

The CAST-128 Encryption Algorithm

Status of this Memo

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

Abstract

There is a need in the Internet community for an unencumbered encryption algorithm with a range of key sizes that can provide security for a variety of cryptographic applications and protocols.

This document describes an existing algorithm that can be used to satisfy this requirement. Included are a description of the cipher and the key scheduling algorithm (Section 2), the s-boxes (Appendix A), and a set of test vectors (Appendix B).

TABLE OF CONTENTS

STATUS OF THIS MEMO.....	1
ABSTRACT.....	1
1. INTRODUCTION.....	1
2. DESCRIPTION OF ALGORITHM.....	2
3. INTELLECTUAL PROPERTY CONSIDERATIONS.....	8
4. SECURITY CONSIDERATIONS.....	8
5. REFERENCES.....	8
6. AUTHOR'S ADDRESS.....	8
APPENDICES	
A. S-BOXES.....	9
B. TEST VECTORS.....	15

1. Introduction

This document describes the CAST-128 encryption algorithm, a DES-like Substitution-Permutation Network (SPN) cryptosystem which appears to have good resistance to differential cryptanalysis, linear cryptanalysis, and related-key cryptanalysis. This cipher also possesses a number of other desirable cryptographic properties, including avalanche, Strict Avalanche Criterion (SAC), Bit Independence Criterion (BIC), no complementation property, and an absence of weak and semi-weak keys. It thus appears to be a good

candidate for general-purpose use throughout the Internet community wherever a cryptographically-strong, freely-available encryption algorithm is required.

Adams [Adams] discusses the CAST design procedure in some detail; analyses can also be obtained on-line (see, for example, [Web1] or [Web2]).

2. Description of Algorithm

CAST-128 belongs to the class of encryption algorithms known as Feistel ciphers; overall operation is thus similar to the Data Encryption Standard (DES). The full encryption algorithm is given in the following four steps.

INPUT: plaintext $m_1 \dots m_{64}$; key $K = k_1 \dots k_{128}$.

OUTPUT: ciphertext $c_1 \dots c_{64}$.

1. (key schedule) Compute 16 pairs of subkeys $\{K_{mi}, K_{ri}\}$ from K (see Sections 2.1 and 2.4).
2. $(L_0, R_0) \leftarrow (m_1 \dots m_{64})$. (Split the plaintext into left and right 32-bit halves $L_0 = m_1 \dots m_{32}$ and $R_0 = m_{33} \dots m_{64}$.)
3. (16 rounds) for i from 1 to 16, compute L_i and R_i as follows:
 $L_i = R_{i-1}$;
 $R_i = L_{i-1} \wedge f(R_{i-1}, K_{mi}, K_{ri})$, where f is defined in Section 2.2 (f is of Type 1, Type 2, or Type 3, depending on i).
4. $c_1 \dots c_{64} \leftarrow (R_{16}, L_{16})$. (Exchange final blocks L_{16} , R_{16} and concatenate to form the ciphertext.)

Decryption is identical to the encryption algorithm given above, except that the rounds (and therefore the subkey pairs) are used in reverse order to compute (L_0, R_0) from (R_{16}, L_{16}) .

See Appendix B for test vectors which can be used to verify correctness of an implementation of this algorithm.

2.1. Pairs of Round Keys

CAST-128 uses a pair of subkeys per round: a 32-bit quantity K_m is used as a "masking" key and a 5-bit quantity K_r is used as a "rotation" key.

2.2. Non-Identical Rounds

Three different round functions are used in CAST-128. The rounds are as follows (where "D" is the data input to the f function and "Ia" - "Id" are the most significant byte through least significant byte of I, respectively). Note that "+" and "-" are addition and subtraction modulo 2^{32} , "^" is bitwise XOR, and "<<<" is the circular left-shift operation.

Type 1: $I = ((K_{mi} + D) \lll K_{ri})$
 $f = ((S1[Ia] \wedge S2[Ib]) - S3[Ic]) + S4[Id]$

Type 2: $I = ((K_{mi} \wedge D) \lll K_{ri})$
 $f = ((S1[Ia] - S2[Ib]) + S3[Ic]) \wedge S4[Id]$

Type 3: $I = ((K_{mi} - D) \lll K_{ri})$
 $f = ((S1[Ia] + S2[Ib]) \wedge S3[Ic]) - S4[Id]$

Rounds 1, 4, 7, 10, 13, and 16 use f function Type 1.

Rounds 2, 5, 8, 11, and 14 use f function Type 2.

Rounds 3, 6, 9, 12, and 15 use f function Type 3.

2.3. Substitution Boxes

CAST-128 uses eight substitution boxes: s-boxes S1, S2, S3, and S4 are round function s-boxes; S5, S6, S7, and S8 are key schedule s-boxes. Although 8 s-boxes require a total of 8 KBytes of storage, note that only 4 KBytes are required during actual encryption / decryption since subkey generation is typically done prior to any data input.

See Appendix A for the contents of s-boxes S1 - S8.

2.4. Key Schedule

Let the 128-bit key be $x_0x_1x_2x_3x_4x_5x_6x_7x_8x_9x_Ax_Bx_Cx_Dx_Ex_F$, where x_0 represents the most significant byte and x_F represents the least significant byte.

Let $z_0..z_F$ be intermediate (temporary) bytes.

Let $S_i[]$ represent s-box i and let " \wedge " represent XOR addition.

The subkeys are formed from the key $x_0x_1x_2x_3x_4x_5x_6x_7x_8x_9xAxBxCxDxExF$ as follows.

