& m_3\} \\ Z_1 &= \{S_0(X_0) \& m_1\} \wedge \{S_1(X_1) \& m_2\} \wedge \{S_0(X_2) \& m_3\} \wedge \{S_1(X_3) \& m_0\} \\ Z_2 &= \{S_0(X_0) \& m_2\} \wedge \{S_1(X_1) \& m_3\} \wedge \{S_0(X_2) \& m_0\} \wedge \{S_1(X_3) \& m_1\} \\ Z_3 &= \{S_0(X_0) \& m_3\} \wedge \{S_1(X_1) \& m_0\} \wedge \{S_0(X_2) \& m_1\} \wedge \{S_1(X_3) \& m_2\} \end{aligned}$$

where $m_0 = 0xFC$, $m_1 = 0xF3$, $m_2 = 0xCF$, and $m_3 = 0x3F$.

To increase the efficiency of G function, four extended S-boxes "SS-box" (see [Appendix A.2](#)) are defined as follows:

$$\begin{aligned} SS_0(X_0) &= \{S_0(X_0) \& m_3\} || \{S_0(X_0) \& m_2\} || \{S_0(X_0) \& m_1\} || \{S_0(X_0) \& m_0\} \\ SS_1(X_1) &= \{S_1(X_1) \& m_0\} || \{S_1(X_1) \& m_3\} || \{S_1(X_1) \& m_2\} || \{S_1(X_1) \& m_1\} \\ SS_2(X_2) &= \{S_0(X_2) \& m_1\} || \{S_0(X_2) \& m_0\} || \{S_0(X_2) \& m_3\} || \{S_0(X_2) \& m_2\} \\ SS_3(X_3) &= \{S_1(X_3) \& m_2\} || \{S_1(X_3) \& m_1\} || \{S_1(X_3) \& m_0\} || \{S_1(X_3) \& m_3\} \end{aligned}$$

New G function, Z , can be defined as follows:

$$Z = SS_0(X_0) \wedge SS_1(X_1) \wedge SS_2(X_2) \wedge SS_3(X_3)$$

This new G function is faster than the original G function but takes more memory to store four SS-boxes.

2.3. Key Schedule

The key schedule generates each round's subkeys. It uses the function G , addition in modular 2^{32} , subtraction in modular 2^{32} , and (left/right) circular rotation. A 128-bit input key is divided into four 32-bit blocks (Key0, Key1, Key2, Key3). The two 32-bit subkeys of the i th round, K_{i0} and K_{i1} , are generated as follows:

```
- Type 1 : Odd round
  Ki0 = G(Key0 + Key2 - KCi)
  Ki1 = G(Key1 - Key3 + KCi)
  Key0 || Key1 = (Key0 || Key1) >> 8

- Type 2 : Even round
  Ki0 = G(Key0 + Key2 - KCi)
  Ki1 = G(Key1 - Key3 + KCi)
  Key2 || Key3 = (Key2 || Key3) << 8
```

Where K_{i0} is the most significant 32 bits of K_i , and K_{i1} is the least significant 32 bits of K_i (where $i=0, \dots, 3$).

The following table shows constants used in K_{Ci} :

i	Value	i	Value
KC1	0x9E3779B9	KC2	0x3C6EF373
KC3	0x78DDE6E6	KC4	0xF1BBCDCC
KC5	0xE3779B99	KC6	0xC6EF3733
KC7	0x8DDE6E67	KC8	0x1BBCDCCF
KC9	0x3779B99E	KC10	0x6EF3733C
KC11	0xDDE6E678	KC12	0xBBDCDCF1
KC13	0x779B99E3	KC14	0xEF3733C6
KC15	0xDE6E678D	KC16	0xBCDCF1B

A pseudo code for the key schedule is as follows:

```
Input : (Key0, Key1, Key2, Key3)

for i = 1 to 16
  Ki0 = G(Key0 + Key2 - KCi)
  Ki1 = G(Key1 - Key3 + KCi)
  if i is odd
    Key0 || Key1 = (Key0 || Key1) >> 8
  else
    Key2 || Key3 = (Key2 || Key3) << 8

Output : (Keyi0, Keyi1), i=1 to 16
```


2.4. Decryption Procedure

Decryption procedure is the reverse step of the encryption procedure. It can be implemented by using the encryption algorithm with reverse order of the round subkeys.

