DIGITAL CONTROL APPLICATION

FOR THE ADVANCED BOILING WATER REACTOR

L. E. FENNERN
T. PEARSON
H. D. WILLS
L. SWIRE RHODES
R. L. PEARSON GENERAL ELECTRIC SAN-JOSE USA.

Paper for "Specialists' Meeting on Use of Digital Computing Devices in Systems Important to Safety", November 28-30, 1984 - Paris, France.

INTRODUCTION

The Advanced Boiling Water Reactor (ABWR) is a 1300 MWe class Nuclear Power Plant whose design studies and demonstration tests are being performed by the three manufacturers, General Electric, Toshiba and Hitachi, under requirement specifications from the Tokyo Electric Power Company. The goals are to apply new technology to the BWR in order to achieve enhanced operational efficiencies, improved safety measures and cost reductions. In the plant instrumentation and control areas, traditional analog control equipment and wire cables will be replaced by distributed digital microprocessor based control units communicating with each other and the control room over fiber optic multiplexed data bases.

CONTROL & INSTRUMENTATION

The ABWR will include nonessential and essential multiplexing networks for intraplant data communications between sensors, control units, actuators and the control room. Fault tolerant digital feedwater, recirculation flow and pressure control systems will communicate over the nonessential data buses. Safety system logic and control will access data and provide control signals over essential data buses.

The essential multiplexing system is divided into four physically separate safety channels using separate divisional power sources. Each division has independent multiplexing units and triplicated data buses and bus control units to achieve high availability.

It is proposed that digital logic and control be implemented using NUMAC-based systems.

NUMAC CONCEPT

NUMAC, an acronym for NUclear Measurement, Analysis and Control, is a digital microprocessor based product for implementing all principal BWR Nuclear Steam Supply System monitoring and control functions. Current NUMAC systems can replace analog nuclear power plant instrumentation and process control systems in operating plants, or NUMAC-based systems can be used for newly designed plant systems such as ABWR. The term "NUMAC-based" refers to the many technical advantages of the NUMAC product line, such as self-testing, automatic calibration, user-interactive displays, full multiplex system compatibility, and packaging concepts, including instrument size, power requirements and the use of common circuit cards throughout the plant, where possible. Use of NUMAC features reduces calibration, adjustments, diagnostics and repair time, and reduces control room instrumentation volume and spare circuit card inventory requirements.

NUMAC TECHNICAL DESCRIPTION

NUMAC systems contain various modular hardware functions, including:

Sensor Signal Processing
Instrument and Sensor Power Supplies
Functional Microcomputer
High Speed Parallel Internal Data Bus
Fiber Optics External Bus Interface
Front Panel Man-Machine Interface

These hardware functions reside in a standard 17.8 cm tall by 48.3 cm wide rack mounted instrument. This instrument is configurable through firmware and provides system distributed intelligence, isolated cross-talk between safety channels, self-testing, and signal and engineering units conversion as required.

The High Speed Parallel Data Bus is functionally similar to the widely used IEEE 796 bus. The IEEE 796 bus and implementing circuitry uses transistor transistor logic (TTL). NUMAC instruments, however, use complimentary metal oxide semiconductor (CMOS) technology, which, because of low power dissipation, allows passive convection cooling and component longevity.

NUMAC instruments, where possible, use military standard components and redundant power supplies. NUMAC requirements include less than one hour average detection of failure and less than 30 minutes average replacement of defective modules.

Application software consists of functional, self-test and display modules, and emphasizes the man-machine interface, which simplifies operation and reduces operator error.

CONCLUSIONS

The NUMAC concept provides high reliability, high availability and high performance safety grade nuclear control instruments.

DIGITAL CONTROL APPLICATION FOR THE ADVANCED BOILING WATER REACTOR

L. E. FENNERN , GENERAL ELECTRIC COMPANY
T. PEARSON , GENERAL ELECTRIC COMPANY
H. D. WILLS , GENERAL ELECTRIC COMPANY
L. SWIRE RHODES, GENERAL ELECTRIC COMPANY
R. L. PEARSON , GENERAL ELECTRIC COMPANY

Paper for "Specialists' Meeting on Use of Digital Computing Devices in Systems Important to Safety", November 28-30, 1984 - Paris, France

INTRODUCTION

The Advanced Boiling Water Reactor (ABWR) is a 1300 MWe class Nuclear Power Plant whose design studies and demonstration tests are being performed by the three manufacturers, General Electric, Toshiba and Hitachi, under requirement specifications from the Tokyo Electric Power Company. The goals are to apply new technology to the BWR in order to achieve enhanced operational efficiencies, improved safety measures and cost reductions. In the plant instrumentation and control areas, traditional analog control equipment and wire cables will be replaced by distributed digital microprocessor based control units communicating with each other and the control room over fiber optic multiplexed data buses.

