Protecting Last Four Rounds of CLEFIA is Not Enough Against Differential Fault Analysis

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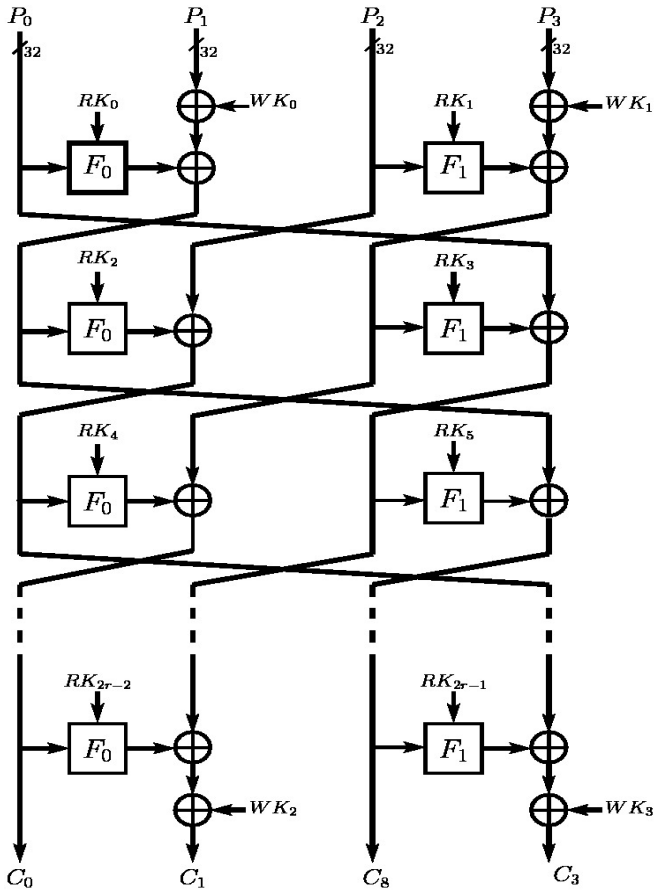
Outline

- Introduction
- CLEFIA
- Recent contribution
- Basic DFA
- DFA on CLEFIA-128
- DFA on CLEFIA-192 and CLEFIA-256
- Conclusion

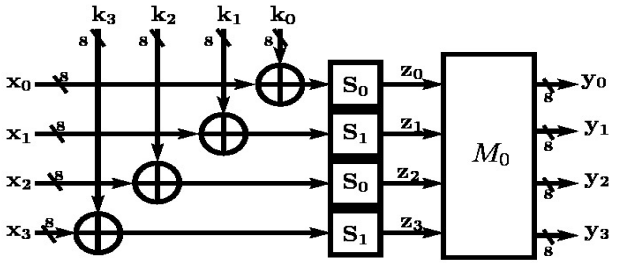
CLEFIA Block Cipher

- 128 bit block cipher
- Support three key length: 128, 192, 256 bits
- 4-way Feistel structure $GFN_{4,r}$
- Two F-function with two S-box
- Number of rounds: 18, 22, 26

