US 20020061158A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2002/0061158 A1**

Ducellier (43) **Pub. Date: May 23, 2002**

(54) **OPTICAL SWITCH**

(76) Inventor: **Thomas Ducellier**, Ottawa (CA)

Correspondence Address:
Juliusz Szereszewski
JDS Uniphase Corporation
570 West Hunt Club Road
Nepean (Ottawa), ON K2G 5W8 (CA)

(21) Appl. No.: **09/988,539**

(22) Filed: **Nov. 20, 2001**

(30) **Foreign Application Priority Data**

Nov. 20, 2000 (CA) 2,326,362
Dec. 6, 2000 (CA) 2,327,862

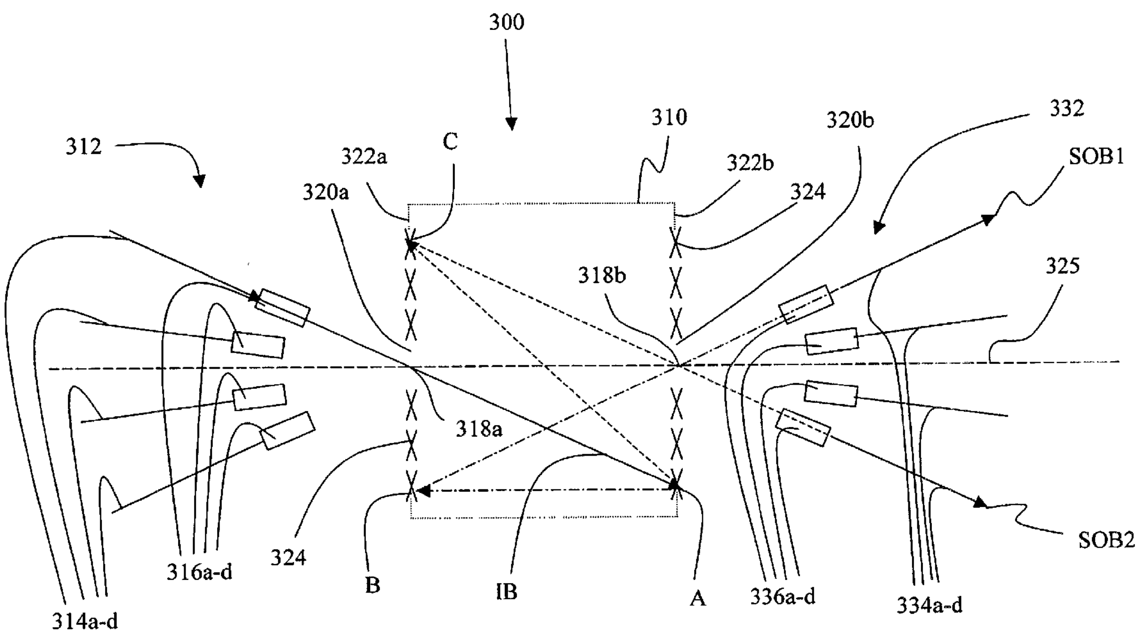
Publication Classification

(51) **Int. Cl.**[7] **G02B 6/35**

(52) **U.S. Cl.** **385/17**; 385/18

(57) **ABSTRACT**

The invention provides and optical switch having a first plurality of independently moveable deflectors with a first optical bypass for allowing the beam of light launched into an input port to pass therethrough, and a second plurality of independently moveable deflectors with a second optical bypass for allowing the beam of light to pass therethrough to any one of a plurality of output ports, said second plurality of independently moveable deflectors being disposed so as to receive the beam of light that passed through the first optical bypass, and wherein a switching is carried out by the first and second plurality of independently moveable deflectors. The optical elements are disposed about a common optical axis. Advantageously, the optical switch includes relay lenses for directing the light beam to the first optical bypass and for receiving it from the second optical bypass and directing it to the output ports. Furthermore, an ATO element can be disposed between first and the second plurality of independently moveable deflectors.



