ASCON

Authenticated Encryption
CAESAR and NIST LWC Winner

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Outline

Abstract

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Abstract

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Key Points

- **Authentication** - AEAD, Single Pass, Online
- **Device Versatility** - High End CPU, Small Devices
- **Primitive Options** - Encryption, Hash, XOF
- **Cryptanalysis** - Linear, Differential, Zero-Sum, Integral

Cipher Specifications

Recommended parameters for ASCON authenticated encryption

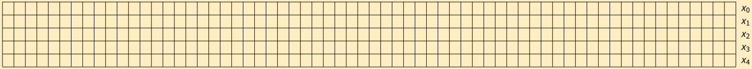
Cipher	Bit size of					Rounds	
	key	nonce	tag	rate	capacity	p^a	p^b
ASCON-128	128	128	128	64	256	12	6
ASCON-128a	128	128	128	128	192	12	8

Sponge Construction

- **State** (**s**) - The sponge operates on a state of 320 bits
- **Rate** (**r**) - Rate at which message is consumed
- **Capacity** (**c**) - Encryption, Hash, XOF
- **Tag** (**t**)- Associated with Authentication.
- **a**, **b** - Number of Rounds in **End** and **Core** Permutations

State (S)

$S = x_0||x_1||x_2||x_3||x_4$



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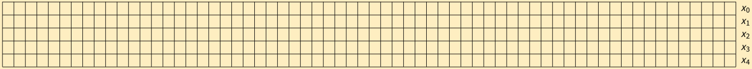
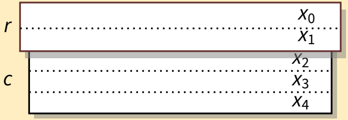


$S = S_r||S_c$

ASCON-128

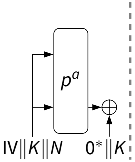
- **Rate** (**r**) - 64 Bits Block
- **Capacity** (**c**) - 256 Bits

ASCON-128a



- **Rate** (**r**) - 128 Bits Block
- **Capacity** (**c**) - 192 Bits

Authenticated Encryption

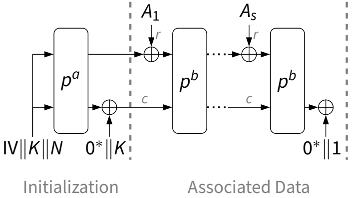


Initialization

Duplex-Sponge Construction

- **Initialization** - Initialize the 320-Bit State S with Initialization Vector IV, key K , and Nonce N. Run it through **End Permutation** p^a and inject padded K.

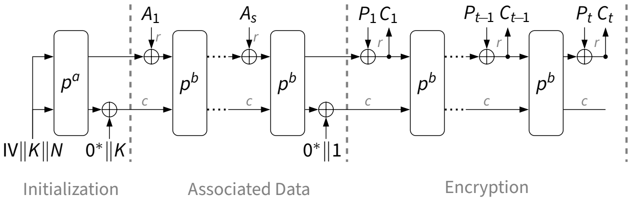
Authenticated Encryption



Duplex-Sponge Construction

- **Initialization** - Initialize the 320-Bit State S with Initialization Vector IV, key K , and Nonce N. Run it through **End Permutation** p^a and inject padded K.
- **Associated Data Processing** - Inject S with Associated Data blocks A_i and and digest through **Core Permutation** p^b.

Authenticated Encryption



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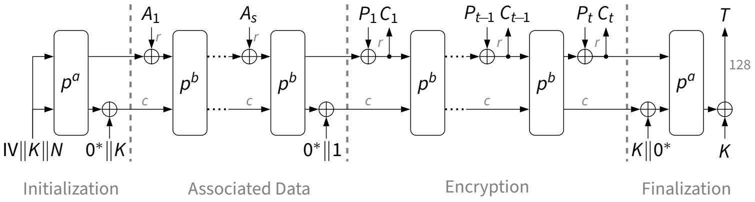
- **Encryption** - Inject S with plaintext blocks P_i and extract ciphertext blocks C_i after each run of p_b.

Authenticated Encryption



Duplex-Sponge Construction

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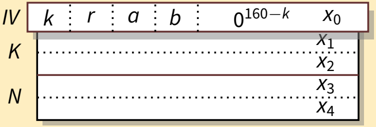
- **Associated Data Processing** - Inject S with Associated Data blocks A_i and and digest through **Core Permutation** p^b.
- **Encryption** - Inject S with plaintext blocks P_i and extract ciphertext blocks C_i after each run of p_b.
- **Finalization** - Inject padded K again and extract the Tag T for authentication after running through p^a.

Initialization and Associated Data Processing

Initialization

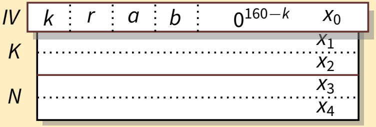


$$IV_{k,r,a,b} \leftarrow k||r||a||b||0^{160-k}$$
$$S \leftarrow IV||K||V$$
$$S \leftarrow p^a(S) \oplus \left(0^{320-k}||K\right)$$

- $|IV|$ - 64, $|K|$ - 128, $|N|$ - 128
- ASCON-128 - `80400c0600000000`
- ASCON-128a - `80800c0800000000`

Initialization and Associated Data Processing

Initialization



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- $|IV|$ - 64, $|K|$ - 128, $|N|$ - 128
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Associated Data Processing

- Padding the Associated Data A and splitting s r-Bit Blocks

$$A_1, \ldots, A_s \leftarrow A||1||0^{r-1-(|A| \bmod r)}$$

- Digesting Associated Data Blocks

$$S \leftarrow p^b\left((S_r \oplus A_i)||S_c\right), \; 1 \leq i \leq s$$

- Adding 1-bit Domain Separation Constant

$$S \leftarrow S \oplus \left(0^{319}||1\right)$$

Encryption and Finalisation

Encryption

- Padding the Plaintext P and splitting t r-Bit Blocks

$$P_1, \dots, P_t \leftarrow P||1||0^{r-1-(|P| \bmod r)}$$

- Injecting Plaintext and Extracting Ciphertext

$$C_i \leftarrow S_r \oplus P_i \quad 1 \leq i \leq t$$

$$S \leftarrow \begin{cases} p^b\left(C_i||S_c\right) & \text{if } 1 \leq i < t \\ C_i||S_c & \text{if } i = t \end{cases}$$

- Unpadding Last Ciphertext C_t

$$C_t' \leftarrow \lfloor C_t \rfloor_{|P| \bmod r}$$

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- Unpadding Last Ciphertext C_t

$$C'_t \leftarrow \lfloor C_t \rfloor_{|P| \bmod r}$$

Finalization

- Adding Padded Key to State

$$S \leftarrow S \oplus \left(0^r||K||0^{c-k}\right)$$

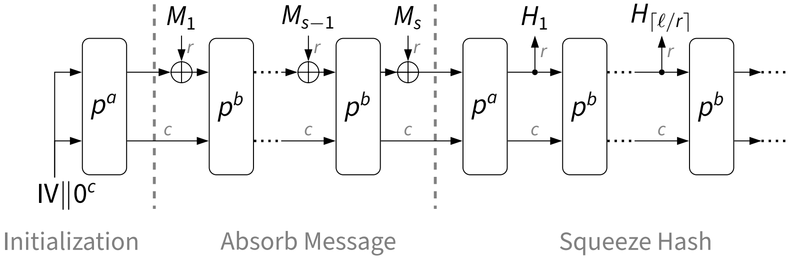
- End Permutation

$$S \leftarrow p^a(S)$$

- Extracting Tag T from the Least Significant 128 Bits after adding Key

$$T \leftarrow \lceil S \rceil^{128} \oplus \lceil K \rceil^{128}$$

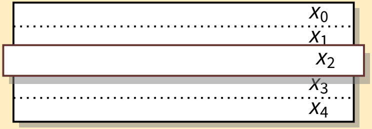
Hash


M_1
M_{s-1}
M_s
H_1
$H_{\lceil \ell/r \rceil}$
r
c
p^a
p^b
$\mathrm{IV}||0^c$
Initialization
Absorb Message
Squeeze Hash

Round Constant (p_C)

