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CNEA-I&C architecture design of FPGA-based Reactor Protection System for new Argentine reactors and other FPGA development experiences

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I&C Department

Comisión Nacional de Energía Atómica

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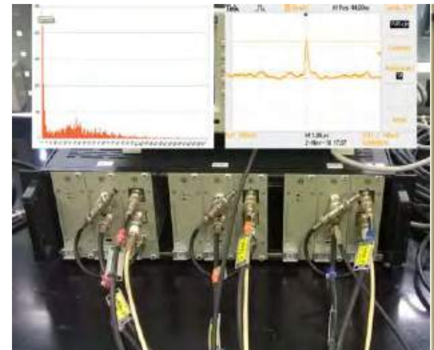
CNEA-I&C Department

Introduction

- Placed in Ezeiza Atomic Center
- More than 40 years of developments
- Currently: 30 professionals, 9 technicians, 6 administrative
- ISO 9001:2015 Certification



CNEA-I&C Department

Current RPS Projects

- Primary RPS for CAREM25 (Prototype of Small Modular Reactor)

- RPS for RA10 (New Multipurpose Research Reactor)

RPS

Shared Requirements

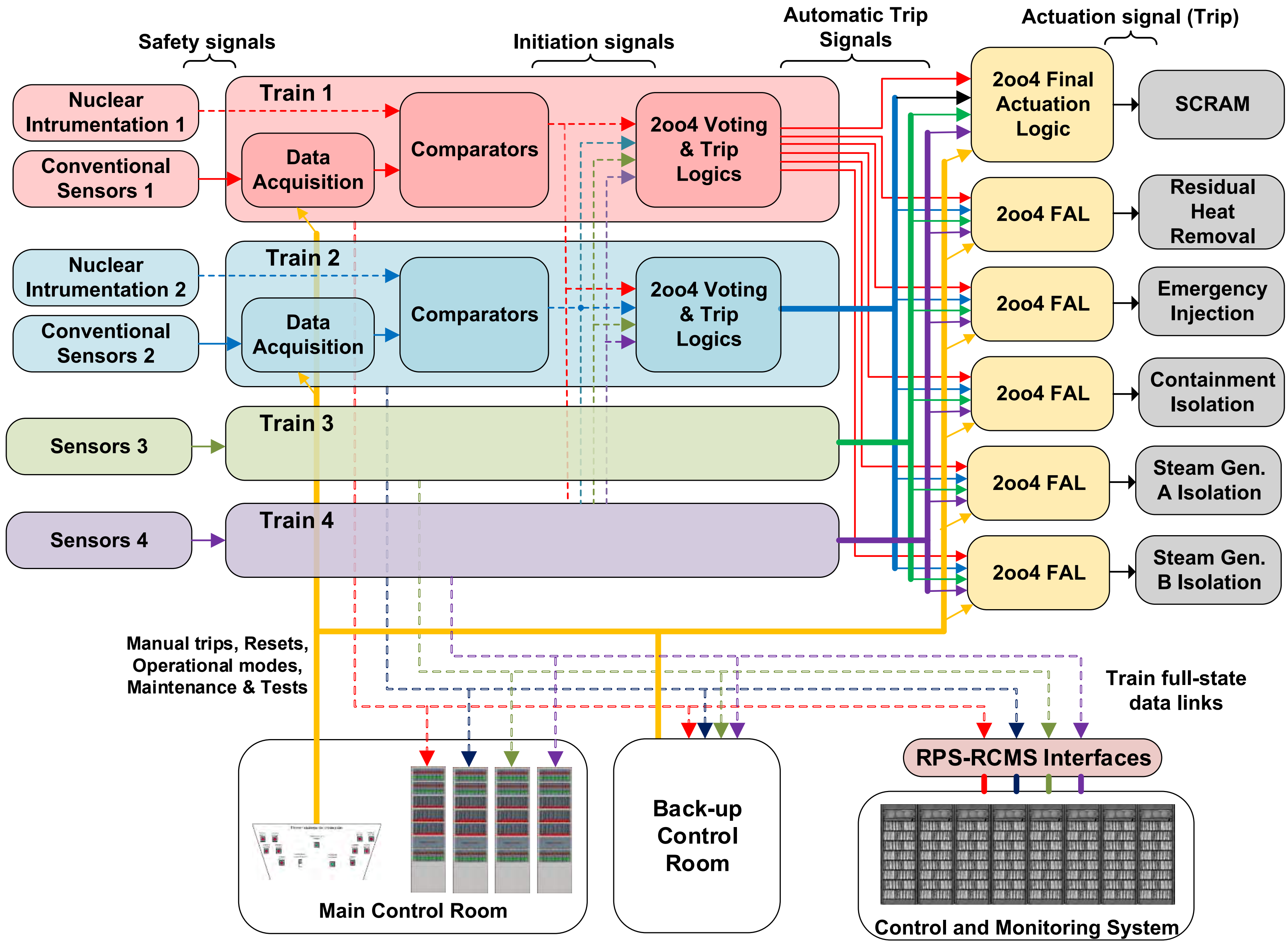
- **Safety Functions Category A (IEC 61226)**
- **System Class 1 (IEC 61513)**
- Simple design
- Proven technology
- Independence
- Single Failure Criterion
- Self-check
- Fail Safe Design
- Testability
- Online Monitoring
- Manual and Automatic Trips
- Maintenance and Test features
- Demands several actuation systems

