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International Conference on Opportunities and Challenges for Water Cooled Reactors in the 21st Century 27-30 October 2009
Vienna, Austria

Qualification of FPGA-based Safety-Related PRM System

Oct. 29, 2009

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Part 1: Introduction

Introduction (1/2)

History of Safety-Related Digital I&C systems

Computer-based I&C systems have been used in nuclear power plants since 1980s, they have many advantages than older analog-based systems.

Issues of Computer-based I&C systems

- **Complex software and resultant expensive Verification and Validation (V&V) effort.**
- **Short product life cycle due to device obsolescence.**

Emergence of Field Programmable Gate Array (FPGA), a semiconductor device, in 1990s

- **Promising simpler systems and reasonable V&V effort.**
- **Long product life cycle owing to long time device support.**

Introduction (2/2)

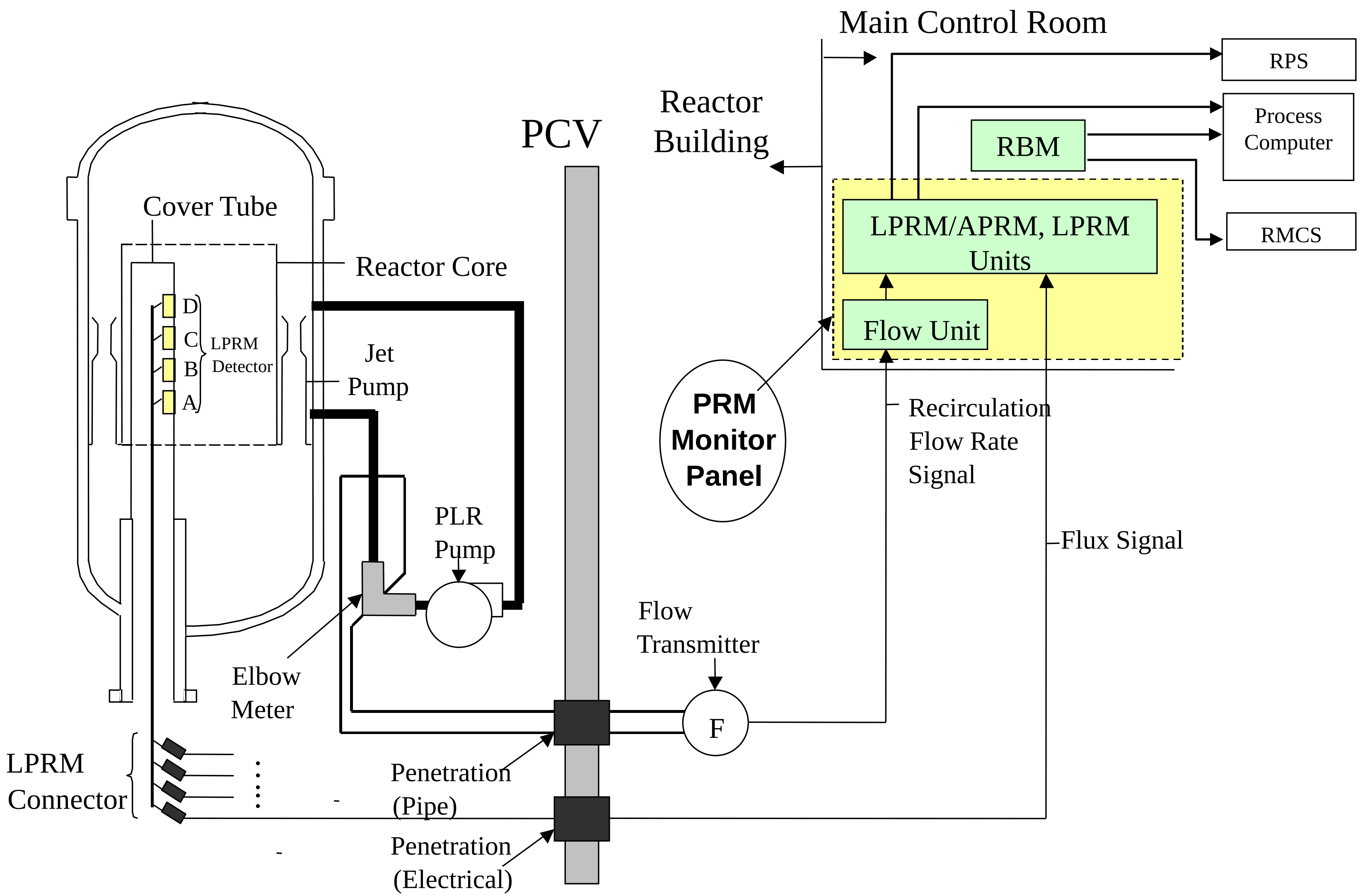
- **Toshiba chose Non-Rewritable (NRW)-FPGA as a next generation device for nuclear power plants I&C systems.**
  - Nonvolatile
  - One-time programmable

