Optical switch port density for major Metropolitan areas

SWITCHING THE Lightwave

OXC's - The Centerpiece of all Optical Network

UPDATE - 2001

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Summary of Concepts

This chapter offers the reader a quick overview of the contents of this report. These entries are taken directly out of the text of the report. No effort has been made to provide continuity between the thoughts, as that is one of the jobs of the full text. Since these are the fundamental concepts, they have not changed in this update.

The great national and international carriers have built fiber/DWDM networks that promise (and deliver) bandwidth that was only dreamed of two or three years ago. Now the issue is learning that QoS involves more than electrical and optical parameters. It also involves service flexibility, rapid provisioning, rearrangements, and the ability to support new, 'on-demand' services. – Introduction

What is left, however, may be an even greater problem. The question is how to deal with all of this added bandwidth and how to deal with the rapid changes and rearrangements implied by a market growing this fast. – Introduction

'OXC' is a broad term denoting a class of optical devices (and opto-electronic – called OEO devices) that allow a flexible interconnection of lightwaves. These are variously called "Optical Switches," "Optical Routers," "Optical Cross-Connects," and a number of combinations of these and proprietary names. – What Are OXCs?

The original justification for the DACS was to replace the ever-expanding DS-1 cross-connect bays (DSXs). As DS-1s and then the higher layer services became the backbone of the electrical telecommunications world, these physical patch panels became completely unmanageable. It will be seen that this is the same basic driver for the application of OXCs. – What Are OXCs?

OXCs can be thought of as the direct optical equivalent of DACS (digital cross-connect systems) that have been used in the electrical environment since the mid-1980's. – What Are OXCs?

Switches are fundamentally very simple devices, with no intelligence of their own. The application of these simple devices with various kinds of intelligence added gives rise to the array of things that we often ambiguously refer to as 'switches.' – What Are OXCs?

Given all of these considerations, it is projected that OXCs will be both the enabler of, and a major reason for a migration to, an "all-optical" network. – What Are OXCs?

Qwest estimates that the new network will achieve up to 70% savings in operating costs and reduce provisioning cycles by up to 95%. – What are OXCs?

OXC devices depend on a number of technologies to achieve their switching functions as follows (the first of these is known as an 'Opaque Switch' – the light doesn't go through it – and the other three are known as 'Transparent Switches" – the light goes through them). – Technologies

It should be noted that, although some of the press coverage would seem to suggest otherwise, transparent switches are not inherently better than opaque. Like most other technology choices, they each have their advantages and disadvantages. – Technologies

The issue of loss in the use of transparent switches is often misunderstood. The use of transparent switches in 'all-optical' networks can easily be (mistakenly) thought of as a transmission advantage, and the press sometimes misleads us to think this is the case. Transparent switches are the source of optical signal loss in the calculation of the optical path budget. – Technologies

Thus, there are two insertion loss problems, the combination of routes that have been individually engineered, and the loss of the transparent optical switch itself. –Technologies

In order to be able to achieve the functionalities described above for the WIXC, i.e., to be able to switch and translate wavelengths, it is necessary to have a device integrated into the OXC that is capable of translating from one wavelength to another, and to change the 'translated to' wavelength very quickly. –Technologies

As DWDM technology has gained a strong foothold on the backbones of the world's transmission markets, the 'backbone bottleneck' has begun to be eliminated. While this vast increase in transmission capacity has solved one problem, it has also created another problem in the area of control. – Applications
The OXC is beginning to also have significant 'offensive' potential. This comes from being able to offer existing services (bandwidth), but doing it in dramatically different ways, resulting in new services.
- Applications

As discussed in the Technology Section, there is a methodology of defining OXCs by class – FXC, WSXC, and WIXC. By reviewing how each of these may be used, we will be able to illustrate several major applications, and further draw the differences between these classes. – Applications

In summary, the OXC approach is cheaper, offers much greater flexibility, and is faster for making rearrangements. – Applications

Naturally, one of the fundamental uses of OXCs is circuit routing. In fact, one can think of all of the other capabilities as special cases of circuit routing. – Applications

The question with this service provider, was how he would expand his business after establishing the IP rings in the six cities he planned to serve. – Applications

Optical switches can be used in conjunction with routers to achieve the protection desired (actually much faster protection, because it is in the optical domain and it is pre-configured), while reducing the number of expensive router ports needed. -Applications

The growth of the Internet is a major driver and certainly the most important of the market drivers. In fact, it could be said that the other drivers are really just subsets or derivatives of the Internet growth. So how much and how fast is the Internet growing? – Market Drivers

While this is a fairly conservative estimate for the growth of the Internet, it still results in a network requirement in just five years for an infrastructure that is close to 15 times larger than today's PSTN. It should be noted that the above projection would suggest a backbone traffic load of approximately 30 terabits in the busy hour in 2004. – Market Drivers

Although it is somewhat of a second-order effect, another driver (or maybe an indication of a combination of other drivers) is the increase in the number of wavelengths at junction points. – Market Drivers
To understand the magnitude of these possible savings it should be remembered that, Qwest estimates that

the new network will achieve up to 70% savings in operating costs and reduce provisioning cycles by up to 95%, largely through the placement of OXCs. When this savings potential is fully understood by the carriers of the world, there will be a very strong market in OXCs. – Market Drivers

Almost all the usual forecasters predict this market will boom. It is felt (and this thought is expanded in the material in the related section of this book) that the vast increase in the quantity of wavelengths will drive the market for control capabilities. – Market Projections

Using this model-driven approach to the market, the total is the sum of the local model results plus the IXC model. This addition will present the total market projection for OXCs over the five-year timeframe.
– Market Projections

It appears that the market is going to be competitive enough to achieve a very close grouping of prices for both technologies. – Price Projections

OXCs – The Centerpiece of the All-Optical Network

Update Introduction

This original report was issued in November 2000. Much of the technical and architectural material is still accurate and current, but various areas of the report need updating. The purpose of this update to the original report is to bring those areas up-to-date, and to add new information that has developed. The approach to presenting this material has resulted in a completely stand alone document. The original format and organization is preserved, however, the introduction of each chapter will describe the changes made in the update. In most cases this will allow the reader to readily see the changes made from the original report. It is thought that this capability will be most useful in the forecast area. This paragraph is the only change in the Introduction.

