Two New Techniques of Side-Channel Cryptanalysis

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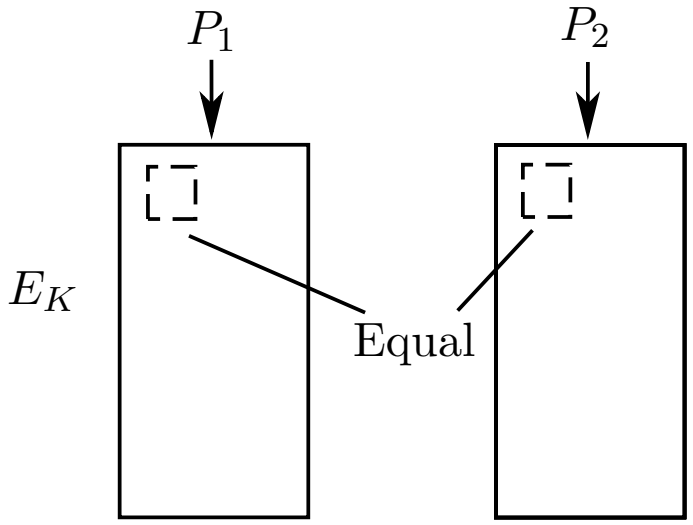
University of Luxembourg

12.09.2007

Side-channel collision attacks

Detect the equality of intermediate variables — the *collision* — measuring the power consumption:



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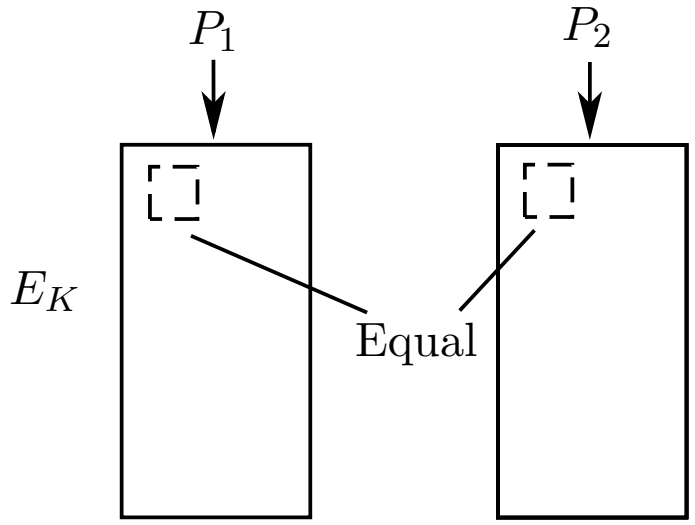

A collision after the first round of AES may imply:

$$S(a + k_1) + S(a + k_2) = S(b + k_1) + S(b + k_2),$$

which gives us information on k_1, k_2 (Schramm et al., 2004).

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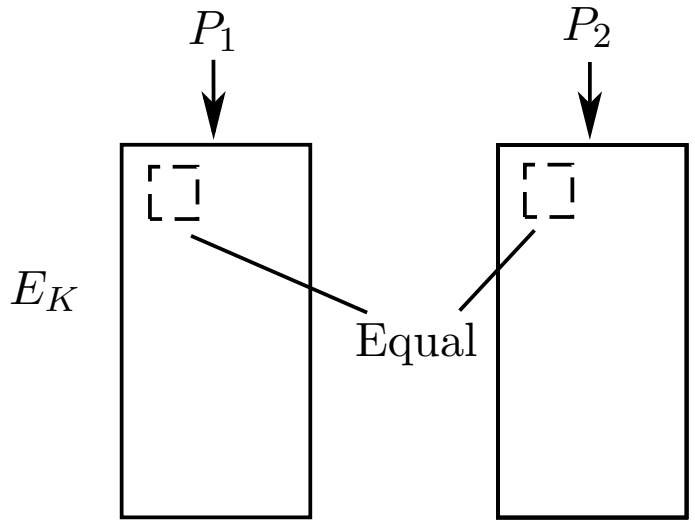

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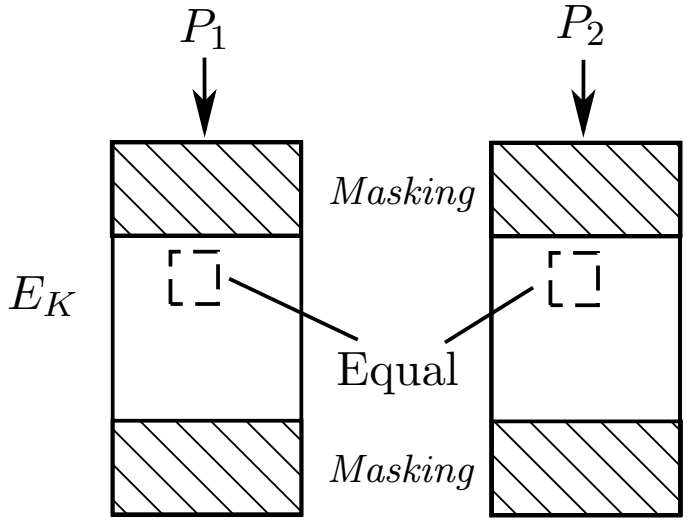
which gives us information on k_1, k_2 (Schramm et al., 2004).
See also a recent attack on Alpha-MAC [BBKK07].

Countermeasures

A typical countermeasure is masking. The idea is to make the dependency between intermediate variables and a plaintext weaker:



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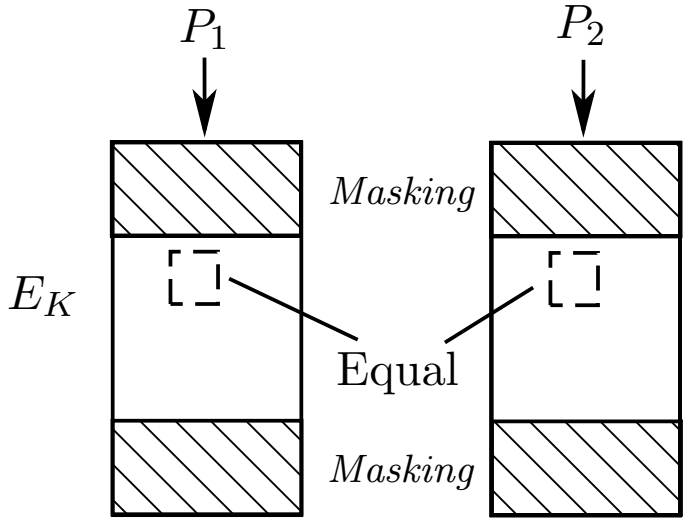