2.5. SEED Object Identifiers

For those who may be using SEED in algorithm negotiation within a protocol, or in any other context that may require the use of Object Identifiers (OIDs), the following three OIDs have been defined.

```
algorithm OBJECT IDENTIFIER ::= { iso(1) member-body(2) korea(410)
    kisa(200004) algorithm(1) }
```

```
id-seedCBC OBJECT IDENTIFIER ::= { algorithm seedCBC(4) }
```

```
seedCBCParameter ::= OCTET STRING (SIZE(16))
-- 128-bit Initialization Vector
```

The id-seedCBC OID is used when the Cipher Block Chaining (CBC) mode of operation based on the SEED block cipher is provided.

```
id-seedMAC OBJECT IDENTIFIER ::= { algorithm seedMAC(7) }
```

```
seedMACParameter ::= INTEGER -- MAC length, in bits
```

The id-seedMAC OID is used when the message authentication code (MAC) algorithm based on the SEED block cipher is provided.

```
pbeWithSHA1AndSEED-CBC OBJECT IDENTIFIER ::=
    { algorithm seedCBCwithSHA1(15) }
```

```
PBEPParameters ::= SEQUENCE { salt          OCTET STRING, iteration
    INTEGER } -- Total number of hash iterations
```

This OID is used when a password-based encryption in CBC mode based on SHA-1 and the SEED block cipher is provided. The details of the Password-Based Encryption (PBE) computation are well described in [Section 6.1 of \[RFC2898\]](#).

3. Security Considerations

No security problem has been found on SEED. See [\[ISOSEED\]](#) and [\[CRYPTREC\]](#).

4. References

4.1. Normative References

- [TTASSEED] Telecommunications Technology Association(TTA), "128-bit Symmetric Block Cipher (SEED)", TTAS.KO-12.0004, September, 1998 (In Korean)
<http://www.tta.or.kr/English/new/main/index.htm>
- [RFC2898] Kaliski, B., "PKCS #5: Password-Based Cryptography Specification Version 2.0", [RFC 2898](#), September 2000.

4.2. Informative References

- [ISOSEED] ISO/IEC, ISO/IEC JTC1/SC 27 N 256r1, "National Body contributions on NP 18033 Encryption algorithms in response to document SC 27 N 2563", October, 2000
- [CRYPTREC] Information-technology Promotion Agency (IPA), Japan, CRYPTREC. "SEED Evaluation Report", February, 2002
http://www.kisa.or.kr/seed/data/Document_pdf/SEED_Evaluation_Report_by_CRYPTREC.pdf

5. Acknowledgements

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Appendix A. S-Boxes

In this part, all data are hexadecimal numbers (not prefixed by "0x").

