# Scan chain encryption in Test Standards

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

# SCAN CHAIN ENCRYPTION IN TEST STANDARDS

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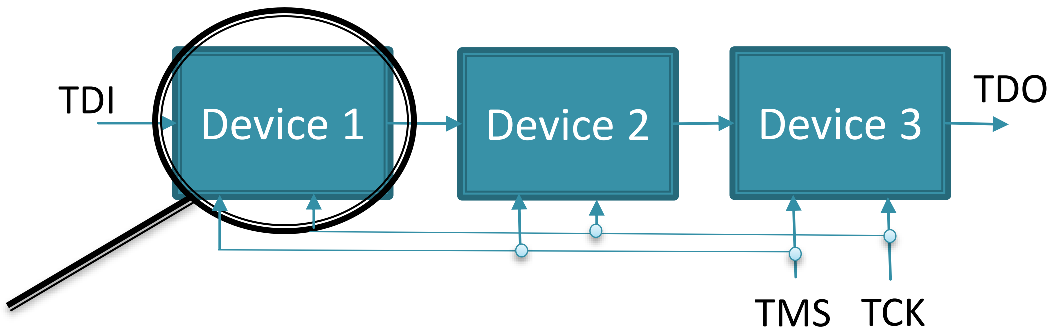
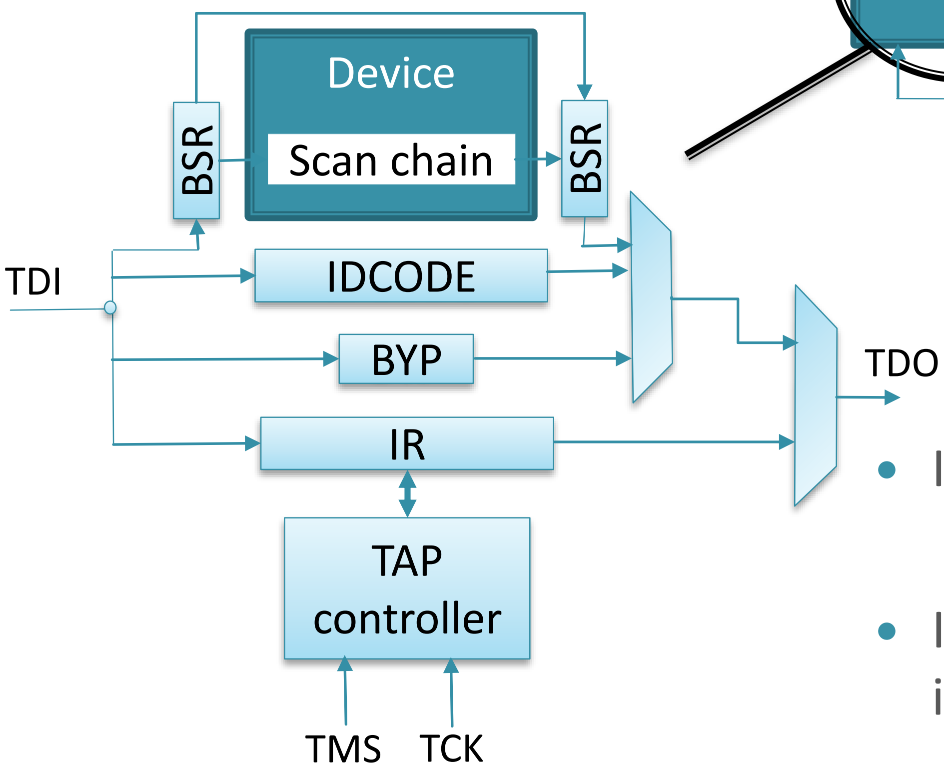
SURREALIST 2018

# CONTEXT

- Test standards
  - IEEE 1149 (JTAG) for board testing

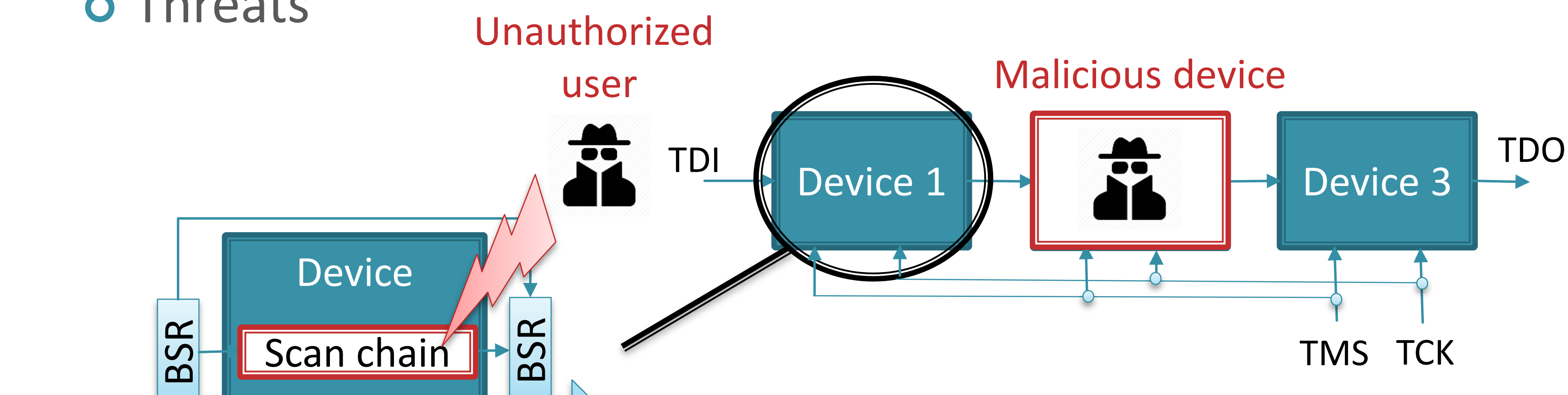


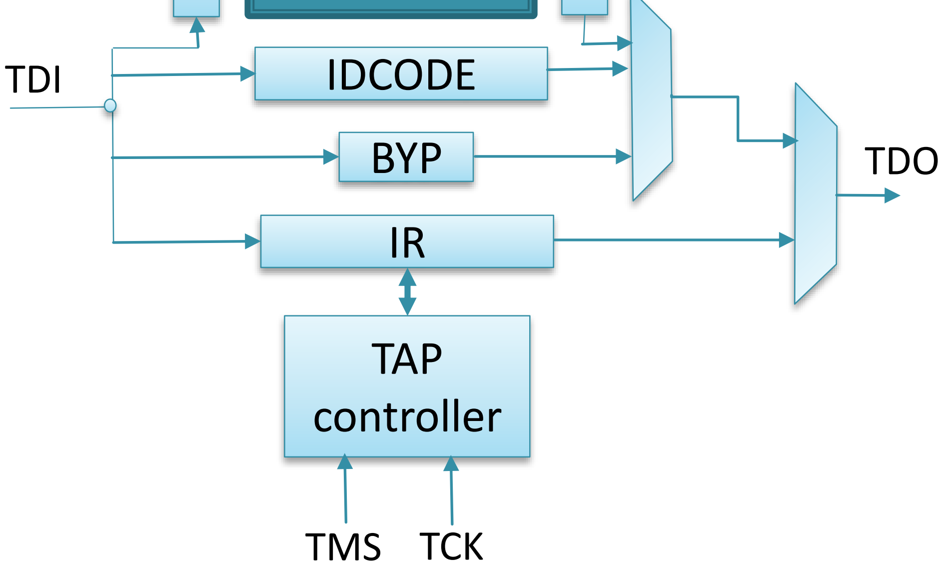




  - IEEE 1500 for cores testing in a SoC
  - IEEE 1687 (IJTAG) for embedded instruments