Introduction

DWDM has brought us the answer to the need for massive amounts of bandwidth, across the city, across the country and now across the world. The need for this bandwidth has been, and continues to be, driven by the emergence of the Internet as the single most significant development in the history of communications. This ever-increasing demand has changed the whole approach to facility and even route provisioning. Bandwidth increments (e.g., OC-48) that would have been the entire cross-section on a given route only two or three years ago, are now not even provisioning interval increments.

We Had a Bottleneck; Now We Have Gridlock

While DWDM has given us the tool to deal with this bandwidth explosion, it has not given us a way to be able to control this massive amount of bandwidth. We were looking for a way to keep up with the unending demand for bandwidth as presented by the Internet and we found it in DWDM. Some of the carriers (AT&T, for example) are estimating that their backbones are increasing at a rate of 400% a year! Trying to keep up with that growth, both the existing growth and the forward looking view of a really scary "hockey stick" growth curve, was the first problem. Now, we can take existing fiber (at least to a great extent – some of the older fiber may not support all of the capabilities of DWDM at all distances), add DWDM and we have an instant increase in bandwidth of up to 100 times. So, that solves the bottleneck problem, at least for now.

What is left, however, may be an even greater problem. The question is how to deal with all of this added bandwidth and how to deal with the rapid changes and rearrangements implied by a market growing this fast. In addition to the growth, and the implied amount of churn (in a market growing like this, the end customers are also in turmoil, trying to devise the best way to deal with growth from their viewpoints, thus causing many change orders to bandwidth providers), the network is largely stuck with an architecture that was singularly unfitted to rapid changes and additions – i.e., SONET. To establish a new wavelength on SONET-derived facilities (SONET on DWDM or SONET directly on fiber), it is often necessary to make physical equipment additions and changes at many nodes – particularly where rings intersect. The additions and changes require significant engineering, equipment procuring, site visits, and carefully coordinated testing and turn up activities. As a result of all of this work, provisioning intervals stretch into many months and service costs continue to be very high in spite of decreasing costs of underlying infrastructure. These factors have all combined to lead us from a bandwidth bottleneck to a gridlock glut – we have a great deal of potential bandwidth, but it is very hard to effectively use it.

The great national and international carriers have built fiber/DWDM networks that promise and deliver bandwidth that was only dreamed of two or three years ago. Now the issue is learning that QoS involves more than electrical and optical standards. It also involves service flexibility, rapid provisioning and rearrangements, and the ability to support new, 'on-demand' services. These are the qualities that will support the new strategies of service providers in the era of IP, the Internet, B2B, etc. They are also the parameters that will turn all of that bandwidth into useful and marketable services.

The answer that is developing to this gridlock glut, is the Optical Switch (OXC.) This new (new in these sizes and with the capabilities now becoming available) device will (1) allow extremely rapid service provisioning and rearrangements, (2) facilitate mesh topologies that more directly support data traffic and that can save on equipment, facilities, and operations costs, (3) provide an extremely fast optical level circuit (fiber/wavelength/route) restoration capability, and (4) support new services on a wavelength level based on rapid and remotely controlled switching.

This report will explore this new device in depth. It will: develop a basic understanding of OXCs, explore all aspects of the technology, review applications, evaluate market drivers, project market demand and prices, and describe available equipment and vendors.

Except where specifically noted differently, this report deals with existing, available (or nearly so) technology for OXCs. The current versions of the OXCs are primarily "dumb" switches. Some vendors (particularly some of the OEO switch vendors) are adding significant software to the peripheral control systems allowing some very useful (and in some cases spectacular) services. However, the switches remain fairly dumb. The Applications, Market Forecasts, and Pricing Forecasts are all based on these comparatively dumb systems.

Future development will be focused on two major areas:

1. Producing all-optical switches fully capable of WSXC and WIXC classes of operation. (See the Technology Section for a full discussion of these classes.)
2. Incorporating true optical router capabilities, whereby the OXC will actually be able to parse the incoming optical signal and perform a switching function based on this information in real (or very near real) time.

The first of these will be commercially available in the next few years, and the second will likely take longer.

What are OXCs?

Update Statement

There are no changes in this chapter.

'OXC' is a broad term denoting a class of optical (and opto-electronic – called OEO) devices that allow a flexible interconnection of lightwaves. These are variously called "Optical Switches," "Optical Routers," "Optical Cross-Connects," and a number of combinations of these and proprietary names. The level of flexibility, the underlying technologies used, the amount of electrical involvement, and the allocation of intelligence all determine the precise OXC use and classification. In this report, we will investigate each of these and the impact each has on OXC use, and the OXC market.

OXCs are relatively old devices (in terms of Internet time) in that they have been a long-time internal component of most DWDM terminals. In this application they are very small, simple devices that are connected to detectors (that detect a change in a SONET signal or detect the loss of a light signal) that cause the OXC to switch between fiber paths for restoration or maintenance purposes. The devices and applications discussed in this report are all, more or less, derivatives of this simple function.

