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Integrated Monitoring Hardware Developments at Los Alamos

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1. ABSTRACT

The hardware of the integrated monitoring system supports a family of instruments having a common internal architecture and firmware. Instruments can be easily configured from application-specific personality boards combined with common master-processor and high- and low-voltage power supply boards, and basic operating firmware. The instruments are designed to function autonomously to survive power and communication outages and to adapt to changing conditions. The personality boards allow measurement of gross gammas and neutrons, neutron coincidence and multiplicity, and gamma spectra. In addition, the Intelligent Local Node (ILON) provides a moderate-bandwidth network to tie together instruments, sensors, and computers.

2. INTRODUCTION

The hardware of the integrated monitoring system supports[1,2] a family of instruments which have a common internal architecture and firmware. Various instruments can be configured that share the same design for high- and low-voltage power supplies, processor board, and basic operating firmware. The instruments have the built-in capability for functioning autonomously – integrated battery permits operation for a significant amount of time if power is interrupted, a large local, battery-backed up memory permits storage of many hours of data if communication with the central computer is interrupted, and local decision-making allows the instrument to adapt to changing conditions. The self-diagnostic capability which has been part of our instruments since 1986 is continued and enhanced. Reliable construction, simple assembly and disassembly, and separation of function on separate boards for ease of maintenance are also features of the family.

The instruments are constructed from a set of common boards which provide basic operating functionality, and a set of personality boards which provide the capability of interfacing to different types of detectors and performing different types of analyses.

The instrument family consists of the Mini Gamma Ray and Neutron Detector electronics (MiniGRAND), the Advanced Multiplicity Shift Register/Intelligent Shift Register (AMSR/ISR)[3], and the Mini Analog to Digital Converter electronics (MiniADC). The Intelligent Local Node (ILON) is also a member of this family, being designed around the same processor board[4].

3. HARDWARE

3.1 Common Components

The foundation for the instrument family is provided by the Low-Voltage Power Supply Board (LVPS), Bias Boards (BIAS), and the Master Processor Board (MPB).

3.1.1 Low-Voltage Power Supply (LVPS)

The Low-Voltage power supply board provides all bus voltages that power the master-process board and the application-specific boards, as well as power for the detector preamplifiers.

The LVPS switches automatically to battery power in the event of an external power failure, and provides status to the firmware indicating that external power has failed. The instrument may then react to reduce its power consumption to prolong the operation time while drawing power from the battery.

Specifications:

Readback on the all bus voltages

HV bias control

Analog output voltages: +/-11.3 V DC; total power < 5W

Digital output voltages: +5V DC/750mA

+5V/2mA (for battery backup)

Power Consumption: 33mA @ 12.1V DC (quiescent)

Size: 3.75" x 7.75"

3.1.2 Bias Board (BIAS)

The high voltage bias board includes voltage multiplier chains for two +/- V and +V/4 outputs. The feedback resistor is connected to the +V/4 output. The output filter, output connectors, and 4 bits of configuration information are also part of the board. All HV traces and components are conformal coated.

The board can be built for various configurations, depending on the output voltages desired. Software determines the type of board installed and programs it accordingly.

Specifications:

- Voltage setting controlled by software
- Output voltages are board dependent:
  - +1250, -1250, +1500, -1500, +2000, -2000, +4500, -4500, +1500/-1500 (dual output), +4500/-4500 (dual output), or
  - +1500/+4500/-4500 (triple output)
- Software ON/OFF function
- External shutdown input with software inhibit
- Output impedance 1M
- Board Power Consumption: < 30mA @ 12.1V, no load
- Size: 3.75" x 1.75"

3.1.3 Master Processor Board (MPB)

The Master Processor board provides the intelligence to control the operation of the personality boards, to adjust parameters based on current conditions, to filter data, provide external triggers, store data, and pass data on to a central collect computer when required.

The MPB contains the bulk of the computing capability of the system. Much of the hardware on the MPB is provided in programmable Xilinx gate-arrays, while the rest is provided using discrete components.

