A Versatile Modular Radiation Monitoring System

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ABSTRACT

A modular microprocessor-based Radiation Monitoring System has been developed for the detection of neutron, gamma and beta fields. The system consists of distributed local monitoring stations located close to the radiation detectors. A local monitoring station houses up to two Universal Detector Modules and a power supply in a standard Eurocard cage. The Universal Detector Module supports Geiger-Mueller tubes and photomultiplier detectors. The module provides local display of averaged radiation fields and high radiation level trip contacts. A local station can operate stand-alone or communicate with a supervisory processor on an RS-422 highway. Experience with an installed system is described.

1 INTRODUCTION

TRIUMF and Ebco Technologies Inc. of Vancouver entered a Technology Transfer Agreement to design and build small cyclotrons for medical isotope production. A TR30/15 model, which can deliver 500μa of protons of 30MeV or deuterons of 15MeV energy was installed at the Institute of Nuclear Energy Research (INER) near Taipei, Taiwan. The operation of the cyclotron required a radiation monitoring system, which is an integral part of the safety procedures around particle accelerators. Monitoring equipment used at TRIUMF consists of radiation detectors, a High Voltage (HV) power supply and pulse discriminators in NIM electronics connected to CAMAC scalers that are read by a computer. Detectors typically consist of gamma monitors (Geiger Meuller (GM) tubes), Neutron monitors (BF_3 tubes) and stack air monitors (an air sampling system with a scintillation/photomultiplier tube). The installation at INER required twenty detectors at ten different locations within the cyclotron complex. The NIM/CAMAC based solution used at TRIUMF was considered too expensive within the INER infrastructure. A new design with a distributed modular approach was chosen to provide a more viable solution

The Radiation Monitoring System was designed to monitor areas normally accessible by staff and provide radiation level information that forms part of a safety system. This system was not intended to replace radiation surveys undertaken by a trained radiation surveyor.

2 DESIGN GOALS

Our goal was to design a flexible Radiation Monitoring System (RMS) that could be accessed remotely by a host computer, yet could also function stand-alone. The system had to provide the necessary high voltages and accept three types of detectors: Geiger-Mueller tubes (GM), BF_3 tubes and photomultiplier tubes. To function as a stand-alone instrument, a front panel switch and display were needed. Other essential requirements were that calibration parameters could be modified and modules replaced with no manual reconfiguration. The system had to also convert pulse counts to standard units of radiation dose-rate-equivalent (DRE). An interlock output had to be provided when radiation levels exceed predetermined setpoints.

3 SYSTEM DESIGN

The radiation monitoring system designed and built for the TR30/15 is distributed and modular. It consists of local monitoring stations close to each detector or detector group. A local station consists of several microprocessor-based Universal Detector Modules (UDM) housed in a Eurocard cage. Each detector module is auto-configured from the backplane according to its location in the crate. The module contains no adjustable devices. A local station can operate stand-alone or in communication with a supervisory processor on an RS-422 highway.

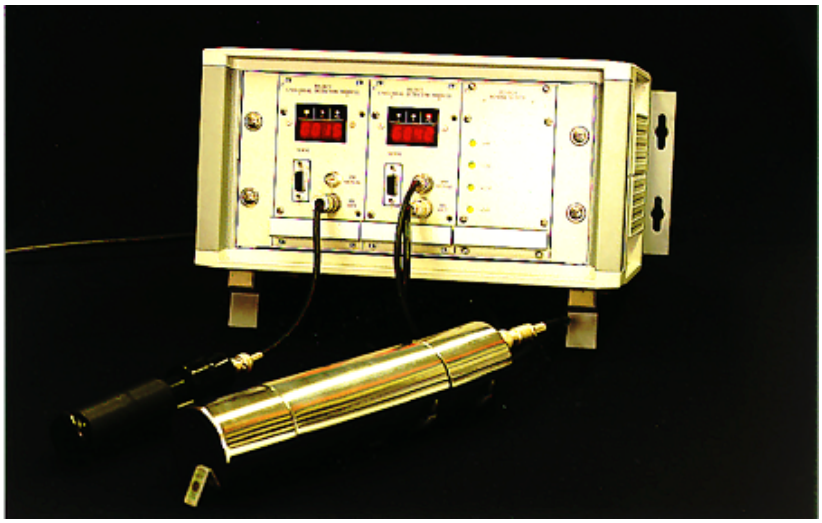

Figure 1. A station crate with two UDMs connected to a Geiger-Mueller tube and a photomultiplier tube

3.1 HARDWARE

Full-width (six slots) or half-width (three slots) station crates are possible. The logic power supply resides in the farthest right-hand slot and the remaining slots may be filled by UDMs. An 8-bit address is set during module configuration.

Station Crate

A Station Crate consists of a standard Eurocard card cage. The card cage is 4U high and has either the standard 19" width of 84HP, or a half width of 42HP. Configuration information is stored in an EEPROM located on the crate backplane. If a defective module is replaced, the new module will configure itself for the same high voltage, calibration constant and other parameters in use by the original module. This reduces the spare parts required.

