A LOW-COST I/O CONCENTRATOR USING THE CAN FIELDBUS

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Abstract

The I/O channels of the control system of the LHC experiments are distributed over the whole detector volume with distances of up to 100 meters. Special requirements on the I/O system arise due to the inaccessibility of the equipment and the hostile environment due to radiation and magnetic field. A general purpose I/O system based on the fieldbus CAN and using the CANOpen software protocol has been developed using standard electronic components. Each of these distributed fieldbus nodes can monitor and control up to some hundred channels. The performance of a low-cost high precision ADC system will be presented together with the results of extensive tests.

1 INTRODUCTION

The very large particle detector ATLAS will start operation at the new proton-proton collider LHC at CERN in 2005. The detector will be installed in an underground cavern in which the radiation environment in the outer parts consists mainly of neutrons with an accumulated dose of 10^{11} n/cm^2 (equiv. 1 MeV Si) during 10 years of operation. The front-end electronics of the Detector Control System (DCS) must operate in this radiation environment and in a magnetic field of up to 500 Gauss. The DCS is a distributed system composed of two main components, a commercial Supervisory Control And Data Acquisition system (SCADA) and a front-end I/O system, interconnected mainly by the industrial fieldbus CAN [1]. CAN was chosen because of its reliability, ease of use and wide acceptance and support by industry, both on the device and the chip level. The CANOpen [1] software protocol specifies standardized communication mechanisms and device functionality, which greatly simplify the system integration of the control system.

The Local Monitor Box (LMB) is an I/O concentrator read out via CANbus and the CANOpen protocol. It is designed using Components Off The Shelf (COTS). Its main design aims were radiation tolerance, high stability, versatile application and very low cost. Specific requirements were differential inputs and opto-isolation in order to eliminate ground loops.

2 LOCAL MONITOR BOX

Each LMB consists of one controller CAN-node and a number of different I/O-modules (Fig. 1). At present two

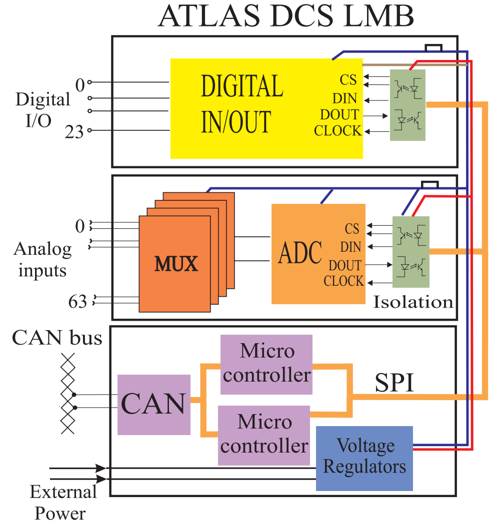

Figure 1 Block diagram of the LMB

types of I/O modules have been produced: a differential ADC for 16 to 64 channels and a module to read out Pt100 temperature sensors. Another module for 24 digital I/O channels is being prototyped. Several of these I/O modules can be connected to a CAN controller via a SPI™ serial bus, which also supplies the power to each module. The LMB is designed to be radiation tolerant for a dose rate corresponding to 10 years of operation in the ATLAS cavern. Furthermore it must be tolerant to Single Even Upsets (SEU) caused by high-energy particles. No components sensitive to magnetic field are used. Special emphasis has been placed on that the LMB has low power consumption to permit the use of remote power supplies. The present version of the LMB is placed in industrial DIN rail housing for ease of use in test systems. But it may also be embedded into a system board at a reduced cost.

2.1 The CANOpen Controller Module

The LMB CAN controller module conforms to the minimal functions of a slave node as defined in the CANOpen specification. The software of the LMB is implemented as a simple state machine with a Programmable Logic Controller (PLC) type of code. In this way reliable performance can be achieved even in a harsh environment. The module consists of one CAN controller chip from the company Siemens (SAE81C91) and two in circuit re-programmable AVR micro controllers from the company ATMEL. This second processor has as main function to allow reading and programming of the other AVR. This permit the downloading and checking of the program in the LMB CAN node via the CAN bus, even when the LMB is installed in the experiment.

