                   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
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S-Box S3
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S-Box S4
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S-Box S5
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S-Box S6
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S-Box S8
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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 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)