Permutation ($p = p_L \circ p_S \circ p_C$)

1 Byte Constant

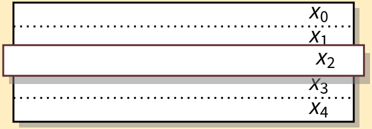


- $x_2 := x_2 \oplus c_r$
- 12 Round Constants
- $p^a \longrightarrow c_r$ and $p^b \longrightarrow c_{a-b+r}$

Round Constant (p_C)

Permutation ($p = p_L \circ p_S \circ p_C$)

1 Byte Constant



- $x_2 := x_2 \oplus c_r$
- 12 Round Constants
- $p^a \longrightarrow c_r$ and $p^b \longrightarrow c_{a-b+r}$

p^{12}	p^8	p^6	Constant	p^{12}	p^8	p^6	Constant
0			0000000000000000f0	6	2	0	000000000000000096
1			0000000000000000e1	7	3	1	000000000000000087
2			0000000000000000d2	8	4	2	000000000000000078
3			0000000000000000c3	9	5	3	000000000000000069
4	0		0000000000000000b4	10	6	4	00000000000000005a
5	1		0000000000000000a5	11	7	5	00000000000000004b

Sbox (p_S) and Linear Layer (p_L)

Permutation ($p = p_L \circ p_S \circ p_C$)

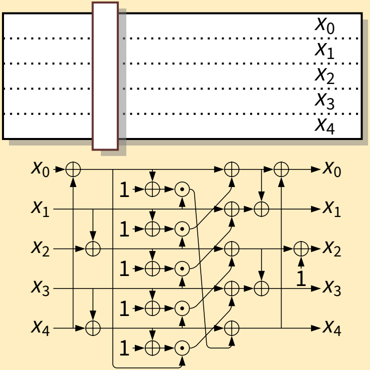
x	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f	10	11	12	13	14	15	16	17	18	19	1a	1b	1c	1d	1e	1f
$S(x)$	4	b	1f	14	1a	15	9	2	1b	5	8	12	1d	3	6	1c	1e	13	7	e	0	d	11	18	10	c	1	19	16	a	f	17

Sbox (p_S) and Linear Layer (p_L)

Permutation ($p = p_L \circ p_S \circ p_C$)

x	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f	10	11	12	13	14	15	16	17	18	19	1a	1b	1c	1d	1e	1f
$S(x)$	4	b	1f	14	1a	15	9	2	1b	5	8	12	1d	3	6	1c	1e	13	7	e	0	d	11	18	10	c	1	19	16	a	f	17

Sbox

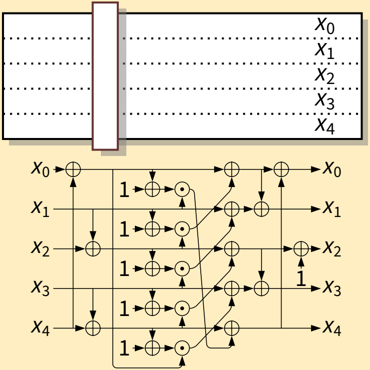


Sbox (p_S) and Linear Layer (p_L)

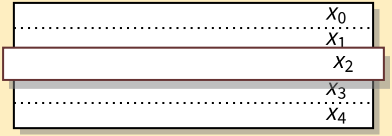
Permutation ($p = p_L \circ p_S \circ p_C$)

x	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f	10	11	12	13	14	15	16	17	18	19	1a	1b	1c	1d	1e	1f
$S(x)$	4	b	1f	14	1a	15	9	2	1b	5	8	12	1d	3	6	1c	1e	13	7	e	0	d	11	18	10	c	1	19	16	a	f	17

Sbox



Linear Layer



$$x_0 := x_0 \oplus (x_0 \ggg 19) \oplus (x_0 \ggg 28)$$
$$x_1 := x_1 \oplus (x_1 \ggg 61) \oplus (x_1 \ggg 39)$$
$$x_2 := x_2 \oplus (x_2 \ggg 1) \oplus (x_2 \ggg 6)$$
$$x_3 := x_3 \oplus (x_3 \ggg 10) \oplus (x_3 \ggg 17)$$
$$x_4 := x_4 \oplus (x_4 \ggg 7) \oplus (x_4 \ggg 41)$$

Outline

DDT

	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f	10	11	12	13	14	15	16	17	18	19	1a	1b	1c	1d	1e	1f
0	32	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
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LAT

	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f	10	11	12	13	14	15	16	17	18	19	1a	1b	1c	1d	1e	1f
0	16	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·
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13	·	·	·	-4	-8	4	·	·	·	4	-4	-4	·	·	-4	·	·	·	·	4	-4	·	-4	-4	4	·	·	·	·	·	4	·
14	·	·	·	-4	8	-4	·	·	·	·	-4	·	·	-4	-4	-4	·	·	·	4	4	·	-4	-4	·	·	4	·	-4	·	·	·
15	·	·	8	-4	-8	-4	·	·	·	-4	·	·	·	·	·	-4	·	·	4	·	4	·	·	·	-4	·	·	·	·	·	-4	·
16	·	·	·	·	·	·	-8	·	·	4	·	-4	-4	·	-4	·	·	·	·	·	4	-4	4	4	4	·	-4	·	-4	·	-4	·
17	·	·	·	·	·	·	·	·	-8	·	-4	4	-4	-4	·	·	·	8	4	-4	-4	-4	·	·	·	·	·	·	·	·	·	·
18	·	-8	·	·	·	·	·	·	·	-4	4	·	-4	·	·	-4	·	·	-4	4	-4	-4	·	·	4	·	4	·	4	·	-4	·
19	·	·	·	·	·	·	-8	-8	·	·	·	·	4	-4	4	-4	·	·	·	·	-4	4	4	-4	·	·	·	·	·	·	·	·
20	·	·	·	4	·	4	·	·	·	4	4	-4	-4	-4	·	-4	·	·	4	·	·	4	-4	4	-4	·	4	4	·	·	·	4
21	·	·	·	4	·	-4	·	·	·	·	·	-4	4	·	-4	4	·	8	·	4	·	4	·	·	·	·	·	4	4	·	-4	-4
22	·	·	·	-4	·	-4	·	·	·	4	·	·	-4	4	4	·	8	·	·	-4	·	4	·	·	4	·	4	4	·	·	·	-4
23	·	·	·	4	·	-4	·	·	8	·	-4	·	-4	·	·	·	·	·	4	·	·	-4	4	-4	·	·	·	4	4	·	4	4
24	·	·	·	·	·	·	·	-8	·	4	4	·	-4	·	·	4	·	·	·	·	4	-4	-4	-4	-4	·	·	-4	4	·	·	-4
25	·	·	·	·	·	·	·	·	·	·	·	·	4	-4	-4	4	·	-8	4	-4	-4	-4	·	·	·	·	4	4	·	·	-4	-4
26	·	8	·	·	·	·	·	·	·	-4	·	-4	-4	·	4	·	·	·	-4	4	-4	-4	·	·	-4	·	·	4	-4	·	·	-4
27	·	·	·	·	·	·	·	·	8	·	-4	4	-4	-4	·	·	·	·	·	·	-4	4	-4	4	·	·	-4	-4	·	·	-4	-4
28	·	·	8	4	·	-4	·	·	·	4	·	·	4	-4	4	·	·	·	-4	·	·	-4	-4	4	4	·	·	·	·	·	4	·
29	·	·	·	-4	·	4	·	·	8	·	4	·	4	·	·	·	·	8	·	-4	·	-4	·	·	·	·	4	·	-4	·	·	·
30	·	·	·	4	·	4	·	·	·	4	-4	4	4	4	·	-4	8	·	·	4	·	-4	·	·	-4	·	·	·	·	·	-4	·
31	·	·	8	4	·	4	·	·	·	·	·	4	-4	·	-4	4	·	·	-4	·	·	4	4	-4	·	·	4	·	-4	·	·	·