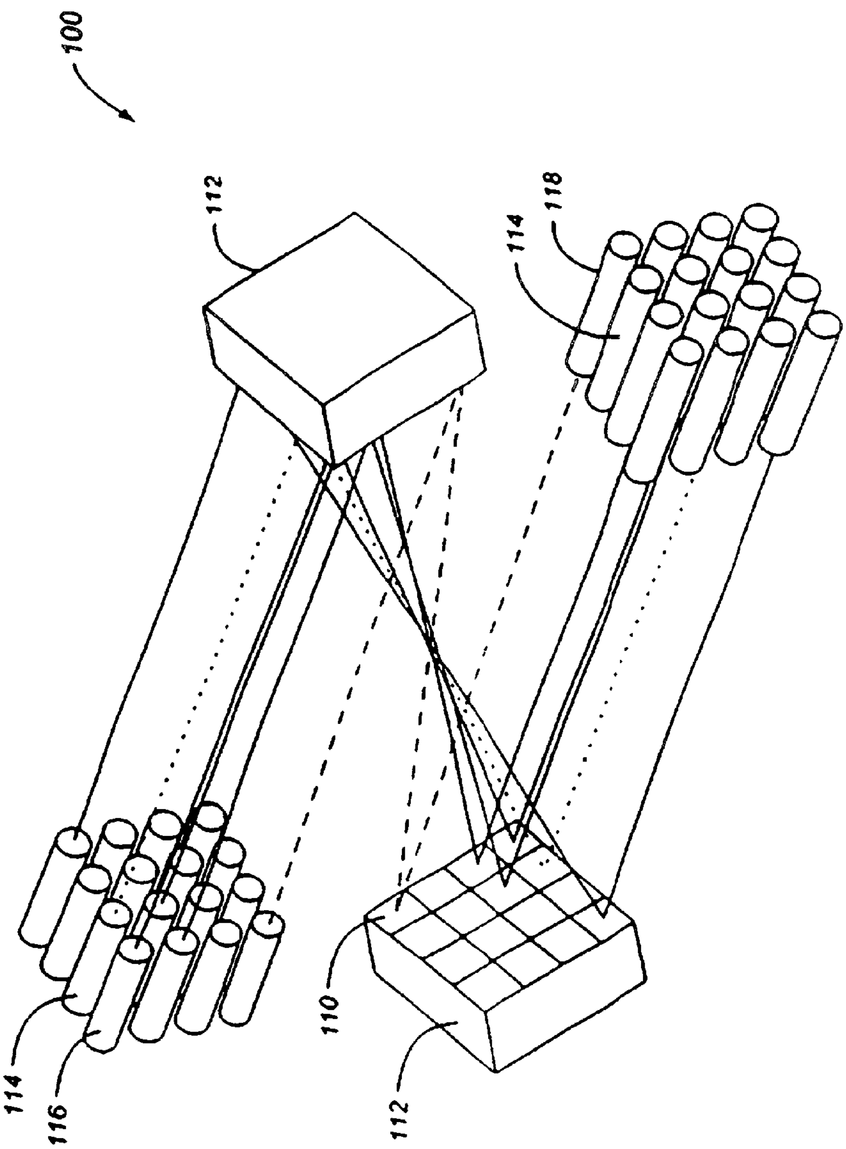


FIG. 1
Prior Art

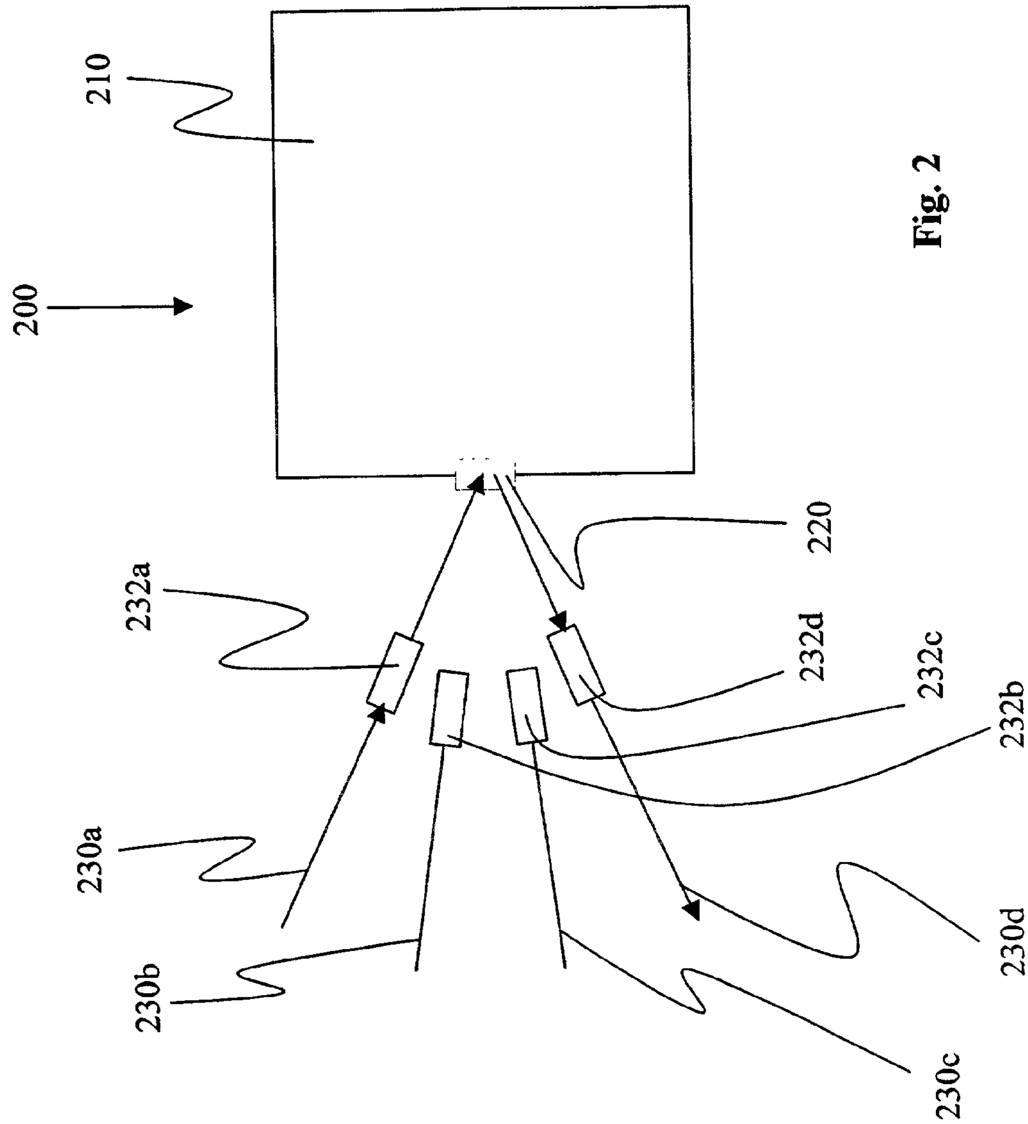


Fig. 2

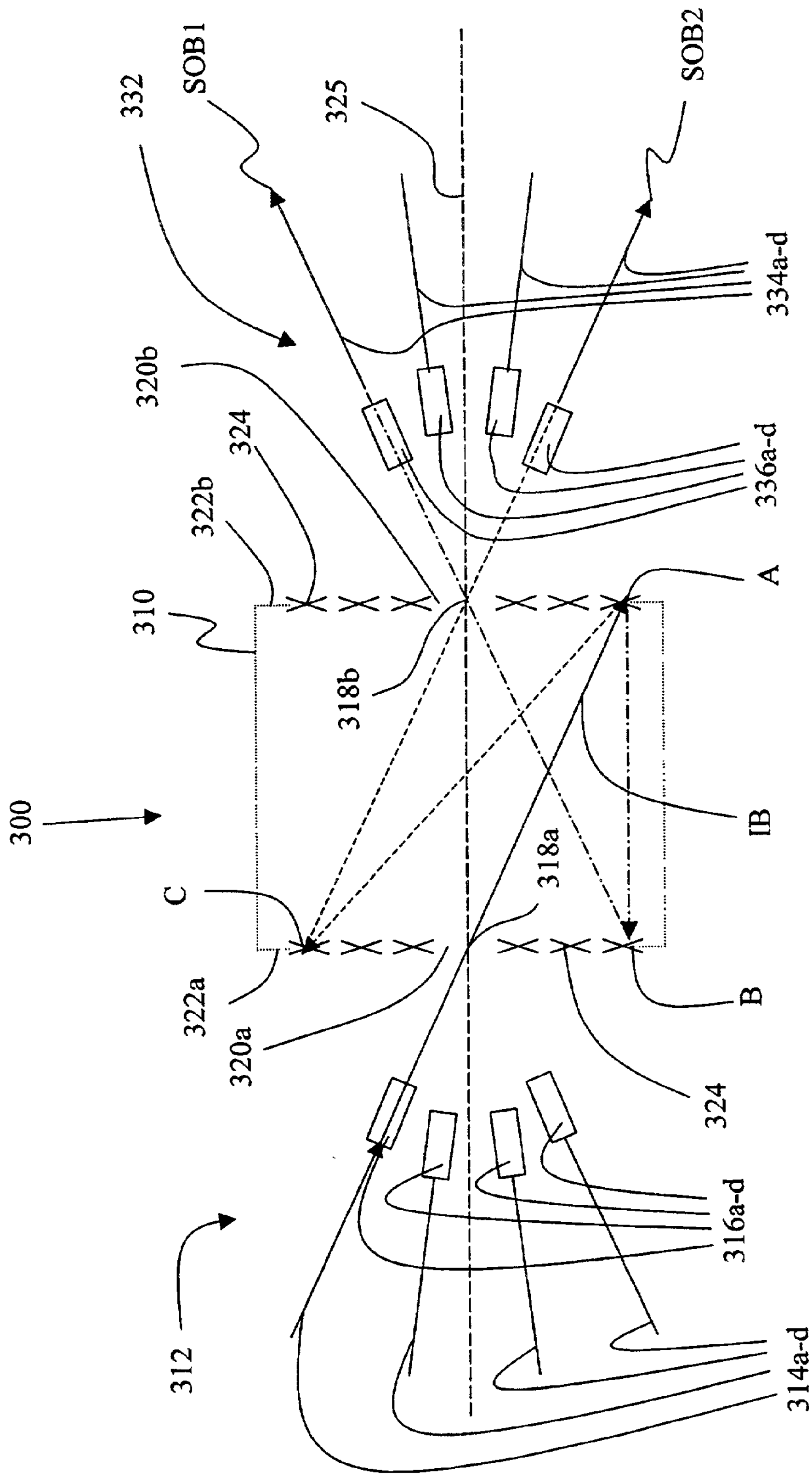

332
SOB1
325
SOB2
334a-d
320b
324
322b
336a-d
310
A
318b
300
IB
C
318a
322a
320a
B
324
316a-d
312
314a-d

Fig. 3

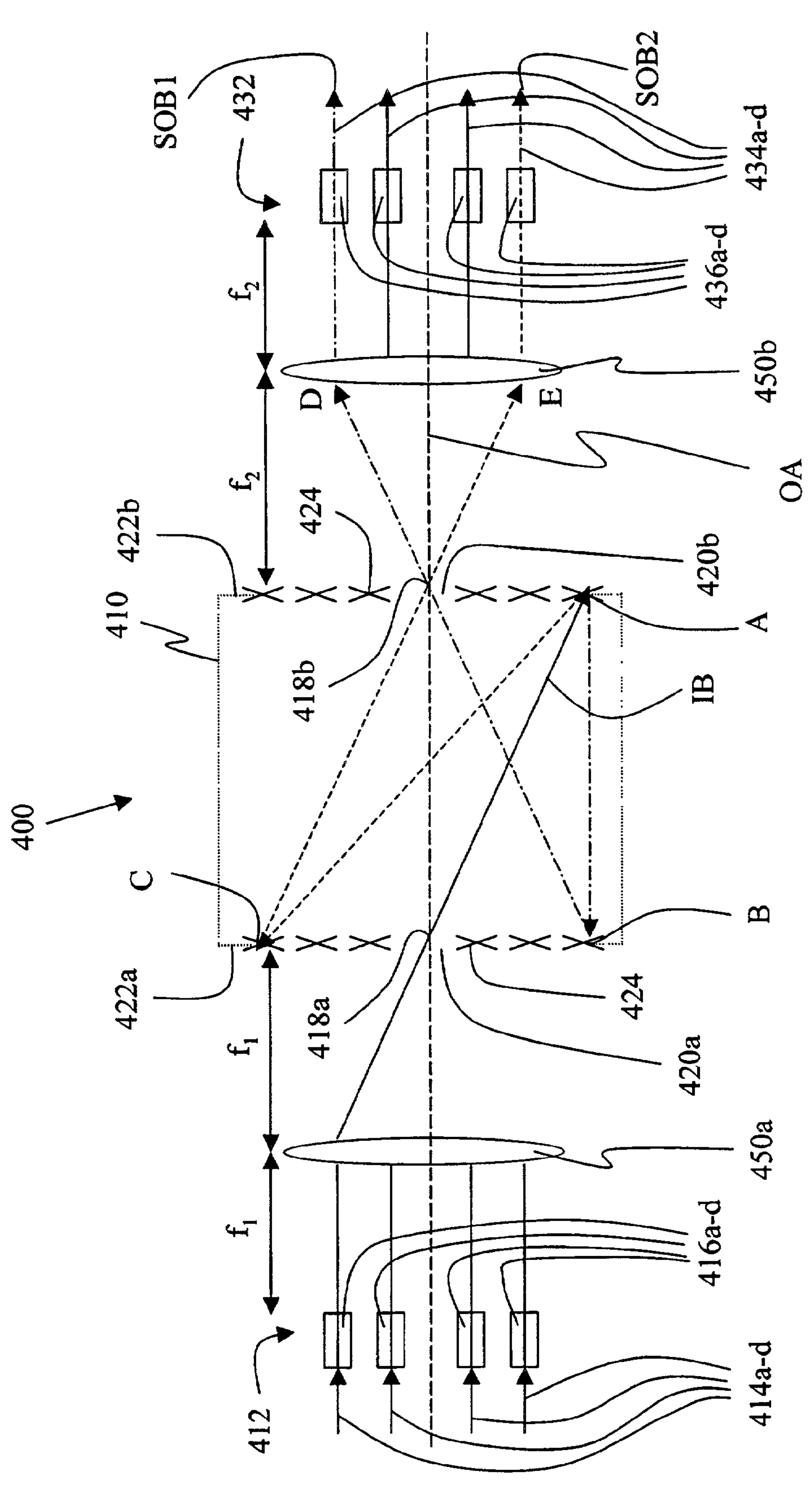

SOB1
432
SOB2
434a-d
436a-d
f_2
f_2
