CMS AND ATLAS TRACKER READOUT SYSTEMS

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Abstract

The electronic systems being developed for the CMS and ATLAS trackers are briefly reviewed and the current status and potentially difficult problems discussed.

1. Introduction

In the oral presentation made to the conference, an outline of the systems being developed for the CMS and ATLAS tracking systems was given. These are thoroughly described in some detail in the Technical Design Reports to which the reader is referred for further information [1-3]. It was not thought necessary to repeat those system descriptions. During the conference there were also many talks reporting progress on components of the tracking electronic systems; the reader is invited to consult them for details.

There are some major differences in philosophy between the systems, most evidently that the ATLAS systems are based entirely on binary readout while those of CMS are fully analogue. While the complete polarisation of readout choices initially seems surprising, the decisions have been based on sound logical differences between the tracking systems and the practical difficulties expected to be encountered in constructing them. One example is the fact that in CMS there is a very high solenoidal magnetic field and this brings with it strong Lorentz effects which were a factor in the choice of analogue readout of the microstrips. In the pixel system this feature has been used to advantage by deliberately organising the barrel region of the pixel detector without the usual tilting which would reduce the width of the charge cloud in the azimuthal direction. However, the charge sharing between pixels of the size chosen (~150μm) then allows to improve the position resolution which can be obtained and allow roughly equal point accuracy in each major co-ordinate.

While it is easy to identify differences in the two systems, it is less usual to focus on the similarities. Structurally, both experiments use silicon pixels and microstrips for the inner region and gaseous detectors in the outer layers. However CMS relies on microstrip gas chambers while ATLAS will employ transition radiation straw tubes. They operate at very different gas gains which has driven some of the front end electronic choices. Both experiments require optical links for much of the data transmission. However CMS relies on edge-emitting lasers operating at a wavelength of 1300nm illuminating single mode fibres; ATLAS is investigating VCSELs at 850nm in multi-mode fibres. Both experiments require low cost links for which the packaging is customised for low mass; this is still a topical item for both of them. Both pixel systems plan to make use of the optical links employed in other parts of the tracker. In ATLAS by transferring binary data; in CMS by packing the data and transmitting several bits as one analogue word.

Perhaps the areas where the two experiments have most in common is in identification of similar problems. These become most clear in many of the issues which have been identified as still to be tackled, or pending, and some of them are summarised below.

2. Technologies

Both CMS and ATLAS are prototyping pixel electronics in DMILL and Honeywell SOI processes with a view to selecting one of them for final production. Both experiments report that the radiation hardness requirements of up to about 30Mrad appear to be obtainable. Having succeeded with "proof of principle" prototypes, both experiments plan to move on to larger matrices and control electronics in the coming year. Issues of adequate noise at low power and control of thresholds and cross-talk have been dealt with successfully.

In the outer trackers, i.e. excluding pixels, the technological choices of CMS and ATLAS are rather different. The binary ATLAS system makes use of a bipolar front end, but CMOS is required for the pipeline and logic. Two alternative approaches are being followed for both the Silicon Tracker and the TRT system: a two chip solution with a bipolar chip in MAXIM and a CMOS pipeline and logic chip using Honeywell bulk CMOS, or a single BiCMOS chip in TEMIC DMILL. Bipolar amplifiers have long been believed to offer best noise for given power compared to available CMOS technologies, but there are overheads from comparators and drivers required in the two chip solution. The BiCMOS solution has the advantage of eliminating a large number of dense bonds which are required for the signal transfer between the comparator and pipeline stages. However, cost is one of the factors which will drive the ATLAS decisions, which are expected next year.