BCT

	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f	10	11	12	13	14	15	16	17	18	19	1a	1b	1c	1d	1e	1f
0	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
1	32	·	·	·	·	·	8	·	·	4	·	4	·	4	8	4	·	4	·	4	4	·	12	·	8	·	8	·	4	4	12	4
2	32	12	4	·	4	·	·	4	8	·	·	·	·	·	·	·	8	8	4	4	4	4	·	8	·	12	·	4	·	4	·	4
3	32	4	8	·	8	4	·	·	·	12	8	8	8	4	·	·	4	·	·	·	4	·	·	·	12	·	8	·	4	·	·	·
4	32	·	·	·	4	8	12	8	·	16	·	16	4	8	12	8	·	16	·	16	4	8	12	8	16	·	16	·	4	8	12	8
5	32	·	·	·	·	·	8	·	·	4	·	4	·	4	8	4	·	4	·	4	4	·	12	·	8	·	8	·	4	4	12	4
6	32	2	·	2	·	2	·	2	·	2	·	2	·	2	·	2	·	2	·	2	·	2	·	2	·	2	·	2	·	2	·	2
7	32	·	8	4	4	·	4	4	·	8	8	12	4	·	4	4	·	·	4	·	4	·	·	·	8	·	12	·	4	·	·	·
8	32	·	·	4	·	·	8	4	4	·	·	·	·	4	4	4	4	8	·	8	·	12	4	12	·	·	·	4	·	·	8	4
9	32	2	·	2	2	·	2	·	2	·	2	·	·	2	·	2	2	·	2	·	·	2	·	2	·	2	·	2	2	·	2	·
10	32	2	2	·	2	·	·	2	·	2	2	·	2	·	·	2	·	2	2	·	2	·	·	2	·	2	2	·	2	·	·	2
11	32	·	2	2	·	·	2	2	·	·	2	2	·	·	2	2	·	·	2	2	·	·	2	2	·	·	2	2	·	·	2	2
12	32	12	16	8	16	8	·	4	12	·	8	·	8	·	4	·	12	16	8	16	8	16	4	16	·	12	·	8	·	8	·	4
13	32	2	·	2	·	2	·	2	2	·	2	·	2	·	2	·	2	·	2	·	2	·	2	·	·	2	·	2	·	2	·	2
14	32	12	4	·	4	·	·	4	8	·	·	·	·	·	·	·	8	8	4	4	4	4	·	8	·	12	·	4	·	4	·	4
15	32	4	8	4	8	·	·	·	8	4	12	·	12	4	·	·	4	·	4	·	·	·	·	·	4	8	·	4	4	4	·	·
16	32	4	16	4	16	8	16	8	·	12	16	12	16	8	16	8	4	·	4	·	8	·	8	·	12	·	12	·	8	·	8	·
17	32	8	·	8	·	8	16	8	16	4	·	4	·	4	16	4	16	12	·	12	·	12	16	12	·	8	·	8	·	8	16	8
18	32	2	·	2	·	2	·	2	·	2	·	2	·	2	·	2	2	·	2	·	2	·	2	·	2	·	2	·	2	·	2	·
19	32	16	12	8	12	8	·	·	16	16	12	8	12	8	·	·	16	·	8	4	8	4	·	·	16	16	8	4	8	4	·	·
20	32	·	·	·	4	4	12	4	·	8	·	8	4	4	12	4	·	·	·	·	·	·	8	·	8	·	8	·	·	·	8	·
21	32	·	·	·	·	4	8	4	·	4	·	4	·	·	8	·	·	12	·	12	·	8	8	8	·	·	·	·	·	4	8	4
22	32	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
23	32	·	8	4	4	·	4	4	·	8	8	12	4	·	4	4	·	·	4	·	4	·	·	·	8	·	12	·	4	·	·	·
24	32	·	·	·	2	2	2	2	·	·	·	·	2	2	2	2	·	·	·	·	2	2	2	2	·	·	·	·	2	2	2	2
25	32	·	·	4	·	·	8	4	4	·	·	·	·	4	4	4	4	8	·	8	·	12	4	12	·	·	·	4	·	·	8	4
26	32	2	2	·	·	2	2	·	2	·	·	2	2	·	·	2	·	2	2	·	·	2	2	·	2	·	·	2	2	·	·	2
27	32	·	2	2	2	2	·	·	·	·	2	2	2	2	·	·	·	·	2	2	2	2	·	·	·	·	2	2	2	2	·	·
28	32	4	8	4	8	·	·	·	8	4	12	·	12	4	·	·	4	·	4	·	·	·	·	·	4	8	·	4	4	4	·	·
29	32	8	·	4	·	4	·	·	12	·	·	·	·	·	4	·	12	8	·	8	·	8	4	8	·	8	·	4	·	4	·	·
30	32	·	·	·	·	·	·	·	2	2	2	2	2	2	2	2	·	·	·	·	·	·	·	·	2	2	2	2	2	2	2	2
31	32	8	12	4	12	4	·	·	8	·	8	·	8	·	·	·	8	·	4	4	4	4	·	·	·	8	·	·	·	·	·	·

Sbox Analysis

- **Differential Branch Number** - 3
- **Differential Uniformity** - 8

DDT Frequency Analysis

$f(\Delta_i, \Delta_o)$	S
0	707
2	176
4	120
6	0
8	20

Sbox Analysis

- **Differential Branch Number** - 3
- **Differential Uniformity** - 8
- **Linear Branch Number** - 3
- **Maximum Absolute Linear Bias** - 8

DDT Frequency Analysis

$f(\Delta_i, \Delta_o)$	S
0	707
2	176
4	120
6	0
8	20

LAT Frequency Analysis

ϵ	S
-8	18
-4	174
0	647
4	162
8	22

BCT BDT

Sbox Analysis

- **Boomerang Uniformity** - 16

BCT Frequency Analysis

$f(\Delta_i, \nabla_o)$	S
0	445
2	176
4	150
8	110
12	50
16	30

BDT Frequency Analysis

$f(\Delta_i, \Delta_o, \nabla_o)$	S
0	31624
2	352
4	720
8	40
32	32

Differential and Linear Cryptanalysis

- **Linear Layer** (Σ_i) - Differential and Linear Branch Number is 4.
- The minimum number of active S-boxes after 3 rounds - (p^3)
  - **Differential Characteristics** - 15
  - **Linear Characteristics** - 13

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Rounds (R)	1	2	3	4	5
Minimum # Active Sboxes (Differential)	1	4	15	≤ 44	≤ 78
Minimum # Active Sboxes (Linear)	1	4	13	≤ 43	≤ 67

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Collision Producing Differentials - Forgery Attack

- Differentials with differences in the rate part (S_r) of State at the input (Δ_I^r) and output (Δ_O^r) of p^b.

$$\Delta_I^r \xrightarrow{p^b} \Delta_O^r$$

- Might be useful in Forgery attack on the AEAD scheme.

Truncated Differential over Sbox

Undisturbed Bits

For a specific input difference Δ_i of an S-box, if some bits of the output difference Δ_o^* remain invariant, then we call such bits **undisturbed**.

$$Pr\left[\Delta_i \xrightarrow{S} \Delta_o^*\right] = 1$$

Truncated Differential over Sbox

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$$Pr\left[\Delta_i \xrightarrow{S} \Delta_o^*\right] = 1$$

Δ_i	Δ_o^*
00001	*1***
00010	1***1
00011	***0*
00100	**110
00101	1****
01111	*1*0*

Δ_i	Δ_o^*
10000	*10**
10001	10**1
10011	0***0
10100	0*1**
10101	****1
10110	1****

Δ_i	Δ_o^*
00110	****1
00111	0**1*
01000	**11*
01011	***1*
01100	**00*
01110	*0***

Δ_i	Δ_o^*
10111	****0
11000	**1**
11100	**0**
11110	*1***
11111	*0***

Truncated Differential over Sbox

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For a specific input difference Δ_i of an S-box, if some bits of the output difference Δ_o^* remain invariant, then we call such bits **undisturbed**.

$$Pr\left[\Delta_i \xrightarrow{S} \Delta_o^*\right] = 1$$

Note - Inverse S-Box only has 2 undisturbed bits.