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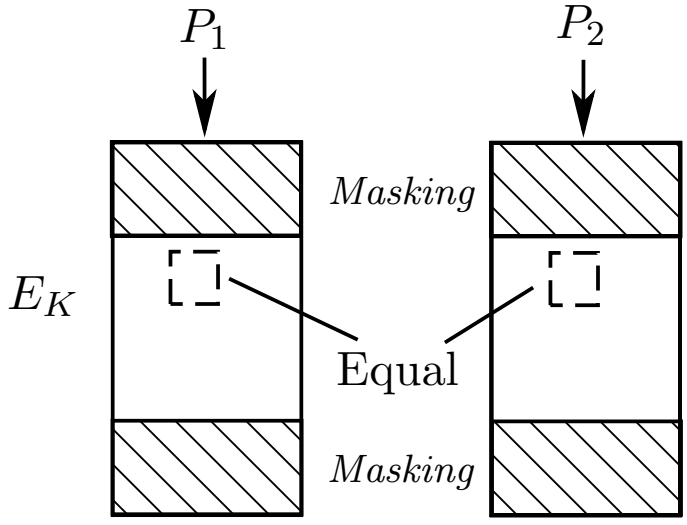

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We propose to use powerful distinguishers that give information on **masked** subkeys.

What we do

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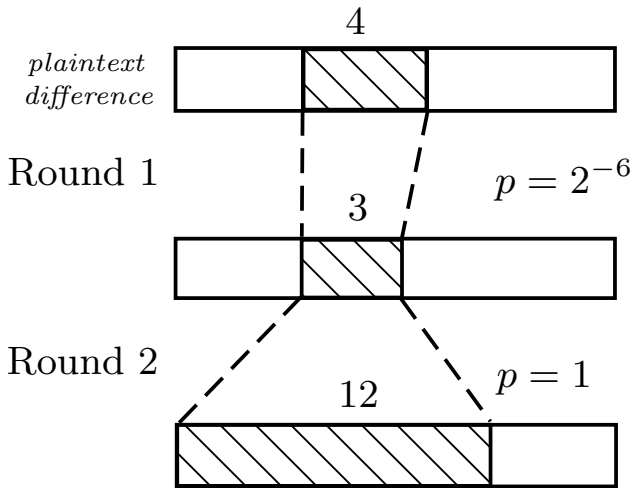
Use the AES differential/square properties to reveal the secret key using the collision technique.

Simple collision attack on AES (2 masked rounds)

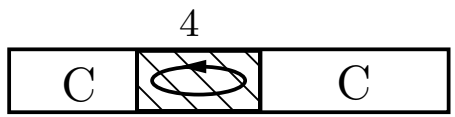
We use 2-round 2^{-6} differential:



and search for 4 collisions before the 3rd round.

Simple collision attack on AES (2 masked rounds)

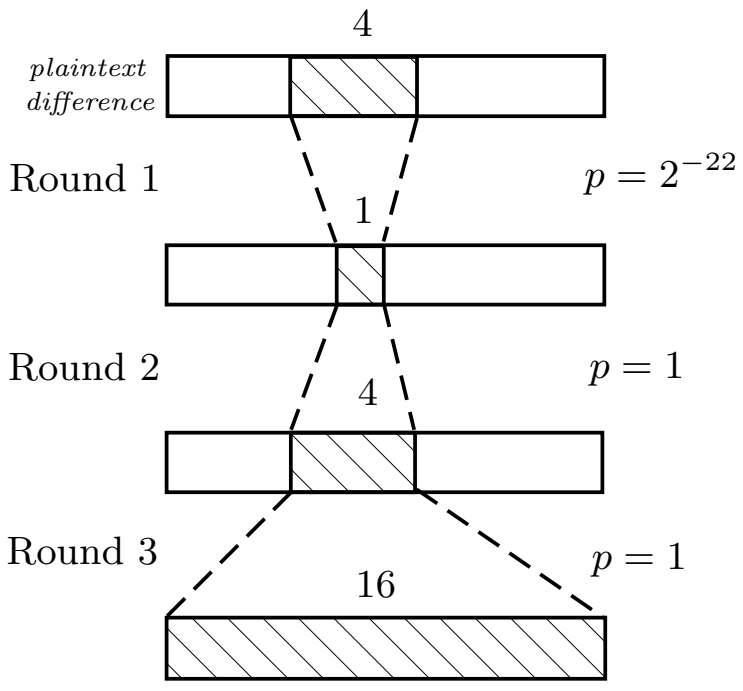
We use structures to reduce the number of measurements:



24 texts $\Rightarrow \sim 2^8$ pairs $\Rightarrow$ 4 right pairs $\Rightarrow$ 32 bits of key.
Overall: 72 measurements $+ \sim 2^{32}$ offline operations (key testing).

Impossible collision attack (3 masked rounds)

We use 3-round 2^{-22} differential:



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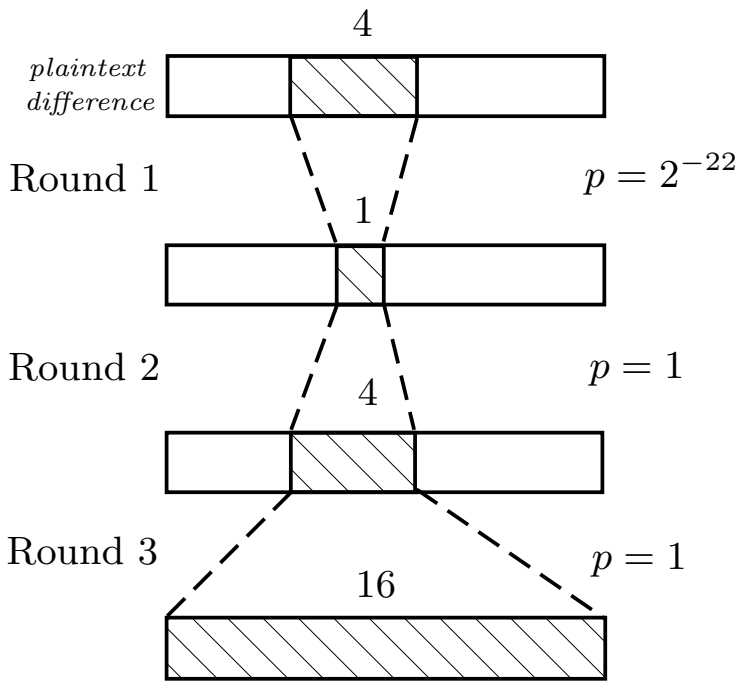

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The probability of a right pair is 2^{-22}. We test 2^{23} pairs to get 2 right ones.