CONTROL & INSTRUMENTATION

General Electric proposes that the ABWR include nonessential and essential multiplexing networks for intraplant data communications between sensors, control units, actuators and the control room. Fault tolerant digital feedwater, recirculation flow and bypass and pressure control systems will communicate over the nonessential data buses. Safety system logic and control will access data and provide control signals over essential data buses. This division of functions preserves separation of control and safety functions and provides for systems independence.

The essential mutiplexing system will be divided into four physically separate safety channels using separate divisional power sources, and will meet the criteria assigned to Class 1E safety related systems. Each division will have independent multiplexing units and triplicated data buses and bus control units to achieve high availability and reliability.

The ABWR hierarchial distributed architecture is illustrated conceptually in Figure 1. Top level control is provided by the Performance Monitoring and Control System which includes subsystems for power generation control and turbine plant control. The primary man-machine interface for the ABWR plant monitoring and control function is the control room operator's station. Monitoring and control data are routed along fiber optic data highways to individual control systems. These systems receive sensor input over either fiber optic data buses or direct wiring, process that input and issue actuator commands.

The decision to multiplex specific plant systems must be considered on a case by case basis. Some systems do not lend themselves to cost effective multiplexing. Others may not be multiplexed for diversity reasons, for example, the remote shutdown and standby liquid control systems.

During the ABWR design study period, General Electric will investigate the benefits of distributed local control. Existing BWRs rely on centralized control, with sensor inputs hardwired to controllers in the control room, which then provide output currents through load drivers to actuators at remote locations. With distributed control, both controllers and load drivers would be located closer to the equipment they control. This provides an opportunity to hardwire certain essential signals without incurring high costs for hardwire routing of those signals to the control room. Multiplexing to the control room would be used for indication and display purposes and for transmission of operator control requests. This concept potentially increases diversity and defense in depth while retaining the cost benefits of multiplexing.

General Electric proposes that digital logic and control be implemented using NUMAC based systems.

NUMAC CONCEPT

NUMAC, an acronym for NUclear Measurement, Analysis and Control, is a digital microprocessor based product for implementing all prinicpal BWR Nuclear Steam Supply System monitoring and control functions. Current NUMAC systems can replace analog nuclear power plant instrumentation and process control systems in operating plants, or NUMAC based systems can be used for newly designed plant systems such as ABWR. The terms "NUMAC based" refers to the many technical advantages of the NUMAC product line, such as self-testing, automatic calibration, user-interactive front panels, full multiplex system compatibility, and packaging concepts, including instrument size, power requirements and the use of common circuit cards throughout the plant, where possible. Use of NUMAC features reduces calibration, adjustments, diagnostics and repair time, and reduces control room instrumentation volume and spare circuit card inventory requirments.

For ABWR, General Electric proposes that NUMAC basing be used for the following systems:

- Startup Range Neutron Monitoring
- Power Range Neutron Monitoring
- Automated Traversing-In-Core-Probe
- Process Radiation Monitoring
- Area Radiation Monitoring
- Feedwater Flow Control
- Recirculation Flow Control
- Steam Bypass and Pressure Control
- Rod Control and Information System
- Plant Multiplexing System

NUMAC TECHNICAL DESCRIPTION

NUMAC systems contain various modular hardware functions, including:

- Sensor Signal Processing
- Sensor Power Supplies
- Functional Mirocomputer
- High Speed Parallel Internal Data Bus
- Fiber Optics External Bus Interface
- Front Panel Man-Machine Interface
- Trip and Analog Outputs
- Redundant Instrument Power Supplies

These hardware functions reside in a standard 17.8 cm tall by 48.3 cm wide rack mounted instrument (Figures 2 & 3). This instrument is configurable through firmware and provides system distributed intelligence, isolated cross-talk between safety channels, self-testing, and signal and engineering units conversion as required.

