EXTERNAL ENCODINGS DO NOT PREVENT TRANSIENT FAULT ANALYSIS

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OUTLINE

1 INTRODUCTION

- Motivation
- Externally encoded DES
- Assumptions

2 DESCRIPTION OF THE ATTACK

- The principle
- The basic attack
- An improved version
- Classical counter-measures

3 CONCLUSION

- Lessons
- Open problems

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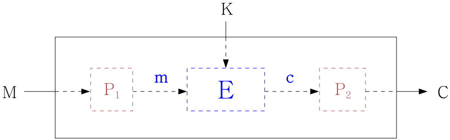
Any known transient fault analysis on a cryptographic algorithm requires the knowledge of either the input or the output:

- *Differential Fault Analysis*, DFA (Biham and Shamir, Crypto ’97)
  - Exploits paires $(c, \overset{\leadsto}{c})$ of normal and faulty ciphertexts
  - Requires the knowledge of the output
- *Collision Fault Analysis*, CFA (Hemme, Ches ’04)
  - Given a faulty cipertext $\overset{\leadsto}{c}$ corresponding to some input m, try to find another input $m^\star$ encrypting to the same output
  - Requires the knowledge (even the control) of the input

MOTIVATION

A POSSIBLE DESIGN

A way to design a secret (proprietary) block cipher could be to enclose a public and well studied ciphering function E (DES, AES, . . .) between two secret external encodings



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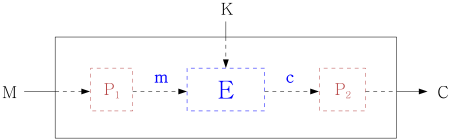
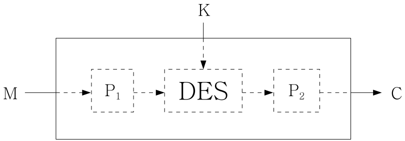


- P_1 and P_2 are two secret and deterministic one-to-one mappings.
- The design inherits its cryptographic strength from the core function E.
- Fault analysis should be prevented by the *obfuscation* layers P_1 and P_2 which conceal inputs m and outputs c of cipher E from the attacker.

THE CASE OF OBFUSCATED DES

THIS PAPER

An externally encoded DES is not secure against transient fault analysis.



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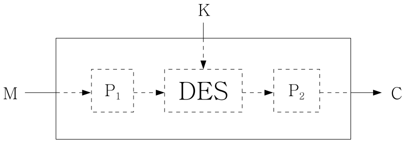

The hereafter described attack allows to recover the DES key without any knowledge about P_1 and P_2.

- Also applies to obfuscated Triple-DES
- Practically relevant if such constructions actually exist

ASSUMPTIONS FOR THE ATTACK TO WORK

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- with a natural (straightforward) implementation,
- and without counter-measure (discussed later).