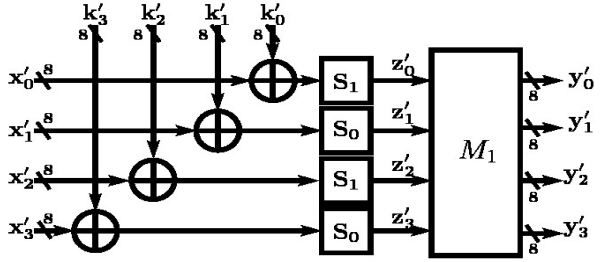
Block Diagram of CLEFIA



Encryption



Function F_0



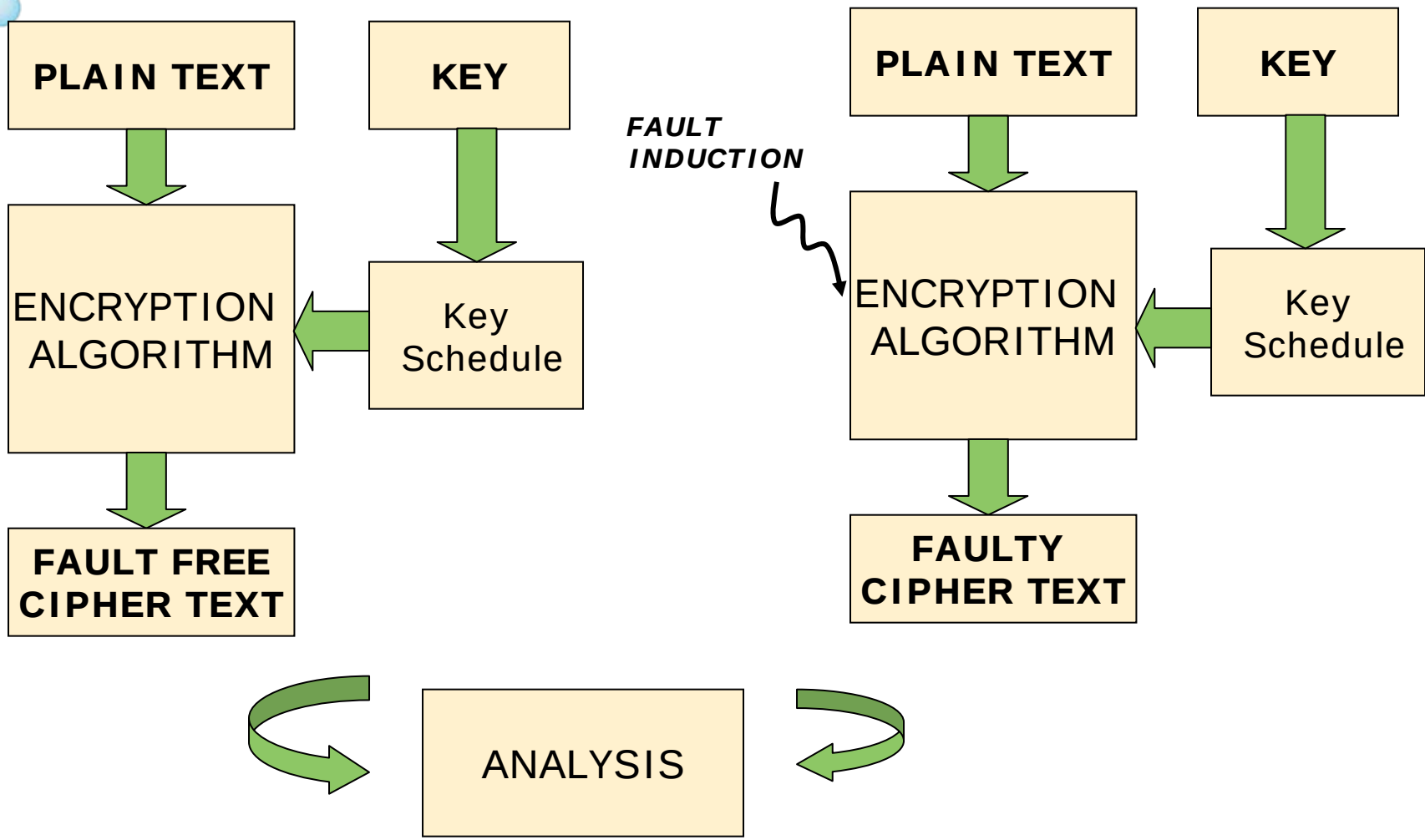
Function F_1

Research on DFA on the CLEFIA

- Chen *et al.*
  - ✓ Byte level fault
  - ✓ 18 faulty ciphertexts
  - ✓ Fault at 17^{th}, 16^{th}, and 15^{th} round

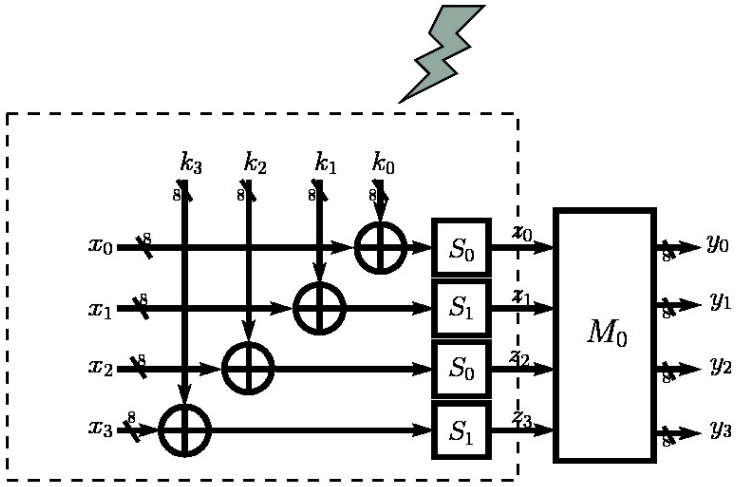
- Fukunaga *et al.*
  - ✓ Byte level fault
  - ✓ 2 faulty ciphertexts
  - ✓ Fault at 17^{th} round

