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# Optical Switching Spectrum including MEMS

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***ABSTRACT:*** **The switching speeds of electronics cannot keep up with the transmission capacity offered by optics. All-optical switch fabrics play a central role in the effort to migrate the switching functions to the optical layer. Optical packet switching provides an almost arbitrary fine granularity but faces significant challenges in the processing and buffering of bits at high speeds. Generalized multiprotocol label switching seeks to eliminate the asynchronous transfer mode and synchronous optical network layers, thus implementing Internet protocol over wavelength-division multiplexing. Optical burst switching attempts to minimize the need for processing and buffering by aggregating flows of data packets into bursts. In this paper, we present an extensive overview of the current technologies and techniques concerning optical switching. Theoretically optical switches seem to be future proof with features of scalability, flexibility, bit rate and protocol independent coupled with lower infrastructure costs but a network service provider must evaluate the pros and cons and all possible options to select optimum combination of electronic and photonic switches to meet the capacity and traffic management requirements. This seminar presents an overview on optical switches. Optical switching technologies and Optical switches including MEMS, Bubble, Thermo-optical, Liquid crystal and non-linear optical switches have been discussed. Finally all optical switching a technology that's still in its infancy but holds tremendous potential, since it switches optical packets, is also with.**

***Key words: MEMS, Crystal, Optical, Exciton, DWDM***

## 1. INTRODUCTION

Telecommunication networks are demanding a dramatic increase of capacity, mostly due to the exponential growth of IP traffic. To this aim, considerable research is devoted to design an optical network layer, in order to relieve the capacity bottleneck of electronic-switched networks. Explosive information demand in the internet world is creating enormous needs for capacity expansion in next generation telecommunication networks. It is expected that the data-oriented network traffic will double every year. A single optical fiber offers a potentially huge transmission capacity: just in the wavelength window, 5 or 10 THz are there to be mined, if only we could be able to exploit such tremendous bandwidth with adequate technology. Recently, optical Dense Wavelength Division Multiplexing (DWDM) has been developed, which made available commercial systems providing impressive transmission capacities. Unfortunately, switching is still performed mostly by electronics. The extension of optics from transmission to switching is thus the second step needed. In this context, all optical switching fabrics play a central role and will be a significant breakthrough on this way. These devices allow switching directly in the optical domain, avoiding the need of several optical-electrical-optical conversions.

In this paper, the state of the art of optical switching fabrics is reviewed, by outlining the main technologies that are under development to realize these devices. Finally, some possible applications and performance data are summarized, based on a market analysis that we carried out in the latest months. Therefore, a snapshot on the state of the art of optical switching devices is provided indeed. We believe that this review is valuable to researchers envisaging new all-optical switching network architectures for telecommunications networks of the future.

## 2. NEED FOR OPTICAL SWITCHING

Computers get faster and communication signals get faster, but the interface between them--where the electrons in the computer circuits are converted into photons for the fiber-optic cable--remains clunky and slow. New transistors that rely on virtual particles called excitons could change that. An exciton is a state of electrical excitement that can pass from one atom to another, much as an electric current does. When an exciton loses energy, it emits a photon, so excitons are good at translating between electrical and optical signals.

The problem in existing systems is the barrier at the interconnect between the optical signal and the electrical signal," says Alex High, a graduate at the University of California, San Diego (UCSD), who conducted the research along with colleagues there and at the University of California, Santa Barbara. "This cuts out that extra step. Because excitons are carriers of light, you can manipulate them, do logic processes on the light in exciton form, and then release that light in another place." The researchers have created tiny, super cooled integrated circuits made of gallium arsenide that can send exciton signals in different directions or merge two signals into one--jobs necessary to handle the rudiments of computer logic just as electronic circuits do. A smoother optical-electronic interface has wide implications. Fiber optics is the most efficient way to carry large amounts of data at the speed of light, and it's used in a myriad of applications, from telecommunications to temperature sensing to simply carting information from one computer chip to another. But at some point, optical signals almost always need to be converted into electrical signals--whether it's so your desktop PC can understand them or so they can be amplified during a long trip. Not only is that conversion slow, but the traditional converters are expensive, relatively large, and power hungry.