OXCs can be thought of as the direct optical equivalent of DACS (digital cross-connect systems) that have been used in the electrical environment since the mid-1980s. DACS are used as a replacement for the old physical patch panel, providing a "point of flexibility" among many physical facilities, devices, and routes. DACS are used to cross connect SONET signals (originally they were used to connect asynchronous signals, e.g., DS-1's, DS-3's, etc.) of various levels. This report will examine the various technologies, applications, and approaches for these devices.

When is a Switch Really a Switch?

If one thing is clear from the above, it is that the vendors have done us no favors in clarifying the nomenclature for these devices. After discussing the generalities of the answer to the question of "What is an OXC?" it will be instructive to review various devices often lumped in to the category of "switches," and their differences. A review of general definitions for each of the relative devices will help explain this situation.

"Switch" Types

Switches are fundamentally very simple devices, with no intelligence of their own. The application of these simple devices with various kinds of intelligence added gives rise to the array of things that we often ambiguously refer to as "switches." We shall consider these devices beginning with routers, the most intelligent, and ending with DACS, the least intelligent.

Routers

Routers have internal switches that are controlled by integrated "rules" tables. These are the most intelligent of all devices considered here. A router is a network device that uses Layer 3 of the OSI (Open System Interconnect) Model (the IP layer) to obtain the intended destination of an IP frame. It then uses this destination address to run against an internal look-up table to determine how the frame should be forwarded. Routers are "intelligent" elements because of the look-up tables that they contain. These tables can be formed by outside input (e.g., by a system administrator) or by special protocols that allow routers to be "network sensitive." This means that they can "learn" about the environment of the network in which they exist, and they can adapt to changes.

A router obtains the destination address by parsing IP frames down to the Layer 3 addressing information. It then uses this information to forward the frame. While it is looking up the port address for forwarding, the data frame is buffered in the router.

Like IP switches, routers do not hold a circuit, or really use the concept of a 'call.'

TDM Switches

TDM (Time Division Multiplex) switches include the POTS (Plain Old Telephone System) voice switches. They have address signaling (the 'called to' number) information provided with each call. This signaling information drives the switch (in the pre-electronic days – ancient history in Internet time – the switch was directly driven, a digit at a time) to make the appropriate connection to the desired party. The switch holds a path (a time slot) dedicated to that call for the duration of the call. The modern, electronic, stored program switch can use extensive routing functions to direct calls on the paths most likely to connect, and can retry if they run in to blockages.

ATM

ATM switches are in many ways a cross between TDM and IP switches. They use the Header information (like IP switches) to establish a path that is held for the length of the call (like TDM switches). Asynchronous Transfer Mode (ATM) actually uses a synchronous form of transmission, in that it continuously transmits cells of a constant size in a fixed relationship to each other. However the way the cells are assigned to user traffic is on an "as required" basis, (rather than on a fixed basis as is the case in SONET), thus it is characterized as 'asynchronous' as related to the end user.

As mentioned, ATM uses a cell concept in transmitting data. The cell size is fixed as the SONET frame is; but it is much smaller. If only a small amount of data is to be transmitted, then a partially filled cell is not much (at least not as much as with SONET) of a penalty because the cells are relatively small. Also, the cells can be interleaved so that virtually any size bandwidth requirement can be achieved by simply transmitting more cells. Thus ATM was perhaps the origin of the 'bandwidth on demand' idea.

Although the ATM specifications allow for handling connectionless (i.e., messages sent without establishing an end-to-end connection), or connection-oriented traffic (i.e., an end-to-end circuit is assured and reserved before traffic is sent), it is a connection -oriented protocol. It is this characteristic that provides ATM with one of its most important assets - the ability to (before the fact) guarantee quality of service (QoS) to a given call for its duration. An end-to-end virtual circuit is established and reserved for the duration of the transmission based on a 'class mark' indicating the quality of service the given call is entitled. QoS is defined specifically in a number of ways (usually in terms of bit error rates or lost bits) depending on the provider of the service, but it always relates to the reserved bandwidth and delay of the virtual circuit provided to a given service.

ATM is a transmission and a switching method that is based on packet techniques, but as noted above, it uses fixed cell lengths of 53 bytes. These cells are composed of 5 bytes of header (containing address, and housekeeping information) and 48 bytes of payload (only 44 for some cases of traffic) that gives an overhead loss of at least 9.4%. The transmission portion of ATM corresponds fairly closely to the Layers 1 (physical) and 2 (Data Link) of the OSI Model. Some authors note that ATM also provides some of the higher Layer (OSI Model) services.

IP Switches

IP switches use the IP (Internet Protocol) header information to forward each packet to the next node. There is no concept of "circuit" or "call" involved in this transmission, but merely the forwarding of packets of information from node to node until the data reaches the destination node. Ethernet switches work in the same manner, except that they use the information in the Ethernet header (Layer 2 of the OSI model) rather than the IP information (Layer 3) to determine the forwarding of the data packet.

DACS

DACS are the least intelligent of the devices using switches. The detail that follows was previously presented, but is repeated for completeness. DACS are used as a replacement for the old physical patch panel, providing for a "point of flexibility" among many physical facilities, devices, and routes. DACS are used to cross connect SONET signals (originally they were used to connect asynchronous signals, e.g., DS-1's, DS-3, etc.) of various levels. These interconnections allow:

- Maintenance functions (turning down a route to allow equipment replacement or testing, for example);
- Facility rearrangements;
- Access to test equipment on an automated basis
- Restoration functions by having a preprogrammed response to the loss of a particular facility, route, or device;
- Service establishment and pre-testing by reconfiguring to a given service arrangement at a particular time;
- Service design by providing, for example, voice circuits during the day on one route and then switching at night to provide a broadband data route.

