FRONTEND I/O VIA CANBUS OF THE ATLAS DECTOR CONTROL SYSTEM

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Abstract

The ATLAS Detector Control System (DCS) will be organised in several hierarchical levels. The lowest one connects to the subdetector hardware and to the sensors and actuators. This connection will mainly be achieved via the commercial CAN fieldbus, which is very well suited for such distributed readout and control. The concept of the "Local Monitor Box" (LMB) as a modular building block for this work is proposed. The first implementation consists of a CAN bus node and a 16+7 bit delta-sigma ADC for the readout of Pt100 high precision temperature sensors. The CANOpen standard is employed as high-level software protocol. The general implementation will be discussed and results from tests performed with the ATLAS LAr calorimeter and first results from radiation tests will be presented.

1. INTRODUCTION

A distributed control system which uses the CANbus will provide the basic control and monitoring functions for the ATLAS detector [1]. CANbus is one of the CERN recommended fieldbuses [2]. It is especially suited for sensor readout and control functions in the implementation of a distributed control system. Reliability, availability of inexpensive controller chips from different suppliers, ease of use, wide acceptance by industry and the expectation that CAN will be available for a long period of time, were strong arguments in favour of this choice. Unlike traditional networks, such as Ethernet, where performance is measured in terms of throughput of large data blocks, fieldbuses are optimised for controls i.e. exchange of status and command messages. The ATLAS DCS system has particular requirements, which usually are not found in commercial systems. The environment close to the ATLAS detector necessitates the use of components that are tolerant to radiation. The magnetic field around the detector requires that non-ferromagnetic components be employed in the font-end electronics. The number of parameters to measure and control requires multi-channel solutions to be economical.

In the next sections of the paper the main aspects of CAN hardware and of CANopen software is covered. Then the concept of the LMB will be introduced and the results of the first measurements will be discussed.

2. THE CANBUS

Controller Area Network (CAN) [3] is a fast serial bus that is designed to provide reliable and very cost effective links. CAN uses a twisted pair cable to communicate at speeds of up to 1 Mbit/s with up to 127 nodes. It was originally developed to simplify wiring in automobiles.

2.1 Data Exchanges and Communication

A CAN message contains an identifier field, a data field and error, acknowledgement and CRC fields. The identifier field consists of 11 bits for CAN 2.0A or 29 bits for CAN 2.0B. The size of the data field is variable from zero to 8 bytes. When data are transmitted over a CAN network no individual nodes are addressed. Instead the message is assigned an identifier which uniquely identifies its data content. The identifier not only defines the message content but also the message priority. Any node can access the bus. After successful arbitration of one node all other nodes on the bus become receivers. After having received the message correctly, these nodes then perform an acceptance test to determine if the data is relevant to that particular node. Therefore, it is not only possible to perform communication on a peer to peer basis, where a single node accepts the message, but also to perform broadcast and synchronised communication whereby multiple nodes can accept the same message that is sent in a single transmission.

2.2 Arbitration and error checking

CAN employs the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) mechanism in order to arbitrate access to the bus. Contrary to other bus systems CAN does not use acknowledgement messages, which cost bandwidth on the bus. All nodes check each frame for errors and any node in the system that detects an error immediately signals this to the transmitter. This means that CAN has high network data security as a transmitted frame is checked for errors by all nodes.

The error checking include Cyclic Redundancy Check (CRC), Acknowledgement Errors, Frame Errors, Bit Errors and Bit Stuffing Errors. The concept of Bit Stuffing is, that, if more than five consecutive bits are of the same polarity, a bit of opposite polarity is inserted. If an error is detected by any of the other nodes, regardless of whether the message was meant for it or not, the current transmission is aborted by transmission of an active error frame. An active error frame consists of six consecutive dominant bits and prevents other nodes from accepting the erroneous message. The active error frame violates bit stuffing and may also corrupt the fixed form of the frame causing other nodes to transmit their own active error frames. After an active error frame, the transmitting node begins re-transmission of the frame automatically within a fixed period of time.

2.3 . *CANbus speed and lengths*

Table 1 shows the relation between the bit rate and the cable length:

Table 1: Bit rates for different cable length

Bit rate	Cable length
10 kbits/s	6.7 km
20 kbits/s	3.3 km
50 kbits/s	1.3 km
125 kbits/s	530 m
250 kbits/s	270 m
500 kbits/s	130 m
1 Mbits/s	40 m

The length of a CAN message varies not only depending on the number of data bytes transmitted but also on the contents of the message. This is due to the error checking methods (bit stuffing) described above.