# 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

1) **Scan chain encryption**

2) State-of-the-art based on test communication encryption

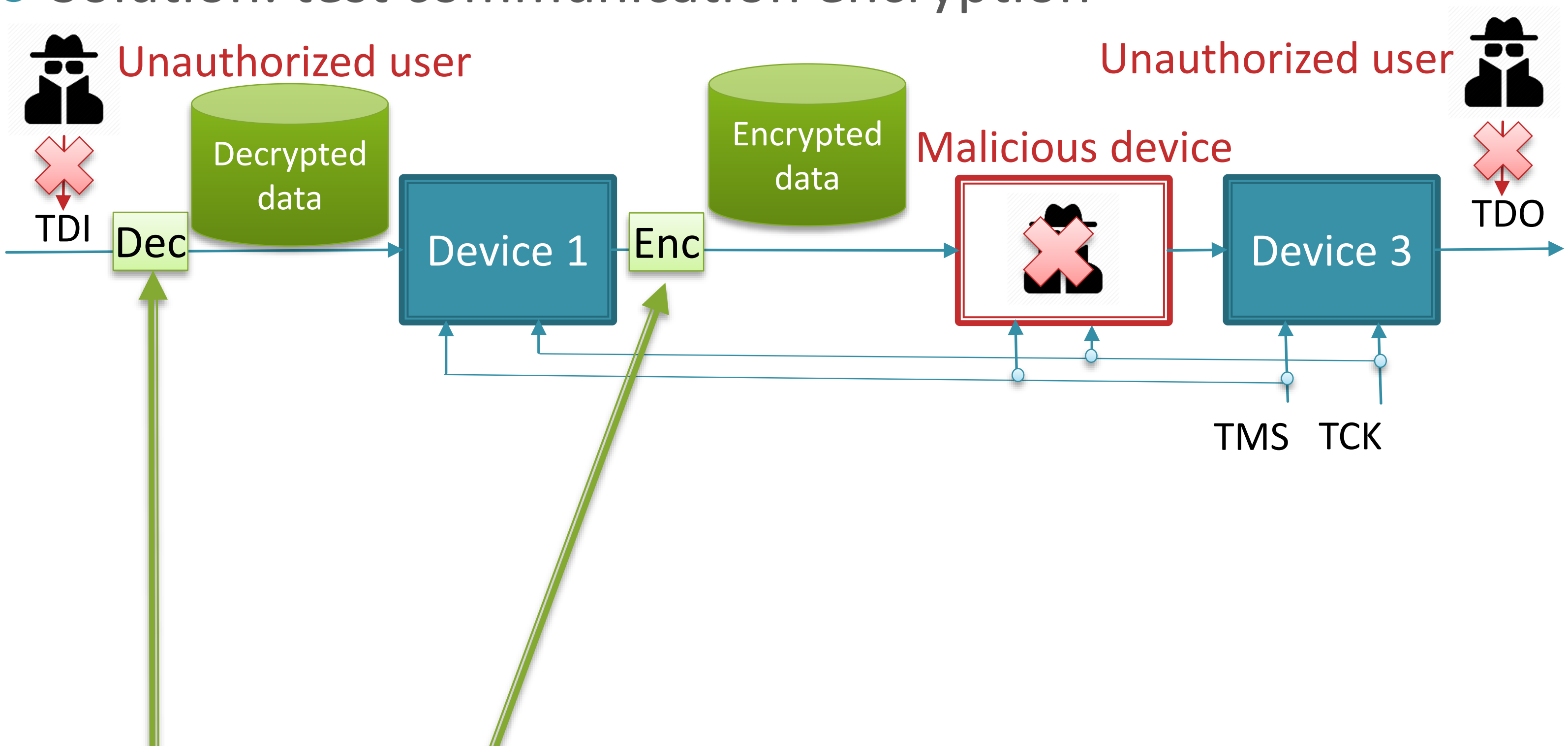
3) Implementation with block cipher

4) Implementation with stream cipher

5) Conclusion

# SCAN CHAIN ENCRYPTION

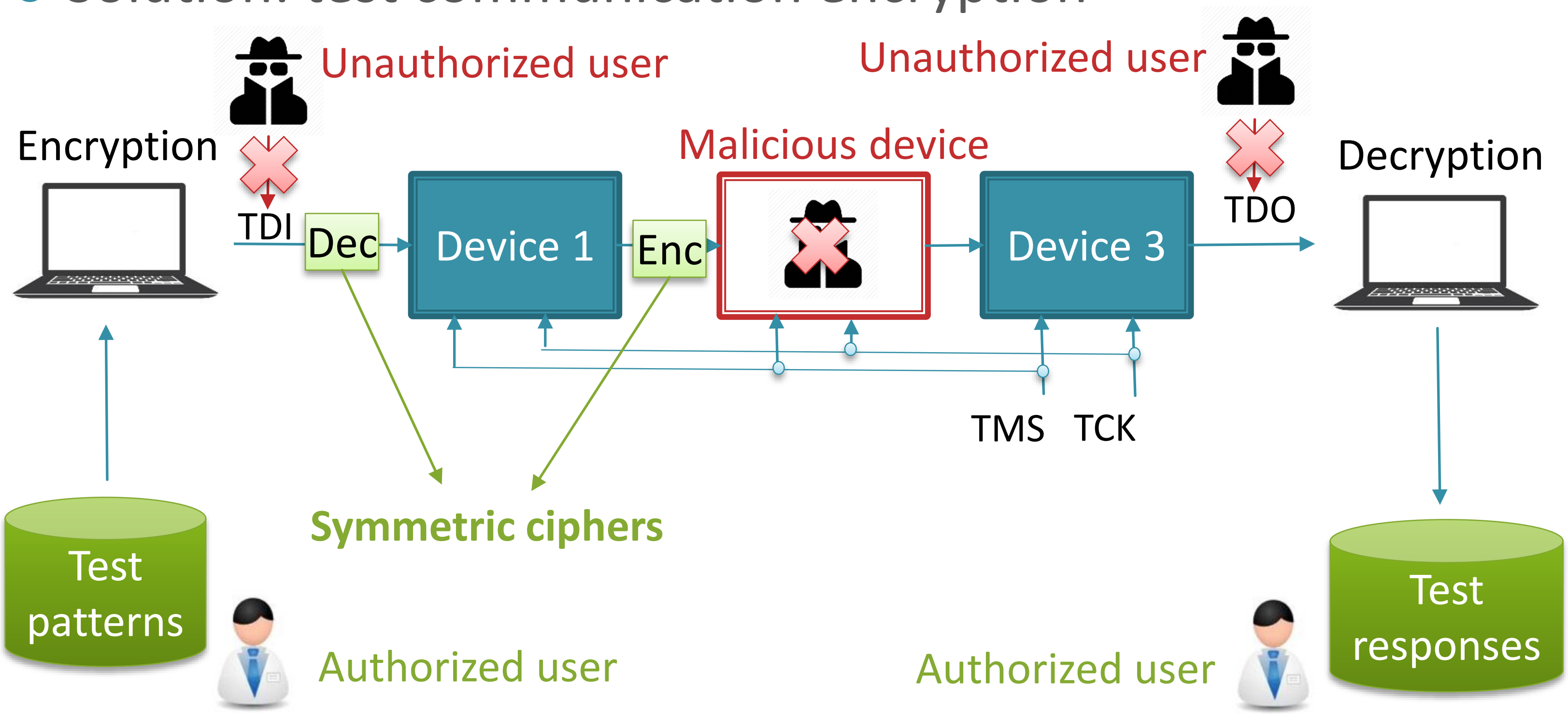
- Solution: test communication encryption