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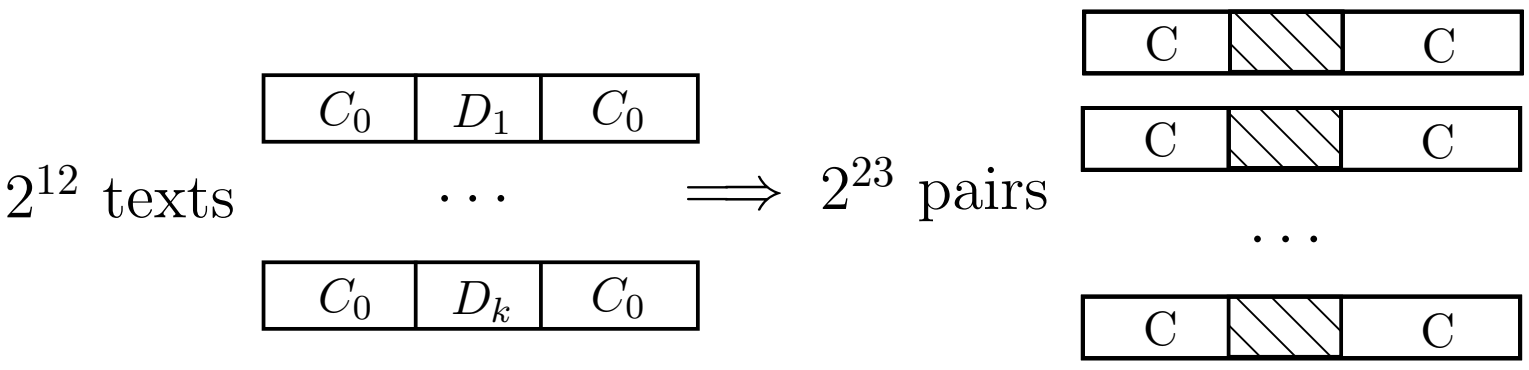

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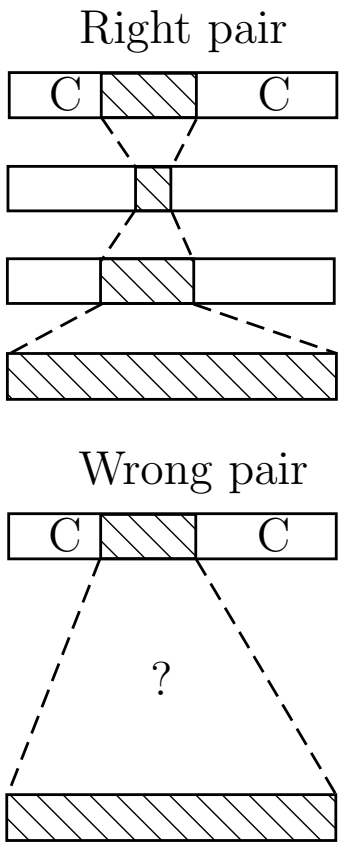
The probability of the wrong pair to survive is $\sim 15/16$. We need to filter them.



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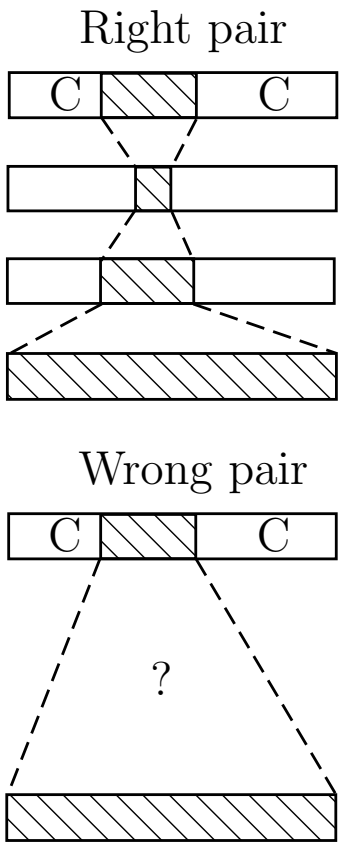

If we modify constants a right pair survives while a wrong one may not with $p = \frac{1}{16}$.

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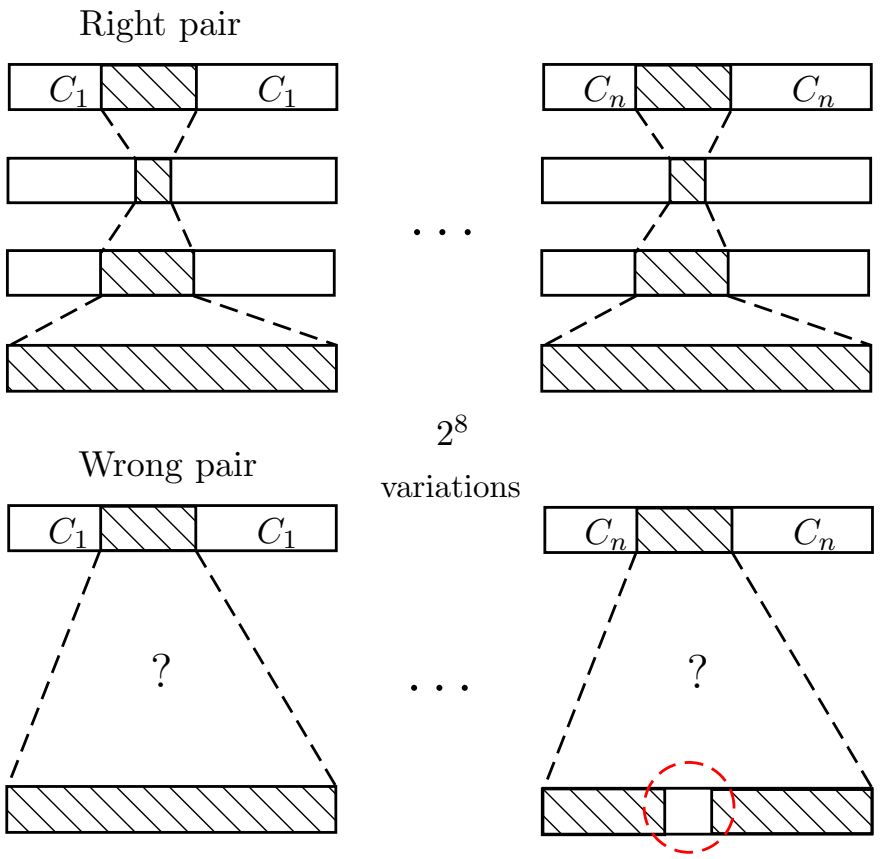