The High Speed Parallel Data Bus is functionally similar to the widely used IEEE 796 bus. The IEEE 796 bus and implementing circuitry uses transistor transistor logic (TTL). NUMAC instruments, however, use complimentary metal oxide semiconductor (CMOS) technology, which, because of low power dissipation, allows passive convection cooling and compnent longevity.

NUMAC instruments, where possible, use highly reliable components and redundant power supplies, which reduce the mean time between failures (MTBF). NUMAC requirements include less than 30 minutes mean time to detect a failure (MTTD) and less than 30 minutes mean time to repair (MTTR) a defective module. Since availability is defined as ($\frac{MTBF}{MTBF + MTTD + MTTR}$), all elements of the equation are improved by NUMAC design compared to current BWR instruments, and availability is improved.

Application software consists of functional, self-test and display modules, and emphasizes the man-machine interface. NUMAC software emphasizes the man-machine interface. The user controls the instrument by menu keys utilizing a menu-driven display with LCD readout. Control switches select the appropriate modes and display for the configuration desired. Cursor control switches permit set point selection and ramping test signals over required ranges. A keypad also allows numerical data entry. A special "HELP" key is provided in case of menu difficulties. The above interfaces simplify and speed operation and reduce operator error. Examples of front panel displays are illustrated in Figure 4 for the Logarithmic Radiation Monitor.

FAULT TOLERANT DIGITAL CONTROL SYSTEMS

As an example of NUMAC application, a General Electric proposal for NUMAC based Fault Tolerant Digital Controllers, to be utilized for major ABWR process control systems, is described here. The proposed ABWR Fault Tolerant Digital Controller (FTDC) is a highly reliable general purpose process control system. It is modular, both in hardware and software, enabling different ABWR control systems to be constructed of identical hardware. Only the FTDC's imbedded application firmware and the quantity and types of input and output modules differentiates these systems. The FTDC is recommended for each of the three major ABWR process control systems:

Feedwater Flow Control System
Recirculation Flow Control System
Steam Bypass and Pressure Control System

The FTDC hardware includes three identical microprocessor based processing channels, each with its own processing capabilities, control programs in firmware, and multiplexing system interface hardware. The three channels exchange data over serial links to enable cross-channel voting and to avoid processor divergence. Each of the channels send demand signals to actuators. The actuators either accept the three signals, and carry the fault tolerance and redundancy down to the actuator level, or rely on an analog voter, considered as part of the actuator, to perform signal neckdown.

Figure 5 illustrates the FTDC top level architecture. The interrelationship of the FTDC with the other components of the process control system is shown. Figure 6 shows the configuration of the various major components within the FTDC.

The key goal of the FTDC is to provide process control functions while at the same time assuring that no single active component failure within any system process sensing, control or communications equipments shall result in loss of continuous validated signals to the system actuators and critical operator displays. Self-test features and on-line diagnostic capabilities permit identification and isolation of a failed device. The faulty FTDC electronics hardware may then be repaired without requiring the system to be taken off-line.

SUMMARY & CONCLUSIONS

The ABWR will incorporate modern digital control and multiplexing technologies. NUMAC based digital control applications can provide cost effective, highly reliable and available ABWR control and instrumentation systems. With these technologies ABWR can achieve the goals of enhanced operational efficiencies, improved safety measures and cost reductions in the control and instrumentation areas.

