High-bandwidth CX4 optical connector

Dubravko I. Babić, Avner Badihi, Sylvie Rockman

XLoom Communications, 11 Derech Hashalom, Tel-Aviv, Israel 67892

Abstract

We report on the development of a 20-GBaud optoelectronic transceiver based on VCSEL-array technology with footprint and keep-out areas fitting standard CX4 electrical connectors to be used for InfiniBand SDR/DDR interconnections, XAUI extenders, and Fiber-Channel links. The transceivers are based on hybrid integration and are assembled using wafer-level assembly process on 6" wafers. The technology has been proven for 4+4 channel transceivers and 12-channel parallel interconnects, and lends itself for larger channel counts, while the size of the hybrid-integrated optical chip serves are direct insertion into high bandwidth optical backplanes and proprietary systems.

Recent years have seen a dramatic increase in the interconnection bandwidth requirements in networking central offices, data storage facilities, and computing centers. These applications, commonly referred to as data-communications or datacom, need bandwidths approaching 10 Gbytes/s over short distances (meters to hundreds of meters) and constitute the highest concentration of interconnects in any network. These numerous short-distance links represent the most cost-sensitive point in today's networks. The critical attributes of components in such systems are cost, power consumption, reach, and bandwidth. Numerous technologies have been explored to address this application space in the recent years: from individual component assembly to both monolithic and hybrid integration.

Two physical-media technologies are used in short-distance interconnects: Electrical and optical cabling. The choice of technology is governed by reach and price. For a given line rate, electrical wires and supporting electrical circuitry are generally less expensive than optics but require more power than optics, while optical fiber reach is significantly larger than that of electrical wires due to distortion. For this reason, at multi-Giga-Baud line rates, electrical signals are used for short distances (meters) and optics for long distances (tens of meters and beyond).

Present-day point-to-point interconnect bandwidth requirements in 10G Ethernet [1], Fibre-Channel [2] and InfiniBand™ [3] range from 2 Gbytes/s to beyond 10 Gbytes/s. This level of throughput is realized using parallel interconnects in both copper and optical media. The per-channel line rates in use range from 2.5 GBaud per channel to 5 Gbaud per channel being rapidly adopted, and 10 GBaud expected to be adopted in 2008. At multi-gigabit-per-second line-rates, copper-interconnect solutions are limited to reaches of several meters and hence optical interconnects are being feverishly investigated to meet the demand. As history has shown, optoelectronic devices for use in interconnects with aggregate bandwidths approaching 10

Gbytes/s and beyond have many challenges. Since late 1990-ties, manufacturers of such optical solutions have repeatedly offered novel technologies, but very few found market acceptance due to cost of the components, fibers, and connectors relative to copper technology. Other factors, such as, time of development and market conditions have played a significant role. It is generally accepted that integration of optical components and channels is the only path to interconnect cost reduction. The difficulty lies in that the density of the optical integrated circuits is limited by the wavelength of light used for communication. For this reason at least, the density of optical integrated circuits does not follow Moore's Law (doubling the number of active devices every 18 months). Instead, the optical integration approaches involve innovative solutions that address light coupling, packaging, heat management, and electronics to provide cost-effective solutions.

There are three main elements that promise to bring optical interconnects into the mainstream and in competition with electrical interconnects: (i) multimode optical communications use quasi-incoherent sources (vertical-cavity surface-emitting lasers) that provide low mode-selective loss in optical coupling and reduced manufacturing tolerance requirements resulting in lower component cost; (ii) wafer-level integration for cost reduction in manufacturing and test, and (iii) form, fit, and function compatibility with incumbent electrical interconnect solutions enables quick adoption of optical solutions in place of copper. With successful implementation of all of these elements, the cost of optical solutions will be equal or better than their copper counterparts for short distances, yet offer distance extension and subsequently take over as the ultimate interconnect technology in the computing systems world.

