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# Free-Space Optical Interconnects for Cableless Readout in Particle Physics

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Particle physics detectors utilize readout data links requiring a complicated network of copper wires or optical fibers. These links are both massive and costly. Upgrades to such detectors may require additional bandwidth to be provisioned with limited space available to route new cables or fibers. In contrast, free-space optical interconnects will offer cableless readout, thereby resulting in significant reductions of material and labor. A collaborative effort between Vega Wave Systems and Fermilab is pursuing the development of a unique free-space optical link design that utilizes the transparency of silicon at 1300nm and 1550nm wavelengths; such free-space links will offer significant advantages in future detector systems. Experiments have been performed to characterize the bit error rate performance of a prototype link through bulk silicon and detector samples at multi-gigabit rates. Further experiments will explore the use of wavelength division multiplexing to combine data, control, and trigger information on the same physical link.

## Summary

As the demands of data communications in particle physics detectors increase, the need to explore novel ways to meet those demands becomes more important. Limits on the provisioning of additional cables or fibers in existing systems are imposed by the need to minimize mass and power dissipation within the detector volume. A collaborative effort between Vega Wave Systems and Fermilab has begun to explore the use of free space optical links to provide the necessary bandwidth for these communications. These techniques offer the promise of low mass links which can operate within the harsh radiation and magnetic field environments typical of high energy physics experiments. These experiments utilize commercially available components whenever feasible.

Experiments have already been conducted by this collaboration which have yielded promising results in the transmission of high bit-rate data streams through bulk silicon over a free-space optical link. These experiments (intended as a first proof of concept) demonstrate that it is possible to transmit un-encoded data at rates including 6.25 Gbps over such a link completely free of error. These tests have been carried out using single-channel SFP+ transceivers operating at a wavelength of 1310 nm (at which wavelength silicon is transparent). Addition tests will be conducted to demonstrate the effectiveness of the same approach through actual samples of a silicon vertex detector such as that in use in the CMS pixel detector at the Large Hadron Collider.

The use of wavelength division multiplexing (WDM) also offers advantages for detector data communications. The use of differing wavelengths makes it possible to use the same optical fiber (attached to a free space receiver outside of the detector volume) to convey multiple channels of data to an upstream data acquisition system. Different wavelengths can also be used to identify the source of the transmitted data, reducing the need for addressing information that consumes bandwidth on the link. Additional tests are being planned to instrument a prototype link using multiple wavelengths with commercially available devices (10GBASE-LX4) that transmit signals at wavelengths longer than 1200 nm through bulk silicon and detector material over a free-space link. In addition, the use of integrated optical assemblies (known as silicon optical benches) is being explored. Limits on the parameters of the physical link (delivered power, focusing constraints, jitter, and compatibility with receiver sensitivity of commercially available components) will be determined as a result of these experiments.

**Primary author:** Dr MORETTI, Tony (Vega Wave Systems)

**Co-authors:** Mr PROSSER, Alan (Fermilab); Dr SUGG, Alan (Vega Wave Systems); Mr CHRAMOWICZ, John (Fermilab); Dr KWAN, Simon (Fermilab)

**Presenter:** Mr PROSSER, Alan (Fermilab)

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