Logic Power Supply

The logic power supply consists of a commercial unit built into a 3U by 14HP module and provides +5, +/-12 and +24 VDC. The power supply may be powered by either 90-132 or 175-264 VAC at 47-63Hz.

Universal Detector Module

The module is 3U high and 14HP wide. It will accept either a photomultiplier tube, a GM tube or a neutron detector. The UDM uses a Signetics 80C552 microcontroller as CPU.

The UDM can operate in stand-alone or supervised mode. A block diagram is shown in figure 2.

High Voltage Power Supply

The high voltage power supply is a switching one and converts +24VDC from the backplane to a maximum of 2500V. The three nominal voltage ranges to be used are: 1850V for the neutron detectors, 1200V for the photomultiplier tube and 900V for the gamma detectors. These nominal voltages are the default values. The manufacturer's specified tube voltage is entered during module configuration. The microcontroller sets the high voltage with a pulse width modulated output converted to a DC voltage and monitors it through a resistor divider fed into a 10 bit ADC. The voltage can be set to one part in 256 for a range of 0 to 2500 volts.

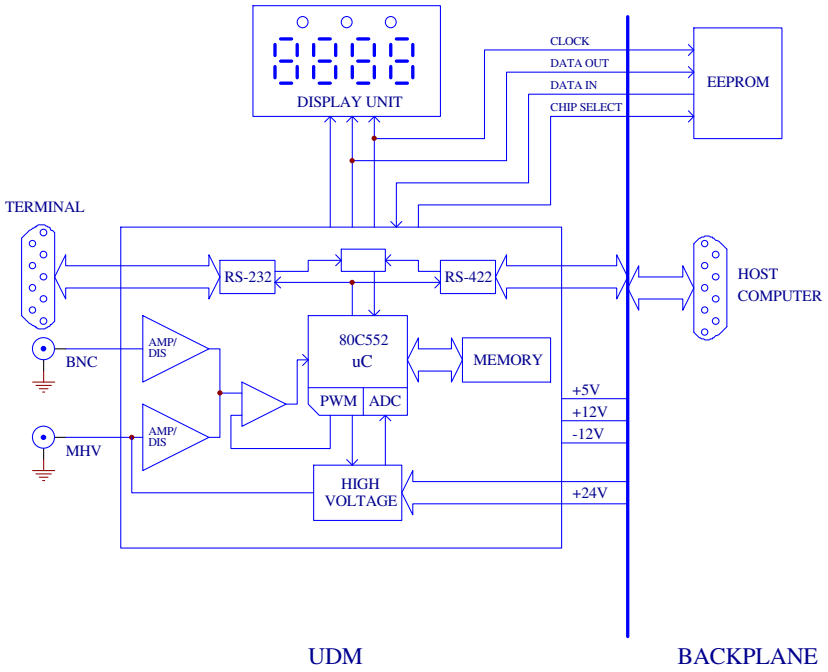

Figure 2. Block diagram of the UDM

Amplifier Section

Two independent amplifier and discriminator sections have been implemented in the UDM, one for the gamma, residual and neutron detectors and the other for the photomultiplier detector. The two amplifier stages are necessary because of the difference in pulse amplitude between the GM tubes and the photomultiplier tube. The gain of the amplifiers is fixed. The threshold for the discriminator section is set by the microcontroller to one part in 256. The microcontroller selects the amplifier stage according to the configuration information.

Pulse Counting

After the pulses have been amplified and discriminated they are fed directly into the microcontroller's count register. This accumulated count is sampled every second. An average is taken of the last four samples (thirty for the neutron detector) then the DREt value is calculated and displayed.

Front Panel

A display on the UDM front panel provides anyone in the area with an indication of the radiation DRE in both supervised and stand-alone operation. All indicators are designed to be readable from a distance of two metres.
The front panel (see Fig. 1) has:

- a four-digit LED display to show the adiation DRE and HV status
- three individual LED lamps to indicate the detector configuration, green for the gamma detector (GM tube), red for the stack air (photomultiplier tube) and yellow for the neutron detector
- one MHV connector for high voltage; for the GM and neutron tubes this connector is also used for the pulse input
- one BNC connector for the pulse from the photomultiplier tube
- one subminiature "D" nine pin connector for a terminal connection (RS-232)
- a momentary switch to enable/disable the high voltage during stand-alone operation

The four digit LED display shows:

- “OFF” if the high voltage is disabled
- the radiation DRE in microsieverts/hr for the gamma and neutron detectors
- the radiation flux in counts/minute for the stack air monitors
- "con" when a terminal is plugged in for configuration of the UDM
-"rrr" when the module is acquiring data, but no valid average has been established

-"FAIL" if the module detects a difference of greater than 100 volts between HV setpoint and HV readback
-"---" if the module detects a bad configuration on power up.
-Flashing "9999" when the display is over ranged.