$$\begin{aligned} z_0z_1z_2z_3 &= x_0x_1x_2x_3 \wedge S5[xD] \wedge S6[xF] \wedge S7[xC] \wedge S8[xE] \wedge S7[x8] \\ z_4z_5z_6z_7 &= x_8x_9xAxB \wedge S5[z0] \wedge S6[z2] \wedge S7[z1] \wedge S8[z3] \wedge S8[xA] \\ z_8z_9zAzB &= xCxDxExF \wedge S5[z7] \wedge S6[z6] \wedge S7[z5] \wedge S8[z4] \wedge S5[x9] \\ zCzDzEzF &= x_4x_5x_6x_7 \wedge S5[zA] \wedge S6[z9] \wedge S7[zB] \wedge S8[z8] \wedge S6[xB] \\ K1 &= S5[z8] \wedge S6[z9] \wedge S7[z7] \wedge S8[z6] \wedge S5[z2] \\ K2 &= S5[zA] \wedge S6[zB] \wedge S7[z5] \wedge S8[z4] \wedge S6[z6] \\ K3 &= S5[zC] \wedge S6[zD] \wedge S7[z3] \wedge S8[z2] \wedge S7[z9] \\ K4 &= S5[zE] \wedge S6[zF] \wedge S7[z1] \wedge S8[z0] \wedge S8[zC] \\ x_0x_1x_2x_3 &= z_8z_9zAzB \wedge S5[z5] \wedge S6[z7] \wedge S7[z4] \wedge S8[z6] \wedge S7[z0] \\ x_4x_5x_6x_7 &= z_0z_1z_2z_3 \wedge S5[x0] \wedge S6[x2] \wedge S7[x1] \wedge S8[x3] \wedge S8[z2] \\ x_8x_9xAxB &= z_4z_5z_6z_7 \wedge S5[x7] \wedge S6[x6] \wedge S7[x5] \wedge S8[x4] \wedge S5[z1] \\ xCxDxExF &= zCzDzEzF \wedge S5[xA] \wedge S6[x9] \wedge S7[xB] \wedge S8[x8] \wedge S6[z3] \\ K5 &= S5[x3] \wedge S6[x2] \wedge S7[xC] \wedge S8[xD] \wedge S5[x8] \\ K6 &= S5[x1] \wedge S6[x0] \wedge S7[xE] \wedge S8[xF] \wedge S6[xD] \\ K7 &= S5[x7] \wedge S6[x6] \wedge S7[x8] \wedge S8[x9] \wedge S7[x3] \\ K8 &= S5[x5] \wedge S6[x4] \wedge S7[xA] \wedge S8[xB] \wedge S8[x7] \\ z_0z_1z_2z_3 &= x_0x_1x_2x_3 \wedge S5[xD] \wedge S6[xF] \wedge S7[xC] \wedge S8[xE] \wedge S7[x8] \\ z_4z_5z_6z_7 &= x_8x_9xAxB \wedge S5[z0] \wedge S6[z2] \wedge S7[z1] \wedge S8[z3] \wedge S8[xA] \\ z_8z_9zAzB &= xCxDxExF \wedge S5[z7] \wedge S6[z6] \wedge S7[z5] \wedge S8[z4] \wedge S5[x9] \\ zCzDzEzF &= x_4x_5x_6x_7 \wedge S5[zA] \wedge S6[z9] \wedge S7[zB] \wedge S8[z8] \wedge S6[xB] \\ K9 &= S5[z3] \wedge S6[z2] \wedge S7[zC] \wedge S8[zD] \wedge S5[z9] \\ K10 &= S5[z1] \wedge S6[z0] \wedge S7[zE] \wedge S8[zF] \wedge S6[zC] \\ K11 &= S5[z7] \wedge S6[z6] \wedge S7[z8] \wedge S8[z9] \wedge S7[z2] \\ K12 &= S5[z5] \wedge S6[z4] \wedge S7[zA] \wedge S8[zB] \wedge S8[z6] \\ x_0x_1x_2x_3 &= z_8z_9zAzB \wedge S5[z5] \wedge S6[z7] \wedge S7[z4] \wedge S8[z6] \wedge S7[z0] \\ x_4x_5x_6x_7 &= z_0z_1z_2z_3 \wedge S5[x0] \wedge S6[x2] \wedge S7[x1] \wedge S8[x3] \wedge S8[z2] \\ x_8x_9xAxB &= z_4z_5z_6z_7 \wedge S5[x7] \wedge S6[x6] \wedge S7[x5] \wedge S8[x4] \wedge S5[z1] \\ xCxDxExF &= zCzDzEzF \wedge S5[xA] \wedge S6[x9] \wedge S7[xB] \wedge S8[x8] \wedge S6[z3] \\ K13 &= S5[x8] \wedge S6[x9] \wedge S7[x7] \wedge S8[x6] \wedge S5[x3] \\ K14 &= S5[xA] \wedge S6[xB] \wedge S7[x5] \wedge S8[x4] \wedge S6[x7] \\ K15 &= S5[xC] \wedge S6[xD] \wedge S7[x3] \wedge S8[x2] \wedge S7[x8] \\ K16 &= S5[xE] \wedge S6[xF] \wedge S7[x1] \wedge S8[x0] \wedge S8[xD] \end{aligned}$$

[The remaining half is identical to what is given above, carrying on from the last created x0..xF to generate keys K17 - K32.]

```

z0z1z2z3 = x0x1x2x3 ^ S5 [xD] ^ S6 [xF] ^ S7 [xC] ^ S8 [xE] ^ S7 [x8]
z4z5z6z7 = x8x9xAxB ^ S5 [z0] ^ S6 [z2] ^ S7 [z1] ^ S8 [z3] ^ S8 [xA]
z8z9zAzB = xCxDxExF ^ S5 [z7] ^ S6 [z6] ^ S7 [z5] ^ S8 [z4] ^ S5 [x9]
zCzDzEzF = x4x5x6x7 ^ S5 [zA] ^ S6 [z9] ^ S7 [z9] ^ S8 [z8] ^ S6 [xB]
K17 = S5 [z8] ^ S6 [z9] ^ S7 [z7] ^ S8 [z6] ^ S5 [z2]
K18 = S5 [zA] ^ S6 [zB] ^ S7 [z5] ^ S8 [z4] ^ S6 [z6]
K19 = S5 [zC] ^ S6 [zD] ^ S7 [z3] ^ S8 [z2] ^ S7 [z9]
K20 = S5 [zE] ^ S6 [zF] ^ S7 [z1] ^ S8 [z0] ^ S8 [zC]
x0x1x2x3 = z8z9zAzB ^ S5 [z5] ^ S6 [z7] ^ S7 [z4] ^ S8 [z6] ^ S7 [z0]
x4x5x6x7 = z0z1z2z3 ^ S5 [x0] ^ S6 [x2] ^ S7 [x1] ^ S8 [x3] ^ S8 [z2]
x8x9xAxB = z4z5z6z7 ^ S5 [x7] ^ S6 [x6] ^ S7 [x5] ^ S8 [x4] ^ S5 [z1]
xCxDxExF = zCzDzEzF ^ S5 [xA] ^ S6 [x9] ^ S7 [xB] ^ S8 [x8] ^ S6 [z3]
K21 = S5 [x3] ^ S6 [x2] ^ S7 [xC] ^ S8 [xD] ^ S5 [x8]
K22 = S5 [x1] ^ S6 [x0] ^ S7 [xE] ^ S8 [xF] ^ S6 [xD]
K23 = S5 [x7] ^ S6 [x6] ^ S7 [x8] ^ S8 [x9] ^ S7 [x3]
K24 = S5 [x5] ^ S6 [x4] ^ S7 [xA] ^ S8 [xB] ^ S8 [x7]
z0z1z2z3 = x0x1x2x3 ^ S5 [xD] ^ S6 [xF] ^ S7 [xC] ^ S8 [xE] ^ S7 [x8]
z4z5z6z7 = x8x9xAxB ^ S5 [z0] ^ S6 [z2] ^ S7 [z1] ^ S8 [z3] ^ S8 [xA]
z8z9zAzB = xCxDxExF ^ S5 [z7] ^ S6 [z6] ^ S7 [z5] ^ S8 [z4] ^ S5 [x9]
zCzDzEzF = x4x5x6x7 ^ S5 [zA] ^ S6 [z9] ^ S7 [zB] ^ S8 [z8] ^ S6 [xB]
K25 = S5 [z3] ^ S6 [z2] ^ S7 [zC] ^ S8 [zD] ^ S5 [z9]
K26 = S5 [z1] ^ S6 [z0] ^ S7 [zE] ^ S8 [zF] ^ S6 [zC]
K27 = S5 [z7] ^ S6 [z6] ^ S7 [z8] ^ S8 [z9] ^ S7 [z2]
K28 = S5 [z5] ^ S6 [z4] ^ S7 [zA] ^ S8 [zB] ^ S8 [z6]
x0x1x2x3 = z8z9zAzB ^ S5 [z5] ^ S6 [z7] ^ S7 [z4] ^ S8 [z6] ^ S7 [z0]
x4x5x6x7 = z0z1z2z3 ^ S5 [x0] ^ S6 [x2] ^ S7 [x1] ^ S8 [x3] ^ S8 [z2]
x8x9xAxB = z4z5z6z7 ^ S5 [x7] ^ S6 [x6] ^ S7 [x5] ^ S8 [x4] ^ S5 [z1]
xCxDxExF = zCzDzEzF ^ S5 [xA] ^ S6 [x9] ^ S7 [xB] ^ S8 [x8] ^ S6 [z3]
K29 = S5 [x8] ^ S6 [x9] ^ S7 [x7] ^ S8 [x6] ^ S5 [x3]
K30 = S5 [xA] ^ S6 [xB] ^ S7 [x5] ^ S8 [x4] ^ S6 [x7]
K31 = S5 [xC] ^ S6 [xD] ^ S7 [x3] ^ S8 [x2] ^ S7 [x8]
K32 = S5 [xE] ^ S6 [xF] ^ S7 [x1] ^ S8 [x0] ^ S8 [xD]

