HECTOR TRNG design approach and its demonstration

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HECTOR

Outline

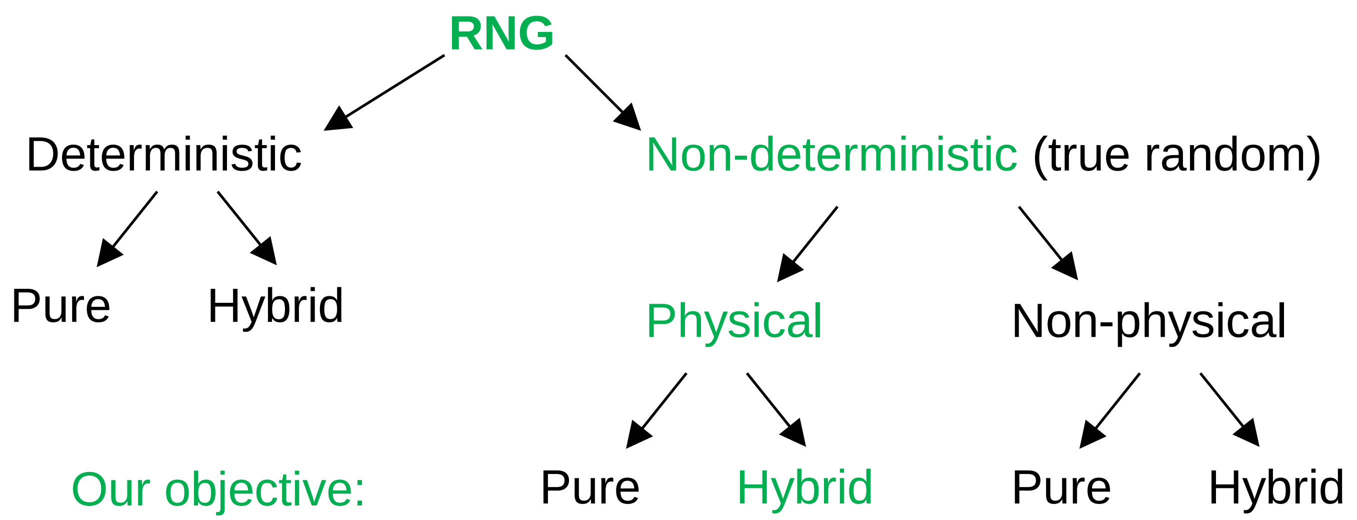
- Introduction – random number generators for cryptography
- Standards for random number generator design
- Illustration of a standard design on HECTOR Demonstrator 1
- Demonstration
- Conclusions

Introduction

- Random number generators (RNGs) constitute essential part of (hardware) cryptographic modules
- Generated random numbers are used as:
  - Cryptographic keys (high security requirements)
  - Masks in countermeasures against side channel attacks
  - Initialization vectors, nonces, padding values, …
- Two main security requirements on RNGs:
  - R1: Good statistical properties of output numbers
  - R2: Unpredictability of output values

Classification of RNGs

- Deterministic RNG (DRNG) – algorithmic generator started with a seed
- True random number generator (TRNG) – non-deterministic (truly random)
  - Physical TRNG (PTRNG) – uses some random physical phenomena
  - Non-physical TRNG (NPTRNG) – uses some non-deterministic events (RAM contents, user interaction (mouse, keyboard), hard disk seek time, etc.)



Evaluation of security requirements

R1: Statistical quality - evaluated using **statistical tests**

- General purpose (black box) statistical tests
  - Standard tests (their speed depends on their precision)
    - FIPS 140-1
    - DIEHARD
    - NIST SP 800-22
- Dedicated (white box) statistical tests (faster and reliable)

R2: Unpredictability – evaluation depends on the generator class

- **Physical unpredictability** - evaluated using **entropy estimation**
  - Entropy is estimated using the stochastic model

- **Computational unpredictability** - evaluated using **cryptoanalysis**
  - Approved cryptographic algorithms are recommended