Illustration of a DFA

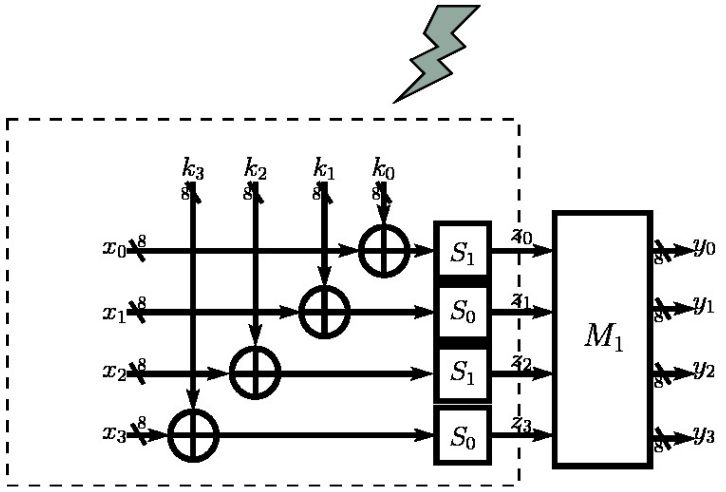


Fault Model

- Single byte fault model
- Fault induced before the MDS operation



Function F_0



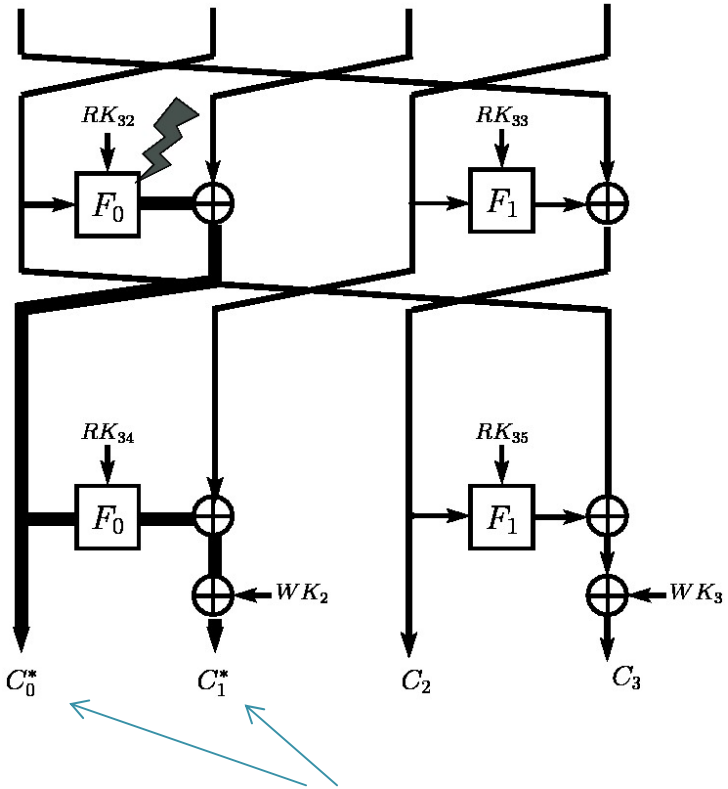
Function F_1

Chen's Attack

- Repeatedly induce faults in $(r-1)^{th}$ round F-function.
- Get the input-output difference of r^{th} round
- Get the r^{th} round key
- Do one round decryption and repeat

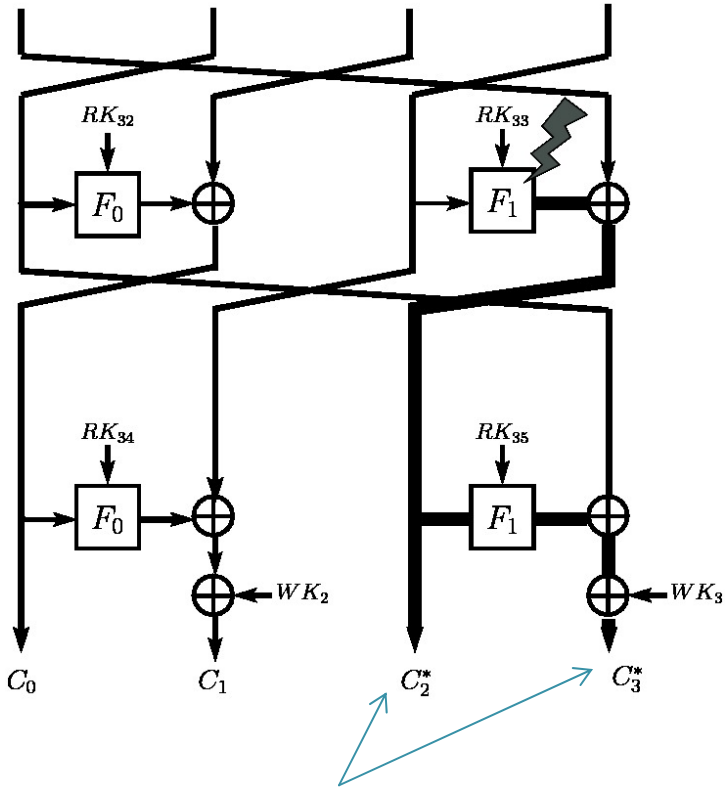
the above steps.

Flow of Faults



Use the input-output difference and get the round key

Flow of Faults



Use the input-output difference and get the round key

Protection Against Chen's Attack

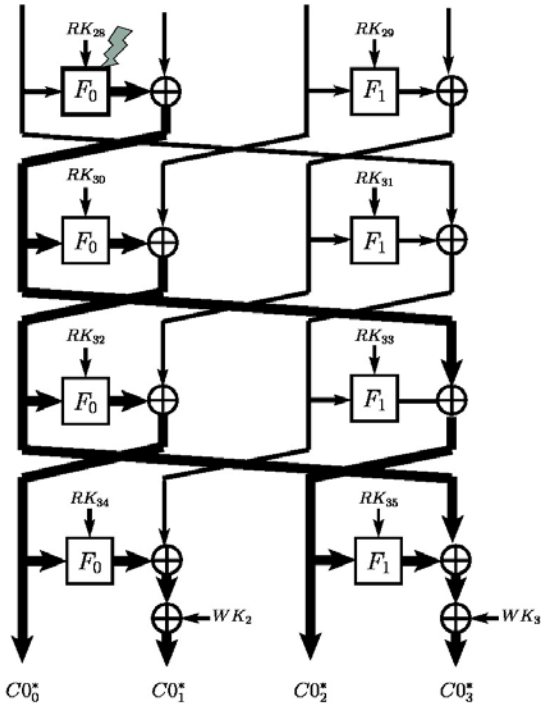
If the last two rounds are protected, the attack will fail.

