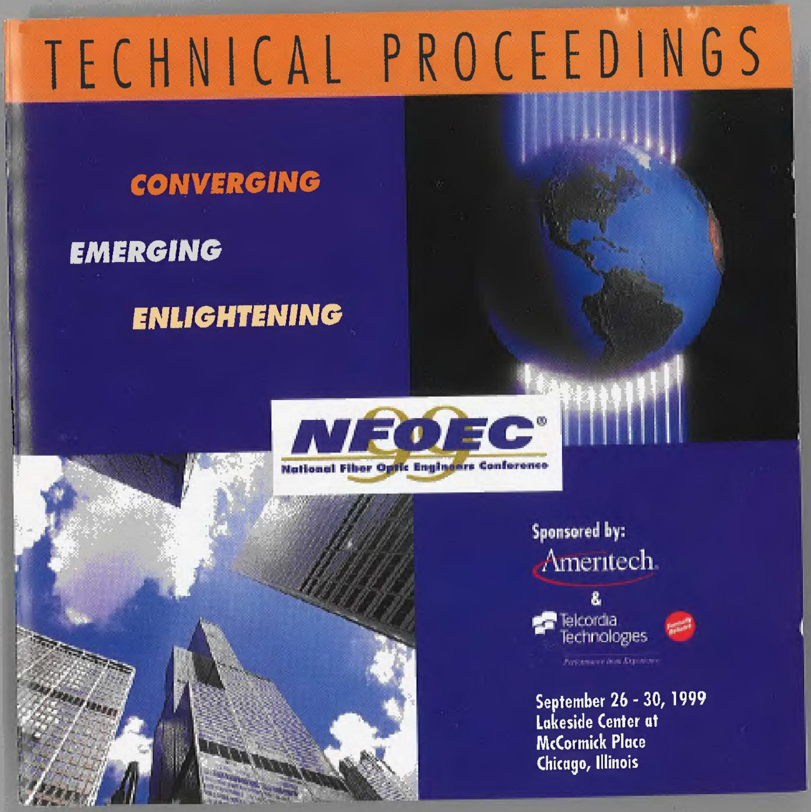

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PERFORMANCE OF A 576x576 OPTICAL CROSS CONNECT

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Abstract

Fiber has been used in the transport of information for over two decades. Over this period the performance of optical transport equipment has skyrocketed while its cost has spiraled down. This has led to the proliferation of fiber in long haul, local, and private networks, and even the appearance of fiber connections to the home or desktop. The recent rise of Dense Wave Division Multiplexing (DWDM) technology added multiplexing and demultiplexing functions to the use of photonics in communications. The next challenge for photonics as we move toward all optical networks is optical switching.

Evolution towards all optical networks necessitates switching equipment that can operate on any rate and format of optical transmission without hardware changes. Such protocol transparency simplifies the network management task. Switching large numbers of fiber optic signals at the photonic level eliminates expensive conversion and switching electronics. This ability to create end-to-end optical channels fuels wavelength routing applications. Until recently, optical switching technology with this capability and capacity was unavailable. Texas Instruments and Astarte Fiber Networks have developed high port count, transparent optical switching technology that is now in evaluation. This paper describes the architecture, components, and operation of this optical switching technology and provides initial test results.

Introduction

The typical central office has thousands of fibers to manage with each fiber capable of carrying millions of dollars worth of traffic each hour. SONET is the most prevalent optical protocol in use today, but other protocols such as optical IP are growing in popularity. Switching equipment used to manage these fibers must have the flexibility to effectively handle any traffic protocol in order to minimize the burden on network management systems. In addition, as transmission speeds increase optical switching equipment should continue to operate without the need to 'forklift upgrade' the switching equipment. Only transparent optical switching equipment has the ability to continue to function normally as rates and formats change or as DWDM migrates into a network.

Network reconfiguration and service provisioning are two areas where a large transparent optical switching system can provide immense benefits in optical networks. For network reconfiguration applications a large optical cross connect (OXC) is located at each hub. Each cross connect is controlled by a management system in a coordinated fashion to create fiber or wavelength connections throughout the network. Since the network can carry multiple rates and formats of optical signals the cross connects must be able to switch any type of optical signal that may traverse the network.

Service provisioning places the OXC in a central office to manage the fiber connections to the outside world. The OXC switches fiber connections to circuit switches, electronic cross connects, ATM switches, or even optical IP switches. In this situation the OXC is likely to see frequent configuration changes as customer services churn. Protocol transparency in this application provides the ability to carry various rates and formats as customer needs require.

