THE SLOW CONTROL SYSTEM FOR THE ALPHA MAGNETIC SPECTROMETER (AMS-02) ON THE INTERNATIONAL SPACE STATION

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Abstract

The slow control system for the various components of the AMS-02 experiment is composed of 48 universal slow control modules. These modules are based on the micro controller DS80C390 to fulfill the requirements of computing power, speed and restricted power consumption and connected via a two-fold CAN bus to the four DAQ computers. The module features serial, digital and analogue inputs / outputs, ports for DALLAS temperature chains and memories for data and program storage. Planned for an operational period of several years in space, special care was given to the design and construction of the system.

INTRODUCTION

The ALPHA Magnetic Spectrometer (AMS-02) will be the first large magnetic spectrometer in space [1]. It will be installed for a period of three years on the International Space Station (ISS) in the year 2006 to perform measurements of the charged particle composition to answer fundamental questions in particle physics and astrophysics. A first version of the experiment (AMS-01) flew on a Space Shuttle mission STS-91 in June 1998. This flight was basically intended to be an engineering test but nevertheless yielded interesting science data. Compared to ground based physics instruments, the transportation of the experiment to ISS and the operation in outer space imply numerous limits and harsh conditions on the apparatus:

- no manual access to the device
- no material supplies (gases, liquids)
- restricted communication channels to the experiment
- a rigid upper limit on weight, yet serious stress during launch
- rigid upper limit on both typical and peak usage of electrical power
- cooling only by radiation
- extreme default temperature differences
- radiation hard components
- strict safety rules
- redundancy of components

The AMS-02 detector (see Figure 1) has seven major components (In addition, there are electronics, support infrastructure and interfaces):

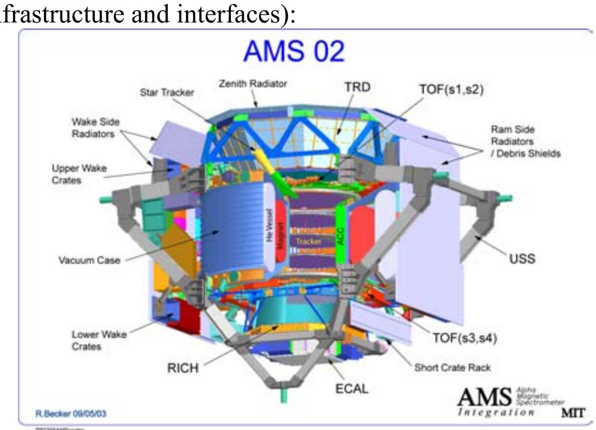

Figure 1: AMS 02 detector integration layout.

Superconducting Magnet : A superconducting magnet cooled by evaporation of liquid helium to a temperature of 1.7 K.

Transition Radiation Detector (TRD) : This system consists of 20 pairs of alternating layers of fleece radiator and 6 mm straw tubes with a length up to two meters. The detector allows to discriminate between positrons and protons up to energies of 300GeV.

Time-of-Flight Detector (TOF) : The four detector planes are made of scintillator bars. It measures the transit time of particles for the distance of the two layers.

Silicon Tracker : The charged particles are bent in the magnetic field. To track the particles, eight layers of Silicon microstrip detectors are arranged in two single sided layers above and below the magnet and three double sided layers inside the volume of the magnet.

Anti-Coincidence Counters (ACC) : The counters comprise a wall of plastic scintillator detectors between the Silicon tracker and the magnet. Its function is to reject particles entering AMS-02 from the side or generated within the experiment.

Ring-Imaging Cherenkov Detector (RICH) : The Cherenkov light is measured using a planar array of photomultiplier tubes.

Electromagnetic Calorimeter (ECAL)

The electromagnetic calorimeter uses layers of Lead and scintillating fibres embedded into it.

