

Network Working Group
Request for Comments: 4269
Obsoletes: 4009
Category: Informational

H.J. Lee
S.J. Lee
J.H. Yoon
D.H. Cheon
J.I. Lee
KISA
December 2005

The SEED Encryption Algorithm

Status of This Memo

This memo provides information for the Internet community. It does not specify an Internet standard of any kind. Distribution of this memo is unlimited.

Copyright Notice

Copyright (C) The Internet Society (2005).

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 (= $Z_3 \parallel Z_2 \parallel Z_1 \parallel Z_0$) of the function G with four 8-bit inputs X (= $X_3 \parallel X_2 \parallel X_1 \parallel X_0$) 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:

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

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(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 $Ki0$ 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	0xBBDCDCF1
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) }
```

```
PBEParameters ::= 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

Alfred Hoenes (ah@tr-sys.de) has contributed significantly to work on the definitions of R1', Z, X, and SS-boxes. Thanks for his contribution to this document.

6. Authors' Addresses

Hyangjin Lee
Korea Information Security Agency
78, Garak-Dong, Songpa-Gu, Seoul, 138-803
REPUBLIC OF KOREA

Phone: +82-2-405-5446
Fax: +82-2-405-5319
EMail: jiinii@kisa.or.kr

Sungjae Lee
Korea Information Security Agency

Phone: +82-2-405-5243
Fax: +82-2-405-5499
EMail: sjlee@kisa.or.kr

Jaeho Yoon
Korea Information Security Agency

Phone: +82-2-405-5434
FAX: +82-2-405-5219
EMail: jhyoon@kisa.or.kr

Donghyeon Cheon
SEC Laboratory

Phone: +82-31-788-3161
FAX: +82-31-707-4017
EMail: dhcheon@mmaa.or.kr

Jaeil Lee
Korea Information Security Agency

Phone: +82-2-405-5300
FAX: +82-2-405-5219
EMail: jilee@kisa.or.kr

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, 3ECEEF2FC, 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,EC2ECEE2,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,FC3ECEF2,40004040,10120212,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,C0C808C8,13141707,
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
=====

```

Full Copyright Statement

Copyright (C) The Internet Society (2005).

This document is subject to the rights, licenses and restrictions contained in BCP 78, and except as set forth therein, the authors retain all their rights.

This document and the information contained herein are provided on an "AS IS" basis and THE CONTRIBUTOR, THE ORGANIZATION HE/SHE REPRESENTS OR IS SPONSORED BY (IF ANY), THE INTERNET SOCIETY AND THE INTERNET ENGINEERING TASK FORCE DISCLAIM ALL WARRANTIES, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO ANY WARRANTY THAT THE USE OF THE INFORMATION HEREIN WILL NOT INFRINGE ANY RIGHTS OR ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

Intellectual Property

The IETF takes no position regarding the validity or scope of any Intellectual Property Rights or other rights that might be claimed to pertain to the implementation or use of the technology described in this document or the extent to which any license under such rights might or might not be available; nor does it represent that it has made any independent effort to identify any such rights. Information on the procedures with respect to rights in RFC documents can be found in BCP 78 and BCP 79.

Copies of IPR disclosures made to the IETF Secretariat and any assurances of licenses to be made available, or the result of an attempt made to obtain a general license or permission for the use of such proprietary rights by implementers or users of this specification can be obtained from the IETF on-line IPR repository at <http://www.ietf.org/ipr>.

The IETF invites any interested party to bring to its attention any copyrights, patents or patent applications, or other proprietary rights that may cover technology that may be required to implement this standard. Please address the information to the IETF at ietf-ipr@ietf.org.

Acknowledgement

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