

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).

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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:
 $L_i = R_{i-1}$;
 $R_i = L_{i-1} \oplus f(R_{i-1}, K_{mi}, K_{ri})$, 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 $x_0x_1x_2x_3x_4x_5x_6x_7x_8x_9x_{Ax}x_{Bx}x_{Cx}x_{Dx}x_{Ex}x_{Fx}$, 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 "^" represent XOR addition.

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

```

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]
K1  = S5[z8] ^ S6[z9] ^ S7[z7] ^ S8[z6] ^ S5[z2]
K2  = S5[zA] ^ S6[zB] ^ S7[z5] ^ S8[z4] ^ S6[z6]
K3  = S5[zC] ^ S6[zD] ^ S7[z3] ^ S8[z2] ^ S7[z9]
K4  = 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]
K5  = S5[x3] ^ S6[x2] ^ S7[xC] ^ S8[xD] ^ S5[x8]
K6  = S5[x1] ^ S6[x0] ^ S7[xE] ^ S8[xF] ^ S6[xD]
K7  = S5[x7] ^ S6[x6] ^ S7[x8] ^ S8[x9] ^ S7[x3]
K8  = 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]
K9  = S5[z3] ^ S6[z2] ^ S7[zC] ^ S8[zD] ^ S5[z9]
K10 = S5[z1] ^ S6[z0] ^ S7[zE] ^ S8[zF] ^ S6[zC]
K11 = S5[z7] ^ S6[z6] ^ S7[z8] ^ S8[z9] ^ S7[z2]
K12 = 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]
K13 = S5[x8] ^ S6[x9] ^ S7[x7] ^ S8[x6] ^ S5[x3]
K14 = S5[xA] ^ S6[xB] ^ S7[x5] ^ S8[x4] ^ S6[x7]
K15 = S5[xC] ^ S6[xD] ^ S7[x3] ^ S8[x2] ^ S7[x8]
K16 = S5[xE] ^ S6[xF] ^ S7[x1] ^ S8[x0] ^ S8[xD]

```

[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 = xCx DxExF ^ S5[z7] ^ S6[z6] ^ S7[z5] ^ S8[z4] ^ S5[x9]
zCzDzEzF = x4x5x6x7 ^ S5[zA] ^ S6[z9] ^ S7[zB] ^ 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]
xCx DxExF = 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 = xCx DxExF ^ 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]
xCx DxExF = 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 $Km1, \dots, Km16$ be 32-bit masking subkeys (one per round).
 Let $Kr1, \dots, Kr16$ 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
alc9e0d6	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	4bfff345d
fd45c240	ad31973f	c4f6d02e	55fc8165	d5b1caad	alac2dae	a2d4b76d	c19b0c50
882240f2	0c6e4f38	a4e4bfd7	4f5ba272	564c1d2f	c59c5319	b949e354	b04669fe
b1b6ab8a	c71358dd	6385c545	110f935d	57538ad5	6a390493	e63d37e0	2a54f6b3
3a787d5f	6276a0b5	19a6fcdf	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	18dcd7d	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
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b8da230c	80823028	dcdef3c8	d35fb171	088a1bc8	bec0c560	61a3c9e8	bca8f54d
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S-Box S3

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S-Box S4

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ce84ffdf f5718801 3dd64b04 a26f263b 7ed48400 547eebe6 446d4ca0 6cf3d6f5
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S-Box S5

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S-Box S6

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S-Box S7

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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	3ffaafb9	76f7ad0e	296693f4	3d1fce6f	c61e45be
d3b5ab34	f72bf9b7	1b0434c0	4e72b567	5592a33d	b5229301	cfda2a87f	60aeb767
1814386b	30bcc33d	38a0c07d	fd1606f2	c363519b	589dd390	5479f8e6	1cb8d647
97fd61a9	ea7759f4	2d57539d	569a58cf	e84e63ad	462e1b78	6580f87e	f3817914
91da55f4	40a230f3	d1988f35	b6e318d2	3ffa50bc	3d40f021	c3c0bdae	4958c24c
518f36b2	84b1d370	0fedce83	878ddada	f2a279c7	94e01be8	90716f4b	954b8aa3

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
12a8dded	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	fdba60b4	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)
```