THE UNIVERSAL SLOW CONTROL MODULE

Slow Control in AMS-02

In the current design plans for the AMS-02 experiment, there are ~500 electronic circuit boards mounted in about 30 crates. The AMS-02 slow control system consists of three hierarchically organized layers inside the detector. The top layer inside the experimental setup is formed by the 4-fold redundant master computers called JMDC. The JMDCs communicate with several copies of the same slave computer, the USCM [2], and with some special subsystems that have their own kind of slow-control slave module, including the super-conducting magnet's control unit (CAB), and the central power distribution system (PDS). The devices to be controlled by USCMs divide into several classes. First, and clearly dominating in terms of number of signals to be managed, come the various subdetectors that contribute to the physical data to be measured by the experimental as a whole. In addition to these, there are various infrastructure elements to be monitored and controlled. All communications in the slow control network from the USCM layer upward happens in terms of abstract "AMS data blocks" that can be transported over various media, including the radio communication links from ISS to the ground. Intermediate stations can either just pass them through, or act upon their contents, or forward them to other nodes in the network.

Design Concept

The 48 copies of the "Universal Slow Control Module" (USCM, see Figure 2) make up the middle of the three tiers of the slow-control system of the AMS-02 apparatus. Each of them serves as a concentrator and distributor of commands and data between the central control computer ("JMDC"), and a subset of the roughly 500 individual circuit boards that form the detector electronics (See Figure 3). These individual modules all have different sets of electronic command inputs and data outputs. Some of those use analogue voltages, others need digital storage. Some boards just need to be switched on or off, others have a large number of sensor states that the central control computers may need to know at certain points of operation. Handling all these signals in a fully centralized manner would require an unbearable amount of cables going to the central computer. The three-tired architecture avoids that by doing a large part of the work locally, collecting information from several signal lines in a single abstract "status message", and reduces the number of cables to the central node by at least one order of magnitude. The USCM is this local mediator between the JMDC and the individual electronics modules.

Figure 2: A pair of USCMs mounted on a special prototyping motherboard. Connectors on the motherboard export all the various analog and digital control lines offered by each USCM to special test equipment.

Its task is to collect, transform and abstract the different house-keeping data sources and command inputs found in the various subsystems, presenting a homogeneous interface to the central computer controlling the entire experiment.

All USCMs are connected to the main computers via a CAN (Controller Area Network) bus running at a speed of 1 Mbit/s. Since CAN bus uses a shared electrical medium, just like classic ethernet on coaxial cable, this even saves another order of magnitude in the amount of cables going to the central computer. CAN-2.0B protocol is used in AMS-02, which gives each message an internal 29-bit address. These are used to select one of the USCMs, and inform the USCM which of the 4 redundant JMDCs the request is from, among other things. The USCM will execute the request and prepare a reply message holding the results. The reply is sent back to the central computer as soon as the bus is free.

HARDWARE

The hardware of the USCM is built around the Dallas DS80C390, a rather heavily extended variant of the time-honored 8051 family of 8-bit microprocessors. The CPU is run at a clock frequency of 16 MHz, which allows for a maximum of 4 million instructions to be executed per second. The DS80C390 is operated in a mode that lets it access up to 16 MByte of memory. The USCM provides less than that, though. There's 256 kByte of data memory (static RAM), 128 kByte of one-time-programmable code memory (either EPROM or OTP), and 128 kByte of non-volatile, but re-writable memory (EEPROM). The one-time-programmable code memory holds a boot-loader and optionally a fall-back version of the main software, whereas the re-writable memory is used to store both the final software and special data blocks to configure it for the particular USCM's environment. The DS80C390 already has internal support for CAN bus networking, so the USCM only has to provide line drivers that transform signal levels between the processor and the shared bus cable linking all USCMs and the JMDCs together. To interface with the electronics modules it controls, the USCM has several I/O lines made available mainly through its two VME-style backplane connectors.

- 16 analogue outputs, 12 bit resolution, 0 ... 4.095 Volts
- 32 analogue inputs, 12 bit resolution, 0 ... 4.095 Volts
- 8 "1-wire" bus lines that can handle up to 256 temperature sensors from the DS1820 family
- 2 serial ports using RS-232 protocol, but 5 Volt signal level
- 8+1 digital "low-voltage differential signal" (LVDS) outputs
- 16+2 digital LVDS combined input/output signals

LVDS is chosen to allow these signals to be transferred over considerable lengths of cables without undue risk of electromagnetic interference in this rather noisy environment.

