



# Scan chain encryption, a countermeasure against scan attacks

Mathieu da Silva, Giorgio Di Natale, Marie-Lise Flottes, Bruno Rouzeyre

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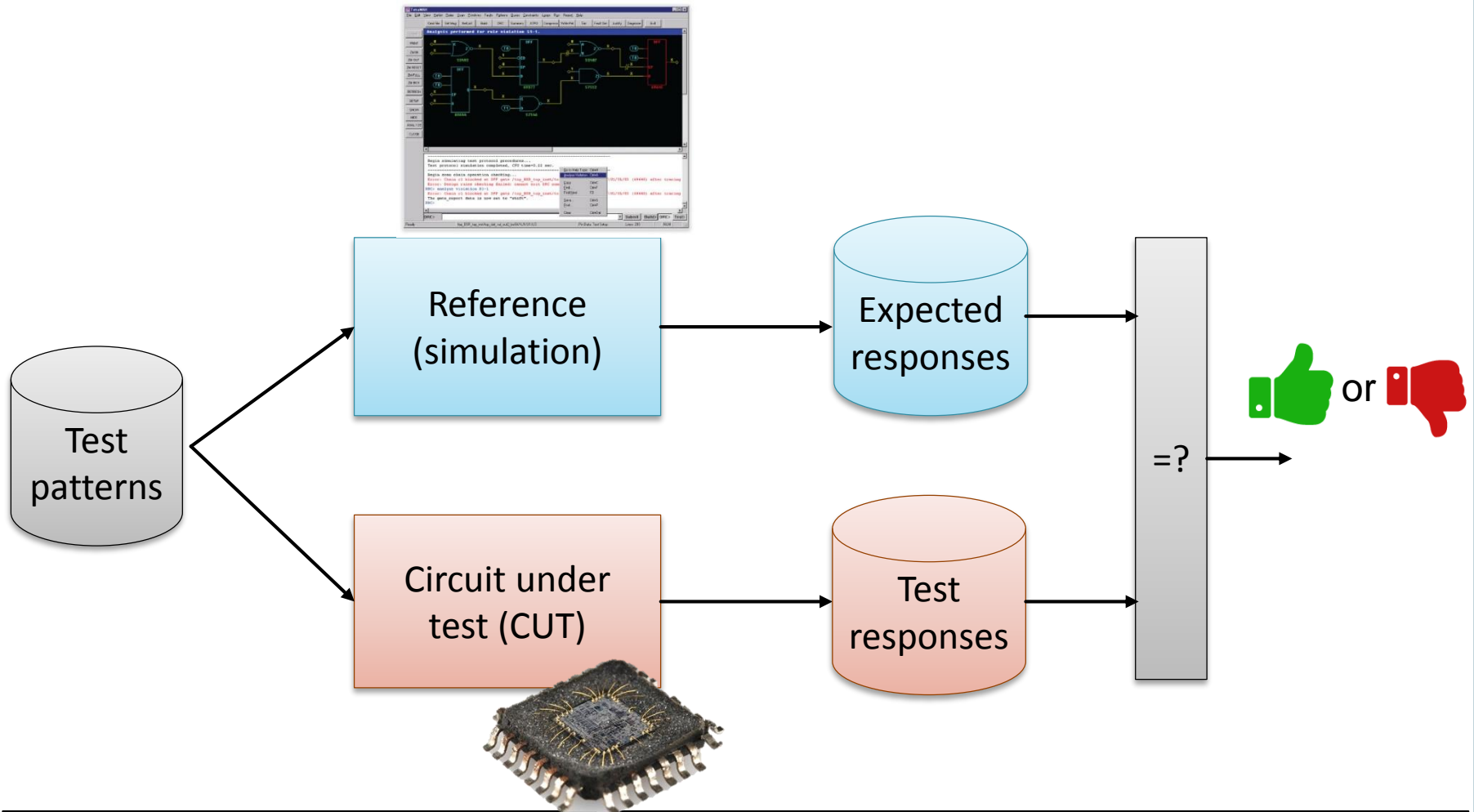
# SCAN CHAIN ENCRYPTION, A COUNTERMEASURE AGAINST SCAN ATTACKS

Mathieu Da Silva, Marie-Lise Flottes, Giorgio Di Natale, Bruno Rouzeyre

PHISIC 2018

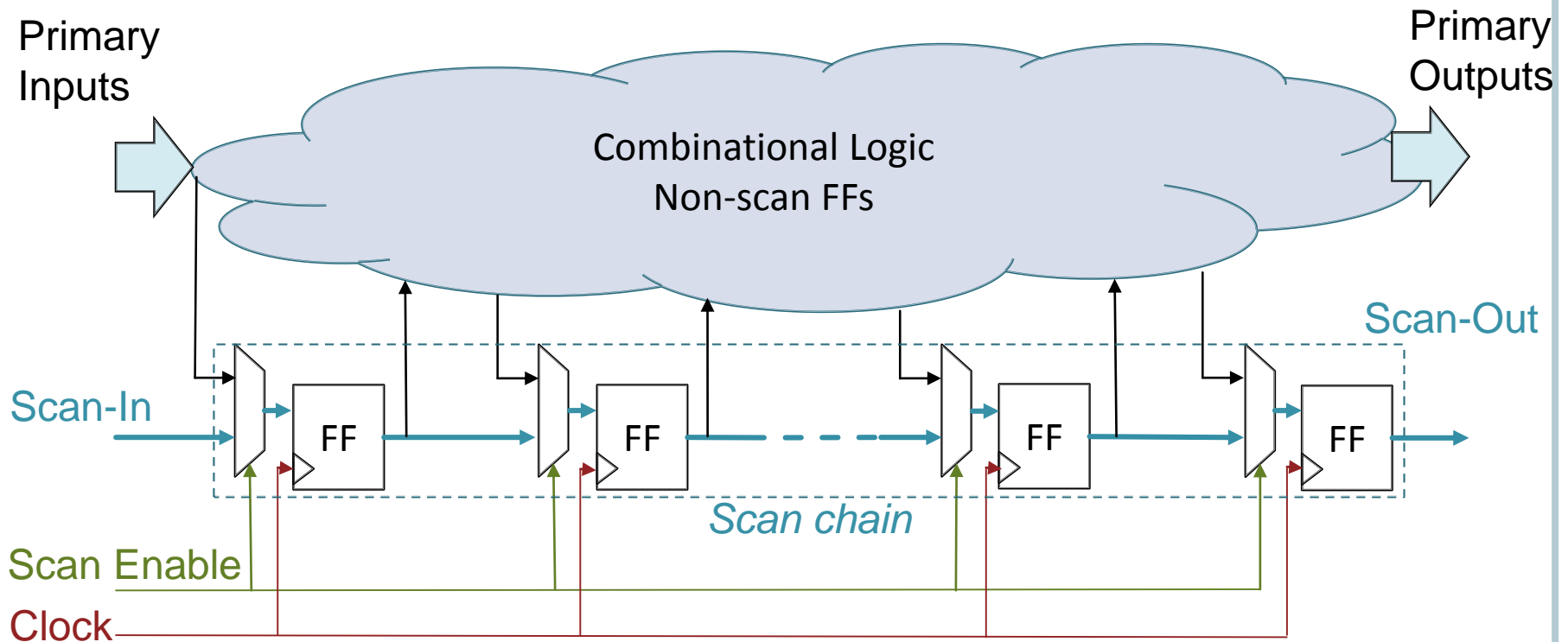
# CONTEXT

- Test of circuit is a mandatory step in IC production



# CONTEXT

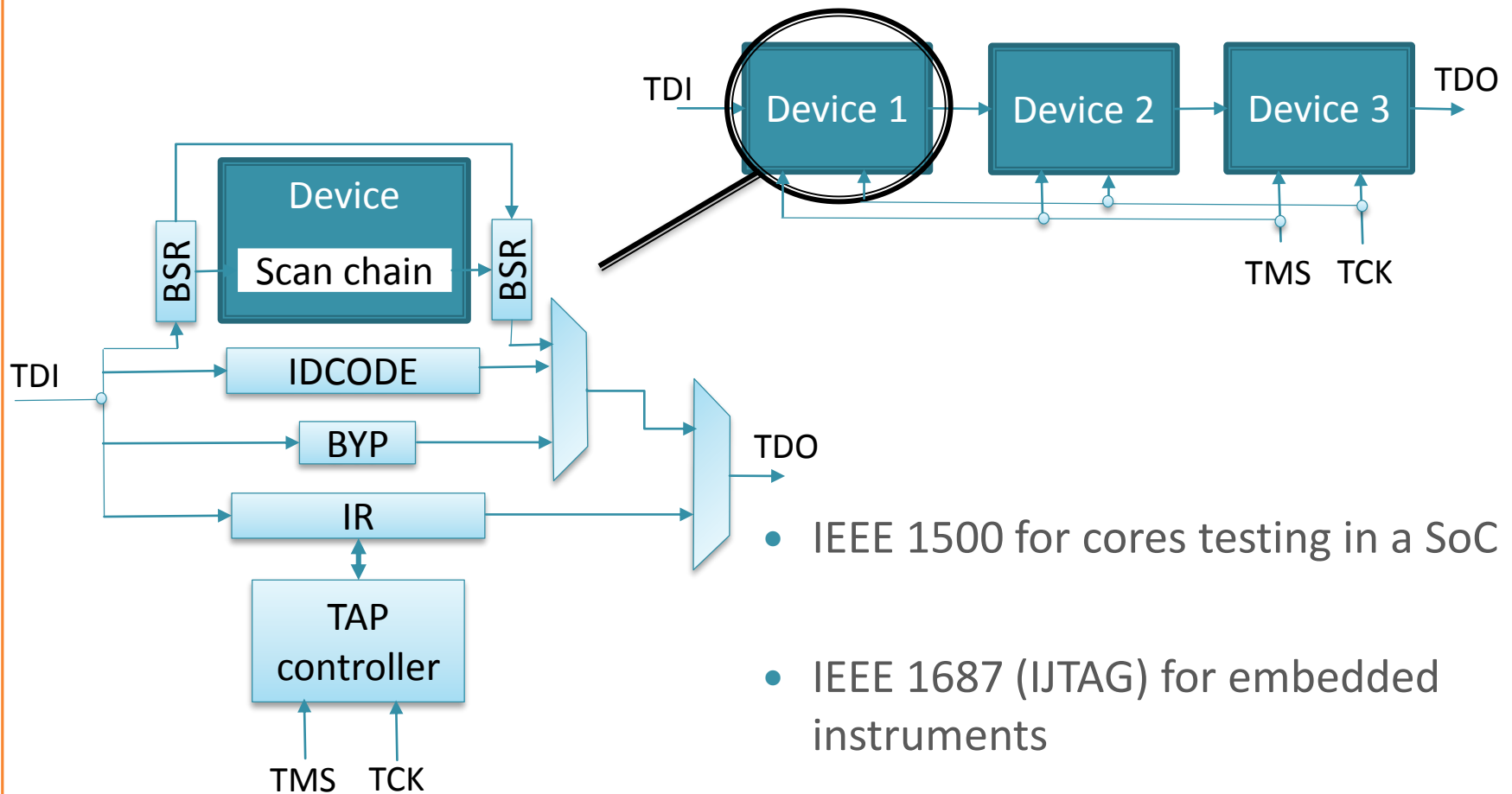
- Most popular method for Design-for-Test = Scan chains
  - Replace original FF by Scan FF connected serially together
  - Extra port « Scan-In » => controllability on internal states
  - Extra port « Scan-Out » => observability on internal states