A.1. S-Boxes(two original S-boxes)**- S-Box S0**

A9, 85, D6, D3, 54, 1D, AC, 25, 5D, 43, 18, 1E, 51, FC, CA, 63, 28,
 44, 20, 9D, E0, E2, C8, 17, A5, 8F, 03, 7B, BB, 13, D2, EE, 70, 8C,
 3F, A8, 32, DD, F6, 74, EC, 95, 0B, 57, 5C, 5B, BD, 01, 24, 1C, 73,
 98, 10, CC, F2, D9, 2C, E7, 72, 83, 9B, D1, 86, C9, 60, 50, A3, EB,
 0D, B6, 9E, 4F, B7, 5A, C6, 78, A6, 12, AF, D5, 61, C3, B4, 41, 52,
 7D, 8D, 08, 1F, 99, 00, 19, 04, 53, F7, E1, FD, 76, 2F, 27, B0, 8B,
 0E, AB, A2, 6E, 93, 4D, 69, 7C, 09, 0A, BF, EF, F3, C5, 87, 14, FE,
 64, DE, 2E, 4B, 1A, 06, 21, 6B, 66, 02, F5, 92, 8A, 0C, B3, 7E, D0,
 7A, 47, 96, E5, 26, 80, AD, DF, A1, 30, 37, AE, 36, 15, 22, 38, F4,
 A7, 45, 4C, 81, E9, 84, 97, 35, CB, CE, 3C, 71, 11, C7, 89, 75, FB,
 DA, F8, 94, 59, 82, C4, FF, 49, 39, 67, C0, CF, D7, B8, 0F, 8E, 42,
 23, 91, 6C, DB, A4, 34, F1, 48, C2, 6F, 3D, 2D, 40, BE, 3E, BC, C1,
 AA, BA, 4E, 55, 3B, DC, 68, 7F, 9C, D8, 4A, 56, 77, A0, ED, 46, B5,
 2B, 65, FA, E3, B9, B1, 9F, 5E, F9, E6, B2, 31, EA, 6D, 5F, E4, F0,
 CD, 88, 16, 3A, 58, D4, 62, 29, 07, 33, E8, 1B, 05, 79, 90, 6A, 2A,
 9A

- S-Box S1

38, E8, 2D, A6, CF, DE, B3, B8, AF, 60, 55, C7, 44, 6F, 6B, 5B, C3,
 62, 33, B5, 29, A0, E2, A7, D3, 91, 11, 06, 1C, BC, 36, 4B, EF, 88,
 6C, A8, 17, C4, 16, F4, C2, 45, E1, D6, 3F, 3D, 8E, 98, 28, 4E, F6,
 3E, A5, F9, 0D, DF, D8, 2B, 66, 7A, 27, 2F, F1, 72, 42, D4, 41, C0,
 73, 67, AC, 8B, F7, AD, 80, 1F, CA, 2C, AA, 34, D2, 0B, EE, E9, 5D,
 94, 18, F8, 57, AE, 08, C5, 13, CD, 86, B9, FF, 7D, C1, 31, F5, 8A,
 6A, B1, D1, 20, D7, 02, 22, 04, 68, 71, 07, DB, 9D, 99, 61, BE, E6,
 59, DD, 51, 90, DC, 9A, A3, AB, D0, 81, 0F, 47, 1A, E3, EC, 8D, BF,
 96, 7B, 5C, A2, A1, 63, 23, 4D, C8, 9E, 9C, 3A, 0C, 2E, BA, 6E, 9F,
 5A, F2, 92, F3, 49, 78, CC, 15, FB, 70, 75, 7F, 35, 10, 03, 64, 6D,
 C6, 74, D5, B4, EA, 09, 76, 19, FE, 40, 12, E0, BD, 05, FA, 01, F0,
 2A, 5E, A9, 56, 43, 85, 14, 89, 9B, B0, E5, 48, 79, 97, FC, 1E, 82,
 21, 8C, 1B, 5F, 77, 54, B2, 1D, 25, 4F, 00, 46, ED, 58, 52, EB, 7E,
 DA, C9, FD, 30, 95, 65, 3C, B6, E4, BB, 7C, 0E, 50, 39, 26, 32, 84,
 69, 93, 37, E7, 24, A4, CB, 53, 0A, 87, D9, 4C, 83, 8F, CE, 3B, 4A,
 B7