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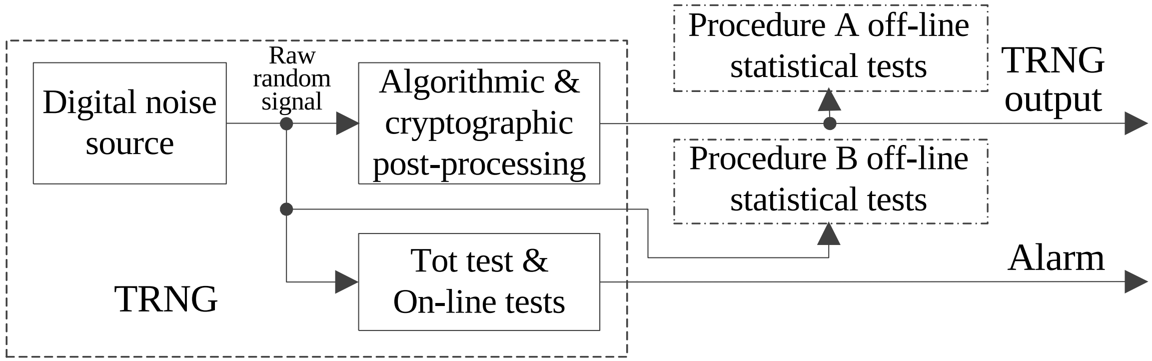
Security standards concerning the TRNG design

- Unlike other cryptographic primitives, TRNGs cannot have standard architectures
- Instead, standard design approach is required
- Currently, two standards are available:
  - **AIS 20/31** of German Federal Office for Information Security (German acronym BSI)
  - **NIST SP 800-90B** of American National Institute for Standards and Technology (NIST)
- The two standards have different design approach, but solutions can be found to fulfill requirements of both of them

European RNG design style

- AIS 20/31 design style



- **Digital noise source** – generates raw random signal
- **Algorithmic post-processing** – enhances statistical properties of generated numbers (increases entropy rate)
- **Cryptographic post-processing** – cryptographic algorithm ensuring computational unpredictability when the source of randomness fails
- **Total failure test** – fast and robust continuous test , no numbers are output if this test fails
- **Online tests** – preferably dedicated tests, based on the stochastic model
- **Off-line tests** (Procedure A and Procedure B) – see later