Specification:

- Motorola MC68HC11A1FN CPU
- 256K x 8 bit flash memory (512 K possible)
- 512k x 8 bit battery backed-up static RAM
- battery backed-up real time clock (time-of-day and date)
- two serial ports (RJ25 connector)
  - asynchronous RS-232 up to 9600 baud or synchronous TTL up to 1.5Mbit/s
  - second asynchronous RS-232 serial interface up to 115K baud
  - long-break reset feature allows remote reset of processor via serial port
- 8 bits each parallel input and output
- one channel analog input with 8-bit resolution
- single channel 32-bit pulse counter with interrupt on overflow
- synchronous expansion bus with multiplexed address and data signals, control signals and power
- optional on-board +5v power supply
- ability to read +5, battery, battery backed-up +5, +-12 volt power supply voltages
- Power Consumption: 90 mA @ +5 VDC
- Size: 3.75" x 7.75"

3.1.4 System Bus

The boards in an instrument connect and communicate via a 17x2-pin bus. Thirteen signals are buffered 68HC11 CPU signals, including 8 data/IO lines, address strobe, processor clock, reset, IRQ interrupt, and read/write. The timing for these signals follows the timing specifications specified in the Motorola 68HC11 data sheets. The bus includes four board address select signals that are used to address individual boards in the stack. Two clocks are run on the bus, the 8MHz SYSCLK and SCLKB, the synchronous serial clock from the 68HC11. Two additional clock signals used in data acquisition are run on the bus.

The bus also contains two digital grounds and two analog grounds, two +5 V supplies (one digital supply and one battery backup), +/-12 V supplies used to power opamps, and VSUPPLY which is used to derive power for all the boards. A signal called VBAT_RET provides for the return for the battery backup.

3.2 Instruments

The LVPS, BIAS, and MPB are mated with different personality boards to create instruments. Each instrument has its own firmware that exercises the different personality boards and also performs required analyses on the data.

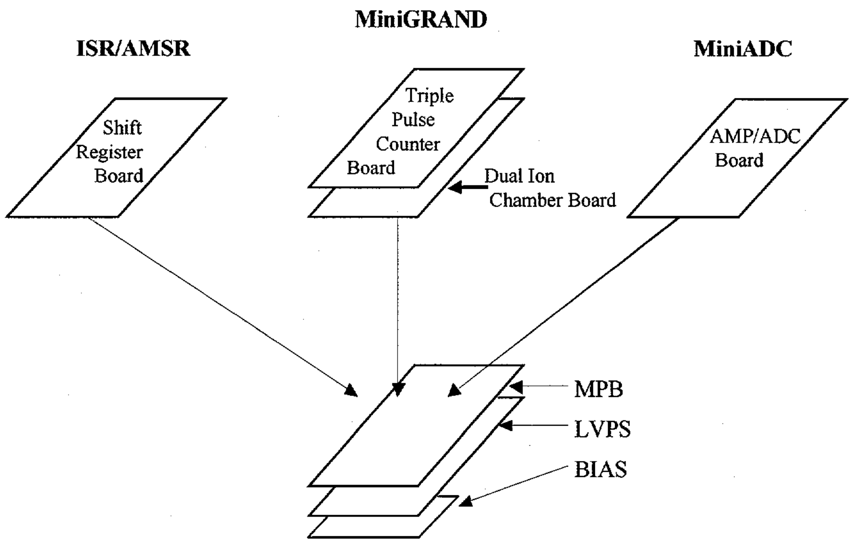

Fig. 1. Instrument construction

3.2.1 MiniGRAND

The MiniGRAND is intended primarily for measuring and monitoring gross gamma rays and neutrons. This instrument provides a digital readout of the current induced by gamma rays in ion chambers and scales pulses produced by neutron detectors and their preamps and discriminators.

The MiniGRAND is comprised of five electronics boards. The basic boards, which are included in all family member electronics packages, are the Master Processor Board, the Low-Voltage Power Supply Board, and a Bias Board. The other boards are the personality boards, Dual Ion Chamber Board and the Triple Pulse Counter Board.

The MiniGRAND is powered from an external DC source or from an internal battery. The MiniGRAND may be configured as a standalone instrument contained in a 24cm x 11cm x 8cm box, or integrated into a board stack for use in detectors where an external box is not necessary. A larger commercial box, with different connectors, is also available.

3.2.1.1 Dual Ion Chamber Personality Board

The Dual Ion Chamber Personality Board has two current mode measurement channels, a single negative bias supply, and output control signals for an external relay to open the current circuit at a remote location.