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

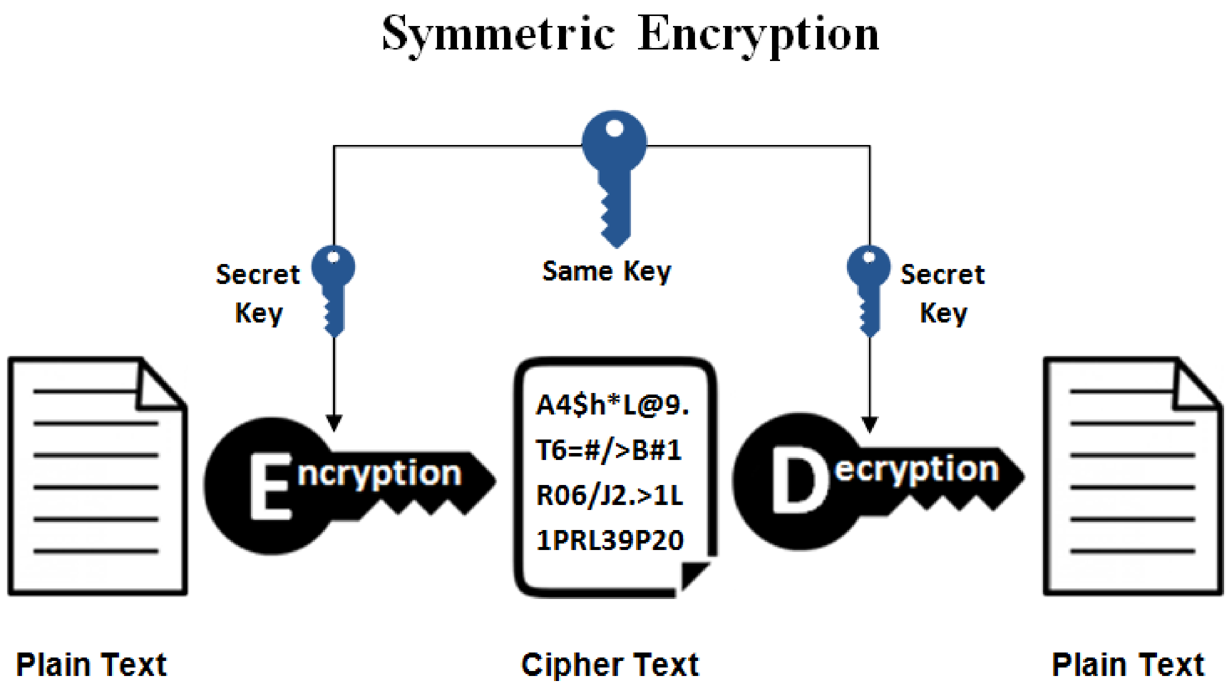
# Scan chain encryption

- 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

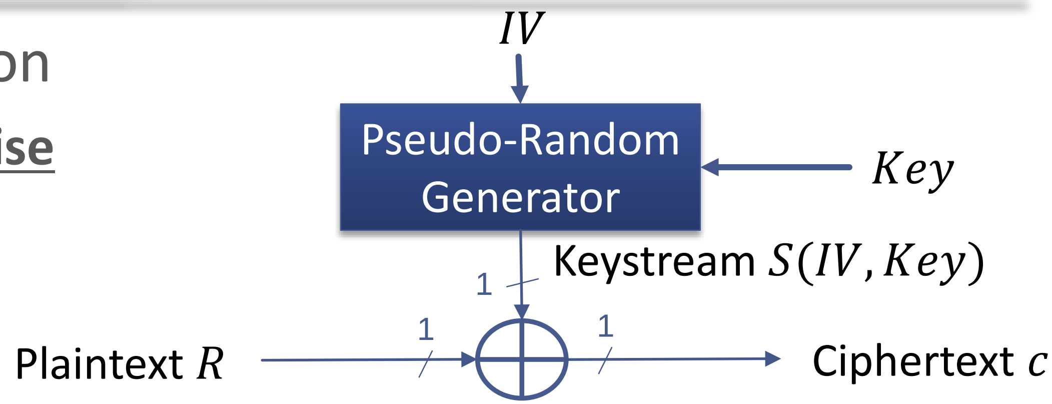
# Symmetric cipher



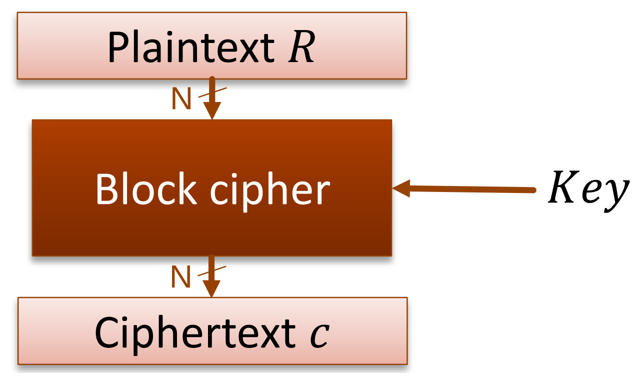

- 2 types of symmetric cipher: stream and block ciphers

# STREAM CIPHER / BLOCK CIPHER

- Stream cipher encryption
  - Keystream XORed **bitwise** with the plaintext



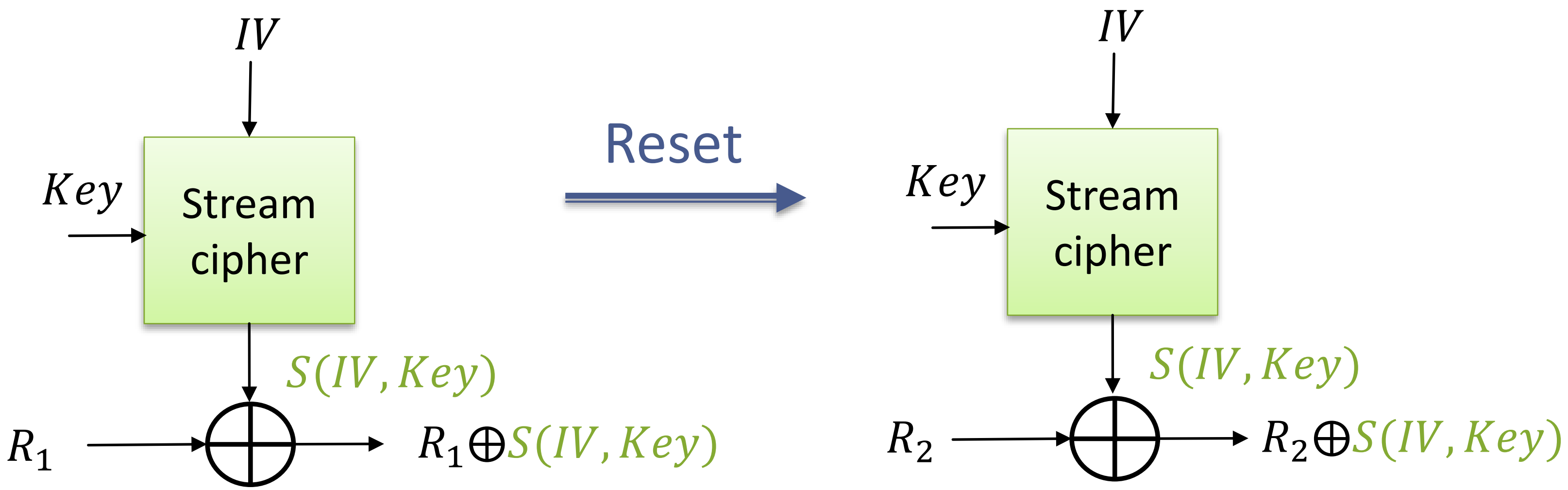

- Block cipher encryption
  - Confusion and diffusion on a **block** of plaintext




- 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 => same keystream generated to encrypt different data




⇒ Possible to carry out attacks if requirement is not fit

$$R1 \oplus \cancel{S(IV, Key)} \oplus R2 \oplus \cancel{S(IV, Key)}$$

⇒ Solution: *IV* generated randomly at each circuit reset

$$R1 \oplus S(IV_1, Key) \oplus R2 \oplus S'(IV_2, Key)$$

# SUMMARY

1) Scan chain encryption
2) **State-of-the-art based on test communication encryption**
3) Implementation with block cipher
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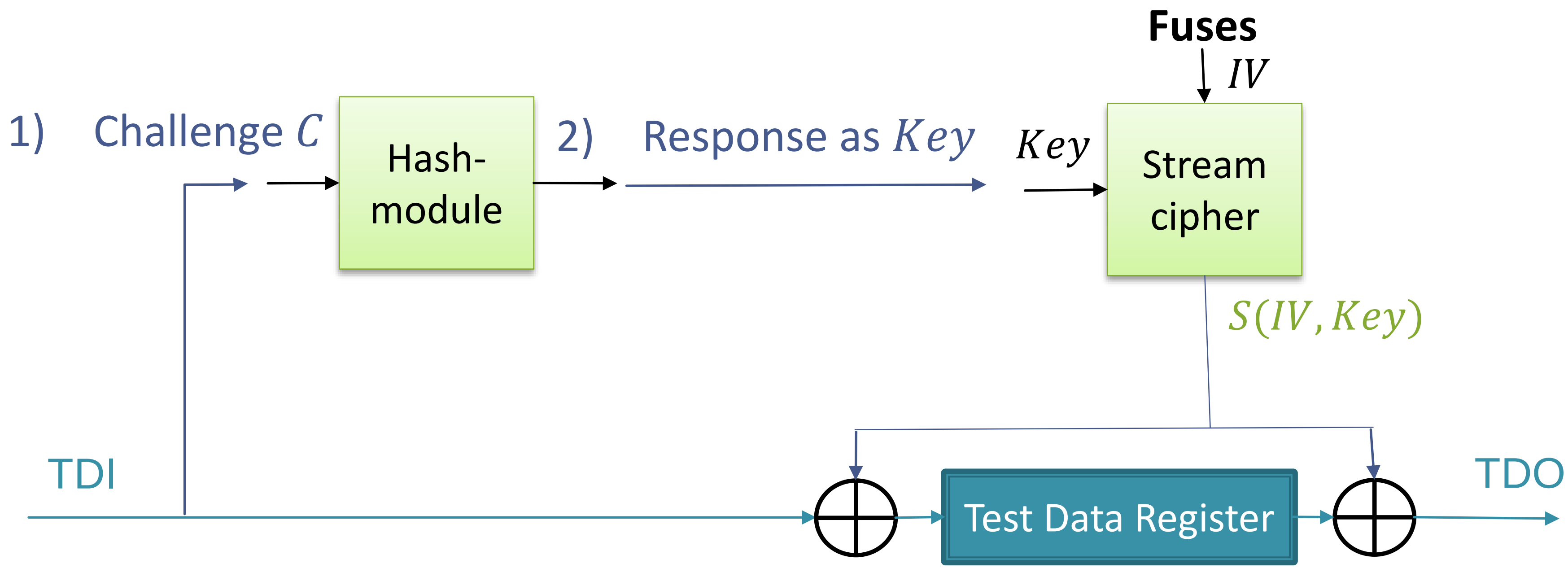
# Stream-based encryption on JTAG interface

- Challenge/Response protocol to encrypt JTAG test communication



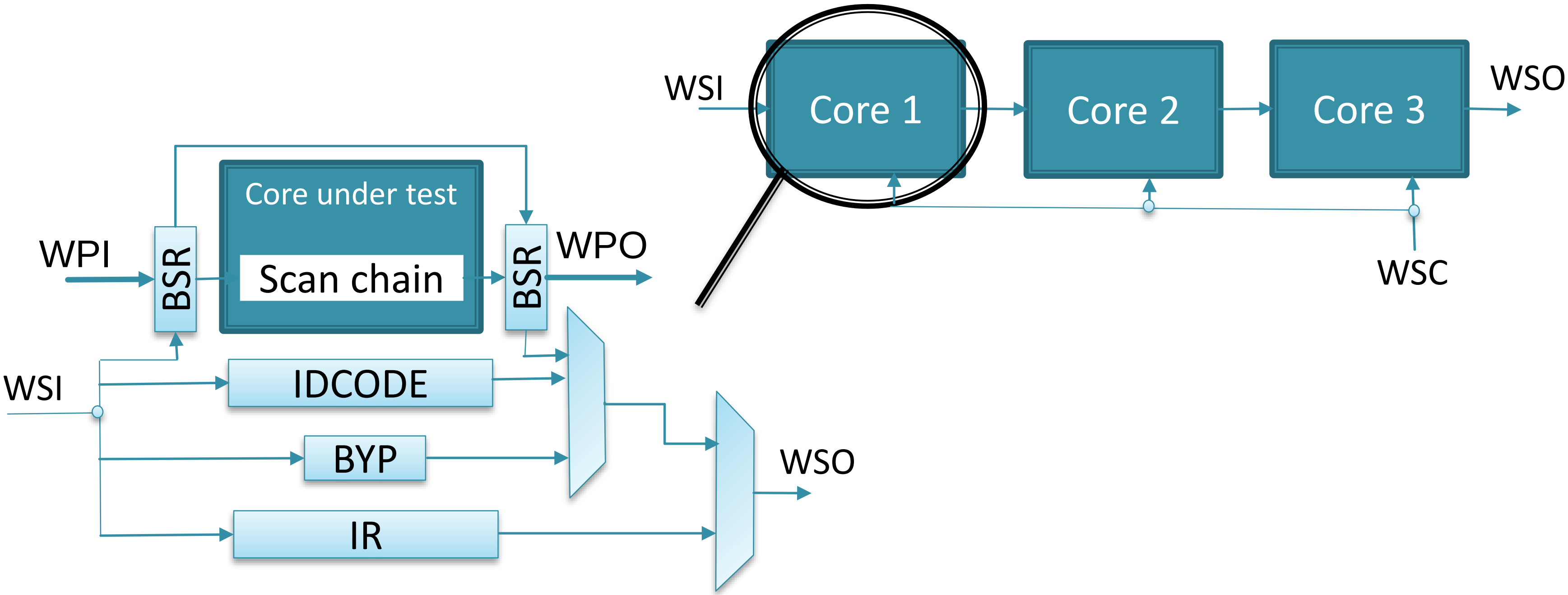

3) Encryption of the JTAG TDR with the keystream $S(IV, Key)$

Requirement not fulfilled

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

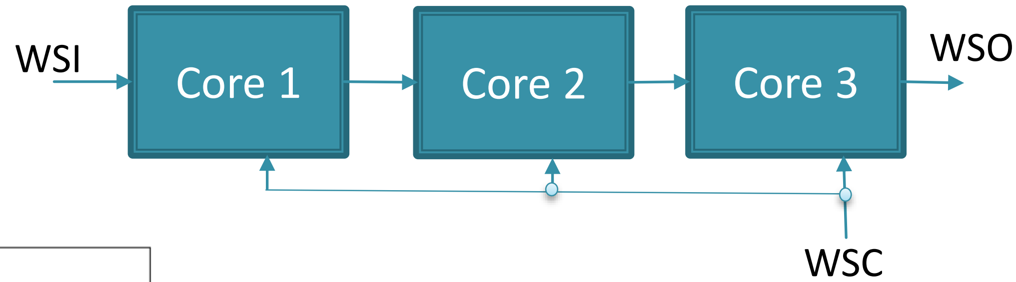
# Stream-based encryption on IEEE 1500 interface

