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Maximizing the Bandwidth Efficiency of the CMS Tracker Readout Optical Links for Super LHC

The maximum attainable data rate in a digital readout system based on the current CMS Tracker optical link components is investigated. Additional digital modulation and demodulation on either side of the current analog link would be required for implementation. The feasibility of such a conversion is explored in terms of performance that can be achieved and implementation complexity. Several bandwidth-efficient digital modulation schemes together with bit error rate (BER) reducing techniques are considered. The results from a simulation that includes a realistic model of the physical characteristics of the current components are presented.

Summary

Approximately 40 000 analog readout optical links are being installed in the CMS Tracker sub-detector for operation in the LHC. The next iteration of the CMS Tracker will be operated in the Super LHC (SLHC), and will have to cope with significantly increased data rates due to the tenfold increase in luminosity that is foreseen. In contrast to the telecom industry where the optical fiber and its installation drive the cost of a transmission system, it is the cost of the optoelectronic components that represents a large fraction of the CMS Tracker electronics budget. Hence, a digital system based on the existing components that can deliver sufficient performance for SLHC operation, if feasible, could potentially yield significant financial savings.

Historically, optical transmission systems employ simple binary digital, or on-off keying (OOK), schemes due to the large bandwidth available in optical fiber. In contrast, fast transmission through wireless and copper-based communication channels which are severely band-limited requires modulation techniques that are more bandwidth-efficient. Research into multi-level signaling for optical systems is a relatively recent subject of research, prompted by the desire to reach even higher data rates.

The current CMS Tracker optical readout links are equivalent to a digital system capable of pulse amplitude modulation (PAM) at 40MS/s with 8bit resolution (=320Mbps). The excellent noise characteristic (typical SNR ˜50dB) means that the current link is particularly suited to a bandwidth efficient, multi-level digital modulation scheme. Moreover, the short transmission lengths (˜65m) suggest immunity to attenuation, phase noise and dispersion which are typical performance-limiting factors in optical transmission systems. It is the bandwidths of the laser driver chip and receiver amplifier (˜100MHz) that ultimately restrict the achievable data rate.

ADSL is an example of how digital communication theory can be used to fully exploit a system's available bandwidth. Copper telephone lines, typically having a 3-dB bandwidth of ˜20kHz, attenuate a signal by as much as 90dB at 1MHz, which is the outer edge of the frequency band used by ADSL. Using advanced techniques which are variations of Orthogonal Frequency Division Multiplexing (OFDM) and Quadrature Amplitude Modulation (QAM), data rates between 2 and 6MBps are accomplished.

Measurements on the Tracker analog links show an attenuation of around 50-60dB at a frequency of ˜700MHz. If similar digital modulation schemes can be employed over this vastly increased bandwidth and superior Signal to Noise Ratio (SNR), data rates in the Gbps range could be envisaged.

A simulation using MATLAB Simulink has been developed in order to evaluate the benefits and drawbacks of various well-documented digital modulation techniques. The simulation can be used to produce eye diagrams as well as compute BER. The

problem is treated as that of the design of a digital communication system, with the analog channel (or medium) over which signals are transmitted being the current Tracker readout link. Extensive testing on the Tracker links allows accurate modeling of the channel as a frequency-selective filter which adds Additive White Gaussian Noise (AWGN). Hence the effects of amplitude and phase distortion that cause Inter Symbol Interference (ISI) are included. In addition to performance assessment of modulation schemes, the simulation model can be used to identify the methods of Forward Error Correction (FEC) that are appropriate for this particular system. Moreover, source encoding (i.e. at the front end) in the form of data compression or optimal digitization of the analog detector signals can be easily explored.
The results of the study will demonstrate the feasibility of maximizing the bandwidth utilization of the current CMS Tracker optical links to achieve a Gbps link, and guide in the choice of method required. The application of advanced communication theory in the context of a HEP experiment is novel and would, in practice, present serious technological challenges. Nevertheless, the knowledge gained in this project could benefit future experiments by providing insight into fundamental engineering concepts never implemented before in HEP instrumentation.

Author: Mr DRIS, Stefanos (Imperial College and CERN)

Co-authors: Dr NOAH, Etam (CERN); Dr VASEY, Francois (CERN); Dr TROSKA, Jan (CERN); Dr GILL, Karl (CERN); Dr AXER, Markus (CERN); MACIAS, Raquel (Universidad Autonoma de Madrid and CERN); Mr GRABIT, Robert (CERN)

Presenter: Mr DRIS, Stefanos (Imperial College and CERN)