```

2.4.1. Masking Subkeys And Rotate Subkeys

Let Km1, ..., Km16 be 32-bit masking subkeys (one per round).
 Let Kr1, ..., Kr16 be 32-bit rotate subkeys (one per round); only the
 least significant 5 bits are used in each round.

```
for (i=1; i<=16; i++) { Kmi = Ki; Kri = K16+i; }
```

2.5. Variable Keysize

The CAST-128 encryption algorithm has been designed to allow a key size that can vary from 40 bits to 128 bits, in 8-bit increments (that is, the allowable key sizes are 40, 48, 56, 64, ..., 112, 120, and 128 bits). For variable keysize operation, the specification is as follows:

- 1) For key sizes up to and including 80 bits (i.e., 40, 48, 56, 64, 72, and 80 bits), the algorithm is exactly as specified but uses 12 rounds instead of 16;
- 2) For key sizes greater than 80 bits, the algorithm uses the full 16 rounds;
- 3) For key sizes less than 128 bits, the key is padded with zero bytes (in the rightmost, or least significant, positions) out to 128 bits (since the CAST-128 key schedule assumes an input key of 128 bits).

Note that although CAST-128 can support all 12 key sizes listed above, 40 bits, 64 bits, 80 bits, and 128 bits are the sizes that find utility in typical environments. Therefore, it will likely be sufficient for most implementations to support some subset of only these four sizes.

In order to avoid confusion when variable keysize operation is used, the name CAST-128 is to be considered synonymous with the name CAST5; this allows a keysize to be appended without ambiguity. Thus, for example, CAST-128 with a 40-bit key is to be referred to as CAST5-40; where a 128-bit key is explicitly intended, the name CAST5-128 should be used.

2.6. CAST5 Object Identifiers

For those who may be using CAST in algorithm negotiation within a protocol, or in any other context which may require the use of OBJECT IDENTIFIERS, the following OIDs have been defined.

```
algorithms OBJECT IDENTIFIER ::=
  { iso(1) memberBody(2) usa(840) nt(113533) nsn(7) algorithms(66) }
```

```
cast5CBC OBJECT IDENTIFIER ::= { algorithms cast5CBC(10) }
```

```
Parameters ::= SEQUENCE {  
    iv          OCTET STRING DEFAULT 0,  -- Initialization vector  
    keyLength   INTEGER                  -- Key length, in bits  
}
```

Note: The iv is optional and defaults to all-zero. On the encoding end, if an all-zero iv is used, then it should be absent from the Parameters. On the decoding end, an absent iv should be interpreted as meaning all-zeros.

This is encryption and decryption in CBC mode using the CAST-128 symmetric block cipher algorithm.

```
cast5MAC OBJECT IDENTIFIER ::= { algorithms cast5MAC(11) }
```

```
Parameters ::= SEQUENCE {  
    macLength   INTEGER,                -- MAC length, in bits  
    keyLength   INTEGER                  -- Key length, in bits  
}
```

This is message authentication using the CAST-128 symmetric block cipher algorithm.

```
pbeWithMD5AndCast5CBC OBJECT IDENTIFIER ::=  
    { algorithms pbeWithMD5AndCAST5-CBC(12) }
```

```
Parameters ::= SEQUENCE {  
    salt          OCTET STRING,  
    iterationCount INTEGER,          -- Total number of hash iterations  
    keyLength     INTEGER            -- Key length, in bits  
}
```

Note: The IV is derived from the hashing procedure and therefore need not be included in Parameters.

This is password-based encryption and decryption in CBC mode using MD5 and the CAST-128 symmetric block cipher. See PKCS #5 (which uses the DES cipher) for details of the PBE computation.

2.7. Discussion

CAST-128 is a 12- or 16-round Feistel cipher that has a blocksize of 64 bits and a keysize of up to 128 bits; it uses rotation to provide intrinsic immunity to linear and differential attacks; it uses a mixture of XOR, addition and subtraction (modulo 2^{32}) in the round function; and it uses three variations of the round function itself throughout the cipher. Finally, the 8x32 s-boxes used in the round function each have a minimum nonlinearity of 74 and a maximum entry of 2 in the difference distribution table.

This cipher appears to have cryptographic strength in accordance with its keysize (128 bits) and has very good encryption / decryption performance: 3.3 MBytes/sec on a 150 MHz Pentium processor.

3. Intellectual Property Considerations

The CAST-128 cipher described in this document is available worldwide on a royalty-free basis for commercial and non-commercial uses.

4. Security Considerations

This entire memo is about security since it describes an algorithm which is specifically intended for cryptographic purposes.

5. References

[Adams] Adams, C., "Constructing Symmetric Ciphers using the CAST Design Procedure", *Designs, Codes, and Cryptography* (to appear).

[Web1] "Constructing Symmetric Ciphers using the CAST Design Procedure" (identical to [Adams] but available on-line) and "CAST Design Procedure Addendum", <http://www.entrust.com/library.htm>.

[Web2] "CAST Encryption Algorithm Related Publications", <http://adonis.ee.queensu.ca:8000/cast/cast.html>.