RNG classes according to AIS 20/31

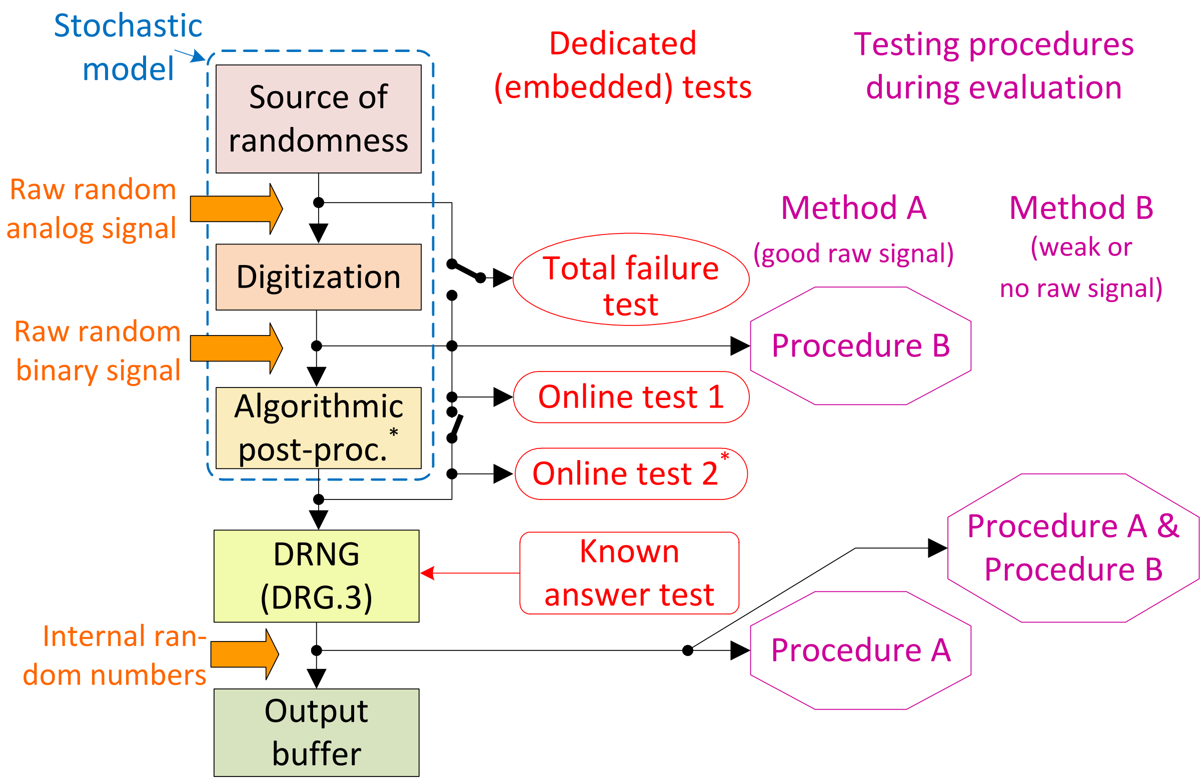
RNG classes

- Three physical TRNG classes
  - **PTG.1** – Physical RNG with internal tests that detect a total failure of the entropy source and non-tolerable statistical defects of the internal random numbers
  - **PTG.2** – PTG.1 + a stochastic model of the entropy source and statistical tests of the raw random numbers (instead of the internal random numbers)
  - **PTG.3** – PTG.2 + cryptographic post-processing (hybrid PTRNG) – HECTOR objective

- One non-physical RNG class
  - **NTG.1**
- Four deterministic RNG classes
  - **DRG.1** to **DRG.4**

Out of HECTOR scope

Class PTG.3 – the highest AIS 31 security class



Stochastic model

- Must be used to estimate entropy

Dedicated tests & entropy

- Total failure, online and startup test requirements as in PTG.2
- Shannon entropy of internal random numbers > 0,997
- Cryptographic post-proc. must be tested by a KAT

Evaluation procedures

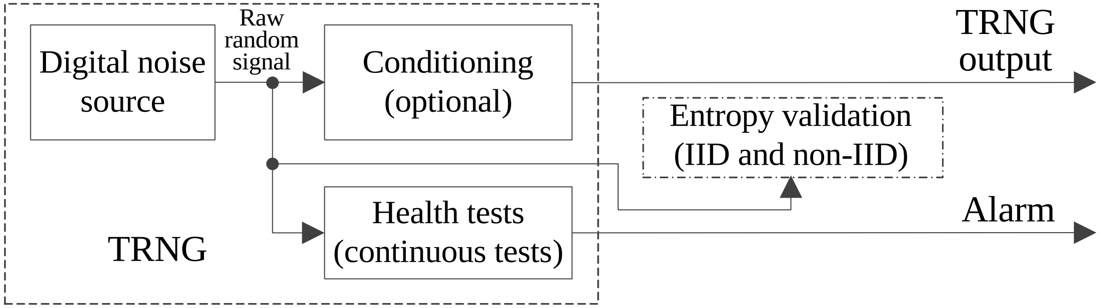
- Depending on availability and quality of the raw binary signal: Method A (preferable) or Method B

- Highest security – the information-theoretical security combined with the computational security

* Algorithmic post-processing and Online test 2 are optional

American RNG design style

- NIST SP 800-90B design style



  - **Digital noise source** – generates raw random signal
  - **Conditioning** – enhances statistical properties of generated numbers (increases entropy rate): by vetted or non-vetted algorithms
  - **Health tests** – fast and robust continuous tests, no numbers are output if these test fail, two tests are recommended (other equivalent or better are allowed):
    - Repetition count
    - Adaptive proportion
  - **Off-line tests** – entropy validation on two branches: IID and non-IID

Recommendation of the French DGA-MI (DoD)

- Recommendations for high-end TRNGs (first draft in progress)
- Additional requirements on high-security TRNGs comparing to AIS 31
  - Only the source of the digital noise is considered (not the post-processing)
  - Stochastic model of the source of randomness is required (not only of the whole TRNG)
  - All the deterministic parts of the generator must be tested by a KAT (not only the cryptographic post-processing)

