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- HIGHT -

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List of Symbols

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Chapter 1

HIGHT

1.1 Specification

Table 1.1: Specification Comparison between AES and HIGHT Block Ciphers

Specification	AES	HIGHT
Block Size (bits)	128	64
Key Size (bits)	128/192/256	128
Structure	Substitution-Permutation Network	Generalized Feistel Network (ARX - Add-Rotation-Xor)
Rounds	10/12/14 (depends on key size)	24/28/32 (depends on key size)
Design Year	1998	2013

Table 1.2: Parameters of the Block Cipher HIGHT

Algorithms	Block Size (N_b-byte)	Key Length (N_k-byte)	Number of Rounds (N_r)	Round-Key Length (byte)	Total Size of Round-Keys ($(N_r * 192)$-bit)
bit	16(4-word)	16(4-word)	24	24	4608 (144-word)
byte (8-bit)	16(4-word)	24(6-word)	28	24	5376 (168-word)
word (32-bit, 4-byte)	16(4-word)	32(8-word)	32	24	6144 (192-word)

1.2 State Representation

Let $\mathsf{state}[0], \mathsf{state}[1], \ldots$ be representation of arrays of bytes. Note that

$$\mathsf{state}[i] := \left\{input_{8i}, input_{8i+1}, \ldots, input_{8i+7}\right\} \in \mathbb{F}_{2^8}$$

for $input_i \in \mathbb{F}_2$. For example, $\mathsf{state}[0] = \left\{input_0, input_1, \ldots, input_7\right\}$.

The 128-bit plaintext P of LEA is represented as an array of four 32-bit words $P[0], P[1], P[2]$ and $P[3]$. Then

$$P[i] = \mathsf{state}[4i+3] \parallel \mathsf{state}[4i+2] \parallel \mathsf{state}[4i+1] \parallel \mathsf{state}[4i] \quad \text{for} \quad 0 \le i \le 3.$$

Here, $P[i] \in \mathbb{F}_{2^{32=8\cdot 4}}$The key K of LEA is also represented as the same way.

Table 1.3: Representations for words, bytes, and bits

Input Bit Sequence	24	$\cdots$	31	16	$\cdots$	23	8	$\cdots$	15	0	$\cdots$	7
Word Number	0											
Byte Number	3			2			1			0		
Bit Numbers in Word	31	$\cdots$										1

Example 1.1.

128-bit Input String	`0x0f1e2d3c4b5a69788796a5b4c3d2e1f0`											
Split into Words	0x0f1e2d3c $P[0]$			0x4b5a6978 $P[1]$			0x8796a5b4 $P[2]$			0xc3d2e1f0 $P[3]$		
$P[0]$ **(Word)**	0x0f1e2d3c											
$P[0]$ **(Bit)**	0b 0000:1111:0001:1110:0010:1101:0011:1010											
Split into Bytes	0x0f state[3]			0x1e state[2]			0x2d state[1]			0x3c state[0]		
state[0] **(Byte)**	0x3c											
Split into Bits	1111:0000			-			-			-		
	24	$\cdots$	31	16	$\cdots$	23	8	$\cdots$	15	0	$\cdots$	7

```c
void stringToWordArray(const char* hexString, u32* wordArray) {
    size_t length = strlen(hexString);
    for (size_t i = 0; i < length; i += 8) {
        sscanf(&hexString[i], "%8x", &wordArray[i / 8]);
    }
}

const char* inputString = "0f1e2d3c4b5a69788796a5b4c3d2e1f0";
u32 key[4];
stringToWordArray(inputString, key);
```

```
(gdb) x/16xb key
0x7fffffffd9c0: 0x3c    0x2d    0x1e    0x0f    0x78    0x69    0x5a    0x4b
0x7fffffffd9c8: 0xb4    0xa5    0x96    0x87    0xf0    0xe1    0xd2    0xc3
```

1.3 Key Schedule

$$\text{KeySchedule}^{\text{enc}}_{128} : \{0, 1\}^{128=32\cdot 4} \longrightarrow \{0, 1\}^{192\cdot 24=4608=32\cdot 144}$$

$$\text{KeySchedule}^{\text{enc}}_{192} : \{0, 1\}^{192=32\cdot 6} \longrightarrow \{0, 1\}^{192\cdot 28=5376=32\cdot 168}$$

$$\text{KeySchedule}^{\text{enc}}_{256} : \{0, 1\}^{256=32\cdot 8} \longrightarrow \{0, 1\}^{192\cdot 32=6144=32\cdot 192}$$