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Appendix A. S-Boxes

S-Box S1

30fb40d4	9fa0ff0b	6beccd2f	3f258c7a	1e213f2f	9c004dd3	6003e540	cf9fc949
bfd4af27	88bbbdb5	e2034090	98d09675	6e63a0e0	15c361d2	c2e7661d	22d4ff8e
28683b6f	c07fd059	ff2379c8	775f50e2	43c340d3	df2f8656	887ca41a	a2d2bd2d
a1c9e0d6	346c4819	61b76d87	22540f2f	2abe32e1	aa54166b	22568e3a	a2d341d0
66db40c8	a784392f	004dff2f	2db9d2de	97943fac	4a97c1d8	527644b7	b5f437a7
b82cbaef	d751d159	6ff7f0ed	5a097a1f	827b68d0	90ecf52e	22b0c054	bc8e5935
4b6d2f7f	50bb64a2	d2664910	bee5812d	b7332290	e93b159f	b48ee411	4bff345d
fd45c240	ad31973f	c4f6d02e	55fc8165	d5b1caad	a1ac2dae	a2d4b76d	c19b0c50
882240f2	0c6e4f38	a4e4bfd7	4f5ba272	564c1d2f	c59c5319	b949e354	b04669fe
b1b6ab8a	c71358dd	6385c545	110f935d	57538ad5	6a390493	e63d37e0	2a54f6b3
3a787d5f	6276a0b5	19a6fcd5	7a42206a	29f9d4d5	f61b1891	bb72275e	aa508167
38901091	c6b505eb	84c7cb8c	2ad75a0f	874a1427	a2d1936b	2ad286af	aa56d291
d7894360	425c750d	93b39e26	187184c9	6c00b32d	73e2bb14	a0bebc3c	54623779
64459eab	3f328b82	7718cf82	59a2cea6	04ee002e	89fe78e6	3fab0950	325ff6c2
81383f05	6963c5c8	76cb5ad6	d49974c9	ca180dcf	380782d5	c7fa5cf6	8ac31511
35e79e13	47da91d0	f40f9086	a7e2419e	31366241	051ef495	aa573b04	4a805d8d
548300d0	00322a3c	bf64cddf	ba57a68e	75c6372b	50afd341	a7c13275	915a0bf5
6b54bfab	2b0b1426	ab4cc9d7	449ccd82	f7fbf265	ab85c5f3	1b55db94	aad4e324
cfa4bd3f	2deaa3e2	9e204d02	c8bd25ac	eadf55b3	d5bd9e98	e31231b2	2ad5ad6c
954329de	adbe4528	d8710f69	aa51c90f	aa786bf6	22513f1e	aa51a79b	2ad344cc
7b5a41f0	d37cfbad	1b069505	41ece491	b4c332e6	032268d4	c9600acc	ce387e6d
bf6bb16c	6a70fb78	0d03d9c9	d4df39de	e01063da	4736f464	5ad328d8	b347cc96
75bb0fc3	98511bfb	4ffbcc35	b58bcf6a	e11f0abc	bfc5fe4a	a70aec10	ac39570a
3f04442f	6188b153	e0397a2e	5727cb79	9ceb418f	1cacd68d	2ad37c96	0175cb9d
c69dff09	c75b65f0	d9db40d8	ec0e7779	4744ead4	b11c3274	dd24cb9e	7e1c54bd
f01144f9	d2240eb1	9675b3fd	a3ac3755	d47c27af	51c85f4d	56907596	a5bb15e6
580304f0	ca042cf1	011a37ea	8dbfaadb	35ba3e4a	3526ffa0	c37b4d09	bc306ed9
98a52666	5648f725	ff5e569d	0ced63d0	7c63b2cf	700b45e1	d5ea50f1	85a92872
af1fbda7	d4234870	a7870bf3	2d3b4d79	42e04198	0cd0ede7	26470db8	f881814c
474d6ad7	7c0c5e5c	d1231959	381b7298	f5d2f4db	ab838653	6e2f1e23	83719c9e
bd91e046	9a56456e	dc39200c	20c8c571	962bda1c	e1e696ff	b141ab08	7cca89b9
1a69e783	02cc4843	a2f7c579	429ef47d	427b169c	5ac9f049	dd8f0f00	5c8165bf

S-Box S2

1f201094	ef0ba75b	69e3cf7e	393f4380	fe61cf7a	eec5207a	55889c94	72fc0651
ada7ef79	4e1d7235	d55a63ce	de0436ba	99c430ef	5f0c0794	18dcdb7d	a1d6eff3
a0b52f7b	59e83605	ee15b094	e9ffd909	dc440086	ef944459	ba83ccb3	e0c3cdfb
d1da4181	3b092ab1	f997f1c1	a5e6cf7b	01420ddb	e4e7ef5b	25a1ff41	e180f806
1fc41080	179bee7a	d37ac6a9	fe5830a4	98de8b7f	77e83f4e	79929269	24fa9f7b
e113c85b	acc40083	d7503525	f7ea615f	62143154	0d554b63	5d681121	c866c359
3d63cf73	cee234c0	d4d87e87	5c672b21	071f6181	39f7627f	361e3084	e4eb573b
602f64a4	d63acd9c	1bbc4635	9e81032d	2701f50c	99847ab4	a0e3df79	ba6cf38c
10843094	2537a95e	f46f6ffe	a1ff3b1f	208cfb6a	8f458c74	d9e0a227	4ec73a34
fc884f69	3e4de8df	ef0e0088	3559648d	8a45388c	1d804366	721d9bfd	a58684bb
e8256333	844e8212	128d8098	fed33fb4	ce280ae1	27e19ba5	d5a6c252	e49754bd

```

c5d655dd eb667064 77840b4d a1b6a801 84db26a9 e0b56714 21f043b7 e5d05860
54f03084 066ff472 a31aa153 dadc4755 b5625dbf 68561be6 83ca6b94 2d6ed23b
eccf01db a6d3d0ba b6803d5c af77a709 33b4a34c 397bc8d6 5ee22b95 5f0e5304
81ed6f61 20e74364 b45e1378 de18639b 881ca122 b96726d1 8049a7e8 22b7da7b
5e552d25 5272d237 79d2951c c60d894c 488cb402 1ba4fe5b a4b09f6b 1ca815cf
a20c3005 8871df63 b9de2fcb 0cc6c9e9 0beeff53 e3214517 b4542835 9f63293c
ee41e729 6e1d2d7c 50045286 1e6685f3 f33401c6 30a22c95 31a70850 60930f13
73f98417 a1269859 ec645c44 52c877a9 cdf33a6 a02b1741 7cbad9a2 2180036f
50d99c08 cb3f4861 c26bd765 64a3f6ab 80342676 25a75e7b e4e6d1fc 20c710e6
cdf0b680 17844d3b 31eef84d 7e0824e4 2ccb49eb 846a3bae 8ff77888 ee5d60f6
7af75673 2fdd5cdb a11631c1 30f66f43 b3faec54 157fd7fa ef8579cc d152de58
db2ffd5e 8f32ce19 306af97a 02f03ef8 99319ad5 c242fa0f a7e3ebb0 c68e4906
b8da230c 80823028 dcdef3c8 d35fb171 088a1bc8 bec0c560 61a3c9e8 bca8f54d
c72feffa 22822e99 82c570b4 d8d94e89 8b1c34bc 301e16e6 273be979 b0ffea6
61d9b8c6 00b24869 b7ffce3f 08dc283b 43daf65a f7e19798 7619b72f 8f1c9ba4
dc8637a0 16a7d3b1 9fc393b7 a7136eeb c6bcc63e 1a513742 ef6828bc 520365d6
2d6a77ab 3527ed4b 821fd216 095c6e2e db92f2fb 5eea29cb 145892f5 91584f7f
5483697b 2667a8cc 85196048 8c4bacea 833860d4 0d23e0f9 6c387e8a 0ae6d249
b284600c d835731d dcb1c647 ac4c56ea 3ebd81b3 230eabb0 6438bc87 f0b5b1fa
8f5ea2b3 fc184642 0a036b7a 4fb089bd 649da589 a345415e 5c038323 3e5d3bb9
43d79572 7e6dd07c 06dfdf1e 6c6cc4ef 7160a539 73bfbe70 83877605 4523ecf1