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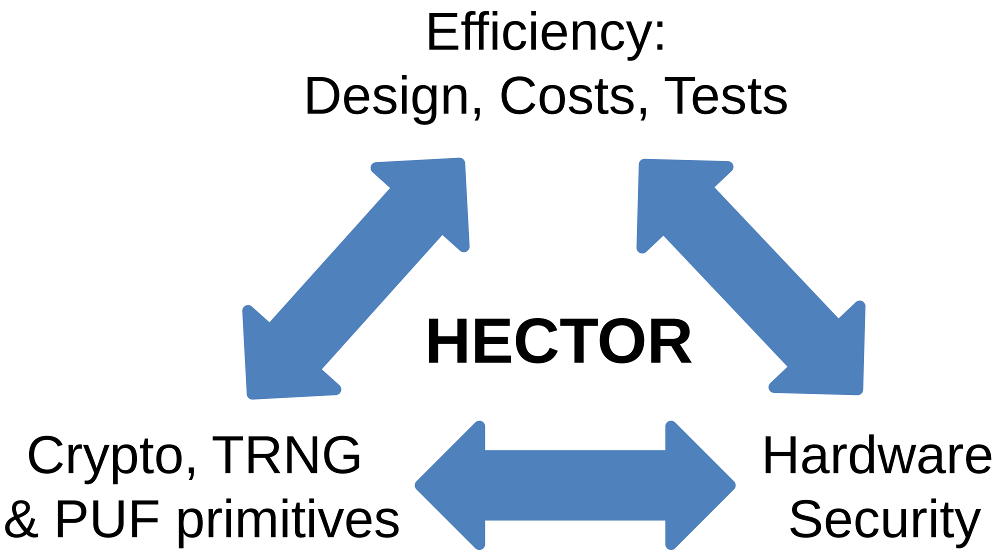
HECTOR – Hardware Enabled CrypTO and Randomness

- European Union's Horizon 2020 research and innovation programme under grant agreement number 644052
- 3-year project starting from March 2015
- 9 partners (3 universities, 3 big companies, 3 SME):
  - Technicon GMBH, Villach, Austria (coordinator)
  - Katholieke Universiteit Leuven, Belgium
  - Université Jean Monnet Saint-Etienne, France
  - Thales Communications & Security SAS, Gennevilliers, France
  - STMicroelectronics Rousset SAS, Rousset, France
  - STMicroelectronics SRL, Agrate Brianza, Italy
  - Micronic AS, Bratislava, Slovakia
  - Technische Universitaet Graz, Graz, Austria
  - Brightsight BV, Delft, Netherlands

HECTOR – Hardware Enabled CrypTO and Randomness

- HECTOR core problem
  - Find solutions for the tension between mathematical security, implementation security and efficiency:

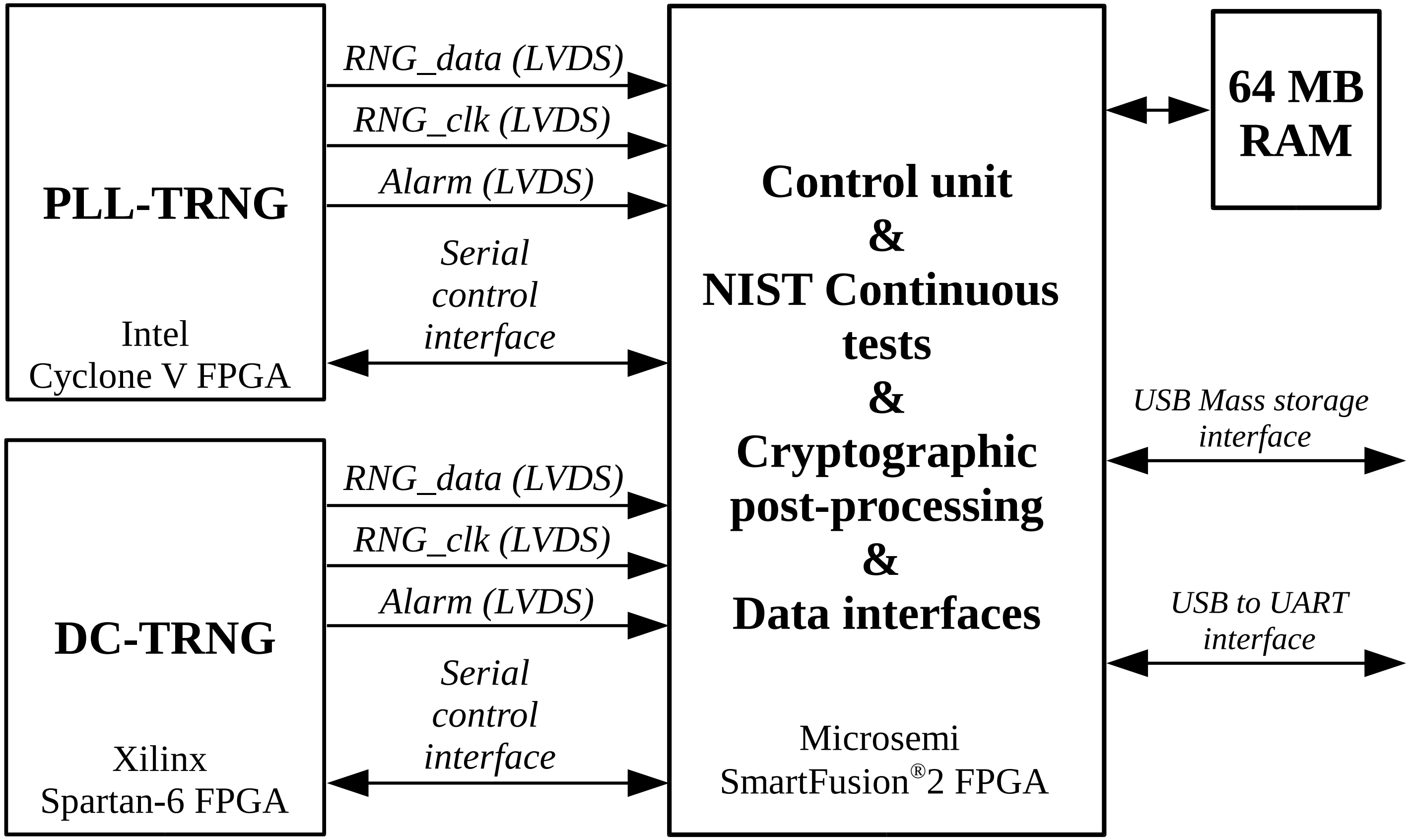


HECTOR – Hardware Enabled CrypTO and Randomness

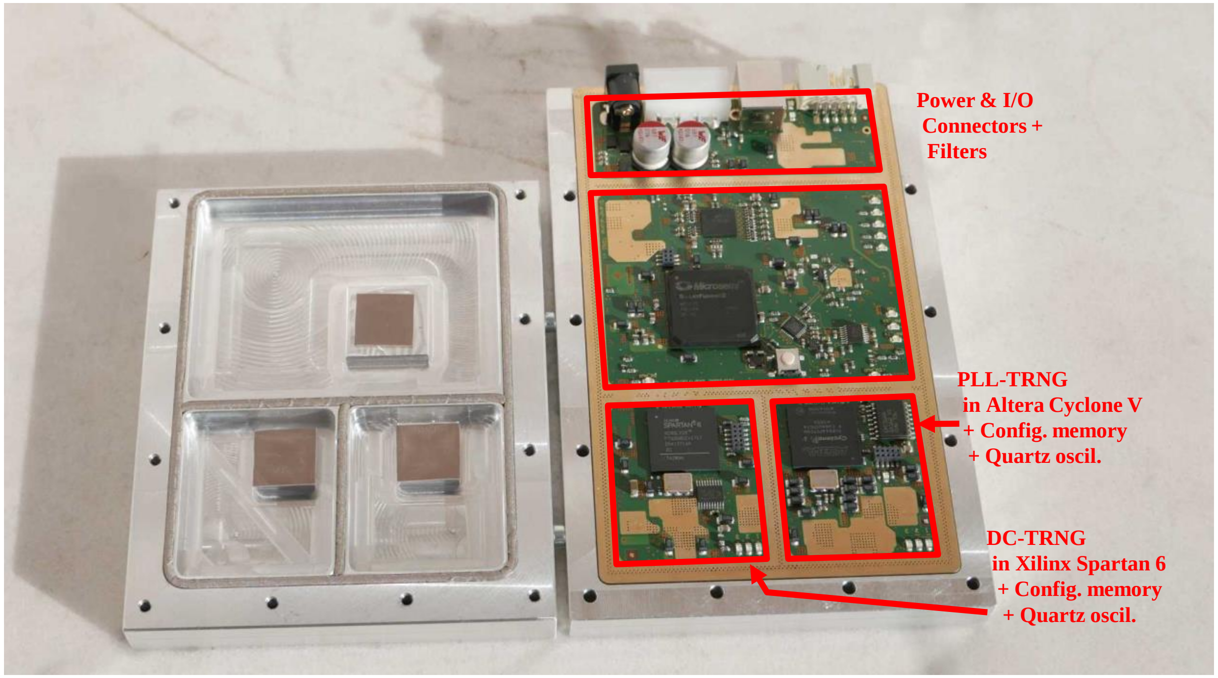
- Main initial objectives in TRNG design
  - Hardware **RNG design approach** based on thorough entropy estimation and management
  - **Stochastic models** of RNGs that can be used to build **efficient and fast dedicated embedded tests**
  - Verify the **robustness** of the proposed TRNGs **against passive and active attacks**
  - Validate AIS31 **certification feasibility** and process simplification by actually going through the full process for a HECTOR TRNG design with an accredited certification lab
- Additional objective
  - Propose RNG, which is compliant with AIS20/31, NIST SP 800-90B and French high security RNG design recommendations