Δ_i	Δ_o^*
00001	*1***
00010	1***1
00011	***0*
00100	**110
00101	1****
01111	*1*0*

Δ_i	Δ_o^*
10000	*10**
10001	10**1
10011	0***0
10100	0*1**
10101	****1
10110	1****

Δ_i	Δ_o^*
00110	****1
00111	0**1*
01000	**11*
01011	***1*
01100	**00*
01110	*0***

Δ_i	Δ_o^*
10111	****0
11000	**1**
11100	**0**
11110	*1***
11111	*0***

3.5 Round Truncated Differential Distinguisher

	1000000000000000000000000000000000000000000000000000000000000000
	0000000000000000000000000000000000000000000000000000000000000000
I	0000000000000000000000000000000000000000000000000000000000000000
	1000000000000000000000000000000000000000000000000000000000000000
	1000000000000000000000000000000000000000000000000000000000000000

3.5 Round Truncated Differential Distinguisher

I	1000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000 1000000000000000000000000000000000000000000000000000000000000000 1000000000000000000000000000000000000000000000000000000000000000
S_1	0000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000

3.5 Round Truncated Differential Distinguisher

I	1000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000 1000000000000000000000000000000000000000000000000000000000000000 1000000000000000000000000000000000000000000000000000000000000000
S_1	0000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000
P_1	0000000000000000000000000000000000000000000000000000000000000000 ⋆00000000000000000000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000000000000000000000000000000000000000000000000000000000 ⋆000000000⋆000000⋆0000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000

3.5 Round Truncated Differential Distinguisher

I	1000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000 1000000000000000000000000000000000000000000000000000000000000000 1000000000000000000000000000000000000000000000000000000000000000
S_1	0000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000
P_1	0000000000000000000000000000000000000000000000000000000000000000 ⋆00000000000000000000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000000000000000000000000000000000000000000000000000000000 ⋆000000000⋆000000⋆0000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000
S_2	⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆000000000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00

3.5 Round Truncated Differential Distinguisher

I	1000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000 1000000000000000000000000000000000000000000000000000000000000000 1000000000000000000000000000000000000000000000000000000000000000
S_1	0000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000
P_1	0000000000000000000000000000000000000000000000000000000000000000 ⋆00000000000000000000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000000000000000000000000000000000000000000000000000000000 ⋆000000000⋆000000⋆0000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000
S_2	⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆000000000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00
P_2	⋆⋆0⋆00⋆000⋆00000⋆⋆0⋆⋆0000⋆00⋆⋆0000⋆0⋆0⋆⋆00000⋆000000000000⋆00⋆00 ⋆⋆0⋆00⋆⋆00⋆000⋆00⋆000000000000000000⋆00⋆⋆0000⋆000⋆000000⋆0⋆00⋆⋆0 ⋆⋆⋆⋆00⋆⋆00⋆⋆⋆000⋆⋆⋆0000⋆000000000000000⋆⋆0000⋆000000000000000⋆⋆0 ⋆⋆0000⋆⋆00⋆⋆00⋆0⋆⋆⋆0⋆00⋆000⋆000000⋆0000⋆000000000⋆000000⋆0000⋆00 ⋆000⋆00⋆00⋆00000⋆⋆000000⋆0000000000000⋆⋆0⋆0000⋆0000⋆000000⋆00⋆00

3.5 Round Truncated Differential Distinguisher

	1000000000000000000000000000000000000000000000000000000000000000
	0000000000000000000000000000000000000000000000000000000000000000
I	0000000000000000000000000000000000000000000000000000000000000000
	1000000000000000000000000000000000000000000000000000000000000000
	1000000000000000000000000000000000000000000000000000000000000000
	0000000000000000000000000000000000000000000000000000000000000000
	⋆000000000000000000000000000000000000000000000000000000000000000
S_1	⋆000000000000000000000000000000000000000000000000000000000000000
	⋆000000000000000000000000000000000000000000000000000000000000000
	0000000000000000000000000000000000000000000000000000000000000000
	0000000000000000000000000000000000000000000000000000000000000000
	⋆00000000000000000000000000000000000000⋆000000000000000000000⋆00
P_1	⋆⋆0000⋆000000000000000000000000000000000000000000000000000000000
	⋆000000000⋆000000⋆0000000000000000000000000000000000000000000000
	0000000000000000000000000000000000000000000000000000000000000000
	⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00
	⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00
S_2	⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00
	⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00
	⋆000000000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00
	⋆⋆0⋆00⋆000⋆00000⋆⋆0⋆⋆0000⋆00⋆⋆0000⋆0⋆0⋆⋆00000⋆000000000000⋆00⋆00
	⋆⋆0⋆00⋆⋆00⋆000⋆00⋆000000000000000000⋆00⋆⋆0000⋆000⋆000000⋆0⋆00⋆⋆0
P_2	⋆⋆⋆⋆00⋆⋆00⋆⋆⋆000⋆⋆⋆0000⋆000000000000000⋆⋆0000⋆000000000000000⋆⋆0
	⋆⋆0000⋆⋆00⋆⋆00⋆0⋆⋆⋆0⋆00⋆000⋆000000⋆0000⋆000000000⋆000000⋆0000⋆00
	⋆000⋆00⋆00⋆00000⋆⋆000000⋆0000000000000⋆⋆0⋆0000⋆0000⋆000000⋆00⋆00
	⋆⋆⋆⋆⋆0⋆⋆00⋆⋆⋆0⋆0⋆⋆⋆⋆⋆00⋆⋆⋆0⋆⋆⋆0000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0
	⋆⋆⋆⋆⋆0⋆⋆00⋆⋆⋆0⋆0⋆⋆⋆⋆⋆00⋆⋆⋆0⋆⋆⋆0000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0
S_3	⋆⋆⋆⋆⋆0⋆⋆00⋆⋆⋆0⋆0⋆⋆⋆0⋆00⋆⋆00⋆000000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0
	⋆⋆⋆⋆⋆0⋆⋆00⋆⋆⋆0⋆0⋆⋆⋆⋆⋆00⋆⋆⋆0⋆⋆⋆0000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0
	⋆⋆0⋆⋆0⋆⋆00⋆⋆00⋆0⋆⋆⋆⋆⋆00⋆⋆⋆0⋆⋆⋆0000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0

3.5 Round Truncated Differential Distinguisher

I	1000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000 1000000000000000000000000000000000000000000000000000000000000000 1000000000000000000000000000000000000000000000000000000000000000
S_1	0000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000
P_1	0000000000000000000000000000000000000000000000000000000000000000 ⋆00000000000000000000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000000000000000000000000000000000000000000000000000000000 ⋆000000000⋆000000⋆0000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000
S_2	⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆000000000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00
P_2	⋆⋆0⋆00⋆000⋆00000⋆⋆0⋆⋆0000⋆00⋆⋆0000⋆0⋆0⋆⋆00000⋆000000000000⋆00⋆00 ⋆⋆0⋆00⋆⋆00⋆000⋆00⋆000000000000000000⋆00⋆⋆0000⋆000⋆000000⋆0⋆00⋆⋆0 ⋆⋆⋆⋆00⋆⋆00⋆⋆⋆000⋆⋆⋆0000⋆000000000000000⋆⋆0000⋆000000000000000⋆⋆0 ⋆⋆0000⋆⋆00⋆⋆00⋆0⋆⋆⋆0⋆00⋆000⋆000000⋆0000⋆000000000⋆000000⋆0000⋆00 ⋆000⋆00⋆00⋆00000⋆⋆000000⋆0000000000000⋆⋆0⋆0000⋆0000⋆000000⋆00⋆00
S_3	⋆⋆⋆⋆⋆0⋆⋆00⋆⋆⋆0⋆0⋆⋆⋆⋆⋆00⋆⋆⋆0⋆⋆⋆0000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0 ⋆⋆⋆⋆⋆0⋆⋆00⋆⋆⋆0⋆0⋆⋆⋆⋆⋆00⋆⋆⋆0⋆⋆⋆0000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0 ⋆⋆⋆⋆⋆0⋆⋆00⋆⋆⋆0⋆0⋆⋆⋆0⋆00⋆⋆00⋆000000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0 ⋆⋆⋆⋆⋆0⋆⋆00⋆⋆⋆0⋆0⋆⋆⋆⋆⋆00⋆⋆⋆0⋆⋆⋆0000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0 ⋆⋆0⋆⋆0⋆⋆00⋆⋆00⋆0⋆⋆⋆⋆⋆00⋆⋆⋆0⋆⋆⋆0000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0
P_3	⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆0⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆0 ⋆⋆⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆0⋆⋆⋆⋆0⋆0⋆⋆⋆⋆⋆0⋆⋆⋆ ⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆00⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆⋆⋆0⋆⋆⋆⋆00⋆⋆⋆⋆⋆0⋆⋆⋆ ⋆⋆⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆⋆0⋆⋆⋆⋆0⋆0⋆⋆⋆⋆⋆0⋆⋆⋆ ⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆

