Network Working Group
Request for Comments: 2612
Category: Informational

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June 1999

The CAST-256 Encryption Algorithm

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Abstract

There is always a desire in the Internet community for unencumbered encryption algorithms 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, the s-boxes, and a set of test vectors (Appendix A).

Table of Contents

1. Introduction

This document describes the CAST-256 encryption algorithm, a DES-like Substitution-Permutation Network (SPN) cryptosystem built upon the CAST-128 encryption algorithm [1] 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.

CAST-256 has a block size of 128 bits and a variable key size (128, 160, 192, 224, or 256 bits).

2. CAST-256 Algorithm Specification

2.1 CAST-128 Notation

The following notation from CAST-128 [1] is relevant to CAST-256.

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

Three different round functions are used in CAST-128. The rounds are as follows (where D is the data input to the operation, Ia - Id are the most significant byte through least significant byte of I, respectively, Si is the ith s-box (see Section 2.1.1 for s-box contents), and O is the output of the operation). Note that "+" and "-" are addition and subtraction modulo 2**32, "^" is bitwise eXclusive-OR, and "<<<" is the circular left-shift operation.

```
Type 1:  I = ((Kmi + D) <<< Kri)
         O = ((S1[Ia] ^ S2[Ib]) - S3[Ic]) + S4[Id]

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

Type 3:  I = ((Kmi - D) <<< Kri)
         O = ((S1[Ia] + S2[Ib]) ^ S3[Ic]) - S4[Id]
```

Let f1, f2, f3 be keyed round function operations of Types 1, 2, and 3 (respectively) above.

CAST-128 uses four round function substitution boxes (s-boxes), S1 - S4. These are defined as follows (entries -- written in hexadecimal notation -- are to be read left-to-right, top-to-bottom).

2.1.1 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

 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 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
 1f97c090 081bdb8a 93a07ebe b938ca15 97b03cff 3dc2c0f8 8d1ab2ec 64380e51
 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
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 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
6e85cb75 be07c002 c2325577 893ff4ec 5bbfc92d d0ec3b25 b7801ab7 8d6d3b24
20c763ef c366a5fc 9c382880 0ace3205 aac9548a eca1d7c7 041afa32 1d16625a
6701902c 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 cfcbd12f 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 932bcdf6 b657c34d 4edfd282
7ae5290c 3cb9536b 851e20fe 9833557e 13ecf0b0 d3ffb372 3f85c5c1 0aef7ed2
```

2.2 CAST-256 Notation

The following notation is employed in the specification of CAST-256.

Let f1, f2, f3 be as defined for CAST-128.

Let BETA = (ABCD) be a 128-bit block where A, B, C and D are each 32 bits in length.

Let "BETA <- Qi(BETA)" be short-hand notation for the following:

```
C = C ^ f1(D, Kr0_(i), Km0_(i))
B = B ^ f2(C, Kr1_(i), Km1_(i))
A = A ^ f3(B, Kr2_(i), Km2_(i))
D = D ^ f1(A, Kr3_(i), Km3_(i))
```

Let "BETA <- QBARi(BETA)" be short-hand notation for the following:

```
D = D ^ f1(A, Kr3_(i), Km3_(i))
A = A ^ f3(B, Kr2_(i), Km2_(i))
B = B ^ f2(C, Kr1_(i), Km1_(i))
C = C ^ f1(D, Kr0_(i), Km0_(i))
```

(Q(*) is called a "forward quad-round" and QBAR(*) is called a "reverse quad-round".)

Let Kr_(i) = {Kr0_(i), Kr1_(i), Kr2_(i), Kr3_(i)} be the set of rotation keys for the ith quad-round, where Krj_(i) is a 5-bit rotation key for f1, f2, or f3 (as specified above).

Let Km_(i) = {Km0_(i), Km1_(i), Km2_(i), Km3_(i)} be the set of masking keys for the ith quad-round, where Kmj_(i) is a 32-bit masking key for f1, f2, or f3 (as specified above).

Let KAPPA = (ABCDEFGH) be a 256-bit block where A, B, ..., H are each 32 bits in length.

Let "KAPPA <- Wi(KAPPA)" be short-hand notation for the following:

```
G = G ^ f1(H, Tr0_(i), Tm0_(i))
F = F ^ f2(G, Tr1_(i), Tm1_(i))
E = E ^ f3(F, Tr2_(i), Tm2_(i))
D = D ^ f1(E, Tr3_(i), Tm3_(i))
C = C ^ f2(D, Tr4_(i), Tm4_(i))
B = B ^ f3(C, Tr5_(i), Tm5_(i))
A = A ^ f1(B, Tr6_(i), Tm6_(i))
H = H ^ f2(A, Tr7_(i), Tm7_(i))
```

(W(*) is called a "forward octave".)

```
            Let "Kr_(i) <- KAPPA" be short-hand notation for the
            following:  Kr0_(i) = 5LSB(A), Kr1_(i) = 5LSB(C), Kr2_(i) =
            5LSB(E), Kr3_(i) = 5LSB(G)
         where 5LSB(x) denotes "the five least significant bits of x".

         Let "Km_(i) <- KAPPA" be short-hand notation for the following:
            Km0_(i) = H, Km1_(i) = F, Km2_(i) = D, Km3_(i) = B
```

2.3 The CAST-256 Cipher

```
   BETA = 128bits of plaintext.

        for (i=0; i<6; i++)
            BETA <- Qi(BETA)
        for (i=6; i<12; i++)
            BETA <- QBARi(BETA)

   128bits of ciphertext = BETA
```

Round Key Re-Ordering for Decryption

The cipher employs a 256-bit primary key K. Decryption is identical to encryption except that the sets of quad-round keys Kr_(i), Km_(i) derived from K are used in reverse order as follows.

```
        for (i=0; i<12; i++)
        {
            KrNEW_(i) = Kr_(11-i)
            KmNEW_(i) = Km_(11-i)
        }
```

2.4 The CAST-256 Key Schedule

Initialization:

```
        Cm = 2**30 * SQRT(2) = 5A827999 (base 16)
        Mm = 2**30 * SQRT(3) = 6ED9EBA1 (base 16)
        Cr = 19
        Mr = 17
```

```
        for (i=0; i<24; i++)
        {
            for (j=0; j<8; j++)
            {
                Tmj_(i) = Cm
                Cm = (Cm + Mm) mod 2**32
                Trj_(i) = Cr
                Cr = (Cr + Mr) mod 32
            }
        }
```

Key Schedule:

```
        KAPPA = ABCDEFGH = 256 bit of primary key, K.

        for (i=0; i<12; i++)
        {
            KAPPA <- W2i(KAPPA)
            KAPPA <- W2i+1(KAPPA)
            Kr_(i) <- KAPPA
            Km_(i) <- KAPPA
        }