```

S-Box S3

```

8defc240 25fa5d9f eb903dbf e810c907 47607fff 369fe44b 8c1fc644 aececa90
beb1f9bf eefbcaea e8cf1950 51df07ae 920e8806 f0ad0548 e13c8d83 927010d5
11107d9f 07647db9 b2e3e4d4 3d4f285e b9afa820 fade82e0 a067268b 8272792e
553fb2c0 489ae22b d4ef9794 125e3fbc 21fffcee 825b1bfd 9255c5ed 1257a240
4e1a8302 bae07fff 528246e7 8e57140e 3373f7bf 8c9f8188 a6fc4ee8 c982b5a5
a8c01db7 579fc264 67094f31 f2bd3f5f 40fff7c1 1fb78dfc 8e6bd2c1 437be59b
99b03dbf b5dbc64b 638dc0e6 55819d99 a197c81c 4a012d6e c5884a28 ccc36f71
b843c213 6c0743f1 8309893c 0feddd5f 2f7fe850 d7c07f7e 02507fbf 5afb9a04
a747d2d0 1651192e af70bf3e 58c31380 5f98302e 727cc3c4 0a0fb402 0f7fef82
8c96fdad 5d2c2aae 8ee99a49 50da88b8 8427f4a0 leac5790 796fb449 8252dc15
efbd7d9b a672597d ada840d8 45f54504 fa5d7403 e83ec305 4f91751a 925669c2
23efe941 a903f12e 60270df2 0276e4b6 94fd6574 927985b2 8276dbcb 02778176
f8af918d 4e48f79e 8f616ddf e29d840e 842f7d83 340ce5c8 96bbb682 93b4b148
ef303cab 984faf28 779faf9b 92dc560d 224d1e20 8437aa88 7d29dc96 2756d3dc
8b907cee b51fd240 e7c07ce3 e566b4a1 c3e9615e 3cf8209d 6094d1e3 cd9ca341
5c76460e 00ea983b d4d67881 fd47572c f76cedd9 bda8229c 127dadaa 438a074e
1f97c090 081bdb8a 93a07ebe b938ca15 97b03cff 3dc2c0f8 8d1ab2ec 64380e51
68cc7bfb d90f2788 12490181 5de5ffd4 dd7ef86a 76a2e214 b9a40368 925d958f
4b39fffa ba39aee9 a4ffd30b faf7933b 6d498623 193cbcf8 27627545 825cf47a
61bd8ba0 d11e42d1 cead04f4 127ea392 10428db7 8272a972 9270c4a8 127de50b
285ba1c8 3c62f44f 35c0eaa5 e805d231 428929fb b4fcd82 4fb66a53 0e7dc15b
1f081fab 108618ae fcfd086d f9ff2889 694bcc11 236a5cae 12deca4d 2c3f8cc5
d2d02dfe f8ef5896 e4cf52da 95155b67 494a488c b9b6a80c 5c8f82bc 89d36b45
3a609437 ec00c9a9 44715253 0a874b49 d773bc40 7c34671c 02717ef6 4feb5536
a2d02fff d2bf60c4 d43f03c0 50b4ef6d 07478cd1 006e1888 a2e53f55 b9e6d4bc

```

```

a2048016 97573833 d7207d67 de0f8f3d 72f87b33 abcc4f33 7688c55d 7b00a6b0
947b0001 570075d2 f9bb88f8 8942019e 4264a5ff 856302e0 72dbd92b ee971b69
6ea22fde 5f08ae2b af7a616d e5c98767 cf1febd2 61efc8c2 f1ac2571 cc8239c2
67214cb8 b1e583d1 b7dc3e62 7f10bdce f90a5c38 0ff0443d 606e6dc6 60543a49
5727c148 2be98a1d 8ab41738 20e1be24 af96da0f 68458425 99833be5 600d457d
282f9350 8334b362 d91d1120 2b6d8da0 642b1e31 9c305a00 52bce688 1b03588a
f7baefd5 4142ed9c a4315c11 83323ec5 dfef4636 a133c501 e9d3531c ee353783