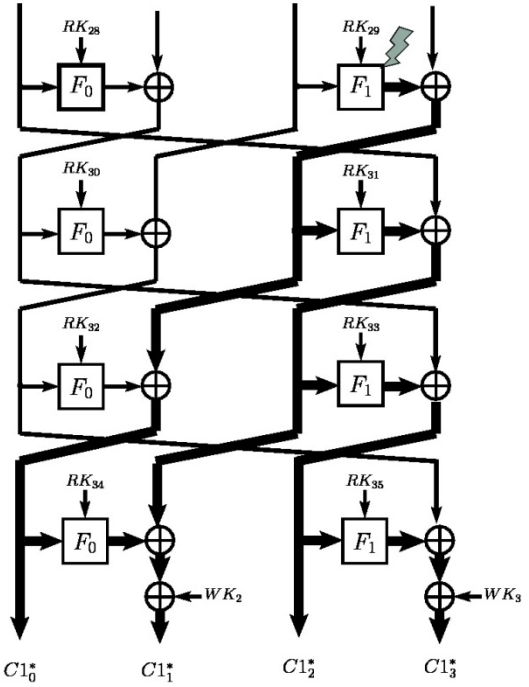
Fukunaga's Attack

- Induce two faults in 15th round F-functions.
  1. Get the input-output difference of 18th round
  2. Get the 18th round key

- Repeat step 1-2 for other round keys.

Flow of Faults



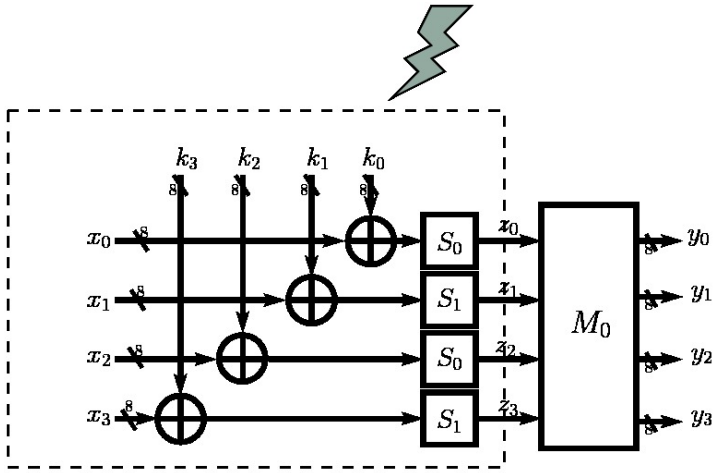


Protection Against Chen's Attack

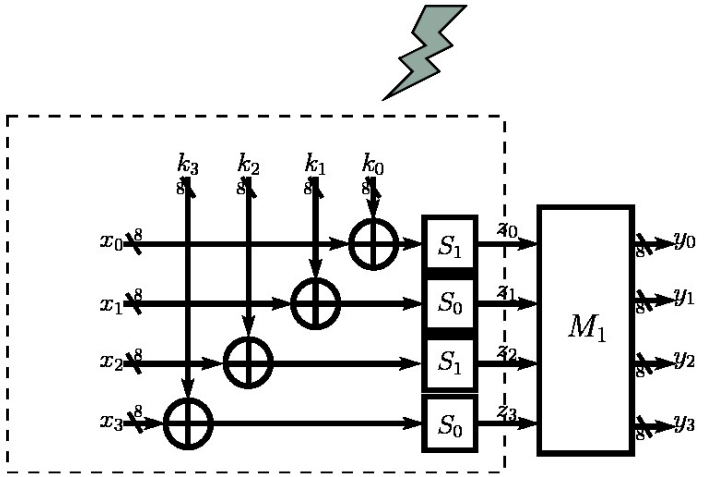
If the last four rounds are protected, the attack will fail.