DACS do not use address signaling at all, and they do not have a call concept. They are primarily static devices. However, as can be seen from the listing above they have a very dramatic role in the electrical telecommunications network.

OXCs – The Centerpiece of the All-Optical Network

The original justification for the DACS was to replace the ever-expanding DS-1 cross-connect bays (DSXs). As DS-1s and then the higher layer services, became the backbone of the electrical telecommunications world, these physical patch panels became completely unmanageable. It will be seen that this is the same basic driver for the application of OXCs.

Drivers to DACS Deployment

What had originally been contemplated as a bay (the DSX bay) that would allow easy access for making needed changes, had become in itself a major source of trouble. DS-1 (and later DS-3) became the common denominator for everything in the telephone office. Switches, facilities, remote terminals, and other devices all interfaced at DS-1. To allow for flexibility it was necessary to terminate all of these devices on the DSXs. As time went on, these panels built up layers of jumpers. Making a change was as likely to cause a fault, as it was to achieve the desired change. In addition, as new services, particularly of a wideband nature, developed, they required changes more or less simultaneously at many nodes in the DS network. This meant expensive visits to these sites, and a real effort to make all of the changes on a coordinated basis. The result was that the services were very expensive to provide, and very slow to implement.

DACS were the answer to this problem. While the layers of jumpers continued to increase, once in place, they no longer had to be moved. The DACS could achieve all of the necessary changes without moving any of the jumpers, or even touching the jumpers. They could also do this under remote control, automatically and on a perfectly coordinated basis over very wide geographic areas. They eliminated the physical problems; dramatically reduced the time and cost impacts; and made feasible new services and restoration capabilities.

The Parallel Universe of OXCs

Now we have come to a time with DWDM when wavelengths are terminated at multiple nodes in nationwide ring-based architectures. The growth of the Internet has driven traffic on the DWDM backbone routes so that at a minimum they are doubling every year and at the highest estimates are increasing by 400% a year. End customers are requiring wavelength services to keep pace with their own demand. To implement a new wavelength (or to reroute one for a new service), requires visits to each of the nodes. It also requires carefully coordinated (both in time and as to the types of changes) steps at the many nodes. All taken together, these impacts are causing delays of up to 6 to 8 months to provision a wavelength service. In addition, the costs of the provisioning process are such that a service with intrinsically very small marginal costs in terms of equipment, is still very expensive because of the difficulties in providing the services. Testing is also very difficult because it generally requires that an OTDR (optical time domain reflectometer) be transported to the appropriate node location, and physically connected to the appropriate fiber.

If this situation sounds familiar to the scenario that was the driver of the DACS deployment a decade and a half ago – it is. It is the same set of circumstances. The answer this time will be the OXC – the optical switch. We are already seeing major service providers taking steps to move in this direction. Witness Qwest's announced (January 2000) plans to overbuild its entire network with an all-optical solution. If one looks carefully at this announcement (which is remarkable in light of the fact that it came almost immediately on the heels of Qwest completing its existing network), it is clear that the main thrust is an attempt to achieve operational improvements by going to a network that is controlled by OXCs. In fact, Qwest estimates that the new network will achieve up to 70% savings in operating costs and reduce provisioning cycles by up to 95%. Several other carrier companies including Williams, Extant, Broadwing, and Global Crossing have subsequently announced similar plans.

OXCs can solve all of the problems outlined above and can make new services and applications possible. In addition, they are likely to be cheaper than alternatives.

In addition to solving the operational problems associated with the quantity issue, OXCs promise to offer an elegant solution to the quality problem of an all-optical network. In today's world, restoration (for facility or component failure) is almost exclusively handled by the APS (Automatic Protection Switching) features of SONET. In an all-optical network SONET rings may not be an available answer and that architecture may not be the most appropriate for data – the vast majority of the traffic load on our developing networks. In this coming world, a mesh architecture is the best answer for the data traffic, but there is a question as to how to achieve the protection function. This can be achieved with OXCs with pre-programmed failure reaction scenarios. (It is also possible, to some extent, for OXCs to react to failures on an "on-the-fly" basis, but that is not going to be the primary method for the near term.)

In addition to providing a more appropriate architecture for data, mesh promises to be a more economical approach to failure protection, due to its ability to share protection routes, rather than having 100% protection bandwidth, as is the case with traditional approaches. Studies have suggested that optical switches and mesh architectures can achieve as great as 50%-60% savings in capital costs over the traditional SONET ring approach.

Given all of these considerations, it is projected that OXCs will be both the enabler of, and a major reason for a migration to, an "all-optical" network. (It will be seen, however, that "all-optical" may not always mean only optical as we go forward in this report.)

General Features of an OXC

Having looked at a working definition of an OXC, we would now like to present a general list of basic requirements for OXCs. It will be clear as we go through the Technologies Section, that applications and technical approaches will cause differences in emphasis on various of these requirements, however the list will still be instructive to use as a future yardstick.

An OXC is a device that allows a given number of optical inputs to access a selection of optical outputs. These inputs and outputs may be wavelengths or fibers (with multiple wavelengths.) General requirements:

Reconfigurability – Maybe this goes without saying, but it should be stated. It just means that the switch can switch inputs to outputs, under external control.

Nonblocking – These network devices must be able to terminate and switch all of their inputs to an available output under all circumstances. There is no room for a 'busy signal' in this kind of switching.

Scaleable – In backbone network applications particularly, this is of great importance. No carrier wants to face the prospect of having to make a 'fork lift' replacement of a device like an OXC with so much traffic going through it. Devices that start at only 32 x 32 must be able to scale at least to 1000 x 1000 (in backbone applications), given the current and projected growth rates of the network.