```

S-Box S4

```

9db30420 1fb6e9de a7be7bef d273a298 4a4f7bdb 64ad8c57 85510443 fa020ed1
7e287aff e60fb663 095f35a1 79ebf120 fd059d43 6497b7b1 f3641f63 241e4adf
28147f5f 4fa2b8cd c9430040 0cc32220 fdd30b30 c0a5374f 1d2d00d9 24147b15
ee4d111a 0fca5167 71ff904c 2d195ffe 1a05645f 0c13fefe 081b08ca 05170121
80530100 e83e5efe ac9af4f8 7fe72701 d2b8ee5f 06df4261 bb9e9b8a 7293ea25
ce84ffdf f5718801 3dd64b04 a26f263b 7ed48400 547eebe6 446d4ca0 6cf3d6f5
2649abdf aea0c7f5 36338cc1 503f7e93 d3772061 11b638e1 72500e03 f80eb2bb
abe0502e ec8d77de 57971e81 e14f6746 c9335400 6920318f 081dbb99 ffc304a5
4d351805 7f3d5ce3 a6c866c6 5d5bcc9a daec6fea 9f926f91 9f46222f 3991467d
a5bf6d8e 1143c44f 43958302 d0214eeb 022083b8 3fb6180c 18f8931e 281658e6
26486e3e 8bd78a70 7477e4c1 b506e07c f32d0a25 79098b02 e4eabb81 28123b23
69dead38 1574ca16 df871b62 211c40b7 a51a9ef9 0014377b 041e8ac8 09114003
bd59e4d2 e3d156d5 4fe876d5 2f91a340 557be8de 00eae4a7 0ce5c2ec 4db4bba6
e756bdfc dd3369ac ec17b035 06572327 99afc8b0 56c8c391 6b65811c 5e146119
6e85cb75 be07c002 c2325577 893ff4ec 5bbfc92d d0ec3b25 b7801ab7 8d6d3b24
20c763ef c366a5fc 9c382880 0ace3205 aac9548a ecald7c7 041afa32 1d16625a
7701902c 9b757a54 31d477f7 9126b031 36cc6fdb c70b8b46 d9e66a48 56e55a79
026a4ceb 52437eff 2f8f76b4 0df980a5 8674cde3 edda04eb 17a9be04 2c18f4df
b7747f9d ab2af7b4 efc34d20 2e096b7c 1741a254 e5b6a035 213d42f6 2c1c7c26
61c2f50f 6552daf9 d2c231f8 25130f69 d8167fa2 0418f2c8 001a96a6 0d1526ab
63315c21 5e0a72ec 49bafefd 187908d9 8d0dbd86 311170a7 3e9b640c cc3e10d7
d5cad3b6 0caec388 f73001e1 6c728aff 71eae2a1 1f9af36e cfcdbd12f c1de8417
ac07be6b cb44a1d8 8b9b0f56 013988c3 b1c52fca b4be31cd d8782806 12a3a4e2
6f7de532 58fd7eb6 d01ee900 24adffc2 f4990fc5 9711aac5 001d7b95 82e5e7d2
109873f6 00613096 c32d9521 ada121ff 29908415 7fbb977f af9eb3db 29c9ed2a
5ce2a465 a730f32c d0aa3fe8 8a5cc091 d49e2ce7 0ce454a9 d60acd86 015f1919
77079103 dea03af6 78a8565e dee356df 21f05cbe 8b75e387 b3c50651 b8a5c3ef
d8eeb6d2 e523be77 c2154529 2f69efdf afe67afb f470c4b2 f3e0eb5b d6cc9876
39e4460c 1fda8538 1987832f ca007367 a99144f8 296b299e 492fc295 9266beab
b5676e69 9bd3ddda df7e052f db25701c 1b5e51ee f65324e6 6afce36c 0316cc04
8644213e b7dc59d0 7965291f ccd6fd43 41823979 932bcd6f b657c34d 4edfd282
7ae5290c 3cb9536b 851e20fe 9833557e 13ecf0b0 d3ffb372 3f85c5c1 0aef7ed2

```

S-Box S5

```

7ec90c04 2c6e74b9 9b0e66df a6337911 b86a7fff 1dd358f5 44dd9d44 1731167f
08fbf1fa e7f511cc d2051b00 735aba00 2ab722d8 386381cb acf6243a 69befd7a
e6a2e77f f0c720cd c4494816 ccf5c180 38851640 15b0a848 e68b18cb 4caadeff
5f480a01 0412b2aa 259814fc 41d0efe2 4e40b48d 248eb6fb 8dba1cfe 41a99b02
1a550a04 ba8f65cb 7251f4e7 95a51725 c106ecd7 97a5980a c539b9aa 4d79fe6a

```

```
f2f3f763 68af8040 ed0c9e56 11b4958b e1eb5a88 8709e6b0 d7e07156 4e29fea7
6366e52d 02d1c000 c4ac8e05 9377f571 0c05372a 578535f2 2261be02 d642a0c9
df13a280 74b55bd2 682199c0 d421e5ec 53fb3ce8 c8adedb3 28a87fc9 3d959981
5c1ff900 fe38d399 0c4eff0b 062407ea aa2f4fb1 4fb96976 90c79505 b0a8a774
ef55a1ff e59ca2c2 a6b62d27 e66a4263 df65001f 0ec50966 dfdd55bc 29de0655
911e739a 17af8975 32c7911c 89f89468 0d01e980 524755f4 03b63cc9 0cc844b2
bcf3f0aa 87ac36e9 e53a7426 01b3d82b 1a9e7449 64ee2d7e cddbbl1da 01c94910
b868bf80 0d26f3fd 9342ede7 04a5c284 636737b6 50f5b616 f24766e3 8eca36c1
136e05db fef18391 fb887a37 d6e7f7d4 c7fb7dc9 3063fcdf b6f589de ec2941da
26e46695 b7566419 f654efc5 d08d58b7 48925401 c1bacb7f e5ff550f b6083049
5bb5d0e8 87d72e5a ab6a6ee1 223a66ce c62bf3cd 9e0885f9 68cb3e47 086c010f
a21de820 d18b69de f3f65777 fa02c3f6 407edac3 cbb3d550 1793084d b0d70eba
0ab378d5 d951fb0c ded7da56 4124bbe4 94ca0b56 0f5755d1 e0e1e56e 6184b5be
580a249f 94f74bc0 e327888e 9f7b5561 c3dc0280 05687715 646c6bd7 44904db3
66b4f0a3 c0f1648a 697ed5af 49e92ff6 309e374f 2cb6356a 85808573 4991f840
76f0ae02 083be84d 28421c9a 44489406 736e4cb8 c1092910 8bc95fc6 7d869cf4
134f616f 2e77118d b31b2be1 aa90b472 3ca5d717 7d161bba 9cad9010 af462ba2
9fe459d2 45d34559 d9f2da13 dbc65487 f3e4f94e 176d486f 097c13ea 631da5c7
445f7382 175683f4 cdc66a97 70be0288 b3cdcf72 6e5dd2f3 20936079 459b80a5
be60e2db a9c23101 eba5315c 224e42f2 1c5c1572 f6721b2c 1ad2fff3 8c25404e
324ed72f 4067b7fd 0523138e 5ca3bc78 dc0fd66e 75922283 784d6b17 58ebb16e
44094f85 3f481d87 fcfeae7b 77b5ff76 8c2302bf aaf47556 5f46b02a 2b092801
3d38f5f7 0ca81f36 52af4a8a 66d5e7c0 df3b0874 95055110 1b5ad7a8 f61ed5ad
6cf6e479 20758184 d0cefa65 88f7be58 4a046826 0ff6f8f3 a09c7f70 5346aba0
5ce96c28 e176eda3 6bac307f 376829d2 85360fa9 17e3fe2a 24b79767 f5a96b20
d6cd2595 68ff1ebf 7555442c f19f06be f9e0659a eeb9491d 34010718 bb30cab8
e822fe15 88570983 750e6249 da627e55 5e76ffa8 b1534546 6d47de08 efe9e7d4
```