1.3.1 Round Constant

The constant $\delta[i] \in \mathbb{F}_{2^{32}}$ ($i \in \{1, \ldots, 7\}$) is as follows:

i	$\delta[i]$	value
0	$\delta[0]$	`0xc3efe9db`
1	$\delta[1]$	`0x44626b02`
2	$\delta[2]$	`0x79e27c8a`
3	$\delta[3]$	`0x78df30ec`
4	$\delta[4]$	`0x715ea49e`
5	$\delta[5]$	`0xc785da0a`
6	$\delta[6]$	`0xe04ef22a`
7	$\delta[7]$	`0xe5c40957`

1.3.2 Rotation Function

Algorithm 1: Rotation to Left and Right

/* `RotL` : $\{0,1\}^{32} \times \{0,1\}^{32} \rightarrow \{0,1\}^{32}$ */

Function `RotL`(value, shift):

    return (value $\ll$ shift) | (value $\gg$ (32 − shift));

end

/* `RotR` : $\{0,1\}^{32} \times \{0,1\}^{32} \rightarrow \{0,1\}^{32}$ */

Function `RotR`(value, shift):

    return (value $\gg$ shift) | (value $\ll$ (32 − shift));

end

1.3.3 Encryption Key Schedule of LEA-128

Algorithm 2: Encryption Key Schedule (LEA-128)

Input: User-key $\mathsf{UK} = \mathsf{UK}[0] \,\|\, \mathsf{UK}[1] \,\|\, \mathsf{UK}[2] \,\|\, \mathsf{UK}[3]$ ($\mathsf{UK}[i] \in \{0,1\}^{32}$)

Output: Encryption Round-keys $\{\mathsf{RK}_i^{\mathsf{enc}}\}_{i=0}^{23}$ ($\mathsf{RK}_i^{\mathsf{enc}} \in \{0,1\}^{192}$)

/* $\mathsf{UK} \in \{0,1\}^{128}$ is 16-byte and $\left\{\mathsf{RK}_i^{\mathsf{enc}}\right\}_{i=0}^{23} \in \{0,1\}^{4608}$ is 576-byte */

for $i = 0$ **to** 3 **do**

    $T[i] = \mathsf{UK}[i]$ // $T = T[0] \,\|\, \cdots \,\|\, T[3] \in \{0,1\}^{128=32*4}$

end

for $i = 0$ **to** 23 **do**

    $T[0] \leftarrow \mathtt{RotL}(T[0] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i+0), 1)$ // $T[i] \in \{0,1\}^{32}$

    $T[1] \leftarrow \mathtt{RotL}(T[1] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i+1), 3)$

    $T[2] \leftarrow \mathtt{RotL}(T[2] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i+2), 6)$

    $T[3] \leftarrow \mathtt{RotL}(T[3] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i+3), 11)$

    $\mathsf{RK}_i^{\mathsf{enc}} \leftarrow T[0] \,\|\, T[1] \,\|\, T[2] \,\|\, T[1] \,\|\, T[3] \,\|\, T[1]$ // $\mathsf{RK}_i^{\mathsf{enc}} \in \{0,1\}^{196=32*6}$

end

return $\left\{\mathsf{RK}_i^{\mathsf{enc}}\right\}_{i=0}^{23}$

1.3.4 Decryption Key Schedule of LEA-128

Algorithm 3: Decryption Key Schedule (LEA-128)

Input: User-key $\mathsf{UK} = \mathsf{UK}[0] \parallel \mathsf{UK}[1] \parallel \mathsf{UK}[2] \parallel \mathsf{UK}[3]$ ($\mathsf{UK}[i] \in \{0,1\}^{32}$)

Output: Decryption Round-keys $\{\mathsf{RK}_i^{\mathsf{dec}}\}_{i=0}^{23}$ ($\mathsf{RK}_i^{\mathsf{dec}} \in \{0,1\}^{192}$)

/* $\mathsf{UK} \in \{0,1\}^{128}$ is 16-byte and $\left\{\mathsf{RK}_i^{\mathsf{dec}}\right\}_{i=0}^{23} \in \{0,1\}^{4608}$ is 576-byte */

for $i = 0$ **to** 3 **do**
- $T[i] = \mathsf{UK}[i]$ // $T = T[0] \parallel \cdots \parallel T[3] \in \{0,1\}^{128=32*4}$

end

for $i = 0$ **to** 23 **do**
- $T[0] \leftarrow \mathtt{RotL}(T[0] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i+0), 1)$ // $T[i] \in \{0,1\}^{32}$
- $T[1] \leftarrow \mathtt{RotL}(T[1] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i+1), 3)$
- $T[2] \leftarrow \mathtt{RotL}(T[2] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i+2), 6)$
- $T[3] \leftarrow \mathtt{RotL}(T[3] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i+3), 11)$
- $\mathsf{RK}_{\mathbf{23-i}}^{\mathsf{dec}} \leftarrow T[0] \parallel T[1] \parallel T[2] \parallel T[1] \parallel T[3] \parallel T[1]$ // $\mathsf{RK}_i^{\mathsf{dec}} \in \{0,1\}^{196=32*6}$