        Note:  (|K| = 128) => (E = F = G = H = 0)
               (|K| = 160) => (F = G = H = 0)
               (|K| = 192) => (G = H = 0)
               (|K| = 224) => (H = 0)
```

3. Cipher Naming

In order to avoid confusion when variable keysize operation is used, the name CAST-256 is to be considered synonymous with the name CAST6; this allows a keysize to be appended without ambiguity. Thus, for example, CAST-256 with a 192-bit key is to be referred to as CAST6-192; where a 256-bit key is explicitly intended, the name CAST6-256 should be used.

4. Cipher Usage

The CAST-256 cipher described in this document is available worldwide on a royalty-free and licence-free basis for commercial and non-commercial uses.

5. Security Considerations

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

6. References

[1] Adams, C., "The CAST-128 Encryption Algorithm", RFC 2144, May 1997.

7. Authors' Addresses

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Appendix A: Test Vectors

Intermediate Values Known Answer Test. The data listed is:

KEYSIZE=the current key length in bits
KEY=the key in hexadecimal format
PT=the plaintext to be encrypted
R=the quad-round number (1 to 12)
ROTK1,ROTK2,ROTK3,ROTK4=the rotation keys for the current quad-round
MASK1,MASK2,MASK3,MASK4=the masking keys for the current quad-round
OUT=the output of the quad-round
CT=the ciphertext corresponding to the given plaintext.

For each key size, an encryption and the corresponding decryption are shown.

KEYSIZE=128
KEY=2342bb9efa38542c0af75647f29f615d

PT=00000000000000000000000000000000

R=1
ROTK1=1c ROTK2=1d ROTK3=18 ROTK4=06
MASK1=f364d7f9 MASK2=233500c0 MASK3=83cee501 MASK4=01f857c6
OUT=e2c604af966715811b377f12de19e459

R=2
ROTK1=1e ROTK2=18 ROTK3=13 ROTK4=02
MASK1=ae877786 MASK2=ef78852e MASK3=0aa1c41f MASK4=a28ec9c4
OUT=5375c3be208f38eed0419d98f50dd9b3

R=3
ROTK1=02 ROTK2=1d ROTK3=01 ROTK4=0b
MASK1=a3eedefb MASK2=ac426ecf MASK3=2e8220ec MASK4=cd92c34a
OUT=732e4ec0f205e39afaf407c956d83728

R=4
ROTK1=0d ROTK2=1d ROTK3=04 ROTK4=12
MASK1=3046827f MASK2=568ab6b9 MASK3=b86e7c10 MASK4=ef290a58
OUT=af23fd837033dc81a60be8a69865c543

R=5
ROTK1=01 ROTK2=14 ROTK3=0c ROTK4=06
MASK1=302e76c3 MASK2=cf429964 MASK3=e9ecad47 MASK4=8850a515
OUT=8b5e011401e1124f731135fa780c59ef

R=6
ROTK1=17 ROTK2=1d ROTK3=0e ROTK4=09

```
   MASK1=bb903fdc    MASK2=a9915d2f    MASK3=0974e50a    MASK4=0c1708f1
   OUT=bdea3985cd08c7902096561b76f20944

   R=7
   ROTK1=03          ROTK2=13          ROTK3=07          ROTK4=0e
   MASK1=13330f06    MASK2=5e1906f5    MASK3=fb2bce75    MASK4=8331aed4
   OUT=438053fe465c299bcb35f273b10ea71a

   R=8
   ROTK1=07          ROTK2=02          ROTK3=14          ROTK4=14
   MASK1=a29189c1    MASK2=d1aeff98    MASK3=c9b55ba7    MASK4=c149f70c
   OUT=172c3a9a2791509d5939f58b703f2533

   R=9
   ROTK1=1c          ROTK2=08          ROTK3=1f          ROTK4=1f
   MASK1=5687e118    MASK2=bc4f5d80    MASK3=cca4c042    MASK4=bab3fb68
   OUT=79178d5f90187732f8007fd3884cc309

   R=10
   ROTK1=15          ROTK2=12          ROTK3=04          ROTK4=0f
   MASK1=cdb18671    MASK2=f06a3c64    MASK3=0c7031f9    MASK4=7dfbff4e
   OUT=e9e2b1f23e82479baec3b3b35fdf890f

   R=11
   ROTK1=1f          ROTK2=1a          ROTK3=01          ROTK4=0e
   MASK1=317654b5    MASK2=a1433222    MASK3=f6d8c69f    MASK4=304dfbeb
   OUT=1f3270101b2b38adc4818ca2aafc334a

   R=12
   ROTK1=0b          ROTK2=11          ROTK3=0f          ROTK4=18
   MASK1=9339b14f    MASK2=971d14bb    MASK3=f3b7ca97    MASK4=2b8a06f9
   OUT=c842a08972b43d20836c91d1b7530f6b

   CT=c842a08972b43d20836c91d1b7530f6b

   R=1
   ROTK1=0b          ROTK2=11          ROTK3=0f          ROTK4=18
   MASK1=9339b14f    MASK2=971d14bb    MASK3=f3b7ca97    MASK4=2b8a06f9
   OUT=1f3270101b2b38adc4818ca2aafc334a

   R=2
   ROTK1=1f          ROTK2=1a          ROTK3=01          ROTK4=0e
   MASK1=317654b5    MASK2=a1433222    MASK3=f6d8c69f    MASK4=304dfbeb
   OUT=e9e2b1f23e82479baec3b3b35fdf890f