Low Insertion Loss - This refers to the optical insertion loss (i.e., the attenuation of the light.) We will see in detail later the reason for this requirement, but in general, it is obvious that it is desirable for any light path element to have a low loss characteristic.

Low Crosstalk – Again, this refers to an optical signal impact. If crosstalk is too high between any two internal paths, the signals will be degraded, and perhaps unusable.

Fast Switching Time – In many of the applications of OXCs the switching time is of most importance. An example is in restoration applications. The total time on restoring a failed link must be no greater than 50 ms (based on SONET standards). Thus, the time for the OXC to internally switch must be as small as possible so as to be able to meet this standard.

Low Cost and Reliable – These devices will be central to very high capacity network points. In order to achieve their greatest usefulness, they must be relatively cheap. Also, because of their central location, it is imperative that they be virtually fault free (internally).

Technologies

Update Statement

This section is revised extensively in that the lists of vendors are completely revised. The status of ownership of the companies, the status of products and the latest products are all areas of revision to these lists. The descriptions of the basic technologies remain unchanged. In addition this section has been updated to include a discussion of OMO (optical – millimeter wave – optical) switches, and of 1 D (one dimension) technology.

Underlying Technologies

OXC devices depend on a number of technologies to achieve their switching functions. A major grouping of these is as follows

> **Electronic Crosspoint** – The most prevalent, to date, uses an internal light-to-electrical conversion prior (and back afterwards) to the switching function.
>
> **MEMS** – Micro electro-mechanical systems – mirrors - these are arrays of tiny mirrors that are electrically controlled to bend the light from a given input to a desired output.
>
> **LCD** – Liquid crystal display – Uses liquid to bend light to the desired output.
>
> **Ink-Jet Printer/Fluidics** – Uses heat to cause bubbles in fluid channels that reflect and redirect light.

(The first of these is known as an 'Opaque Switch' – the light doesn't go through it – and the other three are known as 'Transparent Switches' – the light goes through them).

The following is a much more detailed review of these underlying technologies.

Review of Basic Technologies

OEO

Optical-Electrical-Optical switches are the traditional way to perform this function. There are several systems shipping at this point with up to 512 x 512 ports. Many of the systems available are much smaller than this however, with many limited to 32 x 32. These switches offer high-speed switching; 0 db insertion loss (actually they can offer optical gain, depending on the system and the needs), and they offer the possibility of using system intelligence. There are also shortcomings (see section comparing opaque to transparent switches), particularly the lack of upgrade flexibility.

These switches largely use well-known and widely available ASIC VLSI technology. The optical signal is terminated on a diode, where it is converted to an electrical signal. After conversion, the digital information can be monitored, switched, and used as a basis for intelligence in directing the output. It is converted back to an optical signal as the output of a laser.

OEO Vendors

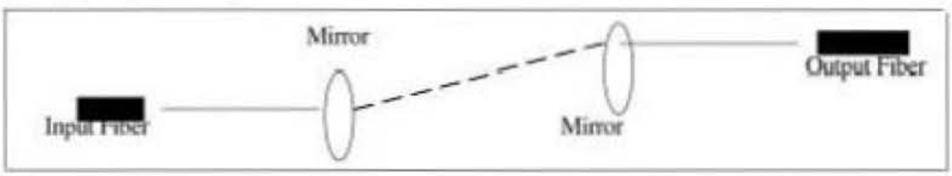
See the Summary of Vendors sections for details of various vendors' systems.

MEMS

Micro-electromechanical systems (MEMS - also sometimes called MOEMS – micro-optoelectromechanical systems) may be the most promising of the all-optical technologies. MEMS are actually a part of a very broad technology development that goes far past OXCs and even far past telecommunications. It is really a class of developments that focuses on the growth of tiny, complex machines on silicon chips. It has applications in computer design (computer on a chip), medicine (both medicine delivery and internal imaging from tiny cameras), and fluidics (microfluidic devices) and in many other areas. Products from this technology area have included automobile airbag sensors, pressure sensors, displays, scanners, printers, data storage, and adaptive optics.

The development in just the last two years of prototypes, and the very imminent production models of large scale, carrier grade all-optical OXCs from this technology has grabbed the attention of the entire industry. The fact that this development is not limited to one manufacturer (or even to a single technical approach) has made this a somewhat spectacular introduction of an entirely new (in this application) technology.

Figure 1, MEMS Layout



As previously noted, MEMS is the use of arrays of mirrors to switch light from a set of input fibers to a set of output fibers. The mirrors can be repositioned so as to achieve the switching function. These tiny mirrors (on the order of 2 millimeters in diameter) are arranged in two arrays and positioned so as to reflect an input on one mirror to a mirror on the second array and then to an output. Figure 1 is a representation of the general arrangement.

It should be noted that in some vendors' approaches to this technology, a "fold mirror" is located between the two mirrors shown. This is a stationary mirror included to redirect the light backwards to the moving mirror location.

Two Approaches to MEMS

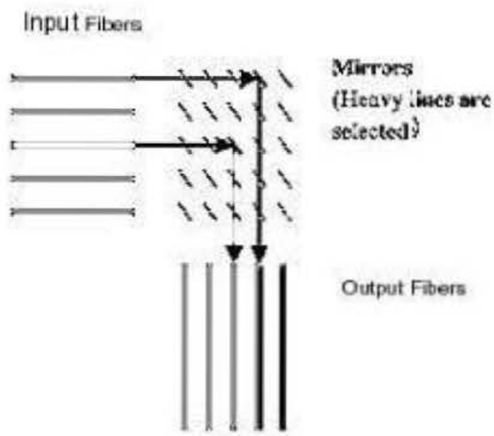
Even with this brand new approach to switching lightwaves there are two methodologies being advocated and developed. These are a digital (or two dimensional – 2D) approach and an analog (or three dimensional – 3D) approach.