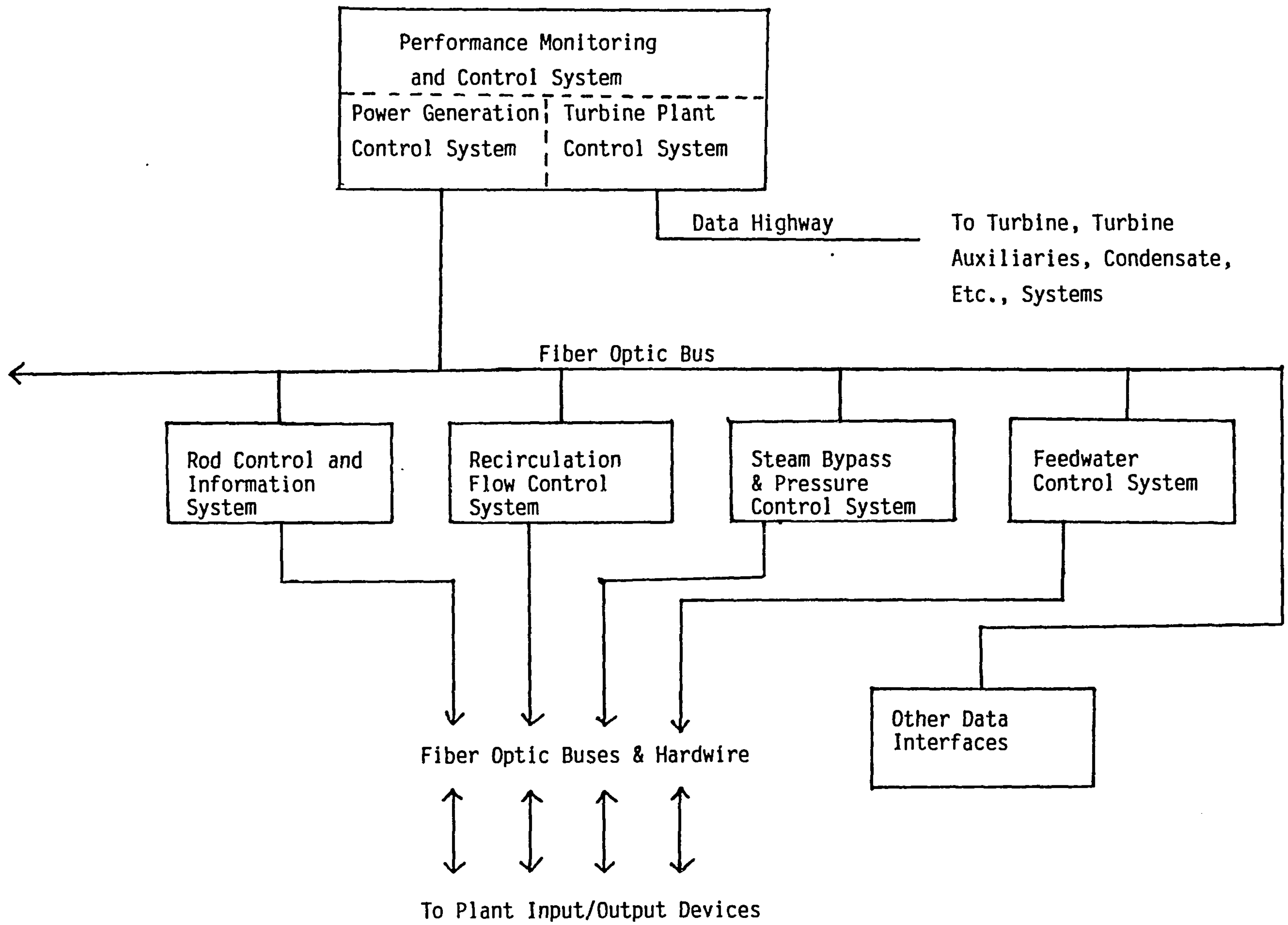


Figure 1. ABWR "Hierarchical Distributed Architecture"

151

Upgrade your radiation/neutron monitoring and control functions with advanced microprocessor technology.