A.2. S-Boxes (four extended S-boxes)**- S-Box SS0**

2989A1A8, 05858184, 16C6D2D4, 13C3D3D0, 14445054, 1D0D111C, 2C8CA0AC, 25052124,
 1D4D515C, 03434340, 18081018, 1E0E121C, 11415150, 3CCCF0FC, 0ACAC2C8, 23436360,
 28082028, 04444044, 20002020, 1D8D919C, 20C0E0E0, 22C2E2E0, 08C8C0C8, 17071314,
 2585A1A4, 0F8F838C, 03030300, 3B4B7378, 3B8BB3B8, 13031310, 12C2D2D0, 2ECEE2EC,
 30407070, 0C8C808C, 3F0F333C, 2888A0A8, 32023230, 1DCDD1DC, 36C6F2F4, 34447074,
 2CCCE0EC, 15859194, 0B0B0308, 17475354, 1C4C505C, 1B4B5358, 3D8DB1BC, 01010100,
 24042024, 1C0C101C, 33437370, 18889098, 10001010, 0CCCC0CC, 32C2F2F0, 19C9D1D8,
 2C0C202C, 27C7E3E4, 32427270, 03838380, 1B8B9398, 11C1D1D0, 06868284, 09C9C1C8,
 20406060, 10405050, 2383A3A0, 2BCBE3E8, 0D0D010C, 3686B2B4, 1E8E929C, 0F4F434C,
 3787B3B4, 1A4A5258, 06C6C2C4, 38487078, 2686A2A4, 12021210, 2F8FA3AC, 15C5D1D4,
 21416160, 03C3C3C0, 3484B0B4, 01414140, 12425250, 3D4D717C, 0D8D818C, 08080008,
 1F0F131C, 19899198, 00000000, 19091118, 04040004, 13435350, 37C7F3F4, 21C1E1E0,
 3DCDF1FC, 36467274, 2F0F232C, 27072324, 3080B0B0, 0B8B8388, 0E0E020C, 2B8BA3A8,
 2282A2A0, 2E4E626C, 13839390, 0D4D414C, 29496168, 3C4C707C, 09090108, 0A0A0208,
 3F8FB3BC, 2FCFE3EC, 33C3F3F0, 05C5C1C4, 07878384, 14041014, 3ECEF2FC, 24446064,
 1ECED2DC, 2E0E222C, 0B4B4348, 1A0A1218, 06060204, 21012120, 2B4B6368, 26466264,
 02020200, 35C5F1F4, 12829290, 0A8A8288, 0C0C000C, 3383B3B0, 3E4E727C, 10C0D0D0,
 3A4A7278, 07474344, 16869294, 25C5E1E4, 26062224, 00808080, 2D8DA1AC, 1FCFD3DC,
 2181A1A0, 30003030, 37073334, 2E8EA2AC, 36063234, 15051114, 22022220, 38083038,
 34C4F0F4, 2787A3A4, 05454144, 0C4C404C, 01818180, 29C9E1E8, 04848084, 17879394,
 35053134, 0BCBC3C8, 0ECEC2CC, 3C0C303C, 31417170, 11011110, 07C7C3C4, 09898188,
 35457174, 3BCBF3F8, 1ACAD2D8, 38C8F0F8, 14849094, 19495158, 02828280, 04C4C0C4,
 3FCFF3FC, 09494148, 39093138, 27476364, 00C0C0C0, 0FCFC3CC, 17C7D3D4, 3888B0B8,
 0F0F030C, 0E8E828C, 02424240, 23032320, 11819190, 2C4C606C, 1BCBD3D8, 2484A0A4,
 34043034, 31C1F1F0, 08484048, 02C2C2C0, 2F4F636C, 3D0D313C, 2D0D212C, 00404040,
 3E8EB2BC, 3E0E323C, 3C8CB0BC, 01C1C1C0, 2A8AA2A8, 3A8AB2B8, 0E4E424C, 15455154,
 3B0B3338, 1CCCD0DC, 28486068, 3F4F737C, 1C8C909C, 18C8D0D8, 0A4A4248, 16465254,
 37477374, 2080A0A0, 2DCDE1EC, 06464244, 3585B1B4, 2B0B2328, 25456164, 3ACAF2F8,
 23C3E3E0, 3989B1B8, 3181B1B0, 1F8F939C, 1E4E525C, 39C9F1F8, 26C6E2E4, 3282B2B0,
 31013130, 2ACAE2E8, 2D4D616C, 1F4F535C, 24C4E0E4, 30C0F0F0, 0DCDC1CC, 08888088,
 16061214, 3A0A3238, 18485058, 14C4D0D4, 22426260, 29092128, 07070304, 33033330,
 28C8E0E8, 1B0B1318, 05050104, 39497178, 10809090, 2A4A6268, 2A0A2228, 1A8A9298