Digital Approach

In this approach the mirrors can only be in two positions – on or off, thus digital. It is an extremely simple approach to the MEMS technology because of the simplified control system. The digital approach is known as an NxN (N squared) architecture, because it requires NxN mirrors to allow N inputs to be routed to N outputs.

A difficulty with this architecture is that the light travels in free space as it goes to the selection mirror. As the size of the switch goes up the distance the light must travel (its maximum distance) squares. A beam of light tends to expand in diameter as it travels in free space, causing a need to tightly focus the beam, and carefully align the mirrors. This problem is generally believed to limit this approach to 32x32 ports on a single chip. Of course, it is possible to build switch architectures with multiple chips, but that adds to the complexity, and adds to the insertion loss problem.

Figure 2, Sketch of Two Dimensional MEMS



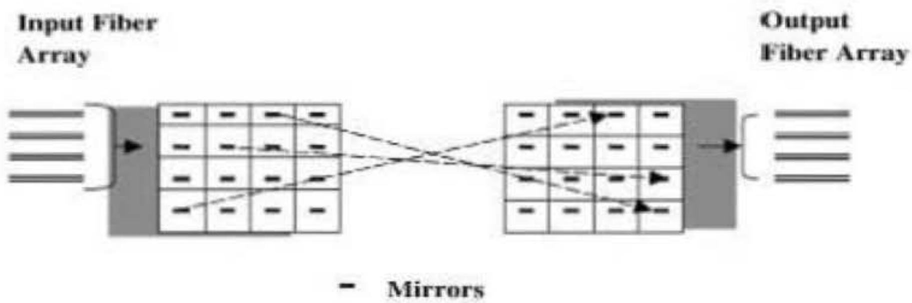
Siemens TransXpress Optical Service Node is a known example of using the digital approach. Figure 2 illustrates the digital approach.

Analog Approach

In the analog approach to MEMS the mirrors can take many positions. While this design results in the use of less mirrors, it is much more complex in terms of the control system for the mirrors and the alignments required. On the other hand, this approach only uses 2N mirrors (to allow interconnection between N inputs and N outputs), and it is not constrained by the light propagation distance as the digital version is. As a result, it is thought that this technology can scale to, perhaps, thousands of ports. Systems are available, or nearly so, that will provide over 1000x1000 ports.

In spite of the complexity, this approach is the one being used by the highest profile planned switches – Lucent's LambdaRouter and the Xros (Nortel) X-1000. Figure 3 illustrates this approach.

Figure 3, Sketch of Multi-Dimensional MEMS



In general, the MEMS analog approach is currently viewed as the most likely to be a real success in carrier grade, high port count OXCs. The devices can be produced in a relatively inexpensive production process, with high reliability. There is a question as to the ongoing reliability of the mirrors' positioning systems. This is a complex system that must function with a high degree of precision over long time periods. Only the testing of full commercial products will determine this factor.

MEMS switches tend to have relatively high insertion losses. Reports to date indicate that this loss is going to be approximately 7 to 8 db from input to output.

MEMS Developers and Vendors

The following provides a listing of the major vendors developing either MEMS components or systems, or both. The systems vendors have more extensive comments in the 'Summary of Vendors' section of this report.

ADC

PO.Box1101
Minneapolis, MN 55440
Tel. 612-938-8080
Fax 612-964-3292
www.adc.com

ADC is primarily a system vendor, but in this area they are developing a MEMS-based, OEM product. ADC's experience in diffractive optics, semiconductor manufacturing processes, and volume manufacturing has been leveraged to develop research and development for integrated optics. Integrated optics is a high-level integration of several technologies, including micro-electromechanical systems (MEMS). The integrated optics products are compact, with low-power consumption due to passive temperature compensation.

Agere Systems

555 Union Blvd.
Allentown, PA 18109
Tel. 866-243-7347
www.agere.com

Agere Systems, formerly the Microelectronics division of Lucent Technologies, is a leader in sales of communications components. It is currently in the process of being spun off. That process is expected to be completed by March 2002.They design, develop and manufacture optoelectronic components for communications networks, and integrated circuits for use in a broad range of communications and computer equipment.

Agere produces a 64X64 MEMS switch module for inclusion in OO switching systems. It is the 5200-Series Optical Switch Module. It is based on the 3-D architecture. This is in a very small package – approximately 3x9 inches.

Astarte Fiber Networks

2555 55th St. Suite 100
Boulder, CO 80301
Tel. 303-443-8778
Fax 303-449-2975
www.tellium.com

Tellium (see "Summary of Vendors") completed the acquisition of Astarte Fiber in October of 2000.

Astarte produced a product line of switches intended for somewhat slower speed applications (up to OC-48), although the switch fabric itself is not limiting. The products are designed for the campus, data center, and enterprise environments. They use MEMS matrixes as the switching point for reconfiguring fiber networks in these environments.

Products in the Star Switch family include the 7200, the 7202, and the 7250 for various applications. All can be expanded up to 72x72 ports. These products are currently available.

C Speed Corp.

120 Cremona Dr., Suite C
Santa Barbara, CA 93117
Tel. 805-562-3100
Fax 805-562-3199
www.cspeed.com

C Speed integrates sophisticated micro-photonics, optics and control systems in a robust and manufacturable package that can be configured as an optical cross connect subsystem offering 32x32 to 1024x1024 or higher port counts.

C Speed uses "3D" or "Beam Steered" MEMS, which is one of the leading technologies capable of meeting port count and reliability requirements of tomorrow's wavelength-rich optical networks. C Speed 3D MEMS design and packaging is said to enable the development of switches that meet telecom reliability requirements.