CMS will use modified versions of the same front end APV chip for both silicon and gas microstrips. It is being prototyped in Harris AVLSI-RA bulk CMOS and in the TEMIC DMILL process. The arguments for the CMOS analogue design are based on the desire to construct an analogue readout for robustness and common mode noise immunity and the desire to avoid on-chip thresholds. However, it requires the development of an analogue optical link for data transmission, which is now in an advanced state. The non-technical arguments for the use of CMOS include the desire to ensure the availability of two vendors during the procurement period to minimise both cost and technical risk. However, another risk was the possibility that the chip would become large relative to ATLAS front ends and production yield would therefore be more unfavourable with obvious cost implications. The actual size of 6.4mm x 12mm is not now expected to be excessive.

Despite the advanced stage of prototyping, the impressive results from the deep sub-micron CMOS technologies, which would offer improved noise and power performance, have stimulated interest from CMS in considering this option. Since the radiation tolerance of the process investigated also seems to be excellent, the potential cost savings are difficult to ignore.

The jury is still out on the front end technology decisions to be finally made by the two experiments, and is likely to remain so indefinitely except to those who relish the debating opportunities so offered.

On the data links, the ATLAS TRT has chosen the conservative approach of differential electrical transmission over low mass twisted pairs. This seems most cost effective for the relatively small number of links required. However, for the inner tracker and the pixel detectors, digital optical links were favoured because of the impact on the material budgets. While initially the baseline solution was LED transmitters, the degradation during irradiation appeared to be risky, particularly for the high radiation levels in the pixel volume. Therefore interest has been stimulated in Vertical Cavity Surface Emitting Lasers (VCSELs) which may be an inexpensive alternative once suitable packages have been finalised.

The CMS solution to both data and control and monitoring links has been based on work which was undertaken originally by the RD23 collaboration, which concluded in 1996 with a decision by CMS to utilise 1300nm edge-emitting III-V lasers mounted on silicon carriers. Transmitters, pin diode receivers and fibres and connectors have shown excellent radiation hardness and several prototype links have been operated to demonstrate good characteristics for both analogue and digital data transmission. The remaining issues include the cost and availability of second sources for the packaged transmitters and receivers, since suitable lasers and pin diodes can be obtained from a number of vendors.

3. System summary

ATLAS

Pixel 140M channels
50μm x ~500μm
Binary readout with zero suppression
Radiation hard CMOS
Occupancy $< 5 \times 10^{-4}$

Inner: Silicon microstrips 6M channels
Binary readout with zero suppression
Bipolar amplifier/discriminator + CMOS pipeline MUX
Digital optical transmission *8k links*
VCSEL transmitters
Occupancy <1%

Outer tracker : TRT 420k channels
Dual threshold binary readout with zero suppression
Bipolar amplifier/discriminator + CMOS pipeline/MUX
Digital electrical transmission (LVDS) *27k links*
Occupancy 10-40%

CMS

Pixel 40M channels
150μm x 150μm
Analogue readout
Radiation hard CMOS
Occupancy $2\text{-}3 \times 10^{-4}$

Inner: Silicon microstrips 6M channels
Outer: MSGC 6M channels
Common analogue readout system
CMOS amplifier/pipeline/MUX
Analogue optical data transfer *50k links*
No zero suppression on detector
Occupancy <1-2%

4. Some pending items

In private discussions and progress reports the common issues are readily identified:

Radiation hard electronics

There has been constant progress for several years but final solutions are still evolving, mainly for technological reasons; some technical difficulties have been encountered in several prototyping runs. There is still concern about the present and future number of available technologies and their projected cost. Questions of Single Event Effects have not been much investigated yet but they have been on the agenda for some time; progress is now beginning to become apparent.

Hybrids and electrical services

Low mass solutions are under development but not complete. Distributed power and grounds still require demonstration and the location, accessibility and maintenance of supplies is an open question, but where both experiments have chosen the baseline of placing their power supplies remote from the cavern. They are therefore concerned about the cost and cooling of large cables as well as the practical problems of delivering the high currents over long distances with no local voltage regulation. This could have consequences for system noise along with other sources of coherent noise in addition to the front end amplifier, which must dominate for the systems to function well. Measurements are certainly needed.