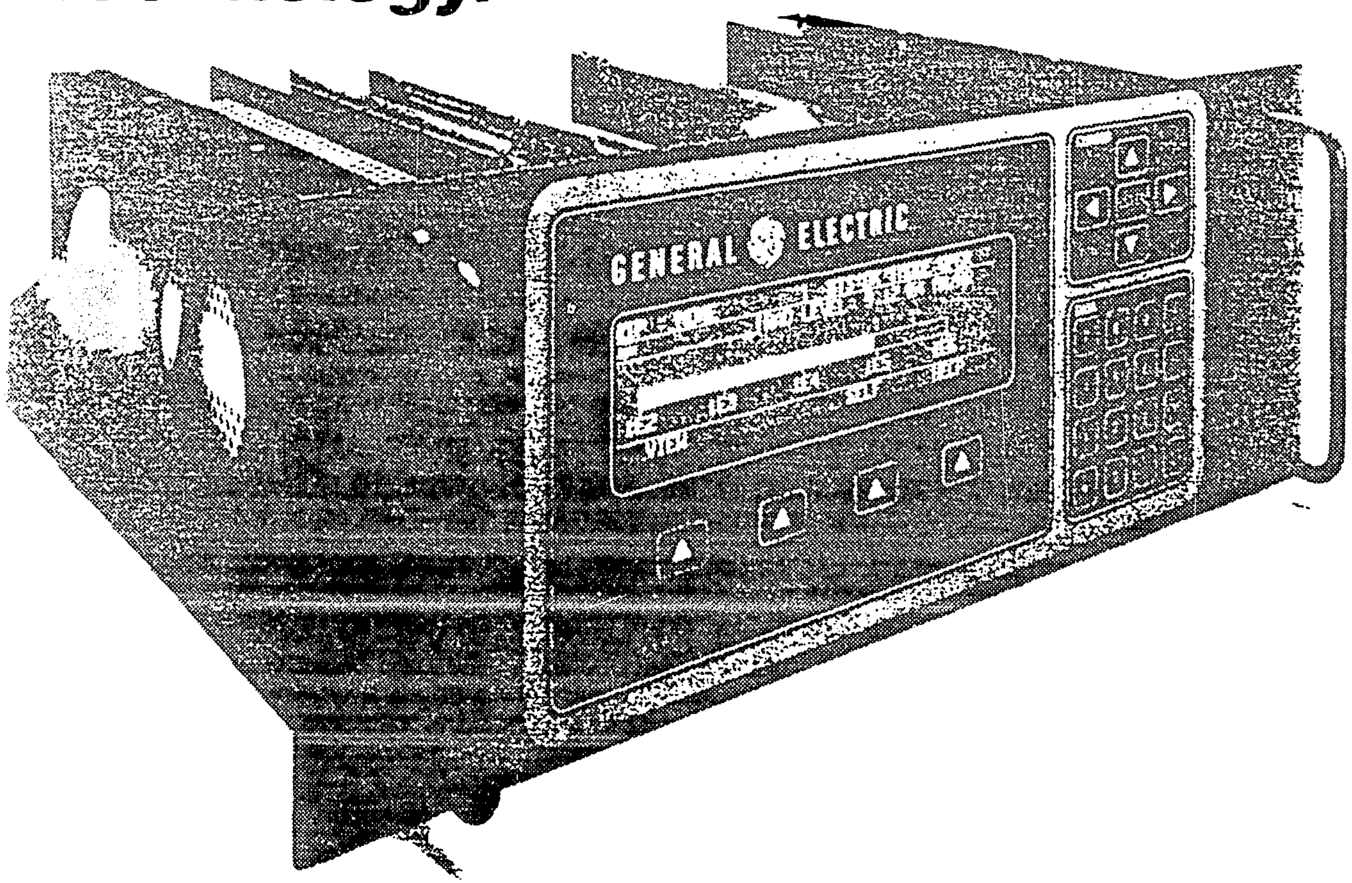


Figure 2. NUMAC Front Panel

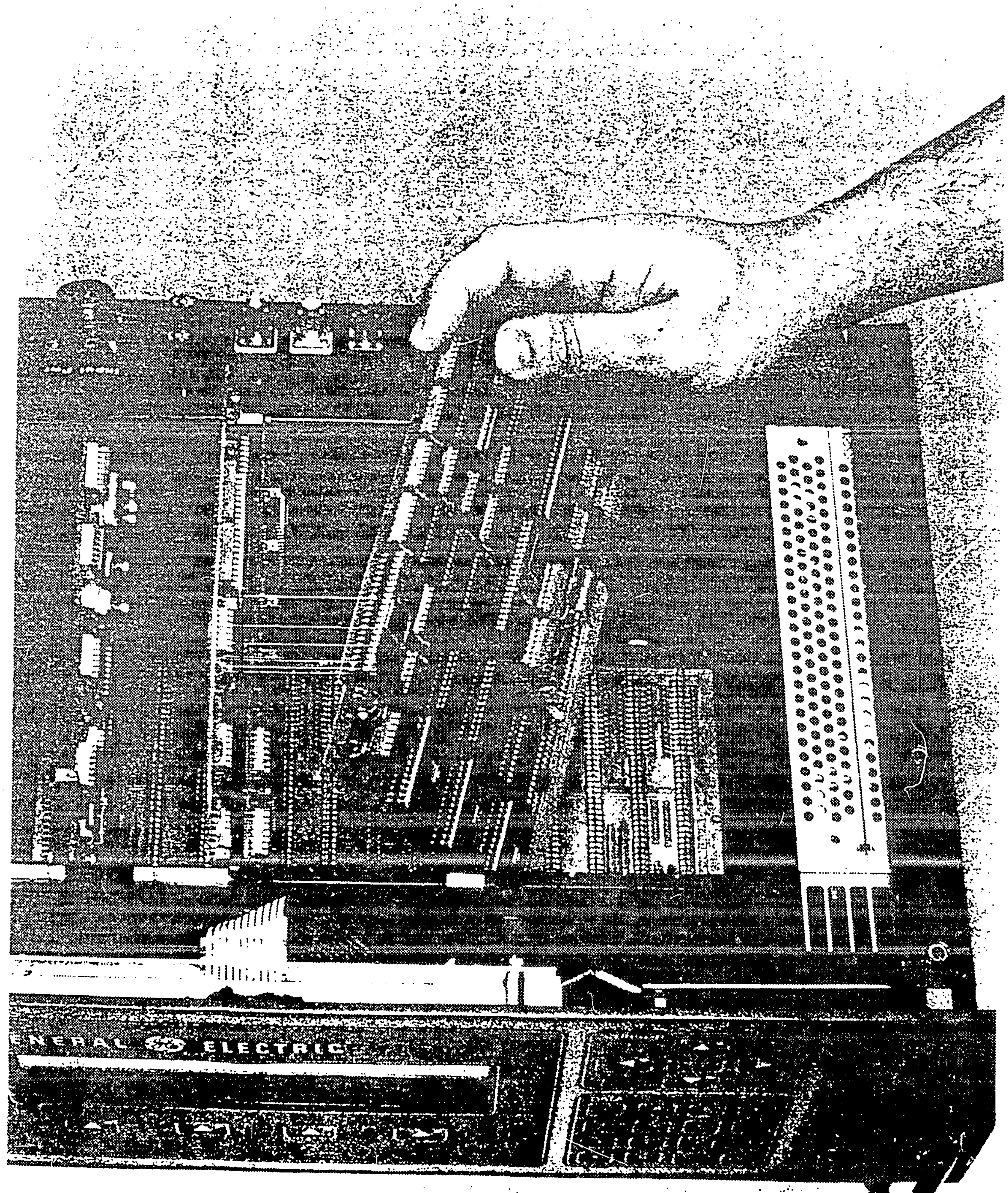