3.5 Round Truncated Differential Distinguisher

I	1000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000 1000000000000000000000000000000000000000000000000000000000000000 1000000000000000000000000000000000000000000000000000000000000000
S_1	0000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 ⋆000000000000000000000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000
P_1	0000000000000000000000000000000000000000000000000000000000000000 ⋆00000000000000000000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000000000000000000000000000000000000000000000000000000000 ⋆000000000⋆000000⋆0000000000000000000000000000000000000000000000 0000000000000000000000000000000000000000000000000000000000000000
S_2	⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆⋆0000⋆000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00 ⋆000000000⋆000000⋆000000000000000000000⋆000000000000000000000⋆00
P_2	⋆⋆0⋆00⋆000⋆00000⋆⋆0⋆⋆0000⋆00⋆⋆0000⋆0⋆0⋆⋆00000⋆000000000000⋆00⋆00 ⋆⋆0⋆00⋆⋆00⋆000⋆00⋆000000000000000000⋆00⋆⋆0000⋆000⋆000000⋆0⋆00⋆⋆0 ⋆⋆⋆⋆00⋆⋆00⋆⋆⋆000⋆⋆⋆0000⋆000000000000000⋆⋆0000⋆000000000000000⋆⋆0 ⋆⋆0000⋆⋆00⋆⋆00⋆0⋆⋆⋆0⋆00⋆000⋆000000⋆0000⋆000000000⋆000000⋆0000⋆00 ⋆000⋆00⋆00⋆00000⋆⋆000000⋆0000000000000⋆⋆0⋆0000⋆0000⋆000000⋆00⋆00
S_3	⋆⋆⋆⋆⋆0⋆⋆00⋆⋆⋆0⋆0⋆⋆⋆⋆⋆00⋆⋆⋆0⋆⋆⋆0000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0 ⋆⋆⋆⋆⋆0⋆⋆00⋆⋆⋆0⋆0⋆⋆⋆⋆⋆00⋆⋆⋆0⋆⋆⋆0000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0 ⋆⋆⋆⋆⋆0⋆⋆00⋆⋆⋆0⋆0⋆⋆⋆0⋆00⋆⋆00⋆000000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0 ⋆⋆⋆⋆⋆0⋆⋆00⋆⋆⋆0⋆0⋆⋆⋆⋆⋆00⋆⋆⋆0⋆⋆⋆0000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0 ⋆⋆0⋆⋆0⋆⋆00⋆⋆00⋆0⋆⋆⋆⋆⋆00⋆⋆⋆0⋆⋆⋆0000⋆0⋆0⋆⋆⋆⋆000⋆⋆00⋆0⋆0000⋆0⋆00⋆⋆0
P_3	⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆0 ⋆⋆⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆0⋆⋆⋆⋆0⋆0⋆⋆⋆⋆⋆0⋆⋆⋆ ⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆00⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆⋆⋆0⋆⋆⋆⋆00⋆⋆⋆⋆⋆0⋆⋆⋆ ⋆⋆⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆⋆0⋆⋆⋆⋆0⋆0⋆⋆⋆⋆⋆0⋆⋆⋆ ⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆⋆0⋆⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆
S_4	⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆ ⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆ ⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆ ⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆ ⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆

Impossible Differential

5 Round Differential

x_0	0000000000000000
x_1	0000000000000000
x_2	0000000000000000
x_3	0000000000000000
x_4	8000000000000000
$\not\rightarrow$	
x_0	0100000000100002
x_1	0000000000000000
x_2	0000000000000000
x_3	0000000000000000
x_4	0000000000000000

Impossible Differential

5 Round Impossible Truncated Differential
3.5 Truncated Differential Distinguisher

5 Round Differential

x_0	0000000000000000
x_1	0000000000000000
x_2	0000000000000000
x_3	0000000000000000
x_4	8000000000000000
	$\not\to$
x_0	0100000000100002
x_1	0000000000000000
x_2	0000000000000000
x_3	0000000000000000
x_4	0000000000000000

Impossible Differential

5 Round Differential

x_0	0000000000000000
x_1	0000000000000000
x_2	0000000000000000
x_3	0000000000000000
x_4	8000000000000000
$\not\to$	
x_0	0100000000100002
x_1	0000000000000000
x_2	0000000000000000
x_3	0000000000000000
x_4	0000000000000000

5 Round Impossible Truncated Differential	
3.5 Truncated Differential Distinguisher	
S_4	**0*********
	0*******
	0*******
	\textbf{0}*******
	0*******
1.5 Round Impossible Backward Differential	

Impossible Differential

5 Round Differential

x_0	0000000000000000
x_1	0000000000000000
x_2	0000000000000000
x_3	0000000000000000
x_4	8000000000000000
	$\not\to$
x_0	0100000000100002
x_1	0000000000000000
x_2	0000000000000000
x_3	0000000000000000
x_4	0000000000000000

5 Round Impossible Truncated Differential	
3.5 Truncated Differential Distinguisher	
S_4	⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆
	⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆
	⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆
	⋆⋆**0**⋆⋆⋆⋆⋆⋆⋆⋆⋆
	⋆⋆0⋆⋆⋆⋆⋆⋆⋆⋆⋆
1.5 Round Impossible Backward Differential	
S_4	⋆⋆
	⋆⋆
	⋆⋆
	111000010110001011001111101111110101010010100011010001**1**010100101
	⋆⋆
P_4	0⋆⋆0⋆0⋆⋆0⋆00⋆0000⋆⋆00⋆⋆⋆⋆0⋆⋆⋆⋆0⋆⋆⋆0⋆⋆⋆00⋆0⋆0⋆00⋆⋆⋆000⋆0000⋆00⋆0⋆
	0⋆⋆0⋆0⋆⋆0⋆00⋆0000⋆⋆00⋆⋆⋆⋆0⋆⋆⋆⋆0⋆⋆⋆0⋆⋆⋆00⋆0⋆0⋆00⋆⋆⋆000⋆0000⋆00⋆0⋆
	0⋆⋆0⋆0⋆⋆0⋆00⋆0000⋆⋆00⋆⋆⋆⋆0⋆⋆⋆⋆0⋆⋆⋆0⋆⋆⋆00⋆0⋆0⋆00⋆⋆⋆000⋆0000⋆00⋆0⋆
	0110101101001000011001111011110111011100101010011100010000100101
	0⋆⋆0⋆0⋆⋆0⋆00⋆0000⋆⋆00⋆⋆⋆⋆0⋆⋆⋆⋆0⋆⋆⋆0⋆⋆⋆00⋆0⋆0⋆00⋆⋆⋆000⋆0000⋆00⋆0⋆
S_5	0000000000000000000000000000000000000000000000000000000000000000
	0000000000000000000000000000000000000000000000000000000000000000
	0000000000000000000000000000000000000000000000000000000000000000
	0110101101001000011001111011110111011100101010011100010000100101
	0000000000000000000000000000000000000000000000000000000000000000
P_5	0000000000000000000000000000000000000000000000000000000000000000
	0000000000000000000000000000000000000000000000000000000000000000
	0000000000000000000000000000000000000000000000000000000000000000
	1000000000000000000000000000000000000000000000000000000000000000
	0000000000000000000000000000000000000000000000000000000000000000

Zero Sum Distinguisher

ASCON Sbox - χ Keccak Mapping

- χ has branch number 2, Fix Point at 0, Outputs depend on 3 Inputs
- ASCON S-box is designed by adding lightweight affine transformations to the input and output of .