HECTOR – Demonstrator 1

- Functional diagram

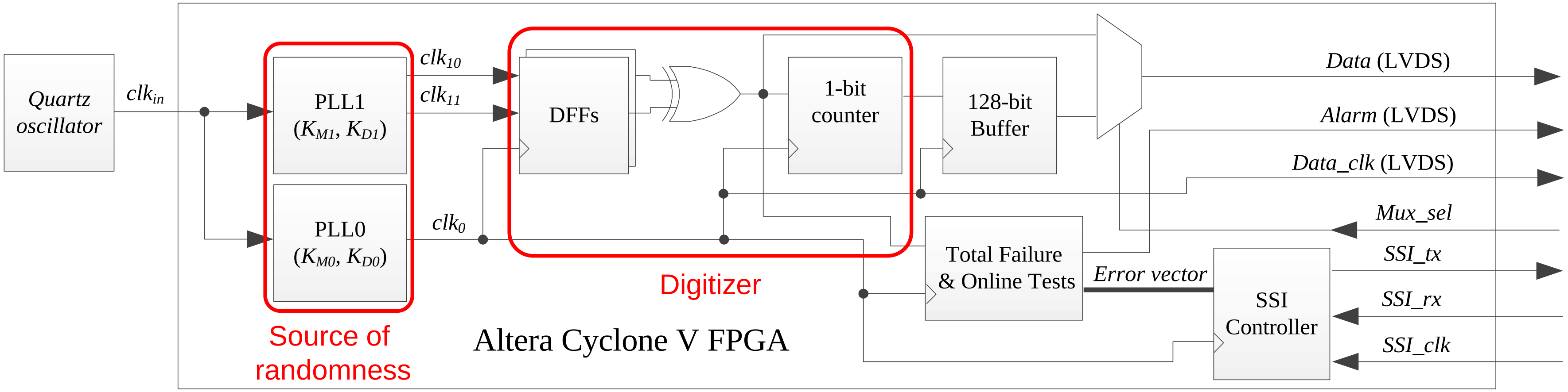


- Three FPGA areas separated by a ground plate
- Three separated chambers inside a metallic shielding



