AMS-02 Electronics

M. Capell[1], E. Cortina[2], for the AMS-02 Collaboration,
(1) Massachusetts Institute of Technology, Cambridge MA, USA
(2) Univeristy of Geneva, Geneva, Switzerland

Introduction

AMS-02 is a precision TeV particle spectrometer manifested for a three year mission aboard the International Space Station (ISS) [1]. The transformation of particle physics electronics for use in space is driven by the electrical interfaces provided on the ISS, subdetector requirements and the challenges of operating for year in low earth orbit with limited power and weight.

1. Electrical Interfaces to the International Space Station

The AMS-02 experiment has three electrical interfaces with ISS: Power, the Low Rate Data Link (LRDL) and the High Rate Data Link (HRDL). An allocation of 2,000 W is provided from the ISS solar arrays to AMS at 120 VDC with stringent electromagnetic compatibility (EMC) requirements.

The Low Rate Data Link is based on the MIL-STD-1553B dual serial bus. Monitoring data pass over the bus, through ISS for transmission on the Ku-band via TDRS satellites to the ground, through NASA centers and the Internet to the AMS-02 Payload Operations and Control Center (POCC) in real time. The available date rate is $\sim$ 10 Kbit/s with a duty cycle of 55 to 90 %. 10 byte/s is transmitted continuously. The LRDL is also the command path from the POCC to AMS. At most one 120 byte command is allowed each second.

The High Rate Data Link is based on an ISS specific implementation of the TAXI protocol over fiber optic cables operating at 125 MBaud. This data stream contains the event data and a copy of the monitoring data. Within ISS the data flows to the AMS Crew Operations Post (ACOP), where it is archived for eventual retrieval by the shuttle. ACOP also provides crew access to the monitoring data. When the Ku-band is available, data can be replayed from ACOP or streamed live from the experiment to the POCC and to the AMS-02 science operations center. AMS is allocated an orbital average of 2 Mbit/s downlink. To allow the contingency loading of software into the experiment and as a backup command path data can be transmitted over the HRDL from ACOP to AMS.

pp. 2173–2176

2. Subdetector Readout Requirements

The silicon tracker measures the trajectory of passing charged particles to 10 microns and the particle charge in 192 ladder elements, each with 1024 readout strips with signals are as small as a few femtocoulombs.

The Time of Flight (ToF) system is made from 34 plastic scintillator paddles with 2 PMTs on each end. To measure the particle velocity, the relative time of passage through different paddles is required with 100 picosecond accuracy. The energy deposited is also measured. The ToF electronics provides a history of any particles that entered off time, complemented by the 16 paddles of the Anticoincidence counters (ACC), with 1 PMT for two adjacent ends. Together these scintillators provide the primary trigger for the experiment.

The Transition Radiation Detector (TRD) measures very high velocities to discriminate high energy positrons from protons using 5,248 proportional wire straw tubes, in which control of the gas gain is critical.

The Ring Imaging Cerenkov Counter (RICH) identifies particles by measuring the location and number of photons collected by 680 16-pixel PMTs. Dynamic range of each pixel must be sensitive from single photons (single charged particles) up to 10,000 (heavy ions).

The Electromagnetic Calorimeter (ECal) distinguishes electromagnetic particles from hadrons by the shower shape and energy as measured in 324 4-pixel PMTs. To reach our TeV goals requires a dynamic range of 60,000. The ECal also provides a trigger for $> 2\,\mathrm{GeV}$ gammas.

In total there are about 227,300 channels and each channel provides 16 bits of information for each trigger with event rates up to 2 kHz. The resulting raw data rate is over 7 Gbit/s. The electronics must reduce the event size and filter out mistriggers to reach the allocated 2 Mbit/s downlink data rate.

3. Particle Physics Electronics in Low Earth Orbit

The existing electronics certified to operate in orbit cannot meet the requirements derived from the previous two sections. For AMS-02 we have designed and qualified a unique new set of electronics for use in space. This process has been validated by our work on the electronics for the AMS-01 precursor experiment in June 1998.

Special care was taken in the the mechanical design of the electronics enclosures to meet the static loads (40 g) and random vibration ($6.8\,\mathrm{g}_{rms}$) and allow complete depresurrization. For the readout boards the design is a VME like crate with backplane. The power converters associated with each crate are housed separately. In total 600 boards of 60 different types are mounted around the experiment in 50 boxes. Each box is vibrated before installation.

When on orbit the electronics must be able to operate over a wide temperature range (-20 to $+50\,$C) in the absence of cooling. Extended industrial range parts were selected and detailed thermal modeling at the board and box level were input into the mechanical design. To ensure reliable operation each box under goes a complete thermal and thermal-vacuum test cycle before installation.