Power supply reliability is an important issue and would become more so if supplies were relocated to the cavern in the case that radiation tolerant versions became available. Protection circuits to ensure safety of the internal tracker electronics are an issue in either case since access will be limited and response time for problems will be long. The cooling of both racks and cables is a difficult question but which is shared with many other sub-systems.

Data links

Good progress has been made on both optical fibre and electrical links using low mass twisted pairs. Working links exist, and excellent radiation results on components have been obtained. However questions remain on the large scale implementation, since only a few manufacturers have produced packaged transmitters meeting the requirements and low cost is an important target which seems possible but is not yet proven. The congested spaces in the interiors of CMS and ATLAS force the development of low volume interconnections, which is in progress. This is also an issue for other services, especially gas and cooling connections.

System issues

The large scale production and test of components is beginning to occupy more and more of the attention of the system developers and some papers at this conference describe promising progress using customised or commercial test systems. It still has to be agreed whether in-house testing is the right approach for large production volumes or whether this is a task which can be sub-contracted to industry; first steps are being taken to identify the possibilities – and costs.

Quality assurance

This is a phrase which is being used more and more frequently. It has still to be identified what it implies at each level of the system, not only the electronics. However maintenance of production standards of front end chips and assembled hybrids is known to be an important issue. What is often neglected is that the module assembly stage, often envisaged to take place in home laboratories, even small drops in module yield could be very expensive since each rejected module would involve the loss of several front end chips, at a cost at least as large as the detector and sometimes much greater. A question also asked more frequently is whether industrial production at module level is a possibility.

Large scale assembly and test

Hybrid and module assembly raise questions not only about quality control at module level but exact criteria and test methods, as well as test time. A more difficult point is the exact methods to be used for testing, since high throughput is essential. However some detectors, like MSGCs, can only be tested at present with the electronics assembled and mounted. Many developers have emphasised the importance of system evaluation, which can take place at several levels. This is known to be important for major issues like overall synchronisation of the sub-detectors with the rest of the experiment, but also for identifying "minor" faults in components which could have much larger implications at the system level, preferably at an early enough point that they can be corrected with sufficiently small cost penalty.

Slow control

The requirements are still being defined. An implied issue of interfaces, protocols, connectors and standards is at an early discussion stage.

Financial issues

The large spending required on many items which are required early in the critical path of detector construction is still a concern. Front end electronics costs are still a major part of the overall detector budget and the components must be delivered on a short timescale to complete construction on time. To manage the income and expenditure profiles will need careful planning to avoid this becoming a major constraint.

5. Summary and conclusions

Many talks at this workshop demonstrate the steady progress which has been made on components and systems. Some of these, such as the results on deep sub-micron CMOS technologies, may hold a key to constructing large systems within the limited budgets and timescales which prevail. However, if so, further developments must be rapid.

There are many issues outstanding but also other positive developments. To name a few, an LHC-like beam now seems to be about to be approved by CERN, although the date is still not finally clear, which will aid in many system tests. There is wider interest in many system issues, especially the organisation and schedules for production and their implications. A better understanding of the procedures for management of large contracts has been achieved in the last year; a radiation hard foundry market survey is under way, which is the first stage of the tendering process, required before contracts are placed. CMS will establish an "Electronic Integration Centre" which will cover areas of common sub-detector interest to be staffed by several full time engineers and it is hoped that this area will, in time, receive as much support as the mechanical integration of the experiment.

Nevertheless, there is a long way to go…

Acknowledgements

I thank many colleagues for valuable discussions, especially P. Farthouat, A. Grillo and G. Stefanini.

References

[1] ATLAS Inner Detector Technical Design Report, CERN/LHCC 97-17 (1997)

[2] ATLAS Pixel Detector Technical Design Report, CERN/LHCC 98-13 (1998)

[3] CMS Tracker Detector Technical Design Report, CERN/LHCC 98-6 (1998)