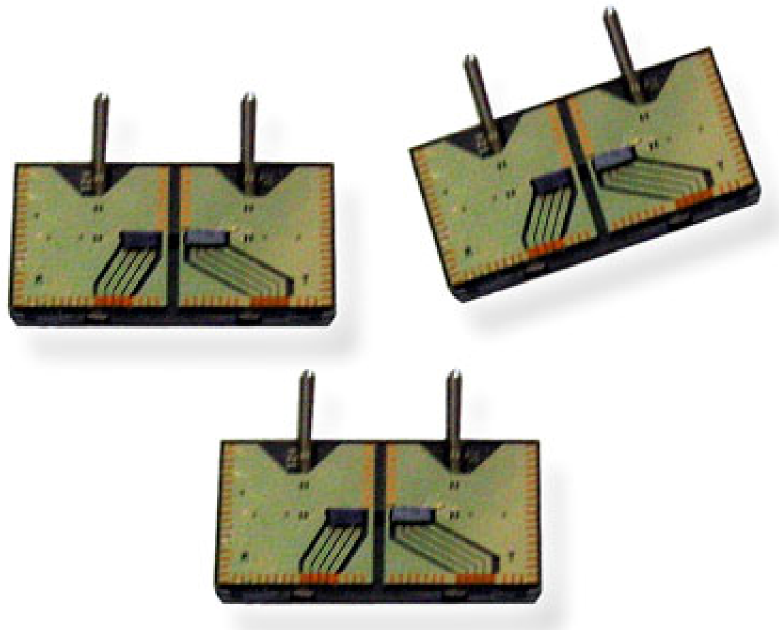
In order to increase the aggregate bandwidth of an electrical interconnect, multiple wires are run in parallel while the signaling rate per wire is kept low to limit the distortion. Similar approaches are being used in optics and this technology is commonly known as multi-channel or parallel optics. The connection system with broadest field deployment is the electrical four-channel architecture. This architecture supports 10 Gigabit Ethernet extension (XAUI) [1] with four 3.125 GBaud lanes, 10 Gigabit Fibre Channel with four 3.187 GBaud lanes [2], and InfinBand™ with four lanes operating at 2.5 GBaud (SDR), 5 GBaud (DDR), and 10 GBaud (QDR) [3]. Today's choice electrical connector used for the four-channel interconnects is Fujitsu's microGigaCN™ connector [4] defined by SFF8470 [5] and commonly known as the "CX4 electrical connector". This connector is commercially used for short-distance electrical interconnects up to 5 GBaud per channel, a 20 GBaud total bandwidth in each direction over distances up ten meters.

To address the three enabling elements discussed above, we have developed a CX4 compatible optical connector that is a drop-in replacement for the CX4 electrical connector receptacle (see **Figure 1**). It converts an electrical port into an optical port on an interface card. This CX4-compatible optical connector has been designed to fit within the keep-out areas specified for the CX4 electrical connector receptacle and to be electrically compatible with the printed-circuit-board traces used by the CX4 electrical connector electrical leads. Furthermore, when seen by the interface card circuitry (I/O drivers), the CX4 optical connector appears indistinguishable from any other active plug-in solution, such as, a media converter or an active electrical or optical cable: The developed connector maintains all of the functionality of an optical interface, it's size and simplicity of implementation levels the playing field between optics and electrical interconnects.

Figure 1 – CX4 optical connector next to a CX4 electrical connector receptacle

The technology enabling this small-size CX4 optical connector is embedded in the hybrid-integrated optical chip shown in **Figure 2**. This chip features micro-optics built into a composite substrate, flip-chip mounted optoelectronic devices, and MT pins for alignment to the MT ferrule of an MPO connector plug [6]. The low profile (less than 1 mm) of this component and the flexibility of building different channel counts makes it an ideal component for implementation in conjunction with present-day and future multi-channel optical connectors. Furthermore, the manufacturing of this optical chip is realized on the wafer level using standard semiconductor processes. It includes simultaneous passive alignment of optical coupling elements (mirrors and light guides) and chip assembly of many devices on four and six inch wafers. The automation of this process gives rise to a dramatic reduction in the labor cost.

