238´238 Surface Micromachined Optical Crossconnect With 2dB Maximum Loss

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Abstract

A fully provisioned 238×238 beam-steering optical crossconnect constructed using surface micromachined mirrors is described. The mean fiber-to-fiber insertion loss of the fabric is 1.33dB and the maximum insertion loss is 2dB.

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Applications for large optical switch matrices include flexible network management for load balancing and traffic routing, rapid deployment of new services, and comprehensive network protection switching and restoration. In the longer term these switch fabrics are critical to Optical Networking: building end-to-end transparent networks. With increasing port count and data rate, electronics based switching becomes increasingly difficult due to the inherent limited scalability of electrical interconnects illustrated by the use of optical interconnect backplanes in many 'electronic' switches. A transparent optical crossconnect (OXC) can be built using micromachines (MEMS) that is not subject to the scalability concerns of electrical interconnects. Additionally, a transparent OXC, since it carries the native optical traffic, will be data rate and format independent.

Scalable micromechanical beam steering crossconnects have been demonstrated previously [1], but exhibited relatively high insertion loss, with a mean of 7.5dB and a variability of ±2.5dB. In this paper, we present a large (238x238) switch fabric having a mean insertion loss of 1.33dB and maximum loss of 2.0dB for all 56,644 connections, as shown in Figure 1. Low insertion loss is important to the success of optical cross connects since it reduces the optical power requirements and hence cost

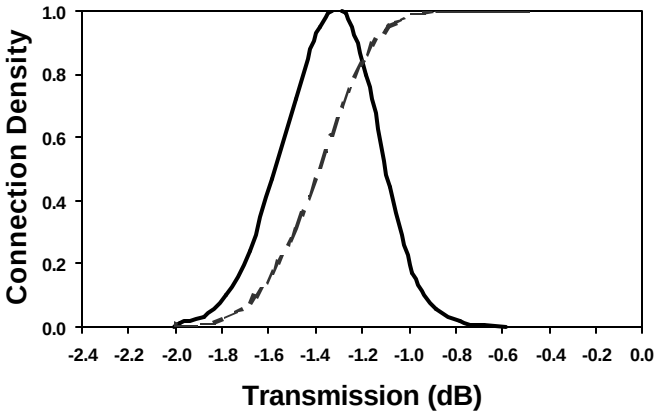

Figure 1: Insertion loss graph for all the connections, and cumulative distribution in the 238x238 OXC.

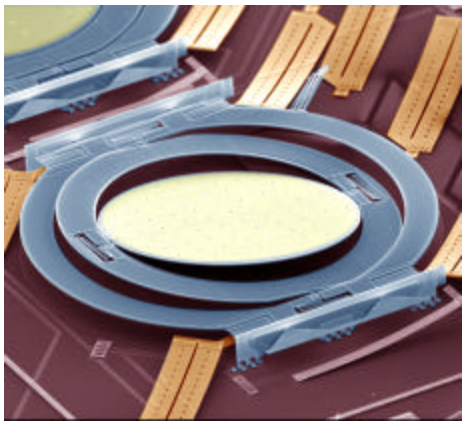

Figure 2 : Two axis beam steering micro-mirror built using surface micromachined technology.

of the transmitters and receivers in the network. As well as low loss, low variability of the loss is also important, so that protection switching between fabrics or connections does not cause significant outages while receivers adapt to varying signal levels.

These MEMS switches have been described as '*exquisite engineering*' by several authors [4-6] who highlight the multitude of technical challenges that must be addressed. There has been debate as to the appropriate MEMS technology to use for OXCs with the assumption that bulk micro-machining [6] is the only way to achieve sufficiently flat mirrors for low-loss fabrics. The switch described in this work utilizes surface micromachined two-axis tilt mirrors [2] similar to that illustrated in Figure 2, which exhibit a curvature-induced loss of <0.3dB. Surface micromachining is an established technology platform with demonstrable reliability [3]. This low-loss cross connect result indicates that the perceived limitations of surface micromachines do not provide a barrier to high performance components suitable for network deployment. The Lucent optical crossconnect network element – the *LambdaRouter*^{TM} All Optical Switch – of which this fabric is the switch core is a NEBS^{TM} level 3 compliant carrier grade switch.