S-Box S6

```
f6fa8f9d 2cac6ce1 4ca34867 e2337f7c 95db08e7 016843b4 eced5cbc 325553ac
bf9f0960 dfa1e2ed 83f0579d 63ed86b9 1ab6a6b8 de5ebe39 f38ff732 8989b138
33f14961 c01937bd f506c6da e4625e7e a308ea99 4e23e33c 79cbd7cc 48a14367
a3149619 fec94bd5 a114174a eaa01866 a084db2d 09a8486f a888614a 2900af98
01665991 e1992863 c8f30c60 2e78ef3c d0d51932 cf0fec14 f7ca07d2 d0a82072
fd41197e 9305a6b0 e86be3da 74bed3cd 372da53c 4c7f4448 dab5d440 6dba0ec3
083919a7 9fbaeed9 49dbcfb0 4e670c53 5c3d9c01 64bdb941 2c0e636a ba7dd9cd
ea6f7388 e70bc762 35f29adb 5c4cdd8d f0d48d8c b88153e2 08a19866 1ae2eac8
284caf89 aa928223 9334be53 3b3a21bf 16434be3 9aea3906 efe8c36e f890cdd9
80226dae c340a4a3 df7e9c09 a694a807 5b7c5ecc 221db3a6 9a69a02f 68818a54
ceb2296f 53c0843a fe893655 25bfe68a b4628abc cf222ebf 25ac6f48 a9a99387
53bddd65 e76ffbe7 e967fd78 0ba93563 8e342bc1 e8a11be9 4980740d c8087dfc
8de4bf99 a11101a0 7fd37975 da5a26c0 e81f994f 9528cd89 fd339fed b87834bf
5f04456d 22258698 c9c4c83b 2dc156be 4f628daa 57f55ec5 e2220abe d2916ebf
4ec75b95 24f2c3c0 42d15d99 cd0d7fa0 7b6e27ff a8dc8af0 7345c106 f41e232f
35162386 e6ea8926 3333b094 157ec6f2 372b74af 692573e4 e9a9d848 f3160289
3a62ef1d a787e238 f3a5f676 74364853 20951063 4576698d b6fad407 592af950
36f73523 4cfb6e87 7da4cec0 6c152daa cb0396a8 c50dfe5d fcd707ab 0921c42f
89dff0bb 5fe2be78 448f4f33 754613c9 2b05d08d 48b9d585 dc049441 c8098f9b
```

```

7dede786 c39a3373 42410005 6a091751 0ef3c8a6 890072d6 28207682 a9a9f7be
bf32679d d45b5b75 b353fd00 cbb0e358 830f220a 1f8fb214 d372cf08 cc3c4a13
8cf63166 061c87be 88c98f88 6062e397 47cf8e7a b6c85283 3cc2acfb 3fc06976
4e8f0252 64d8314d da3870e3 1e665459 c10908f0 513021a5 6c5b68b7 822f8aa0
3007cd3e 74719eef dc872681 073340d4 7e432fd9 0c5ec241 8809286c f592d891
08a930f6 957ef305 b7fbffbd c266e96f 6fe4ac98 b173ecc0 bc60b42a 953498da
fbalae12 2d4bd736 0f25faab a4f3fceb e2969123 257f0c3d 9348af49 361400bc
e8816f4a 3814f200 a3f94043 9c7a54c2 bc704f57 da41e7f9 c25ad33a 54f4a084
b17f5505 59357cbe edbd15c8 7f97c5ab ba5ac7b5 b6f6deaf 3a479c3a 5302da25
653d7e6a 54268d49 51a477ea 5017d55b d7d25d88 44136c76 0404a8c8 b8e5a121
b81a928a 60ed5869 97c55b96 eaec991b 29935913 01fdb7f1 088e8dfa 9ab6f6f5
3b4cbf9f 4a5de3ab e6051d35 a0e1d855 d36b4cf1 f544edeb b0e93524 bebb8fbf
a2d762cf 49c92f54 38b5f331 7128a454 48392905 a65b1db8 851c97bd d675cf2f

