Rotational-XOR Cryptanalysis of Reduced-round SPECK

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FSE, March 2018

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- ARX ciphers designed by the NSA in 2013

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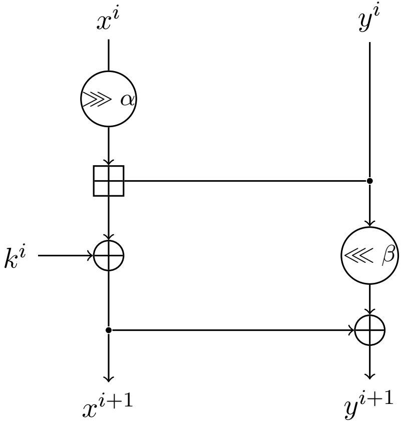

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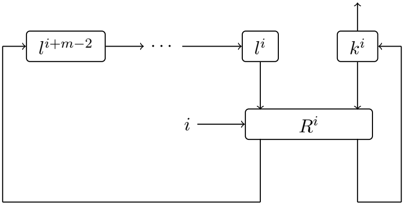

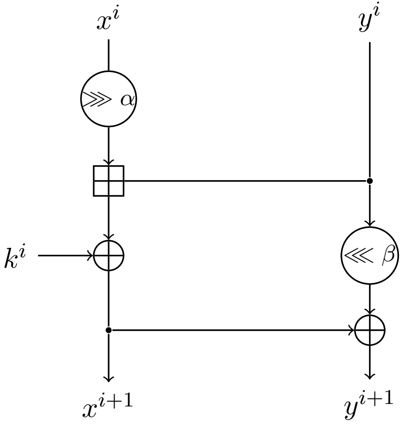

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SPECK versions	32/64	48/96	64/128	96/144	128/256
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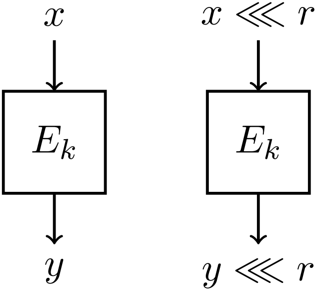

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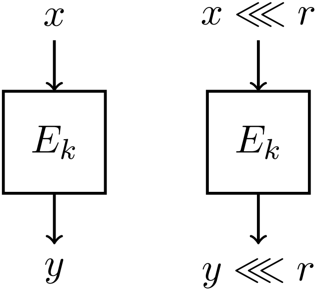

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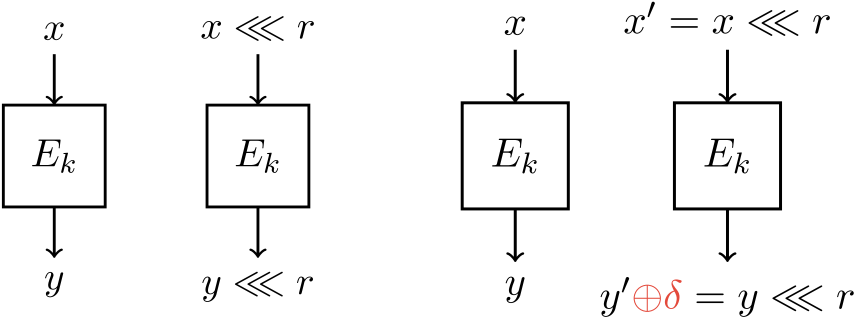

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Automatic search techniques

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  - SAT/SMT: CryptoSMT, etc

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- Challenge: find an efficient method to encode the cryptographic problem

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Rotational-XOR Difference

RX-difference v1

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The RX-difference of a pair (x_1, x_2):

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Given an RX-difference δ, an RX-pair is $(x, (x \lll \gamma) \oplus \delta)$.