## 3. ROLE OF NLO IN OPTICAL SWITCHING

The role of nonlinear optics in optical switching has become extremely significant. Non-linear materials are those, which interact with light and modulate its properties. Several of the optical components require efficient nonlinear materials for their operations. What in fact restrains the widespread use of all optical devices is the in efficiency of currently available nonlinear materials, which require large amount of energy for responding or switching. Organic materials have many features that make them desirable for use in optical devices such as

1. High nonlinearities
2. Flexibility of molecular design
3. Damage resistance to optical radiations

Some organic materials belonging to the classes of phthalocyanines and polydiacetylenes are promising for optical thin films and wave guides. These compounds exhibit strong electronic transitions in the visible region and have high chemical and thermal stability up to 400 degree Celsius. Polydiacetylenes are among the most widely investigated class of polymers for nonlinear optical applications. Their sub Pico second time response to laser signals makes them candidates for high-speed optoelectronics and information processing. To make thin polymer film for electro-optic applications, NASA scientists dissolve a monomer (the building block of a polymer) in an organic solvent. This solution is then put into a growth cell with a quartz window, shining a laser through the quartz can cause the polymer to deposit in specific pattern.

## 4. OPTICAL SWITCHING TECHNIQUES

Optical switches will switch a wavelength or an entire fiber-form one pathway to another, leaving the data-carrying packets in a signal untouched. An electronic signal from electronic processor will set the switch in the right position so that it directs an incoming fiber – or wavelengths within that fiber- to a given output fiber. But none of the wavelengths will be converted to electrons for processing. Optical switching may eventually make obsolete existing light wave technologies based on the ubiquitous SONET (Synchronous Optical Network) communications standard, which relies on electronics for conversion and processing of individual packets. In tandem with the gradual withering away of Asynchronous Transfer Mode (ATM), another phone company standard for packaging information.

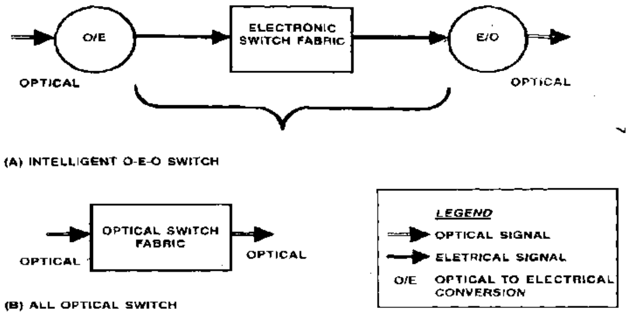

Figure 1. Optical Switches

4.1. *All optical switching approaches:* Switching is an important and essential functionality in telecommunications, which can be understood at two levels: a higher level that requires sophisticated electronics and the physical level comprised by components and devices that “switch” signals within the network. Only component sat the physical level can be “all-optical”, and this chapter focuses on various types of all-optical switching components that are available or in development for switching functions. In practice, many optical switches actually are optoelectronic, with input optical signals converted to electronic form for switching, and the switched electronic signals then driving an optical transmitter. All-optical switches manipulate signals in the form of light, either by redirecting all signals in a fiber or by selecting signals at certain wavelengths in wavelength-division multiplexed systems. Some switches can isolate individual wavelengths, but typically their input is an individual optical channel that was previously separated from other channels by a demultiplexing system. That means they operate at the optical-channel level, without regard to what data stream the optical channel is carrying.

Electronic or optoelectronic switches are still required to manipulate the data stream transmitted on each optical channel, such as breaking up a time-division multiplexed signal into its component pieces for distribution at the end of a long-distance transmission line. One further distinction is between “transparent” and “opaque” optical switches. The most current are transparent all-optical switches, because they transmit the original input light, without converting it into some other form, as if you could “look” right through it. One simple example is a moving-mirror switch, which reflects the input photons in different directions. Opaque optical switches convert the input photons into some other form, and thus do not transmit them exactly as they were received. They include optoelectronic types and others that convert the signal to a different wavelength using optical or electronic techniques.