Proposed New Attack

- A single byte fault spread to 4 bytes at MDS



Function F_0

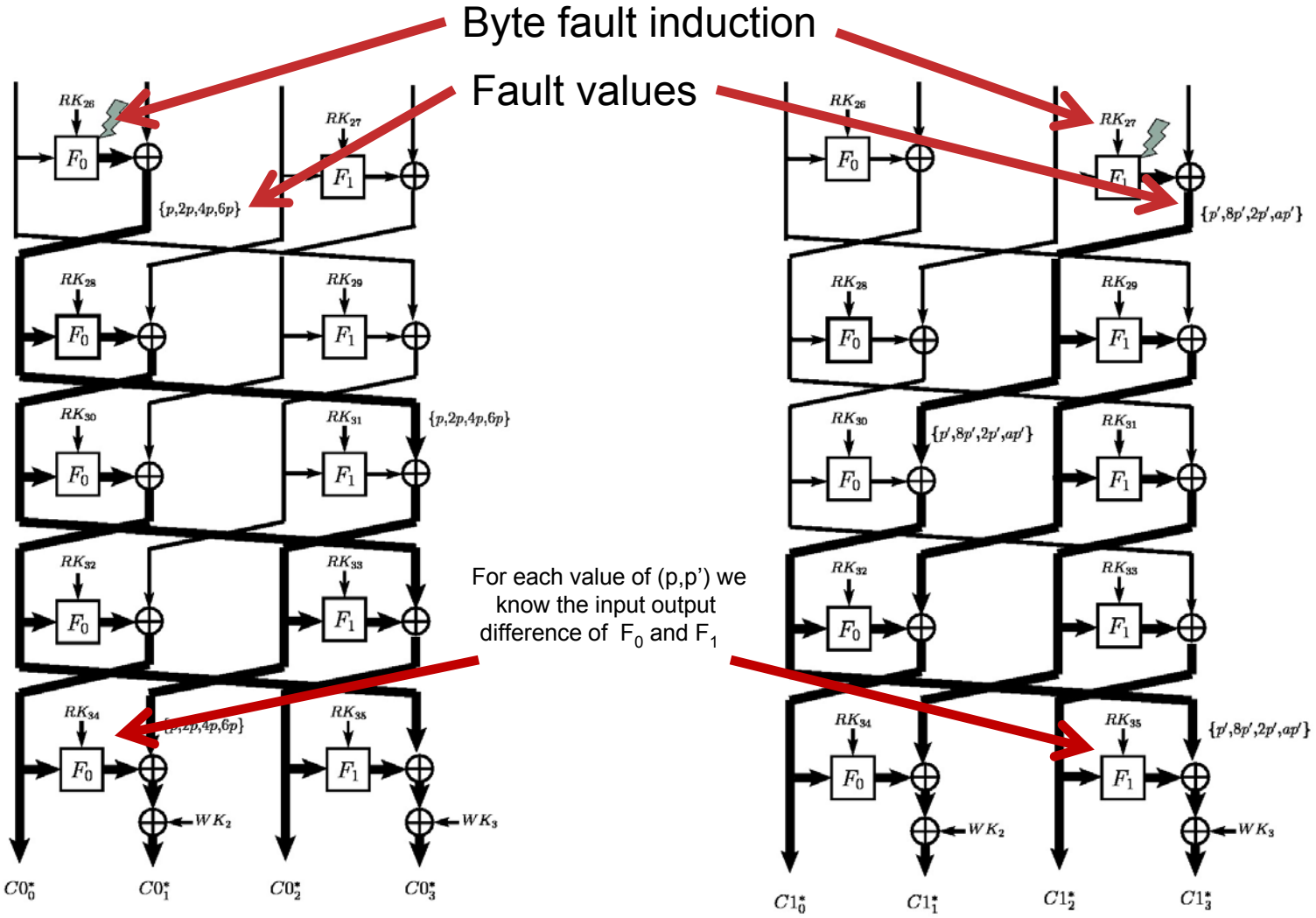


Function F_1

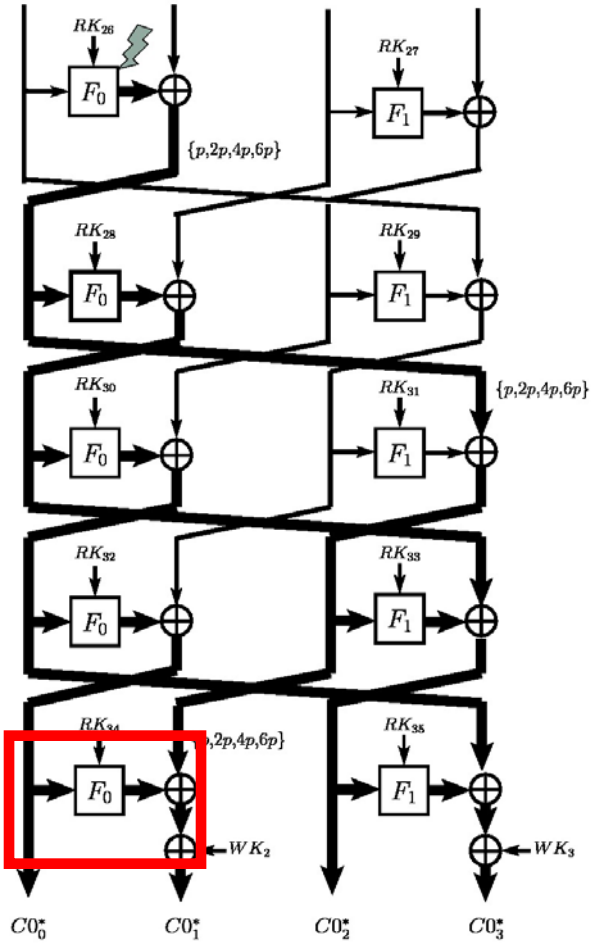
P=> {p,2p,4p,6p}

p'=> {p',8p',2p',ap'}

Fault Analysis

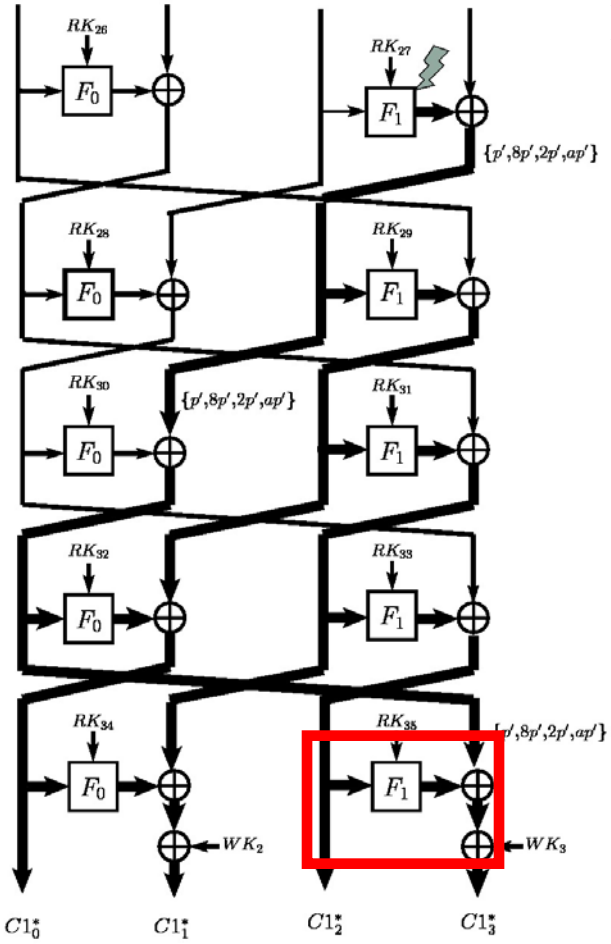


Flow of Faults



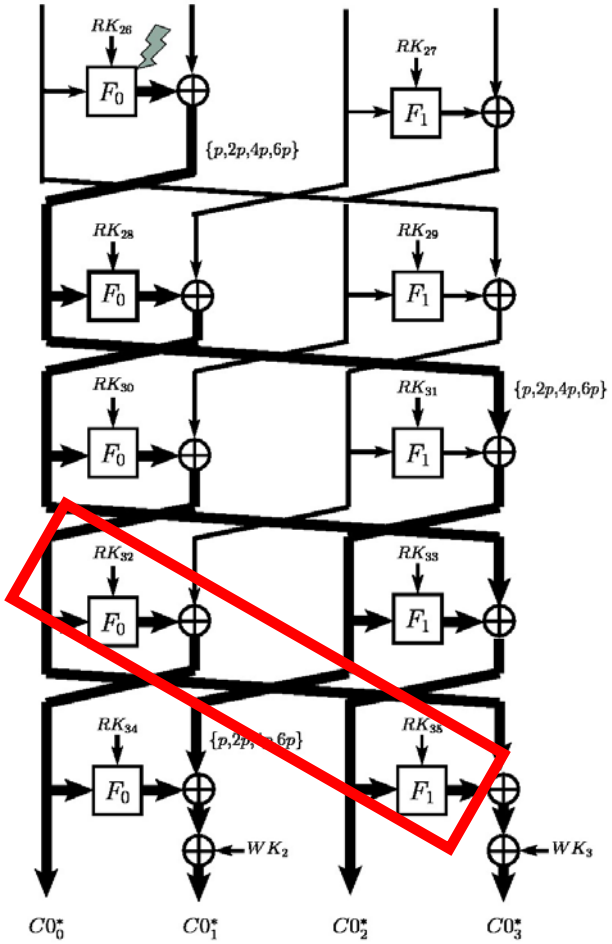
- For each value of (*p,p')* we,
  - ✓ Retrieve the values of RK_{34} from the input-output difference of F_0

Fault Analysis



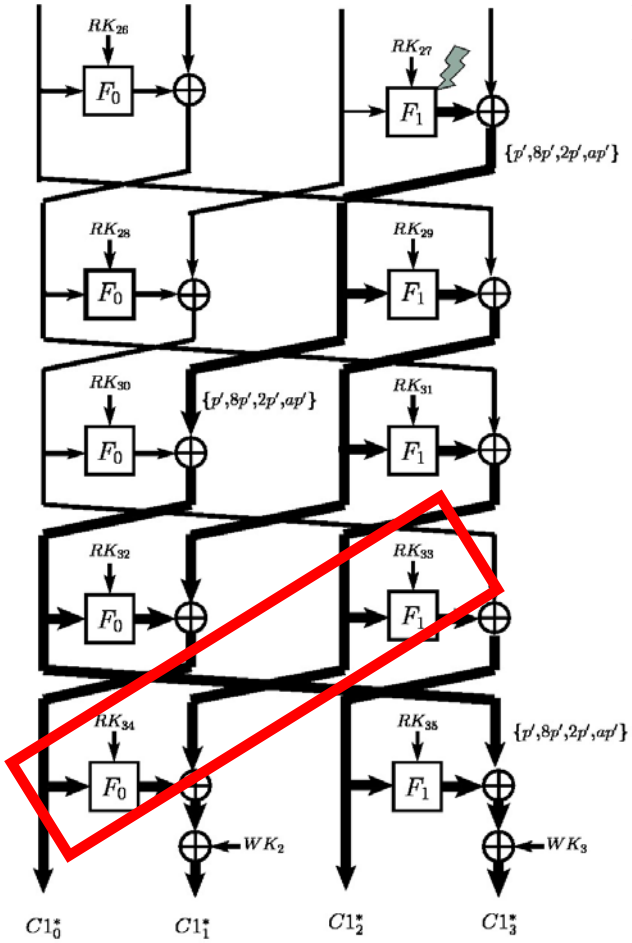
- For each value of (*p,p')* we,
  - ✓ Retrieve the values of RK_{34} from the input-output difference of F_0
  - ✓ Retrieve the values of RK_{35} from the input-output difference of F_1

Fault Analysis



- For each value of (*p,p'*) we,
  - ✓ Retrieve the values of RK_{34} from the input-output difference of F_0
  - ✓ Retrieve the values of RK_{35} from the input-output difference of F_1
  - ✓ Decrypt one round using RK_{34} and RK_{35}
  - ✓ Retrieve the value of $RK_{32} \oplus WK_3$ from F_0