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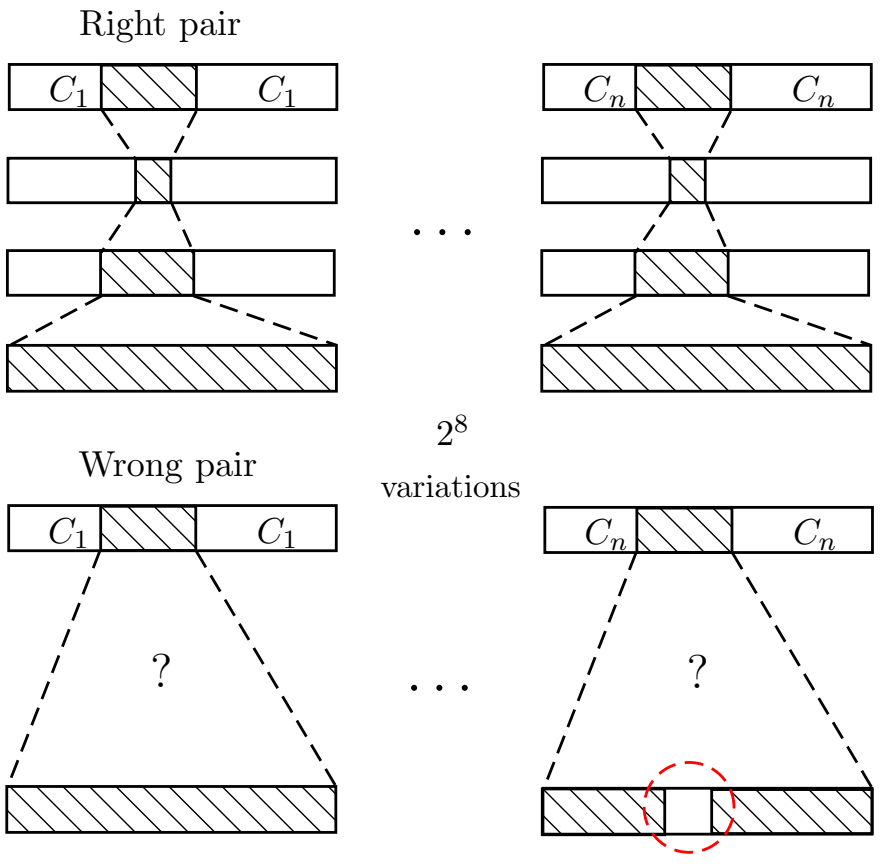

We need 2^{20} measurements and about 2^{27} time.

However, we have to detect the absence of collisions accurately.

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which implies $\beta < \alpha$.

How to satisfy the last one?

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α_B — the probability of a difference in a single byte to be recognized;
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So the condition is

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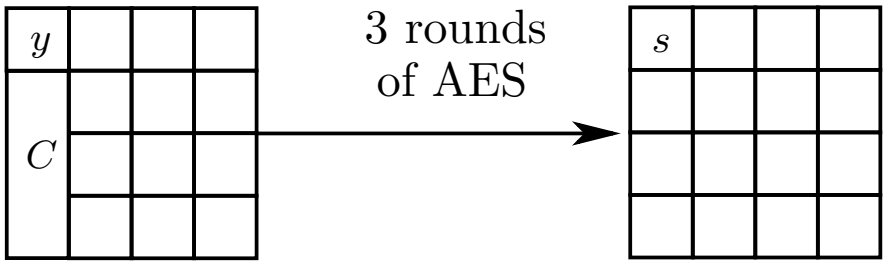
Multiset collisions. Distinguisher

3-round Gilbert-Minier distinguisher:



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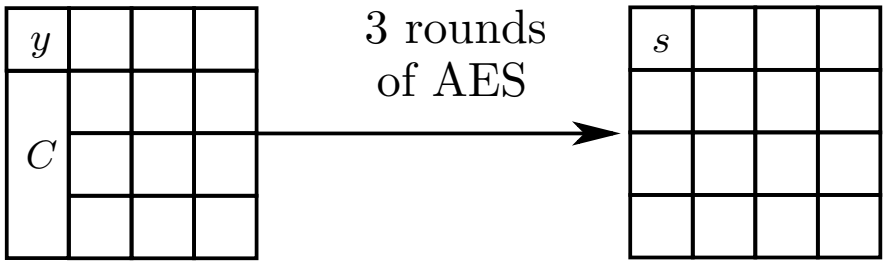

Among 2^{16} distinct C's always exist C', C'':

$$s^{C'}[y] \equiv s^{C''}[y] \text{ (256 collisions).}$$

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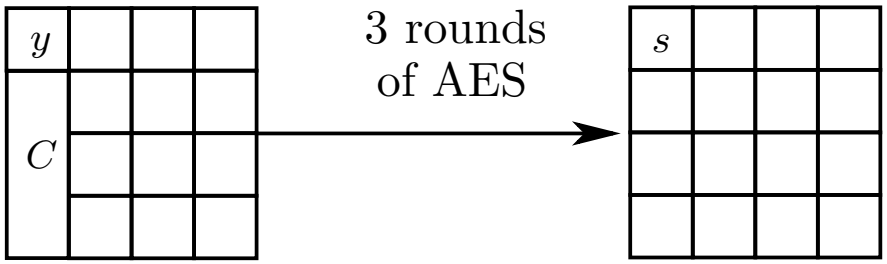