# CONTEXT

- Test standards

- IEEE 1149 (JTAG) for board testing

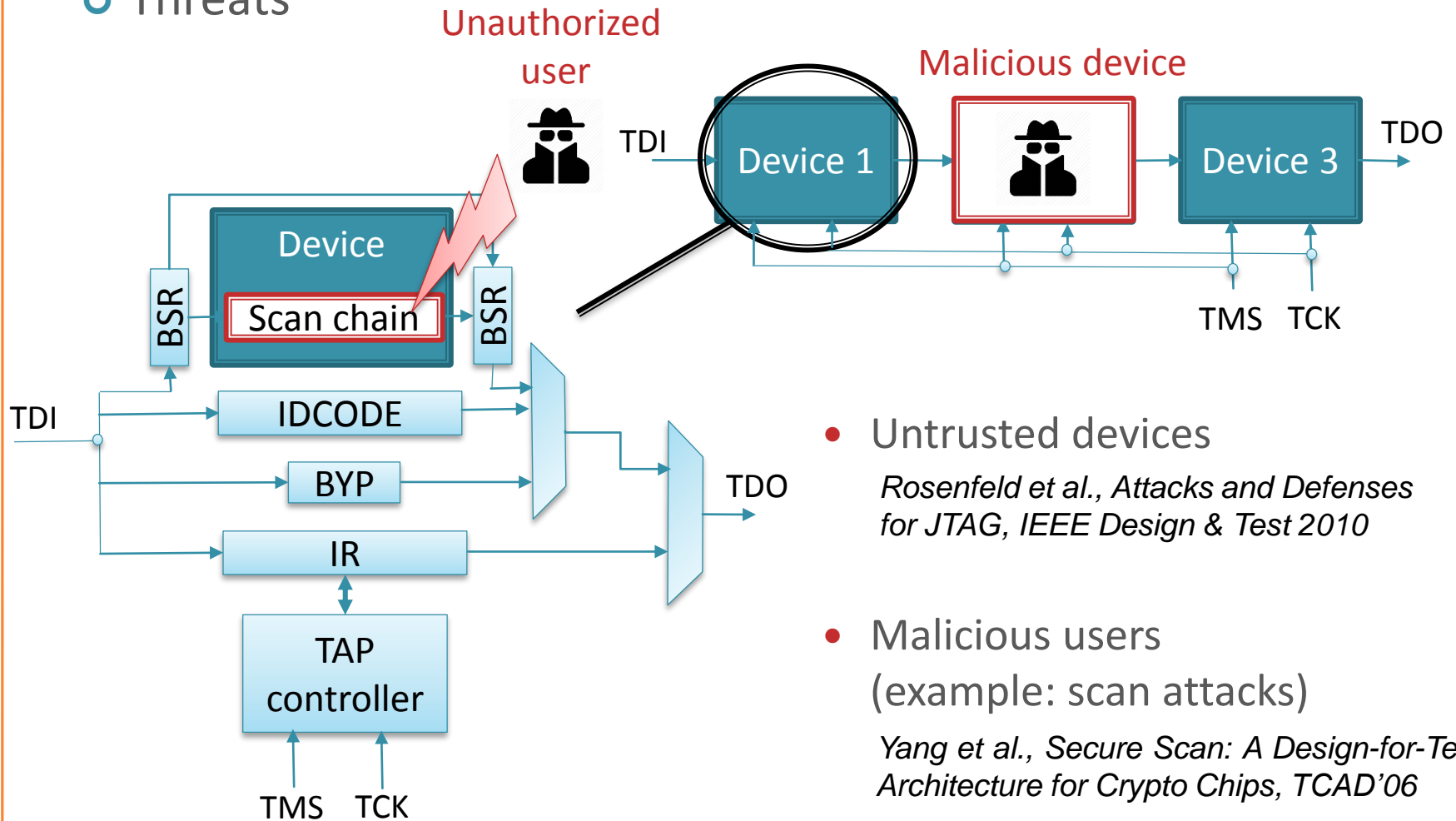


- IEEE 1500 for cores testing in a SoC
- IEEE 1687 (IJTAG) for embedded instruments



# CONTEXT

## Threats



- Untrusted devices

*Rosenfeld et al., Attacks and Defenses for JTAG, IEEE Design & Test 2010*

- Malicious users  
(example: scan attacks)

*Yang et al., Secure Scan: A Design-for-Test Architecture for Crypto Chips, TCAD'06*



# SUMMARY

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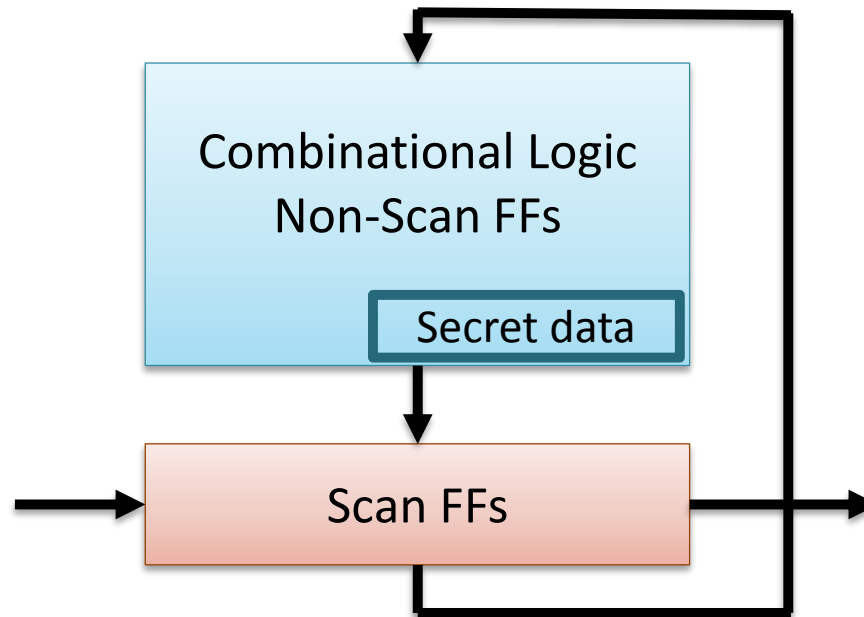
- 1) **Scan attacks**
- 2) A new countermeasure: Scan chain encryption
- 3) Implementation with block cipher
- 4) Implementation with stream cipher
- 5) Conclusion



# SCAN ATTACK PRINCIPLE

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- Goal: Retrieve embedded secret data
- Exploit observability or controllability offered by scan chains
- Principle: switch between functional and scan modes
- Main target: secret key of crypto-processors (example: AES)





# SCAN ATTACK ON AES

- Advanced Encryption Standard (AES)

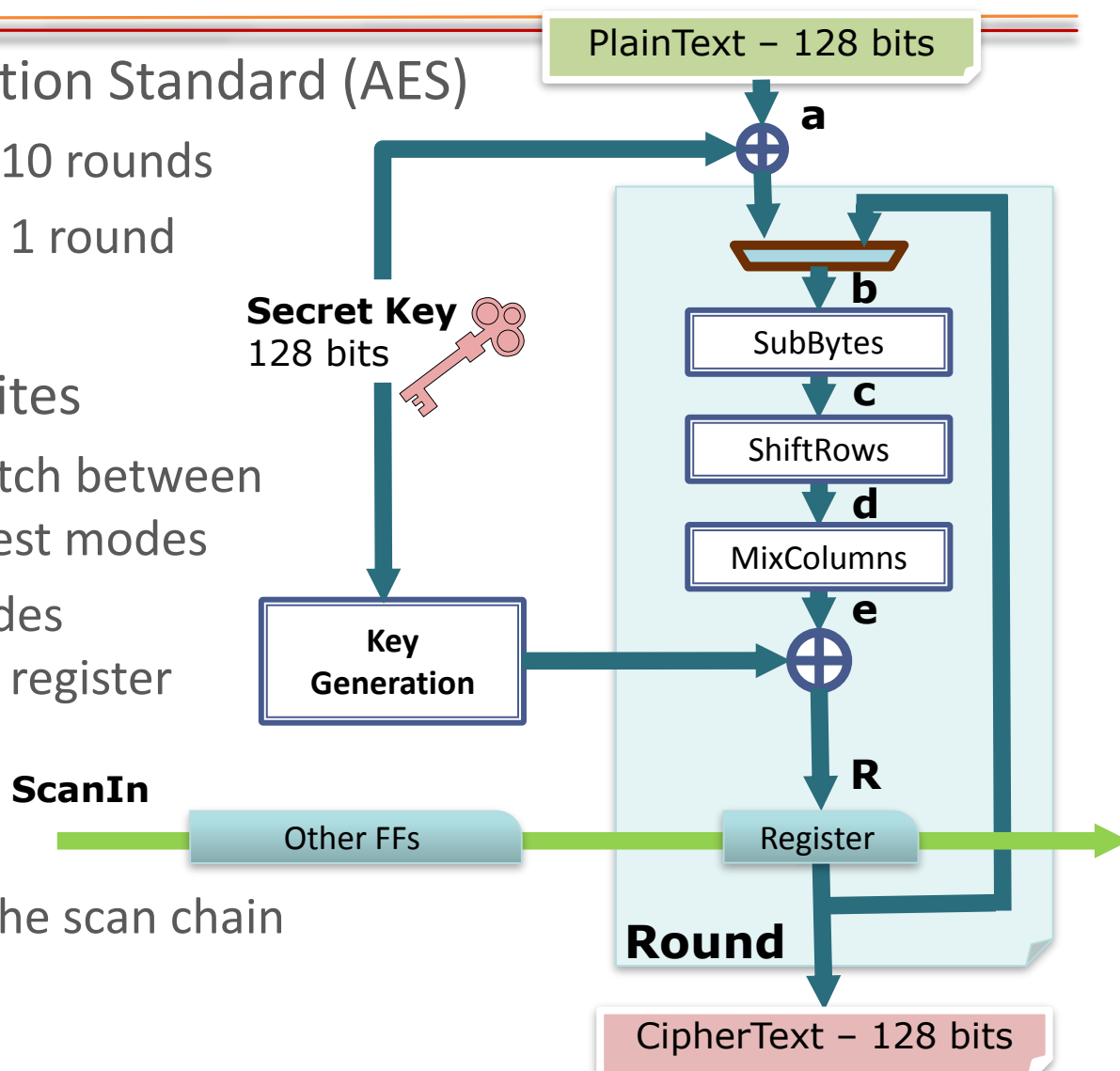
- Ciphertext after 10 rounds
- Not secure after 1 round