- S-Box SS1

38380830, E828C8E0, 2C2D0D21, A42686A2, CC0FCFC3, DC1ECED2, B03383B3, B83888B0,
 AC2F8FA3, 60204060, 54154551, C407C7C3, 44044440, 6C2F4F63, 682B4B63, 581B4B53,
 C003C3C3, 60224262, 30330333, B43585B1, 28290921, A02080A0, E022C2E2, A42787A3,
 D013C3D3, 90118191, 10110111, 04060602, 1C1C0C10, BC3C8CB0, 34360632, 480B4B43,
 EC2FCFE3, 88088880, 6C2C4C60, A82888A0, 14170713, C404C4C0, 14160612, F434C4F0,
 C002C2C2, 44054541, E021C1E1, D416C6D2, 3C3F0F33, 3C3D0D31, 8C0E8E82, 98188890,
 28280820, 4C0E4E42, F436C6F2, 3C3E0E32, A42585A1, F839C9F1, 0C0D0D01, DC1FCFD3,
 D818C8D0, 282B0B23, 64264662, 783A4A72, 24270723, 2C2F0F23, F031C1F1, 70324272,
 40024242, D414C4D0, 40014141, C000C0C0, 70334373, 64274763, AC2C8CA0, 880B8B83,

F437C7F3, AC2D8DA1, 80008080, 1C1F0F13, C80ACAC2, 2C2C0C20, A82A8AA2, 34340430,
D012C2D2, 080B0B03, EC2ECEEE2, E829C9E1, 5C1D4D51, 94148490, 18180810, F838C8F0,
54174753, AC2E8EA2, 08080800, C405C5C1, 10130313, CC0DCDC1, 84068682, B83989B1,
FC3FCFF3, 7C3D4D71, C001C1C1, 30310131, F435C5F1, 880A8A82, 682A4A62, B03181B1,
D011C1D1, 20200020, D417C7D3, 00020202, 20220222, 04040400, 68284860, 70314171,
04070703, D81BCBD3, 9C1D8D91, 98198991, 60214161, BC3E8EB2, E426C6E2, 58194951,
DC1DCDD1, 50114151, 90108090, DC1CCCD0, 981A8A92, A02383A3, A82B8BA3, D010C0D0,
80018181, 0C0F0F03, 44074743, 181A0A12, E023C3E3, EC2CCCE0, 8C0D8D81, BC3F8FB3,
94168692, 783B4B73, 5C1C4C50, A02282A2, A02181A1, 60234363, 20230323, 4C0D4D41,
C808C8C0, 9C1E8E92, 9C1C8C90, 383A0A32, 0C0C0C00, 2C2E0E22, B83A8AB2, 6C2E4E62,
9C1F8F93, 581A4A52, F032C2F2, 90128292, F033C3F3, 48094941, 78384870, CC0CCCC0,
14150511, F83BCBF3, 70304070, 74354571, 7C3F4F73, 34350531, 10100010, 00030303,
64244460, 6C2D4D61, C406C6C2, 74344470, D415C5D1, B43484B0, E82ACAE2, 08090901,
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- S-Box SS2

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- S-Box SS3

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Appendix B. Test Vectors

This appendix provides test vectors for the SEED cipher described in this document.

All data are hexadecimal numbers (not prefixed by "0x").

B.1.

```
Key       : 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
Plaintext : 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F
Ciphertext: 5E BA C6 E0 05 4E 16 68 19 AF F1 CC 6D 34 6C DB
```

