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A System-Level Model for High-Speed, Radiation-Hard Optical Links in HEP Experiments Based on Silicon Mach-Zehnder Modulators

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Silicon Mach-Zehnder modulators that are resistant to a total ionizing dose of 1MGy have recently been demonstrated. Such devices could potentially be installed close to the interaction points in future LHC experiments. Because they require an external continuous wave light source, radiation-hard optical links based on Mach-Zehnder modulators will need to have a different system design when compared to existing VCSEL-based optical links. A first model for such a system is presented, including estimates for the optical power budget, the electrical power dissipation and the architecture of the proposed system.

Summary

Silicon Mach-Zehnder Modulators (MZMs) are based on highly doped pn-junctions incorporated into two waveguides forming an optical interferometer. Due to the high doping concentration used, MZMs have been shown to be relatively insensitive to displacement damage well beyond a 1 MeV-equivalent neutron fluence of 2e15n/cm2. Recent investigations on optimized device designs have also led to a high resistance against total ionizing dose (TID) levels of above 1MGy. These values indicate that silicon MZMs have the potential to replace electrical and/or optical links that are currently installed close to the interaction points in LHC experiments.

In order to determine whether such a system can be competitive with, and ideally advantageous over, currently used optical or electrical links, the optical power budget of the optical links and the electrical power dissipation of the components needs to be estimated. Aside from that, open questions regarding integration of MZMs and driver ICs, module packaging and interfacing with the particle sensors have to be addressed.

The last important aspect of such a system concept is that of the light source to use, where to place it and how to connect it to the MZMs. This is especially relevant as silicon is an indirect bandgap material and efficient light sources are thus not available. External continuous wave (CW) light sources must be used with silicon MZMs regardless of their operating environment. In commercial applications, the light source is typically an edge-emitting laser diode tightly integrated with the MZM. Since those laser diodes are sensitive to radiation damage, the light source has to be placed further away from the MZM for radiation-hard links. In this way, radiation damage to the light source could be reduced, enabling the use of MZM-based optical links in very harsh radiation environments.

We present a concept for a silicon MZM-based radiation hard optical link system. The optical power budget and the electrical power dissipation of the envisioned system are quantified and a proposal for a light source and a fiber cabling scheme is given. We finally highlight what components will need to be further investigated to fully assess the viability of using this technology in high energy physics applications.

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