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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 m1...m64; key K = k1...k128.
OUTPUT: ciphertext c1...c64.

1. (key schedule) Compute 16 pairs of subkeys {Kmi, Kri} from K (see Sections 2.1 and 2.4).
2. (L0,R0) <-- (m1...m64). (Split the plaintext into left and right 32-bit halves L0 = m1...m32 and R0 = m33...m64.)
3. (16 rounds) for i from 1 to 16, compute Li and Ri as follows:
   Li = Ri-1;
   Ri = Li-1 ^ f(Ri-1,Kmi,Kri), where f is defined in Section 2.2
   (f is of Type 1, Type 2, or Type 3, depending on i).
4. c1...c64 <-- (R16,L16). (Exchange final blocks L16, R16 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 (L0,R0) from (R16,L16).

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 Km is used as a "masking" key and a 5-bit quantity Kr 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 = ((Kmi + D) <<< Kri)
         f = ((S1[Ia] ^ S2[Ib]) - S3[Ic]) + S4[Id]

Type 2:  I = ((Kmi ^ D) <<< Kri)
         f = ((S1[Ia] - S2[Ib]) + S3[Ic]) ^ S4[Id]

Type 3:  I = ((Kmi - D) <<< Kri)
         f = ((S1[Ia] + S2[Ib]) ^ 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 x0x1x2x3x4x5x6x7x8x9xAxBxCxDxExF, where x0 represents the most significant byte and xF represents the least significant byte.

Let z0..zF be intermediate (temporary) bytes.
Let Si[] represent s-box i and let "^" represent XOR addition.

The subkeys are formed from the key x0x1x2x3x4x5x6x7x8x9xAxBxCxDxExF 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 = xCxDxExF ^ 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]
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 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 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 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 cdff33a6 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 b0ffeaa6
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
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S-Box S3

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8defc240 25fa5d9f eb903dbf e810c907 47607fff 369fe44b 8c1fc644 aececa90
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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 1eac5790 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
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68cc7bfb d90f2788 12490181 5de5ffd4 dd7ef86a 76a2e214 b9a40368 925d958f
4b39fffa ba39aee9 a4ffd30b faf7933b 6d498623 193cbcfa 27627545 825cf47a
61bd8ba0 d11e42d1 cead04f4 127ea392 10428db7 8272a972 9270c4a8 127de50b
285ba1c8 3c62f44f 35c0eaa5 e805d231 428929fb b4fcdf82 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
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a2048016 97573833 d7207d67 de0f8f3d 72f87b33 abcc4f33 7688c55d 7b00a6b0
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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
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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 5d5bcca9 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
e756bdff dd3369ac ec17b035 06572327 99afc8b0 56c8c391 6b65811c 5e146119
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6701902c 9b757a54 31d477f7 9126b031 36cc6fdb c70b8b46 d9e66a48 56e55a79
026a4ceb 52437eff 2f8f76b4 0df980a5 8674cde3 edda04eb 17a9be04 2c18f4df
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63315c21 5e0a72ec 49bafefd 187908d9 8d0dbd86 311170a7 3e9b640c cc3e10d7
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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 932bcdf6 b657c34d 4edfd282
7ae5290c 3cb9536b 851e20fe 9833557e 13ecf0b0 d3ffb372 3f85c5c1 0aef7ed2

S-Box S5
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e6a2e77f f0c720cd c4494816 ccf5c180 38851640 15b0a848 e68b18cb 4caadeff
5f480a01 0412b2aa 259814fc 41d0efe2 4e40b48d 248eb6fb 8dba1cfe 41a99b02
1a550a04 ba8f65cb 7251f4e7 95a51725 c106ecd7 97a5980a c539b9aa 4d79fe6a
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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 cddbb1da 01c94910
b868bf80 0d26f3fd 9342ede7 04a5c284 636737b6 50f5b616 f24766e3 8eca36c1
136e05db fef18391 fb887a37 d6e7f7d4 c7fb7dc9 3063fcdf b6f589de ec2941da
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324ed72f 4067b7fd 0523138e 5ca3bc78 dc0fd66e 75922283 784d6b17 58ebb16e
44094f85 3f481d87 fcfeae7b 77b5ff76 8c2302bf aaf47556 5f46b02a 2b092801
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d6cd2595 68ff1ebf 7555442c f19f06be f9e0659a eeb9491d 34010718 bb30cab8
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S-Box S6
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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
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284caf89 aa928223 9334be53 3b3a21bf 16434be3 9aea3906 efe8c36e f890cdd9
80226dae c340a4a3 df7e9c09 a694a807 5b7c5ecc 221db3a6 9a69a02f 68818a54
ceb2296f 53c0843a fe893655 25bfe68a b4628abc cf222ebf 25ac6f48 a9a99387
53bddb65 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
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b81a928a 60ed5869 97c55b96 eaec991b 29935913 01fdb7f1 088e8dfa 9ab6f6f5
3b4cbf9f 4a5de3ab e6051d35 a0e1d855 d36b4cf1 f544edeb b0e93524 bebb8fbd
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S-Box S7
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4e7b3aff 5f43671b 9cf6e037 4981ac83 334266ce 8c9341b7 d0d854c0 cb3a6c88
47bc2829 4725ba37 a66ad22b 7ad61f1e 0c5cbafa 4437f107 b6e79962 42d2d816
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2ec01b9c 15488aa9 d716e740 40055a2c 93d29a22 e32dbf9a 058745b9 3453dc1e
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```

S-Box S8

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82f3d055 66fb9767 15b80b4e 1d5b47a0 4cfde06f c28ec4b8 57e8726e 647a78fc
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a223736f 9fb4c428 25d04979 34c713f8 c4618187 ea7a6e98 7cd16efc 1436876c
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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 eaee6801 8db2a283 ea8bf59e
```

Appendix B. Test Vectors

This appendix provides test vectors for the CAST-128 cipher described 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)
```