Calient Networks

5853 Rue Ferrari
San Jose, CA 95138
Tel. 408-972-3600
Fax 408-972-3800
www.calient.net

Calient Optical Components, originally known as Kionix, Inc., was acquired by Calient Networks in December 2000. Kionix was founded in 1993 to commercialize next-generation MEMS (Micro-ElectroMechanical Systems) technology developed at Cornell University in Ithaca, New York. Through its use of Reactive Ion Etching, the company developed diverse products such as inertial sensors, microswitches, microfluidic systems and mechanical data storage, in addition to micro-mirror arrays and other optical components. Calient Optical Components will utilize these advances to address the burgeoning demand in the optical components market. Calient Optical Components is a wholly owned subsidiary of Calient Networks and will continue operations in Ithaca, New York.

Calient Optical Components' MEMS fabrication technique results in high-aspect ratio structures that can be used in systems of capacitative sensors, electrostatic actuators, switch contacts, holes and channels for guiding fibers or fluids, and other applications. Calient Optical Components' micro-mirror arrays push MEMS technology to the limit, taking advantage of the many mechanical, electrical and optical characteristics that result when using silicon as a building material.

Corning

MP-RO-03
Corning, NY 14831
Tel. 607-786-8125
www.corning.com

Corning is working with IntelliSense to develop MEMS-based communications devices. Corning is also involved in Liquid Crystal devices. They have also more recently (12/2000) announced the collaboration with Sycamore on the development of 3D MEMS.

Corning and Sycamore will collaborate on defining the functionality and testing the application of new 3D MEMS technology in telecommunications networks. The collaborative effort is expected to accelerate the deployment of 3D MEMs optical switch technology as part of an intelligent optical networking solution.

CoreTek (Nortel)

299 Ballardvale St.
Wilmington,MA 01887
Tel. 978-570-1200
Fax 978-570-1300
www.coretekinc.com

CoreTek has a strong background in MEMS and in work with vertical-cavity, surface-emitting lasers. They have described work that combines these technologies for a tunable MEMS device. (See the Section of the Report on Tunable components for the impact of this combination.)

The VCSEL tunable MEMS device is described as follows:

Features:

- Integrated functionality
- High power tunable CW laser
- Broadband wavelength locker - locks to the ITU 50 GHz grid
- High Output Power (+13 dBm) for use with existing external modulator
- Tunable across 80 channels in either the C or L bands
- Compact footprint and low power consumption

- Integral TEC
- Hermetically sealed 26-pin butterfly package

Benefits:

- Enables network agile applications, and greatly reduces sparing costs
- Reliable and rapid tuning across the complete C or L band
- Improved signal/noise ratio
- Compatible with existing link budgets
- Global managed-wavelength provisioning is now a reality
- High density design-in
- Excellent temperature control
- Enhanced long-term performance and reliability

Cronos (JDS Uniphase)

300 Aerial Ctr. Pkw, S110
Morrisville, NC 27560
Tel. 919-380-1316
www.mensrus.com

Cronos was acquired by JDS Uniphase in a stock transaction in April 2000. Prior to joining JDS Uniphase, the company operated as a division of MCNC, a non-profit technology incubator located in Research Triangle Park, N.C.

Cronos is the only MEMS supplier that provides bulk, surface, and high-aspect ratio (LIGA) micromachining - the three key processes used to fabricate MEMS devices. Cronos has produced over 50 MEMS patents and patents pending, a manufacturing facility that supports state-of-the-art MEMS fabrication processes, and a base of high profile customers, including many Fortune 500 companies. Cronos manufactures MEMS components, primarily for communications applications, using foundry services and proprietary MEMS devices.

Cronos is unique because it has focused all of its efforts on simplifying the implementation of MEMS components for original equipment manufacturers (OEMs). To this end Cronos has created, and commercially demonstrated, standardized building blocks for MEMS processing and MEMS components.

These building blocks are the beginning of a complete platform that will eventually lead to an application-specific approach to MEMS, very similar to the application-specific approach that has been so successful in the integrated circuit industry.
Initial products from Cronos – MEMS microrelays, optical attenuators, and photonic switch components – are available at the chip-level as stand-alone components or in array formats, and are currently being qualified by several major telecom equipment OEMs. Cronos also delivers a fully qualified, surface micromachining process for both prototyping and manufacturing of customer-proprietary MEMS designs.

IntelliSense Corp. (Corning)

36 Jonspin Rd.
Wilmington, MA 01887
Tel. 978-988-8000
Fax 978-988-8001
www.intellisense.com

IntelliSense offers a generalized design, manufacturing and integration software capability for MEMS devices. IntelliSense had (prior to the acquisition by Corning) a joint development agreement with Corning to develop telecommunications devices based on MEMS. IntelliSense is a manufacturer of software (IntelliSuite) for assisting in the development of MEMS-based devices for a number of other industries.

Corning Incorporated, a leading producer of optical fiber and components, is developing optical switch modules for next-generation networks. As part of these modules, IntelliSense assisted in the design of MEMS-based mirror arrays which reflect optical signals without electrical regeneration. These new switches will be used in next-generation networks to reduce operating costs and increase network capacity and reliability

Corning announced an agreement in mid-2000 to acquire the remaining portion of IntelliSense for $500 million in stock.

Lucent

600 Mountain Ave.
Murray Hill, NJ 07974
Tel. 888-4-Lucent
www.lucent-optical.com

Agere Systems, the former Microelectronics Group of Lucent Technologies, has announced a fully integrated, three-dimensional (3D) microelectromechanical systems (MEMS) optical switch component that will be marketed to makers of optical networking systems. It offers 64 input and 64 output ports in a small form-factor, and contains the control electronics needed to form a self-contained subsystem - permitting quick integration into optical networking system designs. (Also see Agere, under this heading.)