RPS

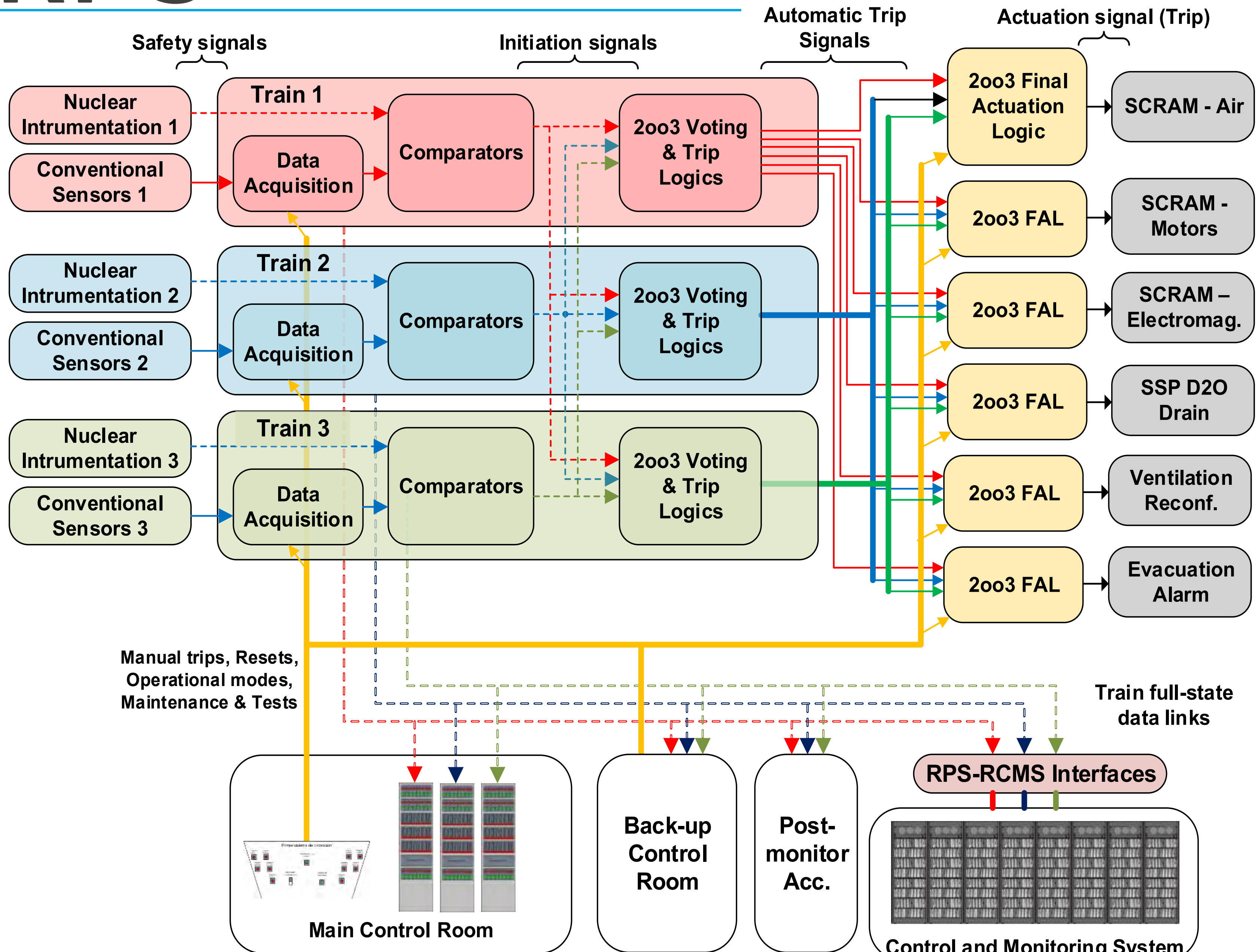
CNEA-I&C RPS main characteristics

- Digital Processing
- **Diverse** FPGA Implementation
- 2oo3 or 2oo4 Voting at two levels
- IEC 62566 life-cycle and V&V process
- Modular Eurocard System

RPS 2oo4 Architecture for CAREM 25 NPP



RPS 2oo3 Architecture for RA10 MRR



Diverse FPGA Implementation

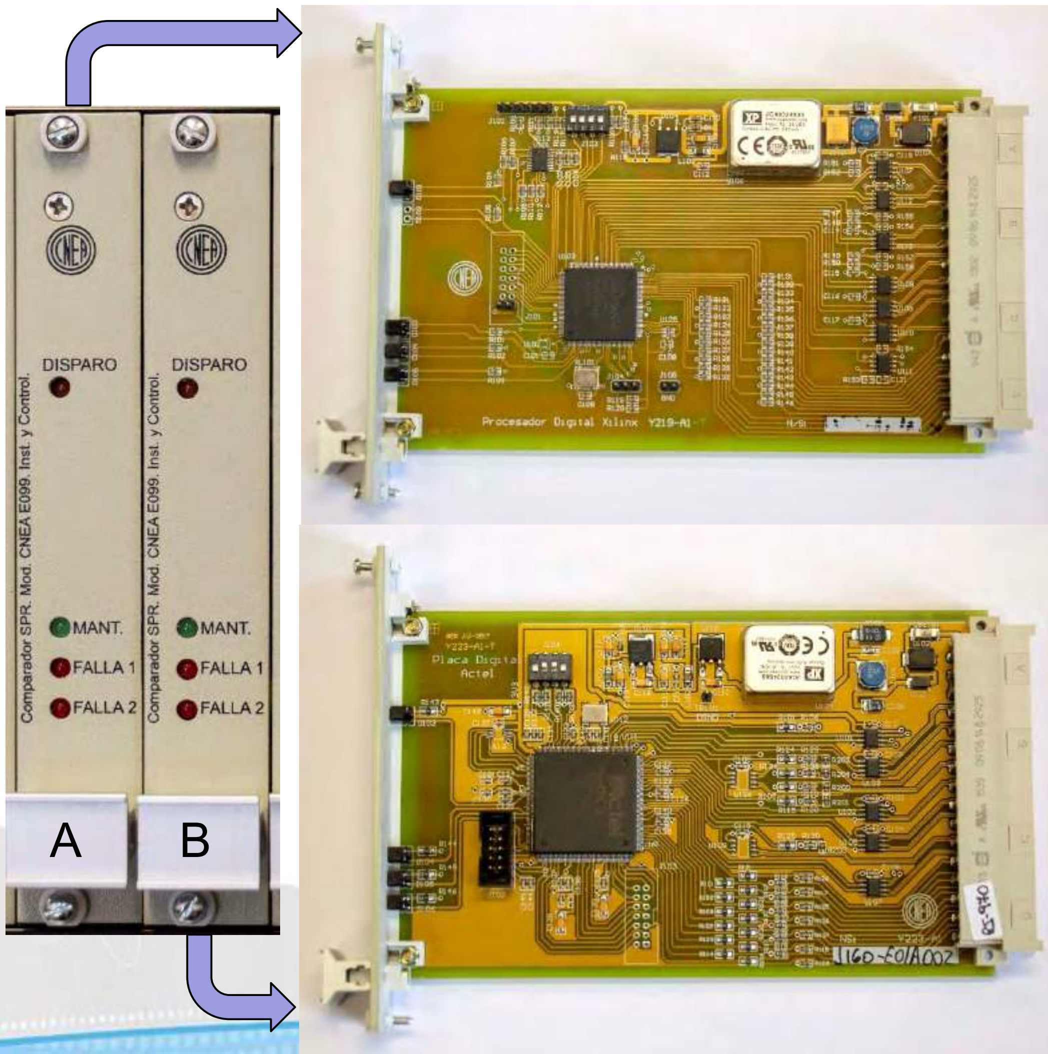
Common Cause Failure Issue

The Common Cause Failure (CCF) is an important issue in safety systems based on software and FPGA technology.

It is known that the *implementation of* ***diversity reduces*** *the probability of* ***CCF*** *occurrences* (IEC 61508 Part 7 Section B.1.4 and many other references).