- Attack pre-requisites

- Attacker can switch between functional and test modes
- Scan chain includes FFs of the round register

- Attack principle

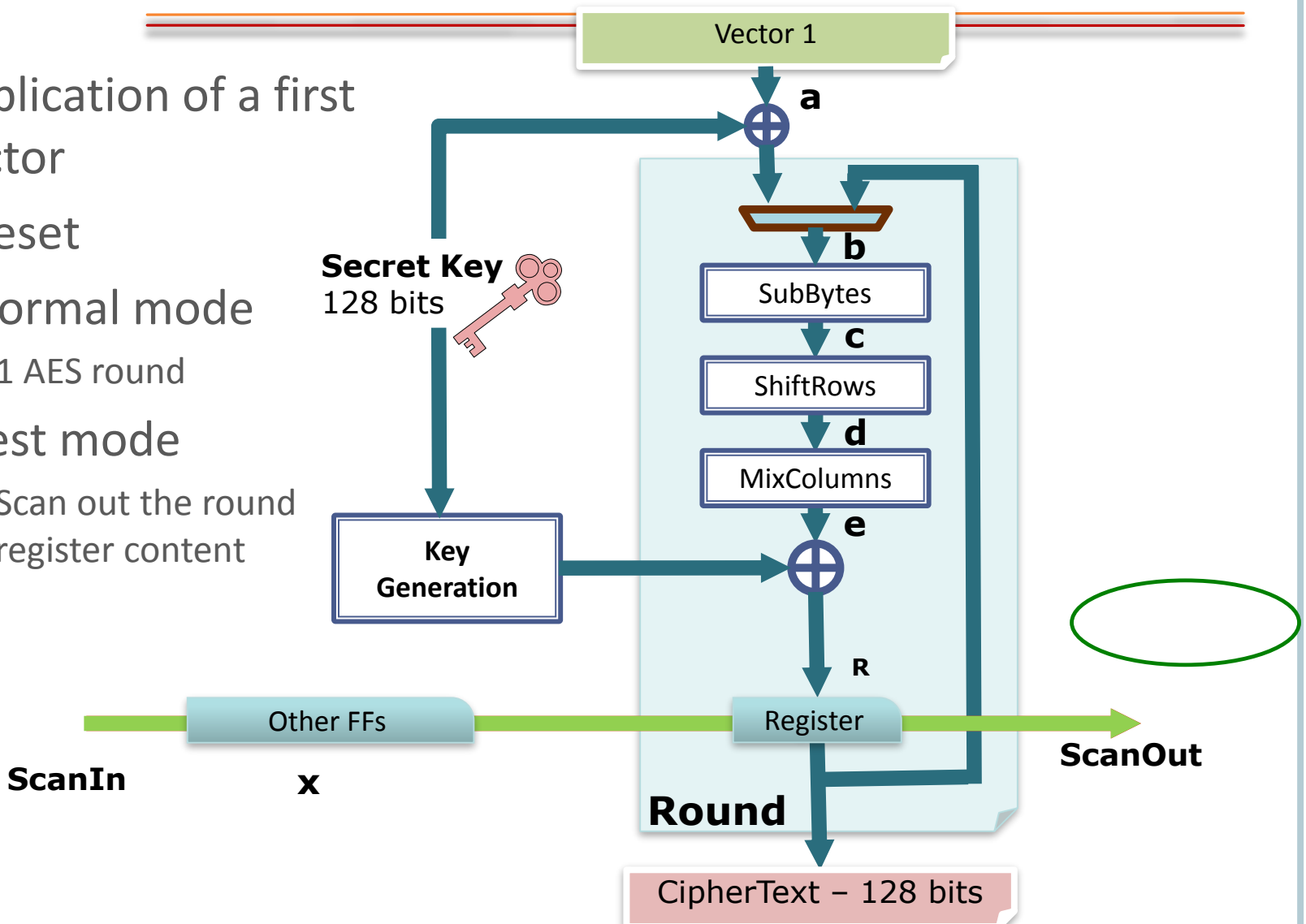
- Observation of the scan chain after 1 round



# DIFFERENTIAL ATTACK

- Application of a first vector

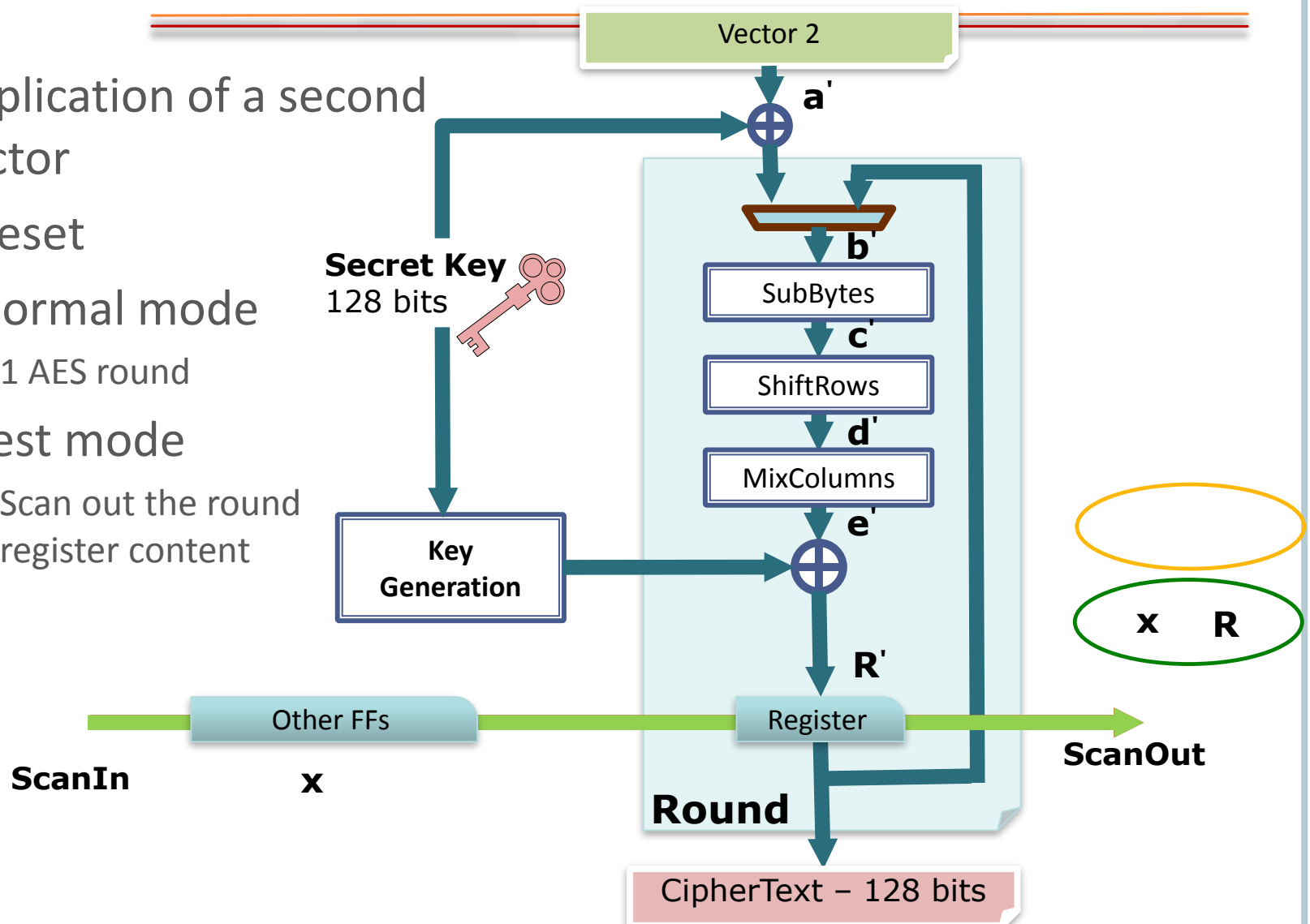
- 1) Reset
- 2) Normal mode
  - 1 AES round
- 3) Test mode
  - Scan out the round register content



# DIFFERENTIAL ATTACK

- Application of a second vector

- 1) Reset
- 2) Normal mode
  - 1 AES round
- 3) Test mode
  - Scan out the round register content



# DIFFERENTIAL ATTACK

- Hamming distance



- Attacker applies pairs of input values until hamming distance equal to specific values => key byte revealed

- On average, 32 trials

⇒ 512 trials to retrieve the whole 128-bit key



# SUMMARY

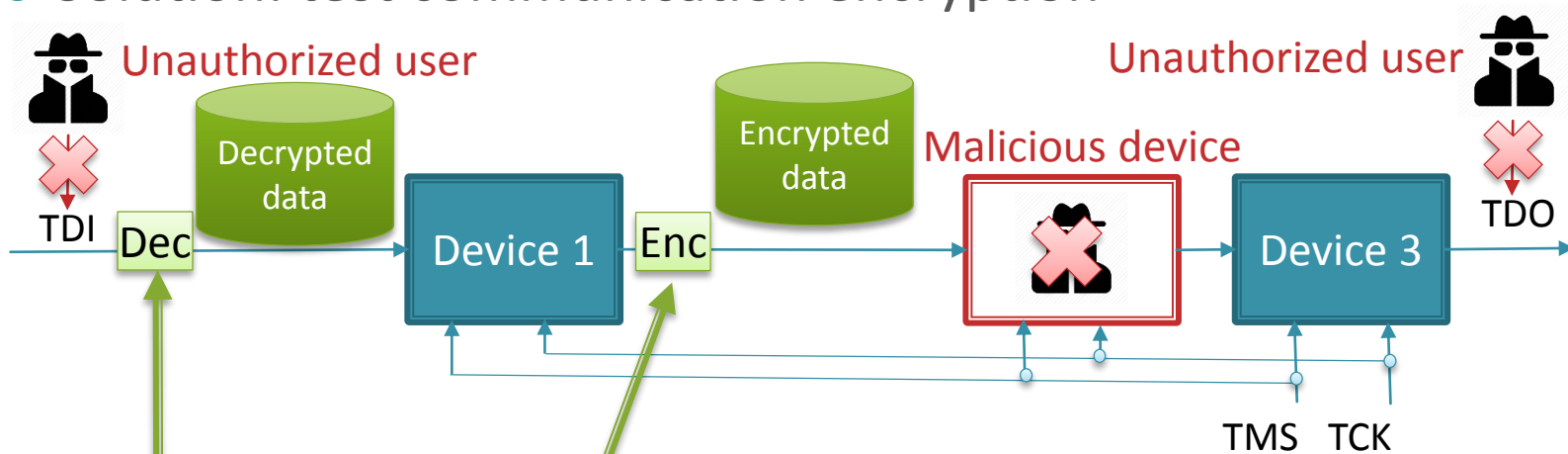
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- 1) Scan attacks
- 2) **A new countermeasure: Scan chain encryption**
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# SCAN CHAIN ENCRYPTION

