Fast Non-blocking N×N Optical Switch Using Diffractive MOEMS

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Abstract: We have developed a scalable free-space optical switch with a 12 microsecond reconfiguration time that can be implemented into an all-optical-cross connect for data communication architecture, or as a wavelength selective switch in a CDC ROADM for telecommunication networks. The foundation of the switch is the Texas Instruments DLP™ MOEMS that is used as a diffractive element displaying computer generated holograms to redirect the signal from any port to any port.
OCIS codes: 060.0060, 060.6718, 050.1940

1. Introduction

Today's data center architecture, infrastructure, and topology is becoming increasingly strained by the 50% annual growth in IP traffic [1]. Solutions to keeping pace with this exponential growth involve not just evolution of existing paradigms and hardware but revolutionary changes that can improve transmission speeds to 100 Gb/s and beyond, simplify architectures, and dramatically reduce the energy per bit required to access and transmit data.

This transformation is underway and telecommunication networks are moving from ring or star shaped networks to mesh topologies where all nodes are interconnected. Bandwidth allocation is becoming increasingly dynamic with software defined networking and flexible grid components. The reconfigurable add-drop multiplexers (ROADM) at the core of each node are becoming more agile and should be able to accept traffic of any wavelength, from any direction while preventing allocation conflicts by being colorless, directionless, and contentionless (CDC). The basis of these new ROADMs are optical wavelength selective switches (WSS) [2].

In the meantime, data centers are becoming smarter and more flexible, principally by virtualizing the servers for better resource allocation, and by moving from brute force electronic packet switching to a hybrid architecture where large packets are handled by optical cross connect switches [3,4]. The efficiency of such an architecture has been demonstrated both in terms of hardware, with a factor of 3 reduction for the capital expenditure (CapEx), and services, as evidenced by a reduction by a factor of 9 in power consumption (operational expenditure, or OpEx) [5,6]. Putting these numbers in the perspective of the national electrical power consumption of data centers, this represents a projected saving of 355 TWhr for year 2020 alone.

It has long been recognized that optical switching has significant advantages over electronic switching for some applications. The performance of an optical switch is constant as a function of data rate with demonstrated performances of 100Gb/s, is protocol agnostic, and requires significantly less energy per bit than electronic switching [4]. Optical switches are a key enabler in the next generation hardware and software architectures of data centers, metro networks and super computers.

The present technology, already deployed in the field and based either on gimbal mounted micro-mirrors or liquid crystal on silicon (LCoS) technology, has proven itself very useful in replacing electronic switching in a variety of systems. However, the reconfiguration time of these switches have so far been limited to the millisecond domain [7]. This dramatically restrains their use in some applications where a faster optical switch will enable new topologies and services. In this context, we introduce a scalable, non-blocking optical switch with a 12 microsecond reconfiguration time. This new switch is power efficient, and can be configured as a cross-connect for data centers or as a wavelength selective switch in a CDC ROADM for telecommunication networks.

2. System design

Instead of the gimbal mirror MOEMS, we developed our switch around the Texas Instruments digital light processor (DLP™). The DLP™ is indeed very attractive as a core component for an optical switch since it is polarization insensitive, the mirror size is very small (~ 10 μm pitch), the power consumption is reduced due to its bistable nature, and the reconfiguration time is extremely short: the refresh rate of the mirror orientation over the entire surface is 23 kHz, with a loss of light time that has been measured to be only 12 µs [8].

However, mirrors on the DLP™ chipset can only take 2 orientations, either +12° or -12° relative to the surface plane. Thus, by using reflection on the mirrors it is only possible to redirect the light from one source to two output positions. This results is a 1×2 switch capability which has very limited application. So, instead of relying on reflection, we are using diffraction properties, and are able to access a large number of output ports.

In our switch implementation, the DLP™ surface is divided into multiple sub-apertures, one for each input port. These sub-apertures individually display a computer generated holographic pattern (CGH) which has been calculated to diffract the incident beam in a specific direction [9,10]. When the switch needs to be reconfigured, different CGHs are displayed by the DLP™, and the light is diffracted towards other output ports.