Specifications:

- Input Signal:
  - two independent channels, each with 12-bit resolution
  - each channel has 12 scaled gain ranges with automatic ranging controlled by firmware
  - input current dynamic range extends from $3x10^{-14}$ A to $3x10^{-4}$ A
  - firmware gain matching capability on each channel.
  - automatic zero-offset compensation on each scale.
  - internal and external signal disconnect for zero-offset compensation.
- Bias Output:
  - -50 VDC to -600 VDC, firmware settable with 12-bit resolution
  - bias readback with 12-bit resolution and independentreference
  - ON/OFF control via firmware
- Miscellaneous:
  - 8-bit processor readable serial number
  - 8-bit processor readable configuration jumpers
  - Power Consumption: 200 mA @ +5 VDC
  - Size: 3.75" x 7.75"

3.2.1.2 Triple Pulse Counter Personality Board

The Triple Pulse Counter Personality Board has three independent pulse counting channels. Each counter channel has a capacity of 2^{32}-1 counts and count frequency from 0(DC) to 20 MHz.

Specifications:

Input Signal:

three independent digital-input counting channels
selectable and readable fixed or adjustable thresholds
thresholds range from +0.3 VDC to +1.9 VDC
minimum pulse width ??? ns
pulse pair resolution ??? ns with ???ns wide ????V pulse.
maximum count rate capability 20 MHz
counter capacity 32 bits
single time base
external gate control
jumper-selectable 50-ohm termination

Miscellaneous:

8-bit processor readable serial number
8-bit processor readable configuration jumpers
Power Consumption: 25 mA @ +5 VDC
Size: 3.75" x 7.75"

3.2.2 Intelligent Shift Register (ISR)/Advanced Multiplicity Shift Register (AMSR)

The Intelligent Shift Register (ISR) consists of the foundation boards (LVPS and MPB) in combination with the shift-register hardware. The shift register board connects to neutron detectors and provides neutron totals, doubles, and multiplicity counting.

Specifications:

4 MHz shift register frequency

sixteen deep FIFO-type derandomizer receives the input signal and sends it on at 16 MHz

36 bit synchronous counter for Totals

48 bit synchronous counters for Reals+Accidentals and Accidentals

adjustable input pulse threshold

256 channel/32 bits per channel Reals+Accidentals and Accidentals multiplicity counters

The AMSR contains the ISR components plus a front panel display. The AMSR provides the following additional capabilities:

Front panel display with local operating controls

Rotary encoder "adjust" knob

Multi-position discrete knob

Keypad

Discrete switches, toggle and locking toggle

Momentary push-button switch

The following capabilities are provided by the PCMCIA interface of the application board:

Flash memory storage cards

Ethernet via network interface cards

These instruments are fully compatible with the IAEA Neutron Coincidence Counting (INCC) program.

3.2.3 MiniADC

The MiniADC combines the functionality of a multi-channel analyzer (MCA) and an unattended radiation monitor. It is comprised of the foundation boards which are included in all family member electronics packages, the Master Processor Board, the Low-Voltage Power Supply Board, and a Bias Board, as well as an AMP/ADC board.

In manual mode, the user can use the instrument as a 1024-channel MCA to acquire spectra and analyze them. In unattended mode, the user can define and permanently store the instrument's settings and allow it to run continuously, acquiring spectra automatically, one after another, analyzing each one and storing and alarming on selected data from each spectrum.

Specifications:

3.2.4 Intelligent Local Node (ILON)

ILONs provide connectivity among components of a radiation monitoring system used for attended or unattended monitoring. Components which may be connected using the ILON include computers, instruments, sensors, and cameras. The ILON also provides the capability to time-synchronize the system components, using a time signal from a GPS or multicamera optical surveillance system (MOS)[5]; additional time-synchronization sources may be easily added.

The ILON processor board is based on the Master Processor Board and contains all the same circuitry except that the pulse counting channel, one of the serial connectors, and the system bus are missing. Both serial channels are still available on the board, but only one may be connected to the outside world at a time. In addition, the ILON processor board contains headers to which Echelon-standard daughter cards may be attached.