   R=3
   ROTK1=15          ROTK2=12          ROTK3=04          ROTK4=0f
   MASK1=cdb18671    MASK2=f06a3c64    MASK3=0c7031f9    MASK4=7dfbff4e
```

```
   OUT=79178d5f90187732f8007fd3884cc309

   R=4
   ROTK1=1c          ROTK2=08          ROTK3=1f          ROTK4=1f
   MASK1=5687e118    MASK2=bc4f5d80    MASK3=cca4c042    MASK4=bab3fb68
   OUT=172c3a9a2791509d5939f58b703f2533

   R=5
   ROTK1=07          ROTK2=02          ROTK3=14          ROTK4=14
   MASK1=a29189c1    MASK2=d1aeff98    MASK3=c9b55ba7    MASK4=c149f70c
   OUT=438053fe465c299bcb35f273b10ea71a

   R=6
   ROTK1=03          ROTK2=13          ROTK3=07          ROTK4=0e
   MASK1=13330f06    MASK2=5e1906f5    MASK3=fb2bce75    MASK4=8331aed4
   OUT=bdea3985cd08c7902096561b76f20944

   R=7
   ROTK1=17          ROTK2=1d          ROTK3=0e          ROTK4=09
   MASK1=bb903fdc    MASK2=a9915d2f    MASK3=0974e50a    MASK4=0c1708f1
   OUT=8b5e011401e1124f731135fa780c59ef

   R=8
   ROTK1=01          ROTK2=14          ROTK3=0c          ROTK4=06
   MASK1=302e76c3    MASK2=cf429964    MASK3=e9ecad47    MASK4=8850a515
   OUT=af23fd837033dc81a60be8a69865c543

   R=9
   ROTK1=0d          ROTK2=1d          ROTK3=04          ROTK4=12
   MASK1=3046827f    MASK2=568ab6b9    MASK3=b86e7c10    MASK4=ef290a58
   OUT=732e4ec0f205e39afaf407c956d83728

   R=10
   ROTK1=02          ROTK2=1d          ROTK3=01          ROTK4=0b
   MASK1=a3eedefb    MASK2=ac426ecf    MASK3=2e8220ec    MASK4=cd92c34a
   OUT=5375c3be208f38eed0419d98f50dd9b3

   R=11
   ROTK1=1e          ROTK2=18          ROTK3=13          ROTK4=02
   MASK1=ae877786    MASK2=ef78852e    MASK3=0aa1c41f    MASK4=a28ec9c4
   OUT=e2c604af966715811b377f12de19e459

   R=12
   ROTK1=1c          ROTK2=1d          ROTK3=18          ROTK4=06
   MASK1=f364d7f9    MASK2=233500c0    MASK3=83cee501    MASK4=01f857c6
   OUT=00000000000000000000000000000000

   PT=00000000000000000000000000000000
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KEYSIZE=192
KEY=2342bb9efa38542cbed0ac83940ac298bac77a7717942863

PT=00000000000000000000000000000000

R=1
ROTK1=1e ROTK2=1a ROTK3=1b ROTK4=16
MASK1=21daa501 MASK2=fcdfc612 MASK3=62f629b3 MASK4=9ec93bfa
OUT=4d468c8ca43c1ab66eae0bb9062fe876

R=2
ROTK1=1a ROTK2=1d ROTK3=19 ROTK4=1f
MASK1=d7f04aaf MASK2=76a4b0c2 MASK3=7364327b MASK4=fe0602c3
OUT=1fd808cfd82ac7354728e719a4cc0ebe

R=3
ROTK1=13 ROTK2=19 ROTK3=15 ROTK4=18
MASK1=c5b5a24e MASK2=20577cc0 MASK3=e58b12aa MASK4=a87da0f1
OUT=d3507d51934db5335cebdbb550b774b6

R=4
ROTK1=0f ROTK2=00 ROTK3=15 ROTK4=08
MASK1=5b1b847c MASK2=3d700297 MASK3=310383e1 MASK4=a1a19785
OUT=fab3a20243c1c67bf1759f40c4b732e8

R=5
ROTK1=01 ROTK2=0f ROTK3=0f ROTK4=11
MASK1=34422fa1 MASK2=745d0d3c MASK3=0804535e MASK4=42de73d8
OUT=cf003a27ba91d2346ddfa8ec76bdf029