450b
D
E
OA
422b
424
410
420b
A
IB
418b
400
C
B
422a
418a
424
420a
f_1
f_1
450a
416a-d
412
414a-d

Fig. 4

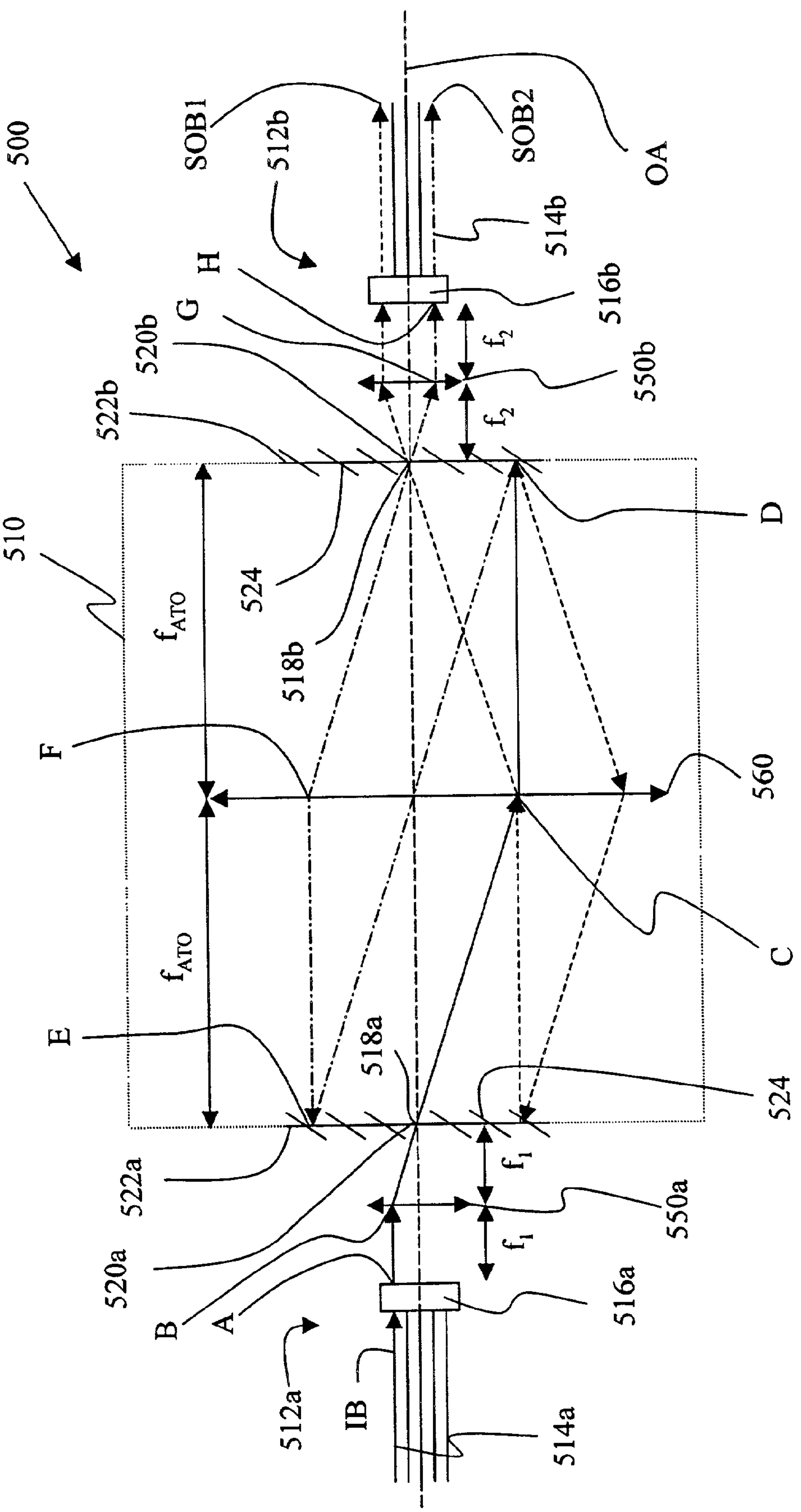

500
510
SOB1
SOB2
OA
512b
514b
H
G
516b
520b
522b
550b
f_2
f_2
524
518b
D
f_{ATO}
f_{ATO}
F
560
C
E
518a
524
522a
f_1
f_1
550a
520a
B
A
516a
512a
IB
514a

Fig. 5

OPTICAL SWITCH

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This applications claims priority from Canadian Patent Application No. 2,326,362 filed on Nov. 20, 2000 and Canadian Patent Application No. 2,327,862 filed on Dec. 6, 2000.

MICROFICHE APPENDIX

[0002] Not Applicable

FIELD OF THE INVENTION

[0003] The present invention relates to the field of optical switches.