One Echelon daughter card is the LTM-10 LonTalk Module manufactured by Echelon Corporation that encapsulates all the software necessary to communicate with the network connecting the ILONs. As network data packets are received by an ILON, the LTM-10 authenticates their contents and passes them to the firmware running in the 68HC11 on the ILON processor board for further processing.

When the 68HC11 needs to communicate with the other ILONs on the network it passes data to the LTM-10, which adds the necessary network and authentication information and sends the data to the network.

The other daughter card plugged onto the ILON processor board is one of a set of standard transceiver types produced by Echelon Corporation; Echelon calls these transceivers SMX-transceivers. The FTM-10 SMX transceiver is commonly used because of the freedom it allows in laying out the topology of the network, but other types such as fiber-optic, RS-485 twisted-pair, or power-line are also available. The transceivers handle the electronic end of moving data across the network.

The ILON processor board includes connectors that allow it to communicate with the other two devices in the ILON unit. Instruments, sensors, computers, etc., are connected to the serial and parallel ports on the ILON processor board.

3.2.5 Application Board

All radiation-monitoring instruments support the addition, via the system bus, of an application board to expand the capabilities of the instrument. The application board consists of an interface between the instrument family system bus and a PC-104 bus, implemented via a gate-array, as well as support for special functions to allow efficient communication between the instrument and an attached PC-104 board processor module.

The application board is intended to be used with a PC-104 computer module installed, along with up to two PCMCIA interfaces to allow addition of industry-standard devices such as flash-memory cards and ethernet network interfaces. The application board has been used to provide front-panel support and flash-memory card support for the AMSR, and is will also be used to allow the addition of higher-level processing capabilities unassociated with the instrument's functionality, such as data encryption and authentication, as well as ethernet networking support. Long-term standalone instrument operation (>30 days) will also be supported via firmware running on the application board.

4. FIRMWARE

4.1 Basic Operating Firmware

The instrument family utilizes the same basic set of firmware for non-instrument specific functions. This firmware suite consists of the following programs:

Bootloader The Bootloader is the firmware that runs immediately after the processor is reset or powered-on and loads a prespecified file from the flash memory and starts it executing.

Ttymon TTYMON is always loaded in the instrument and provides a basic means by which the programs may be loaded by hand, the hardware may be checked out, or low-level operations may be performed.

Flashmon This code allows access to the flash file system and the programs stored in the flash memory. Using Flashmon new code may be loaded into the flash memory, and the program that is run at reset may be changed. Flashmon also provides utility functions such as viewing the directory of programs stored in the flash and viewing the flash memory directly.

Loaders Each instrument application is paired with a loader, which reads the application from flash and transfers control to it.

4.2 Monitor Program

The functionality of each instrument contains, in addition to whatever code is required to operate the specific hardware and acquire data, code to process the data after it is acquired and communicate with a remote computer which collects the data. This code is called the Monitor.

While in Monitor mode the system performs two function, collecting and storing data from the sensors, and receiving and responding to commands from the Multi-Instrument Collect software to provide the stored data to the Collect computer.

The Monitor receives each data point after it is acquired and, while the next acquisition is proceeding, performs instrument specific analysis to determine what to do with the data point. The monitor maintains a buffer of recently acquired points, and when the buffer fills the monitor analyzes the data in the buffer to see if the points are statistically the same. If so, one point from the buffer is saved to represent all the points; this process is called data filtering. If points in the buffer are statistically different, the entire buffer is saved. Data filtering is important in keeping the data down to a reasonable amount. The Monitor also saves instrument state of health information at regular intervals and as needed to track noteworthy events.

The monitor also calculates a local, moving average of the signal levels for each channel, and may be configured to watch for signal excursions beyond configured thresholds, which can be absolute or relative to the local average. Excursions are not reported immediately but are counted for a configurable period to ensure they are not just noise spikes. When they are reported, a time-stamped status message is saved with the collected data and trigger outputs on the instruments can be activated. After the signal has returned below the threshold it is monitored for a period to ensure that it is staying below the threshold and not just spiking. The Monitor also watches for changing signal conditions, in which the signal changes a significant amount beyond the local average, but does not necessarily cross a threshold.

The monitor communicates with a computer running (MIC) over a serial communications line using a protocol that ensures no data is lost during transfer. MIC may request records from the instrument; these requests are acted on as they arrive. If the instrument has data to send, it sends it when requested.