Basically there are four types of optical switching mechanisms. They are as shown in the below figure.

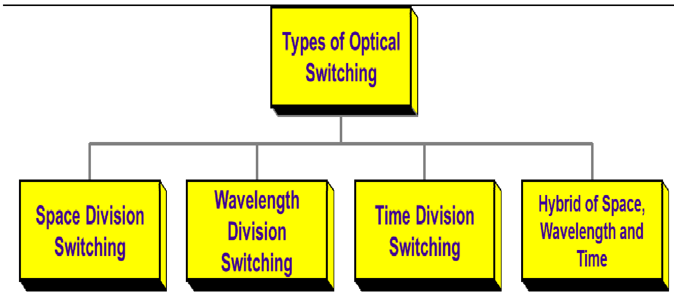

Figure 2. Types of optical switching techniques

4.2. *Space Division Switching:* The different switching mechanisms involved in space division switching are MEMS (Micro Electro Mechanical Systems), thermo-optical switching, liquid crystal switching, nonlinear optical switches, bubble switches etc.

4.2.1. *MEMS (Micro Electro Mechanical Systems):* MEMS technology has enabled us to realize advanced micro devices by using processes similar to VLSI technology. When MEMS devices are combined with other technologies new generation of innovative technology will be created. This will offer outstanding functionality. Such technologies will have wide scale applications in fields ranging from automotive, aerodynamics, and hydrodynamics, bio-medical and so forth. The main challenge is to integrate all these potentially non-compatible technologies into a single working Microsystems that will offer outstanding functionality.

The use of MEMS technology for permanent, semi-permanent or temporary interconnection of non-compatible technologies like CMOS, BJT, GaAs, SiGe, and so forth into a System-on-Chip environment can be described using an example application. It is a hearing instrument in which an array of acoustical sensors is used to provide dynamic directional sensitivity that can minimize background noise and reverberation thereby increasing speech intelligibility for the user. The micro array can provide dynamically variable directional sensitivity by employing suitable beam forming and tracking algorithms while implanted completely inside the ear canal.

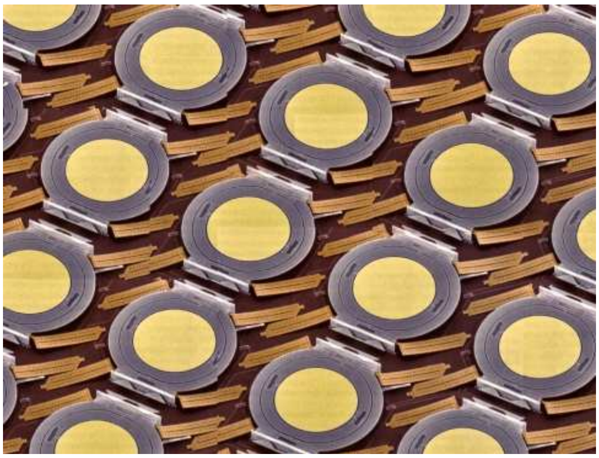

Figure 3. MEMS Microscopic Mirror Optical Switch Array

*Switch design and operation:* The geometry of a capacitive MEMS switch is shown in Fig.4.3 the switch consists of a lower electrode fabricated on the surface of the glass wafer and a thin aluminum membrane suspended over the electrode. The membrane is connected directly to grounds on either side of the electrode while a thin dielectric layer covers the lower electrode. The air gap between the two conductors determines the switch off-capacitance. With no applied actuation potential, the residual tensile stress of the membrane keeps it suspended above the RF path. Application of a DC electrostatic field to the lower electrode causes the formation of positive and negative charges on the electrode and membrane conductor surfaces. These charges exhibit an attractive force which, when strong enough, causes the suspended metal membrane to snap down onto the lower electrode and dielectric surface, forming a low impedance RF path to ground.