BACKGROUND OF THE INVENTION

[0004] Optical matrix switches are commonly used in communications systems for transmitting voice, video and data signals. Generally, optical matrix switches include multiple input and/or output ports and have the ability to connect, for purposes of signal transfer, any input port/output port combination, and preferably, for N×M switching applications, to allow for multiple connections at one time. At each port, optical signals are transmitted and/or received via an end of an optical waveguide. The waveguide ends of the input and output ports are optically connected across a switch core. In this regard, for example, the input and output waveguide ends can be physically located on opposite sides of a switch core for direct or folded optical pathway communication therebetween, in side-by-side matrices on the same physical side of a switch interface facing a mirror, or they can be interspersed in a single matrix arrangement facing a mirror.

[0005] Establishing a connection between an input port and a selected output port, involves configuring an optical pathway across the switch core between the input ports and the output ports. One known way to configure the optical path is by moving or bending optical fibers using, for example, piezoelectric actuators. The actuators operate to displace the fiber ends so that signals from the fibers are targeted at one another so as to form the desired optical connection across the switch core. The amount of movement is controlled based on the electrical signal applied to the actuators. By appropriate arrangement of actuators, two-dimensional targeting control can be effected.

[0006] Another way of configuring the optical path between an input port and an output port involves the use of one or more moveable mirrors interposed between the input and output ports. In this case, the waveguide ends remain stationary and the mirrors are used to deflect a light beam propagating through the switch core from the input port to effect the desired switching. Microelectromechanical devices with mirrors disposed thereon are known in the art that can allow for two-dimensional targeting to optically connect any input port to any output port. For example, U.S. Pat. No. 5,914,801, entitled "Microelectromechanical Devices Including Rotating Plates And Related Methods", which issued to Dhuler et al. on Jun. 22, 1999; U.S. Pat. No. 6,087,747, entitled "Microelectromechanical Beam For Allowing A Plate To Rotate In Relation To A Frame In A Microelectromechanical Device", which issued to Dhuler et al. on Jul. 11, 2000; and U.S. Pat. No. 6,134,042, entitled "Reflective MEMS Actuator With A Laser", which issued to Dhuler et al. on Oct. 17, 2000, disclose microelectromechanical systems (MEMS) having mirrors disposed thereon that can be controllably moved in two dimensions to effect optical switching.

[0007] U.S. Pat. No. 6,097,858, entitled "Sensing Configuration For Fiber Optic Switch Control System", and U.S. Pat. No. 6,097,860, entitled "Compact Optical Matrix Switch With Fixed Location Fibers", both of which issued to Laor on Aug. 1, 2000, disclose switch control systems for controlling the position of two-dimensionally movable mirrors in an optical switch. The mirrors can allow for two-dimensional targeting to optically connect any of the input fibers to any of the output fibers.

[0008] An important consideration in optical switch design is minimizing physical size for a given number of input and output ports that are serviced, i.e., increasing the packing density of ports and beam directing units. It has been recognized that greater packing density can be achieved, particularly in the case of a movable mirror-based beam directing unit, by folding the optical path between the ports and the movable mirror and/or between the movable mirror and the switch interface. Such a compact optical matrix switch is disclosed in U.S. Pat. No. 6,097,860. In addition, further compactness advantages are achieved therein by positioning control signal sources outside of the fiber array and, preferably, at positions within the folded optical path selected to reduce the required size of the optics path.

[0009] Another example of a compact optical switch is disclosed by Laor in WO 99/66354, entitled "Planar Array Optical Switch and Method". The optical switch disclosed therein includes two arrays of reflectors and a plurality of input and output fibers associated with a respective reflector on one of the arrays. The optical signal is directed along a "Z-shape" optical path from the input fibers via the first array of reflector and the second array of reflector to the output fibers.

[0010] However, the design of these prior art optical switches is such that the optical components are arranged along the optical path in a "Z-shape" pattern. A "Z-shape" arrangement of optical components is not spatially efficient. Furthermore, the physical size of an optical switch is determined by the number of input and output ports. A plurality of input/output locations are provided so that the input and output beams can enter/exit the switching core. These input/output locations are commonly provided in the form of rectangular or other arrays.

[0011] Referring to **FIG. 1, a** schematic presentation of a prior art optical switch **100** having a Z-shaped arrangement of optical components is shown. A light beam is launched into an input fiber of input fiber bundle **116** and switched to a selected output fiber of output fiber bundle **118** along a Z-shaped optical path through switch **100**, wherein micro-mirrors **110** on MEMS chips **112** are used to fold the design. Such a folded optical pathway configuration allows for a more compact switch design using a movable mirror based beam directing unit. However, the general approach in prior art optical switches is to individually collimate the beam from each input fiber and to direct this beam to its dedicated mirror. This mirror then deflects the beam to any one of the plurality of output mirrors which then redirects the beam, i.e. compensates for the angle, to its dedicated output fiber. As is seen from **FIG. 1**, this design requires the use of a lens **114** for each individual input fiber of input fiber bundle **116** and each individual output fiber of output fiber bundle **118**.

[**0012**] The Z-shape approach for switching an optical signal, requires particular consideration with respect to the physical spacing between the optical elements since the beam of light should not be obstructed by any of the optical elements along the optical path through the switch. It is apparent that this is not an efficient design since physical size requirements are not optimized in such an "off-axis" design.

[**0013**] The present invention provides an optical switch having an "on-axis" design, and hence it can provide a more compact optical switch than the prior art. In addition, arranging an angle-to-offset (ATO) element between the deflection elements provides for a re-imaging, and hence a small and low loss optical switch can be provided in accordance with the invention.

[**0014**] Accordingly, it is an object of the invention to provide a compact optical switch. It is a further object to provide a switch with improved spatial efficiency in order to minimize a physical size of the optical switch for a given number of input/output ports.

[**0015**] It is yet a further object of the invention to provide an optical switch having a common input/output region at the switching core where the input/output light beams enter/exit the switching core.

[**0016**] Another object of this invention is to provide a compact optical cross-connect arrangement having a large number of ports.