## ○ Solution: test communication encryption

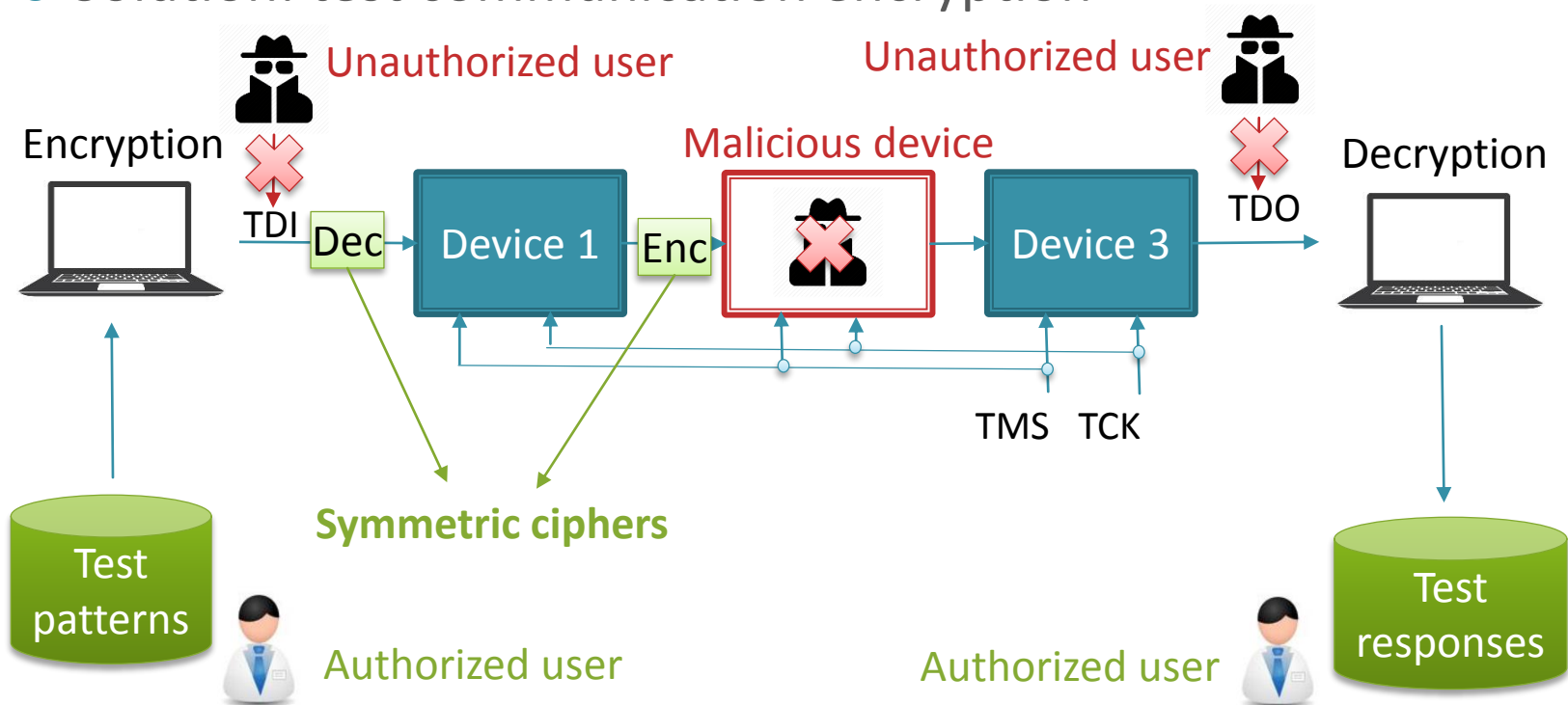


- **Input decryption** prevents sending desired test data
- **Output encryption** prevents reading plain test responses



# CONTEXT

## ○ Solution: test communication encryption

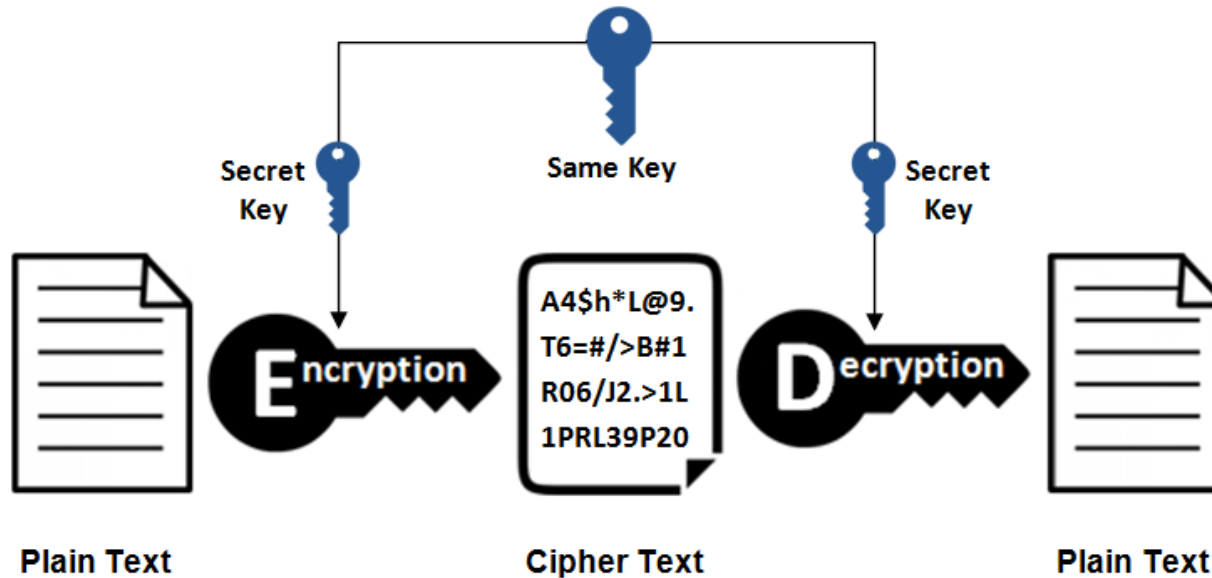


- Input decryption prevents sending desired test data
- Output encryption prevents reading plain test responses
- Test/debug only possible by authorized user knowing the secret key



