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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( $K_i$ , R);
    L = T;

L = L ^ F( $K_{16}$ , 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 (R_0 , R_1) 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, $Ki0$ and $Ki1$, are generated as follows:

- Type 1 : Odd round
 - $Ki0 = G(\text{Key0} + \text{Key2} - KCi)$
 - $Ki1 = G(\text{Key1} - \text{Key3} + KCi)$
 - $\text{Key0} \parallel \text{Key1} = (\text{Key0} \parallel \text{Key1}) \gg 8$
- Type 2 : Even round
 - $Ki0 = G(\text{Key0} + \text{Key2} - KCi)$
 - $Ki1 = G(\text{Key1} - \text{Key3} + KCi)$
 - $\text{Key2} \parallel \text{Key3} = (\text{Key2} \parallel \text{Key3}) \ll 8$

Where $Ki0$ is the most significant 32 bits of Ki , and $Ki1$ is the least significant 32 bits of Ki (where $i=0, \dots, 3$).

The following table shows constants used in KCi :

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	0xBBCCDCF1
KC13	0x779B99E3	KC14	0xEF3733C6
KC15	0xDE6E678D	KC16	0xBCDCCF1B

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, 2ECEEE2EC, 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, 3ECEFE2FC, 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, 74364672, 18190911, FC3ECEFE2, 40004040, 10120212, E020C0E0, BC3D8DB1, 04050501, F83ACAF2, 00010101, F030C0F0, 282A0A22, 5C1E4E52, A82989A1, 54164652, 40034343, 84058581, 14140410, 88098981, 981B8B93, B03080B0, E425C5E1, 48084840, 78394971, 94178793, FC3CCCF0, 1C1E0E12, 80028282, 20210121, 8C0C8C80, 181B0B13, 5C1F4F53, 74374773, 54144450, B03282B2, 1C1D0D11, 24250521, 4C0F4F43, 00000000, 44064642, EC2DCDE1, 58184850, 50124252, E82BCBE3, 7C3E4E72, D81ACAD2, C809C9C1, FC3DCDF1, 30300030, 94158591, 64254561, 3C3C0C30, B43686B2, E424C4E0, B83B8BB3, 7C3C4C70, 0C0E0E02, 50104050, 38390931, 24260622, 30320232, 84048480, 68294961, 90138393, 34370733, E427C7E3, 24240420, A42484A0, C80BCBC3, 50134353, 080A0A02, 84078783, D819C9D1, 4C0C4C40, 80038383, 8C0F8F83, CC0ECEC2, 383B0B33, 480A4A42, B43787B3

- S-Box SS2

A1A82989, 81840585, D2D416C6, D3D013C3, 50541444, 111C1D0D, A0AC2C8C, 21242505, 515C1D4D, 43400343, 10181808, 121C1E0E, 51501141, F0FC3CCC, C2C80ACA, 63602343, 20282808, 40440444, 20202000, 919C1D8D, E0E020C0, E2E022C2, C0C80C8C, 13141707, A1A42585, 838C0F8F, 03000303, 73783B4B, B3B83B8B, 13101303, D2D012C2, E2EC2ECE, 70703040, 808C0C8C, 333C3F0F, A0A82888, 32303202, D1DC1DCD, F2F436C6, 70743444, E0EC2CCC, 91941585, 03080B0B, 53541747, 505C1C4C, 53581B4B, B1BC3D8D, 01000101, 20242404, 101C1C0C, 73703343, 90981888, 10101000, C0CC0CCC, F2F032C2, D1D819C9, 202C2C0C, E3E427C7, 72703242, 83800383, 93981B8B, D1D011C1, 82840686, C1C809C9, 60602040, 50501040, A3A02383, E3E82BCB, 010C0D0D, B2B43686, 929C1E8E, 434C0F4F, B3B43787, 52581A4A, C2C406C6, 70783848, A2A42686, 12101202, A3AC2F8F, D1D415C5, 61602141, C3C003C3, B0B43484, 41400141, 52501242, 717C3D4D, 818C0D8D, 00080808, 131C1F0F, 91981989, 00000000, 11181909, 00040404, 53501343, F3F437C7, E1E021C1, F1FC3DCD, 72743646, 232C2F0F, 23242707, B0B03080, 83880B8B, 020C0E0E, A3A82B8B, A2A02282, 626C2E4E, 93901383, 414C0D4D, 61682949, 707C3C4C, 01080909, 02080A0A, B3BC3F8F, E3EC2FCF, F3F033C3, C1C405C5, 83840787, 10141404, F2FC3ECE, 60642444, D2DC1ECE, 222C2E0E, 43480B4B, 12181A0A, 02040606, 21202101, 63682B4B, 62642646, 02000202, F1F435C5, 92901282, 82880A8A, 000C0C0C, B3B03383, 727C3E4E, D0D010C0, 72783A4A, 43440747, 92941686, E1E425C5, 22242606, 80800080, A1AC2D8D, D3DC1FCF, A1A02181, 30303000, 33343707, A2AC2E8E, 32343606, 11141505, 22202202, 30383808, F0F434C4, A3A42787, 41440545, 404C0C4C, 81800181, E1E829C9, 80840484, 93941787, 31343505, C3C80BCB, C2CC0ECE, 303C3C0C, 71703141, 11101101, C3C407C7, 81880989, 71743545, F3F83BCB, D2D81ACA, F0F838C8, 90941484, 51581949, 82800282, C0C404C4,

