Optical links for LHC: experience from the CMS project and future prospects

Francois Vasey

CERN, PH Department, 1211 Geneva 23, Switzerland
francois.vasey@cern.ch

Abstract

Optoelectronic technology is used worldwide to an unprecedented scale. In LHC also, optical links will be the preferred means of transferring data.

This paper first highlights the specificities of High Energy Physics data links in a field driven by data and telecommunication networks.

In a second part, the paper focuses on the lessons learned from producing a system comprising over 50'000 fibres for the CMS detector. Where were the bottlenecks, where have failures occurred and how were they remedied, how could economies of scale be realized? These lessons are generalized in a way such that they can be useful when planning new projects of similar scale.

Finally, the evolution of optoelectronic technology is reviewed and an upgrade path towards operation in a higher luminosity detector is sketched.

I. Introduction

Optoelectronic technology is used worldwide to an unprecedented scale. In LHC also, optical links will be the preferred means of transferring data. As an order of magnitude, more than 100'000 point to point optical links will be implemented to readout and control LHC detectors, providing an estimated 50Tb/s raw capacity. This is comparable to the bandwidth connecting a large city to its global telecommunication network, but is achieved with a two orders of magnitude higher fibre count than typically found in backbone networks. This striking difference in fibre count and bandwidth usage raises the issue of the specificity of the optoelectronic systems developed for LHC. Understanding this specificity is key to preparing efficient next-generation data transfer systems.

II. Specificities

The harsh environment surrounding the experiments is undoubtedly the most specific feature of LHC-related projects [1]. For optical link components, resistance to radiation can be achieved by reducing as much as possible the active volume of lasers and photodiodes and by strictly controlling the levels of impurities and dopants present in the glass fibres. Immunity to magnetic field is achievable by selecting appropriate non-magnetic materials. Low mass and compact assemblies can be built by compromising on device ruggedness. Technology is thus available in most cases to meet the stringent LHC environmental constraints. It however remains the responsibility of the High Energy Physics (HEP) user to qualify on a case by case basis the selected component in its specific environment [2].

From an organizational point of view, the multi-national collaborations building LHC experiments present a model specific to our field. The distributed nature of the decision centres and of the funding sources needs to be taken into account early on when planning the projects. The fact that LHC collaborations are not operating for profit also means that time can be used as contingency when problems occur, an option not open to most commercial enterprises.

Despite the above mentioned environmental and organizational specificities, optical links developed for LHC rely extensively on commercially available optoelectronic technology developed for modern communication networks. The fact that these networks operate globally and reliably indicates that organizational and operational models have successfully been put in place worldwide. Such models will provide very useful information when designing next generation optical systems for high energy physics.

III. Lessons learned

The need to gain expertise in the use of optoelectronics for data transfer was recognized early on by the HEP community. In 1992 CERN launched the research and development project RD23 which was open to all LHC experiments [3]. After a few years spent with an industrial partner developing a fully customized data link system, the collaboration eventually realized that the only way to develop an affordable and functional system was to make use of commercial off the shelf (COTS) components wherever possible, while keeping open as many supplier sources as possible. Lessons learned in that early phase of the project summarize to:

1) *Do not delegate developments, keep abreast of technology and control technology choices.*

2) *Use COTS wherever possible and implement robust qualification programs. If necessary, customize the product to fit the application specific requirements.*

The R&D and development phases of the CMS tracker optical link project lasted 6 years. It is only as developments were reaching completion that the complexity of the following tendering phase was realized: it took another 3 years to place all contracts for all components of the optical system. The lesson learned in this procurement phase is:

3) *Commercial readiness is as important as technical readiness. The tendering phase is complex and should be integrated as tightly as possible into the development phase of the project.*

Contract placement for the CMS tracker optical link components was immediately followed by the launch of pre-production. Out of the 12 component types for which pre-production qualification was required (Transmitters, Receivers, ASICs, connectors, fibre, cables, etc…), only 4 could be qualified outright. The other 8 types failed the specified test procedure on various grounds, causing 3 to 9 months delays to the launch of their production. In several cases, non-conformities continued occurring once production was started. This triggered the launch of return procedures followed by corrective actions and in some rare cases re-qualification. Production thus rarely followed the initially drafted schedule and delays frequently accumulated. It is worth noting that most difficulties occurred with components which included some level of customization such as non-magnetic parts, analogue electronics etc.... Here, the lesson learned is:

4) *Manufacturers sometimes learn on the job and non-conformities occur as a consequence. A robust qualification program must be put in place, and the production schedule must contain some slack allowing for failures and delays.*

Numerous instruments are available to tightly control the manufacturers and follow up production. These include commercial and legal tools. However, it must be realized that if manufacturers may take actions that affect the project in a negative way, we as customers also frequently need their flexibility to accommodate late changes in the requirements or updates to the schedule. During production, the relationship with industry is thus a balanced sequence of compromises requiring constant adjustments and flexibility from both partners. Hence, the lesson learned is:

5) *Good and tight relationship to industry is key to project success.*

Retrospectively, it is encouraging to note that in several cases common efforts across detectors and experiments have been possible. The joint development of a dense multi-ribbon cable for CMS and ATLAS is one example [4], the design of the GOL serializer ASIC used by all experiments is another one [5]. Overall however, we find that most detectors have engineered their own links meeting their own requirements. The lesson to be learned is:

6) *Common efforts and economies of scale are possible. They could be encouraged further in the future by for instance clearly including manpower costs into the project budgets.*

Finally, we should not forget that the installation and commissioning phases of LHC experiments are still ahead of us. We will thus keep a few additional lesson-learned entries free for these future activities.

IV. FUTURE TRENDS

Since a few years, the amount of data traffic over the network has overcome voice traffic and grows by a factor of more than two every year. Together with the radical increase in available computer processing power, this growth is a clear indicator of the trend towards generalized broadband access and data-intensive communication. Optical technology is ready to meet this challenge as the ultimate broad bandwidth provider, but alternative technologies such as wireless and copper may be more competitive in the short term. As fibre is installed in the access part of the network, and as intelligence migrates from its core to its edges, optical components and systems will improve in cost and performance. ASICs are enabling these improvements as illustrated by electro-optical modules now including functionalities such as control, diagnostic and error correction. On the backbone part of the networks, migration from 10Gb/s to 40Gb/s rates is taking place in overloaded stretches. The technological step towards 40Gb/s is however a difficult one and it is unlikely that such high data rates will become available to short haul link users in the next few years.

All progress reported above will ultimately benefit the next generation of HEP experiments. Some work will however be required to fully profit from the advancement of technology:

- The models underlying the successful organization and operation of modern global data and telecommunication networks should be studied and understood.
- Electronics and optoelectronics should be jointly developed from the system level down to the component level.
- The established links to industry should be maintained and new ones should be created.
- A rolling validation programme should be put in place to continuously assess the functionality and environmental resistance of emerging components and technologies.

It will be at this price that new bandwidth and cost effective data transfer systems will be successfully developed and built for the HEP community.

V. REFERENCES

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