Diverse FPGA Implementation

Diversification styles in CNEA-I&C RPS

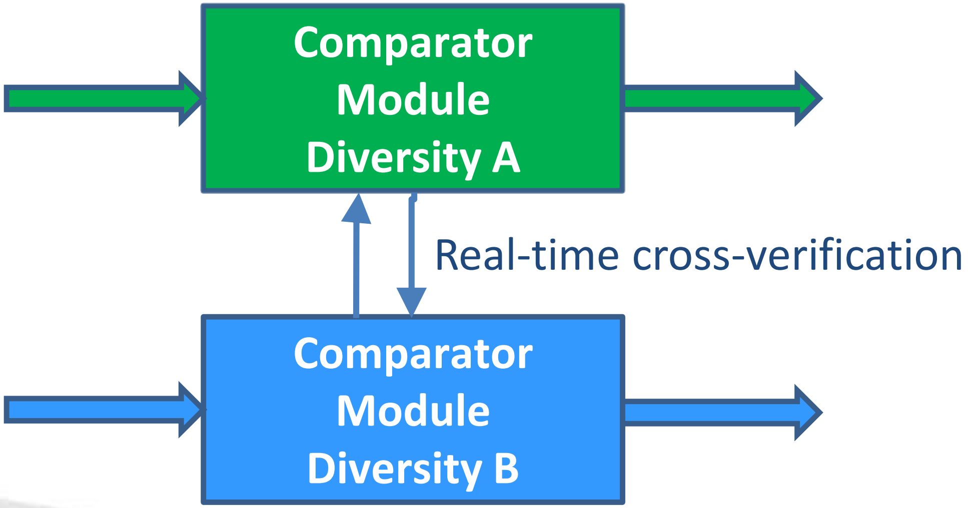


- Developers team
- FPGA Manufacturer
- FPGA Technology
- FPGA software tools

Diverse FPGA Implementation

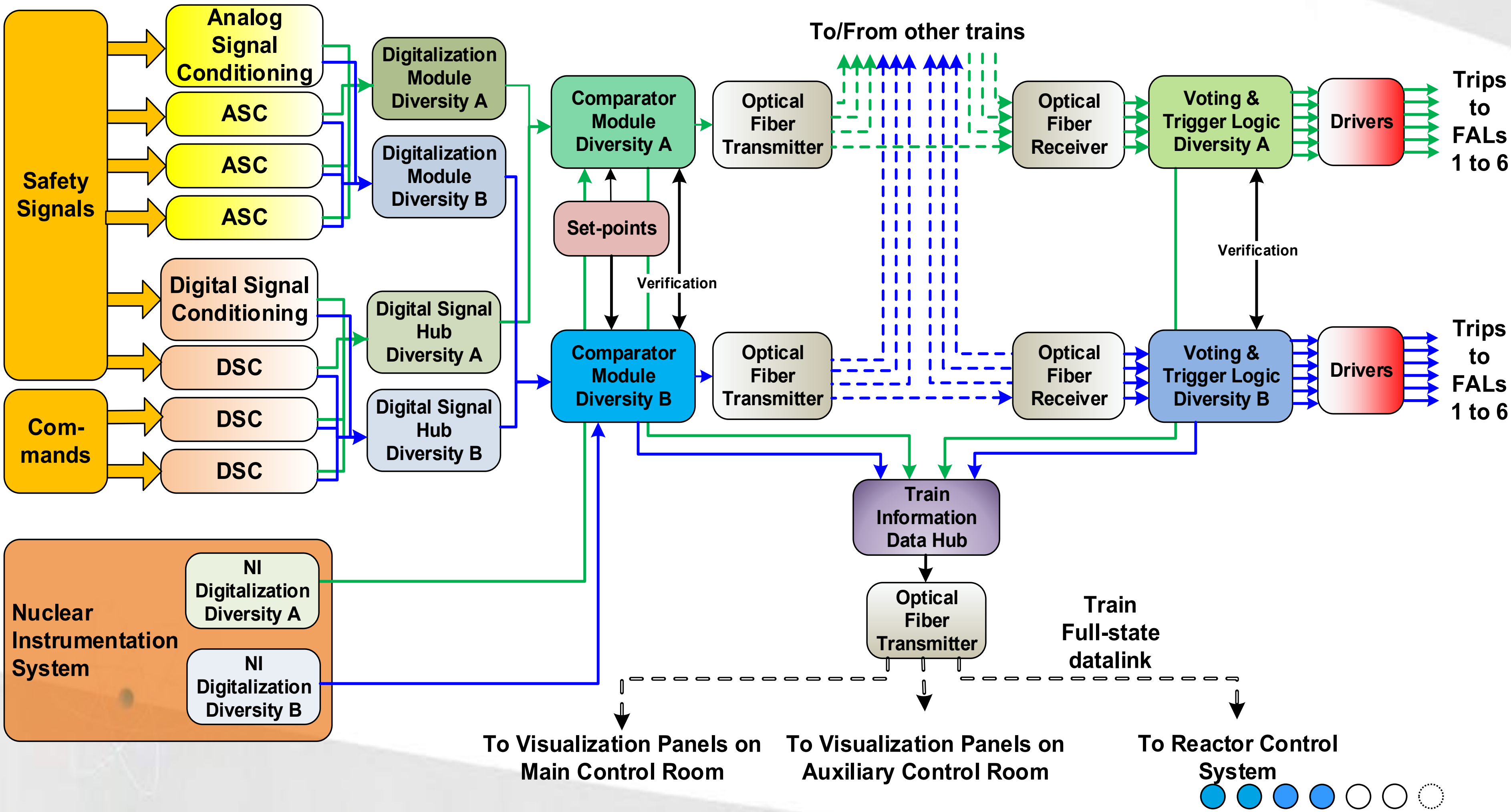
Diversification styles in CNEA I&C RPS

- Each pair of modules works in parallel in the same train
- There is no priority between diversities
- Real-time cross-verification between diverse modules