SUMMARY OF THE INVENTION

[**0017**] In accordance with the invention there is provided, an optical switch comprising, at least one input port for launching a beam of light into the optical switch, at least two output ports for selectively receiving a beam of light, a switch core in optical communication with the at least one input port and the at least two output ports, at least a first optical bypass, disposed at the switch core, comprising a first transmissive point through which output beams pass out of the switch core, said output beams substantially overlap each other at the first optical bypass, and a plurality of beam deflectors disposed in the switch core for switching the beam of light from the at least one input port to a selected one of the at least two output ports through the transmissive point of the at least first optical bypass.

[**0018**] In accordance with one embodiment of the invention, the at least first optical bypass is in optical communication with the at least one input port for allowing input beams to pass into the switch core via the first transmissive point.

[**0019**] In a further embodiment of the present invention, at least one of the plurality of beam deflectors is an independently moveable beam deflector.

[**0020**] In yet another embodiment of the invention, the plurality of beam deflectors includes a first plurality of independently moveable beam deflectors, said first plurality of independently moveable beam deflectors being disposed on a first surface comprising the at least first optical bypass.

[**0021**] The optical switch in accordance with the invention further includes at least a second optical bypass for allowing at least one of input and output beams to pass into and out of the switch core.

[**0022**] If desired, the plurality of beam deflectors includes a second plurality of independently moveable beam deflectors, said second plurality of independently moveable beam deflectors being disposed on a second surface opposed to the first surface comprising the at least second optical bypass.

[**0023**] In accordance with another embodiment of the invention, at least one of the first and second surface is one of a planar and a spherical surface.

[**0024**] Advantageously, the at least first optical bypass and the at least second optical bypass are disposed along an axis of symmetry.

[**0025**] In another embodiment of the present invention, the first plurality of independently moveable beam deflectors is disposed about the at least first optical bypass and the second plurality of independently moveable beam deflectors is disposed about the at least second optical bypass, said at least first optical bypass being in optical communication with the at least one input port and said at least second optical bypass being in optical communication with the at least two output ports. If desired, the optical switch further includes a first relay lens disposed about the axis of symmetry between the at least one input port and the first plurality of independently moveable beam deflectors, said first relay lens for receiving a beam of light from the at least one input port and for directing a beam of light to the first optical bypass. Advantageously, the at least one input port and the first plurality of independently moveable beam deflectors are disposed near or at a focal plane of the first relay lens.

[**0026**] In accordance with a further embodiment of the present invention, the optical switch further includes a second relay lens disposed about the axis of symmetry between the second plurality of independently moveable beam deflectors and the at least two output ports, said second relay lens for receiving a beam of light from the at least second optical bypass and for directing a beam of light to a selected one of the at least two output ports. Advantageously, the second plurality of independently moveable beam deflectors and the at least two output ports are disposed near or at a focal plane of the second relay lens.

[**0027**] If desired, a focal length of the first relay lens is approximately equal to a focal length of the second relay lens.

[**0028**] In accordance with yet a further embodiment of the present invention, the optical switch comprises an ATO element, said ATO element being disposed between the first and the second plurality of independently moveable beam deflectors along the axis of symmetry, said axis of symmetry being an optical axis of the ATO element. In accordance with an embodiment of the present invention, the ATO element is for passing a beam of light three times therethrough along an optical path between the at least one input port and a selected one of the at least two output ports. Advantageously, the first and the second plurality of independently moveable beam deflectors are disposed near or at a focal plane of the ATO element. If desired, the ATO element has a focal length approximately equal to a near zone length or Rayleigh range of a beam of light incident thereon.

[0029] In accordance with another embodiment of the invention, the first plurality of independently moveable beam deflectors and the second plurality of independently moveable beam deflectors comprise an array of micromirrors. The array of micromirrors can be a linear, rectangular, or radial array.

[0030] If desired, micro-lenses are disposed at the input and/or output ports to operate as collimators.

[0031] The input and/or output ports can have a parallel arrangement with respect to an axis of symmetry or they can be radially disposed about the axis of symmetry.

[0032] In accordance with the invention, there is further provided an optical switch comprising at least one input port for launching a beam of light into the optical switch, at least two output ports for selectively receiving the beam of light, a first plurality of independently moveable deflectors disposed about a first optical bypass for allowing a beam of light launched from the at least one input port to pass therethrough, and wherein input beams passing through the first optical bypass are substantially overlapping at the first optical bypass, and a second plurality of independently moveable deflectors disposed about a second optical bypass for allowing a beam of light to pass therethrough to any one of the at least two output ports, said second plurality of independently moveable deflectors being disposed so as to receive a beam of light that has passed through the first optical bypass, and wherein the first and second plurality of independently moveable deflectors are adapted to switch a beam of light, and wherein output beams passing through the second optical bypass are substantially overlapping at the second optical bypass.

[0033] In accordance with an embodiment of the invention, the first and second optical bypasses comprise a transmissive point through which input and output beams pass into and out of the optical switch.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] Exemplary embodiments of the invention will now be described in conjunction with the drawings in which:

[0035] **FIG. 1** is a schematic presentation of a prior art optical switch having a Z-shaped arrangement of optical components;

[0036] **FIG. 2** shows a schematic illustration of an optical switch in accordance with an embodiment of the present invention;

[0037] **FIG. 3** shows a schematic illustration of an optical switch in accordance with a further embodiment of the present invention having a radial arrangement of input and output ports;

[0038] **FIG. 4** shows a schematic illustration of an optical switch in accordance with a further embodiment of the present invention further including relay lenses; and

[0039] **FIG. 5** shows a schematic illustration of yet another embodiment of an optical cross-connect in accordance with the present invention further including an ATO element.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0040] The present invention provides an optical switch in which light beams enter/exit a switch core through a common region where the input/output beams intersect.

[0041] The optical switch in accordance with the present invention allows for switching of optical signals between optical waveguides, e.g. optical fibers. In an optical network, the fibers entering and exiting a switching core may be bundled into a group of input fibers and a group of output fibers. The ends of the input and output fibers may further be arranged into two separate rectangular arrays. If desired, the ends of the input and output fibers may be mixed together in one rectangular array. However, in certain applications, the input and output fibers may be arranged in other suitable manners, as will be explained in further detail below, particularly in conjunction with **FIG. 2**. Further, an individual fiber may function as an input fiber as well as an output fiber depending upon the direction of propagation of an optical signal in a bidirectional communication environment. Accordingly, although this description includes references to input and output fibers for purposes of illustration, it will be understood that each of the fibers may send and receive optical signals.