3. CANOPEN

A high level standard is needed to define how the different nodes on a bus segment use the 11-bit identifier and the 8 data bytes. Among the standards, which use the CAN bus, CERN has chosen CANopen. The CAN in Automation (CiA) organisation [3] supports this protocol. CANopen was originally developed from an EEC ESPRIT III project and has found applications in industrial automation applications.

3.1 Device profiles

CANopen uses the concept of device profiles. Manufacturers can produce standardised devices by conforming to the guidelines contained in a CANopen device profile. Modules from different manufacturers can operate together with the same low level software. Basic network operation is guaranteed by defining mandatory device characteristics. It is possible to implement additional functions with the help of the optional and the manufacturer specific part of the profiles. There are a number of standard profiles available, which cover e.g. I/O modules, measuring devices and closed loop controllers. The profiles are implemented in a standardised database called object dictionary. There are software tools available to read, configure and change entries in the dictionary of a device. The object dictionary is not stored in the CANopen node itself; it is defined in an Electronic Data Sheet. In this way a network master will know the data type and size of every object.

3.2 The communication profile

The communication profile defines that in a CANopen network there must be at least one master application. The master performs the boot-up process and maintains the network in an operational state. It can also manage the object dictionary entries and the CAN identifiers of the connected devices. Real-time data transfers are called Process Data Objects (PDO). The communication profile specifies several methods for transmission and reception of messages over the CAN bus. Synchronous data transfers allow network wide co-ordinated data acquisition and actuation. Synchronous transfers are supported by predefined communication objects i.e. synchronisation messages transmitted on a cyclic time period and time stamp messages. Asynchronous or event messages may be sent at any time and allow a device to immediately notify another device without having to wait for a synchronous data transfer to take place. The network master using Network Management (NMT) may dynamically configure PDO messages at network boot up. Although CAN is restricted to transfer a maximum of 8 bytes of information, data transfers larger than 8 bytes in length are also provided for by the protocol and are called Service Data Objects. The detailed specifications of the CANopen communication profile are contained in the CiA DS 301 document [4].

3.3 Minimal Functionality Devices

In order to implement simple slave nodes the CiA DS 301 profile specifies what minimal functionality a CANopen device must provide. Default identifiers are available directly after power up but they can also be modified. Only a limited selection of the CAN identifiers has to be supported by a device node. These CAN identifiers can be pre-configured by means of DIPswitches or EEPROM. The 11 bits of the identifier contain in the four most significant bits the function code and in the 7 other bits the node number. After the boot up sequence the device boots into a pre-operational state. NMT messages are used to turn a slave node on or off. A single message from the master then makes the device fully operational. NMT is also used to determine whether nodes are still in operation. The functional status of the device is returned as the reply to a remote frame message. Inhibit times/timeouts may also be implemented, i.e. if the master does not receive a reply from a node within a certain time period the node is regarded as not functional and an error flag may be set. NMT services can also be used to bring all or selected nodes into various operating states at any time. For example, the network master can broadcast message to all nodes to bring them into a state where further configuration information may be downloaded to the device using service data messages. Alternatively, a single node may be brought into its configuration mode by using the same message with different protocol information whilst keeping all other devices fully operational.

4. LOCAL MONITOR BOX

The local monitor box (LMB) is a general-purpose low cost standardised device for the ATLAS DCS front-end. Each LMB consists of one controller CAN-node and up to 6 I/O-modules of different types, (Figure 1), like differential ADC module, digital I/O or DAC module. The modules can be connected via a 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. It contains no components sensitive to magnetic field such as DC to DC converters, chokes and transformers. The LMB has low power consumption. This permits the use of remote power supplies via the CANbus connector and the auxiliary power connector on the housing.