Figure 2 – CX4 optical connector engine: micro-optic chip with optoelectronic devices



Figures 3 and **4** show two views of the CX4 optical connector when compared to the incumbent electrical CX4 connector receptacles and plugs. In **Figure 3** one electrical and one optical connector are mounted and used simultaneously on a two-port host-channel adapter card, while in **Figure 4** the CX4 optical connector is shown relative to a media adapter and an electrical (copper) cable. InfiniBand and Fibre Channel standards allow for plugging-in either a passive electrical cable or active electrical or optical media (equalized electrical cables, media adapters, and active optical cables), requiring power and control signals. The interface adapter card (example shown in **Figure 3**) normally detects the type of externally connected module (passive or active) as required by the Fibre Channel standard [2] and InfiniBand [3], provides power to the active cable, and allows several controls and monitoring signaling. These functions, collectively referred to as "media detection" circuitry, reside on the interface card. The CX4 Optical connector features media identification circuitry and is hence transparent for the interface adapter card designer: it operates as any other active media plugged into the CX4 connector receptacle would.

Figure 3 - An exemplary host-channel adapter populated with one CX4 optical and one CX4 electrical connector receptacles

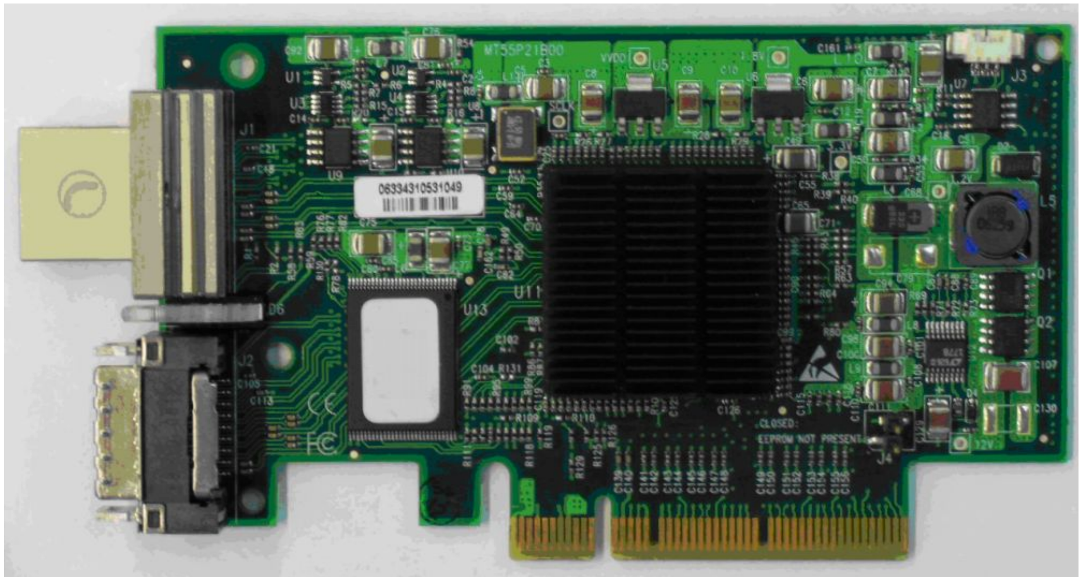
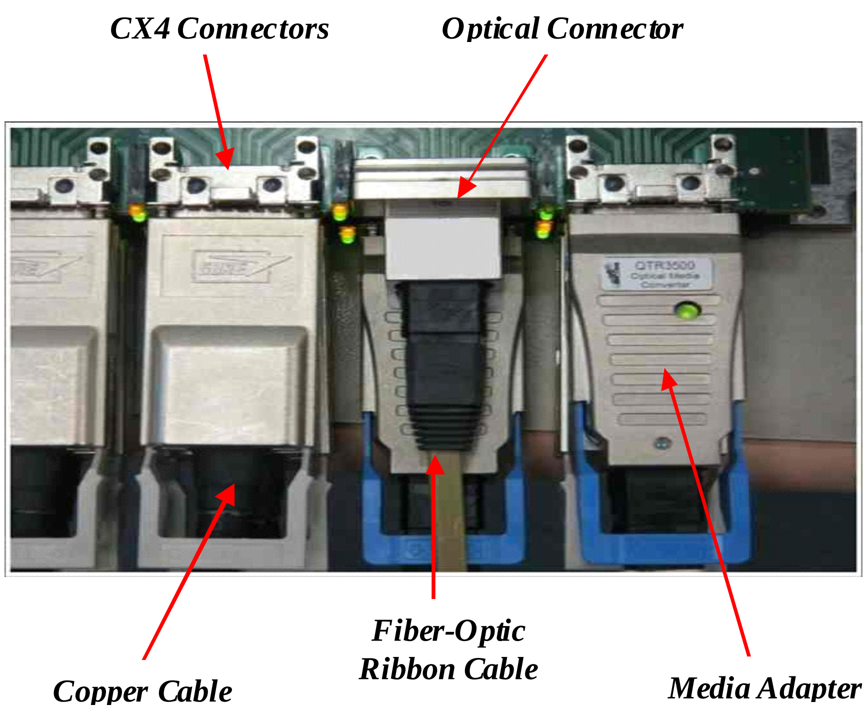