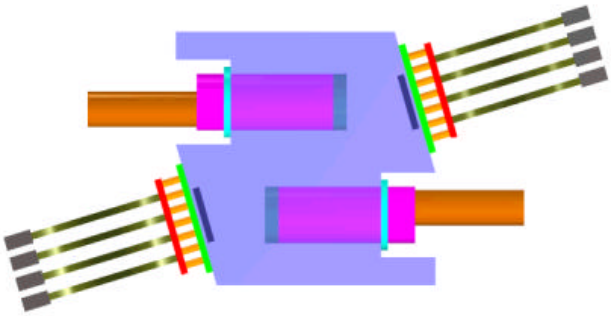

Figure 3: Schematic of OXC Fabric



Figure 4: OXC with 512 LC connectors.

LC Connectors : 0.0dB +/-0.4dB
Microlenses : 0.2+/-0.1dB
Optical Coatings: 0.8+/-0.1dB.
Mirror Curvature : 0.2+/-0.1dB
Beam Clipping: 0.1+/-0.1dB
Total Loss: 1.3dB +/- 0.6dB

Table 1: Break down of loss and loss variability for the MEMS fabric.

It is recognized that suitable micromachines alone are not sufficient to provide low loss switch fabrics [4-6]. The optical system design and optical component performance play a significant role in achieving consistent low loss. The skew angle and angular range must be kept small, <30° to avoid large polarization dependent loss (PDL) that can arise from large angles of incidence on metal mirrors [7]. It is also important to choose a design, which minimizes path length variations and any resultant loss variations. The PDL of the fabric is <0.1dB and the optical cross talk is <-40dB, and there is no measurable path length loss variability (<0.05dB).

Two fiber arrays with collimating microlenses attached are used to project and receive beams from two 2-dimensional arrays of two-axis electrostatic micromirrors, schematically shown in Figure 3. In order to obtain a low-loss system it is necessary to have microlenses with very low aberrations (~λ/10), low wave front errors across entire arrays and high focal-length uniformity (~1%). The array of etched microlenses has losses from 0.1dB to 0.3dB, comparable to

the best individual collimators available today. The breakdown of the sources of loss in the fabric is indicated in Table 1.

One of the significant issues relating to the fabrication and test of low-loss fabrics is the variability of connectors in the test equipment, as well as the connectors on the switch fabric itself, see Figure 4. The use of LC connectors in the fabric and test set results in a +/-0.4dB variability of which only +/-0.15dB may be attributed as being intrinsic to the fabric. This variability has been verified by measuring the fabric on multiple test sets. The measured loss distribution can be de-convolved with the test set variability to give a better understanding of the actual intrinsic loss distribution associated with the MEMS fabric. This distribution is shown in Figure 5, and indicates an intrinsic switch loss of 0.95 to 1.75dB i.e. ±0.4dB variability across 56,644 connections.

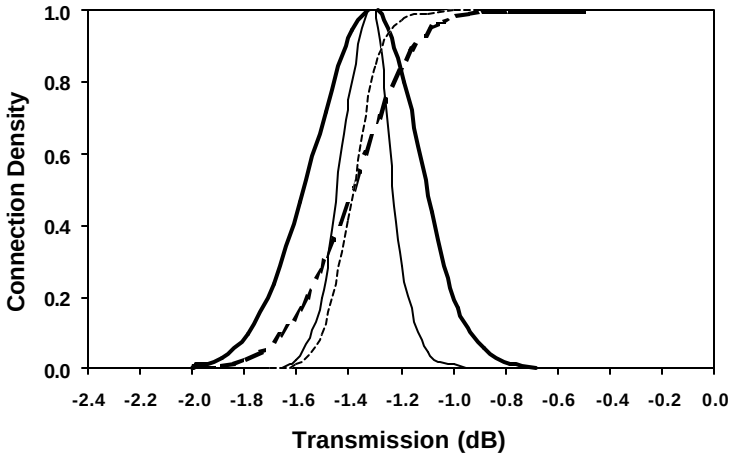

Figure 5: Measured loss distribution (thick) and statistically de-convolved loss distribution (thin) of switch fabric. Cumulative distributions are also shown (broken lines)

In summary, we report the lowest loss MEMS-based optical cross connect to date with a maximum fiber-to-fiber insertion loss of 2.0dB. This low-loss fabric was demonstrated using surface micromachined two-axis tilt mirrors.

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