# SYMMETRIC CIPHER

## Symmetric Encryption



- 2 types of symmetric cipher: stream and block ciphers

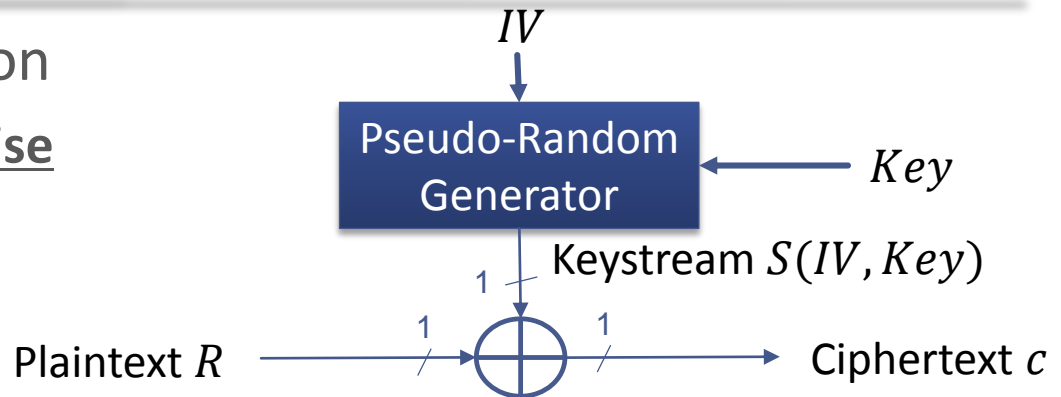




# STREAM CIPHER / BLOCK CIPHER

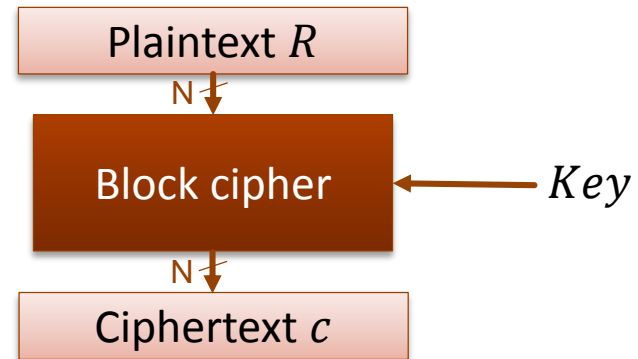
## Stream cipher encryption

- Keystream XORed bitwise with the plaintext



## Block cipher encryption

- Confusion and diffusion on a block of plaintext



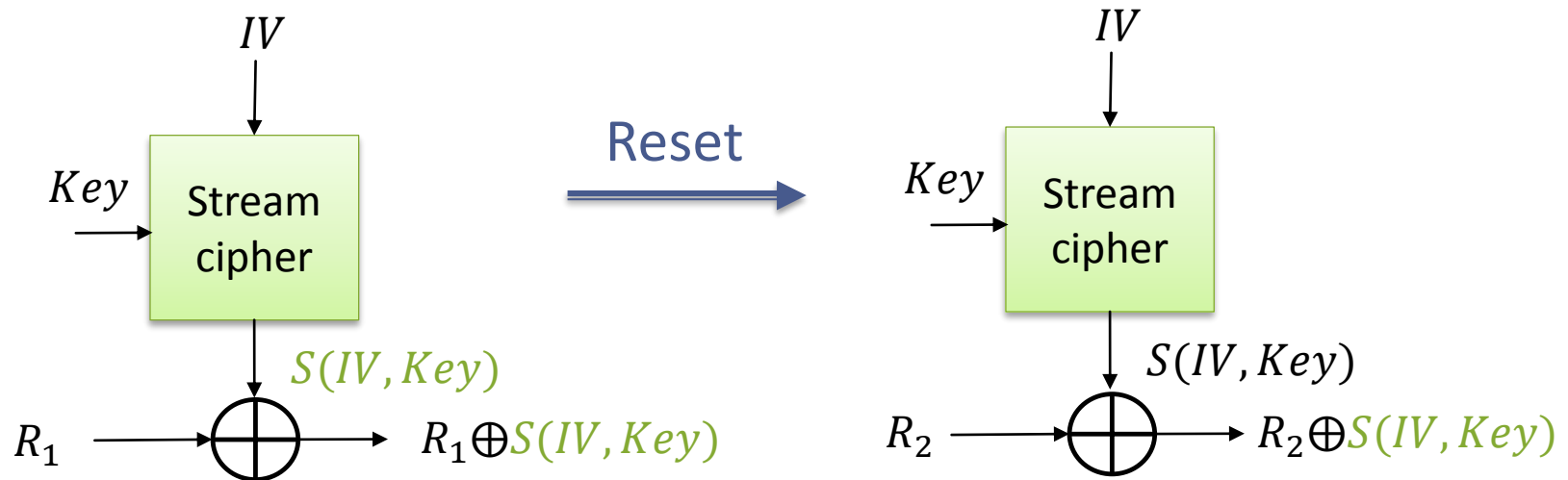
## Preference for stream ciphers

- "Naturally" adapted to serial test communication (JTAG, IEEE 1500, IJTAG)
- Smaller area footprint compared to block ciphers
- But ..



# TWO-TIMES PAD: STREAM CIPHER REQUIREMENT

- Two-times pad: same key and  $IV$  re-used  $\Rightarrow$  same keystream generated to encrypt different data



$\Rightarrow$  Possible to carry out attacks if requirement is not fit

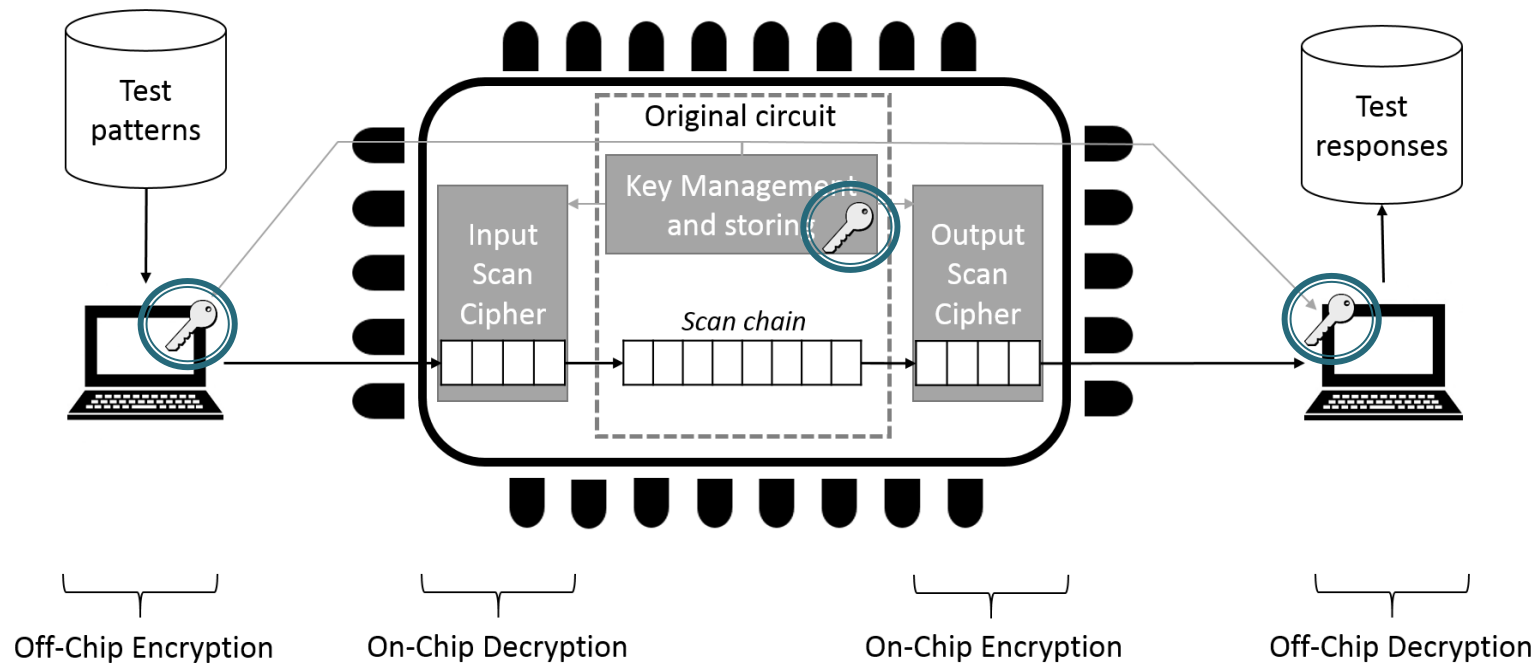
$$R_1 \oplus \cancel{S(IV, Key)} \oplus R_2 \oplus \cancel{S(IV, Key)}$$

$\Rightarrow$  Solution:  $IV$  generated randomly at each circuit reset

$$R_1 \oplus S(IV_1, Key) \oplus R_2 \oplus S'(IV_2, Key)$$



# BASIC SCHEME



- Assumption: original circuit embedded a crypto-core with its key management and storing
- Scan chain encryption solution shares the key management and storing already implemented



# SUMMARY

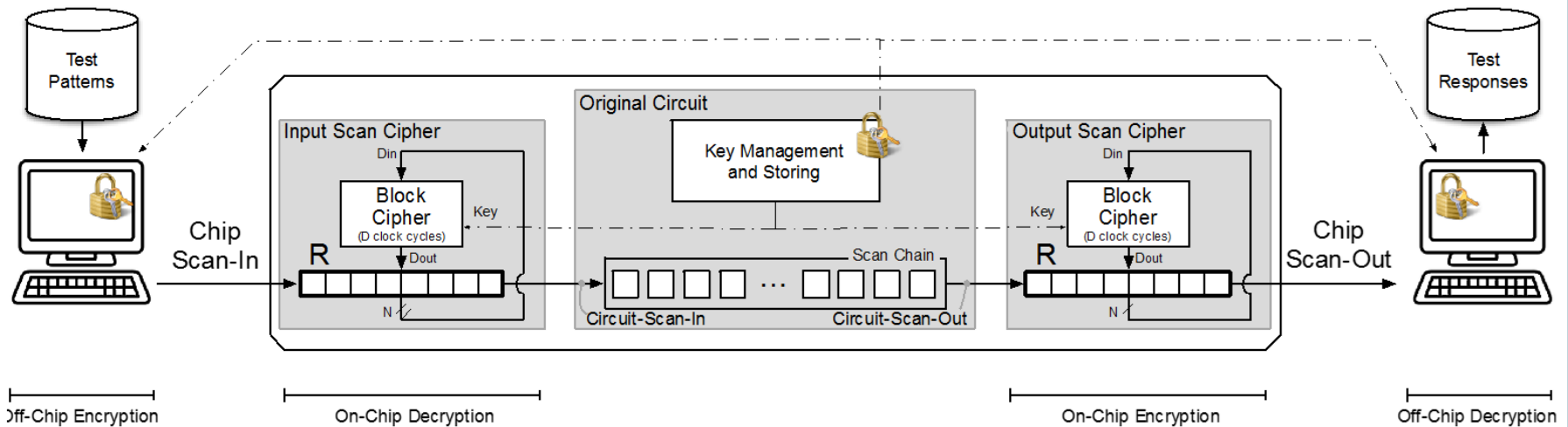
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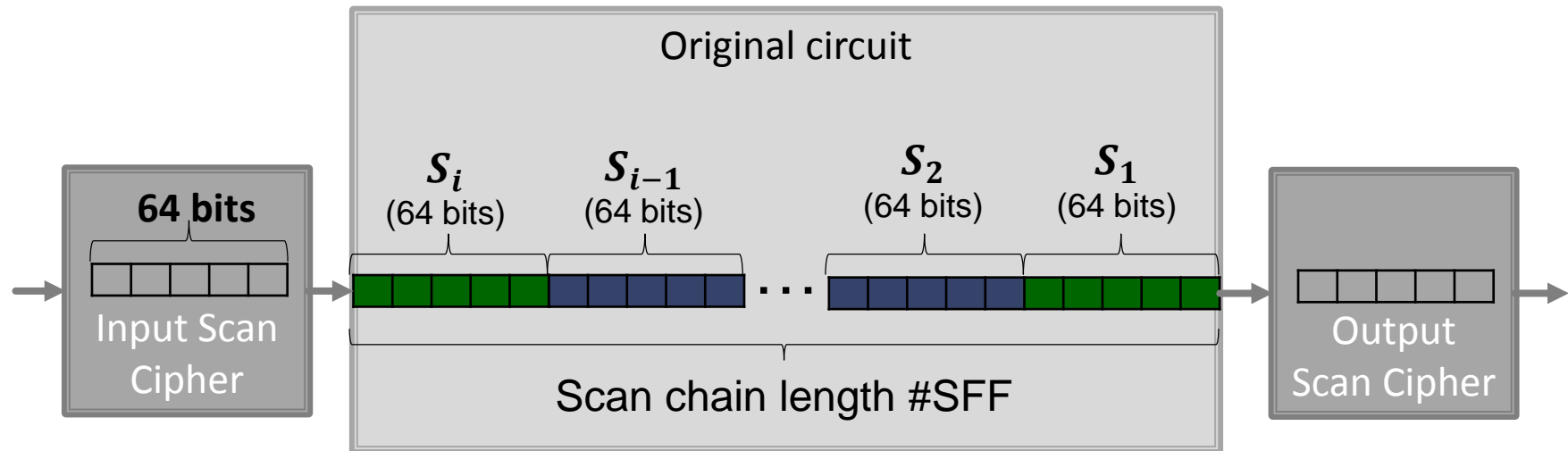
# BLOCK CIPHER-BASED SCAN ENCRYPTION

- Implementation on scan chain with 2 PRESENT block ciphers:
  - Lightweight (1 PRESENT = 2 139 GE)
  - Encryption by 64-bits block size