2.2 The ADC module

Differential inputs are used such that the ADC is insensitive to pickup noise and ground potential differences. The module is based on a low-cost 16-bit ADC (CS5525) from the company Crystal Semiconductor. The input range is selectable from ±25 mV to ±2.5V, however only for ranges smaller ±1V the input impedance is very high (1000 MΩ). A CMOS multiplexer with 16 differential inputs is used to augment the number of inputs of the ADC. The printed circuit board (PCB) contains 16 channels. Four PCBs can be stacked together in order to make a module with 64 differential channels. The ADC PCB can be equipped with adapters for different signal types. A special adapter has been developed for 4-wire-connection of Pt100 sensors. In a cryogenics application an absolute precision of 3 mK has been achieved. For less precise temperature measurements adapters with 2-wire connection are used and a precision of 0.1 degree is easily reached. Adapter boxes to measure voltages and currents have also been developed.

2.3 Digital I/O module

A digital I/O module with 24 channels is under evaluation tests. Each channel has general-purpose digital I/O for TTL/CMOS levels and may be configured as input or output. One output can sink 20 mA and source 10mA. The module contains also an AVR processor and is isolated by optocouplers.

2.4 Interlock box

In some detector applications, the same sensor has to be used for both measuring a quantity and setting an interlock if the signal is outside of a pre-set range. An example is the Pixel detector of the ATLAS Tracker System. Warming up of irradiated Si-Pixel detectors causes irreparable damages to the detector. Therefore each detector module is equipped with a temperature sensor (NTC), which has to automatically switch off the corresponding power supply in the case of an over-temperature of a Pixel detector.

Therefore an Interlock Box [2], which is compatible with the LMB system, has been developed. One main aspect of its design is reliability, therefore a hardware-based solution has been chosen. The circuit should be as simple as possible without multiplexing or setting of thresholds via DACs. The threshold for the interlock signal is set by resistors. As the Interlock Box has to be fail-save, also a short circuit in the sensor or its cables as well as a broken line has to cause an interlock signal. All these conditions are combined in two output bits. The box can also be operated in standalone mode without LMB.

2.5 Cost

The present estimated cost of the modules of the LMB is shown in Table 1. The embedded system cost cover the price of the components used to integrate a LMB into an existing system card using existing infrastructure such as power supplies. The module cost applies to a stand-alone module with build-in power supply regulators and connectors. The cost is based on catalog prices of September 1999 and on realistic volumes of 1000 pieces or more.

Table 1: Estimated Cost of LMB Modules

Module	Embedded	Module
CAN	\$15	\$30
16 ch Differential ADC	\$25	\$50
64 ch Differential ADC	\$90	\$130
24 ch Digital I/O	\$15	\$30

E.g. the projected cost of a 64-channel ADC system is \$105 or \$160 respectively.

3 TEST SET-UP SOFTWARE

In most test systems of ATLAS subdetectors, the LMB is read out by the BridgeView (BV) control software of National Instruments [3]. Such a test system consists of a PC running BV under Windows NT or Windows 95 and with a CAN bus interface board.

BV includes all the functionality of LabVIEW and has additional features needed for industrial automation: a real-time database, historical trending, alarm and event logging, device connectivity and system configuration tools. The graphical programming language 'G' of LabVIEW is used to develop the man-machine interface (MMI) and the LMB server. Via this server information is read out from the different LMB nodes on the bus and transmitted to the real time database.

A CANopen server manages the CAN network, sends and receives data and handles errors. This server is a VI device server for the BV system and is based on National instrument CAN board driver and the Vi library. Standalone programs to monitor and debug the CANbus have also been developed. Also other CAN interface boards are being investigated.