Figure 3. NUMAC Backplane

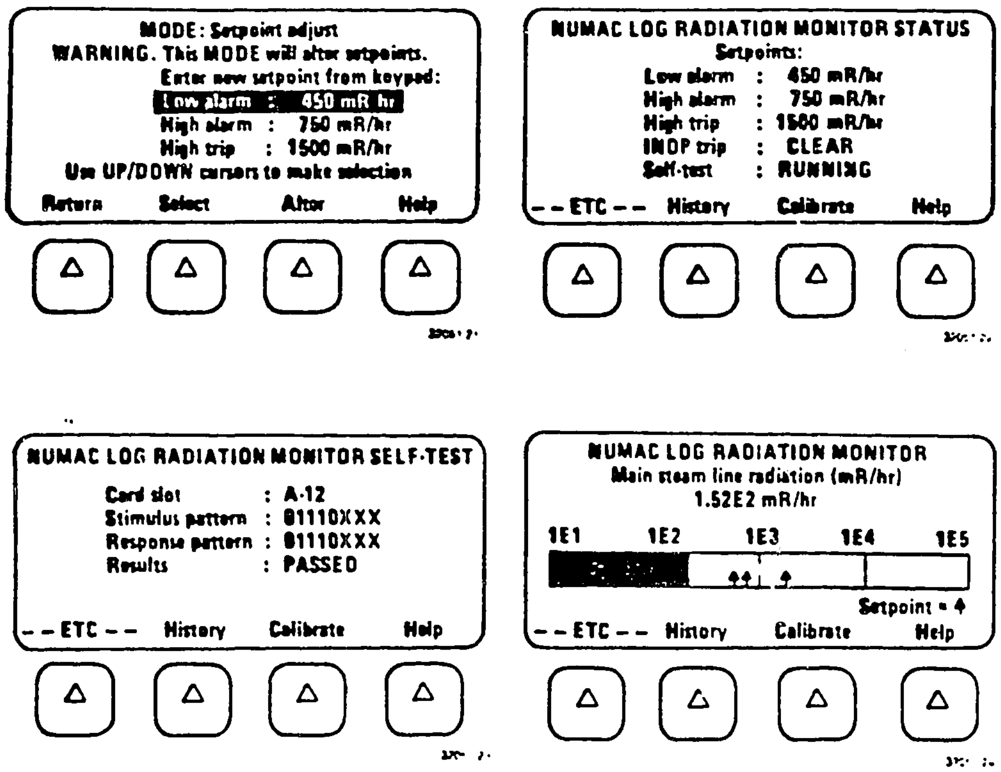


Figure 4, NUMAC Logarithmic Radiation Monitor Displays