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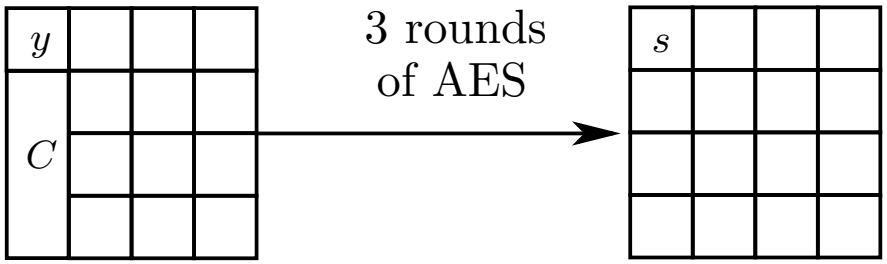

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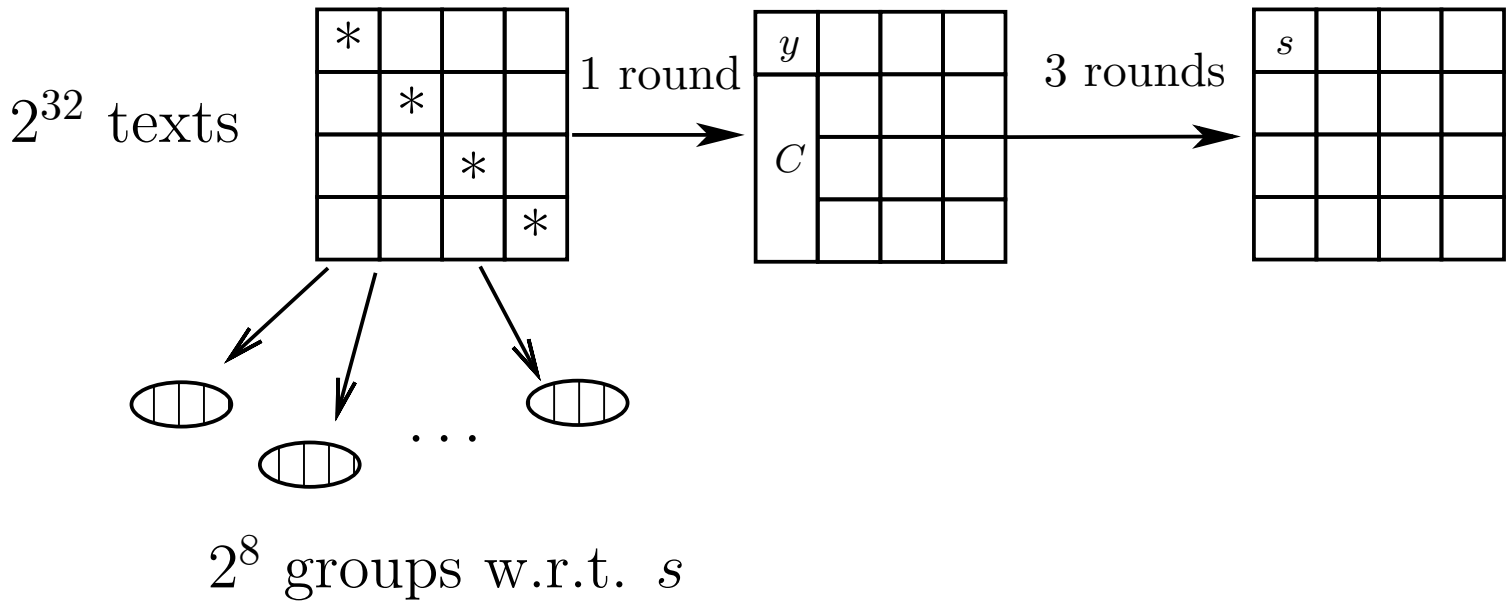
Overall $6 \cdot 2^{16} \approx 2^{18.5}$ plaintexts are needed to find such a C-pair.

Multiset collision attack I (4 masked rounds)

Add a round in the beginning:



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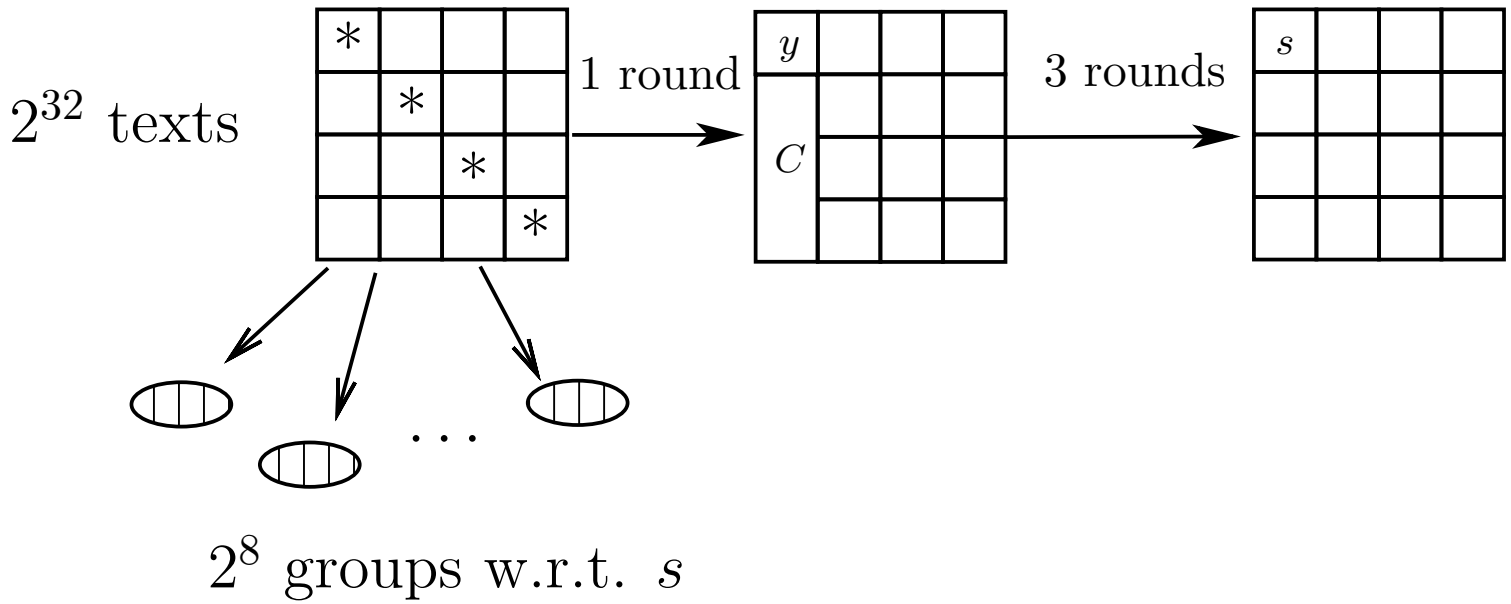