end

return $\left\{\mathsf{RK}_i^{\mathsf{dec}}\right\}_{i=0}^{23}$

1.4 Encryption of LEA-128

Algorithm 4: Encryption of LEA-128

Input: block src = src[0] ‖ src[1] ‖ src[2] ‖ src[3] $\in \{0, 1\}^{128=32*4}$ and $\{\mathsf{RK}_i^{enc}\}_{i=0}^{N_r-1=23}$

Output: block dst = dsc[0] ‖ dsc[1] ‖ dsc[2] ‖ dsc[3] $\in \{0, 1\}^{128=32*4}$

$t_0 = t[0] \parallel t[1] \parallel t[2] \parallel t[3] \leftarrow$ src

for $i = 0$ **to** 23 **do**

  $tmp \leftarrow t[0]$

  $t_{i+1}[0] \leftarrow \mathtt{RotL}(\, t_i[0] \oplus \mathsf{RK}_i^{enc}[0] \boxplus (t_i[1] \oplus \mathsf{RK}_i^{enc}[1])\, , 9)$

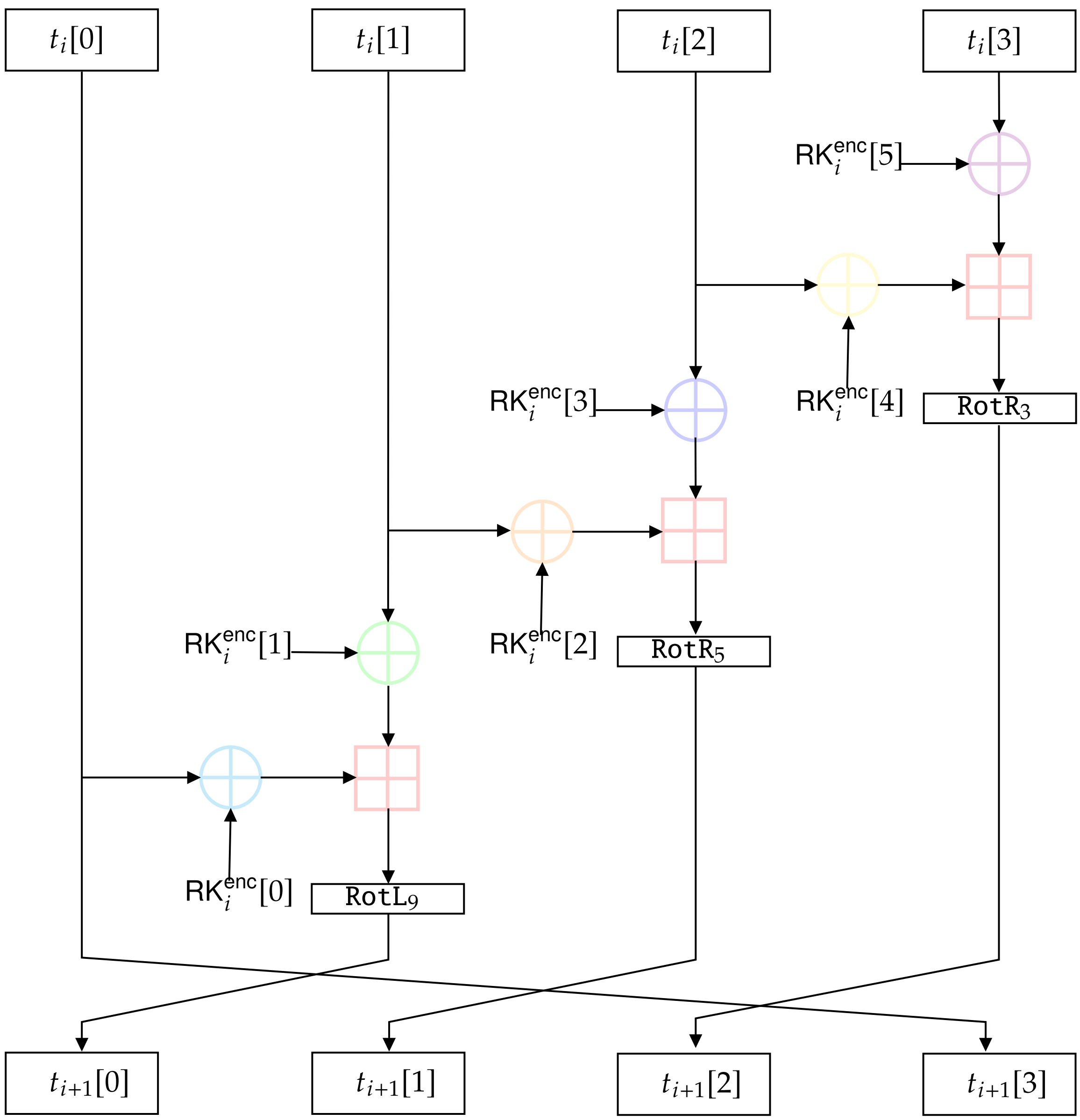
  $t_{i+1}[1] \leftarrow \mathtt{RotR}(\, t_i[1] \oplus \mathsf{RK}_i^{enc}[2] \boxplus (t_i[2] \oplus \mathsf{RK}_i^{enc}[3])\, , 5)$

