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A Silicon Photonic Wavelength Division Multiplex System for High-Speed Data Transmission in Detector Instrumentation

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Current and future particle physics or photon science detectors easily generate raw data rates of hundreds of Tbit/s. Even with massive local data reduction these data cannot be read out with current optical links. We propose a new optical data transmission system based on wavelength division multiplexing (WDM) with multiple monolithically integrated Mach-Zehnder modulators and optical multiplexers. The first demonstrator currently under development aims for a data rate of 160 GBit/s per fiber, scalable to 5 Tbit/s and beyond. Additionally our recently developed silicon photonic electro-optic modulators and Echelle gratings as WDM multiplexers are presented.

Summary

Future detectors, be it in particle physics, nuclear physics, photon science, or materials research, will consist of millions up to billions of channels. Together with sharply rising signaling rates of the individual channels, this will result in a massive increase of raw data rates well beyond hundreds of Tbit/s. The handling of these data rates is a key challenge for future detector systems.

State-of-the-art readout systems employ optical transmitters based on directly modulated laser diodes providing data rates of 5-10 Gbit/s per channel. Each laser diode is connected to an individual optical fiber.

Modulating a continuous-wave (cw) optical carrier by an electro-optic modulator may increase the data rate considerably. By multiplexing numerous wavelength channels and transmitting them over a single optical fiber, data rates up to several Tbit/s can be obtained. Furthermore, the individual carriers can be generated outside the detector system which reduces the net power consumption of the detector system. Such systems are well-known in telecommunication for long-haul networks and offer high bandwidths, low signal attenuation, low power consumption, electrical insulation, and low mass. However, they are entirely new to high energy physics experiments and would revolutionize data transmission, data acquisition, and trigger architectures.

We present the conceptual design of an optical transmission system where individual electro-optic modulators encode data on cw-carriers at different wavelengths. All channels are multiplexed and transmitted over one single optical fiber. Our first demonstrator aims at a data rate per fiber of up to 160 Gbit/s with a possible upgrade to 640 Gbit/s.

For a future system up to 64 wavelength channels and a higher modulation format with at least two bits per symbol are projected, resulting in a data rate of up to 5 Tbit/s. Next to much increased data rates the system would offer a considerable reduction of data cables. Consequently, less passive material is required inside the detector, thereby reducing multiple scattering and improving tracking resolution. The two main elements are the electro-optic modulators and the WDM channel filters. The devices are based on a silicon photonic platform, which enables large-scale photonic-electronic integration based on highly developed CMOS fabrication processes from the microelectronic industry.

The most widely used approach for silicon modulators exploits the plasma dispersion effect by depleting the active region of a pn-junction that is integrated into the photonic waveguide. Conventional depletion-type pn-modulators reach data rates of 50 Gbit/s and a power consumption of just 450 fJ/bit.

The (de-)multiplexers are implemented as Echelle gratings where the spatial separation of the wavelength channels is achieved by means of refraction. They offer a low insertion loss and good scalability in terms of channel numbers and space requirements. We designed, built, and characterized a 24-channel multiplexer which has 5 dB on-chip loss and an adjacent channel crosstalk better than 16 dB. The device area is 0.5 mm^2 only.

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