A RECONFIGURABLE BI-DIRECTIONAL OPTICAL HIGHWAY

G. A. Russell, K.J. Symington and J. F. Snowdon
Department of Physics, Heriot-Watt University, Edinburgh
I.Gourlay and P. Dew
Informatics Research Institute, School of Computing, University of Leads, Leads

Key words to describe the work: Optoelectronics, Smart-Pixels, Optical Interconnect, Liquid Crystal, Polarisation Routing

Key Results: Working interconnect using polarisation routing and liquid crystal plates for reconfiguration

How does the work advance the state-of-the-art?: Proof of principle experiment for part for a future computer interconnect.

Motivation (problems addressed): Practical implementation of an optical interconnect system suitable for use within a computer architecture.

Abstract

A 4-node reconfigurable, bi-directional optical highway was constructed showing both the use of polarisation to route signals and liquid crystal plates to change the topology. Large enough signal swings were detected at the output after 1 and 2 relay stages to suggest that such a system is feasible for many stages.

Introduction

The use of an optical interconnect to form a computer back-plane has been widely reported [1]-[4] both in free-space [5] and fibre or waveguides. These systems have demonstrated the use of optics to create a highly parallel data interconnect.

A demonstration of a reconfigurable version of an optical interconnect has been produced. The optical system is based the idea of an optical highway (OH) in which a highly parallel free-space optical backbone is used to transfer data between points [6]. The data channels are added or dropped from the backbone by controlling the polarisation of the beam with patterned half-wave plates and polarisation beam-splitters (PBS). To make the interconnect reconfigurable the half-wave plates are replaced with liquid crystal plates.

The system constructed also uses polarisation selection at the adding stage to allow data to be transferred in either direction along the OH.

Experimental Set-up

The experimental OH consisted of three relay lens stages each separated by a PBS giving a 4 node system. For identification the nodes will be referred to as *n* (the input node), *n±1* and *n+2*. This scheme was chosen as this system represents the n^{th} node and neighbours of a much larger system.

The lenses used were originally designed for the SCIOS [7] project and are fully described in [8]. They are designed to give diffraction limited performance at large fields of view (>1cm^2) at 850nm allowing for a potential of hundreds of thousands of channels.

An 850nm VCSEL array providing numerous parallel channels at >1Gbit/s per channel was used as the source. Only a small number of channels was used but the SPOEC project has previously demonstrated 4096 channel parallelism showing the scaleablity of the system.

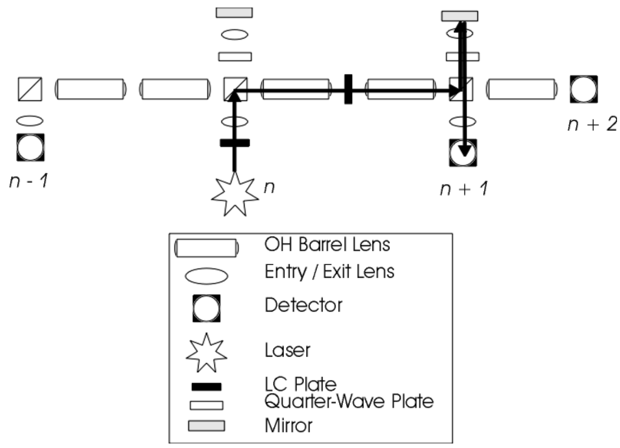

Figure 1 - OH showing path between *n* and *n+1*.

The system is shown in Figure 1. The three possible beam paths are examined below. For ease of description some of the imaging lenses have been neglected. The whole system was constructed on a machined metal base plate with slots for the lens barrels and other components.

The laser first passes through a liquid crystal plate where the polarisation is set. This controls the direction along which the beam travels along the OH. Next the beam goes through a PBS. If the destination is *n+1* or *n+2* the beam is reflected off the PBS into the OH: if not the beam passes thought the PBS, through a quarter-wave plate, off a mirror and back through the wave plate. The beam is now reflected off the PBS into the OH towards *n-1* as the two trips through the quarter-wave plates rotates the polarisation by $\pi/2$. After one relay stage the beam is reflected off a 45° mirror towards the *n-1* detector. If the OH was to be extended in this direction a PBS would replace the mirror.

If the beam was directed in the *n+1* direction a liquid crystal plate is encountered though the relay lens system. If the polarisation is unchanged the beam is reflected off the PBS up through a quarter-wave plate, off the mirror, back through the wave plate and through the PBS into the *n+1* detector. If the liquid crystal is set to rotate the polarisation then the beam can pass straight through the PBS onto *n+2*, which is equivalent to the beam remaining in the OH.