The switch is built on coplanar waveguide (CPW) transmission lines, which have an impedance of 50 that matches the impedance of the system. The width of the transmission line is 160 m and the gap between the ground line and signal line is 30 m. The insertion loss is dominated by the resistive loss of the signal line and the coupling between the signal line and the membrane when the membrane is in the up position. To minimize the resistive loss, a thick layer of metal needs be used to build the transmission line.

The thicker metal layer results in a bigger gap that reduces the coupling between signal and ground yet also requires higher voltage to actuate the switch. To achieve a reasonable actuation voltage, a 4mm thick copper is used as the transmission line. The glass wafer is chosen for the RF switch over a semi-conductive silicon substrate since typical silicon wafer is too lossy for RF signal. When the membrane is in the down position, the electrical isolation of the switch mainly depends on the capacitive coupling between the signal line and ground lines. The dielectric layer plays a key role for the electrical isolation. The smaller the thickness and the smoother the surface of the dielectric layer, the better isolation of the switch is. But there is another trade-off here. When the membrane is pulled down, the biased voltage is directly applied across the dielectric layer. Since this layer is very thin, the electric field within the dielectric layer is very high. The thickness of the dielectric layer should be chosen such that the electric field will never exceed the breakdown electric field of the dielectric material. The silicon nitride film has breakdown electric field as high as several mega-volts per centimeter and can be utilized as dc block dielectric layer. In this project, the thickness of the silicon nitride layer is chosen as 0.2 mm to accomplish the dc block and RF coupling purpose.

MEMS can be considered a subcategory of opto-mechanical switches, however, because of the fabrication process and miniature natures; they have different characteristics, performance and reliability concerns. MEMS use tiny reflective surfaces to redirect the light beams to a desired port by either ricocheting the light off of neighboring reflective surfaces to a port, or by steering the light beam directly to a port. Digital-type, or 2D, MEMS which is as shown in figure 4.4 have reflective surfaces that “pop up” and “lay down” to redirect the light beam propagating parallel to the surface of substrate.

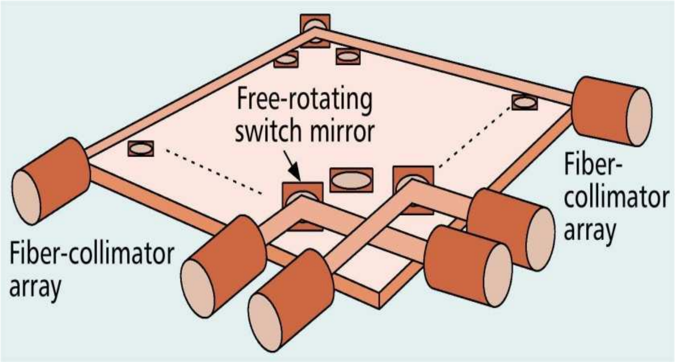

Figure 4. 2D MEMS based Optical Switch Matrix

In 2D MEMS based optical switch matrix mirrors have only two possible positions. Light is routed in a 2D plane and for N inputs and N outputs we need N*N mirrors are required. Loss increases rapidly with N. Analog-type, or 3D, MEMS mirror array switch is as shown in figure 4.5 have reflecting surfaces that pivot about axes to guide the light. The losses are decreased in these 3D MEMS.

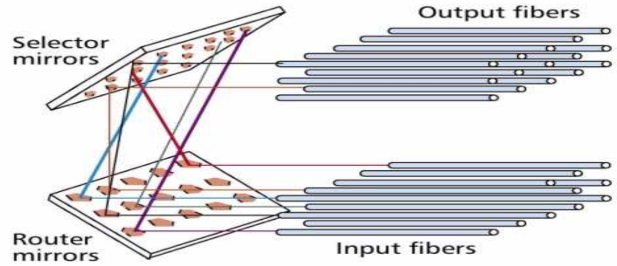

Figure 5. 3D MEMS based Optical Switch Matrix

4.2.2. *Thermo-Optic Switch:* The basic Thermo-optical switching element has an input waveguide and two possible output waveguides. In between there are two short, internal waveguides that first split the input light and then couple the two internal waveguides together again. The recombined light would proceed down the “default” output waveguide. But thermo-optical effect makes it possible to use this coupling of the light as a switching element.

