TuL1(Invited)
10:30am-11:00am

Overview of High Capacity Optical Cross-Connects

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SUMMARY

The extraordinary increases in aggregate bandwidth delivered across the fiber optic backbone infrastructure have been largely enabled by the emergence of all-optical amplification with Erbium doped fiber amplifiers and WDM technology. As optical transport systems mature, the key technical challenge is migrating from high bit-rate point-to-point transmission to an intelligent, dynamically reconfigureable multi-node network. The upcoming generations of optical networks must provide network management delivering rapid provisioning and restoration capabilities. Service layer provisioning requests will require a fast network response and the establishment of new connections in seconds rather than weeks. Additionally, individual service links that fail must be automatically restored to spare capacity in 100-200msec. These network requirements are currently being largely met by electronic core (O-E-O) switches but will likely press the need for all-optical (O-O-O) cross-connects as line bit-rates reach 40Gbit/sec. Among optical switches the most promising technology for achieving a scalable low loss fabric is MEMS [1,2].

There are two emerging approaches to building switch fabrics using optical MEMS. The first is the two-dimensional cross-connect switch first demonstrated by L. Y. Lin et al. at AT&T Research [3]. Here a connection is established from any input port to any output port in a binary fashion, namely the MEMS mirror corresponding to the crosspoint is simply flipped up reflecting the light signal to the correct output port. This approach requires N^2 MEMS mirror elements to construct a single hop strictly non-blocking cross-connect with N ports [3,4,5]. Due to practical yield considerations and MEMS chip fabrication, the largest switch fabric achieved in this one-stage switch is generally 32x32. Although these switches can be scaled, by using multiple stages in a CLOS-architecture for example, this comes at significant costs in power penalties and increased packaging complexity. The primary advantage to the 2D binary approach is the relative simplicity of the mirror control.

The second approach to achieving large scale switching with MEMS is the 3D steered-beam arrangement as shown in Fig. 1 [6,7,8]. Each of the MEMS mirrors can be steered along two-axes much like the macro-sized mirror mounts found in optical labs. An example of this MEMS mirror is shown in Fig. 2. Light propagates from an input fiber port to its uniquely associated MEMS mirror, is steered to the MEMS mirror located on the second array and steered again to the uniquely associated output port. The key advantage of the 3D approach is its scalability to large port counts in a one stage architecture. In addition, the optical path length is reduced which leads to significantly lower losses than in the 2D switch. However, key challenges remain in packaging the optical subassembly and in the control of the MEMS steering system.

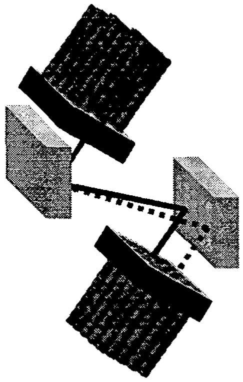

Figure 1: *3D steered-beam optical cross-connect*

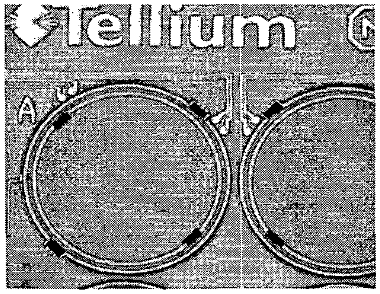

Figure 2: *MEMS mirror used in the 3D switch*

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In the design of 3D-MEMS based optical cross-connects many tradeoffs must be considered between the optical losses, MEMS mechanical design, and control system. For example, the size of the MEMS mirrors is a compromise between minimizing clipping on the optical beam and achieving reasonable mechanical resonant frequencies. To reduce the total optical path it is desirable to have large tilt angles from the MEMS mirrors, however the resulting high voltages (in the typical electrostatic actuation) and increased risk of mirror damage limit the maximum tilts. Furthermore, the mechanical design of the MEMS must accommodate the mirror control system, which needs to achieve mirror movements of hundreds of microradians to maintain the optical connection within the available loss budget.

We consider a typical Z-configuration for a 3D optical cross-connect fabric. In this design the MEMS chips are inclined and located a sufficient distance from each other, so that any one of the input port mirrors can be pointed to any one of the output port mirrors. Applying a physical layer gaussian beam propagation method to model the optical path, we study the required tolerances in assembly and packaging of the optical components by computing the excess loss associated with relative beam deviations from the center optical path. For example as shown in Fig. 3, the excess loss dramatically increases by nearly 3dB as the input fiber is translated from its ideal position in the lateral plane by only 5um. Considering that typical central office loss budgets are ~6dB, this small misalignment is an enormous fraction. Another stringent component requirement is the relative variations in the focal lengths of the lens array elements. As shown in Figure 2, as little as 3% deviation in the focal length of a lens can yield an excess loss of over 4dB for that port.

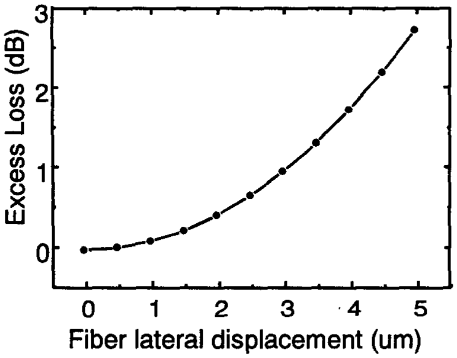

Figure 3: *Losses for lateral fiber position misalignment*

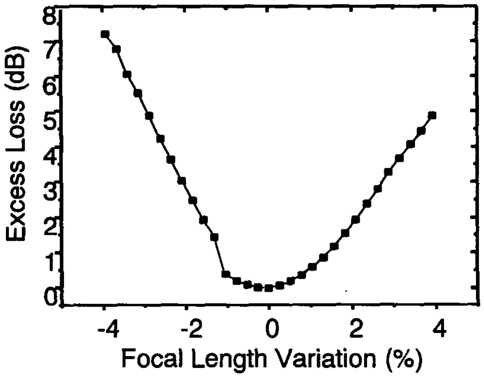

Figure 4: *Losses with focal lengths variations*

These imposing technical difficulties on the critical components in the switching fabric and tight packaging tolerances will make high yields at low losses problematic in the near term. However, as the various technologies and manufacturing processes mature, the unmatched aggregate capacity offered by 3D MEMS cross-connects, in the long-term, will undoubtedly be realized. The rapid growth in optical transport systems accelerated by WDM technologies is presenting exciting opportunities for MEMS in optical switching. These opportunities come hand in hand with many technical and practical challenges.

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