4.3 Instrument-Specific Firmware

4.3.1 MiniGRAND

The MiniGRAND firmware allows the instrument to be operated in one of two modes, Monitor and User[6]. Following power on or reset, the instrument loads the MiniGRAND firmware and begin operation in Monitor mode. If parameters have not been set by the user, default settings are loaded and used. The instrument remains in Monitor mode until the END command is received, at which time it enters User mode.

In the MiniGRAND application, the user specifies the count time and other values and then starts data collection. At this point the program begins collecting counts from the detector boards and storing them in memory. As each count interval is completed, the counts are converted to a count rate and the rate is stored in the buffer, perhaps with other information, for later transmission to MIC.

The MiniGRAND may be configured, as well as operated in attended mode, using a Windows-based software front panel program that emulates and extends the capabilities present in the GRAND3 front panel.

4.3.1.1 Monitor Mode

In Monitor mode, the system acquires data from the counters, stores it in the buffer to be transmitted to the Collect software, and responds to the set of commands sent by the Collect software to retrieve stored information.

4.3.1.2 User Mode

In User mode, the system responds to commands from the serial port that are used to configure the system, setting and/or displaying parameters that control the collection of data from the sensors, or to operate the instrument in attended mode.

While in User mode, the instrument accepts commands at the serial port that configure the instrument's parameters, display parameter settings, display instrument state-of-health values, and return the instrument to Monitor mode. The commands are ASCII strings consisting of two-character operation codes, or opcodes, followed by a carriage return for zero-operand commands, or a space and one or more operands, separated by spaces, for commands that take operands.

User mode also allows the instrument to be operated in attended mode, allowing acquisition of data, calibration of the instrument, and general diagnostics.

4.3.2 Intelligent Shift Register (ISR)/Advanced Multiplicity Shift Register (AMSR)

The ISR and AMSR firmware[7] also provide data-filtering algorithms, local data storage, triggering signals for external sensors such as cameras for real time monitoring, and Ethernet and serial connections into a network for unattended and integrated safeguards monitoring. Encryption and authentication software can be embedded into the module to provide data security. An enhanced feature of the instrument is the embedded physics algorithms that provide new capabilities such as fast accidental sampling to decrease inspector measurement time while improving assay precision.

The instrument can be placed in three principle operating modes: Monitor Mode, PSR Mode, and JSR-12 Mode. A command mode, which permits reading and writing parameters, starting and stopping data acquisition, and accessing stored data is also supported. The command set supported is determined by the operating mode.

4.3.2.1 Monitor Mode

In Monitor Mode the ISR Monitor program continuously acquires data, stores the results in battery backed-up memory, controls the state of trigger port, and responds to commands received from the serial port. Monitor Mode is the principle mode used for unattended operation.

4.3.2.2 PSR Mode

In PSR Mode the ISR Monitor program simulates the behavior of a PSR shift register. PSR Mode is intended to support attended operation, shift register parameter setup, and compatibility with existing software. In addition to the PSR command set, PSR Mode also supports a set of commands to setup the monitor, triggers, and time synchronization parameters, read the state of health data, and control mode switching.

4.3.2.3 JSR-12 Mode

In JSR-12 Mode the ISR Monitor program simulates the behavior of a JSR-12 shift register. JSR-12 Mode is intended to support compatibility with existing software. Not all JSR-12 behavior is simulated. Neither data storage nor operation of the auxiliary scaler separate from that of the principle counters is supported. JSR-12 Mode behavior matches that supported by the PSR shift register.

4.3.3 MiniADC

The MiniADC firmware[8] allows the instrument to be operated in one of two modes, Monitor and User. Following power on or reset, the instrument loads the MiniADC firmware and begins operation in Monitor mode. The instrument remains in Monitor mode until the END command is received, at which time it enters User mode.

In both modes it provides spectral accumulation in 1024 channels

4.3.3.1 Unattended/Monitor Mode

The MiniADC application program contains three basic modules: The Continuous Radiation Measurement System (CRMS), the High Voltage Control System (HVC) and the Monitor. The CRMS acquires spectral data with 1-s resolution, analyzes it, and feeds it to the Monitor at regular intervals. The HVC is responsible for keeping the NaI detector's high voltage bias set at the correct value by considering the temperature history in the detector's operating environment. The Monitor packages spectral data into a specific record format and, upon request, sends all collected/filtered data to MIC. It also stores and provides status and state-of-health records to MIC.