[0042] **FIG. 2** shows a schematic illustration of an optical switch **200** in accordance with an embodiment of the present invention. As can be seen from **FIG. 2**, the optical switch includes a switch core **210**, an optical bypass **220**, at least two deflectors (not shown) within the switch core **210**, an input waveguide **230***a* terminating in a respective optical port **232***a* which incorporates a collimating lens centered on the optical axis of the respective waveguide **230***a*, and output waveguides **230***b-d* terminating in respective optical ports **232***b-d* incorporating collimating lenses centered on the optical axes of the respective waveguides **230***b-d*. The optical ports **232***a-d* are arranged radially about optical bypass **220** so that the respective optical axes of the ports **232***a-d* converge at the optical bypass **220**.

[0043] The term optical bypass in this description is used to provide an unobstructed path through the switch core to enable light beams to enter/exit the switch core. This is accomplished by providing an opening that defines a passage through which light beams can pass. Alternatively, each optical bypass can be provided as a region of the switch core structure that is substantially transparent to optical wavelengths of light beams being switched through optical switch. This latter arrangement can be readily achieved by providing the switch core on a conventional Si and/or SiO_2 substrate, which is typically transparent to the wavelengths of interest. In this case, the optical bypass is readily constructed by providing a suitably sized region of the substrate that is unobstructed by the deflectors and/or associated deflector control circuitry.

[0044] The propagation path of a light beam is indicated by arrowheads. An input beam is launched into optical port **232***a*. The optical port **232***a* with its respective collimating lens guides the input beam into the switch core **210** via bypass **220**. The deflectors provided within the switch core **210** operate to switch the light beam to any of ports **232***b-d*. **FIG. 2** shows an output beam exiting the switch core **210** via bypass **220** to be switched to port **232***d*.

[0045] Turning now to **FIG. 3**, an optical switch **300** is presented in accordance with a further embodiment of the present invention. Switch **300** includes a switch core **310** defined by a pair of opposed arrays **322***a-b*. Each array **322** includes mirrors/micro-mirrors **324** disposed on a MEMS and optical bypasses **320** through which light beams can enter/exit the switch core **310**.

[**0046**] Each MEMS mirror **324** is preferably provided as a two-dimensionally tiltable micro-mirror which can be selectively oriented, in a manner known in the art, to deflect a light beam received from any optical element **320, 324** of the opposite array **322** to any other optical element **320, 324** of the opposite array **322**. In this manner, each MEMS mirror **324** can be selectively positioned to define an optical path between any two optical elements **320, 324** of the opposite optical array **322**. This positioning capability of each MEMS mirror **324** enables highly versatile switching of light beams within the switch core **310**. If desired, the MEMS mirrors can be arranged on any surface, such as a sphere, rather than on a plane.

[**0047**] As shown in **FIG. 3**, optical bypass **320***a* is associated with an input fiber bundle **312** that includes waveguides **314***a-d* terminating in optical ports **316***a-d* which incorporate a collimating lens centered on the optical axes of the respective waveguides **314***a-d,* and optical bypass **320***b* is associated with an output fiber bundle **332** that includes waveguides **334***a-d* terminating in optical ports **336***a-d* which incorporate a collimating lens centered on the optical axes of the respective waveguides **334***a-d.*

[**0048**] Advantageously, as is seen from **FIG. 3**, the optical components of switch **300** are provided about an axis of symmetry **325** passing through optical bypasses **320**. The optical paths of light beams entering/exiting switch core **310** are converging at a transmissive point **318** as they pass through a respective optical bypass **320** into and out of the switch core **310**. In the embodiment presented in **FIG. 3**, this is achieved by radially arranging waveguides **314** and **334** about a respective optical bypass **320**, so that the respective optical axes of ports **316** and **336** converge at a respective optical bypass **320**.

[**0049**] A mirror **324** of one array **322** can be positioned to define a propagation path between any two optical elements **324, 320** of the respective opposite array **322**. In the present invention, this capability is employed to provide a folded path 3D switch core **310** in which the mirrors **324** of the optical arrays **322** can be positioned to switch incoming light beams into multiple switching optical paths.

[**0050**] In general, a switching optical path is a propagation path in which a light beam received (by a respective mirror **324**) from a bypass **320** is deflected to a respective mirror **324** of the opposite array **322**, or vice versa. Thus in a switching optical path, a light beam traverses the switch core **310** with two reflections.

[**0051**] To illustrate the operation of switch **300**, an input beam IB is shown to enter switch **300** from the left via bypass **320***a*. Input beam IB is deflected at point A by mirror **324** on array **322***b*. Mirror **324** deflects the input beam IB towards point B on mirror **324** of the opposed array **322***a,* and from there it is guided out of switch core **310** via bypass **320***b* towards output port **336***a* to result a switched output beam SOB1, as indicated by a dash-dot line. Alternatively, a different output port can be targeted. In this case, mirror **324** on array **322***b* deflects the input beam IB from point A to point C where another mirror **324** on array **322***a* deflects the beam out of switch core **310** via bypass **320***b* towards output port **336***d* to result a switched output beam SOB2, as indicated by a dashed line.

[**0052**] It is appreciated that many more optical pathways can be selected between any of the input waveguides **314** and output waveguides **334**. Furthermore, as is known in the art, light beams may propagate bi-directionally within each waveguide **314, 334**. Similarly, each fiber bundle **312, 332** may carry bi-directional traffic, with beams propagating in one direction in some waveguides, and in the opposite direction in other waveguides of the same fiber bundle. It is further seen that due to the symmetry of the optical arrays **322** defining the switch core **310**, light beams may enter the switch core **310** through any fiber bundle **312, 322**, and may exit the switch core **310** through any other fiber bundle **312, 322**.