Fault Analysis



- For each value of (*p,p')* we,
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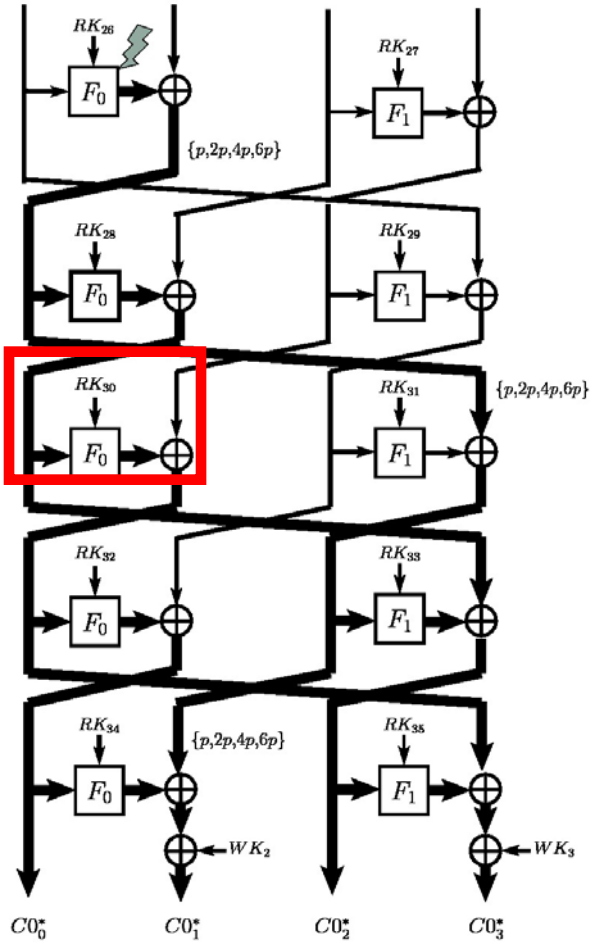
  - ✓ Retrieve the value of $RK_{32} \oplus WK_3$ from F_0
  - ✓ Retrieve the value of $RK_{33} \oplus WK_2$ from F_1

Fault Analysis



- For each value of (*p,p'*) we,
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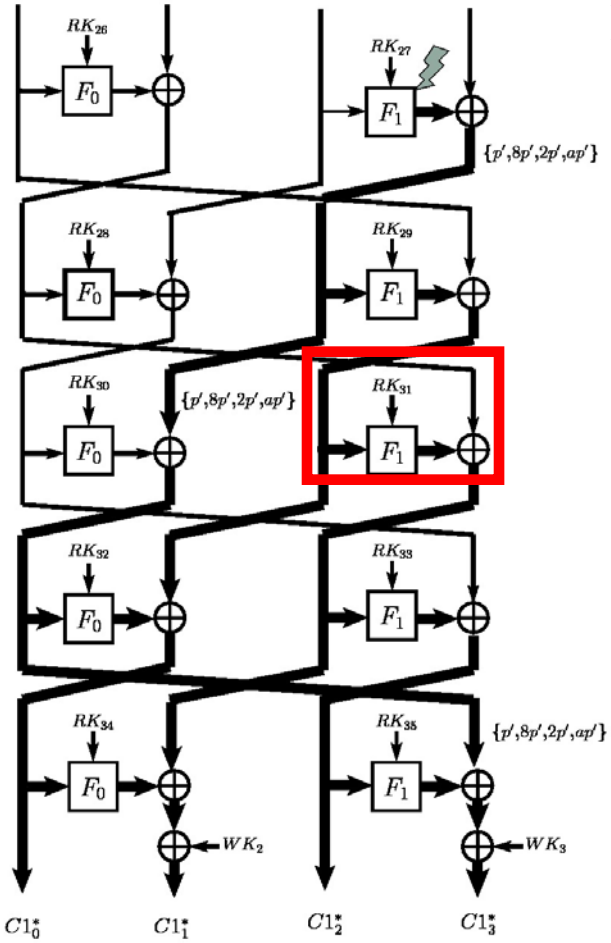
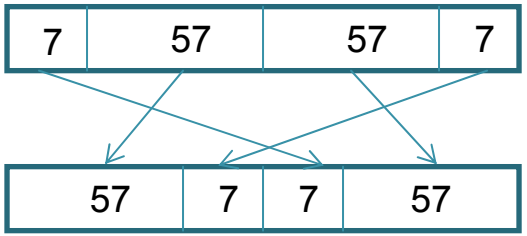
  - ✓ Retrieve the values of RK_{35} from the input-output difference of F_1
  - ✓ Decrypt one round using RK_{34} and RK_{35}
  - ✓ Retrieve the value of $RK_{32} \oplus WK_3$ from F_0
  - ✓ Retrieve the value of $RK_{33} \oplus WK_2$ from F_1
  - ✓ Decrypt one more round and retrieve RK_{30}

Fault Analysis



- For each value of (*p,p')* we,
  - ✓ Retrieve the values of RK_{34} from the input-output difference of F_0
  - ✓ Retrieve the values of RK_{35} from the input-output difference of F_1
  - ✓ Decrypt one round using RK_{34} and RK_{35}
  - ✓ Retrieve the value of $RK_{32} \oplus WK_3$ from F_0
  - ✓ Retrieve the value of $RK_{33} \oplus WK_2$ from F_1
  - ✓ Decrypt one more round and retrieve RK_{30}
  - ✓ Retrieve RK_{31}