Control of the system was via PCs, analogue-digital data acquisition cards (A/D DAQ) and digital signal processors (DSPs). One PC was used as a broadcast node controlling the VCSEL array via a custom programmed DSP. This also controlled the topology of the network by changing the liquid crystal states. Four PCs with high speed A/D DAQ cards were used to interface with the photo-detectors.

Results

Alignment of the optics was the key component for this experiment. As much of the system is polarisation dependent spurious reflections were removed by adding polarisers within the OH. Also to aid alignment the mirrors at the output of the OH were movable to help steer the beam.

Correct placement of the optical component was by use of a metal base plate with slots machined into it. All optical components were mounted in barrel assemblies that fitted into the slots. This system allows for movement along the optic axis for focusing but not off-axis movement.

Once the optics were correctly aligned the detector showed a swing from about 40% to >60% of detector peak output between the off and on conditions of the liquid crystals. This is enough for the eye to detect and much more than required for the detectors to be thresholded for a digital signal.

Conclusion

The results of the experiment carried out suggests this system is feasible as an interconnect fabric. The main problems are alignment and power lose. Given correctly optimised optics it should be feasible to construct an OH capable of providing a completely connected interconnect for >50 nodes with node to node bandwidths of 1 to 10 Gbit/s.

Although this work was carried out using the free-space slotted base plate system the results would be equally valid for the integrated, planar free-space technique more suitable for a commercial system [10].

References

[1] G. Russell , J. Snowdon, T. Lim, I. Gourlay, P. Dew, *Modelling Of Optical Interconnects For Parallel Processing*, Conference Publication, Third Conference on Postgraduate Research in Electronics, Photonics, Communications and Software (PREP 2001), EPSRC, April 2001.

[2] D. A. B. Miller, *Rationale and Challenges for Optical Interconnects to Electronic Chips*, Proceedings of the IEEE, Volume: 88 Issue: 6 , June 2000, pp. 728 -749

[3] R. Lytel, H. Davidson, N. Nettleton, and T. Sze, *Optical Interconnections within Modern High-performance Computing Systems.* Technical report SMLI TR-2000-84, Sun Microsystems, 901 San Antonio Road, Palo Alto, CA 94303-4900, 2000, pp.1-15.

[4] M.W. Haney and M.P. Christensen. Fundamental Geometric Advantages of Free-Space Optical Interconnects. Proceedings of the Third International Conference on Massively Parallel Processing Using Optical Interconnections, 1996. Page(s): 16 –23

[5] E. Bernier, F. Lacroix, M.H. Ayliffe, F.A.P. Tooley, D.V. Plant, and A.G. Kirk, *Implementation of a compact, four-stage, scalable optical interconnect*. In Proc. Optics in Computing 2000, June 18-23, Quebec City, Canada, 2000, pp.253-262

[6] B. Layet, J.F. Snowdon. *Comparison Of Two Approaches For Implementing Free-Space Optical Interconnection Networks.* Optics Communications, Vol. 189, pp. 39-46, March 2001.

[7] D.T. Neilson, S.M. Prince, D.A. Baillie and F.A.P. Tooley. *Optical design of a 1024-channel free-space sorting demonstrator.* Applied Optics, Vol. 36, No. 35, 10 December 1997.

[8] F. A. P. Tooley, S. M. Prince, M. R. Taghizadeh, F. B. McCormick, M. W. Derstine and S. Wakelin, *Implementation of a hybrid lens*, Appl. Opt. 34, 6471-6480 (1995).

[9] A.C. Walker, T.-Y. Yang, J. Gourlay, J.A.B. Dines, M.G. Forbes, S.M. Prince, D.A. Baillie. D.T. Neilson, R. Williams, L.C. Wilkinson, G.R. Smith, M.P.Y.Desmulliez, G.S. Buller, M.R. Taghizadeh, A. Waddie, I. Underwood, C.R. Stanley, F. Pottier, B. Vogele, and W. Sibbett. Optoelectronic Systems Based On InGaAs-Ccomplementary-Metal-Oxide-Semiconductor Smart-Pixel Arrays and Free-Space Optical Interconnects. *Applied Optics*, Vol. 37, No. 14, 10 May 1998

[10] J. Jahns, *Planar packaging of free-space optical interconnections*, Proceedings of the IEEE , Volume: 82 Issue: 11 , Nov. 1994, pp: 1623 -1631