The general principle of thermo-optical switching element is shown in the figure. An input light wave is split onto two separate waveguides. If no heat is applied to the lower branch in the figure, the coupler will output the waveform on to the waveguide labelled output#1 in the figure. The figure shows the heating element activated, and a slightly different phase induced into the waveform on the lower branch. So the output light wave does not take the default waveguide but ends upon the waveguide labelled output#2 instead. Because they can be built on a common material substrate like silicon, waveguides tend to be small and inexpensive, and they can be manufactured in large batches. The substrates, called wafers, can serve as platforms to attach lasers and detectors that would enable transmission or receipt of optical pulses that represent individual bits. Integration of various components could lead to photonic integrated circuit, a miniaturized version of the components that populate physics laboratories, one reason the waveguide technology is sometimes called a Silicon Optical Bench.

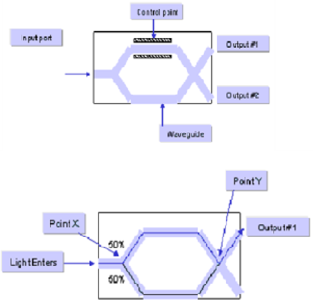

Figure 6. Thermo-optical switch

4.2.3. *Bubble Switch:* The switch consist of a silica waveguide with arrays of intersecting light pipes that from a mesh. A small hole sits at a point where these light pipes intersect. It contains an index-matching fluid (one whose index of refraction is the same as the silica). So if no bubble is present at the junction, the light proceeds down the default waveguide path. If a bubble of fluid is present at the junction, the light is shifted onto the second output waveguide. The bubble act as a mirror that reflects the light wave to another branch of the switching element. An ink-jet printing head underneath can blow a bubble into the hole, causing light to bend and move into another waveguide. But if no bubble is present, the light proceeds straight. That this switch works at all is a testament to the extraordinary sophistication of the fluid technology behind printers.

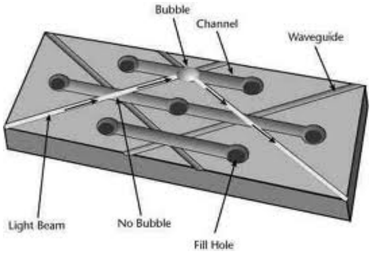

Figure 7. Bubble switch

4.2.4. *Liquid Crystal Switch:* Even more people are familiar with the liquid crystal displays found in digital watches and some forms of computer output devices than are familiar with inkjet printers. Liquid crystals can also be used as a basis for optical switches as well. When an electrical field is applied to the liquid crystal, the molecules line up and so can become opaque.

The Liquid crystal switches rely on a change in the polarization of optical signals with the application of electrical voltage to make a switching element. Because the liquid crystal molecules are so long and thin, they will let only light of a particular orientation pass through the liquid crystal. Liquid crystal switching elements are built with two active components, the cell and the displacer.

The main function of the cell is to reorient the polarized light entering the cell as required. The displacer is a composite crystal that directs the polarized light leaving the cell. Light polarized in one direction is directed to one output waveguide by the displacer, while light polarized at a 90 degree angle is directed to a second output waveguide. The total reflection in liquid crystal switch is as shown in figure4.8