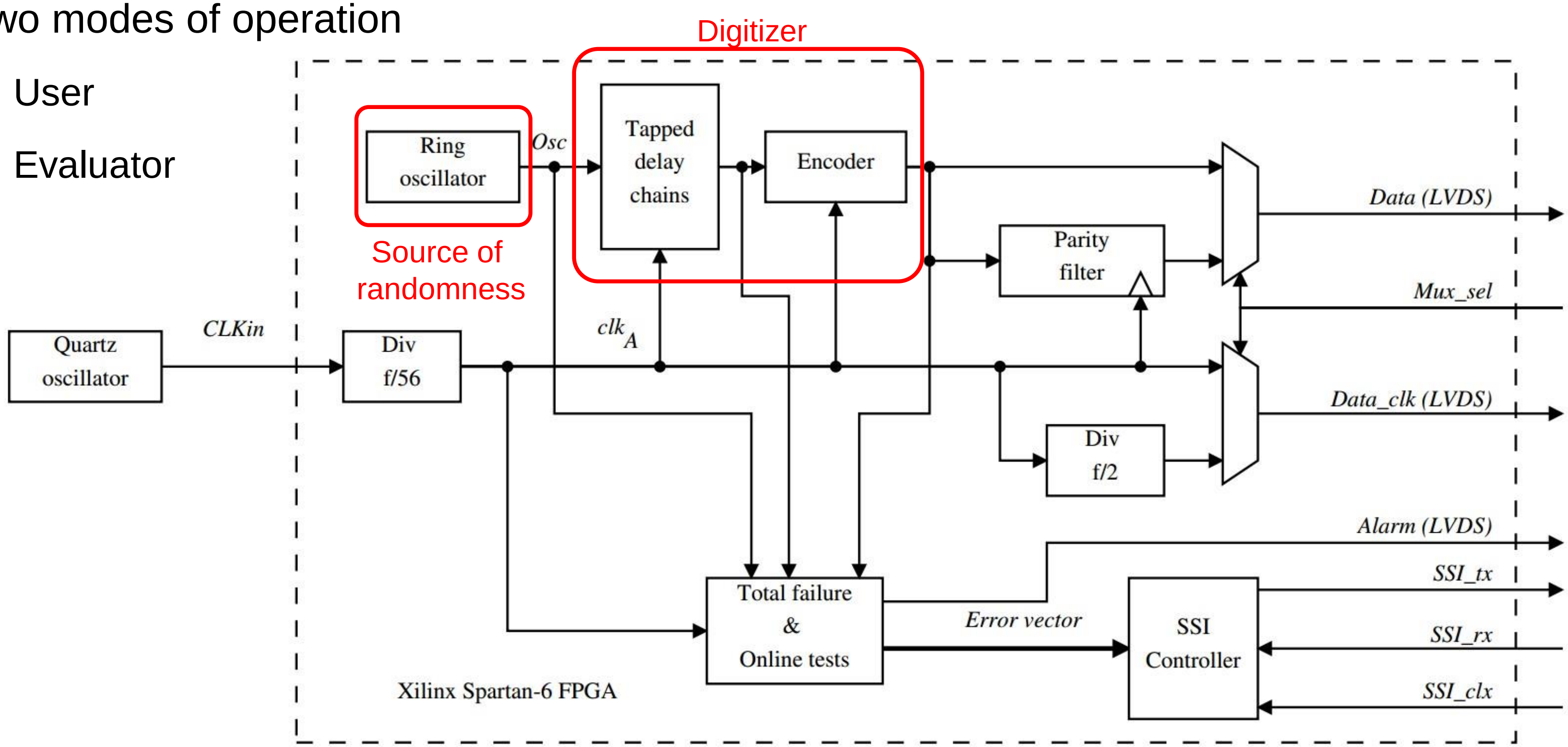
PLL-TRNG core

- Source of randomness – differential jitter between outputs of two PLLs
- Fast data interface (LVDS) and serial control interface (SSI)
- Two modes of operation:
  - User mode – only the raw random binary signal is output
  - Evaluator mode – other internal signals are available
- Dedicated embedded tests (parametric statistical tests)
  - Total failure test
  - Two online tests