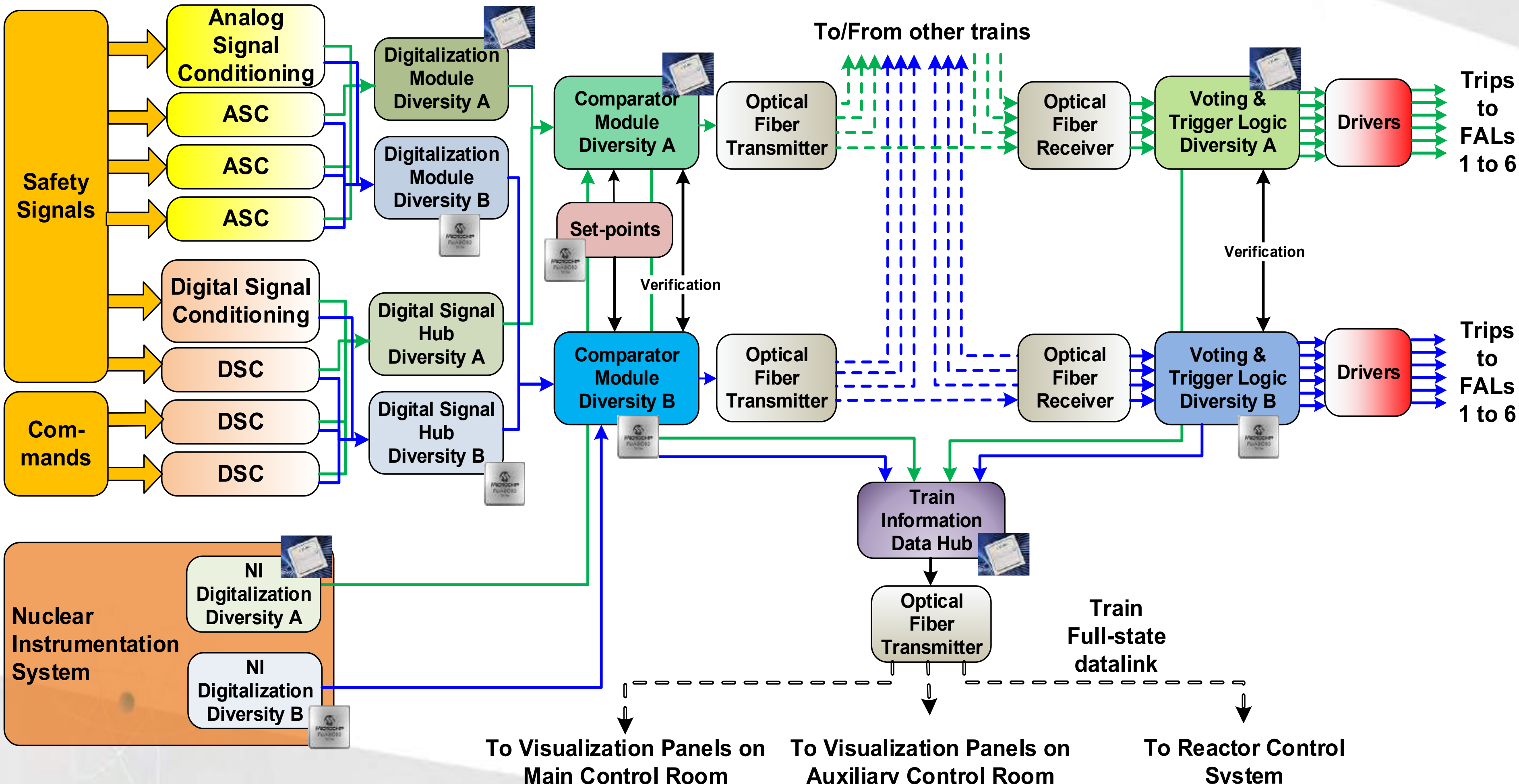
Diverse FPGA Implementation

RPS Train



Diverse FPGA Implementation

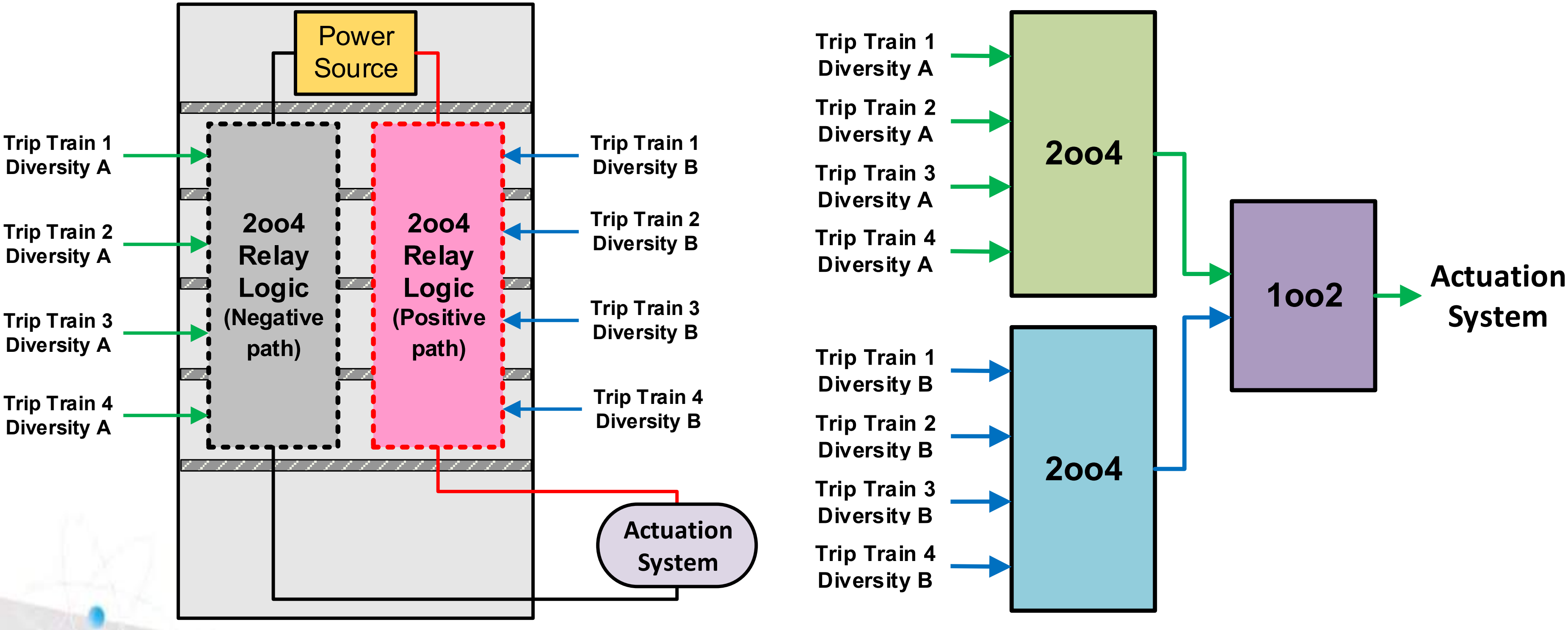
RPS Train



Diverse FAL Implementation

Diversity resolve

- Diversity reaches the Final Actuation Logic



Each path uses different relay manufacturers

Architecture Implementation

Full Redundant Train

Built on 3 Eurocard Sub-racks 19’’ Simple Height (3U)

Architecture Implementation

Full Redundant Train

Built on 3 Eurocard Sub-racks 19’’ Simple Height (3U)

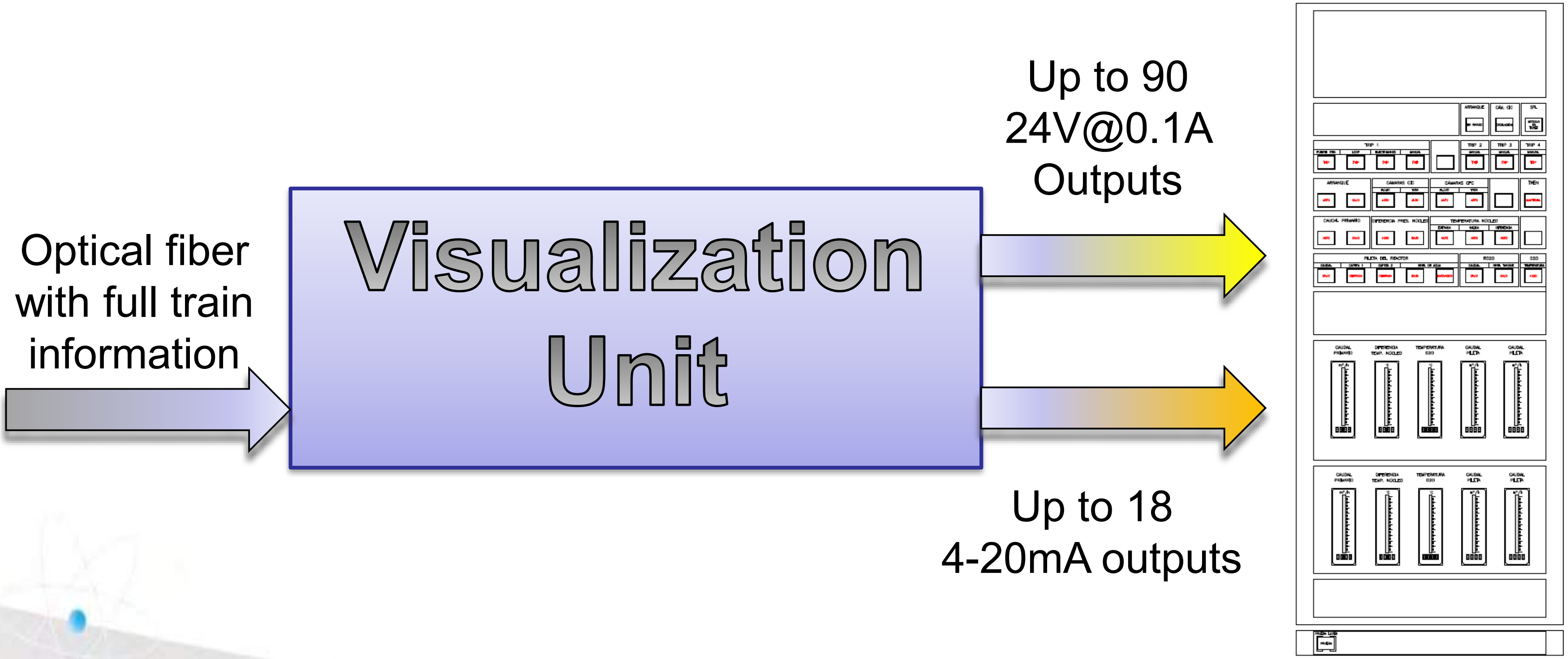
Capability	Maximum w/3 Sub-racks	For CAREM25	For RA10 MRR
Nuclear Instrumentation Chains Inputs	2	2	2
24V Digital Inputs	64	26	36
4-20mA Analog Inputs	30	18	11
24V @ 1A Digital Outputs	16	14	12
Rx/Tx Optical fibers for other trains interconnections	4	4	3
Tx Optical fibers with full train information	8	3	5