Intermediate Value

	Ki0	Ki1	L0	L1	R0	R1
Round 1	7C8F8C7E	C737A22C	00010203	04050607	08090A0B	0C0D0E0F
Round 2	FF276CDB	A7CA684A	08090A0B	0C0D0E0F	8081BC57	C4EA8A1F
Round 3	2F9D01A1	70049E41	8081BC57	C4EA8A1F	117A8B07	D7358C24
Round 4	AE59B3C4	4245E90C	117A8B07	D7358C24	D1738C94	7326CAB0
Round 5	A1D6400F	DBC1394E	D1738C94	7326CAB0	577ECE6D	1F8433EC
Round 6	85963508	0C5F1FCB	577ECE6D	1F8433EC	910F62AB	DDA096C1
Round 7	B684BDA7	61A4AEAE	910F62AB	DDA096C1	EA4D39B4	B17B1938
Round 8	D17E0741	FEE90AA1	EA4D39B4	B17B1938	B04E251F	97D7442C
Round 9	76CC05D5	E97A7394	B04E251F	97D7442C	B86D31BF	A5988C06
Round 10	50AC6F92	1B2666E5	B86D31BF	A5988C06	9008EABF	38DF7430
Round 11	65B7904A	8EC3A7B3	9008EABF	38DF7430	33E47DE0	54EFF76C
Round 12	2F7E2E22	A2B121B9	33E47DE0	54EFF76C	6BE9C434	BF3F378A
Round 13	4D0BFDE4	4E888D9B	6BE9C434	BF3F378A	B8DC3842	03A02D33
Round 14	631C8DDC	4378A6C4	B8DC3842	03A02D33	6679FCF7	9791DFCB
Round 15	216AF65F	7878C031	6679FCF7	9791DFCB	1A415792	A02B8C54
Round 16	71891150	98B255B0	1A415792	A02B8C54	19AFF1CC	6D346CDB

B.2.

```
Key       : 00 01 02 03 04 05 06 07 08 09 0A 0B 0C 0D 0E 0F
Plaintext : 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
Ciphertext: C1 1F 22 F2 01 40 50 50 84 48 35 97 E4 37 0F 43
```

Intermediate Value

	Ki0	Ki1	L0	L1	R0	R1
Round 1	C119F584	5AE033A0	00000000	00000000	00000000	00000000
Round 2	62947390	A600AD14	00000000	00000000	9D8DB62C	911F0C19
Round 3	F6F6544E	596C4B49	9D8DB62C	911F0C19	21229A97	4AB4B7B8
Round 4	C1A3DE02	CE483C49	21229A97	4AB4B7B8	5A27B404	899D7315


```

Round 5 : 5E742E6D 7E25163D | 5A27B404 899D7315 B8489E76 BA0EF3EA
Round 6 : 8299D2B4 790A46CE | B8489E76 BA0EF3EA 04A3DF29 31A27FB4
Round 7 : EA67D836 55F354F2 | 04A3DF29 31A27FB4 EC9C17BF 81AA2AA0
Round 8 : C47329FB F50DB634 | EC9C17BF 81AA2AA0 4FA74E8D CDB21BB8
Round 9 : 2BD30235 51679CE6 | 4FA74E8D CDB21BB8 D93492FE 4F71A4DA
Round 10 : FA8D6B76 A9F37E02 | D93492FE 4F71A4DA B14053D9 A911379B
Round 11 : 8B99CC60 0F6092D4 | B14053D9 A911379B 5A7024D6 3905668B
Round 12 : BDAEFCFA 489C2242 | 5A7024D6 3905668B 605C8C3A 73DFBB75
Round 13 : F6357C14 CFCCB126 | 605C8C3A 73DFBB75 40282F39 31CB8987
Round 14 : A0AA6D85 F8C10774 | 40282F39 31CB8987 E9F834A8 3B9586D4
Round 15 : 47F4FEC5 353AE1BA | E9F834A8 3B9586D4 4B60324B 761C9958
Round 16 : FECCEA48 A4EF9F9B | 4B60324B 761C9958 84483597 E4370F43

```

B.3.

```

Key       : 47 06 48 08 51 E6 1B E8 5D 74 BF B3 FD 95 61 85
Plaintext : 83 A2 F8 A2 88 64 1F B9 A4 E9 A5 CC 2F 13 1C 7D
Ciphertext: EE 54 D1 3E BC AE 70 6D 22 6B C3 14 2C D4 0D 4A