  $t_{i+1}[2] \leftarrow \mathtt{RotR}(\, t_i[2] \oplus \mathsf{RK}_i^{enc}[4] \boxplus (t_i[3] \oplus \mathsf{RK}_i^{enc}[5])\, , 3)$

  $t_{i+1}[3] \leftarrow tmp$

end

return dst $\leftarrow t_{N_r}$



1.5 Decryption of LEA-128

Algorithm 5: Encryption of LEA-128

Input: block $\mathsf{src} = \mathsf{src}[0] \parallel \mathsf{src}[1] \parallel \mathsf{src}[2] \parallel \mathsf{src}[3] \in \{0, 1\}^{128=32*4}$ and $\{\mathsf{RK}_i^{\mathsf{enc}}\}_{i=0}^{N_r-1=23}$

Output: block $\mathsf{dst} = \mathsf{dsc}[0] \parallel \mathsf{dsc}[1] \parallel \mathsf{dsc}[2] \parallel \mathsf{dsc}[3] \in \{0, 1\}^{128=32*4}$

$t_0 = t[0] \parallel t[1] \parallel t[2] \parallel t[3] \leftarrow \mathsf{src}$
for $i = 0$ **to** 23 **do**
  $tmp \leftarrow t[0]$
  $t_{i+1}[0] \leftarrow \mathtt{RotL}(t_i[0] \oplus \mathsf{RK}_i^{\mathsf{enc}}[0] \boxplus (t_i[1] \oplus \mathsf{RK}_i^{\mathsf{enc}}[1]), 9)$
  $t_{i+1}[1] \leftarrow \mathtt{RotR}(t_i[1] \oplus \mathsf{RK}_i^{\mathsf{enc}}[2] \boxplus (t_i[2] \oplus \mathsf{RK}_i^{\mathsf{enc}}[3]), 5)$
  $t_{i+1}[2] \leftarrow \mathtt{RotR}(t_i[2] \oplus \mathsf{RK}_i^{\mathsf{enc}}[4] \boxplus (t_i[3] \oplus \mathsf{RK}_i^{\mathsf{enc}}[5]), 3)$
  $t_{i+1}[3] \leftarrow tmp$
end
return $\mathsf{dst} \leftarrow t_{N_r}$

Algorithm 6: Decryption of LEA-128

Input: block $\mathsf{src} \in \{0, 1\}^{128=8*16}$, decryption round-keys $\{\mathsf{RK}_i^{\mathsf{dec}}\}_{i=0}^{N_r-1=23}$

Output: block $\mathsf{dst} \in \{0, 1\}^{128=8*16}$

$t_0 \leftarrow \mathsf{src}$
for $i = 0$ **to** $N_r - 1$ **do**
  $t_{i+1}[0] \leftarrow t_i[3]$
  $t_{i+1}[1] \leftarrow (\mathtt{RotR}(t_i[0], 9) \boxminus (t_{i+1}[0] \oplus \mathsf{RK}_i^{\mathsf{dec}}[0])) \oplus \mathsf{RK}_i^{\mathsf{dec}}[1]$
  $t_{i+1}[2] \leftarrow (\mathtt{RotL}(t_i[1], 5) \boxminus (t_{i+1}[1] \oplus \mathsf{RK}_i^{\mathsf{dec}}[2])) \oplus \mathsf{RK}_i^{\mathsf{dec}}[3]$
  $t_{i+1}[3] \leftarrow (\mathtt{RotL}(t_i[2], 3) \boxminus (t_{i+1}[2] \oplus \mathsf{RK}_i^{\mathsf{dec}}[4])) \oplus \mathsf{RK}_i^{\mathsf{dec}}[5]$
end
return $\mathsf{dst} \leftarrow t_{N_r}$

Appendix A

Additional Data A

A.1 Substitution-BOX