This presentation shows:

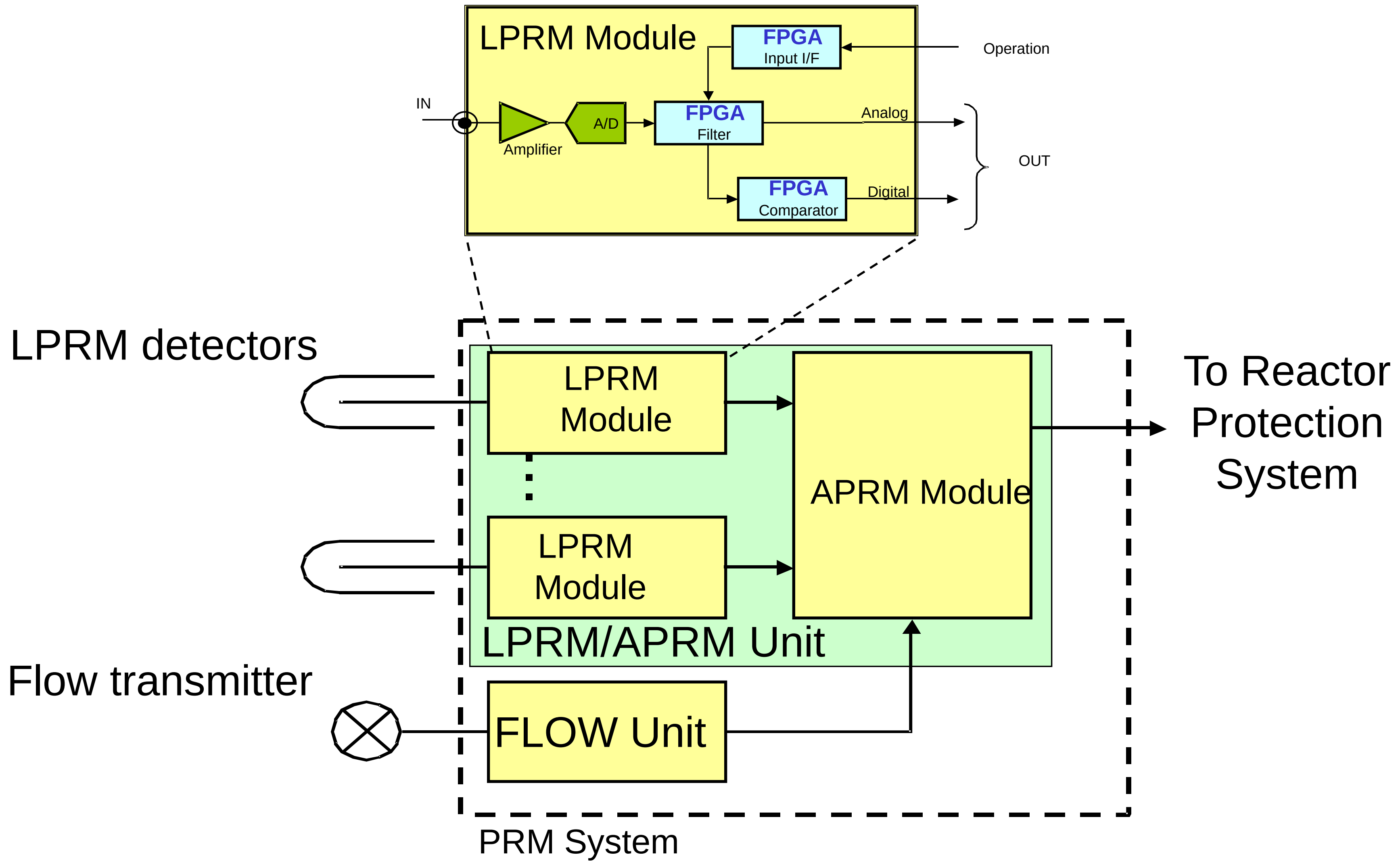
- **Logic Qualification, conducted in accordance with IEEE Std 1012**
- **Hardware Qualification, conducted in accordance with EPRI TR-107330**