Figure 4 – The CX4 optical connector next to electrical CX4 connector plug (copper cable) and a Media Adapter connected to a switch



The CX4 optical connector operated at 3.3 V power with typical power consumption equal to 900 mW. The electrical and optical specifications are compliant with the InfiniBand™ specification. The heat generated by the connector is dissipated by convection through the printed-circuit board and the front metal bracket. This allows for stable component temperature that does not change when the optical cable is plugged in, i.e., there are no thermal transients. The modules support error-free performance at 5 GBaud per channel in an InfiniBand™ switch fabric environment. The optical connectors also comply with FCC emission and IEC laser safety regulations.

CX4 Optical connector allows internet compatibility from Fast Ethernet to 10G Ethernet without requiring any change in the circuitry since it works with the physical-media devices currently used by the industry for the CX4 interface. The interface operates at Baud rates from 100 Mb/s for Fast Ethernet and Gigabit Ethernet, to XAUI line rates, and DDR InfiniBand line rates.

The future of this hybrid-integration technology offers clear path towards 10 GBaud per channel implementation: Both electrical and optical components are available on the market, matched RF design of the optical chip ensures good signal integrity, and the proximity of heat sinking to the electrical components ensured the required temperature performance. Implementing linear receivers and laser drivers with pre-emphasis will enable aggregation of electronic dispersion compensation use in conjunction with multi-channel modules.

In summary, we have developed and demonstrated a CX4-compatible optical connector that allows low-cost optical connectivity in the data centers. The connector is a drop-in replacement for the CX4 electrical-connector receptacle, while it maintains all of the functionality of an optical interface. Its size and ease of mounting, levels the playing field between optics and electrical interconnects.

[1] IEEE 802.3ae-2002 and 802.3ak-2004, 10GBASE-CX4.

[2] Fibre Channel FC-PI2, American National Standard for Information Technology.

[3] InfiniBand™ Architecture Specification, October 2004 (www.infinibandta.org).

[4] Fujitsu microGiGaCN™ I/O Connector (http://www.fcai.fujitsu.com/microgigacn/io.asp).

[5] SFF8470 Multilane Copper Connector (http://www.sffcommittee.com)

[7] IEC 61754-5 MT type connector family, 1996.