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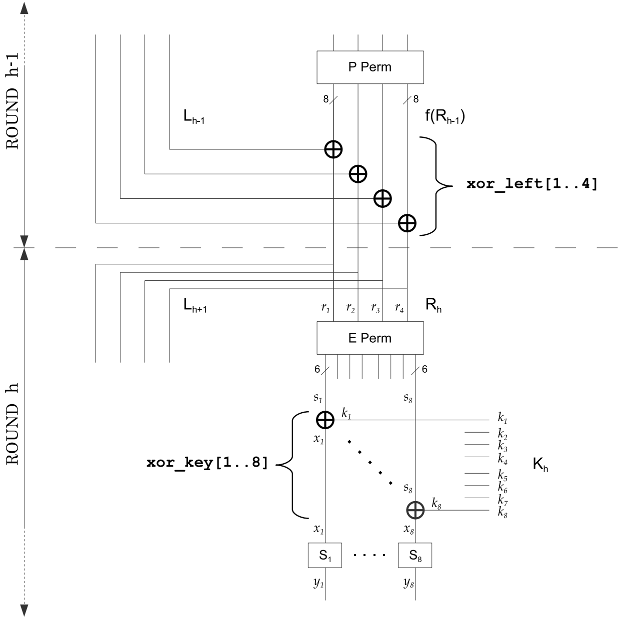
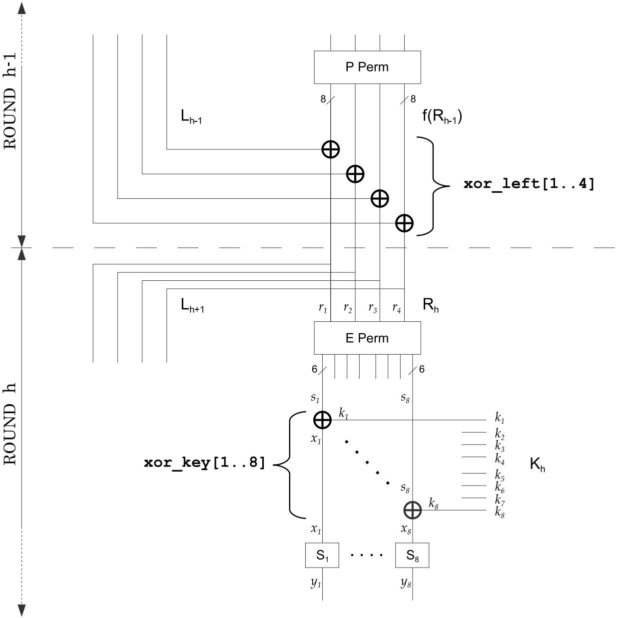
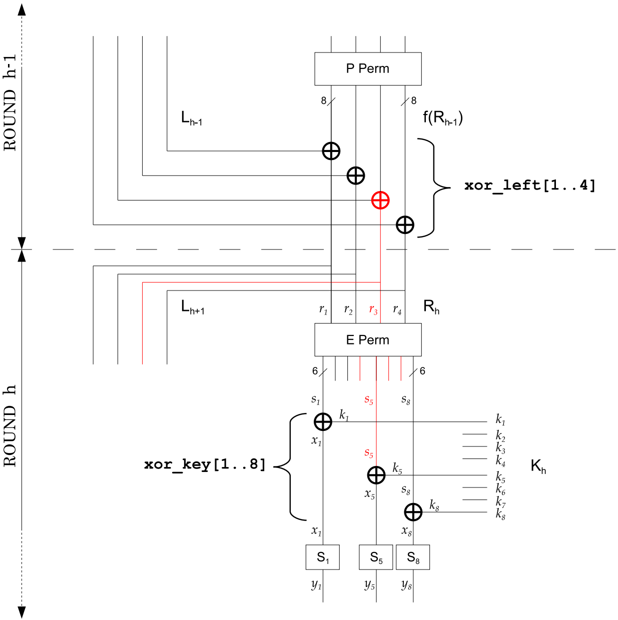
Indeed, the attacker does not need to inject 'multi-faults'.


ROUND h-1
P Perm
8
8
L_{h-1}
f(R_{h-1})
xor_left[1..4]
ROUND h
L_{h+1}
r1 r2 r3 r4
R_h
E Perm
6
6
s1
s8
k1
x1
xor_key[1..8]
k1 k2 k3 k4 k5 k6 k7 k8
K_h
s8
k8
x1
x8
S1
S8
y1
y8



$$M \xrightarrow{normal} C$$



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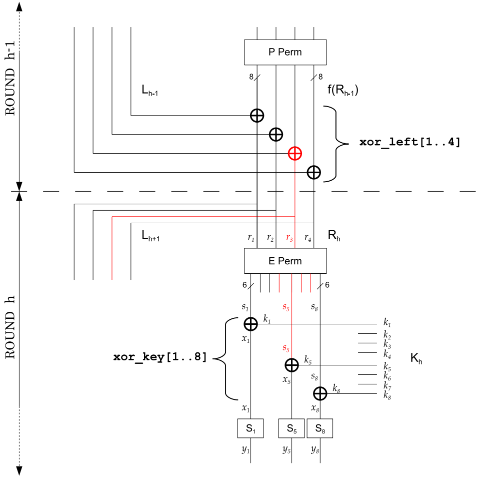