Part 2: FPGA-Based Power Range Monitor

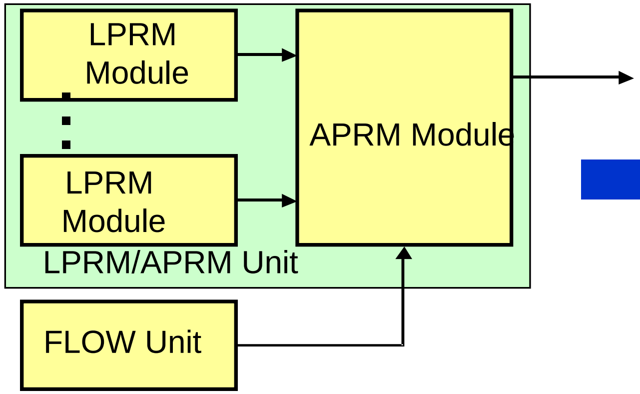
Power Range Monitor for Boiling Water Reactor



Configuration of FPGA-Based PRM



PRM Devices



LPRM Modules APRM Module

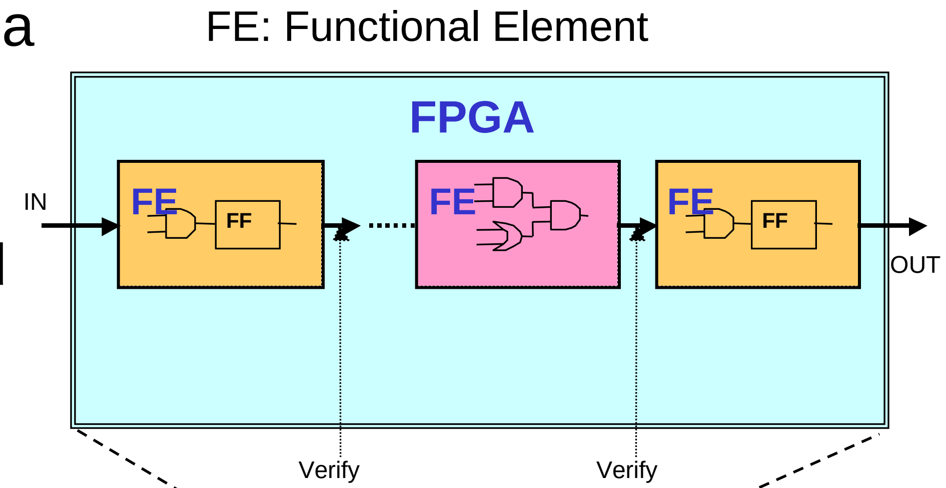
FPGA-Based PRM is compatible with conventional system