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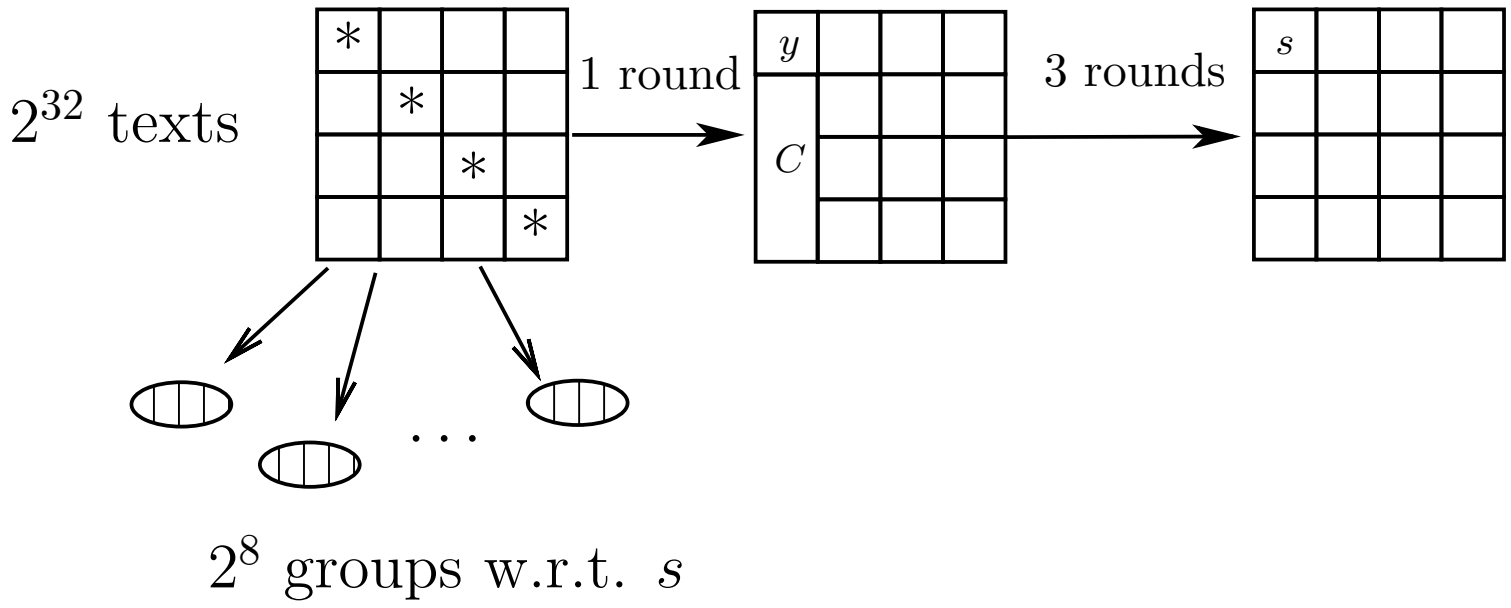

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The offline complexity is 2^{45} AES rounds.

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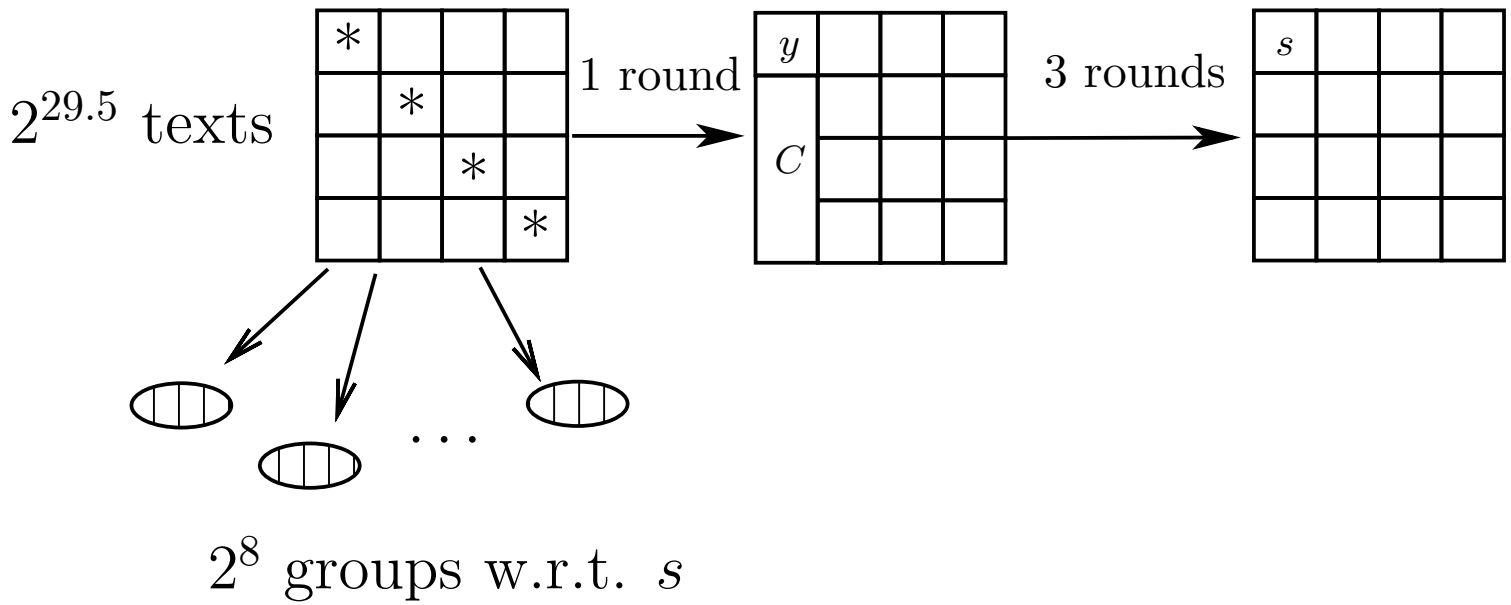