$$M \xrightarrow{normal} C$$

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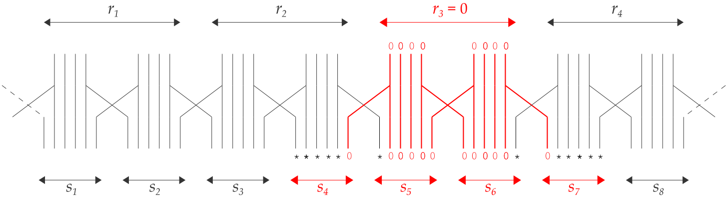
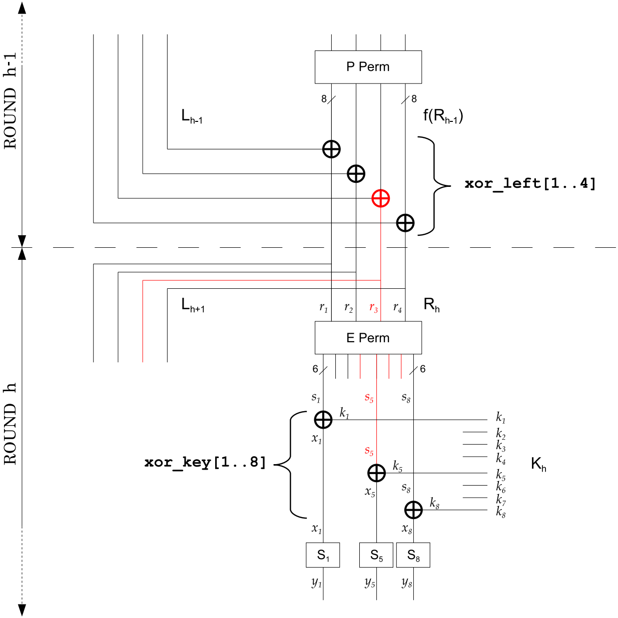
For some input M, observation that $C = \overset{\leadsto}{C}_{\texttt{xor\_left[3]}}$ implies that $r_3 = 0$



$r_3 = 0$ implies that s_5 and s_6 are almost zero after the expansive permutation.

Knowing that $s_5 \approx 0$, it may be interesting to know what happens when next XOR is also faulted: $\overset{\rightsquigarrow}{x_5} = s_5 \overset{\rightsquigarrow}{\oplus} k_5$.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s_1 s_5 s_8
k_1
x_1
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s_5
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x_5
s_8
k_8
x_1
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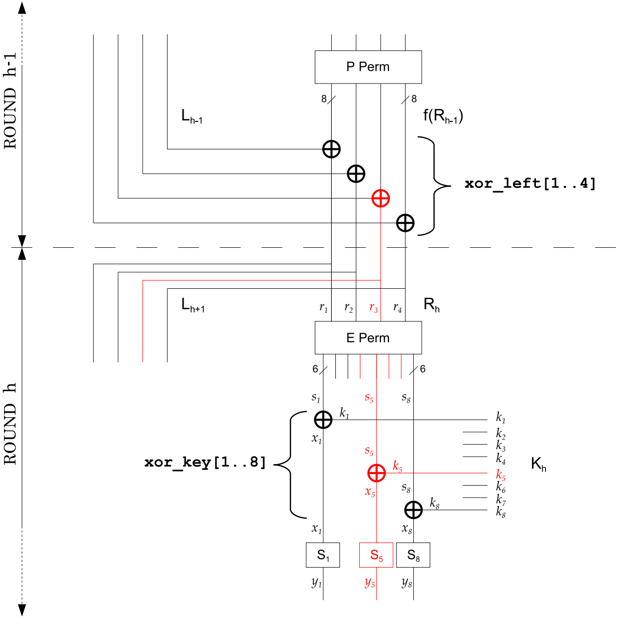
K_h
S_1 S_5 S_8
y_1 y_5 y_8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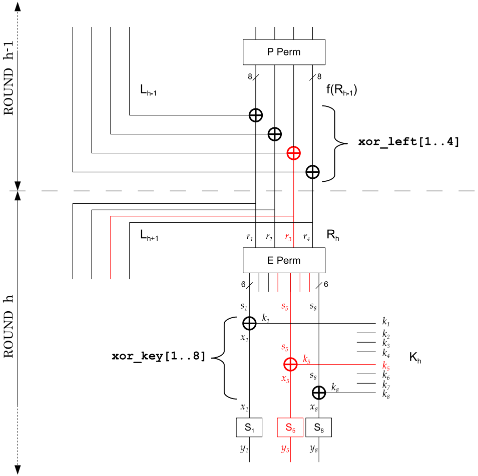