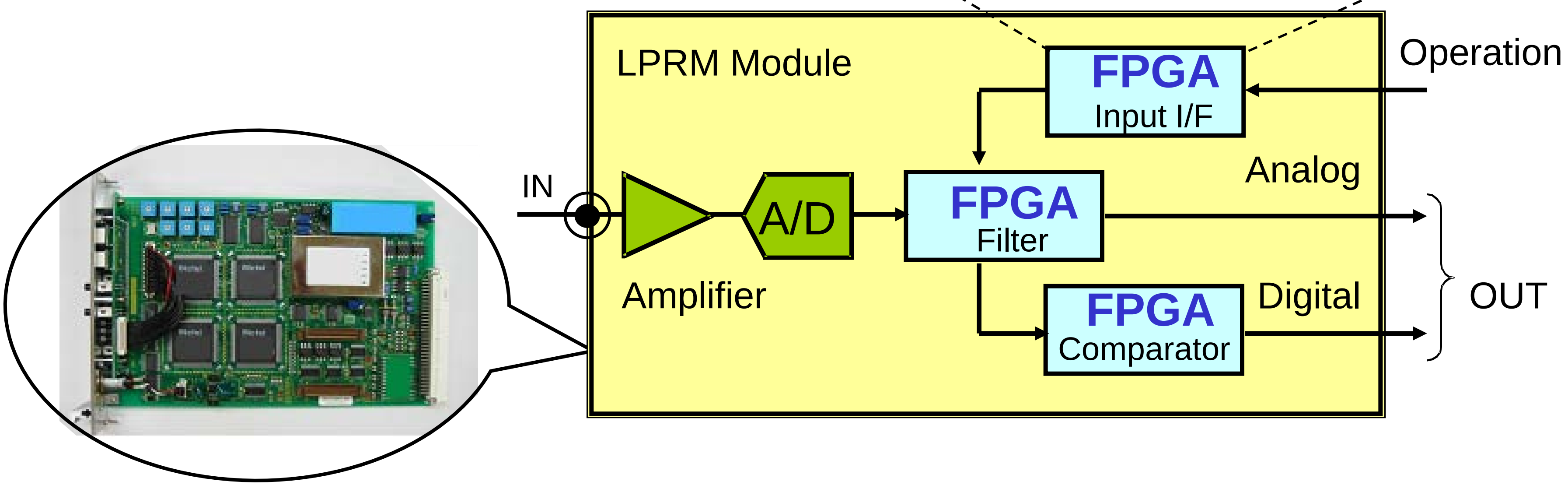
Architecture of FPGA-based Systems

- FPGA-based systems consist of **units**, chassis housing a set of **modules**.
- Module, such as a Local Power Range Neutron Monitor (LPRM) module, is constructed of one or more printed circuit boards
- FPGAs are soldered on the printed circuit board.
- FPGA logic are built from logical blocks, which are referred to as Functional Elements (**FE**s).

Module

- Each module consists of one or more printed circuit boards and a front panel.
- Each module has unique architectural features, based on the differences in interfaces and requirements.
- The module plugs into the backplane through connectors.