R=6
ROTK1=06 ROTK2=10 ROTK3=06 ROTK4=07
MASK1=ae5e85f6 MASK2=d1f789b0 MASK3=e2113794 MASK4=db8768c0
OUT=b4fb78a74bbacccbfa45c36c23ed997e

R=7
ROTK1=09 ROTK2=1d ROTK3=08 ROTK4=1f
MASK1=1a000d83 MASK2=dc6d0e51 MASK3=3b65ccaf MASK4=b0470998
OUT=1cedb6d94abb223765f0fb9364a8f07f

R=8
ROTK1=09 ROTK2=0a ROTK3=01 ROTK4=0d
MASK1=d500ec2c MASK2=77e23f6f MASK3=3d1422b2 MASK4=0e4c04aa
OUT=b3289009a03b021d54cec6628712c165

```
R=9
ROTK1=1b          ROTK2=0d          ROTK3=0b          ROTK4=14
MASK1=f9b1a192    MASK2=aded6200    MASK3=0fc10d02    MASK4=d8bdb797
OUT=a4d8f6d0abd8613d241fff3c2ba02882

R=10
ROTK1=17          ROTK2=1d          ROTK3=1c          ROTK4=17
MASK1=a81550e2    MASK2=44e56b22    MASK3=ac97284c    MASK4=e1021ad2
OUT=61a3f74a9a5da18d53a25ce8f3302357

R=11
ROTK1=19          ROTK2=1e          ROTK3=11          ROTK4=02
MASK1=b09d0346    MASK2=15167c69    MASK3=19990bbd    MASK4=a9258551
OUT=ca5ad45111a662f740c9a94b1d43dfb6

R=12
ROTK1=10          ROTK2=0d          ROTK3=08          ROTK4=01
MASK1=69d0c348    MASK2=c8a3d81d    MASK3=d2714d62    MASK4=8cc3f35a
OUT=1b386c0210dcadcbdd0e41aa08a7a7e8

CT=1b386c0210dcadcbdd0e41aa08a7a7e8

R=1
ROTK1=10          ROTK2=0d          ROTK3=08          ROTK4=01
MASK1=69d0c348    MASK2=c8a3d81d    MASK3=d2714d62    MASK4=8cc3f35a
OUT=ca5ad45111a662f740c9a94b1d43dfb6

R=2
ROTK1=19          ROTK2=1e          ROTK3=11          ROTK4=02
MASK1=b09d0346    MASK2=15167c69    MASK3=19990bbd    MASK4=a9258551
OUT=61a3f74a9a5da18d53a25ce8f3302357

R=3
ROTK1=17          ROTK2=1d          ROTK3=1c          ROTK4=17
MASK1=a81550e2    MASK2=44e56b22    MASK3=ac97284c    MASK4=e1021ad2
OUT=a4d8f6d0abd8613d241fff3c2ba02882

R=4
ROTK1=1b          ROTK2=0d          ROTK3=0b          ROTK4=14
MASK1=f9b1a192    MASK2=aded6200    MASK3=0fc10d02    MASK4=d8bdb797
OUT=b3289009a03b021d54cec6628712c165

R=5
ROTK1=09          ROTK2=0a          ROTK3=01          ROTK4=0d
MASK1=d500ec2c    MASK2=77e23f6f    MASK3=3d1422b2    MASK4=0e4c04aa
OUT=1cedb6d94abb223765f0fb9364a8f07f
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```
R=6
ROTK1=09          ROTK2=1d          ROTK3=08          ROTK4=1f
MASK1=1a000d83    MASK2=dc6d0e51    MASK3=3b65ccaf    MASK4=b0470998
OUT=b4fb78a74bbacccbfa45c36c23ed997e

R=7
ROTK1=06          ROTK2=10          ROTK3=06          ROTK4=07
MASK1=ae5e85f6    MASK2=d1f789b0    MASK3=e2113794    MASK4=db8768c0
OUT=cf003a27ba91d2346ddfa8ec76bdf029

R=8
ROTK1=01          ROTK2=0f          ROTK3=0f          ROTK4=11
MASK1=34422fa1    MASK2=745d0d3c    MASK3=0804535e    MASK4=42de73d8
OUT=fab3a20243c1c67bf1759f40c4b732e8

R=9
ROTK1=0f          ROTK2=00          ROTK3=15          ROTK4=08