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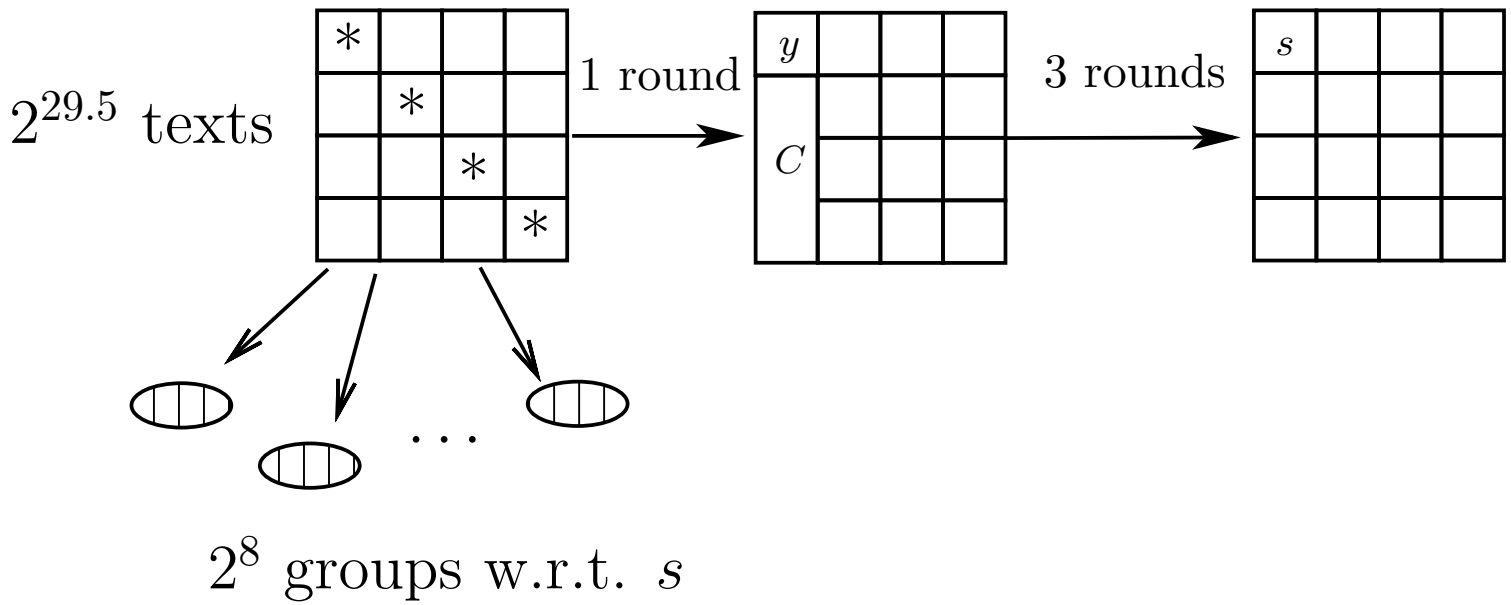

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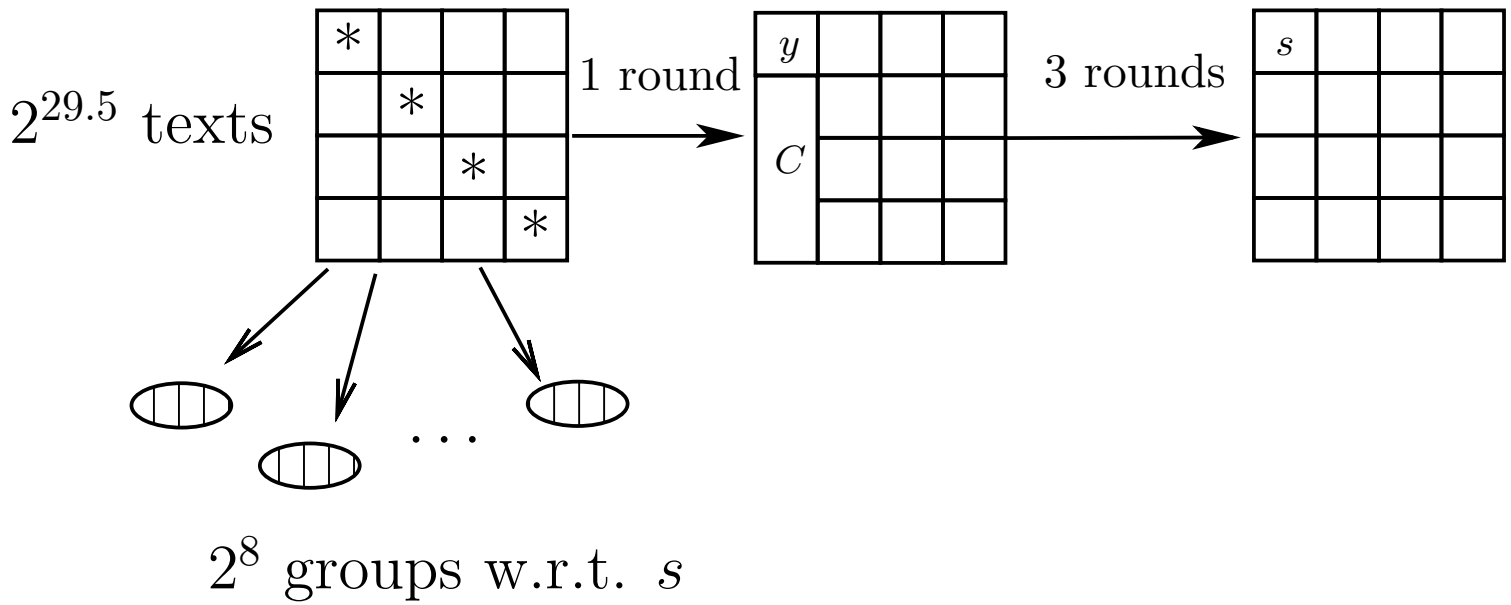