4.3.3.2 User Mode

In User mode, the system responds to commands from the serial port that are used to configure the system, setting and/or displaying parameters that control the collection of data from the sensors, or to operate the instrument in attended mode.

4.3.4 ILON

The ILON was originally implemented as an extension cord to allow delivery of serial data between an instrument and a computer. It quickly evolved into a delivery system for binary data as well, and now can be used to connect a variety of devices in a facility without needing to run many wires between all the devices.

For example, many instruments may be connected to one collect computer via the network. In addition to providing a serial data stream, the instruments change the state of their parallel port pins when an event is occurring. These parallel port outputs may be logically connected, via ILONs, to cameras so that when the parallel port pins become active the cameras are triggered.

Another capability provided by the ILON is time-synchronization. One ILON in a network can be designated as a master-timer node, to which a time-synchronization device is connected. Currently the Trimble Accutime Smart Antenna (TSIP protocol) and the MOS are supported as time-synchronization sources; adding support for additional devices is relatively easy because of the modular design. The master-timer node provides hourly time signals to all other ILONs in the network, and the ILONs attached to other devices can synchronize the attached devices via a serial or parallel protocol configured into the device.

The current definition of the ILON provides for six distinct functions[9]. These functions are orthogonal, and one ILON may contain more than one function, as long as the functions do not use the same set of resources. The functions are:

Instrument	This function is used in an ILON that is attached to an instrument that expects to send and receive data to and from a computer over a serial interface. Data is received from the network by the node and passed to the instrument, and vice versa; no interpretation of the data is performed by the ILON in this mode.
Collect	This is similar to the instrument function in that it expects to send and receive data to and from an instrument over a serial interface. It differs from the instrument function in that it must keep track of which instruments are sending data to which serial ports on the computer, and may also receive and act on commands in the data stream.
Master Timer	This node receives a time synchronization signal from an attached device and uses this to set the clocks of the other devices on the network via a time-synchronization protocol.
Binary Input	This node receives up to eight single-bit inputs from attached instruments or sensors, and passes the sense of the binary input across the network to other devices. Inputs at this node are mapped to outputs at other nodes via configuration information in the node.
Binary Output	This node receives messages from the binary input nodes and acts on them to trigger attached devices such as cameras.

Binary Concentrator This node watches the network for messages from binary input nodes, time stamps them, and formats them into records to be sent to a collect program to allow tracking of the binary input changes.

Each ILON has a unique number which is used in passing data between nodes. All network messages contain the data and the number of the destination node, this information is wrapped in a packet containing addressing and checksum data, and put it on the network. At the receiving node, the network packet information is stripped and the information passed on to the receiving instrument.

A binary output node can be connected to a variety of devices which are activated when binary inputs elsewhere on the network change state. A passive infrared detector may be connected to a binary input, and the network configured to pass a message to a binary output node that controls a light and a camera. When the passive infrared detector sends a message on the network indicating that it has been activated, the logically connected binary output node turns on the light and the camera. If the camera must limit its use of scarce videotape, the binary output node can be configured to drive the camera for a minimum and maximum time, to be sure enough frames are taken but not too many, for example, of a source that has been parked in front of a detector.

The binary concentrator node watches all binary sensor messages sent across the network. Each message contains a flag indicating whether the message should be ignored or logged. Logged messages are saved in an internal buffer until they are read by a program similar to Collect, which collects binary sensor data rather that radiation data.

With such a distribution of monitoring functions, it is important that the devices connected to the network remain time-synchronized. The master timer node uses an attached device, such as a GPS, to receive time signals and distribute them to the network. All nodes receive the time-synchronization messages and act on them in some fashion to set internal clocks. In some cases, such as the instrument node, an attached device might also need to be synchronized. Two methods are available for doing this: a string, the format of which is entered during configuration, is used to send a time to the instrument via the serial port, or a signal is sent to the instrument on a parallel-port line to indicate that a prearranged time has been reached and the instrument's clock should be set.

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