Figure 1 presents sketches of the principle of operation of the switch in different configurations. In FIgure 1A is a cross connect embodiment with the light from the input fibers redirected to any output fiber. Figure 1B depicts a wavelength selective switch with the light being pre-dispersed before being redirected by the DLP™. The sub-apertures of the DLP™ can be reconfigured on the fly according to the frequency spacing of the signal, a feature commonly known as flexible grid [2]. In these schematics, the DLP™ is presented as a transmissive element instead of reflective for ease of visualization. It should also be noted that a double pass geometry can enable directionless capability.

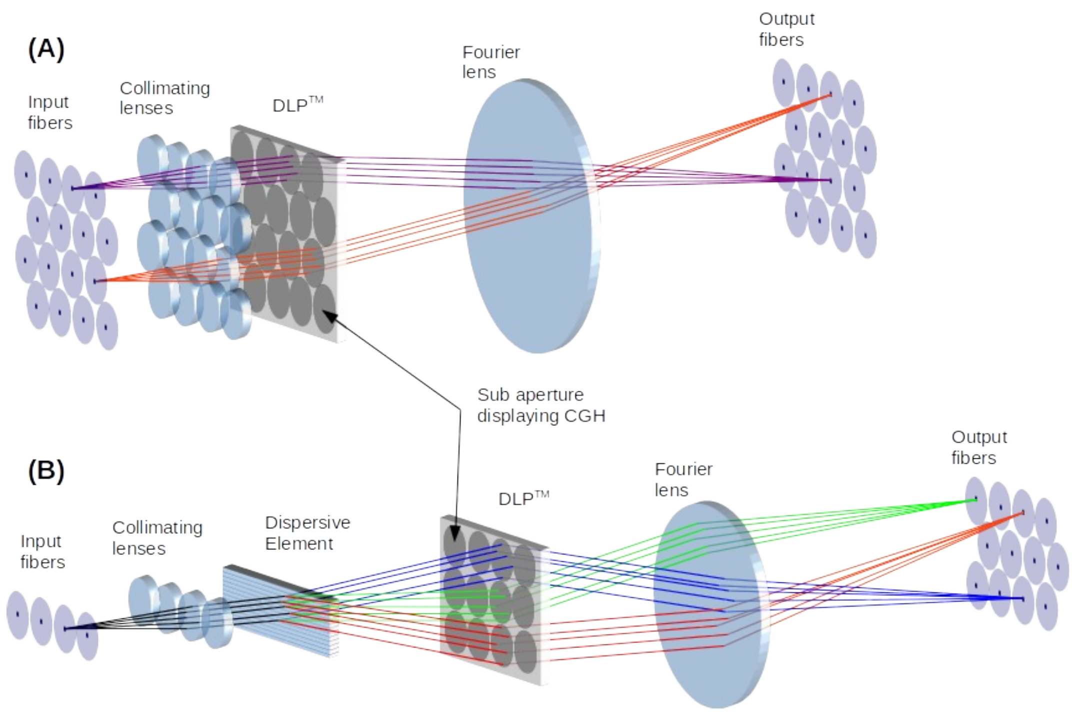

Figure 1: Schematics of a N×N optical switch using the DLP™ as a diffractive element. (A) Cross connect configuration. (B) Wavelength selective switch configuration.

In an early implementation, we demonstrated a single-mode fiber 7×7 cross connect switch, and showed its ability to operate over the entire C-band. The switch was inserted into a networking testbed assembled in support of the Center for Integrated Access Networks (CIAN), a National Science Foundation (NSF) Engineering Research Center (ERC). The testbed provides an environment in which to simulate network traffic and test the data routing functionality of the switch. We successfully transmitted an HD video stream through each switched channel without any packet loss [11].