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$$\overleftarrow{(x \oplus a_1) \boxplus (y \oplus b_1) \oplus \Delta_1} = (\overleftarrow{x} \oplus a_2) \boxplus (\overleftarrow{y} \oplus b_2) \oplus \Delta_2$$

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$$\begin{aligned} X &= x \oplus a_1 \\ Y &= y \oplus b_1 \\ Z &= X \boxplus Y \\ d_x &= \overleftarrow{a_1} \oplus a_2 \\ d_y &= \overleftarrow{b_1} \oplus b_2 \\ d_z &= \overleftarrow{\Delta_1} \oplus \Delta_2 \end{aligned}$$

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RX-difference propagation in modular addition

Assume that input RX-differences are d_x, d_y, output RX-difference is d_z. Then,

$$\Pr[(d_x, d_y) \to d_z] =$$

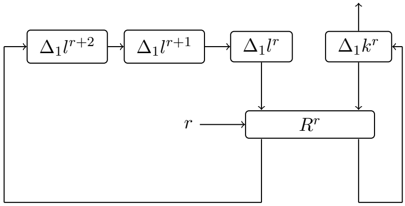
$$1_{(I\oplus SHL)(\delta_x\oplus\delta_y\oplus\delta_z)\oplus 1\preceq SHL((\delta_x\oplus\delta_z)|(\delta_y\oplus\delta_z))} \cdot 2^{-|SHL((\delta_x\oplus\delta_z)|(\delta_y\oplus\delta_z))|} \cdot 2^{-3}$$

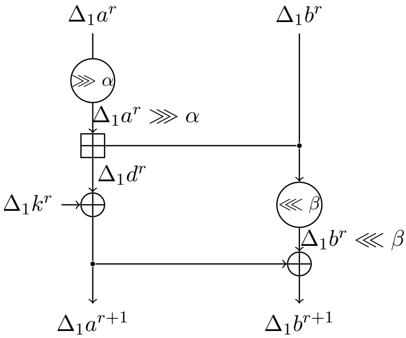
$$+1_{(I\oplus SHL)(\delta_x\oplus\delta_y\oplus\delta_z)\preceq SHL((\delta_x\oplus\delta_z)|(\delta_y\oplus\delta_z))} \cdot 2^{-|SHL((\delta_x\oplus\delta_z)|(\delta_y\oplus\delta_z))|} \cdot 2^{-1.415},$$

where

$$\delta_x = L'(d_x), \delta_y = L'(d_y), \delta_z = L'(d_z).$$

Applications to SPECK32/64





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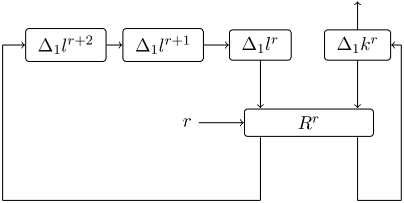

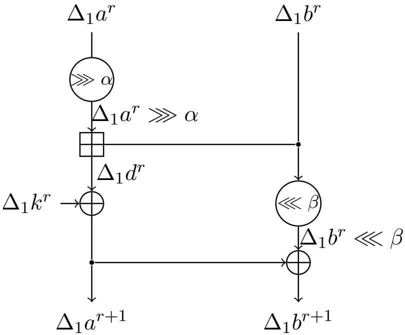

Search for RX-characteristics in the key part and data part

Application to SPECK32/64

SMT file – Modular Addition

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SMT file – Modular Addition

Condition 1

$$
\begin{aligned}
(I \oplus SHL)((\Delta_1 a^r \ggg \alpha) \oplus \Delta_1 b^r \oplus \Delta_1 d^r) \oplus 1 \\
\preceq SHL(((\Delta_1 a^r \ggg \alpha) \oplus \Delta_1 d^r) | (\Delta_1 b^r \oplus \Delta_1 d^r)) \\
w_r = |SHL(((\Delta_1 a^r \ggg \alpha) \oplus \Delta_1 d^r) | (\Delta_1 b^r \oplus \Delta_1 d^r))| + 3
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Total weight of a characteristic $W_{data} = \sum_r w_r$

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$$\Delta_1 d^r \oplus \Delta_1 k^r \oplus \Delta_1 a^{r+1} = 0$$

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SMT file – Objective functions

$$\min W_{data}$$

$$\min W_{key}$$

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- Other strategy?