```

S-Box S7

```

85e04019 332bf567 662dbfff cfc65693 2a8d7f6f ab9bc912 de6008a1 2028da1f
0227bce7 4d642916 18fac300 50f18b82 2cb2cb11 b232e75c 4b3695f2 b28707de
a05fbcf6 cd4181e9 e150210c e24ef1bd b168c381 fde4e789 5c79b0d8 1e8bfd43
4d495001 38be4341 913cee1d 92a79c3f 089766be baeeadf4 1286becf b6eacb19
2660c200 7565bde4 64241f7a 8248dca9 c3b3ad66 28136086 0bd8dfa8 356d1cf2
107789be b3b2e9ce 0502aa8f 0bc0351e 166bf52a eb12ff82 e3486911 d34d7516
4e7b3aff 5f43671b 9cf6e037 4981ac83 334266ce 8c9341b7 d0d854c0 cb3a6c88
47bc2829 4725ba37 a66ad22b 7ad61f1e 0c5cbafa 4437f107 b6e79962 42d2d816
0a961288 e1a5c06e 13749e67 72fc081a b1d139f7 f9583745 cf19df58 bec3f756
c06eba30 07211b24 45c28829 c95e317f bc8ec511 38bc46e9 c6e6fa14 bae8584a
ad4ebc46 468f508b 7829435f f124183b 821dba9f aff60ff4 ea2c4e6d 16e39264
92544a8b 009b4fc3 aba68ced 9ac96f78 06a5b79a b2856e6e laec3ca9 be838688
0e0804e9 55f1be56 e7e5363b b3a1f25d f7debb85 61fe033c 16746233 3c034c28
da6d0c74 79aac56c 3ce4e1ad 51f0c802 98f8f35a 1626a49f eed82b29 1d382fe3
0c4fb99a bb325778 3ec6d97b 6e77a6a9 cb658b5c d45230c7 2bd1408b 60c03eb7
b9068d78 a33754f4 f430c87d c8a71302 b96d8c32 ebd4e7be be8b9d2d 7979fb06
e7225308 8b75cf77 11ef8da4 e083c858 8d6b786f 5a6317a6 fa5cf7a0 5dda0033
f28ebfb0 f5b9c310 a0eac280 08b9767a a3d9d2b0 79d34217 021a718d 9ac6336a
2711fd60 438050e3 069908a8 3d7fedc4 826d2bef 4eeb8476 488dcf25 36c9d566
28e74e41 c2610aca 3d49a9cf bae3b9df b65f8de6 92aeaf64 3ac7d5e6 9ea80509
f22b017d a4173f70 dd1e16c3 15e0d7f9 50b1b887 2b9f4fd5 625aba82 6a017962
2ec01b9c 15488aa9 d716e740 40055a2c 93d29a22 e32dbf9a 058745b9 3453dc1e
d699296e 496cff6f 1c9f4986 dfe2ed07 b87242d1 19de7eae 053e561a 15ad6f8c
66626c1c 7154c24c ea082b2a 93eb2939 17dcb0f0 58d4f2ae 9ea294fb 52cf564c
9883fe66 2ec40581 763953c3 01d6692e d3a0c108 a1e7160e e4f2dfa6 693ed285
74904698 4c2b0edd 4f757656 5d393378 a132234f 3d321c5d c3f5e194 4b269301
c79f022f 3c997e7e 5e4f9504 3ffafbbd 76f7ad0e 296693f4 3d1fce6f c61e45be
d3b5ab34 f72bf9b7 1b0434c0 4e72b567 5592a33d b5229301 cfd2a87f 60aeb767
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97fd61a9 ea7759f4 2d57539d 569a58cf e84e63ad 462e1b78 6580f87e f3817914
91da55f4 40a230f3 d1988f35 b6e318d2 3ffa50bc 3d40f021 c3c0bdae 4958c24c
518f36b2 84b1d370 0fedce83 878ddada f2a279c7 94e01be8 90716f4b 954b8aa3

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S-Box S8

e216300d	bbddfffc	a7ebdabd	35648095	7789f8b7	e6c1121b	0e241600	052ce8b5
11a9cfb0	e5952f11	ece7990a	9386d174	2a42931c	76e38111	b12def3a	37dddfdc
de9adeb1	0a0cc32c	be197029	84a00940	bb243a0f	b4d137cf	b44e79f0	049eedfd
0b15a15d	480d3168	8bbbde5a	669ded42	c7ece831	3f8f95e7	72df191b	7580330d
94074251	5c7dcdfa	abbe6d63	aa402164	b301d40a	02e7d1ca	53571dae	7a3182a2
12a8ddec	fdaa335d	176f43e8	71fb46d4	38129022	ce949ad4	b84769ad	965bd862
82f3d055	66fb9767	15b80b4e	1d5b47a0	4cfde06f	c28ec4b8	57e8726e	647a78fc
99865d44	608bd593	6c200e03	39dc5ff6	5d0b00a3	ae63aff2	7e8bd632	70108c0c
bbd35049	2998df04	980cf42a	9b6df491	9e7edd53	06918548	58cb7e07	3b74ef2e
522fffb1	d24708cc	1c7e27cd	a4eb215b	3cf1d2e2	19b47a38	424f7618	35856039
9d17dee7	27eb35e6	c9aff67b	36baf5b8	09c467cd	c18910b1	e11dbf7b	06cd1af8
7170c608	2d5e3354	d4de495a	64c6d006	bcc0c62c	3dd00db3	708f8f34	77d51b42
264f620f	24b8d2bf	15c1b79e	46a52564	f8d7e54e	3e378160	7895cda5	859c15a5
e6459788	c37bc75f	db07ba0c	0676a3ab	7f229b1e	31842e7b	24259fd7	f8bef472
835ffcb8	6df4c1f2	96f5b195	fd0af0fc	b0fe134c	e2506d3d	4f9b12ea	f215f225
a223736f	9fb4c428	25d04979	34c713f8	c4618187	ea7a6e98	7cd16efc	1436876c
f1544107	bedeee14	56e9af27	a04aa441	3cf7c899	92ecbae6	dd67016d	151682eb
a842eedf	fdb60b4	f1907b75	20e3030f	24d8c29e	e139673b	efa63fb8	71873054
b6f2cf3b	9f326442	cb15a4cc	b01a4504	f1e47d8d	844a1be5	bae7dfdc	42cbda70
cd7dae0a	57e85b7a	d53f5af6	20cf4d8c	cea4d428	79d130a4	3486ebfb	33d3cddc
77853b53	37effcb5	c5068778	e580b3e6	4e68b8f4	c5c8b37e	0d809ea2	398feb7c
132a4f94	43b7950e	2fee7d1c	223613bd	dd06caa2	37df932b	c4248289	acf3ebc3
5715f6b7	ef3478dd	f267616f	c148cbe4	9052815e	5e410fab	b48a2465	2eda7fa4
e87b40e4	e98ea084	5889e9e1	efd390fc	dd07d35b	db485694	38d7e5b2	57720101
730edebc	5b643113	94917e4f	503c2fba	646f1282	7523d24a	e0779695	f9c17a8f
7a5b2121	d187b896	29263a4d	ba510cdf	81f47c9f	ad1163ed	ea7b5965	1a00726e
11403092	00da6d77	4a0cdd61	ad1f4603	605bdfb0	9eedc364	22ebe6a8	cee7d28a
a0e736a0	5564a6b9	10853209	c7eb8f37	2de705ca	8951570f	df09822b	bd691a6c
aa12e4f2	87451c0f	e0f6a27a	3ada4819	4cf1764f	0d771c2b	67cdb156	350d8384
5938fa0f	42399ef3	36997b07	0e84093d	4aa93e61	8360d87b	1fa98b0c	1149382c
e97625a5	0614d1b7	0e25244b	0c768347	589e8d82	0d2059d1	a466bb1e	f8da0a82
04f19130	ba6e4ec0	99265164	1ee7230d	50b2ad80	eae6801	8db2a283	ea8bf59e

Appendix B. Test Vectors

This appendix provides test vectors for the CAST-128 cipher described in this document.

B.1. Single Plaintext-Key-Ciphertext Sets

In order to ensure that the algorithm is implemented correctly, the following test vectors can be used for verification (values given in hexadecimal notation).

```

128-bit key      = 01 23 45 67 12 34 56 78 23 45 67 89 34 56 78 9A
   plaintext     = 01 23 45 67 89 AB CD EF
   ciphertext    = 23 8B 4F E5 84 7E 44 B2

80-bit key      = 01 23 45 67 12 34 56 78 23 45
                = 01 23 45 67 12 34 56 78 23 45 00 00 00 00 00 00
   plaintext     = 01 23 45 67 89 AB CD EF
   ciphertext    = EB 6A 71 1A 2C 02 27 1B

40-bit key      = 01 23 45 67 12
                = 01 23 45 67 12 00 00 00 00 00 00 00 00 00 00 00
   plaintext     = 01 23 45 67 89 AB CD EF
   ciphertext    = 7A C8 16 D1 6E 9B 30 2E

```

B.2. Full Maintenance Test

A maintenance test for CAST-128 has been defined to verify the correctness of implementations. It is defined in pseudo-code as follows, where *a* and *b* are 128-bit vectors, *aL* and *aR* are the leftmost and rightmost halves of *a*, *bL* and *bR* are the leftmost and rightmost halves of *b*, and `encrypt(d,k)` is the encryption in ECB mode of block *d* under key *k*.

```

Initial a = 01 23 45 67 12 34 56 78 23 45 67 89 34 56 78 9A (hex)
Initial b = 01 23 45 67 12 34 56 78 23 45 67 89 34 56 78 9A (hex)

```

```

do 1,000,000 times
{
  aL = encrypt(aL,b)
  aR = encrypt(aR,b)
  bL = encrypt(bL,a)
  bR = encrypt(bR,a)
}

```

```

Verify a == EE A9 D0 A2 49 FD 3B A6 B3 43 6F B8 9D 6D CA 92 (hex)
Verify b == B2 C9 5E B0 0C 31 AD 71 80 AC 05 B8 E8 3D 69 6E (hex)

```