Expandable using more Sub-racks

Architecture Implementation

Visualization Unit for Hard Panels

One Eurocard Sub-racks 19” Simple Height (3U)

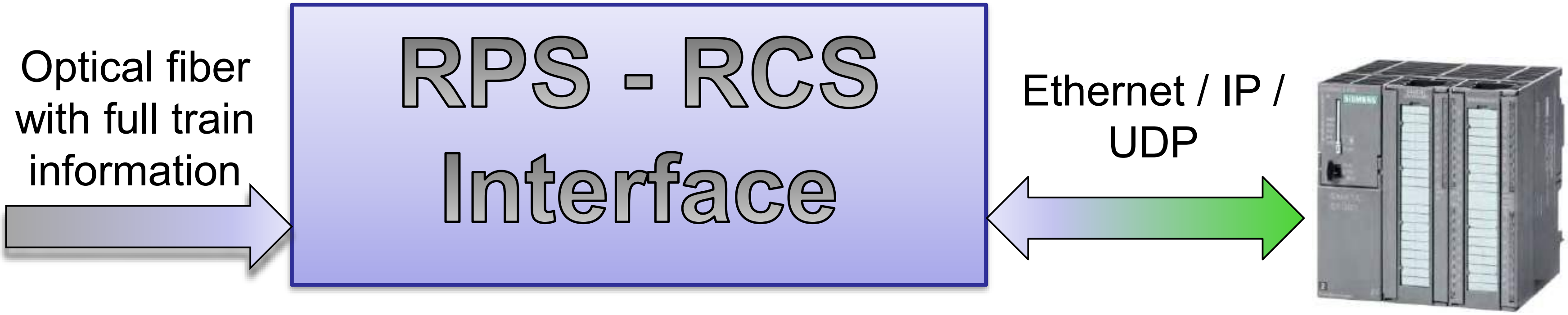


Architecture Implementation

RPS to Control System Interface

1/3 Eurocard Sub-racks 19” Simple Height (3U)

(Safety Category B)

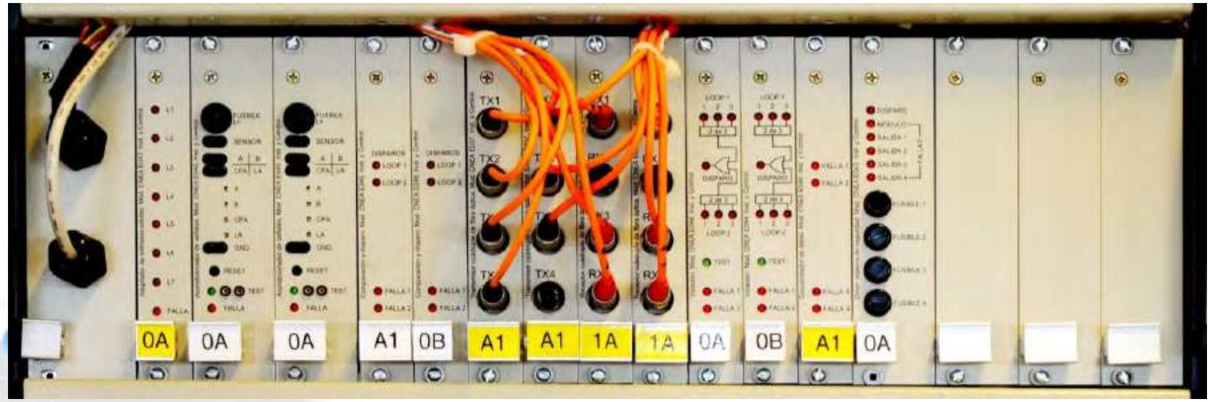


Architecture Implementation

Previous experience

Diverse Trip Instrumentation for Atucha II NPP
Boron Injection Safety System (2012)

- Similar diverse architecture for 2 analog and 6 digital input signals
- Each train was solved in one sub-rack
- Finally, it was not installed, so it only served as a proof of concept



FAT Platform

Conclusions

CNEA-I&C RPS

- The use of FPGA technology, as the main component of RPS design, has proven to be very effective
- The goal of a simple design was achieved by using FPGAs, finite states machines and one-way communication channels.
- CCF issue is addressed using diverse FPGA implementation running in parallel in each train
- The requirements for independence, isolation and wiring complexity reduction are fulfilled using serial transceivers over optical fiber.