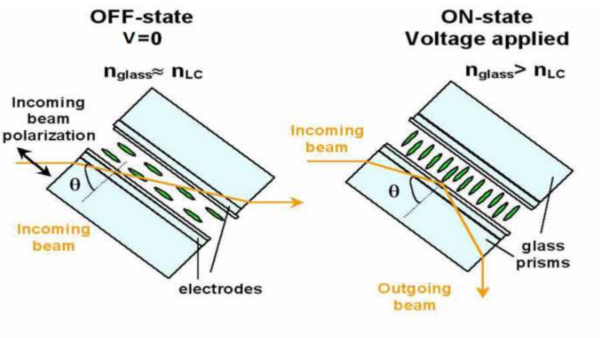

Figure 8. TIR in Liquid Crystal Switch

The upper portion of the figure shows the path of a light wave when no voltage is applied to the cell. Input light of arbitrary polarization lines up with the default polarization orientation of the liquid crystals inside the cell. The displacer also has a default orientation and the light emerges as shown in the figure. The lower portion of the figure shows the path of a light wave when voltage is applied to the cell. Note that the liquid crystals in the cell and those in the displacer both change their orientation under the influence of the voltage. The polarized light now takes the second output path.

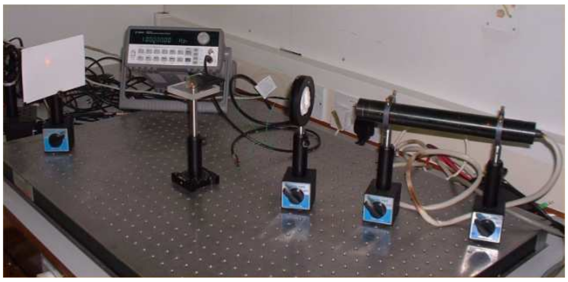

Figure 9. Liquid Crystal Switch

4.2.5. *Nonlinear Optical Switch:* Another type of optical switch takes advantage of the way of the refractive index of glass changes as the intensity of light varies. Most of the optical phenomena in everyday life are linear. If more light is shined on a mirror, the surface reflects more of the incident light and the imaged room appears brighter. A non-linear optical effect, however, changes the material properties through which the light travels. Mirror becomes transparent when more light is shined on it. Glass optical fibers experience non-linear effects, some of which can be used to design very fast switching elements, capable of changing their state in to second (quadrillionth of a second time scale). Consider a non-linear optical loop mirror, a type of interferometer in which two light beams interact. In the mirror a fiber splitter divides an incoming beam. In one instance each segment travels through the loop in opposite directions recombines after completing the circle and exist on the same fiber on which it entered the loop. In cases, though, after the two beams split, an additional beam is sent down one side of the loop but not the other. The intensity of light produced by the interaction of the coincident beams changes the index of refraction in the fiber, which in turn changes the phase of the light. The recombined signal with its altered phase, exits out a separate output fiber.

In general, non-linear optical switching requires the use of very short optical pulses that contain sufficient power to elicit non-linear effects from the glass in the fiber. An optical amplifier incorporated into the switch, however, can reduce the threshold at which these non-linear effects occur. For the purpose of switching the intensity dependent phase change induced by the silica fiber itself could be used as the non-linearity. The pulse traversing the fiber loop clockwise is amplified by an EDFA shortly after it leaves the directional coupler. This configuration is called Non-linear Amplifying Loop Mirror (NALM). The amplified pulse has higher intensity and undergoes a larger phase shift on traversing the loop compared to the unamplified pulse. Although non-linear switches have yet to reach commercial development, the technology shows promise for the future.

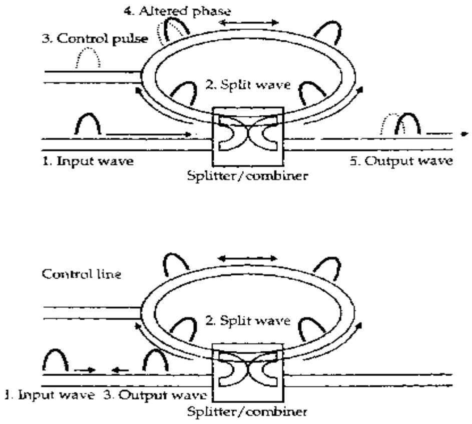

Figure 10. Nonlinear optical switch

4.3. *Wavelength Division Switching:* One of the most promising concepts for high capacity communication systems is wavelength division multiplexing (WDM). Each communication channel is allocated to a different frequency and multiplexed onto a single fiber. At the destination wavelengths are spatially separated to different receiver locations. In this configuration the high carrier bandwidth is utilized to a greater extent to transmit multiple optical signals through a single optical fiber.