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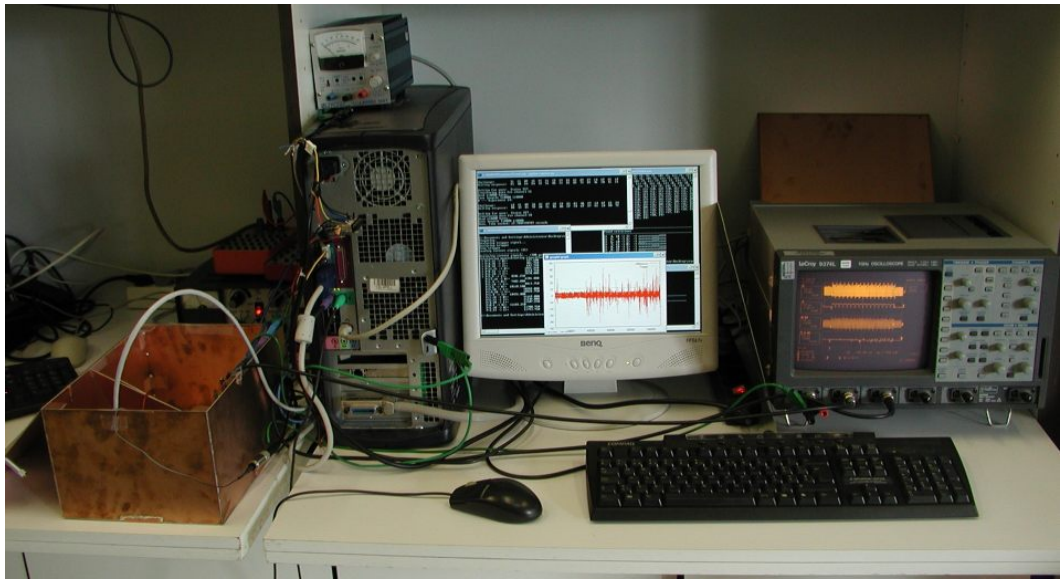
Summary of the results

Method	**Complexity**		**Masked rounds**	**Attack**
	Measur-ts	Off-line		
Simple	2^6–2^7	2^{32}	2	Full key recovery
Impossible	2^{21}	2^{29}	3	Full key recovery
MultiSet	$2^{18.5}$	2^{20}	3	Distinguisher
MultiSet	2^{32}	$2^{44.5}$	4	32 key bits recovery
MultiSet	2^{29}–2^{30}	2^{54}	4	32 key bits recovery

Setup

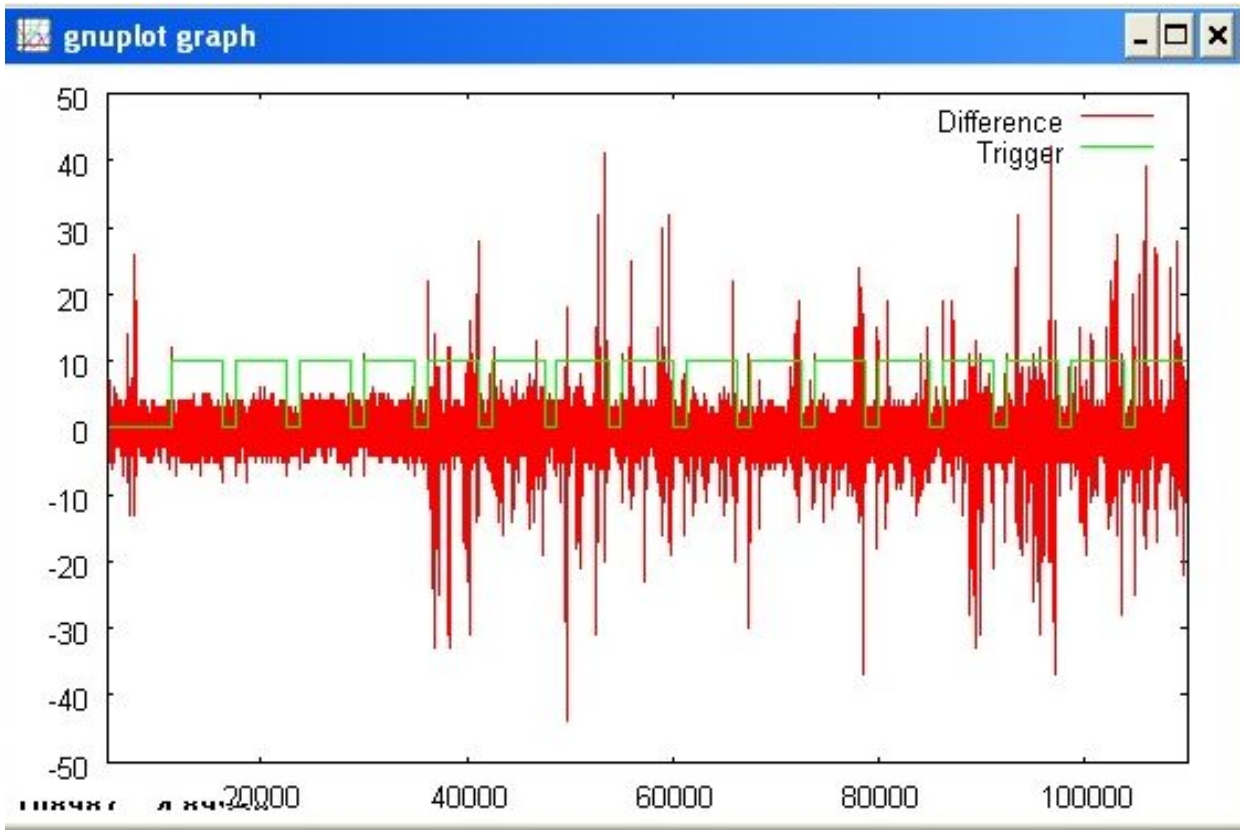
Implemented by André Stemper:

- AES-128 RISC microcontroller;
- Microchip PIC16F87 clocked at 4Mhz;
- LeCroy 9374L 1GHz digital oscilloscope;
- Measurement time: 0.35s per measurement (oscilloscope is the bottleneck).



Attacks inside

Simple collision attack:



The features of implementation

- Protection against EM-radiation (Faraday cage);
- Automatic threshold search in the simple collision attack (4 collisions help);
- Manual search for a threshold to detect a collision in the impossible collision attack;
- Use analog filters for the communication noise removal.

Conclusions

Simple collision attacks for AES with 2 masked rounds.

Detecting the absence of collisions gives information about the key.

A powerful r-round distinguisher can break through $r + 1$ masked rounds.

Perhaps one should mask all 10 rounds of AES-128.