MASK1=5b1b847c    MASK2=3d700297    MASK3=310383e1    MASK4=a1a19785
OUT=d3507d51934db5335cebdbb550b774b6

R=10
ROTK1=13          ROTK2=19          ROTK3=15          ROTK4=18
MASK1=c5b5a24e    MASK2=20577cc0    MASK3=e58b12aa    MASK4=a87da0f1
OUT=1fd808cfd82ac7354728e719a4cc0ebe

R=11
ROTK1=1a          ROTK2=1d          ROTK3=19          ROTK4=1f
MASK1=d7f04aaf    MASK2=76a4b0c2    MASK3=7364327b    MASK4=fe0602c3
OUT=4d468c8ca43c1ab66eae0bb9062fe876

R=12
ROTK1=1e          ROTK2=1a          ROTK3=1b          ROTK4=16
MASK1=21daa501    MASK2=fcdfc612    MASK3=62f629b3    MASK4=9ec93bfa
OUT=00000000000000000000000000000000

PT=00000000000000000000000000000000


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KEYSIZE=256
KEY=2342bb9efa38542cbed0ac83940ac2988d7c47ce264908461cc1b5137ae6b604

PT=00000000000000000000000000000000
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```
R=1
ROTK1=08          ROTK2=12          ROTK3=0e          ROTK4=17
MASK1=420b1cef    MASK2=03f07e80    MASK3=cd2ab3ee    MASK4=15371a16
OUT=f6c3b9a6ffd8a31ce04dbcf7772f1536

R=2
ROTK1=0a          ROTK2=04          ROTK3=01          ROTK4=13
MASK1=bc6025e3    MASK2=d54f5aba    MASK3=17fa667a    MASK4=bb8a840e
OUT=9477ef6fd7d6fce3dcaa27d6132465ee

R=3
ROTK1=1e          ROTK2=0d          ROTK3=10          ROTK4=01
MASK1=446c0950    MASK2=b4542da0    MASK3=523baa91    MASK4=4a914503
OUT=c056ec5748ecd90f992cf07f3529160f

R=4
ROTK1=15          ROTK2=0e          ROTK3=0d          ROTK4=09
MASK1=4106d4de    MASK2=9ce441e7    MASK3=2c390c3b    MASK4=52d1b516
OUT=7bcc57d80603b6c7b9ca75eea5cb1c2d

R=5
ROTK1=09          ROTK2=16          ROTK3=08          ROTK4=16
MASK1=2827db72    MASK2=7920623f    MASK3=10948a1a    MASK4=b639f290
OUT=d62686a2b01d11837fb6a46c79fc1816

R=6
ROTK1=1f          ROTK2=11          ROTK3=17          ROTK4=0a
MASK1=85fcd124    MASK2=c567c5fe    MASK3=a4113025    MASK4=ce949239
OUT=1b03a108d6f1878e03a62e72c9c97662

R=7
ROTK1=1d          ROTK2=06          ROTK3=0b          ROTK4=1c
MASK1=c0e98900    MASK2=8832532c    MASK3=d7403525    MASK4=26ed4609
OUT=b11d972f22ed26d085189ca3b6c79d36

R=8
ROTK1=0b          ROTK2=04          ROTK3=0e          ROTK4=19
MASK1=69b1d027    MASK2=e628d930    MASK3=4904b3cd    MASK4=51fad71a
OUT=4265774a393a8a32ed78c5c1571893e4

R=9
ROTK1=1a          ROTK2=0f          ROTK3=09          ROTK4=10
MASK1=4b81b846    MASK2=9f1d941b    MASK3=ebb8fe8a    MASK4=6616847e
OUT=f4f1322a076d4f5eb2d14dc75815ccf1
```

```
R=10
ROTK1=1b          ROTK2=00          ROTK3=01          ROTK4=01
MASK1=2cf3fd07    MASK2=75580ec1    MASK3=513614b9    MASK4=478097ef
OUT=57c3a554eafe71dc6a33fe0bda83f566

R=11