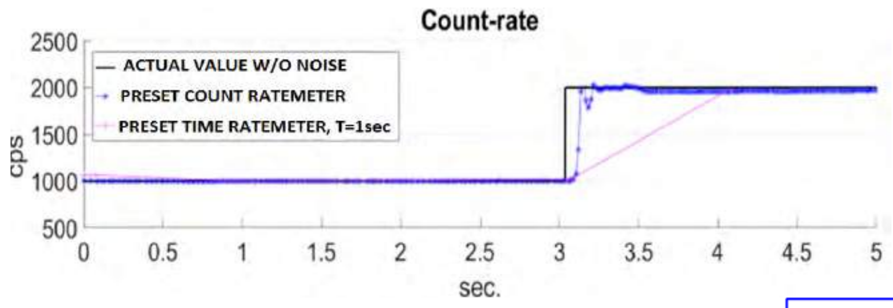
Other FPGA Developments

For Nuclear Instrumentation System

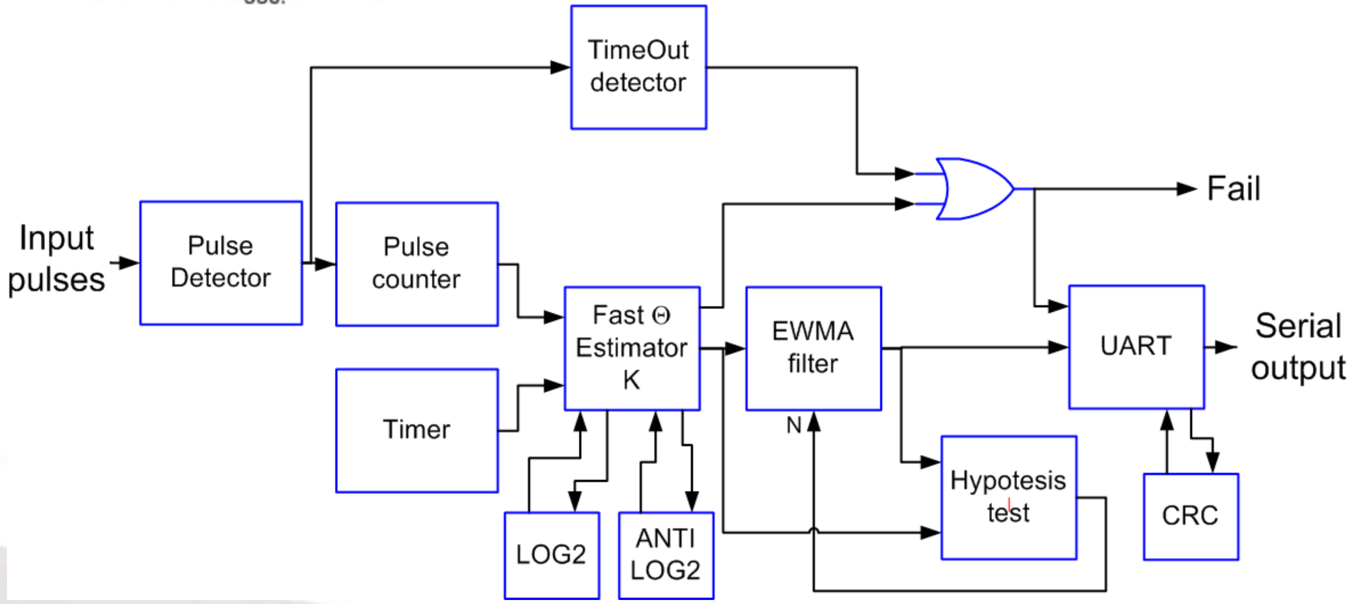
- **Count-rate** meter and **flux-change-rate** meter with automatic adjust of counting time for **pulse-mode** flux [SPL2019, IAEA-TECDOC-1765]
- **Random Pulse Generator** For Emulation of a Neutron Detector System In A Nuclear Reactor [SPL2011]
- Wide Range Neutron Flux Monitoring System using **Campbell** Mode [SPL2019]
- **Wide Range** Neutron Detector **Emulator** and **Current** Mode Neutron Detector **Emulator**

Other FPGA Developments

Count-rate meter for pulse mode



- Automatic adjust of counting time
- Stable output – Bounded error
- Extended range **0.1 to 10^6 cps**
- Linear and Log digital output

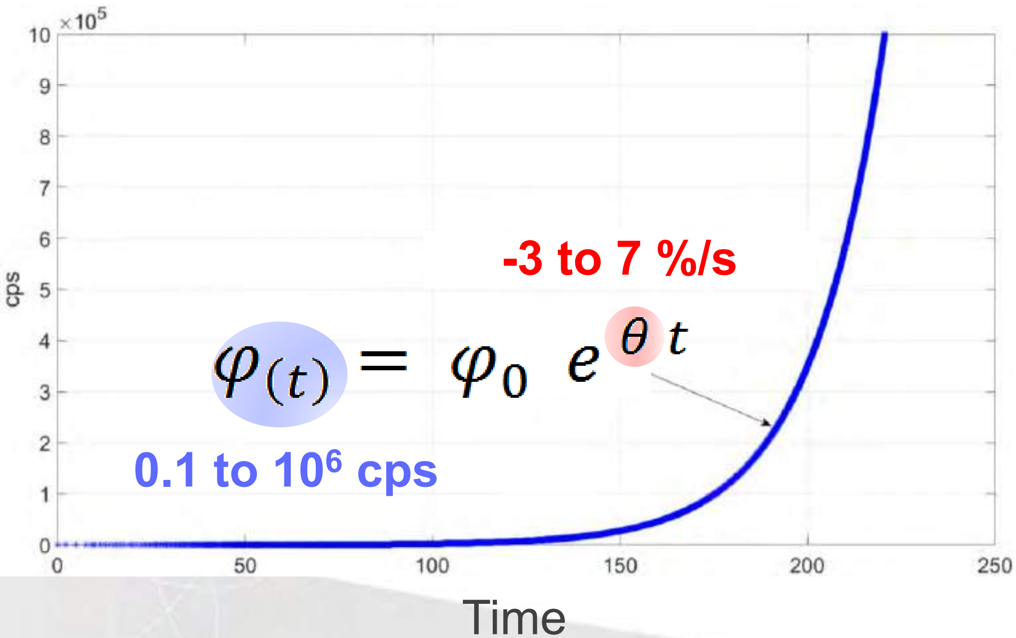


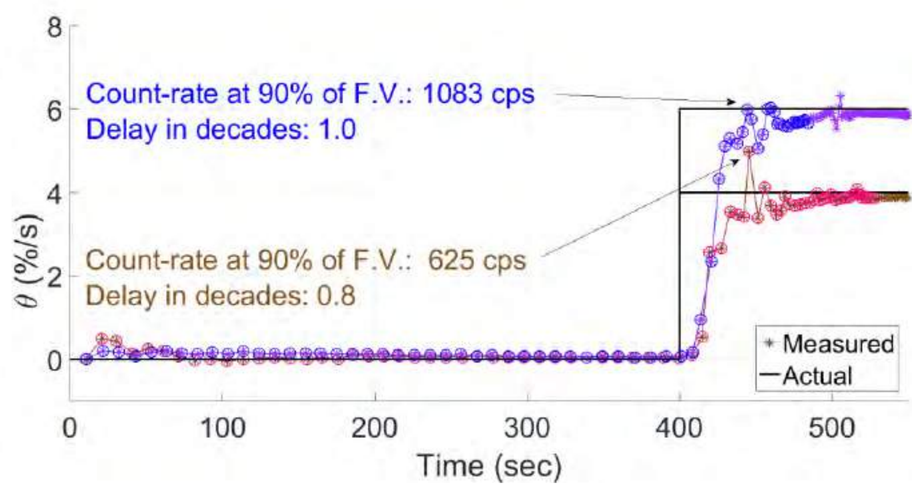
Other FPGA Developments

Count-change-rate meter for pulse mode

- Automatic adjust of counting time
- Stable output (no spurious trip)
- Extended range **0.1 to 10^6 cps**
- Digital Output from -3 to 7%/sec

Full Paper: "Digital count-rate meter and flux-change-rate meter with automatic adjust of counting time based on FPGA for pulse-mode flux measurements in nuclear reactors" Ríos, Estryk, Verrastro. IEEE SPL2019