The effect of the total ionizing radiation dose (600 Rads/year) was measured for all key components and found to be negligible. A much larger concern was heavy ion induced single event effects, including destructive latch ups or gate ruptures and bit flipping upsets. Careful research was done to select candidate high speed, low power components. Then a series of beam tests were performed at GSI, Darmstadt and Catania. In total 60 different components were tested and several rejected and others protected.

Careful materials selection, particularly of the cabling and connectors, and the housing design, avoid problems due to vacuum, free atomic oxygen, solar UV radiation and impacts from micrometeorites and orbital debris.

The power architecture and a comprehensive shielding and grounding scheme ensures EMC requirements and each box design must pass an EMC test campaign. For the small stray magnetic field of up to 500 Gauss, the designs, particularly of power converters, have been verified to operate to specification.

The largest burden on the design comes from ensuring that the electronics will perform without physical intervention over the three year mission. Component level reliability data has been checked. For complex designs, redundant circuits have been implemented. In addition to the vibration and thermal-vacuum qualification mentioned above, long term tests are in progess.

4. The DAQ Chain

Fig. 1 sketches the DAQ chain implemented to achieve these ends. Detector signals are prepared by shapers within purpose built ASIC's specific to each detector. Signals from the ToF, ACC and ECal are split off to the trigger system. The trigger holds the shaped signals, which are then sequentially readout and digitized. Up to 32 data streams then flow into a four event deep memory buffer within the subdetector DAQ module, and the electronics is ready to receive the next trigger ($< 90\,\mu$s). Asynchronously within this module, the data from an event is heavily reduced (pedestals subtracted, zeros suppressed) and the results placed in an output buffer. The reduced event size is $< 2\,$Kbytes.

To ensure that no further dead time is accrued in moving the data further, a purpose built point to point serial link protocol (AMSWire) was developed, with very low latency, net data transfer rates of 10 Mbyte/s, and low power consumption. On request from an intermediate DAQ node, the data for an event from 6 to 24 subdetector DAQ modules is returned, collated, and buffered. Similarly, the next layer receives all the data from an event and passes it into the top level DAQ node within the main DAQ computer. For redundancy, the nodes and links are

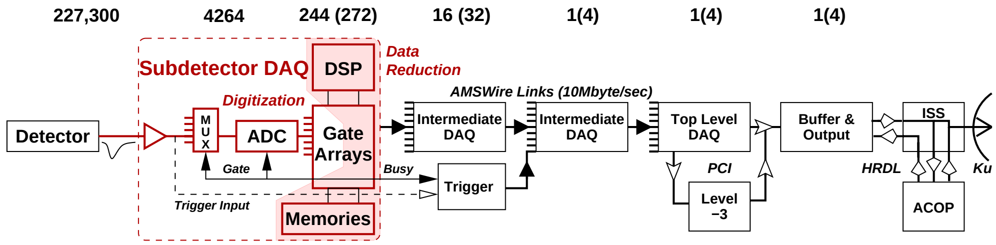

Fig. 1. AMS-02 DAQ chain. The active elements of each type and parenthetically the total including redundant elements are shown. The shaded area is a common design for all subdetectors and the intermediate DAQ modules.

replicated at each level, with the active nodes and links selectable by command. The high fault isolation and fault tolerance of the design rely on the low resource impact of adding additional point to point connections.

The implementation of this requires that part of the subdetector DAQ modules be specific to each subdetector. However the rest of this module is based on a common design for all subdetectors and intermediate DAQ modules. This common approach necessitated the selection and qualification of just a few key elements.

A similar standardized approach was implemented in the slow control and power conversion systems.

Within the main DAQ computer, with the complete event data available, a more precise analysis (Level-3) of the event allows only the interesting events to be kept for buffering, formatting according to ISS requirements, and downlinking and recording via HRDL. This computer is based around a PowerPC chip with a PCI bus to custom peripherals connected to the AMSWire links, the LRDL, the HRDL and the CAN bus used within AMS for monitoring data and slow control.

5. Status and Conclusions

All of the key elements to produce electronics which meet the requirements have been identified. Circuits for each of the subdetectors have been built and used to read out the detectors in test beams and other tests. Board level qualification of the flight designs are in progress and the flight components acquired The main DAQ computer and ISS data interfaces have successfully completed a full, box level qualification cycle and interface tests with NASA. Fabrication of the flight boards, mostly at CSIST, Taiwan, is taking place over the next year.

We thank the many organizations and individuals acknowledged in [1].

6. References

1. S. Gentile, “The Alpha Magnetic Spectrometer on the International Space Station”, these procedings.