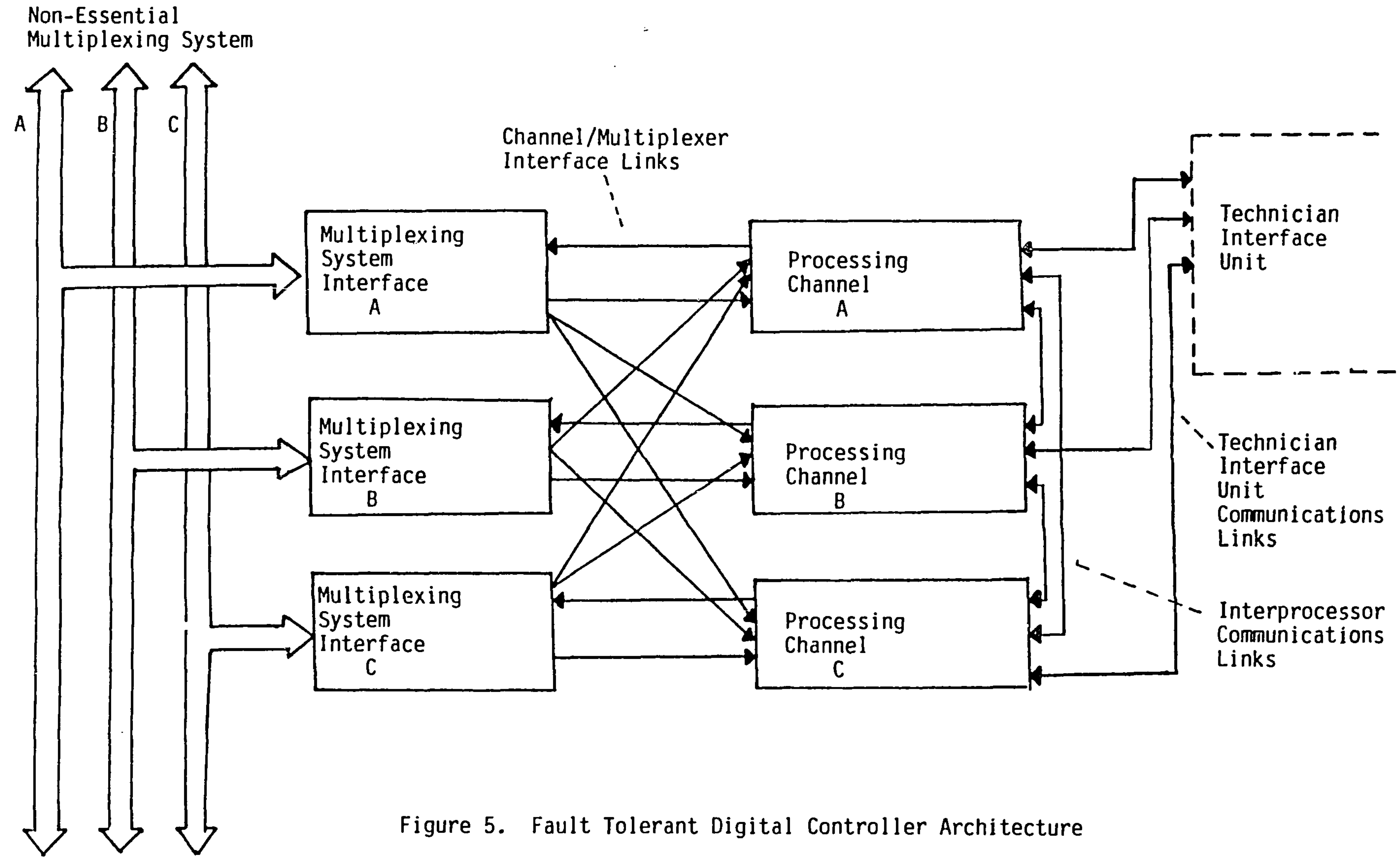
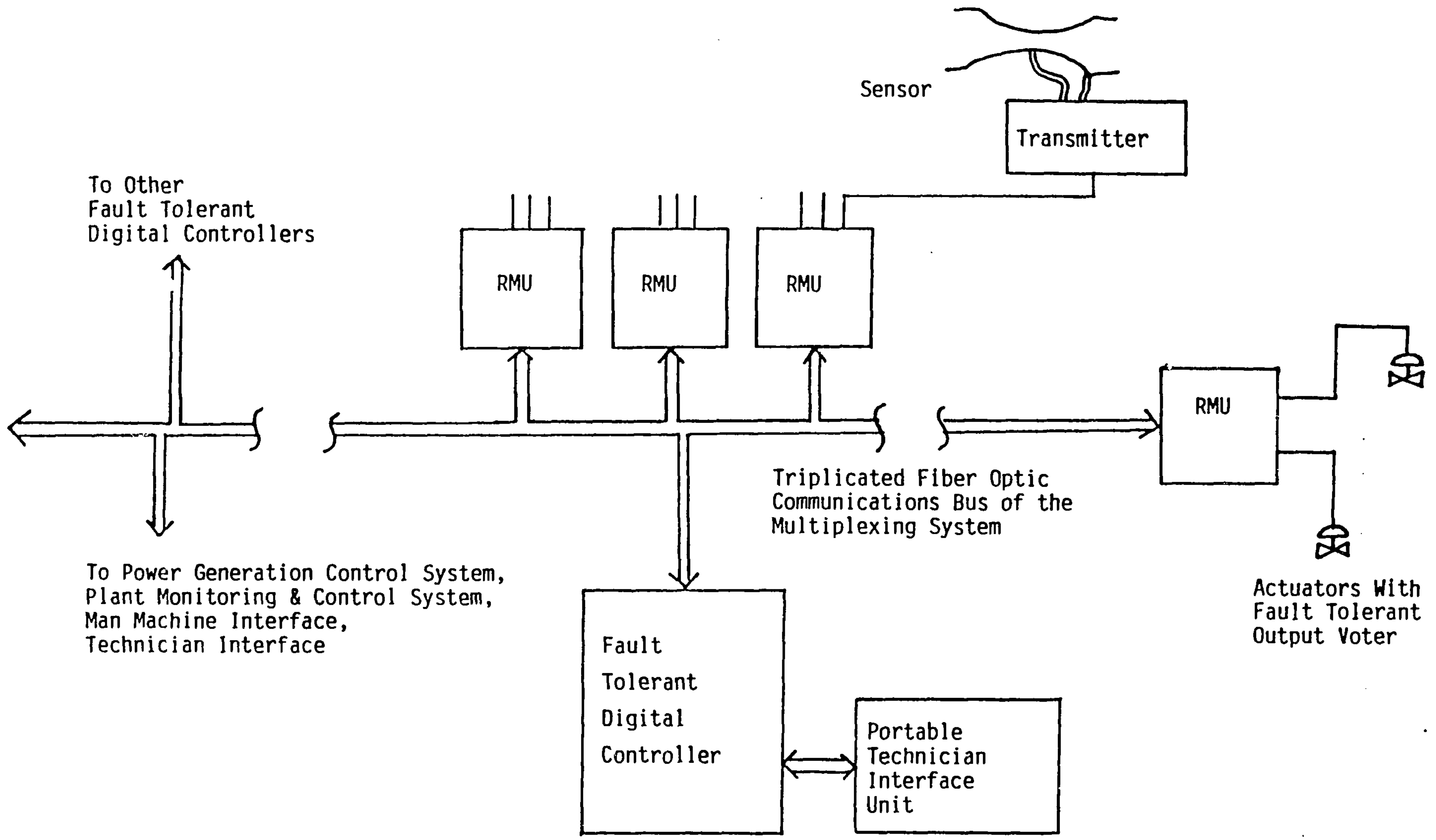


Figure 5. Fault Tolerant Digital Controller Architecture



RMU=Remote Multiplexing Unit

Figure 6. ABWR Process Control Configuration