Zero Sum Distinguisher

ASCON Sbox - χ Keccak Mapping

- χ has branch number 2, Fix Point at 0, Outputs depend on 3 Inputs
- ASCON S-box is designed by adding lightweight affine transformations to the input and output of .

Algebraic Degree

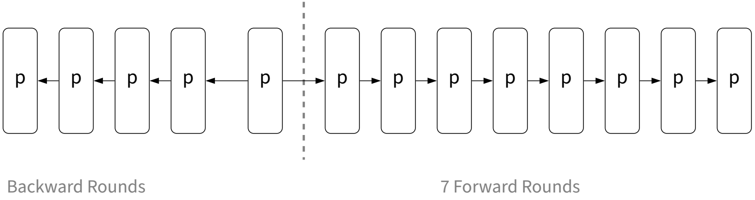
- ASCON S-box (S) $\rightarrow$ ASCON Permutation (p)

$$d(S) = 2 \rightarrow d(p) \leq 2 \rightarrow d(p^r) \leq 2^r$$

- ASCON S-Box Inverse (S^{-1}) $\rightarrow$ ASCON Permutation Inverse (p^{-1})

$$d(S^{-1}) = 3 \rightarrow d(p^{-1}) \leq 3 \rightarrow d\left((p^{-1})^r\right) = 3^r$$

12 Round (p^a) - Zero Sum Distinguisher (2^d)

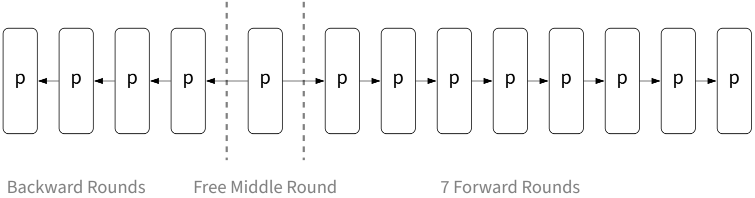


Basic Distinguisher (2^{244})

- 5 Backward Rounds - (3^5)
- 7 Forward Rounds - (2^7)

$d = \max\{3^5, 2^7\} + 1 = 243 + 1 = 244$

12 Round (p^a) - Zero Sum Distinguisher (2^d)



Basic Distinguisher (2^{244})

- 5 Backward Rounds - (3^5)
- 7 Forward Rounds - (2^7)

$d = \max\{3^5, 2^7\} + 1 = 243 + 1 = 244$

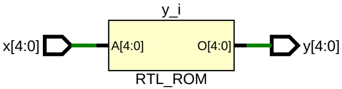
Free Middle Round (2^{130})

- d is a multiple of 5-Bit Sbox
- All d variables positioned in S-box
- S-Box Output also contains d variable and $320 - d$ constant bits
- 4 Backward, 7 Forward Rounds

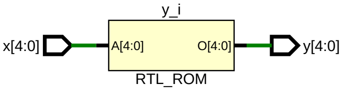
$d = \max\{3^4, 2^7\}+1 = 128+1 = 129 \to 130$

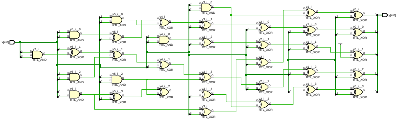
Outline

Sbox

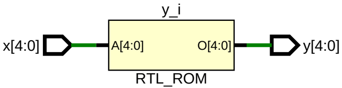


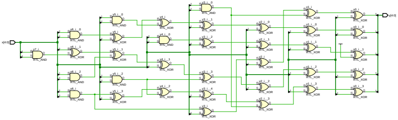
Sbox

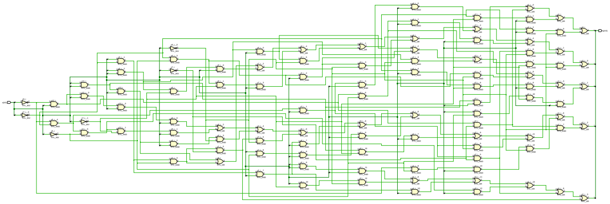




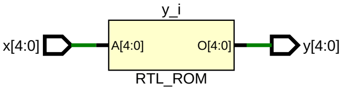
Sbox

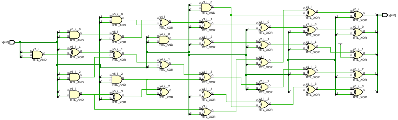






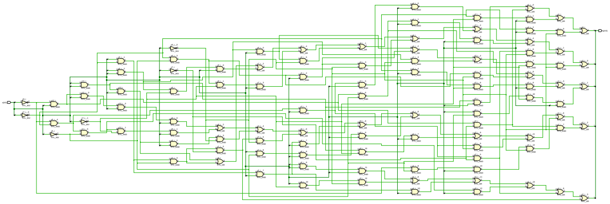
Sbox



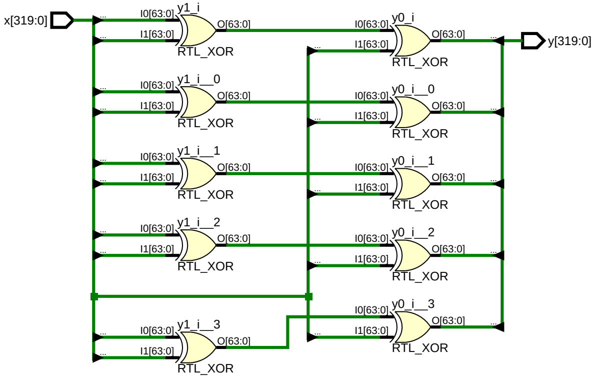


LuT	ANF	K-MAP
43.920	42.480	39.240

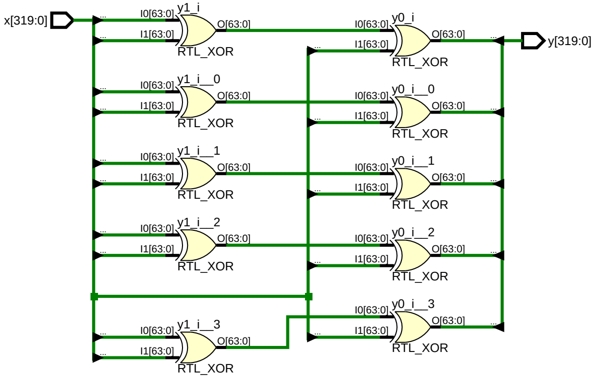
Component	Slice LuT (Logic)	OBUF	IBUF	LUT5	LUT4
Number Used	3	5	5	3	2