If for the same input M, one also observes that $C = \overset{\leadsto}{C}_{\texttt{xor\_key[5]}}$, then:

$$x_5 \oplus s_5 \;=\; k_5 \;\in\; \mathcal{A}_5 \,\cup\, \big(\mathcal{A}_5 \oplus (1,0,0,0,0,0)\big) \qquad (\text{with } \mathcal{A}_5 = S_5^{-1}[S_5(0)])$$

THE BASIC ATTACK

Each such *double ineffective fault* reveals 3 bits of information about a round subkey. (8 remaining candidates out of 64.)

The attack consists in gathering this information about as much subkeys as possible. (This is key dependant)

EXPERIMENTAL RESULTS

Based on 27 000 simulations with random DES keys, the median residual entropy of the key is reduced from 56 bits to:

- 26.49 bits after 50 000 faults
- 22.32 bits after 100 000 faults

AN IMPROVED VERSION

More information about the key may be obtained by analysing ineffectiveness vectors.

DEFINITION

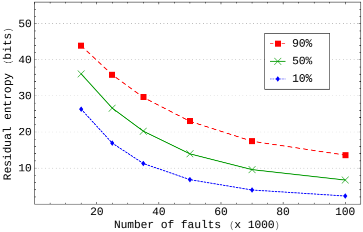
For any message M and any round $r \leqslant 2$, the *ineffectiveness vector* is the joint boolean observation of whether each of the `xor_left[i]` (at round $r-1$) and `xor_key[j]` (at round r) instructions is ineffective or not.

It is possible to compute for each key its *a posteriori* probability given the values of all ineffectiveness vectors observed so far. (See the paper for details.)

EXPERIMENTAL RESULTS

Based on 10 000 simulations, the median residual entropy is reduced to:

- 13.95 bits after 50 000 faults (instead of 26.49)
- 6.68 bits after 100 000 faults (instead of 22.32)



Problem: Final exhaustive search of the key is not possible, except if the attacker has access to an open device implementing the unknown function.

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- Data masking should thwart the attack.
  (Except possibly in the 'multi-faults' model.)
- Random delays and random order should make it very difficult.
  (*Random order only* should be breakable, see paper.)
- Double execution and verification has no effect on the attack.

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Just because access to inputs and outputs of an algorithm is not possible, don't assume it is fault analysis immune.

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Our result: it is possible to retrieve a DES key by transient fault analysis, even if its inputs/ouputs are not known by the attacker.

LESSON 1

Just because access to inputs and outputs of an algorithm is not possible, don't assume it is fault analysis immune.

LESSON 2

Secret specifications does not always prevent key recovery.

OPEN PROBLEMS

Is it possible to devise similar fault attacks:

- based on other fault models?
- applicable to other externally encoded algorithms? (*e.g.* AES)

THANK YOU FOR YOUR ATTENTION !

QUESTIONS ?