Latch-up detection and recovery circuits: If a heavy ion hits one of the integrated circuits, it can enter a self-conserving short-circuit state. To remove that condition, power supply is cut internally on the board, and the affected ICs are explicitly shorted to discharge them.

Redundancy handling: For security by redundancy, there are two USCMs in every crate. Special lines allow one of them to locally turn off/on the other, and to avoid both USCMs trying to drive the digital I/O lines simultaneously.

Power conservation: Since electrical power is a scarce resource on ISS, all devices have to be designed to use as little power as possible. The USCM does this by powering LVDS and Dallas interface drivers only while actually used.

SOFTWARE

The CPU on the USCM runs a small special-purpose pre-emptive multitasking operating system either from one-time-programmable or from re-writable code memory. The code in one-time-programmable memory serves a boot-loader, but is otherwise a complete copy of a (possible out-dated) version of the main program. The boot-loader is started automatically after the USCM is powered up or the reset circuitry fires, e.g. in case of a latch-up event. It then checks for the presence of an updated program in the re-writable memory section. Once running, the system cycles through a fixed number of four programs. The four programs serve separate purposes each:

1) The main console program

This console interface is available via the serial ports of the USCM. Task 1 remains in charge of the serial lines in this case, but doesn't act on the text sent through it. It just buffers the traffic going over those lines, so it can be handed over to/from the master controller via CAN bus. The console interface offers on-board code debugging facilities including a simple assembler and disassembler for machine code, display and editing of memory contents.

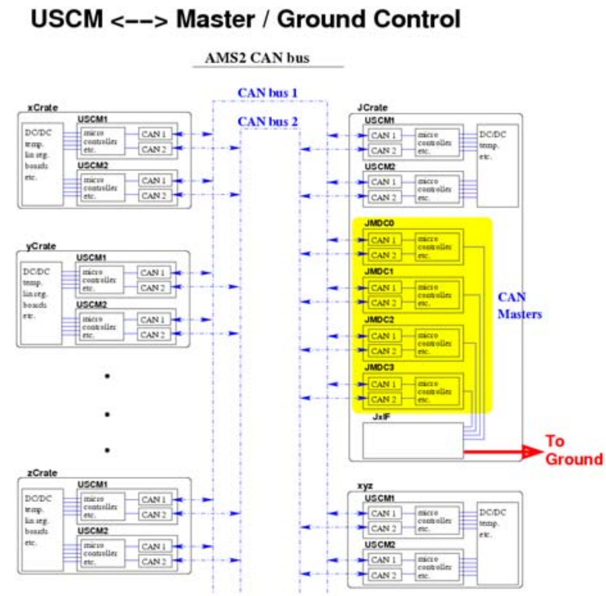

Figure 3: The slow control communications network of AMS-02. Note the general structure of groups of redundant USCMs and JMDCs connecting to 2-fold redundant CAN bus lines. Only USCMs connect between actual electronic components and the JMDC, and only the JMDC connects AMS to the outside world.

2) The analogue I/O handling program

This program manages all the analogue signal lines going from the USCM to the controlled electronic systems, including the Dallas temperature sensor busses. It continuously cycles through a big loop of all known inputs and outputs of this class:

- Analogue input lines
- Analogue output lines
- Temperature sensors

3) CAN bus communication program

This program runs in a loop checking each of the 2 CAN bus controllers built into the processor for newly arrived messages. Since an individual CAN message carries only a maximum of 8 bytes of payload data, some commands are too large to fit into a single message. There's a special transport protocol on top of CAN defined between the master control computer and the USCM to split and re-assemble larger blocks of data, much like TCP works on top of IP.

4) User-specific program

This program is reserved for specific tasks of some USCMs in particular subsystems. This is where e.g., closed-loop control algorithms or subsystem-specific safety procedures to be run directly by the USCM would go. It would be controlled by a configuration item which of those programs a particular USCM should actually run.

REFERENCES

[1] http://ams.cern.ch/AMS/ams_homepage.html

[2] USCM : http://www.physik.rwth-aachen.de/group/IIIphys/Electronics/AMS-II/index.htm