ROTK1=1c          ROTK2=0b          ROTK3=1b          ROTK4=1f
MASK1=4fdf26fe    MASK2=a4850785    MASK3=615eadd0    MASK4=9b507d47
OUT=dd9940f4f2e1786ab6f2bdee519a407e

R=12
ROTK1=0f          ROTK2=09          ROTK3=1d          ROTK4=02
MASK1=4bd673d3    MASK2=36399d66    MASK3=63385006    MASK4=0579675f
OUT=4f6a2038286897b9c9870136553317fa

CT=4f6a2038286897b9c9870136553317fa

R=1
ROTK1=0f          ROTK2=09          ROTK3=1d          ROTK4=02
MASK1=4bd673d3    MASK2=36399d66    MASK3=63385006    MASK4=0579675f
OUT=dd9940f4f2e1786ab6f2bdee519a407e

R=2
ROTK1=1c          ROTK2=0b          ROTK3=1b          ROTK4=1f
MASK1=4fdf26fe    MASK2=a4850785    MASK3=615eadd0    MASK4=9b507d47
OUT=57c3a554eafe71dc6a33fe0bda83f566

R=3
ROTK1=1b          ROTK2=00          ROTK3=01          ROTK4=01
MASK1=2cf3fd07    MASK2=75580ec1    MASK3=513614b9    MASK4=478097ef
OUT=f4f1322a076d4f5eb2d14dc75815ccf1

R=4
ROTK1=1a          ROTK2=0f          ROTK3=09          ROTK4=10
MASK1=4b81b846    MASK2=9f1d941b    MASK3=ebb8fe8a    MASK4=6616847e
OUT=4265774a393a8a32ed78c5c1571893e4

R=5
ROTK1=0b          ROTK2=04          ROTK3=0e          ROTK4=19
MASK1=69b1d027    MASK2=e628d930    MASK3=4904b3cd    MASK4=51fad71a
OUT=b11d972f22ed26d085189ca3b6c79d36

R=6
ROTK1=1d          ROTK2=06          ROTK3=0b          ROTK4=1c
MASK1=c0e98900    MASK2=8832532c    MASK3=d7403525    MASK4=26ed4609
OUT=1b03a108d6f1878e03a62e72c9c97662
```

```
R=7
ROTK1=1f          ROTK2=11          ROTK3=17          ROTK4=0a
MASK1=85fcd124    MASK2=c567c5fe    MASK3=a4113025    MASK4=ce949239
OUT=d62686a2b01d11837fb6a46c79fc1816

R=8
ROTK1=09          ROTK2=16          ROTK3=08          ROTK4=16
MASK1=2827db72    MASK2=7920623f    MASK3=10948a1a    MASK4=b639f290
OUT=7bcc57d80603b6c7b9ca75eea5cb1c2d

R=9
ROTK1=15          ROTK2=0e          ROTK3=0d          ROTK4=09
MASK1=4106d4de    MASK2=9ce441e7    MASK3=2c390c3b    MASK4=52d1b516
OUT=c056ec5748ecd90f992cf07f3529160f

R=10
ROTK1=1e          ROTK2=0d          ROTK3=10          ROTK4=01
MASK1=446c0950    MASK2=b4542da0    MASK3=523baa91    MASK4=4a914503
OUT=9477ef6fd7d6fce3dcaa27d6132465ee

R=11
ROTK1=0a          ROTK2=04          ROTK3=01          ROTK4=13
MASK1=bc6025e3    MASK2=d54f5aba    MASK3=17fa667a    MASK4=bb8a840e
OUT=f6c3b9a6ffd8a31ce04dbcf7772f1536

R=12
ROTK1=08          ROTK2=12          ROTK3=0e          ROTK4=17
MASK1=420b1cef    MASK2=03f07e80    MASK3=cd2ab3ee    MASK4=15371a16
OUT=00000000000000000000000000000000

PT=00000000000000000000000000000000
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Full Copyright Statement

Acknowledgement

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