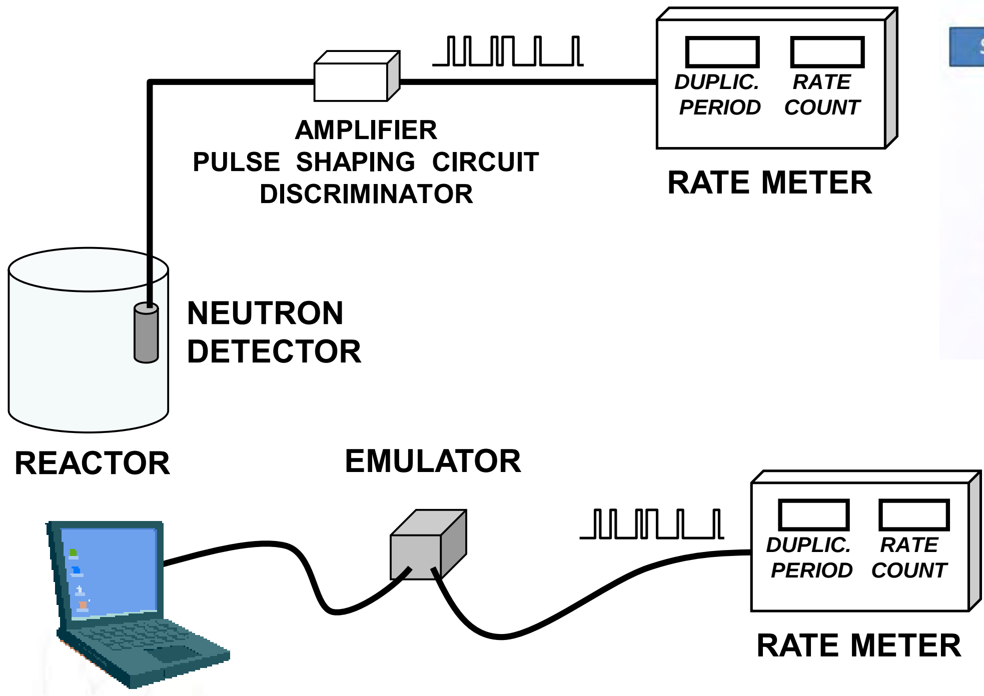




Count-change-rate step from 0 to 4 and 6 %/sec, starting from 100cps

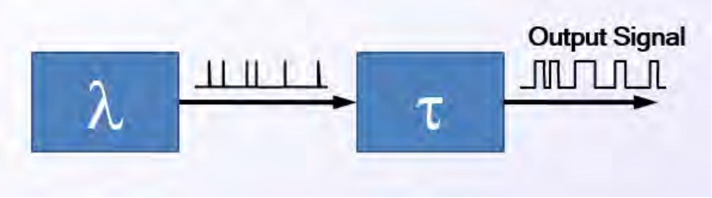
Other FPGA Developments

Random Pulse Generator For Emulation of a Neutron Detector



Emulator Model:

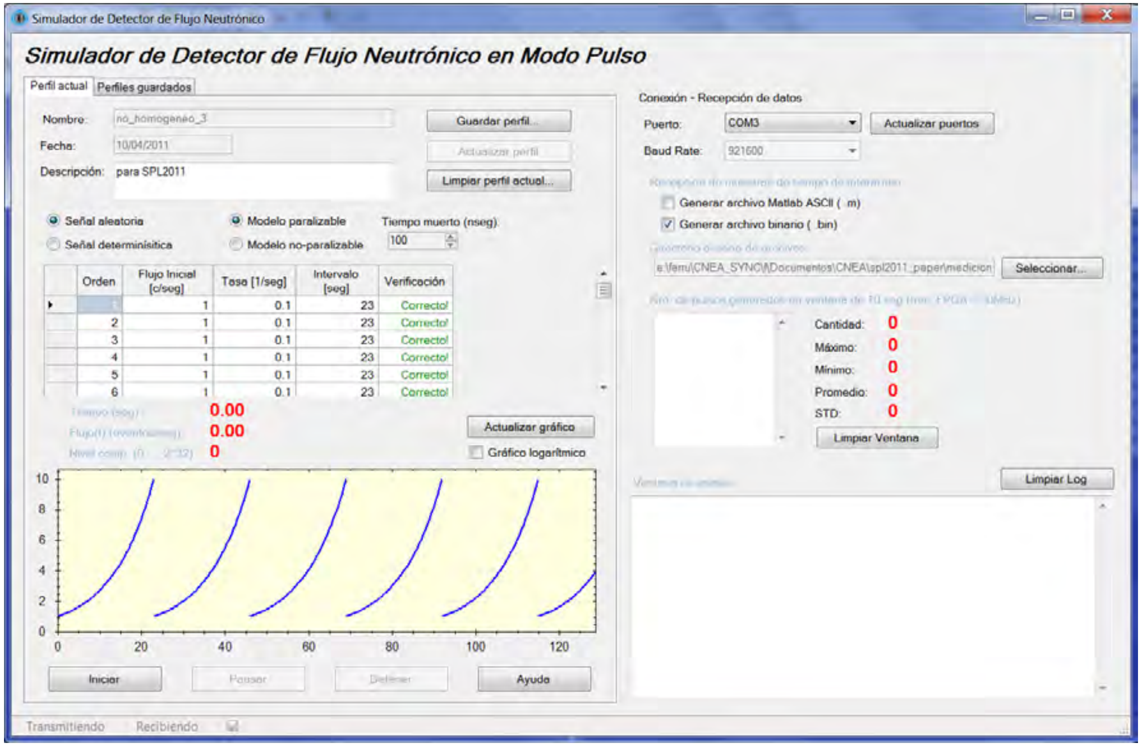
Poisson process emulator +
dead time emulator



Full Paper: "FPGA-based Random Pulse Generator For Emulation Of A Neutron Detector System In A Nuclear Reactor". Ferrucci, Verrastro, Ríos, Estryk. IEEE SPL2011