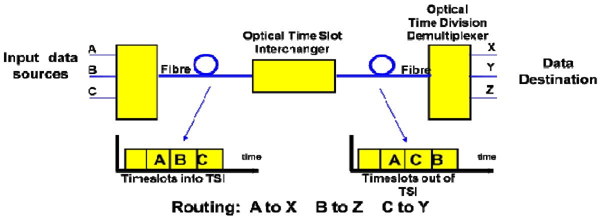

Figure 11. WDM System

For single frequency point-point links the bit rate is limited up to 100 Gbps due to dispersion. This is well below the capability of the optical carrier frequency.WDM can increase the total bit rate of point-to-point systems. During the past few years dense WDM (DWDM) systems have been proposed and are being developed. These systems have wavelength separations on the order of 0.3 – 0.8 nm. System and component development is focused on operation within two low loss wavelength bands in silica fibers. These include the C- and L- bands. S-Band: (1480-1520 nm), C-Band: (1521-1560 nm)

4.4. *Time Division Switching:* It's often practical to combine a set of low-bit-rate streams, each with a fixed and pre-defined bit rate, into a single high-speed bit stream that can be transmitted over a single channel. This technique is called time division multiplexing (TDM) and has many applications, including wire line telephone systems and some cellular telephone systems. The main reason to use TDM is to take advantage of existing transmission lines. It would be very expensive if each low-bit-rate stream were assigned a costly physical channel (say, an entire fiber optic line) that extended over a long distance.

Consider, for instance, a channel capable of transmitting 192 Kbit/sec from Chicago to New York. Suppose that three sources, all located in Chicago, each have 64 Kbit/sec of data that they want to transmit to individual users in New York. As shown in Figure 4.12, the high-bit-rate channel can be divided into a series of time slots, and the time slots can be alternately used by the three sources. The three sources are thus capable of transmitting all of their data across the single, shared channel. This reverse process is called demultiplexing.

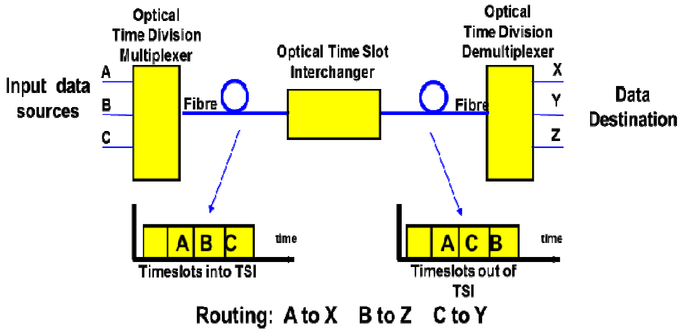

Figure 12. TDM System

Choosing the proper size for the time slots involves a trade-off between efficiency and delay. If the time slots are too small (say, one bit long) then the multiplexer must be fast enough and powerful enough to be constantly switching between sources (and the demultiplexer must be fast enough and powerful enough to be constantly switching between users). If the time slots are larger than one bit, data from each source must be stored (buffered) while other sources are using the channel. This storage will produce delay. If the time slots are too large, then a significant delay will be introduced between each source and its user. Some applications, such as teleconferencing and videoconferencing, cannot tolerate long delays.

## 5. CONCLUSION

In this paper, the current state of production of optical switching fabrics was reviewed, by outlining the main technologies that are under development. Some possible applications and performance data were also summarized, based on a market analysis that we carried out in the latest months, thus providing a valuable support to researchers envisaging new all-optical switching network architectures. Photonic packet switched networks offer the potential of realizing packet-switched networks with much higher capacities than may be possible with electronic packet-switched networks. However, significant advances in technology are needed to make them practical, and there are some significant roadblocks to overcome, such as he lock of economical optical buffering and the difficulty of propagating very high speed signals at tens and hundreds of gigabits/second over any significant distances of optical fiber. There is a need for compact soliton light sources.

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