```

Intermediate Value

```

-----
          Ki0      Ki1      L0      L1      R0      R1
=====
Round 1 : 56BE4A0F E9F62877 | 83A2F8A2 88641FB9 A4E9A5CC 2F131C7D
Round 2 : 68BCB66C 078911DD | A4E9A5CC 2F131C7D 7CE5F012 47F8C1E6
Round 3 : 5B82740B FD24D09B | 7CE5F012 47F8C1E6 AAC99520 609F4CB7
Round 4 : 8D608015 A120E0BE | AAC99520 609F4CB7 3E126D1F 44FA99F0
Round 5 : 810A75AE 1BF223E5 | 3E126D1F 44FA99F0 11716365 9BA775AC
Round 6 : F9C0D2D0 0F676C02 | 11716365 9BA775AC 32C9838F BA5757CB
Round 7 : 8F9B5C84 8A7C8DDD | 32C9838F BA5757CB 77E00C64 CF9F6B32
Round 8 : D4AB4896 18E93447 | 77E00C64 CF9F6B32 3F09B1F7 DE7D6D58
Round 9 : CF090F51 5A4C8202 | 3F09B1F7 DE7D6D58 300E5CAA D0BF2345
Round 10 : 4EC3196F 61B1A0DC | 300E5CAA D0BF2345 9574FDD7 4DF050D1
Round 11 : 244E07C1 D0D10B12 | 9574FDD7 4DF050D1 A15EDA6F 624265FD
Round 12 : 69917C6C 7FF94FB3 | A15EDA6F 624265FD 9F39B682 D841C76F
Round 13 : 9A7EB482 723B5738 | 9F39B682 D841C76F EEBBAD8B C1F488EF
Round 14 : B97522C5 39CC6349 | EEBBAD8B C1F488EF 45CF5D4E BEEA4AA2
Round 15 : FFC2AFD5 1412E731 | 45CF5D4E BEEA4AA2 43B7FE1B BCF87781
Round 16 : A9AF7241 A3E67359 | 43B7FE1B BCF87781 226BC314 2CD40D4A

```


B.4.

Key : 28 DB C3 BC 49 FF D8 7D CF A5 09 B1 1D 42 2B E7
 Plaintext : B4 1E 6B E2 EB A8 4A 14 8E 2E ED 84 59 3C 5E C7
 Ciphertext : 9B 9B 7B FC D1 81 3C B9 5D 0B 36 18 F4 0F 51 22

Intermediate Value

		Ki0	Ki1	L0	L1	R0	R1
Round 1		B2B11B63	2EE9E2D1	B41E6BE2	EBA84A14	8E2EED84	593C5EC7
Round 2		11967260	71A62F24	8E2EED84	593C5EC7	1B31F2F7	3DDE00BA
Round 3		2E017A5A	35DAD7A7	1B31F2F7	3DDE00BA	35CC49C0	2AFB59EA
Round 4		1B2AB5FF	A3ADA69F	35CC49C0	2AFB59EA	D7AB53AA	AE82F1C7
Round 5		519C9903	DA90AAEE	D7AB53AA	AE82F1C7	24139958	B840E56F
Round 6		29FD95AD	B94C3F13	24139958	B840E56F	24AB5291	544C9DBA
Round 7		6F629D19	8ACE692F	24AB5291	544C9DBA	E8152994	75D0B424
Round 8		30A26E73	2F22338E	E8152994	75D0B424	A2CD1153	F32BB23A
Round 9		9721073A	98EE8DAE	A2CD1153	F32BB23A	C386008B	E3257731
Round 10		C597A8A9	27DCDC97	C386008B	E3257731	98396BFD	814F8972
Round 11		F5163A00	5FFD0003	98396BFD	814F8972	E74D2D0D	11D889D1
Round 12		5CBE65DA	A73403E4	E74D2D0D	11D889D1	29D8C7B3	D1B71C0C
Round 13		7D5CF070	1D3B8092	29D8C7B3	D1B71C0C	C4E692C2	D2F57F18
Round 14		388C702B	1BAA4945	C4E692C2	D2F57F18	2FAFB300	5F0C4BFF
Round 15		87D1AB5A	FA13FB5C	2FAFB300	5F0C4BFF	60E5F17C	5626BB68
Round 16		C97D7EED	90724A6E	60E5F17C	5626BB68	5D0B3618	F40F5122

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