Other FPGA Developments

Random Pulse Generator For Emulation of a Neutron Detector

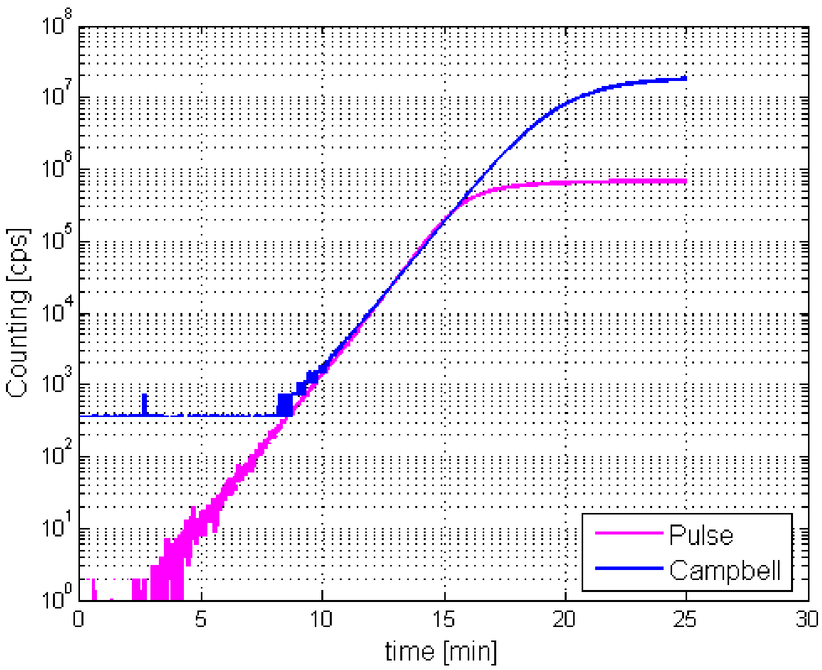


Exponential sweeps can be configured and commanded from the PC

Other FPGA Developments

Wide Range Neutron Flux Monitoring System using Campbell Mode

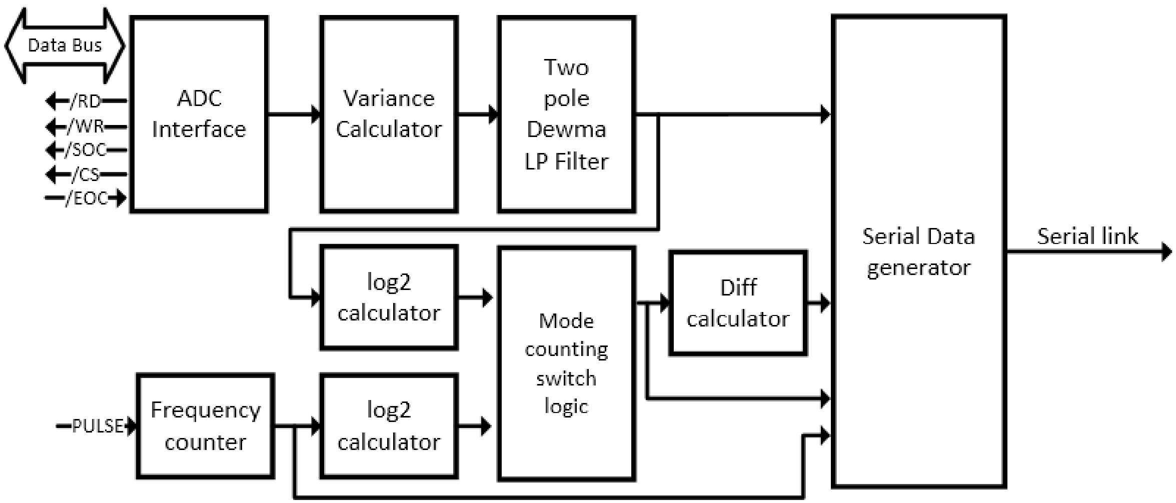
- Based on the Campbell Mean-square theorem
- The variance of the signal is proportional to the neutron flux
- Used with Fission Counters



$$\boxed{\overline{\sigma_I^2} \propto \Phi Q^2}$$

Other FPGA Developments

Wide Range Neutron Flux Monitoring System using Campbell Mode



- Variance signal is filtered by a two pole low-pass IIR DEWMA filter.
- DEWMA filter was used to improve response to fast transients with a good filtering because its adaptive nature
- K constant was update each calculation cycle

Full Paper: "FPGA Based Wide Range Neutron Flux Monitoring System using Campbell mode". Alarcón, Marzano, Verrastro, Thorp. IEEE SPL2019

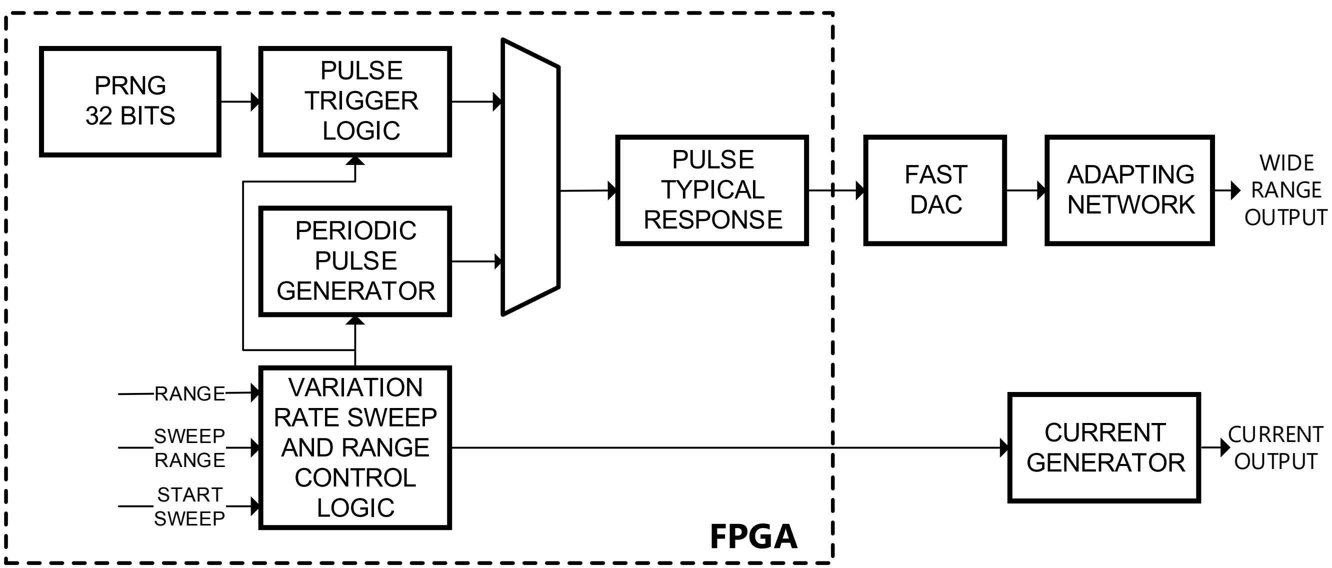
Other FPGA Developments

Wide Range Neutron Detector Emulator and Current Mode Neutron Detector Emulator

- Standalone module, modes and values configurable by the front panel
- Upward sweeps of 3%/sec and 6%/sec (on both outputs)
- Wide Range on a single output
  - Periodic and Random modes (1K/10K/100K/1M cps)
  - Pulse shaping in FPGA with pile up generation
  - Fast DAC
  - Analog output
- Current output range: 500pA / 5nA / 50nA / 500nA

Other FPGA Developments

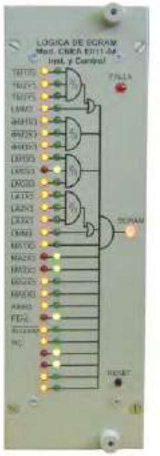
Wide Range Neutron Detector **Emulator** and **Current** Mode Neutron Detector **Emulator**



Other FPGA Developments

Replacement Modules for NPPs and RRs

- FPGA-based Alarm Unit for Embalse NPP Area Radiation Monitoring System
- CPLD-based replacement of Simatic Z24 for Atucha I NPP
- CPLD-based Scram Logic replacement for Argentine RRs [IAEA-CN-100]



Nuclear medicine

- AR-PET: Argentine Positron Emission Tomography Scanner [SPL2010]

Thank You !

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