Communications
The UDM communicates with the host computer's serial port via an RS-422 link at 19,200 baud. This link consists of two twisted pairs, which allow bidirectional, full duplex data communications.

Power Up and AC Fail Recovery
On AC power up the module will start automatically. It first reads its configuration data from the non-volatile memory on the backplane and then starts depending on the module configuration. There are three options for enabling the high voltage after a power up: a) immediately, b) after a host computer "on" command or c) by the front panel switch in stand-alone mode or as a backup if the host computer fails.

Protection from ElectroMagnetic Interference (EMI)

We have taken several steps to prevent and/or to recover from EMI. The UDM is enclosed in an all metal housing. An EMI resistant spray coating was applied to the inside of the plastic rack enclosure and a hardware watchdog timer resets the microcontroller if necessary. Communication with the host computer uses a differential RS-422 shielded cable. In addition the communication protocol includes a parity bit for each character and a checksum per message. All accesses to the backplane EEPROM are verified using a checksum.

3.2 SOFTWARE/OPERATION

The UDM firmware is written in C. The application program consists of a main loop which distinguishes between normal operation mode and configuration mode.

In normal operation mode, the main loop is interrupted every 50 milliseconds by the microcontroller's on-board timer. Every twentieth interrupt (one second) the microcontroller's pulse accumulator is read. This value is placed into a ring buffer of 30 elements for a neutron reading and four for a gamma or photomultiplier reading. The main loop averages the complete buffer to obtain a counts/second value. This value is then passed to the appropriate conversion routine to calculate the radiation DRE in microsieverts/hour using the parameters entered during configuration. The result is output to the display and sent to the host computer when polled. The host computer's poll generates a serial port interrupt, and the microcontroller responds with the current data during the interrupt routine.

Configuration mode is entered when a terminal is connected to the serial port on the front panel of the UDM and the main loop detects Data Terminal Ready. In configuration mode the HV is switched off and the operational parameters may be modified. Preprogrammed into the UDM is a menu system to guide the user through the configuration process. The user will first select the module address and the detector type then enter individual parameters or select the defaults for the detector. Interlock output levels may also be entered. The configuration is saved to the EEPROM on the backplane. When the terminal is disconnected, the microcontroller resets the UDM and returns to normal operation mode

If the UDM is supervised by a host computer, the host is the master using a command-response protocol. Messages are ASCII strings. The detailed message formats are as specified in fig 3.

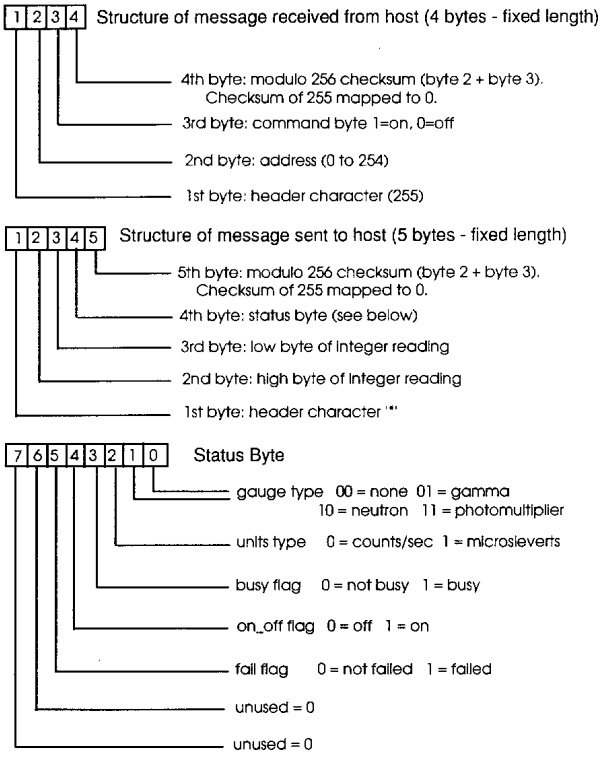

Figure 3.Communication protocol

4 SUMMARY

A versatile radiation monitoring system consisting of a Universal Detector Module and Power Supply housed in a standard Eurocard case has been developed. A system utilizing six GM tubes for residual field measurement inside the vaults, six GM tubes for hallway measurement, six neutron detectors for hallway measurement and two photomultiplier tubes for stack air measurements is currently in operation on the EBCO Technologies Inc. TR30/15 cyclotron at the INER in Taiwan. The ten stations communicate with the cyclotron safety system PLC (Allen-Bradley PLC5/40L). A similar setup was installed for the TR13 Cyclotron at the National University hospital in Seoul, Korea.

Experience at INER suggests two possible improvements to the system: a preamplifier for the neutron detectors, to allow the detector to be moved farther from the module and a higher powered HV supply. The system at INER has been running without interruption since early 1993.

5 ACKNOWLEDGMENTS

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