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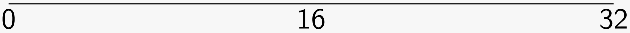

- Binary search on $[0, 32]$

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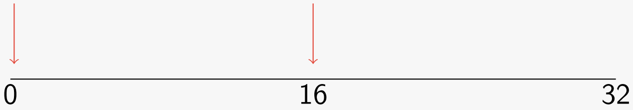

- Binary search on $[0, 32]$
- Red interval indicates the bounds for current objective function

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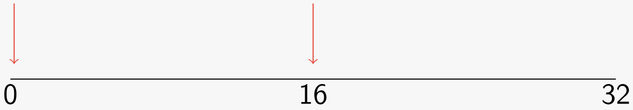

- Binary search on $[0, 32]$
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- Search in $[0, 16]$,

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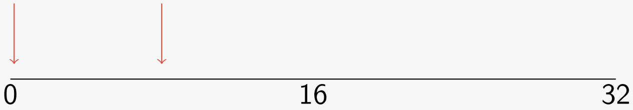

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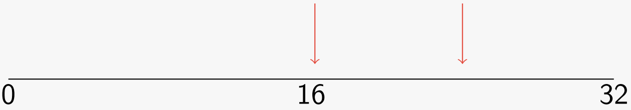

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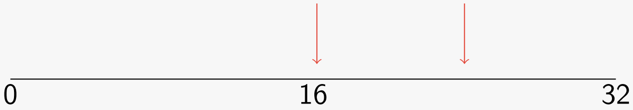

- Binary search on $[0, 32]$
- Red interval indicates the bounds for current objective function
- Search in $[0, 16]$, if solution found, search $[0, 8]$, otherwise $[16, 24]$
- Terminate after the red interval collapsed

Results

RX-characteristics found in SPECK

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Version	Rounds	Data Prob.	Key Class Size	Ref.
32/64	9	2^{-30}	2^{64}	[Din14]
32/64	10	$2^{-19.15}$	$2^{28.10}$	This paper
32/64	11	$2^{-22.15}$	$2^{18.68}$	This paper
32/64	12	$2^{-25.57}$	$2^{4.92}$	This paper
48/96	10	2^{-40}	2^{96}	[Din14]
48/96	11	2^{-45}	2^{96}	[FWG+ 16]
48/96	11	$2^{-24.15}$	$2^{25.68}$	This paper
48/96	11	$2^{-23.15}$	$2^{14.93}$	This paper
48/96	12	$2^{-26.57}$	$2^{43.51}$	This paper
48/96	13	$2^{-31.98}$	$2^{24.51}$	This paper
48/96	14	$2^{-37.40}$	$2^{0.34}$	This paper
48/96	15	$2^{-43.81}$	$2^{1.09}$	This paper

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Results

RX-characteristics found in SPECK

Version	Rounds	Data Prob.	Key Class Size	Ref.
64/128	14	2^{-60}	2^{128}	[Din14]
64/128	15	2^{-62}	2^{128}	[FWG+16]
64/128	13	$2^{-37.98}$	$2^{21.92}$	This paper
96/144	13	2^{-84}	2^{144}	[Din14]
96/144	16	2^{-87}	2^{144}	[FWG+16]
96/144	13	$2^{-37.98}$	$2^{37.92}$	This paper
128/256	14	2^{-112}	2^{256}	[Din14]
128/256	19	2^{-119}	2^{256}	[FWG+16]
128/256	13	$2^{-31.98}$	$2^{182.51}$	This paper

[Din14] I. Dinur. Improved differential cryptanalysis of round-reduced SPECK. SAC 2014

[FWG+16] K. Fu, M. Wang, Y. Guo, S. Sun, and L. Hu. MILP-based automatic search algorithms for differential and linear trails for SPECK. FSE 2016

Conclusion

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https://gitlab.esat.kuleuven.be/Adrian.Ranea/ArxPy

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Thank You!