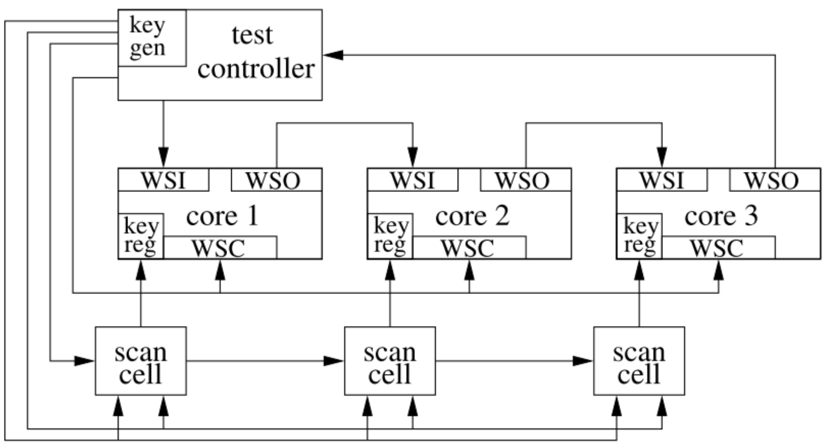
- IEEE 1500 standard
  - Similar as JTAG standard, but for SoC wrappers
  - Parallel test inputs WPI and parallel test outputs WPO



# Stream-based encryption on IEEE 1500 interface

- Encrypt test data on a targeted core (IEEE 1500)
  1) Send the key to the core via specific scan chain non-visible from the others cores

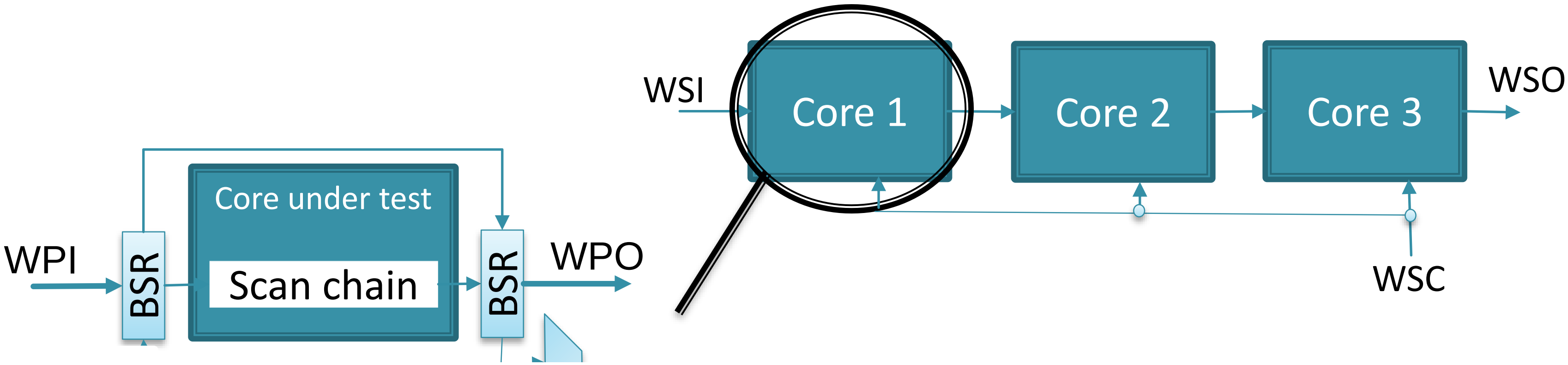


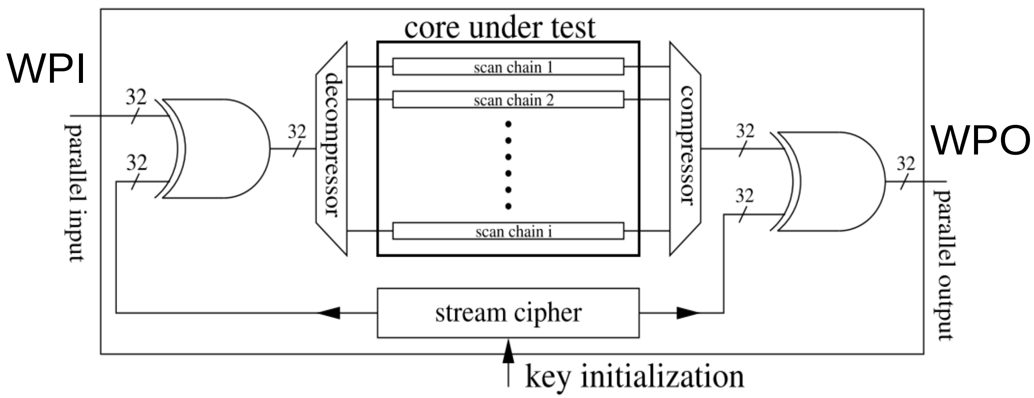




*Rosenfeld et al., Security-Aware SoC Test Access Mechanisms, VTS'11*

# STREAM-BASED ENCRYPTION ON IEEE 1500 INTERFACE

- Encrypt test data on a targeted core (IEEE 1500)
  1) Encrypt the parallel input/output (WPI and WPO)



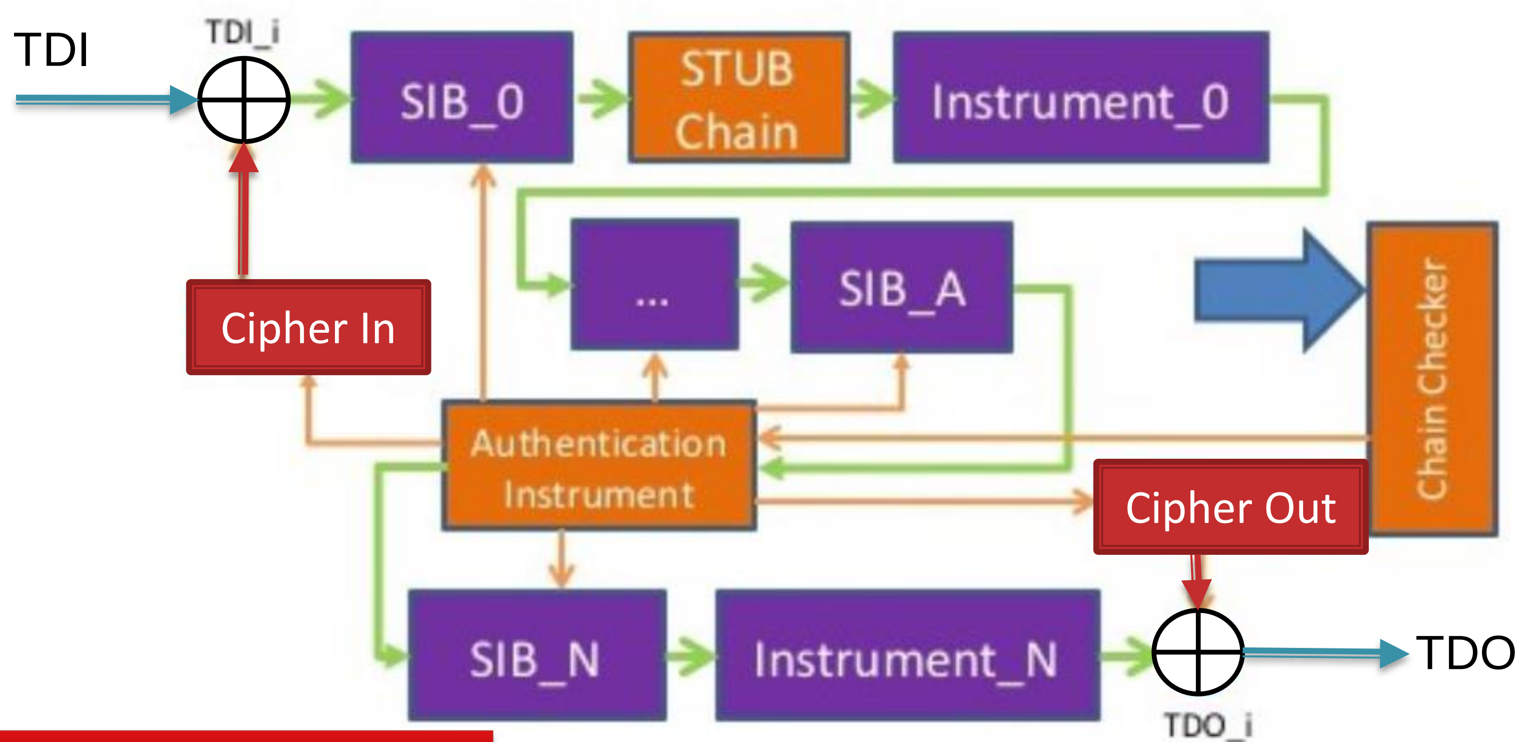




Requirement not fulfilled

*Rosenfeld et al., Security-Aware SoC Test Access Mechanisms, VTS'11*

# Stream-based encryption on IJTAG interface

- Encryption of Test Data Register associated to Instruments in the IJTAG network