# MODE OF OPERATIONS

- 64 bits encrypted every 32 clock cycles



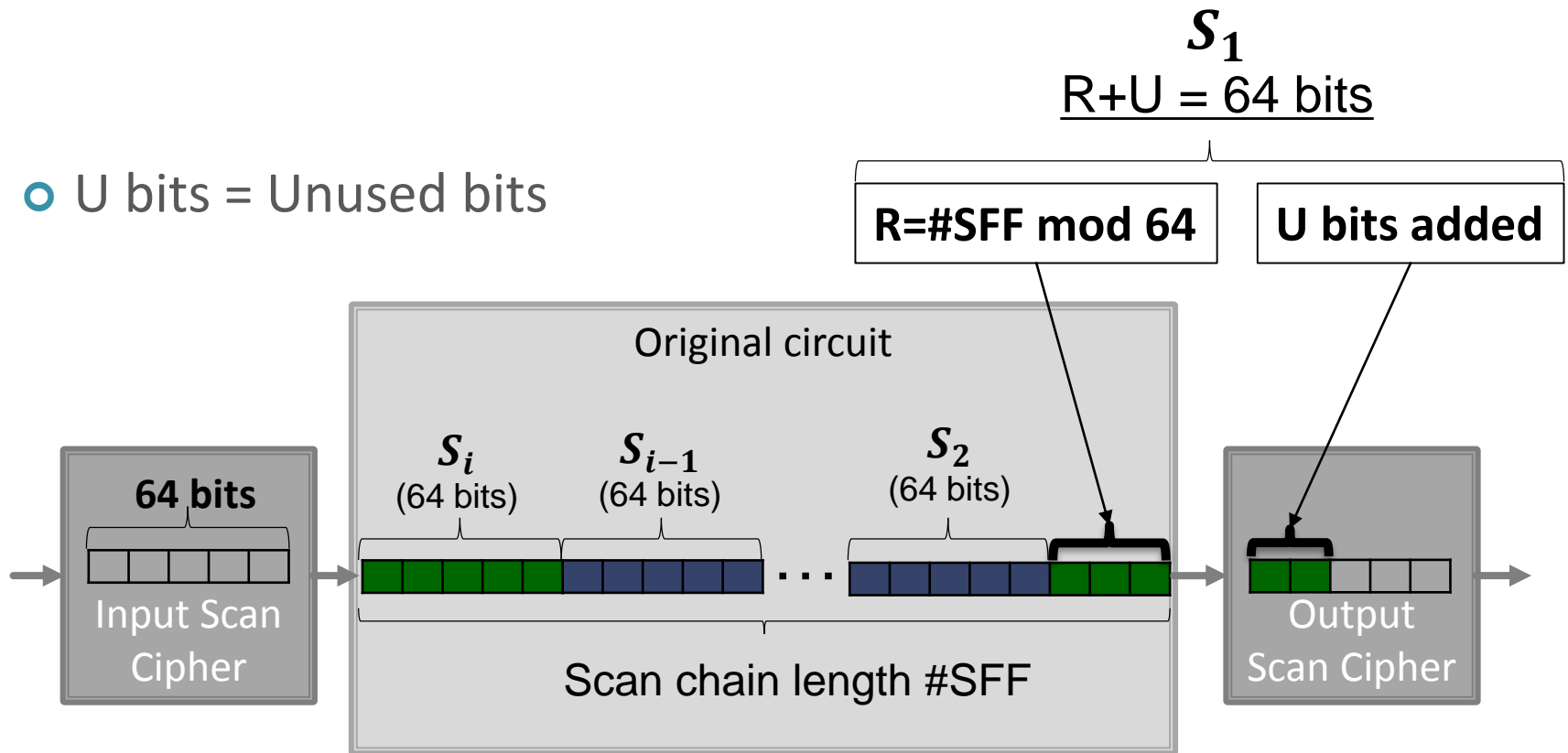
⇒ **#SFF = P x 64**

⇒ **No test time overhead on each pattern**



# MODE OF OPERATIONS

- U bits = Unused bits



$$\Rightarrow \#SFF = P \times 64 + R$$

$\Rightarrow$  Loss of  $U$  clock cycles per pattern



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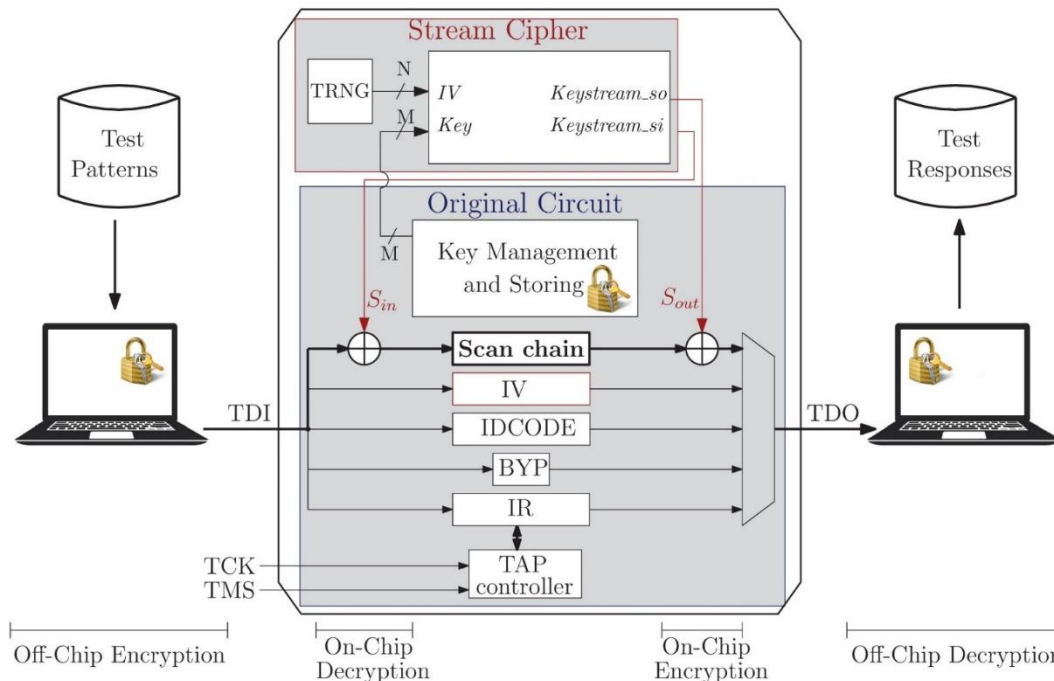




# STREAM CIPHER-BASED SCAN ENCRYPTION

## Implementation on JTAG:

- 1 TRIVIUM stream cipher (2 016 GE)
- TRNG to generate random IV
- New instruction *GetIV* with a test data register IV