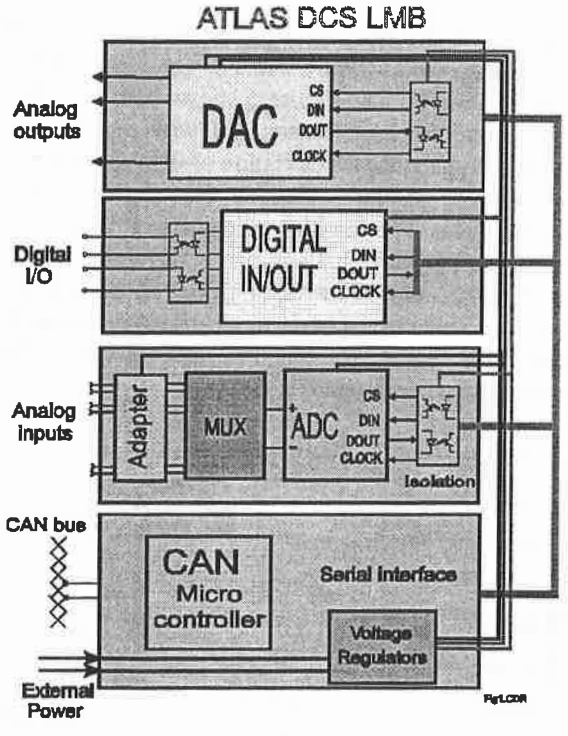

Figure 1 Block diagram of the Local Monitor Box.

4.1 The LMB CAN controller module

A CAN slave node is implemented with the minimal functions as defined in the CANopen specification [3]. The LMB CAN controller (Figure 2) consists of one CAN controller SAE 81C91 from Siemens and a CAN bus transceiver PCA82C250 from Philips. These are standard components and are available at low cost from industry. The SAE81C91 manages automatically the CANbus protocol. It contains registers for 16 CAN identifiers. For each of the identifiers there are 8 bytes of dual port RAM, in total 128 bytes. The initialisation of the SAE81C91 consists of loading 12 registers with default values. This task is done by the microcontroller AT90S1200 from Atmel. This contains 64 bytes of EEPROM for the SAE81C91 initial values. The AT90S1200 has been developed to have low power consumption while providing high processing performance. It contains only 512 words of program and costs less than $2 even in moderate quantities. This flash microprocessor can be programmed while mounted in the circuit with the help of a serial programming interface implemented on-chip. As shown in Figure 2 there is a second AT90S1200 working in parallel with the first on. This second processor has as main function to allow reading and programming of the other AT90S1200. This permits the downloading and checking of the program in the LMB CANnode via the CANbus. This can be done even when the LMB is installed in the experiment.

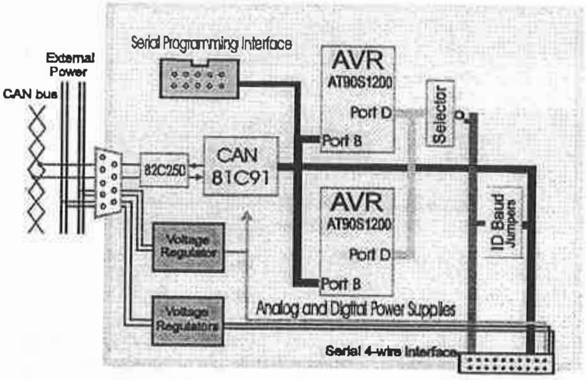

Figure 2 The CAN controller module.

4.2 The ADC module

The module is based on a low-cost 16-bit ADC from Crystal Semiconductor CS5525. The CS5525 ADC combines a differential programmable gain amplifier (7 bits) and a chopper stabilised instrumentation amplifier to ensure signal stability (drift of 5nV/°C) in one integrated circuit. The input range is selectable from ±25 mV to ±2.5V. The ADC, based on the delta-sigma principles, includes digital filters to reject noise at 50 Hz and 60 Hz simultaneously and has a common mode rejection of 120 dB. A CMOS multiplexer with 16 differential inputs is used to augment the number of inputs of the ADC. The selected multiplexer is fault protected to ±35V. The printed circuit board (PCB) contains 16 channels. Four PCBs can be stacked together to make a module with 64 differential channels. As