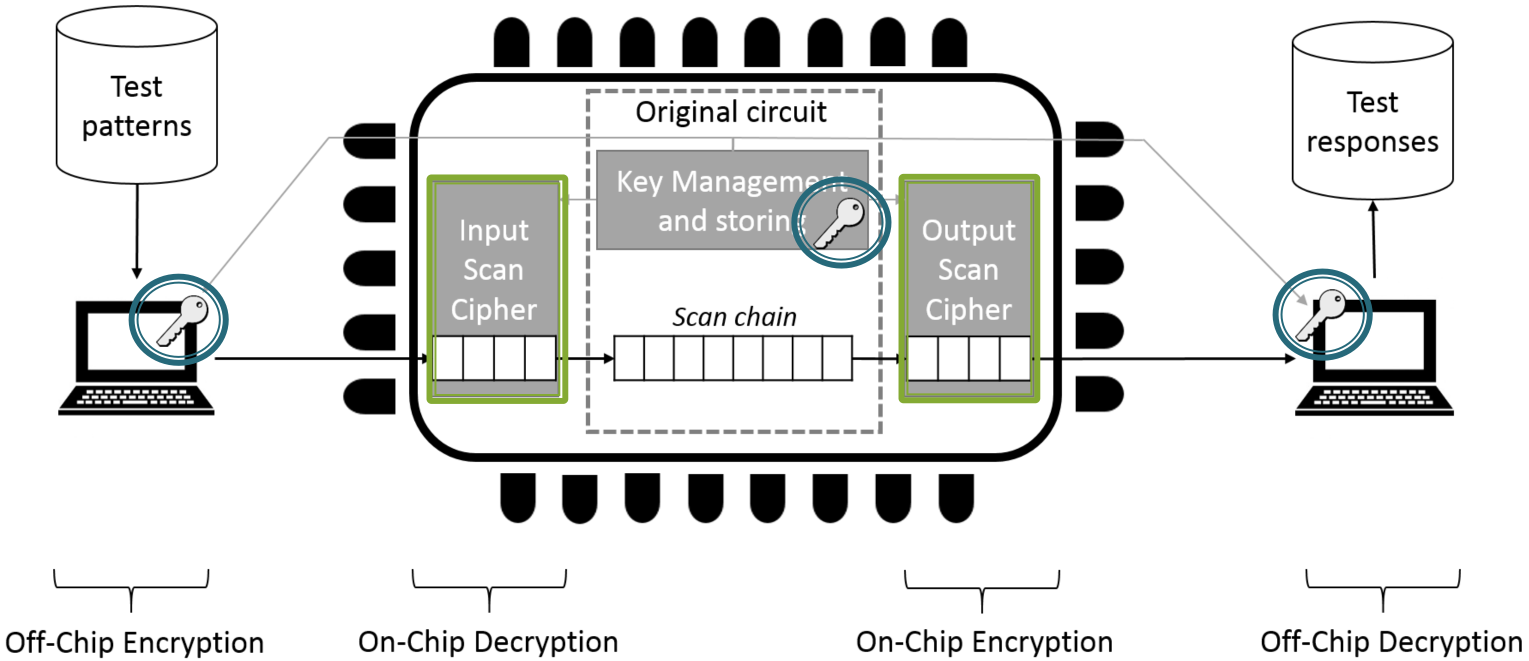



Requirement not fulfilled

*Kan et al., Echeloned IJTAG data protection, AsianHOST 2016.*

# Our proposition

- Insertion of block or stream ciphers at Scan-In and Scan-Out




- 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

1) Scan chain encryption
2) State-of-the-art based on test communication encryption
3) **Implementation with block cipher**
4) Implementation with stream cipher
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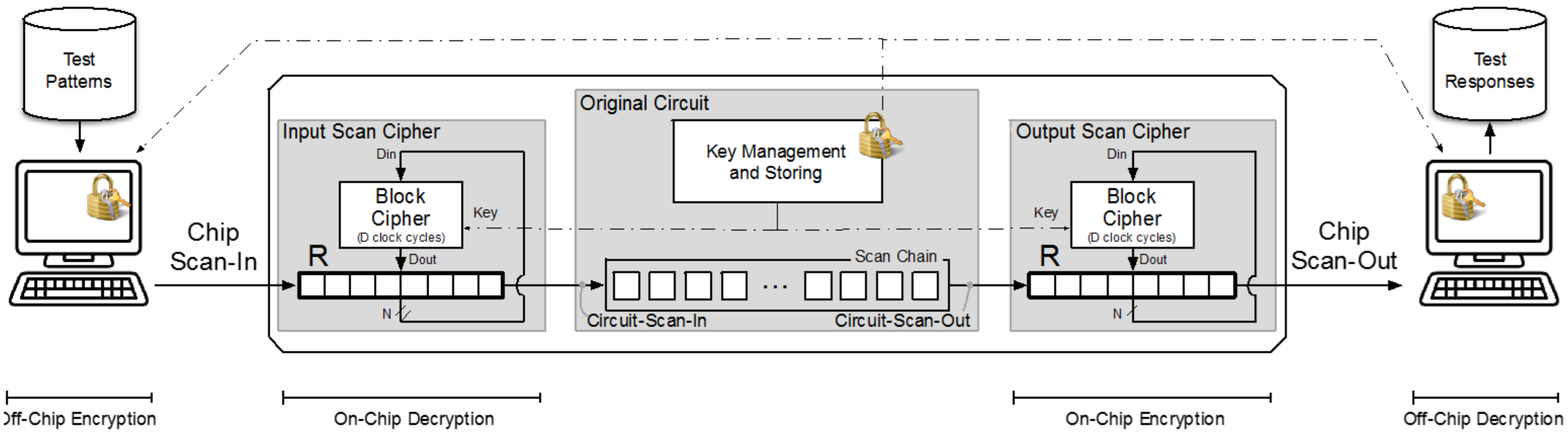
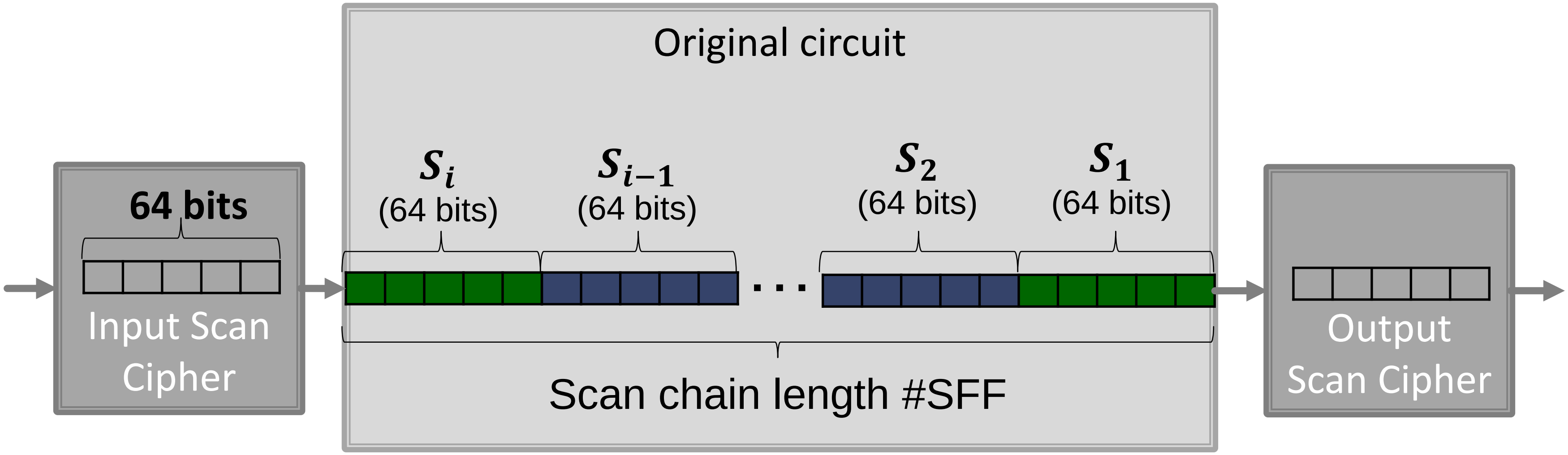
# BLOCK CIPHER-BASED SCAN ENCRYPTION