System configuration

The OXC developed by TI and Astarte is a free space, single stage, strictly non-blocking, transparent, matrix optical switch capable of supporting 1152 fibers. Figure 1 illustrates the general architecture of this OXC. For illustration purposes Figure 1 is simplified to show only sixteen fibers. The illustration shows fibers (on the left) coming into an array of switch actuating modules. Each of these modules represents an electro-optical assembly that is capable of focusing, and accurately controlling the deflection of a light beam coming out of a fiber. All modules face a mirror which turns all optical beams back toward the array of modules. By varying in two axes the deflection angle of a beam coming out of any switch-actuating module, the beam can be aimed at any other module. If the second module is also aimed correctly an optical connection is created between the two modules.

The figure shows three optical connections. Since the beams are projected through free space, a beam can freely cross any other without effect. New connections can be created without any impact on existing connections. Every connection involves only two switch actuating modules. This single stage switch architecture means signal attenuation is low and consistent. Once a connection is established between two modules, any optical signal on one fiber is carried through the switch to the other fiber, bidirectionally, without regard to the rate, format, or protocol of the signal. DWDM signals can be switched very cost effectively as a group or demultiplexed outside the switch and switched individually. With 1152 fibers, 576 connections can coexist on the OXC.

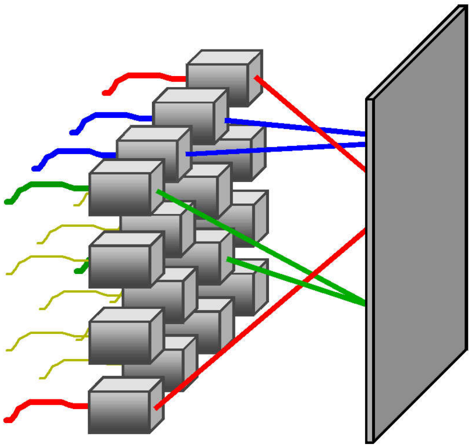


Figure 1 – The OXC architecture showing three simultaneous free-space optical connections

A unique characteristic of this OXC architecture is its modularity. This modularity allows craft to perform board-level replacement of any failed module in-service, as well as the ability to partially equip an OXC and add additional modules as needed.

Also unique to this OXC architecture is the redundancy built into the system. Redundant main processors handle all communications within the OXC, and to the network management system. Two redundant power supply units power the OXC. The processors and power supplies are hot-swappable. Connection commands are generated by the OXC main processors, and downloaded to a Digital Signal Processor (DSP) within each module over redundant communications channels. Each module is then autonomous in performing and maintaining the commanded connection. Rearranging any number of connections does not influence existing connections in the OXC.

The Optical Path

The optical path, representing a connection through two modules, is shown in Figure 2. Light from a fiber passes through a focusing lens. The light is reflected off a fixed mirror which folds the beam to keep device packaging small. It is then reflected off a movable mirror which precisely directs the beam in two axes.

To make an optical connection between modules the moveable mirror directs the beam directly at the moveable mirror of a targeted second unit. At the same time the second unit controls its moveable mirror to deflect the beam toward its fixed mirror, into its lens, and then into its fiber completing the connection. It is the coordinated control of deflection angles by the two moveable mirrors that creates the optical connection between two fibers.

Clearly, if the second mirror is not positioned to deflect the incoming beam to the precise angle where the beam will enter the fiber then no connection will be made. For this reason, a free space beam moving within the switch cavity, which traverses other units, will not induce a crosstalk signal with any other connections.

It should also be noted that the optical path is the same from right to left and left to right. Therefore the optical path through any two modules in a connection is bidirectional. The optical path is the same for every possible connection in the OXC resulting in minimal and consistent optical attenuation in this single stage architecture.

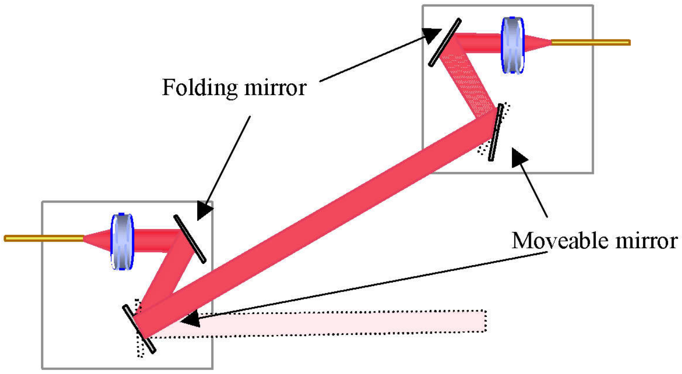


Figure 2 – The optical path through two modules in the OXC

To precisely control the position of the beam with the moveable micromirror, a closed-loop servo control system is employed. This servo control system enables each module to locate and identify an opposing module for targeting. With this control system the moveable micromirror can precisely position the beam on the fiber core and hold it there. This active positioning system provides high optical coupling efficiency into the fiber and protects the optical signal against vibration and drift.