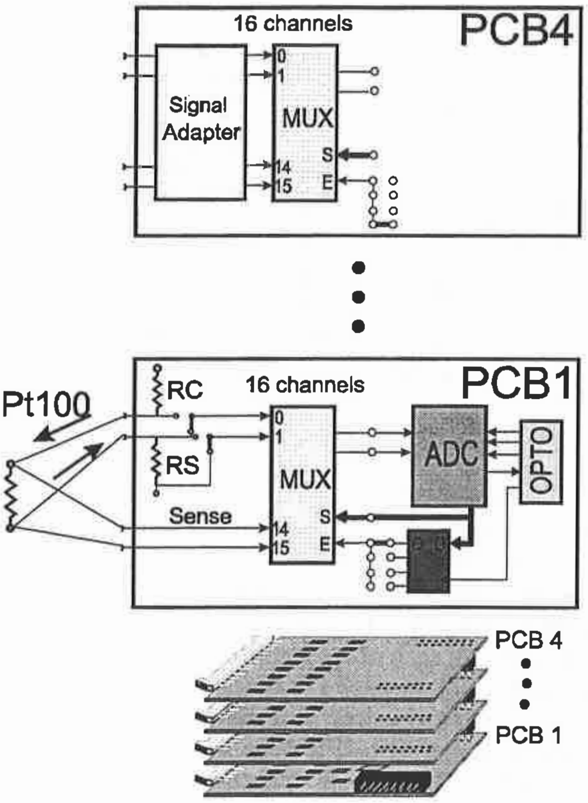

Figure 3 Combined ADC and PT100 module.

shown in Figure 3 only one of them has the ADC and the optocouplers mounted. The PCB can be equipped with adapters for miscellaneous signal types. One of them, the LMB Pt100 module is shown in Figure 3. For each temperature sensor two of the differential channels are required. One is directly measuring the voltage across the sensor while the other measures the current flowing through the sensor. The current measurement is made with the help of a high stability 30 Ω NiCr resistor RS with an accuracy of 0.035% typically. The value of RS is chosen to be the same as the resistance of the sensor at the temperature of interest. As it is the same ADC, which is measuring the voltage and current through the sensor, the measurements are not sensitive to changes in the voltage reference and other common mode changes. The resistor RC determines the DC current through the sensor.

4.3 External power supplies

In order to be able to operate the LMB in a strong magnetic field, the power to the LMB is supplied by the CAN cable or by an external connector. There are two separate power supplies, one analogue and one digital. Low drop voltage regulators are used and therefore the actual voltage supplied to the LMB can be between 5 to 15 V. The current consumption for the digital power supply is 36 mA and from the analogue supply 15 mA per 64 channels.

5. MEASUREMENTS

A series of measurement [5] with the LMB was done in July 1998 at the ATLAS LAr EM End-Cap cryostat in the H6 experimental area in CERN SPS. The setup is shown in Figure 4. A total of 9 sensors were used in the measurements. Eight of them (labelled PT1, PT2, PT8) are standard low-cost Pt100 calibrated probes. One reference probe (labelled PRT) is calibrated to ± 1.5 mK in absolute accuracy.

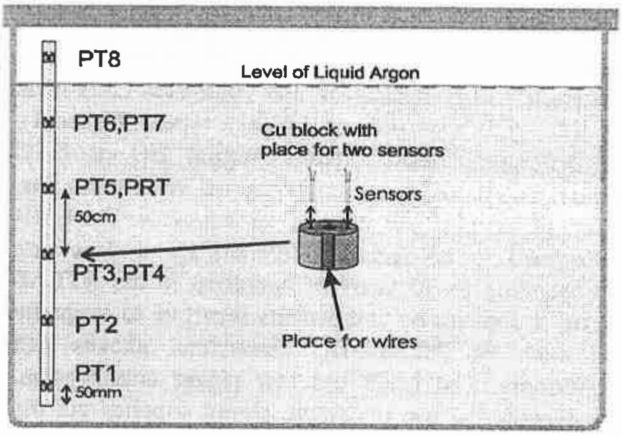

Figure 4 The positions of the sensors in the cryostat.

Examples of the behaviour of the temperature in the cryostat are shown in Figure 5 and 6. The temperature is varying by 20 mK. The Figure 5 shows how the sensor PT5 tracks the precision sensor PRT with a mean value of -3.1 mK and a standard deviation of 0.9 mK. The PRT was measured manually using a 5½ digits precision digital voltmeter. The equithermal sensors PRT and PT5 when measured with LMB show a difference of the order of 1 mK and a standard deviation of 1.2 mK, (Figure 6). This corresponds to an effective resolution of the LMB equal to 0.8 mK per channel. One digitisation step corresponds to 1.5 mK.

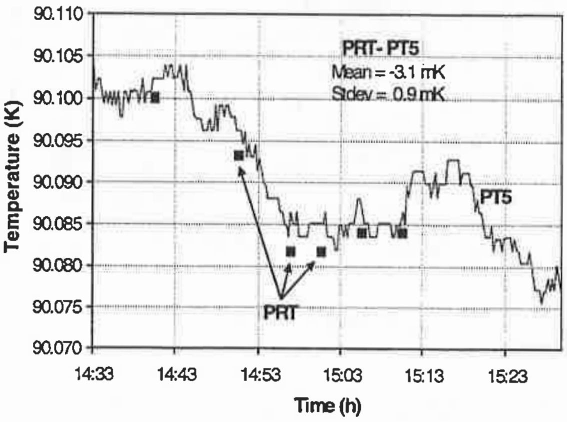

Figure 5 Temperature variations measured by the sensors PRT and PT5.