- 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

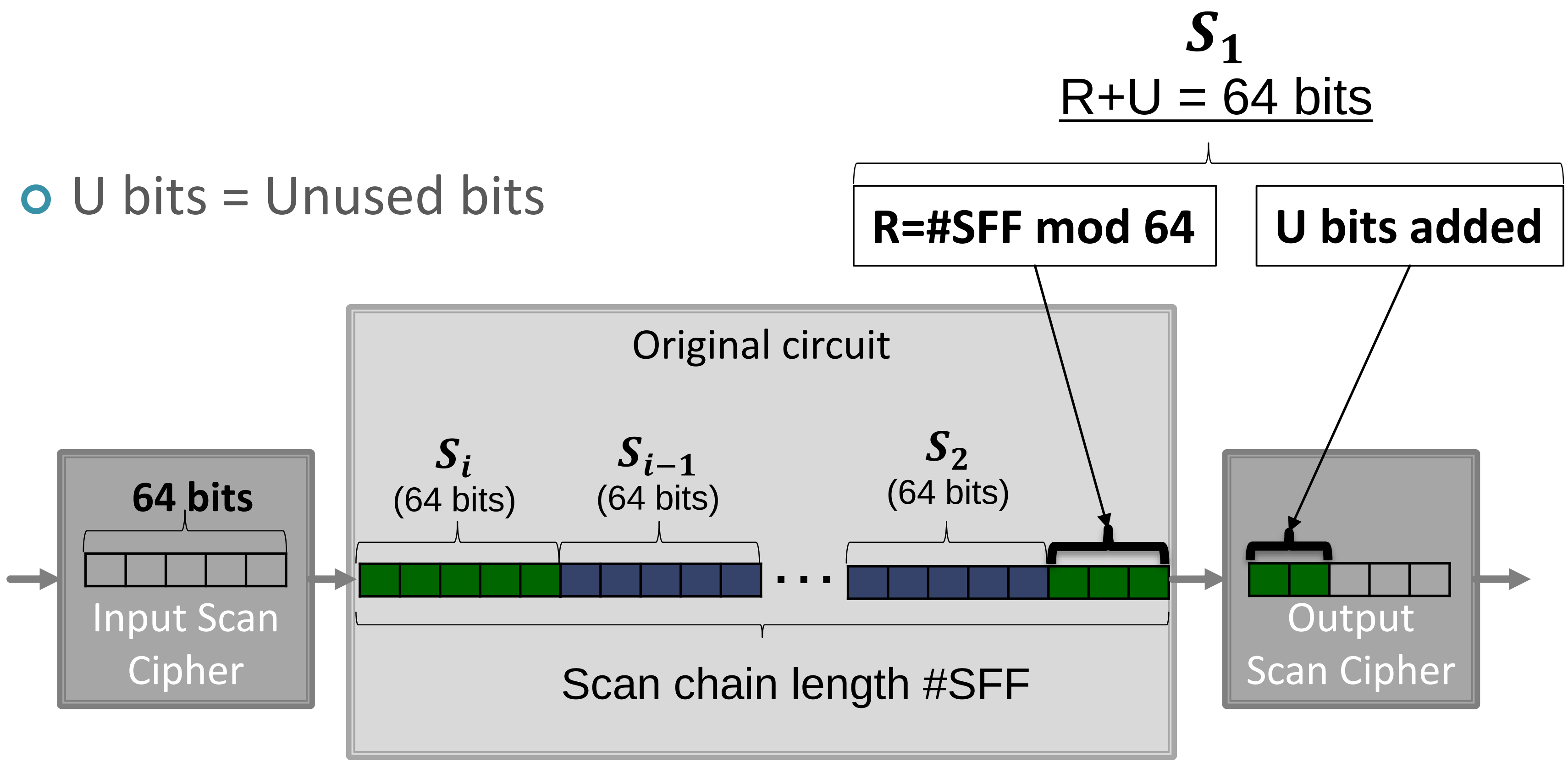



⇒ **#SFF = Px64**

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

# Mode of operations

- U bits = Unused bits




⇒ **#SFF = Px64 + R**

⇒ **Loss of U clock cycles per pattern**

# SUMMARY

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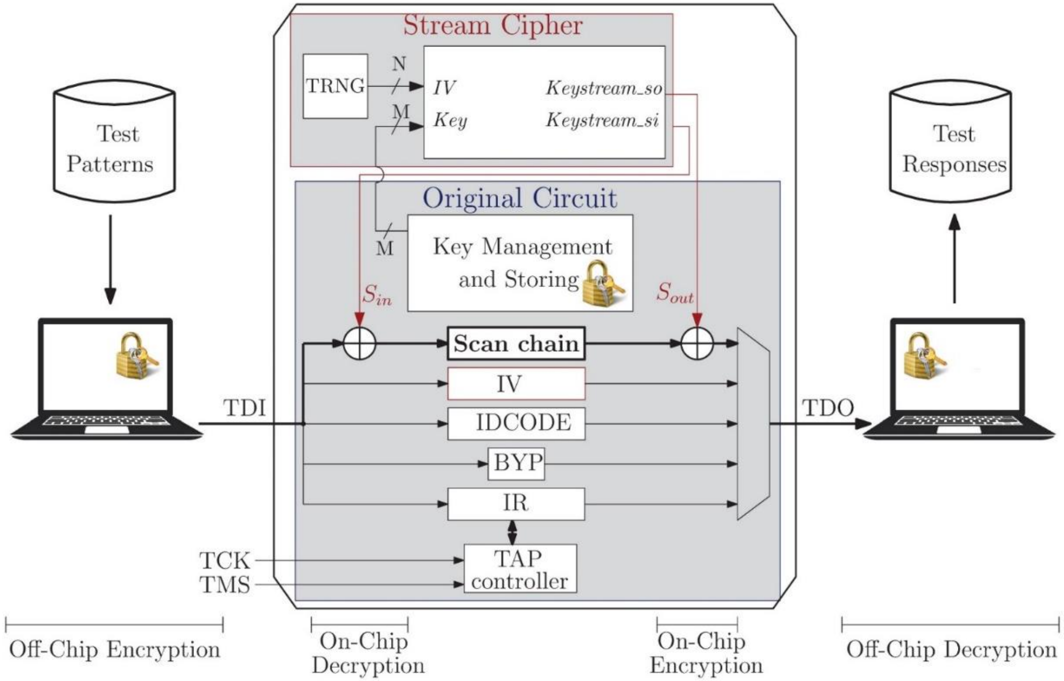
# STREAM CIPHER-BASED SCAN ENCRYPTION

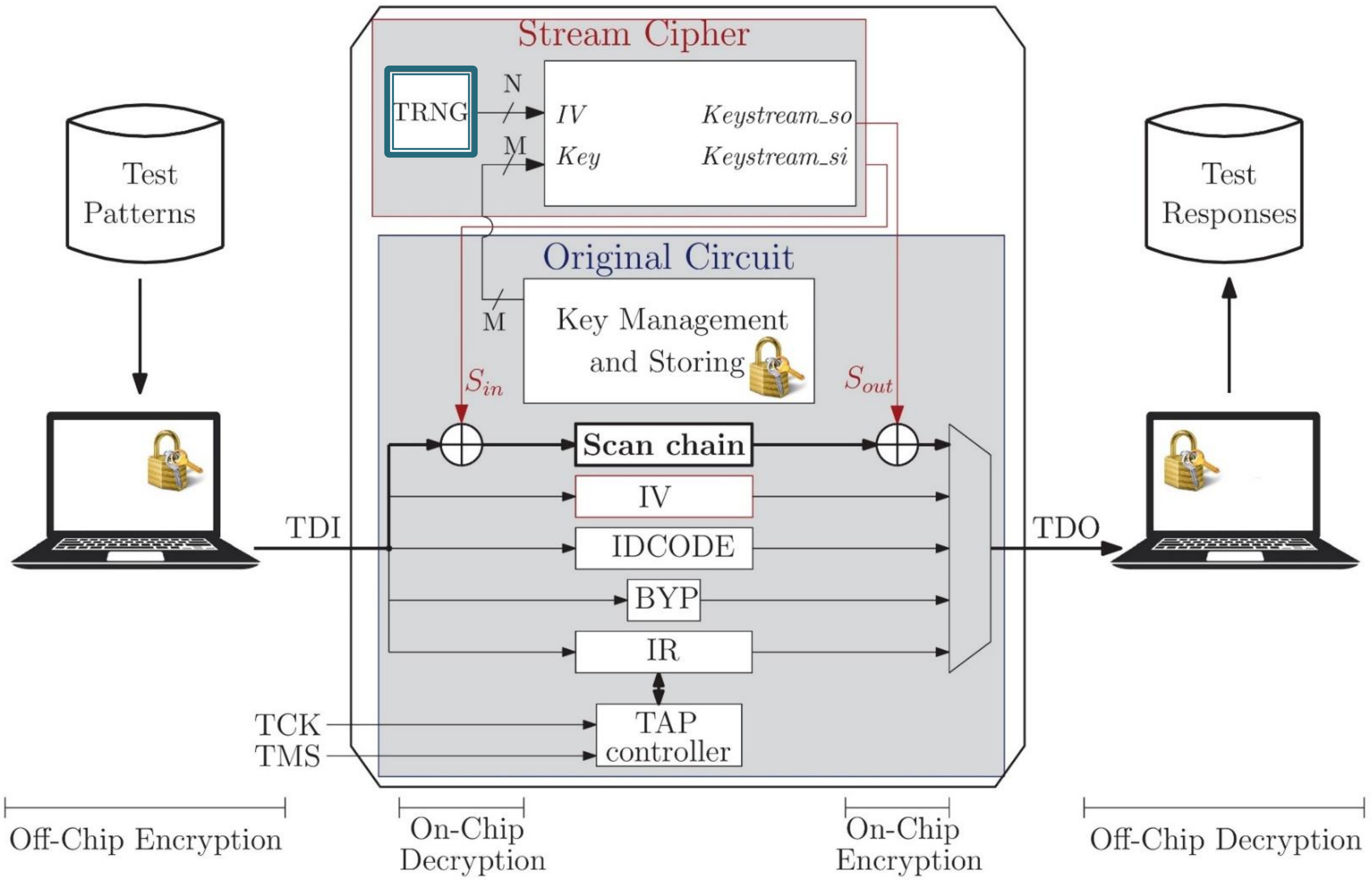
- Implementation on JTAG:
  - 1 TRIVIUM stream cipher (2 016 GE)
  - TRNG to generate random *IV*
  - New instruction *GetIV* with a test data register IV