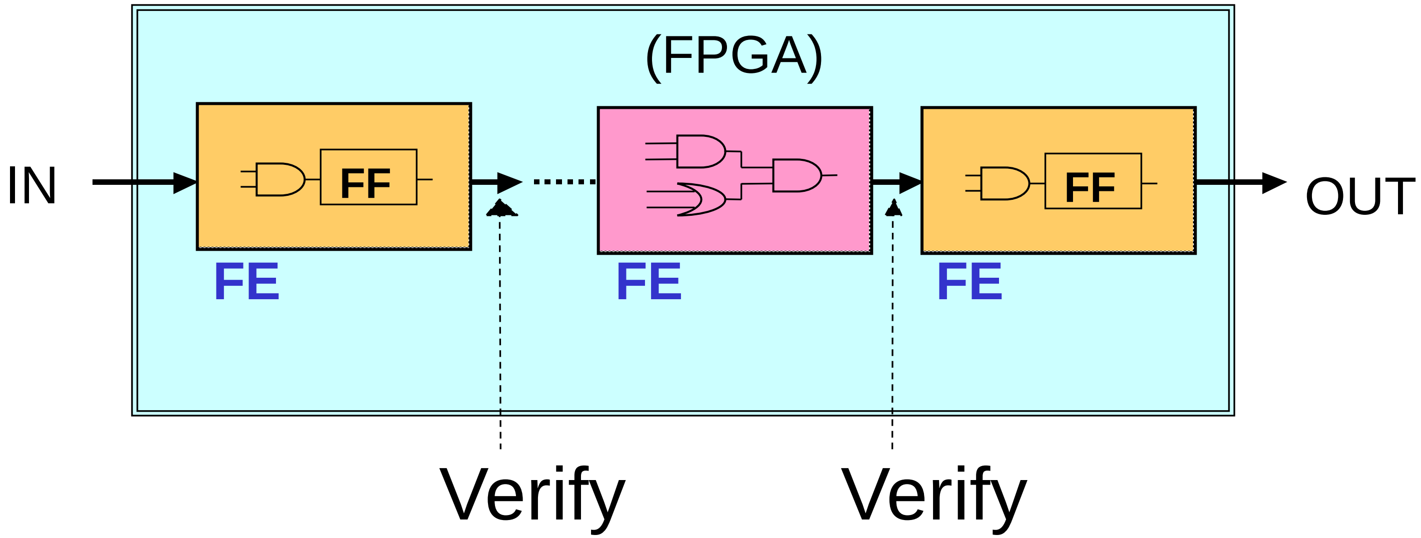




Configuration of FPGA Logic

- FPGA logic is composed as a combination of verified Functional Elements (FE).
- FE contains simple logic that can be verified through exhaustive testing.

FE: Functional Element



Design Process of FPGA-based Systems

FPGA themselves is hardware. However, the logic for these FPGA-based components is designed and manufactured by a process similar to software development process.

The lifecycle consists of the following processes:

(1) Define the system specification.
(2) Define the functional requirements of the components constituting the system.
(3) Design the logic to be embedded in the FPGA.
(4) Embed the logic in the FPGA, and perform FPGA validation testing.
(5) Fabricate the modules containing the FPGAs and units, and perform the module and unit validation testing.
(6) Integrate the system, and perform the system validation testing.

Part 3: Logic Qualification of FPGA-based Systems

Logic Qualification of FPGA-based Systems

There was no guideline or standard for qualification method of FPGA, which is applied to safety systems of nuclear power plant.

Toshiba developed an FPGA qualification process.

Toshiba applied IEEE Std 7-4.3.2-2003 to the process, because the development process of the FPGA-based system is similar to that of computer software.

IEEE Std 7-4.3.2-2003 requires the performance of V&V in accordance with IEEE Std 1012-1998.

Verification of FPGA Logic

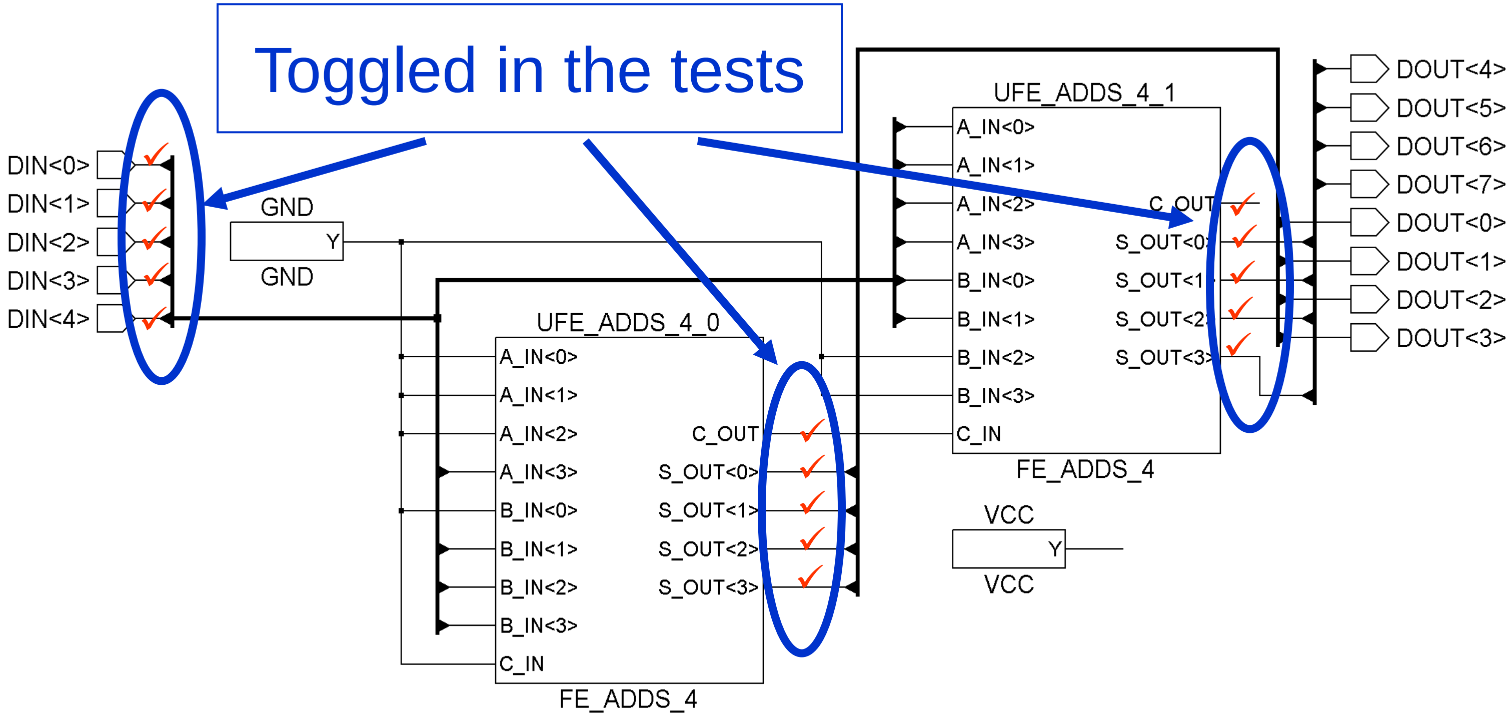
- **Verify FE by full pattern testing.**
- **Develop FPGA logic using verified FE only.**
- **Perform 100% toggle coverage tests to all FE connections.**