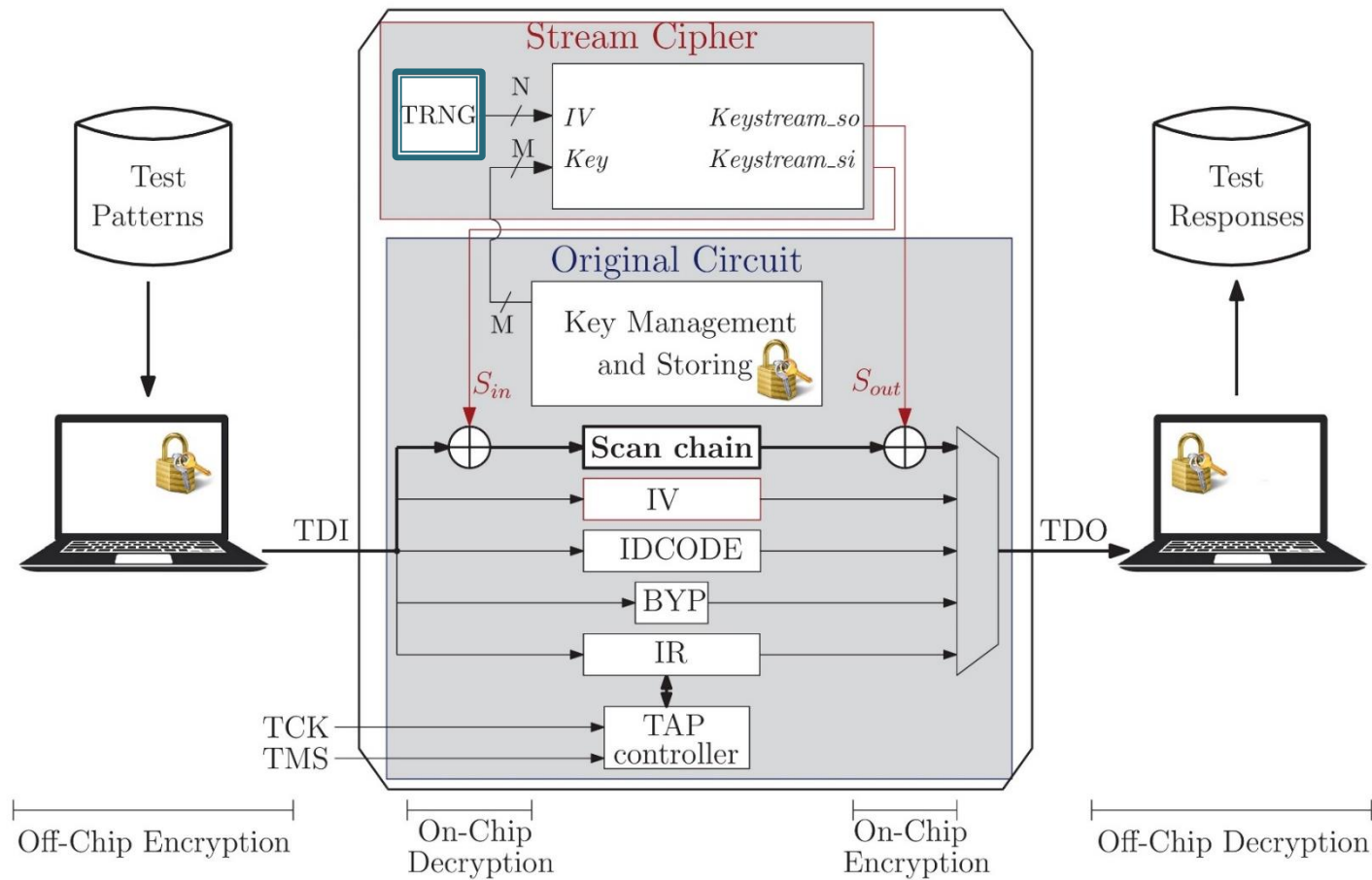


## Mode of operations in 2 phases: initialization and encryption

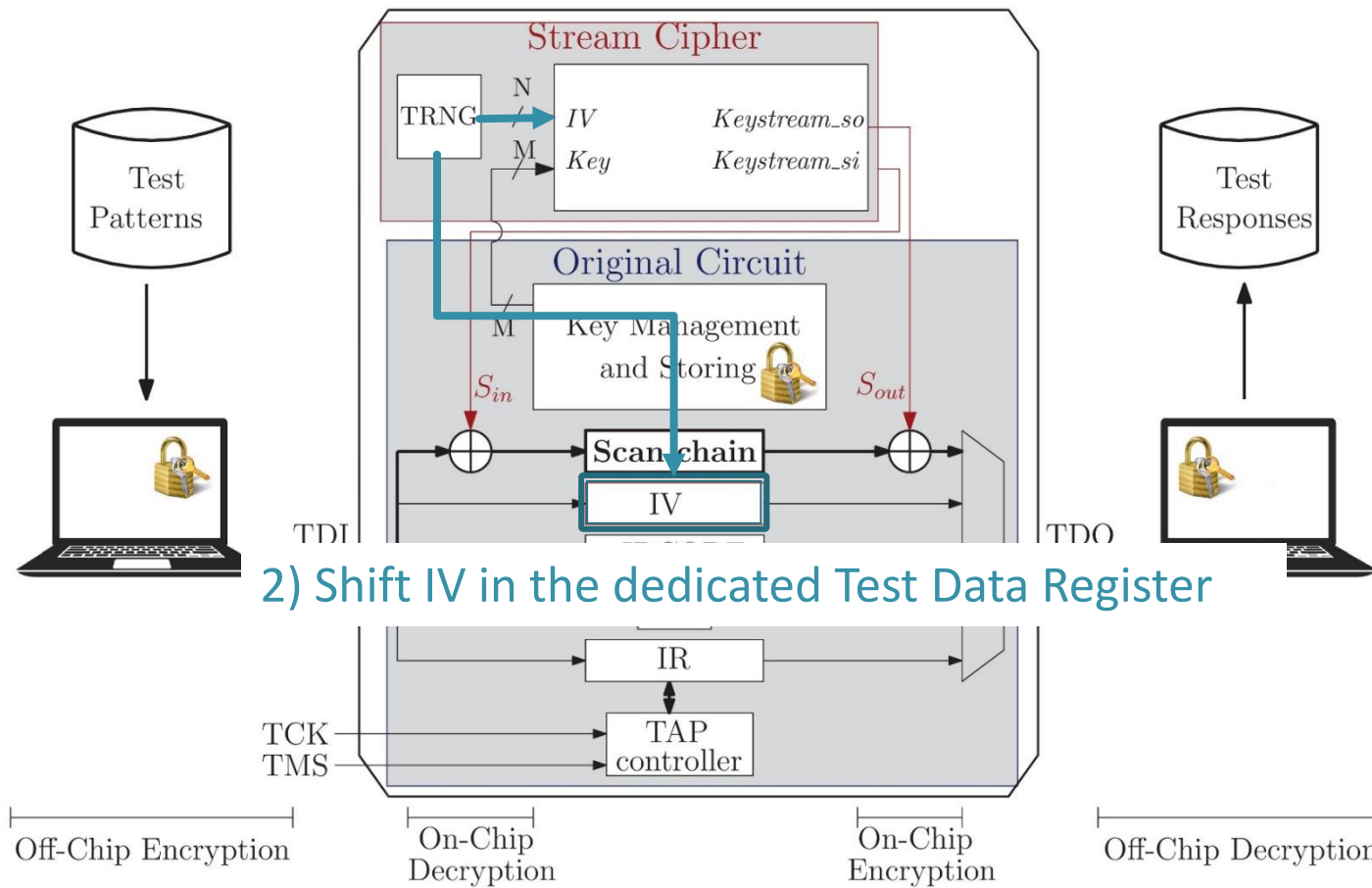


# INITIALIZATION PHASE

## 1) TRNG initialization: reach sufficient entropy to generate random number

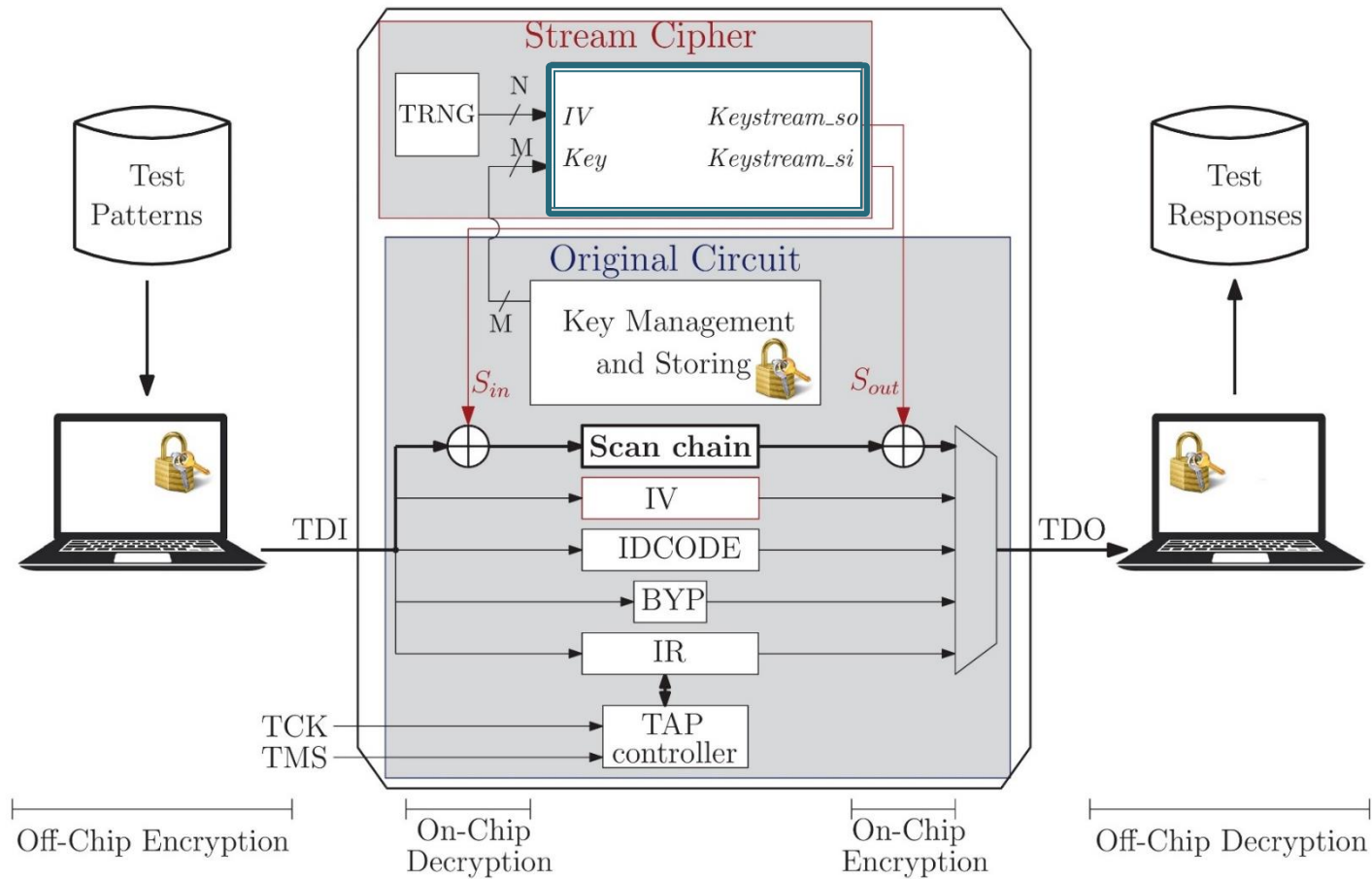


# INITIALIZATION PHASE

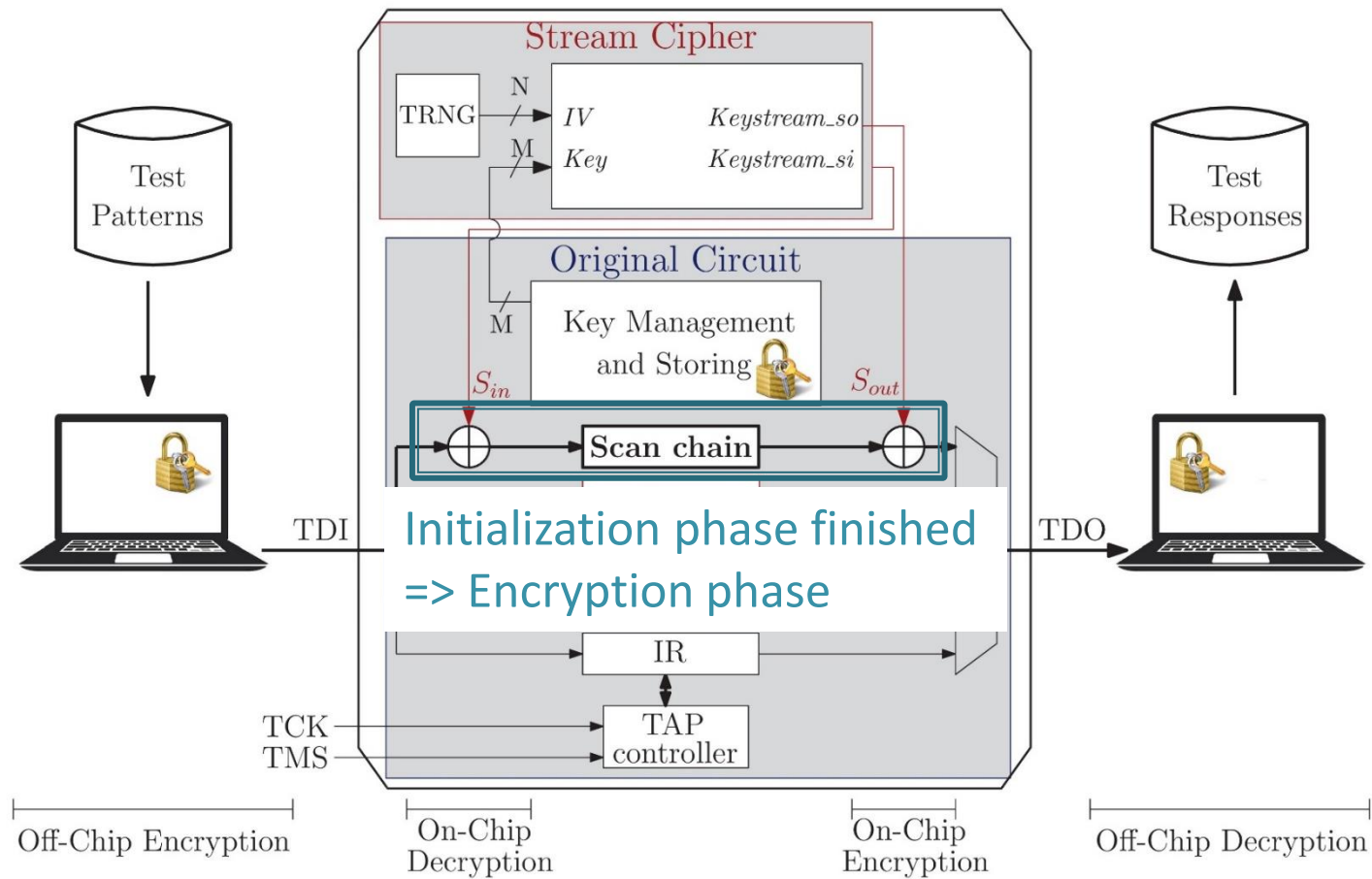


# INITIALIZATION PHASE

## 3) Stream cipher setup

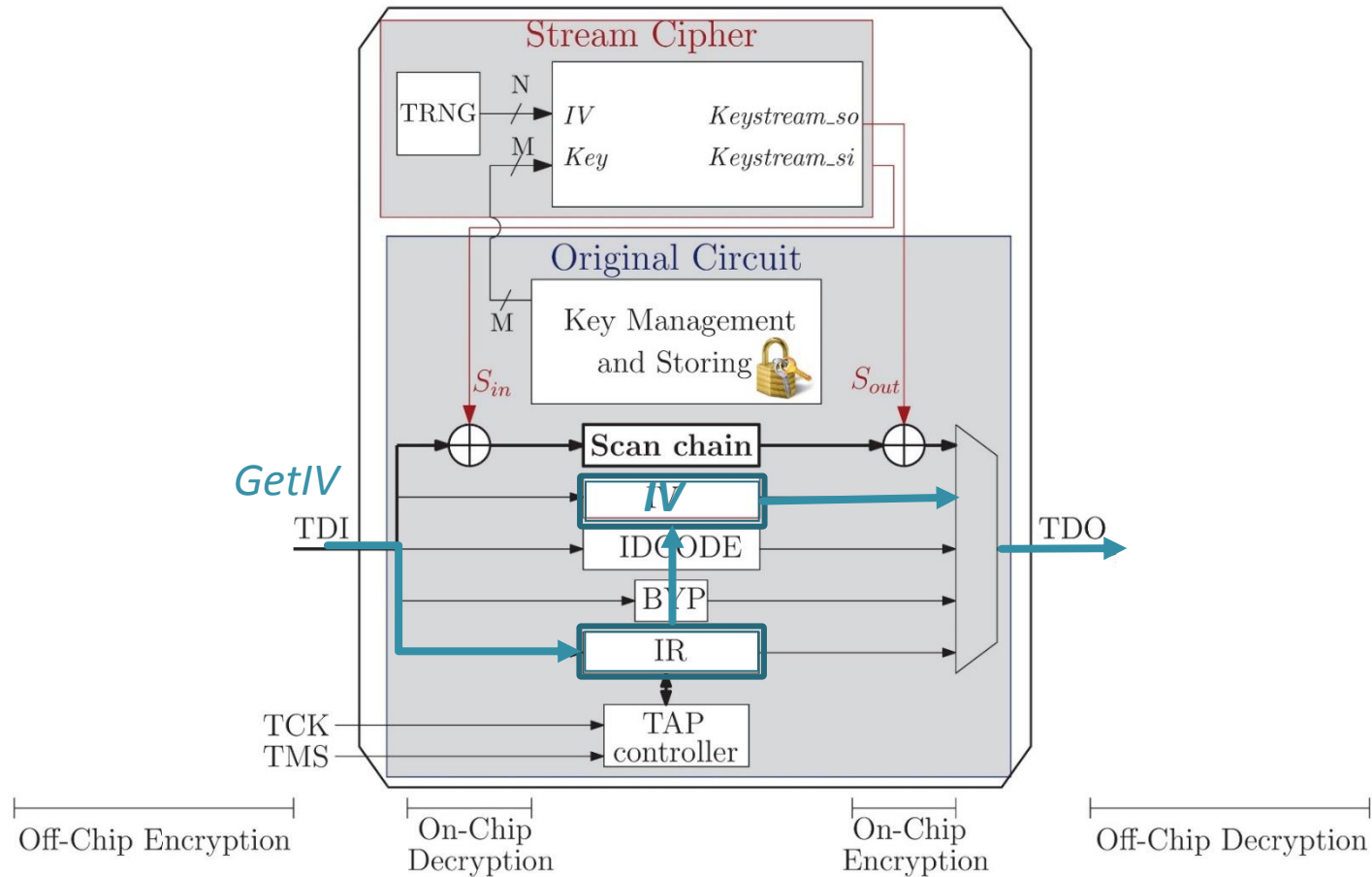


# INITIALIZATION PHASE



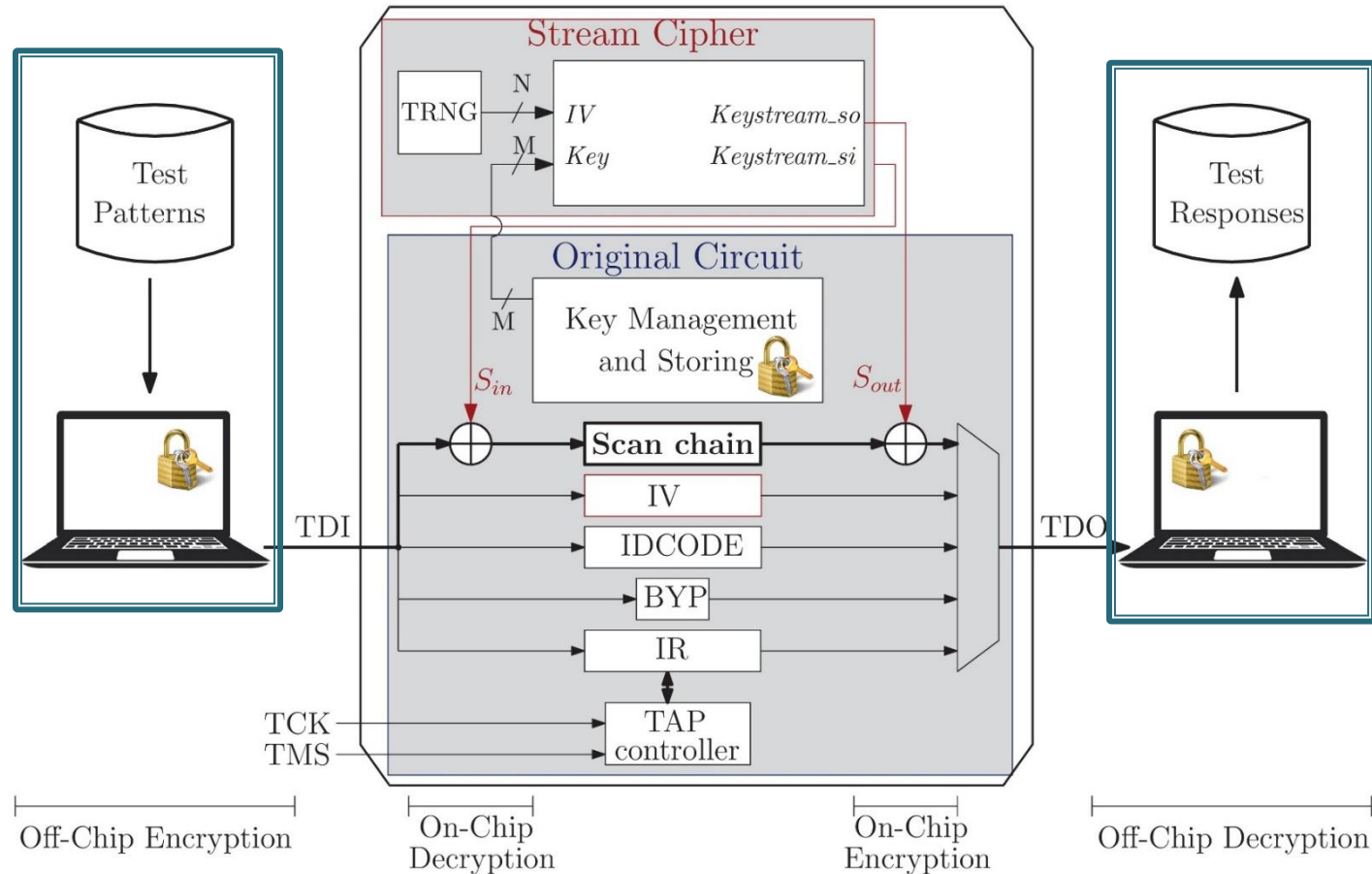
# ENCRYPTION PHASE

- Send *GETIV* instruction
- ⇒ Shift the content of the IV register out the circuit



# ENCRYPTION PHASE

- User can encrypt and decrypt test data with the **obtained IV** and the **shared secret key**



# TIME FOR THE INITIALIZATION PROCESS

- $T_{TRNG\_init}$  to initialize the TRNG
- 80 clock cycles to shift the  $IV$  in the register
- 1 152 clock cycles for the stream cipher setup

Original circuit	Triple-DES	Pipelined AES-128	Pipelined AES-256	RSA 1024	LEON3
Test time* (clock cycles)	687 101	1 944 877	4 559 845	39 405 239	11 612 051
<b>Test time overhead</b>					
Block-based solution (%)	+0.31	+0.81	+0.006	+0.33	+0.004
Stream-based solution (%)**	+0.18	+0.06	+0.03	+0.003	+0.01

\*: Test time considered for a fault coverage of 100%, except for LEON3 where it reaches 70%

\*\*: test time overhead without the initialization of the TRNG





# SUMMARY

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# COMPARISON BETWEEN BOTH SOLUTIONS

	Block cipher-based solution (PRESENT)	Stream cipher-based solution (TRIVIUM)
<b>Security</b>		
- Scan attacks	Protected	Protected (two times pad not possible)
- Malicious core	Protected	Protected
<b>Cost</b>		
- Area	10 658.96 $\mu\text{m}^2$	5 408.52 $\mu\text{m}^2$ (+ 31 200 $\mu\text{m}^2$ for TRNG)
- Test time	Depends on the scan length (multiple or not of the block size)	Clock cycles required for the initialization phase
<b>Integration</b>		
- Diagnosis & debug	Still possible in-field	
- Key management	Re-use key management already implemented	
- Integration in test daisy-chain	Possible issue with the padding of test data	No issue



Thank You



# ACKNOWLEDGEMENTS

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- FUI#20 TEEVA Project

- Partners



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HUBERT CURIEN**  
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