Linear Diffusion - 1958.400 GE

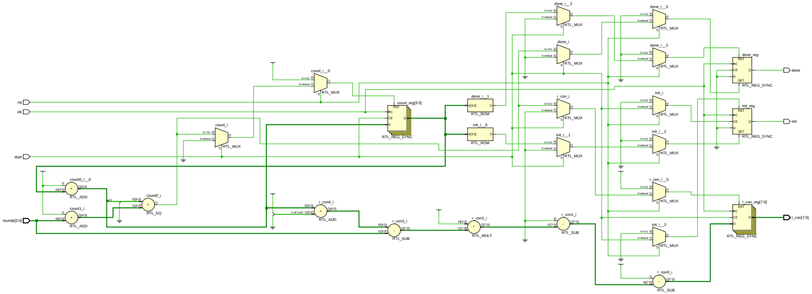


Linear Diffusion - 1958.400 GE

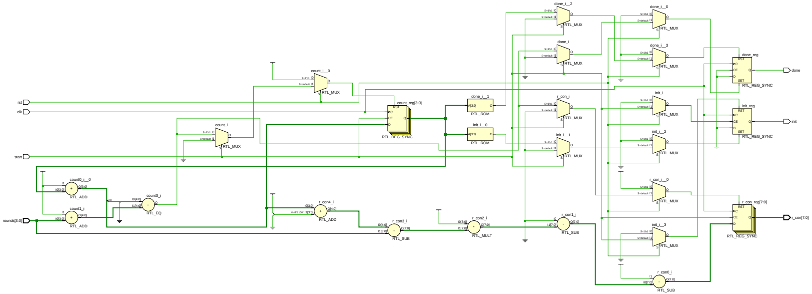


Components	Number Used
Slice LuT (Logic)	169
OBUF	320
LUT3	320
IBUF	320

Round Constant - 321.840 GE

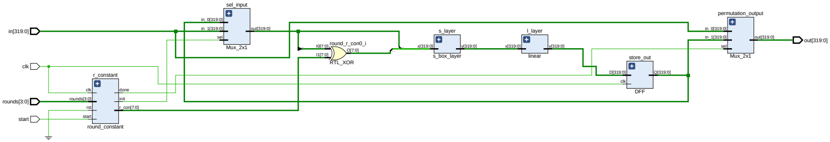


Round Constant - 321.840 GE

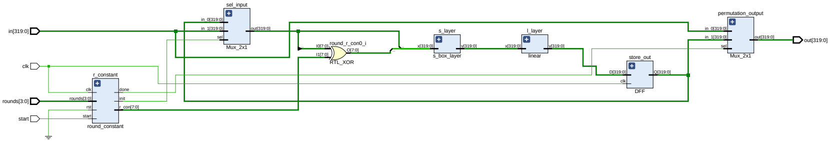


Components	Slice LuT (Logic)	Slice Register (Flip Flop)	FDRE	FDRE	OBUF	LUT1	LUT6	IBUF	LUT4	LUT2	LUT3	FDSE	LUT5	BUFG (Clock)
Number Used	29	14	12	10	9	7	7	7	6	5	3	2	1	1

Permutation



Permutation



- LuT Sbox - 9148.320 GE

Components	Slice LuT (Logic)	Slice Registers (Flip Flop)	LUT3	FDRE	IBUF	OBUF	LUT5	LUT4	LUT6	LUT	1LUT2	BUFG (Clock)
Number Used	740	334	862	334	326	320	196	110	99	9	5	1

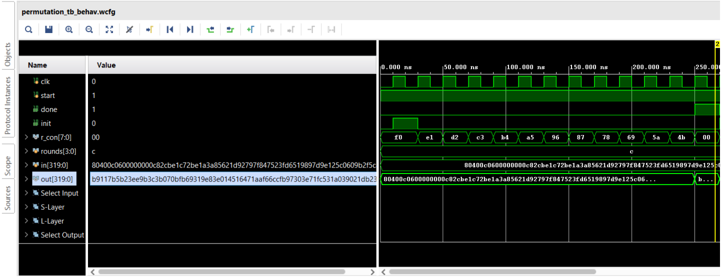
- KMAP Sbox - 8848.800 GE

Components	Slice LuT (Logic)	Slice Registers (Flip Flop)	LUT3	FDRE	IBUF	OBUF	LUT5	LUT6	LUT4	LUT1	LUT2	BUFG (Clock)
Number Used	777	334	955	334	326	320	196	134	13	9	5	1

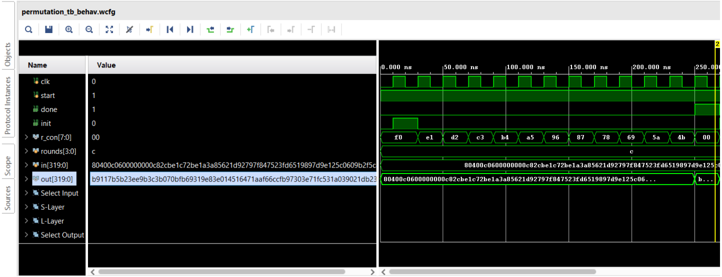
- ANF Sbox - 9056.160 GE

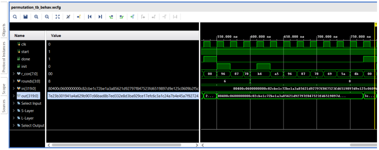
Components	Slice LuT (Logic)	Slice Registers (Flip Flop)	LUT3	FDRE	IBUF	OBUF	LUT6	LUT5	LUT4	LUT1	LUT2	BUFG (Clock)
Number Used	883	334	955	334	326	320	246	140	13	9	5	1

Test Bench - p^{12}, p^8, p^6

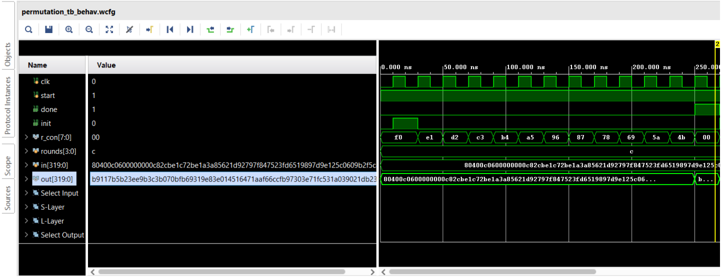


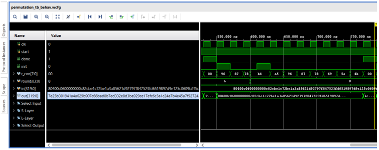
Test Bench - p^{12}, p^8, p^6

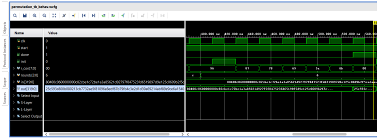




Test Bench - p^{12}, p^8, p^6







Outline

MILP

Number of Active Sboxes - Basic

Variables

MILP

Number of Active Sboxes - Basic

Variables

- $x_{r,w,b} \in \{0, 1\}$ - S-box input Bit b $(0 \leq b \leq 63)$ of word X_w $(0 \leq w \leq 4)$ of round r active or not.

MILP

Number of Active Sboxes - Basic

Variables

- $x_{r,w,b} \in \{0,1\}$ - S-box input Bit b ($0 \le b \le 63$) of word X_w ($0 \le w \le 4$) of round r active or not.
- $y_{r,w,b} \in \{0,1\}$ - S-box output Bit b ($0 \le b \le 63$) of word X_w ($0 \le w \le 4$) of round r active or not.

MILP

Number of Active Sboxes - Basic

Variables

- $x_{r,w,b} \in \{0,1\}$ - S-box input Bit b $(0 \leq b \leq 63)$ of word X_w $(0 \leq w \leq 4)$ of round r active or not.
- $y_{r,w,b} \in \{0,1\}$ - S-box output Bit b $(0 \leq b \leq 63)$ of word X_w $(0 \leq w \leq 4)$ of round r active or not.
- $d_{r,b} \in \{0,1\}$ - b^{th} $(0 \leq b \leq 63)$ S-box of round r is active

MILP

Number of Active Sboxes - Basic

Variables

- $x_{r,w,b} \in \{0,1\}$ - S-box input Bit b $(0 \leq b \leq 63)$ of word X_w $(0 \leq w \leq 4)$ of round r active or not.
- $y_{r,w,b} \in \{0,1\}$ - S-box output Bit b $(0 \leq b \leq 63)$ of word X_w $(0 \leq w \leq 4)$ of round r active or not.
- $d_{r,b} \in \{0,1\}$ - b^{th} $(0 \leq b \leq 63)$ S-box of round r is active
- $u_{r,w,b} \in \{0,1\}$ - Linear layer model in word x_w $(0 \leq w \leq 4)$ of round r.

MILP

Number of Active Sboxes - Basic

Variables

- $x_{r,w,b} \in \{0,1\}$ - S-box input Bit b $(0 \leq b \leq 63)$ of word X_w $(0 \leq w \leq 4)$ of round r active or not.
- $y_{r,w,b} \in \{0,1\}$ - S-box output Bit b $(0 \leq b \leq 63)$ of word X_w $(0 \leq w \leq 4)$ of round r active or not.
- $d_{r,b} \in \{0,1\}$ - b^{th} $(0 \leq b \leq 63)$ S-box of round r is active
- $u_{r,w,b} \in \{0,1\}$ - Linear layer model in word x_w $(0 \leq w \leq 4)$ of round r.