Optical Module

In its physical implementation each optical module supports two fibers, as illustrated in Figure 3. This allows a transmit/receive connection to be configured within the same module simplifying fiber management. A DSP on each module handles communication with the main processor and manages servo control operation for both micromirrors. Once the main processor has communicated connection commands to a module, that module is autonomous in control of the beam position and maintenance of an optical connection. Redundant power supplies and communication paths are provided to the module, and the module is designed to be hot-swappable.

The switch module contains electronics to operate the two actuators that handle the optical signal. One of these actuators is illustrated in Figure 4. This optical switch actuator assembly contains all the optical components: the single mode fiber, a lens, folding mirror, moveable MEMS mirror and several detectors and emitters for the servo system.

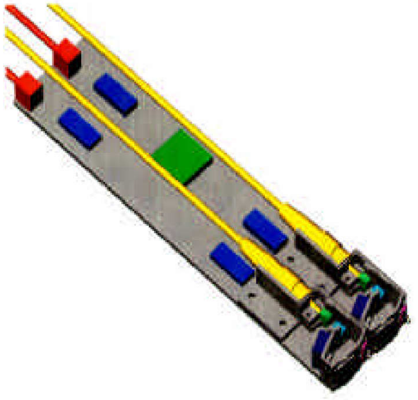
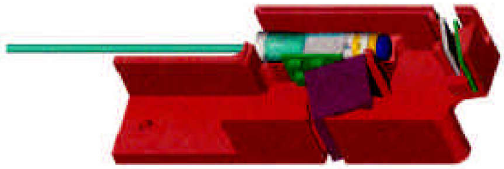


Figure 3 – Illustration of an optical module showing two fibers and redundant communications cables

Figure 4 – The switch actuator assembly containing all the optical components of the OXC.



The moveable micrormirror contained in the actuator assembly is fabricated using Micro Electro-Mechanical Systems (MEMS) technology. This micromirror is electro-magnetically controlled and capable of two-axes movement. Texas Instruments developed this MEMS device specifically for application in the OXC. It provides extremely low optical loss, and the high reliability and switching speed required for OXC applications. The MEMS device is in a sealed package. These devices have been tested for the equivalent of hundreds of millions of switching operations.

Test results

Texas Instruments and Astarte have built prototype hardware as a vehicle for evaluating the performance of the OXC architecture. The fiber in use in the OXC is singlemode. The design of the transparent, single stage, switch architecture means the ability to carry all optical signals with wavelengths from 1250 nm to 1700 nm.

With its closed loop servo control systems the demonstration hardware is able to control the beam within 0.5 microns of the center of the fiber core. This precision results in a measured fiber-to-fiber optical connection with 4.8 dB of optical loss.

The other optical performance parameters are consistent with expectations for a single stage, free space optical switch design. Back reflection typically is less than –40dB. Optical crosstalk typically is less than –80 dB. Polarization dependent loss (PDL) is measured at less than 0.5dB which is at the noise level of the measurement. Dispersion through a switch optical connection is so low that available test equipment cannot provide a reliable measurement.

The worst case switch time with the architecture of this OXC occurs when a module is requested to switch from a connection at one corner to one at the diagonal corner. This worst case switch time is 10 milliseconds from the time the switch command is received at the OXC. Because of the autonomous operation of each module in the OXC a complete switch configuration can occur in the same 10 milliseconds.

Conclusions

This paper describes the architecture of a large, central office class, optical cross connect. This OXC is a free-space, single-stage, strictly non-blocking, transparent, matrix optical switch capable of supporting 1152 fibers. Test results presented verify the excellent optical performance of this switch architecture. The unique redundancy and modularity of the OXC architecture is further support for the suitability of this design in carrier networks.

The OXC technology presented in this paper has been successfully demonstrated with engineering models. The initial implementation of this OXC architecture has been developed to produce a 576 x576 OXC for network restoration and service provisioning applications. Other configurations can be achieved with the same basic technology. Smaller OXCs accommodating 72, 144 or 288 modules, providing 72x72, 144x144 or 288x288 connectivity can be produced. All these smaller OXCs would retain the full modularity designed into the larger unit and will use identical modules to the ones used in the 576x576 OXC. Larger OXCs of 2,000 x 2,000 to 10,000 x 10,000 can also be developed from the technology described in this paper. These immense OXCs would use the same basic technology with second-generation components to provide increased fiber switching density.

The OXC presented in this paper will provide the final piece of photonic technology necessary for construction of effective all optical networks.

References

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