Designed to be in the core of all-optical cross connects and add/drop multiplexers, the 5200 series MEMS switch module uses a scalable, 3D architecture developed by researchers at Lucent Technologies' Bell Labs to manipulate optical signals without the need to convert the signals to electrical form. It is the first in a family of small-form-factor optical switch modules that will be offered by Agere Systems. The new small form factor package measures approximately 9" x 10" x 4".

Nanovation

47050 Five Mile Rd.
Northville, MI 48167
Tel. 734-354-4000
Fax 734-416-0783
www.nanovation.com

This company was founded in 1996, and took its current name in 1999. Nanovation is an OEM that makes a number of optical devices. It filed for Chapter 11 in July of this year (2001), so its future is unclear. Its switch is a very small (1x2 or 2x20) device with a very low (1.5 db) insertion loss. The following describes their optical switch product.

Nanovation's product portfolio is based on integrated, high performance optical components. The company's patented photonic device technologies can be integrated on a single semiconductor wafer. These technologies will ultimately make it possible to integrate large numbers of Nanovation's devices on a single photonic integrated circuit (PIC) for a fraction of the cost of discrete photonic devices to provide advanced optical functionality.

The company's first product line is based on its silica-on-silicon technology, encompassing several patent-pending hybrid silica/MEMS (Nanoshutter) technologies including switches and variable attenuators that can be integrated with waveguides that contain taps, splitters, and filters.

The Nanoshutter optical switch is a low loss, non-blocking, latching component designed for wide-band wavelength switching applications in the 1260 to 1600 nm fiber transmission band. It is ideally suited for long haul, metropolitan and local area fiber optic networks including WDM, DWDM, OADM systems and optical component testing. It is packaged in a rugged housing with integral electrical pinouts and pigtail fiber leads.

Product Features:

- 1x2, 2x2
- Wideband 1260-1600 nm
- Nanoshutter MEMS
- Silica-on-silicon Waveguides
- Fail-safe Latching
- Position Sensing
- Integrated 1-5% Taps
- Low Loss
- Moderate Switching Speed
- Low Cross Talk
- Small Size

Onix Microsystems, Inc.

4138 Lakeside Dr.
Richmond, CA 94806
Tel. 510-669-2020
Fax 520-669-2025
www.onixmicrosystems.com

Onix (sometimes erroneously referred to as Onyx in the press) is a start up (1998) that specializes in MEMS communications devices. They now ship an 8x8 device known as the PASSPORT. The current architecture is digital, but they are said to be at work on an analog device.

The Onix Microsystems PASSPORT 8x8 Optical Switching Engine is the first in a series of building blocks that revolutionize optical networks. The PASSPORT 8x8 provides fully configurable, bi-directional, non-blocking interconnection of eight optical inputs to eight optical outputs, inherently transparent to data bit rate and protocol. The PASSPORT 8x8 is suited for wavelength selective, cross-connect reconfigurable, add-drop multiplexing, dynamic network provisioning, protection and restoration, and remote network monitoring.

The PASSPORT 8x8 utilizes a single-crystal silicon mirror structure to deliver greater mirror planarity, thermal stability, and rigidity.

Features/Benefits:

- Uniform low insertion loss (3 db)
- Millisecond switching time
- Low voltage (5 V) operation
- Configuration latching on power interrupt

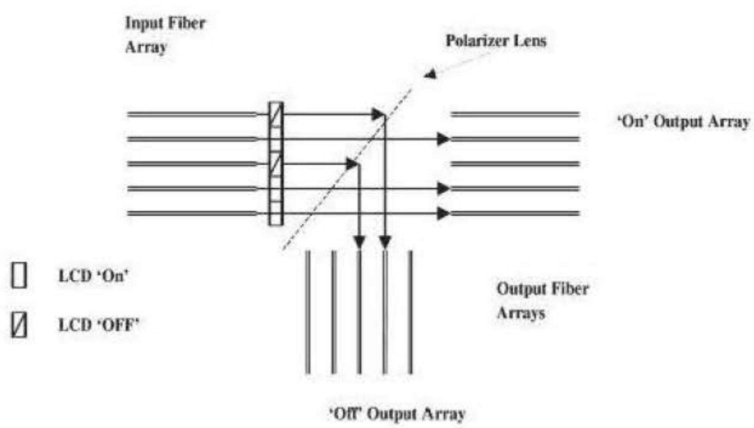
Xros (Nortel)

777 Pastoria Ave.
Sunnyvale, CA 94086
Tel. 408-733-7331
Fax 408-733-7377
www.xros.com

LCD

The LCD (Liquid Crystal Devices) technology is based on a "sandwich" structure of two layers of glass with liquid crystal material between them. The application of small voltages to the sandwich can cause incident light to change its polarization and thus its properties can be controlled. This technology has been used for years for various light displays such as watches, laptop computer, calculators, etc. In the telecommunications arena, these devices can be used for a variety of purposes, including switching, attenuation, and other applications. As a switch it uses an array of ports (fiber connectors) to direct light through a liquid crystal and then to a 'polarized' lens. At the polarizer lens the light beam is either transmitted through to one output or reflected off to another depending on whether the liquid crystal had a voltage applied or not. Figure 4 illustrates this technology.

Figure 4, Sketch of Liquid Crystal Technology



Although the jury is certainly still out on the question, it would appear that the current consensus is that LCD will be a viable technology for switches of small port sizes (under 32x32) and for a variety of other telecommunication optical components, but likely not for the larger port count switches that are possible