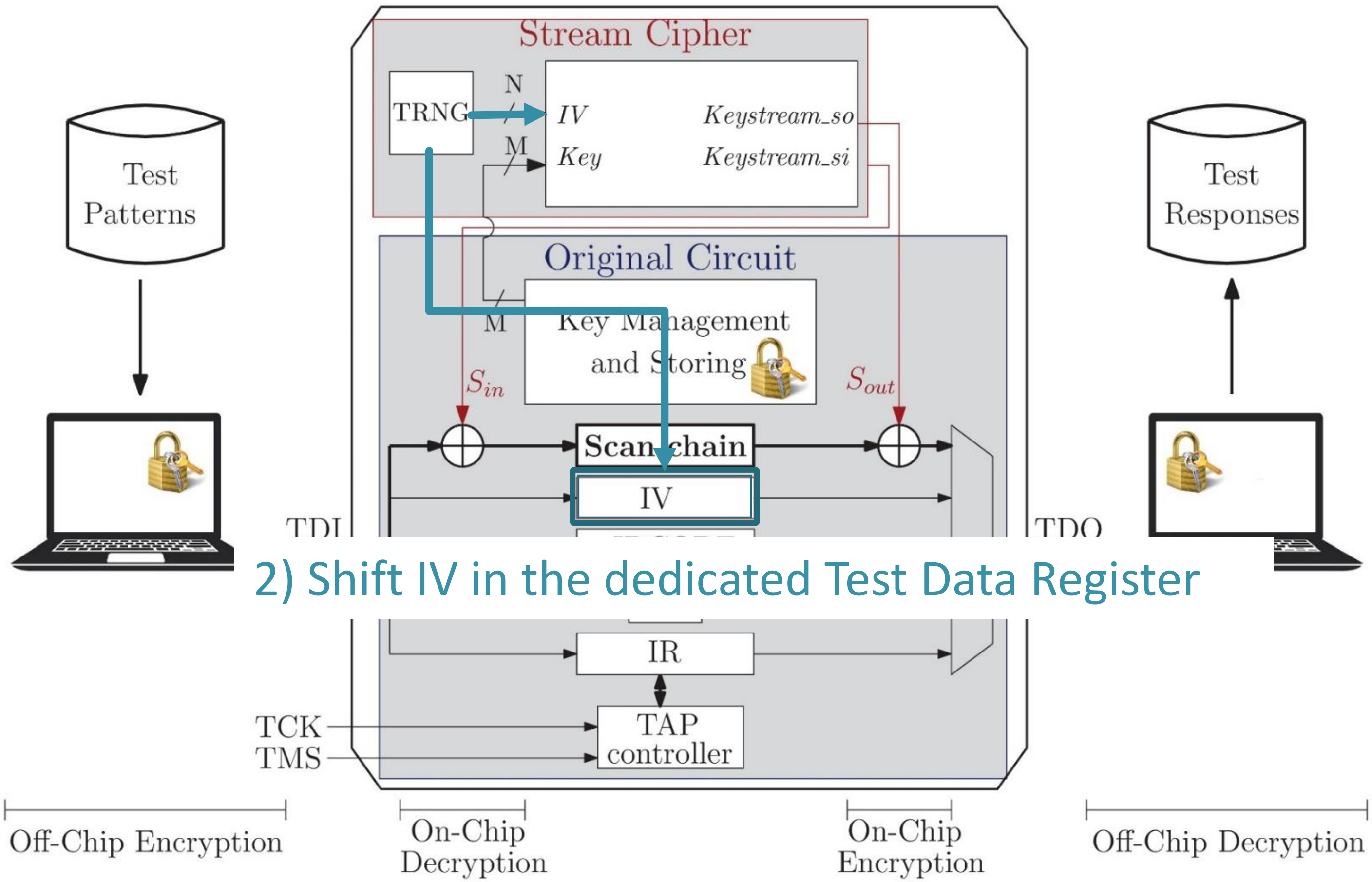

- Mode of operations in 2 phases: initialization and encryption

# INITIALIZATION PHASE

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



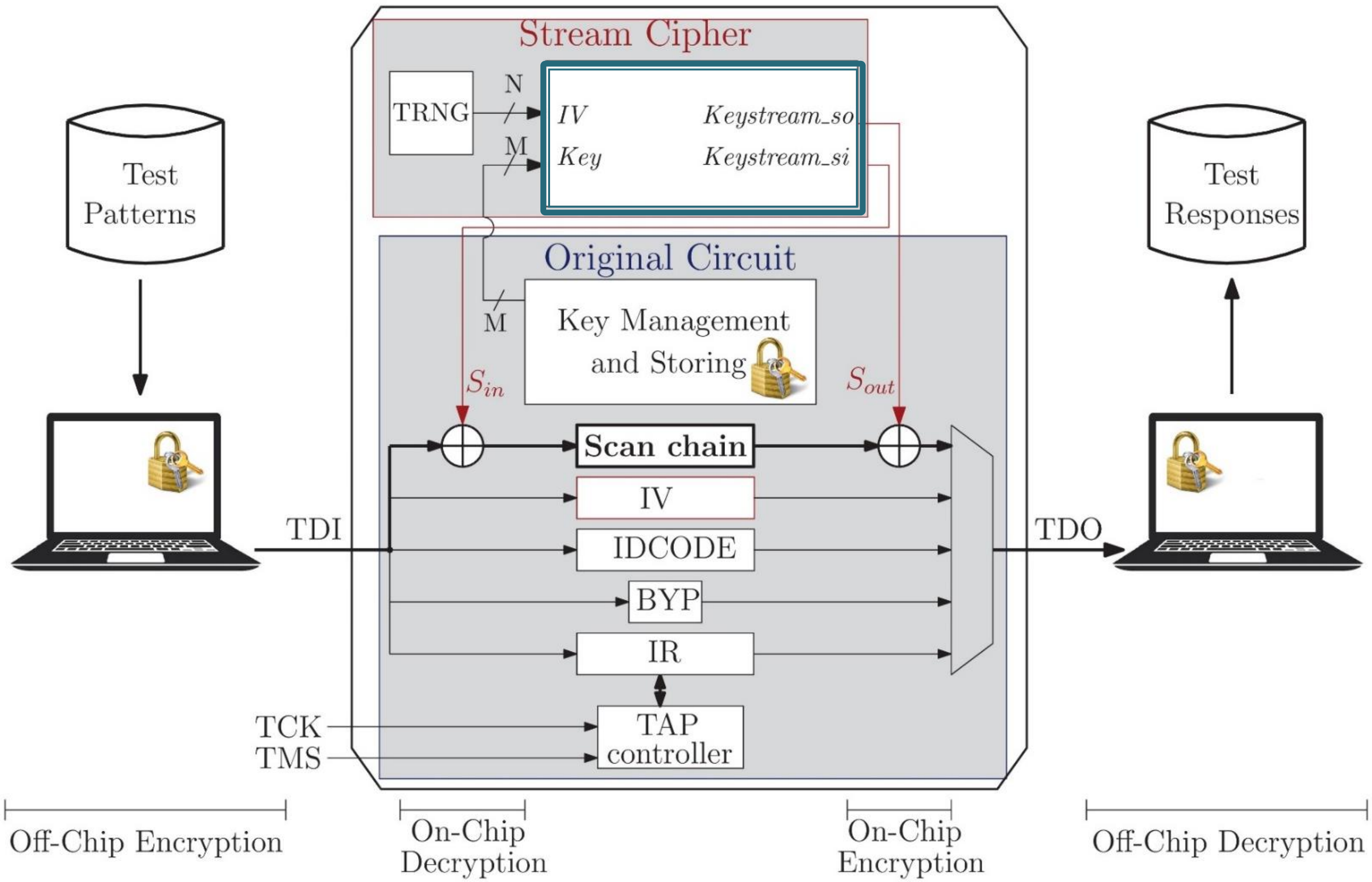
# INITIALIZATION PHASE



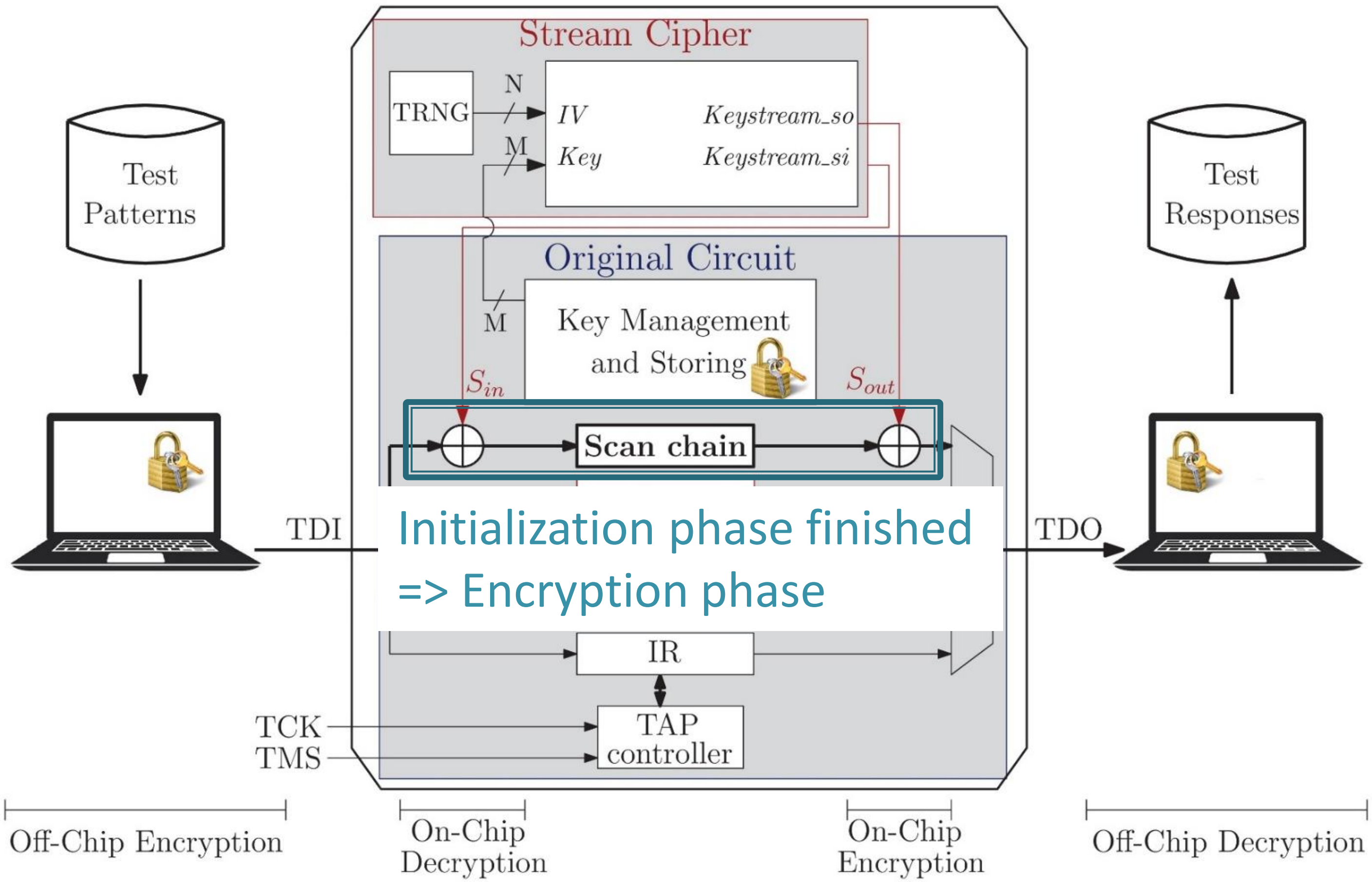

2) Shift IV in the dedicated Test Data Register

# INITIALIZATION PHASE

## 3) Stream cipher setup



# INITIALIZATION PHASE

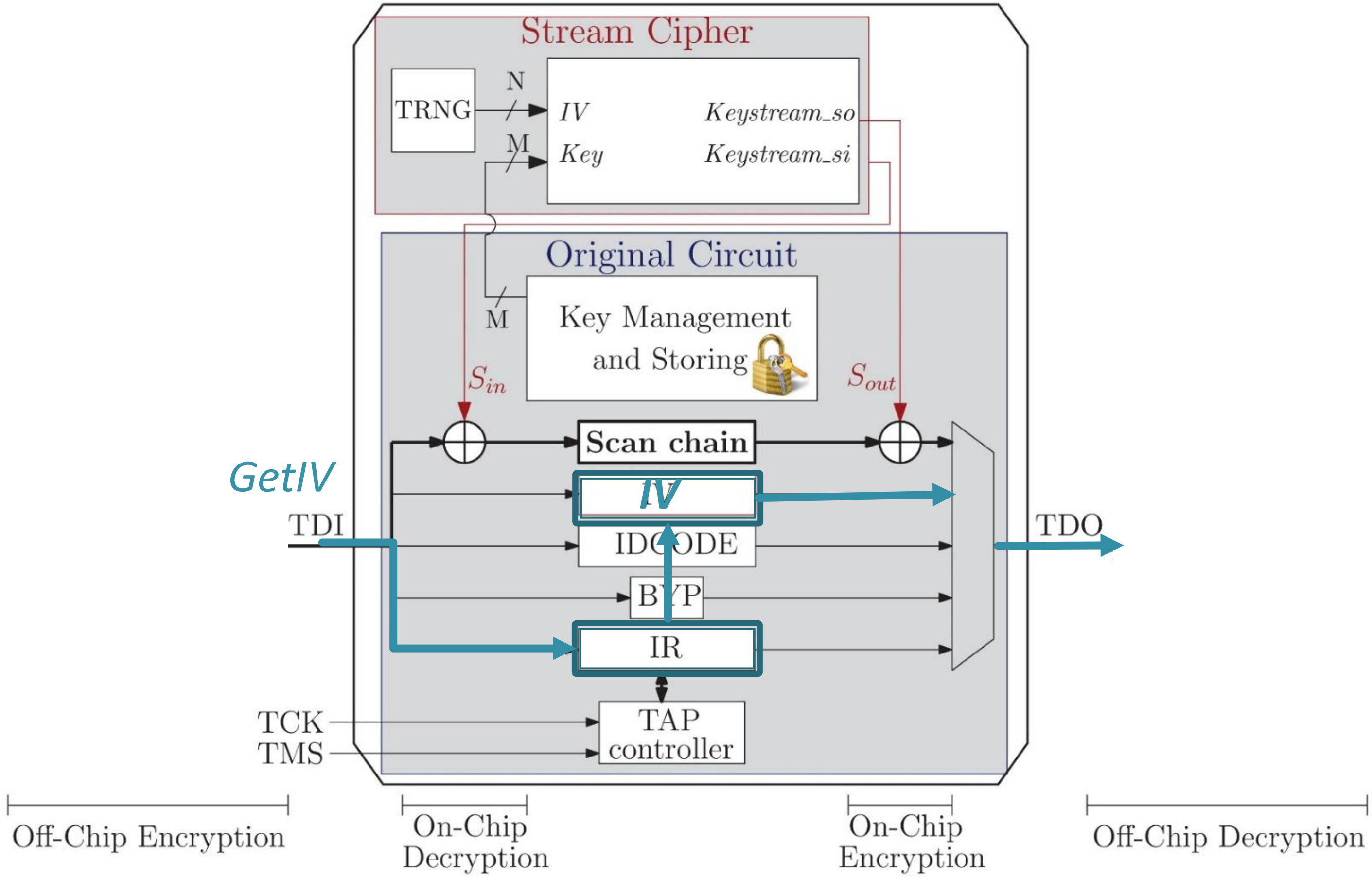



Initialization phase finished
=> Encryption phase

# Encryption phase

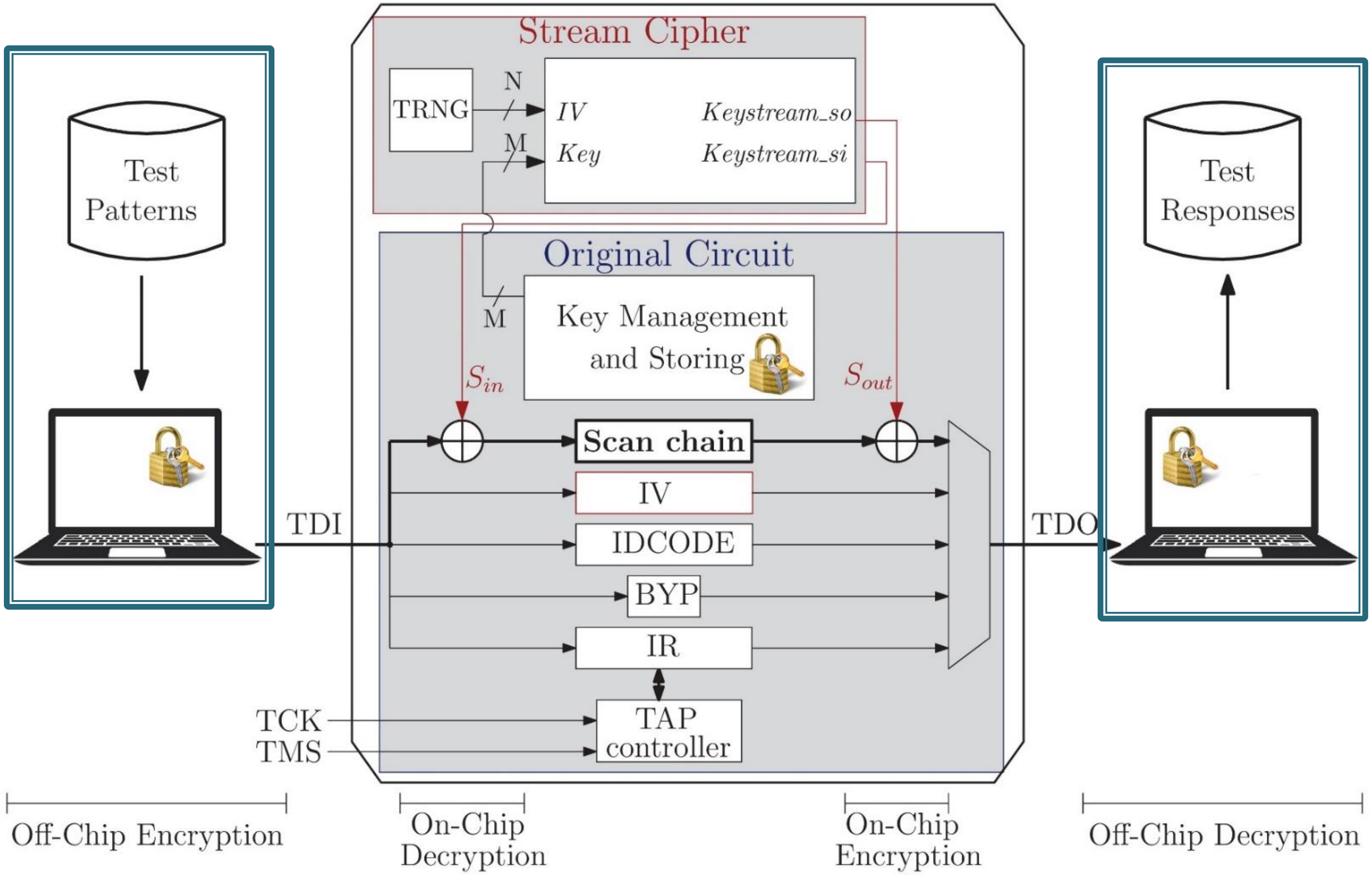
- User sends *GETIV* instruction

⇒ 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 |
| ***Test time overhead*** | | | | | |
| 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) |
|---|---|---|
| ***Security*** | | |
| - Scan attacks | Protected | Protected (two times pad not possible) |
| - Malicious core | Protected | Protected |
| ***Cost*** | | |
| - Area | 10 658.96 µm² | 5 408.52 µm² (+ 31 200 µm² for TRNG) |
| - Test time | Depends on the scan length (multiple or not of the block size) | Clock cycles required for the initialization phase |
| ***Integration*** | | |
| - 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