Toggle coverage is defined as follows:

$$\frac{\textit{Number of Exercised Connections in the test}}{\textit{Number of Operable Connections}}$$

FPGA Testing

Test the FPGA logic using identical FPGA chips that are installed in the products



Validation Testing

Module, Unit, and System validation tests were conducted to meet the specified requirements including:

- **Monitoring functions**
- **Safety-related functions**
- **Accuracy**
- **Response time**

Part 4: Hardware Qualification Tests of FPGA-based Systems

Qualification Tests- Overview

- EPRI TR-107330 describes the hardware qualification tests to demonstrate hardware acceptability for safety-related applications.
- Qualification testing was performed on a test specimen, as a type test.
- The test specimen was composed of all the units needed to duplicate a typical FPGA-based system.
- The test equipment was used to generate input signals to, and monitor the output signals from the test specimen during the qualification tests.

Qualification Tests

Following tests were conducted to demonstrate compliance with the specified requirements, and the suitability of equipment while being subject to stress conditions.

Test	Requirement
Environmental Test	Section 6.3.3 of EPRI TR-107330
Seismic Test	Section 6.3.4 of EPRI TR-107330
Electromagnetic Interference/Radio-Frequency Interference (EMI/RFI) Test	USNRC RG 1.180 Rev.1
Surge Withstand Capability Test	USNRC RG 1.180 Rev.1
Electrical Fast Transient / Burst (EFT/B) Test	USNRC RG 1.180 Rev.1
Electrostatic Discharge (ESD) Test	EPRI TR-102323 Rev. 2
Class 1E to Non Class 1E Isolation Test	Section 4.6.4 of EPRI TR-107330 and IEEE 384-1992

Part 5: Conclusions

Conclusions

- **Toshiba has developed a design process for NRW-FPGA-based I&C systems, and applied the process in the design of PRM system.**
  - Logic qualification satisfied IEEE Std 7-4.3.2-2003 and IEEE Std 1012-1998 requirements.
  - Hardware qualification satisfied EPRI TR-107330 requirements.
- **Toshiba concluded that the PRM system is satisfactory as a nuclear safety-related system.**
- **Toshiba will apply NRW-FPGA-based systems not only to BWRs, but also to other types of nuclear power plants and nuclear facilities in the world.**

- **We believe that the design process for the NRW-FPGA-based systems contributes to world standards of nuclear plants digital safety-related systems.**