4 TESTS

4.1 Radiation tests

The objectives of the tests in the CERN TCC2 beam area were to study the long-term stability of the LMB and its operation in a radiation environment, in particular the behavior of opto-couplers. The setup consisted of three CAN nodes with the following functions:

1) Test of a standard 16 channel LMB,
2) Test of two types of optocouplers,
3) Test of AVR microcontroller for SEU effects.

After a total dose of about 300 Gy and $3{\cdot}10^{12}$ n/cm^2 (equivalent to 1MeV in Si) the LMB CAN node stopped working due to failure of the optocouplers. In the specific test of optocouplers, after this irradiation one type (HCPL-0731) had still 80% of the original gain while the other type (MODC 223), which was actually used in the LMB, had less than 1% gain left. All AVR microcontrollers showed an increase in the current consumption in average from 2.6mA to 44.6mA. The analog multiplexers used in the ADC module stopped working after about 70 Gy. In this test substantially more radiation was accumulated than expected in 10 years of operation of ATLAS. However as the composition of the beam was largely unknown, both in types of particles and their energy, these results can not be interpreted in a quantitative way.

4.2 ATLAS LAr Calorimeter beam tests

The aim of the Liquid Argon (LAr) calorimeter beam tests was to study the monitoring and control of the front-end electronics. LAr front-end crates house custom made electronics boards, which dissipate a total power of 3 kW and are water-cooled. The amount of power and the inaccessibility of the crates in the final experimental configuration make remote monitoring essential for the operation of the electronics.

For the initial test we used three different kinds of measurements:

- Voltage measurements of the different power supplies; currents were measured by the voltage drop in the current leads.
- Temperature measurements of the inlet and outlet water temperature, the individual boards and the overall crate temperature. Pt1000 with 2-wire readout have been used.
- In addition precise measurements of the calorimeter temperature have been performed at 90K by using Pt100 sensors read out by 4-wire connection.

The sensors were connected via 4m flat cables to LMBs grouped on two CAN nodes. Care was taken not to mix grounds with the front-end electronics. The performance of the LMB system was found to be highly sufficient for the monitoring of the electronics. It has been proven, that the read out of the LMB does not inject electronics noise into the sensitive read-out chain of the calorimeter,

4.3 ATLAS Pixel and Silicon Strip cooling tests

A scalable prototype for the cooling system is being built in order to study a one-eighth thermal model of the barrel SCT and pixel detectors with 10kW total heat dissipation. This demonstrator will require a system to monitor about 400 temperatures, and to monitor and control the coolant flow and evaporating pressure in 16 parallel cooling channels supplying around 44 heated structures.

The system described in chapter 3 is used. The bus consists of three LMB nodes and one CAN node from the company WAGO. Two LMB nodes have LMB Pt-100 cards and read temperature data from 64 PT100 sensors placed on the prototypes, while the third LMB has a differential ADC card and monitors parameters of the cooling re-circulator and measures analog voltages from pressure and flow sensors. The WAGO CAN node administers 8 channels of digital output (WAGO 750-504) and two channels of analog output (WAGO 750-556) for the control of the cooling re-circulator. The digital outputs controls 8 isolation valves via Honeywell K2P3LO Electro-pneumatic actuators, and request the application of heater power to the prototypes. This is enabled by lower level hardwired interlocks only if the valves are open and coolant flowing. The analog outputs transmit set points for mass flow and evaporating pressure control.

5 CONCLUSIONS

The LMB system has been used at different subdetector installation and has proven to be very flexible. Its performance together with its low cost will allow its application in the ATLAS experiment at many places and at a large scale. Radiation tolerance needed for 10 years operation in ATLAS can be achieved with standard electronics components, which, however have to be carefully chosen. More quantitative radiation measurements should be done and further types of I/O modules could be developed.

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