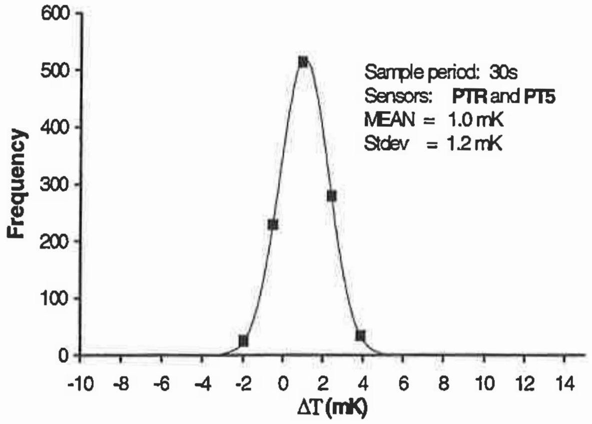

Figure 6 Temperature difference for PRT and PT5.

The long-term stability of the LMB was checked after one month of operation with the help a calibrated precision resistor. The mean value of eight LMB channels had changed by 0.8 mK. The systematic error due to the LMB is estimated to be about 2 mK which corresponds to 20 ppm.

6 RADIATION TESTS

Radiation tests were done at a CERN beam target area in three periods of 11 weeks in total. It has been predicted that the ATLAS Cavern will have an equivalent dose of about 10 Gy and 10^{11} neutrons cm^{-2} in ten years of operation. In the three periods of irradiation the dose rates accumulated were 20 Gy, 50 Gy and 100 Gy respectively with fluences of 10^{11}, 10^{12} and $\sim 3 \cdot 10^{12}$ neutrons cm^{-2} (equivalent 1 MeV Si). The main results are that the tested optocouplers (IL206A) were influenced as shown in Figure 7. The current transfer ration (CTR) changed from 90% to 3%. However, all five tested optocouplers were still functional in a test circuit when changing the load resistor from 2.2 kΩ to 35 kΩ. Other effects observed were that in two of the four tested microcontrollers AT90S1200 one EEPROM memory location was erased and a voltage reference was changed by -4mV. The LMB CAN controller and all other components showed no significant changes due to the radiation.

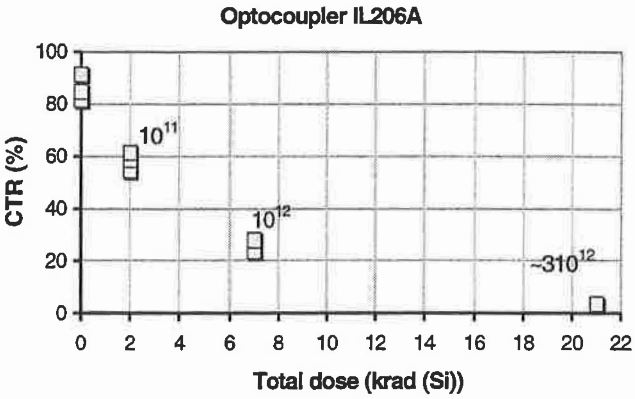

Figure 7 The current transfer ratio versus dose rate

More measurements have recently been performed at a nuclear test reactor with a similar integrated dose rate of neutrons but without gamma rays. The tests were performed during 5h and at this test the LMB was powered and continuously read out. A preliminary analysis confirms the results described above.

7. CONCLUSIONS

The practical experience with CANbus in the design and operation of the LMB as part of the future ATLAS front-end I/O has been very good. The high-level CANopen protocol greatly simplified the effort in programming of the CAN slave controller. The measurements of the temperature in the LAr cryostat show a precision of about 3 mK and a resolution of 0.8 mK. These performances are a factor 10 better than is needed for the cryogenics temperature measurements. The radiation tests show that with some design precautions being taken standard commercial components can be used in the radiation environment of the ATLAS cavern.

8. ACKNOWLEGEMENTS

We are very grateful to the LAr group for giving us the occasion to verify the concept of the LMB and to measure its performance in a realistic environment. L. Poggioli organised the LAr part of the test. A.Karlov from the CERN IT/CO group provided the very user-friendly and efficient data taking and visualisation program in the BridgeView framework.

8 REFERENCES

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