Objective Function

- Minimize the Active S-boxes

$$\min \sum_{r=1}^{R} \sum_{b=0}^{63} d_{r,b}$$

MILP

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Constraints

- **Non-Triviality** - At least 1 Active Input Bit at Start $\sum_{w=0}^{4} \sum_{b=0}^{63} x_{0,w,b} \geq 1$

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Number of Active Sboxes - Basic

Constraints

- **Non-Triviality** - At least 1 Active Input Bit at Start $\sum_{w=0}^{4} \sum_{b=0}^{63} x_{0,w,b} \geq 1$
- **Active S-box** - Minimum 1 and Maximum 5 Active Input and Output Bit(s).

$$d_{r,b} \leq \sum_{w=0}^{4} x_{r,w,b} \leq 5d_{r,b} \qquad d_{r,b} \leq \sum_{w=0}^{4} y_{r,w,b} \leq 5d_{r,b}$$

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- **S-box Branch Number** - 3. $\sum_{w=0}^{4} (x_{r,w,b} + y_{r,w,b}) \geq 3d_{r,b}$

MILP

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Constraints

- **Non-Triviality** - At least 1 Active Input Bit at Start $\sum_{w=0}^{4} \sum_{b=0}^{63} x_{0,w,b} \geq 1$
- **Active S-box** - Minimum 1 and Maximum 5 Active Input and Output Bit(s).

$$d_{r,b} \leq \sum_{w=0}^{4} x_{r,w,b} \leq 5d_{r,b} \qquad d_{r,b} \leq \sum_{w=0}^{4} y_{r,w,b} \leq 5d_{r,b}$$

- **S-box Branch Number** - 3. $\sum_{w=0}^{4} (x_{r,w,b} + y_{r,w,b}) \geq 3d_{r,b}$
- **Linear Layer - XOR Operation Model**

$$y_{r,0,b} + y_{r,0,b-19} + y_{r,0,b-28} + x_{r+1,0,b} = 2u_{r,0,b} \qquad y_{r,2,b} + y_{r,2,b-1} + y_{r,2,b-6} + x_{r+1,2,b} = 2u_{r,2,b}$$

$$y_{r,1,b} + y_{r,1,b-61} + y_{r,1,b-39} + x_{r+1,1,b} = 2u_{r,1,b} \qquad y_{r,3,b} + y_{r,3,b-10} + y_{r,3,b-17} + x_{r+1,3,b} = 2u_{r,3,b}$$

$$y_{r,4,b} + y_{r,4,b-7} + y_{r,4,b-41} + x_{r+1,4,b} = 2u_{r,4,b}$$

Logical Conditional Modelling

MILP

$$x_{r,0,b}, x_{r,1,b}, x_{r,2,b}, x_{r,3,b}, x_{r,4,b}) = (\delta_0, \delta_1, \delta_2, \delta_3, \delta_4) \Rightarrow y_{r,w,b} = \delta$$

$$\sum_{w'=0}^{4} (-1)^{\delta_i} x_{r,w',b} + (-1)^{\delta+1} y_{r,w,b} - \delta + \sum_{w'=0}^{4} \delta_i \geq 0$$

Logical Conditional Modelling

MILP

$$x_{r,0,b}, x_{r,1,b}, x_{r,2,b}, x_{r,3,b}, x_{r,4,b}) = (\delta_0, \delta_1, \delta_2, \delta_3, \delta_4) \Rightarrow y_{r,w,b} = \delta$$

$$\sum_{w'=0}^{4} (-1)^{\delta_i} x_{r,w',b} + (-1)^{\delta+1} y_{r,w,b} - \delta + \sum_{w'=0}^{4} \delta_i \geq 0$$

Recall - Undisturbed Bits

Δ_i	Δ_o^*
00001	*1***
00011	***0*
00101	1****
11111	*0***
01011	***1*

Δ_i	Δ_o^*
10101	****1
10110	1****
11110	*1***
01110	*0***

Δ_i	Δ_o^*
10111	****0
11000	**1**
11100	**0**
00110	****1

Gurobi Implementation

Rounds	Active S-Boxes	Variables (Real)	Variables (Binary)	Inequalities	Time Taken
1	1	960	384	2561	0.03 s
2	4	1920	448	5121	0.51 s
3	12	2880	512	7681	2 min 52.47 s

Table: Basic MILP

Rounds	Active S-Boxes	Variables (Real)	Variables (Binary)	Inequalities	Time Taken
1	1	965	384	3393	0.02 s
2	4	1925	448	6785	1.32 s
3	12	2885	512	10177	3 min 28.54 s

Table: Logical Conditional Modeling

Convex Hull

MILP

```
ascon_hull = list(Polyhedron(vertices=generate_vertices(Ascon)).inequality_generator())

ascon_hull
```

```
[An inequality (-1, 0, 0, 0, 0, 0, 0, 0, 0, 0) x + 1 >= 0,
 An inequality (0, -1, 0, 0, 0, 0, 0, 0, 0, 0) x + 1 >= 0,
 An inequality (0, 0, -1, 0, 0, 0, 0, 0, 0, 0) x + 1 >= 0,
 An inequality (0, 0, 0, -1, 0, 0, 0, 0, 0, 0) x + 1 >= 0,
 An inequality (-1, 0, 0, -1, -1, 0, 0, -1, -1, 0) x + 4 >= 0,
 An inequality (0, -1, 0, -1, -1, 0, 1, 1, 1, 0) x + 2 >= 0,
 An inequality (0, 0, 0, 0, -1, 0, 0, 0, 0, 0) x + 1 >= 0,
 An inequality (1, -1, -1, -1, -1, 0, 1, 0, 0, 0) x + 3 >= 0,
 An inequality (0, 0, 0, 0, 0, 0, 1, 0, 0, 0) x + 0 >= 0,
 An inequality (-1, 0, 0, -1, -1, 0, 0, 1, 1, 0) x + 2 >= 0,
 An inequality (0, 0, -1, -1, -1, 0, 1, 1, 1, 0) x + 2 >= 0,
 An inequality (-3, -2, -3, -4, -6, -1, -3, -3, -3, -1) x + 23 >= 0,
 An inequality (-1, -1, -1, -1, -1, 0, -1, 0, 0, 0) x + 5 >= 0,
 An inequality (-1, -1, -1, -2, -2, 0, -1, -1, -1, 0) x + 8 >= 0,
 An inequality (-1, -1, -1, -1, 1, 0, 1, 0, 0, 0) x + 3 >= 0,
 An inequality (0, -1, -1, -1, -1, 0, 0, -1, -1, 0) x + 5 >= 0,
 An inequality (-2, -2, -2, -1, 1, 0, 2, -1, -1, 0) x + 7 >= 0,
 An inequality (-1, -1, -1, -2, -1, 0, 1, -2, -2, 0) x + 8 >= 0,
 An inequality (-1, -1, -1, -2, -1, 0, 1, 2, 2, 0) x + 4 >= 0,
 An inequality (-1, -1, -1, -3, -2, 0, 2, 3, 3, 0) x + 5 >= 0,
 An inequality (-1, -1, -1, -1, 0, 0, 1, 1, 1, 0) x + 3 >= 0,
 An inequality (1, -1, -1, -2, -2, 0, 2, 1, 1, 0) x + 4 >= 0,
 An inequality (0, 0, 0, -1, -1, -1, 1, 1, 1, -1) x + 3 >= 0,
 An inequality (0, 0, 0, 0, 0, 0, 0, 0, 0, -1) x + 1 >= 0,
 An inequality (0, 0, -1, -1, -1, -1, 0, -1, -1, 0) x + 5 >= 0,
```

Figure: Number of Inequalities generated - 2415

Outline

1. T1 - Construction
2. T2 - Cryptanalysis
3. T3 - Verilog
4. T4 - Automated Analysis
5. Conclusion

References

- https://ascon.iaik.tugraz.at
- **[DEMS15]** *Cryptanalysis of Ascon* - Christoph Dobraunig, Maria Eichlseder, Florian Mendel, and Martin Schläffer. **IACR** - 2015/030 (pp. 28, 31–33, 35).
- **[Tez16]** *Truncated, Impossible, and Improbable Differential Analysis of Ascon* - Cihangir Tezcan. **IACR** - 2016/490 (pp. 28, 33).

Thanks

Brownie Points - LaTeX-Tikz Block Diagrams

- State Design
- Authenticated Encryption
- Zero Sum Distinguisher

Implementation Info

- Github Link: https://github.com/highgroundmaster/ASCON