DC-TRNG core

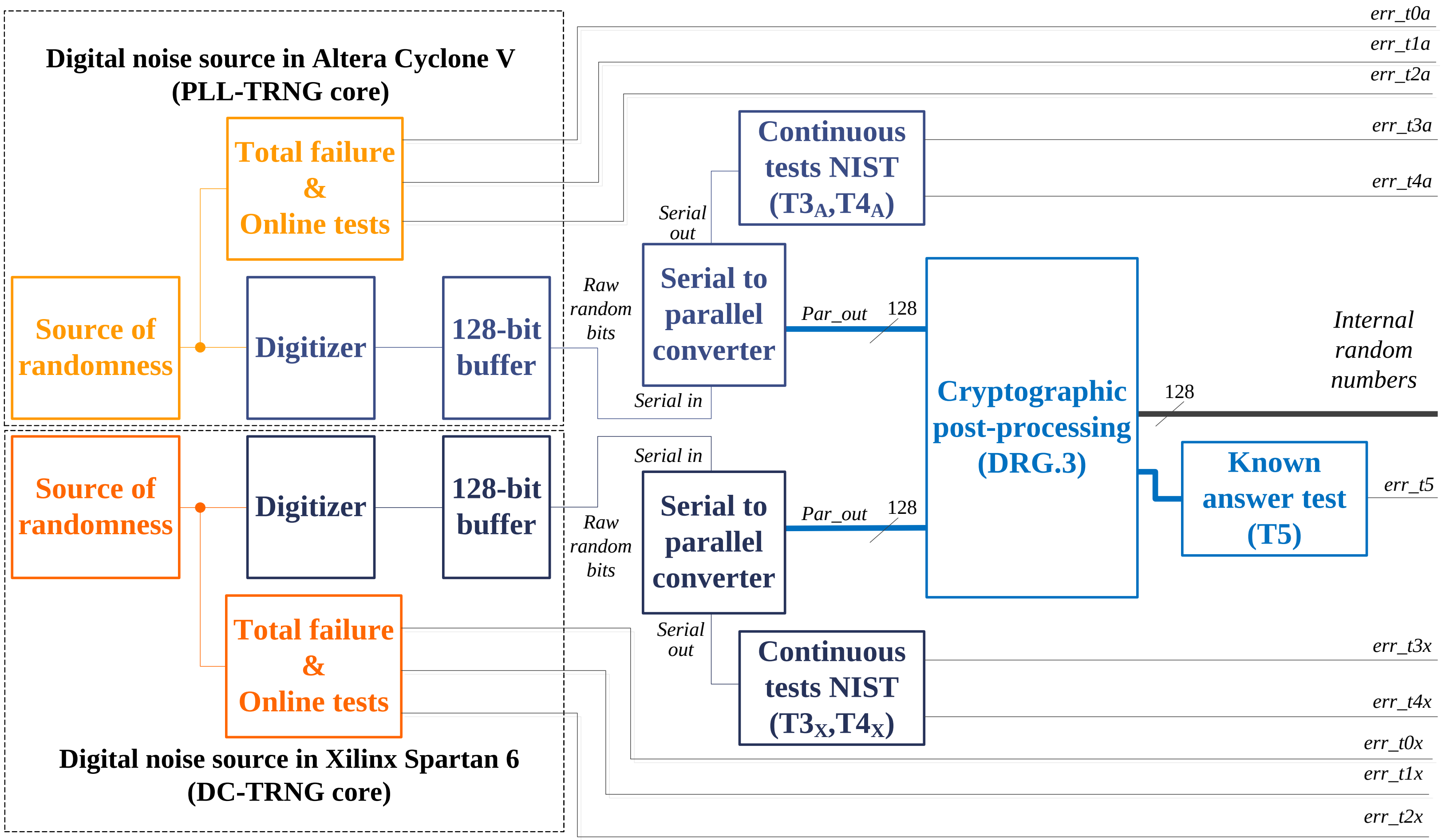
- Source of randomness – jitter of the clock generated in a ring oscillator
- Dedicated embedded tests (parametric statistical tests)
  - Total failure test
  - Two online tests
- Two modes of operation
  - User
  - Evaluator



HECTOR TRNG including embedded tests

HECTOR TRNG contains four essential parts:

- Two sources of the digital noise
- Embedded tests
- Cryptographic post-processing
- Data interface



Embedded tests in HECTOR TRNG

Two total failure tests

PLL-TRNG: T0a: $P_1 > 0$ (Number of random samples during one T_Q)
DC-TRNG: T0x: Detects edges of the ring oscillator clock signal

Four online tests

PLL-TRNG: T1a: $4 < P_1 < K_D/4$ (P_1 computed from 4080 T_Q periods)
T2a: $228 < P_2 < 1280$ (during 4080 T_Q periods)
DC-TRNG: T1x: $35 < N_{111} < 93$ (number of overlapping templates “111”)
T2x: $185 < C_1 < 326$ (number of XORed couples of bits)

Continuous tests (NIST SP 800-90B)

T3: Repetition count test with cutoff value $C_R = 51$
T4: Adaptive proportion test with cutoff value $C_A = 1380$

Known answer test (KAT)

T5: KAT test of the cryptographic post-processing block

Startup procedure

Generated data have to pass Tests T0 to T5

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Demonstration

Two kinds of access to HECTOR Demonstrator 1

- Physical device + tools
  - Hardware – TRNG cores + tests + control unit
  - Firmware – controls data acquisition and exchange
  - Software – controls access to the demonstrator from the host PC (in TCL)
- Random number generator as a service

  https://trng.technikon.com/

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Conclusions

- The HECTOR TRNG fulfills all requirements specified by industrial partners
- It is compliant with the three available documents
  - AIS20/31
  - NIST SP 800-90B
  - Requirements of French DGA

Question:

Can all TRNGs comply with these recommendations? The clear response is: NO.

- Possible problems:
  - A mixture of true- and pseudo-randomness in the raw signal
  - Non-deterministic randomness extraction process
  - Stochastic model not depending on measurable parameters

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