Fault Analysis



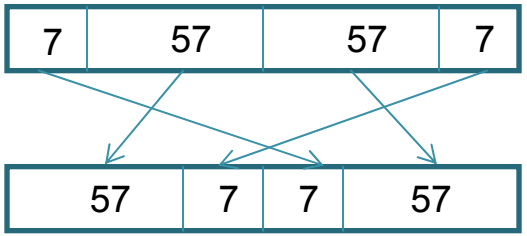
Double Swap function

$RK_{34}|RK_{35} = \sum^{8} (L_2|L_3) \oplus (CON_{58}{}^{128}|CON_{59}{}^{128})$ ... (1)

Known

- For each value of (*p,p'*) we,
  - ✓ Retrieve the values of RK_{34} from the input-output difference of F_0
  - ✓ Retrieve the values of RK_{35} from the input-output difference of F_1
  - ✓ Decrypt one round using RK_{34} and RK_{35}
  - ✓ Retrieve the value of $RK_{32} \oplus WK_3$ from F_0
  - ✓ Retrieve the value of $RK_{33} \oplus WK_2$ from F_1
  - ✓ Decrypt one more round and retrieve RK_{30}
  - ✓ Retrieve RK_{31}

Fault Analysis



Double Swap function

- For each value of (*p,p'*) we,
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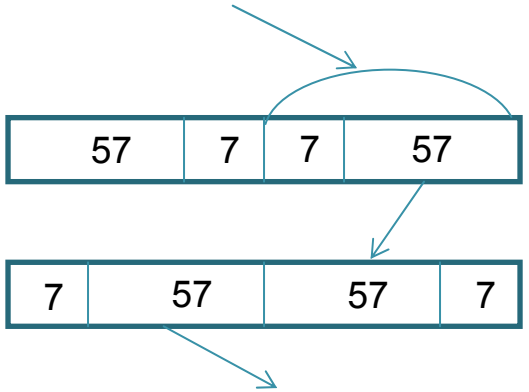
  - ✓ Retrieve the values of RK_{35} from the input-output difference of F_1
  - ✓ Decrypt one round using RK_{34} and RK_{35}
  - ✓ Retrieve the value of $RK_{32} \oplus WK_3$ from F_0
  - ✓ Retrieve the value of $RK_{33} \oplus WK_2$ from F_1
  - ✓ Decrypt one more round and retrieve RK_{30}
  - ✓ Retrieve RK_{31}
  - ✓ Retrieve 57 bits of $(K_2|K_3)$ from $(RK_{34}|RK_{35})$ using inverse of $\sum^8(L)$

$$RK_{34}|RK_{35} = \sum^8 (L_2|L_3) \oplus (CON_{58}{}^{128}|CON_{59}{}^{128}) \quad \ldots (1)$$



Inverse Double Swap function

$$RK_{30}|RK_{31} = \sum^7 (L_2|L_3) \oplus (K_2|K_3) \oplus (CON_{54}{}^{128}|CON_{55}{}^{128}) \quad \ldots (2)$$

Fault Analysis

$(WK_2|WK_3) = (K_2|K_3)$

↓

WK_2 is known and 25 bits of WK_3 is known

↓

Get RK_{33} from $RK_{33} \oplus WK_2$

↓

Get last 7 bits of WK3 from RK_{33}

↓

Use RK_{33} and RK_{32} and get L

- For each value of (*p,p'*) we,
  - ✓ Retrieve the values of RK_{34} from the input-output difference of F_0
  - ✓ Retrieve the values of RK_{35} from the input-output difference of F_1
  - ✓ Decrypt one round using RK_{34} and RK_{35}
  - ✓ Retrieve the value of $RK_{32} \oplus WK_3$ from F_0
  - ✓ Retrieve the value of $RK_{33} \oplus WK_2$ from F_1
  - ✓ Decrypt one more round and retrieve RK_{30}
  - ✓ Retrieve RK_{31}
  - ✓ Retrieve 57 bits of $(K_2|K_3)$ from $(RK_{34}|RK_{35})$ using inverse of $\sum^8(L)$
  - ✓ Get $(WK_2|WK_3)$ and L

Key Recovery

- For each value of (p,p') we get the value of $(K_2|K_3)$ and L
- We do the inverse $GFN_{4,12}$ and get the value of K from L
- If the value of $(K_2|K_3)$ matches with the derived value of K (right half) we accept the key
- Only one value of K satisfy above condition

Proposed New Attack

- Induce two faults in 14th round F-functions.
- For each value of (p,p') do,
  1. Get the input-output difference of 18th round
  2. Get the 18th round key
  3. Repeat step 1-2 for other round keys.
- Get the master key and L from possible round keys.
- From L get the master key:
  - If both the master key matches accept else discard the key.

Attack Results

- The attack will work even if last four rounds are protected.
- Time complexity of the attack 2^{24}
- Uniquely determines the master key
- Required number of faulty ciphertexts is 2

Attack on CLEFIA-192 and CLEFIA-256

- In case of CLEFIA-192 and CLEFIA-256 the attack is same.
- Unlike CLEFIA-128 in this case four faults are induced in (r-4)-th round in order to uniquely determine the last four round key.
- Four more faults are induced in two F-functions of (r-8)-th round to recover four more round keys.
- Last eight round keys are sufficient to retrieve the master key.

Conclusions

- We propose a attack on CLEFIA by inducing faults one round earlier.
- The attack retrieves the secret key in negligible time.
- The attack emphasize the need for protecting last five round of CLEFIA for non-iterative implementation.

Thank You