F3FC3FCF, 41480949, 31383909, 63642747, C0C000C0, C3CC0FCF, D3D417C7, B0B83888, 030C0F0F, 828C0E8E, 42400242, 23202303, 91901181, 606C2C4C, D3D81BCB, A0A42484, 30343404, F1F031C1, 40480848, C2C002C2, 636C2F4F, 313C3D0D, 212C2D0D, 40400040, B2BC3E8E, 323C3E0E, B0BC3C8C, C1C001C1, A2A82A8A, B2B83A8A, 424C0E4E, 51541545, 33383B0B, D0DC1CCC, 60682848, 737C3F4F, 909C1C8C, D0D818C8, 42480A4A, 52541646, 73743747, A0A02080, E1EC2DCD, 42440646, B1B43585, 23282B0B, 61642545, F2F83ACA, E3E023C3, B1B83989, B1B03181, 939C1F8F, 525C1E4E, F1F839C9, E2E426C6, B2B03282, 31303101, E2E82ACA, 616C2D4D, 535C1F4F, E0E424C4, F0F030C0, C1CC0DCD, 80880888, 12141606, 32383A0A, 50581848, D0D414C4, 62602242, 21282909, 03040707, 33303303, E0E828C8, 13181B0B, 01040505, 71783949, 90901080, 62682A4A, 22282A0A, 92981A8A

- S-Box SS3

08303838, C8E0E828, 0D212C2D, 86A2A426, CFC3CC0F, CED2DC1E, 83B3B033, 88B0B838, 8FA3AC2F, 40606020, 45515415, C7C3C407, 44404404, 4F636C2F, 4B63682B, 4B53581B, C3C3C003, 42626022, 03333033, 85B1B435, 09212829, 80A0A020, C2E2E022, 87A3A427, C3D3D013, 81919011, 01111011, 06020406, 0C101C1C, 8CB0BC3C, 06323436, 4B43480B, CFE3EC2F, 88808808, 4C606C2C, 88A0A828, 07131417, C4C0C404, 06121416, C4F0F434, C2C2C002, 45414405, C1E1E021, C6D2D416, 0F333C3F, 0D313C3D, 8E828C0E, 88909818, 08202828, 4E424C0E, C6F2F436, 0E323C3E, 85A1A425, C9F1F839, 0D010C0D, CFD3DC1F, C8D0D818, 0B23282B, 46626426, 4A72783A, 07232427, 0F232C2F, C1F1F031, 42727032, 42424002, C4D0D414, 41414001, C0C0C000, 43737033, 47636427, 8CA0AC2C, 8B83880B, C7F3F437, 8DA1AC2D, 80808000, 0F131C1F, CAC2C80A, 0C202C2C, 8AA2A82A, 04303434, C2D2D012, 0B03080B, CEE2EC2E, C9E1E829, 4D515C1D, 84909414, 08101818, C8F0F838, 47535417, 8EA2AC2E, 08000808, C5C1C405, 03131013, CDC1CC0D, 86828406, 89B1B839, CFF3FC3F, 4D717C3D, C1C1C001, 01313031, C5F1F435, 8A82880A, 4A62682A, 81B1B031, C1D1D011, 00202020, C7D3D417, 02020002, 02222022, 04000404, 48606828, 41717031, 07030407, CBD3D81B, 8D919C1D, 89919819, 41616021, 8EB2BC3E, C6E2E426, 49515819, CDD1DC1D, 41515011, 80909010, CCD0DC1C, 8A92981A, 83A3A023, 8BA3A82B, C0D0D010, 81818001, 0F030C0F, 47434407, 0A12181A, C3E3E023, CCE0EC2C, 8D818C0D, 8FB3BC3F, 86929416, 4B73783B, 4C505C1C, 82A2A022, 81A1A021, 43636023, 03232023, 4D414C0D, C8C0C808, 8E929C1E, 8C909C1C, 0A32383A, 0C000C0C, 0E222C2E, 8AB2B83A, 4E626C2E, 8F939C1F, 4A52581A, C2F2F032, 82929012, C3F3F033, 49414809, 48707838, CCC0CC0C, 05111415, CBF3F83B, 40707030, 45717435, 4F737C3F, 05313435, 00101010, 03030003, 44606424, 4D616C2D, C6C2C406, 44707434, C5D1D415, 84B0B434, CAE2E82A, 09010809, 46727436, 09111819, CEF2FC3E, 40404000, 02121012, C0E0E020, 8DB1BC3D, 05010405, CAF2F83A, 01010001, C0F0F030, 0A22282A, 4E525C1E, 89A1A829, 46525416, 43434003, 85818405, 04101414, 89818809, 8B93981B, 80B0B030, C5E1E425, 48404808, 49717839, 87939417, CCF0FC3C, 0E121C1E, 82828002, 01212021, 8C808C0C, 0B13181B, 4F535C1F, 47737437, 44505414, 82B2B032, 0D111C1D, 05212425, 4F434C0F, 00000000, 46424406, CDE1EC2D, 48505818, 42525012, CBE3E82B, 4E727C3E, CAD2D81A, C9C1C809, CDF1FC3D, 00303030, 85919415, 45616425, 0C303C3C, 86B2B436, C4E0E424, 8BB3B83B, 4C707C3C, 0E020C0E, 40505010, 09313839, 06222426, 02323032, 84808404, 49616829, 83939013, 07333437, C7E3E427, 04202424, 84A0A424, CBC3C80B, 43535013, 0A02080A, 87838407, C9D1D819, 4C404C0C, 83838003, 8F838C0F, CEC2CC0E, 0B33383B, 4A42480A, 87B3B437

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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