The present iteration of the switch includes 32×32 ports, and the insertion loss has been minimized to an average of 6.5 dB by the use of aspheric components. For these systems, an additional 10 dB loss is due to the very nature of the diffraction pattern. Indeed, scalar diffraction theory predicts a 10% maximum efficiency for amplitude binary holograms, [9], which was confirmed experimentally [11]. This loss can be reduced to 0.3 dB by using an 8 level blazed phase diffraction pattern. Such a hologram can be generated on a piston MOEMS where the micro-mirrors are no longer tilted but rather lifted by a fraction of the wavelength. Piston MOEMS that meet our requirements of mirror size and stroke are not yet commercially available but are under investigation by several groups and silicon foundries [12,13].

3. Acknowledgment

The authors would like to acknowledge support from the National Science Foundation through CIAN NSF ERC under grant #EEC-0812072, the I-Corps NSF program under grant #IIP-1402041, Texas Instruments for providing the DLP™ kit, as well as the University of Arizona Tech Launch Arizona for supporting this research effort.

4. References

[1] Global Internet Geography: http://www.telegeography.com/research-services/global-internet-geography/index.html

[2] S. Gringeri, B. Basch, V. Shukla, R. Egorov, T. J. Xia, "Flexible Architectures for Optical Transport Nodes and Networks", IEEE Communications Magazine, July 2010.

[3] A. Greenberg, J. Hamilton, D. A. Maltz, and P. Patel, "The Cost of a Cloud : Research Problems in Data Center Networks," Comput. Commun. Rev., vol. January, 2009.

[4] I. Aldaya, R. Cafini, W. Cerroni, C. Raffaelli, and M. Savi, "Optical switch emulation in programmable software router testbed," Photon. Netw. Commun., vol. 25, no. 1, pp. 10–23, Nov. 2012.

[5] N. Farrington, G. Porter, S. Radhakrishnan, H. H. Bazzaz, V. Subramanya, Y. Fainman, G. Papen, and A. Vahdat, "Helios : A Hybrid Electrical/Optical Switch Architecture for Modular Data Centers," in SIGCOMM '10, 2010, pp. 339–350.

[6] G. Porter, et al., "Integrating Microsecond Circuit Switching into the Data Center", SIGCOMM, Hong Kong, August 2013.

[7] M. Mizukami, J. Yamaguchi, N. Nemoto, Y. Kawajiri, H. Hirata, S. Uchiyama, M. Makihara, T. Sakata, N. Shimoyama, and K. Oda, "128 x 128 three-dimensional MEMS optical switch module with simultaneous optical path connection for optical cross-connect systems," Appl. Opt., vol. 50, no. 21, pp. 4037–4041, 2011.

[8] N. Farrington, G. Porter, P. Sun, A. Forencich, J. Ford, Y. Fainman, G. Papen, and A. Vahdat, "A demonstration of ultra-low-latency data center optical circuit switching," in SIGCOMM 2012, 95–96 (2012).

[9] P.-A. Blanche, "Field Guide to Holography", SPIE Field Guide volume 31, SPIE Press 2014.

[10] B. Lynn, P. Blanche, A. Miles, J. Wissinger, D. Carothers, L. LaComb Jr., R. A. Norwood, and N. Peyghambarian, "Design and Preliminary Implementation of an N × N Diffractive All-optical Fiber Optic Switch," J. Light. Technol., vol. 31, no. 24, pp. 4016–4021, 2013.

[11] A. Miles, B. Lynn, P.-A. Blanche, J. Wissinger, D. Carothers, L. LaComb Jr., R.A. Norwood, N. Peyghambarian, "7 x 7 DMD-Based Diffractive Fiber Switch at 1550nm", Optics Communications, vol. 334, pp 41-45, (2015).

[12] T. Rhoadarmer ; S. Gustafson ; G. Little ; T.-H. Li; "Flexure-beam micromirror spatial light modulator devices for acquisition, tracking, and pointing", SPIE Proceedings, vol. 2221, Acquisition, Tracking, and Pointing VIII, 418 (July 5, 1994)

[13] A.Gehner, "MEMS Adaptive Optics Development at IPMS", Fraunhofer IPMS technical report. http://www.ipms.fraunhofer.de/content/dam/ipms/en/documents/ao-development.pdf