[**0053**] Referring to **FIG. 4**, an optical switch **400** is presented in accordance with a further embodiment of the present invention. Switch **400** includes an input fiber bundle **412**, an output fiber bundle **432**, a switch core **410**, an input relay lens **450***a,* an output relay lens **450***b.* The input fiber bundle **412** includes a plurality of waveguides **414***a-d* terminating in micro-lenses **416***a-d* centered on the optical axis of the respective waveguides **414***a-d.* Analogously, output fiber bundle **432** includes a plurality of waveguides **434***a-d* terminating in micro-lenses **436***a-d* centered on the optical axis of the respective waveguides **434***a-d.* The fiber bundles **412, 432** are arranged on opposite sides of the switch core **410** along an optical axis OA passing through relay lenses **450***a, b.* The switch core **410** is defined by a pair of opposed arrays **422***a-b*. Each array **422***a,b* includes mirrors/micro-mirrors **424** disposed on a MEMS chip and optical bypasses **420***a,b* comprising a transmissive point **418***a, b* through which light beams can enter/exit the switch core **410**.

[**0054**] Each MEMS array **422** is provided with an optical bypass **420**, such as a hole or optically transparent region, as described heretofore, through which light beams propagating to/from waveguides **414, 434** can enter/exit the switch core **410** through the transmissive point **418**. The optical paths of the light beams emerging from waveguides **414, 434** are made to converge within this transmissive point at the optical bypass. In the embodiment presented in **FIG. 4**, this is achieved by means of relay lenses **450***a, b* disposed between fiber bundle **412, 432** and the nearest MEMS array **422***a, b* along the optical axis OA passing through relay lenses **450***a, b.* The fiber bundle **412** and the MEMS array **422***a* are separated from the relay lens **450***a* by a distance that corresponds approximately to a focal length f_1 of relay lens **450***a*. Fiber bundle **432** and the MEMS array **422***b* are separated from the relay lens **450***b* by a distance that corresponds approximately to a focal length f_2 of relay lens **450***b*. Advantageously, relay lenses **450***a, b* are chosen to have a same focal length. This arrangement facilitates a compact switch core design while enabling a light beam to propagate between each waveguide **414, 434** and a respective MEMS mirror **424** on the opposite side of the switch core **410**.

[**0055**] Advantageously, the embodiment of the invention presented in **FIG. 4** provides an optical switch **400** that is easier to package than optical switch **300** presented in **FIG. 3**, for example, because the waveguides **414, 434** of fiber bundles **412, 432** are symmetrically arranged about a respective axis of symmetry that substantially coincides with the optical axis OA. However, more optical components, i.e. the relay lenses **450***a,* **450***b,* are required to realize this embodiment. In the illustrated embodiment, each fiber bundle **412, 432** comprises 4 waveguides **414***a-d,* **434***a-d* arranged in a linear array (that is, lying in the plane of the page). It will be appreciated that each fiber bundle **412, 432** may comprise fewer or more waveguides **414, 434,** and that the waveguides **414, 434** may be arranged in a two-dimensional array, that is, with each waveguide **414, 434** terminating in a plane extending substantially perpendicular to the page of the drawings. Within each fiber bundle **412, 432,** each waveguide **414, 434** terminates in a respective optical port **416, 436** which incorporates a micro-lens centered on the optical axis of the respective waveguide **414, 434.** The optical ports **416, 436** operate to guide a light beam propagating into the switch core **410** from the waveguides **414, 434** and vice versa.

[0056] Generally optical switch **400** operates analogously to switch **300** presented in conjunction with **FIG. 3, i**.e. with the exception of converging the input/output beams in a transmissive point at the optical bypass of the switch core by using a relay lens. An exemplary input beam IB enters switch core **410** via bypass **420***a.* The input beam IB is deflected at point A by one of the micro-mirrors **424** of MEMS array **422***b.* From there, two possible pathways are shown in **FIG. 4** to result in a switched output beam SOB1 (dash-dot line) by deflecting the beam via point B and a switched output beam SOB2 (dashed line) by deflecting the beam via point C. In dependence upon a tilt of mirror **424** of array **422***b* at point A the input beam is deflected to another micro-mirror **424** of the opposite array **422***a* at point B in one switching mode. Mirror **424** at point B directs the beam out of the switch core **410** via transmissive point **418***b* at optical bypass **420***b* to point D at the relay lens **450***b.* In another switching mode, mirror **424** of array **422***b* at point A deflects the input beam to another mirror **424** of the opposite array **422***a* at point C Mirror **424** at point C is operated to deflect the beam out of the switch core **410** via transmissive point **418***b* at the optical bypass **420***b* to point E at the relay lens **450***b.* Both output beams, SOB1 and SOB2, are directed to their respective output ports **436***a,* **436***d* by means of relay lens **450***b.*

[0057] **FIG. 5** shows yet another embodiment of an optical cross-connect **500** in accordance with the present invention. As is shown in **FIG. 5**, the optical cross-connect **500** includes a switch core **510** defined by a pair of opposed optical arrays **522***a, b* symmetrically arranged on opposite sides of an angle-to-offset (ATO) element **560**, such as an ATO lens **560** having a focal length f_{ATO}. The ATO lens **560** operates to deflect the propagation path of light beams within the switch core **510**. For the purposes of the present invention, an ATO lens **560** can be provided as any suitable optical element having optical power, e.g. a mirror or a lens.

[0058] While not essential for the purpose of the present invention, the ATO element preferably has a focal length f_{ATO} that substantially corresponds to the near zone length (multi mode) or the Rayleigh range (single mode) of a beam of light propagating through optical cross-connect **500**. The use of such an ATO element means that the size, i.e. the cross-sectional area, of a beam switched through switch core **510** is substantially the same on both mirror arrays **522***a, b.* If the beam size is the same on both mirror arrays **522***a, b* as a result of providing an ATO lens **560** having a focal length substantially equal to the Rayleigh range, a very compact optical switch can be designed. In addition, the provision of re-imaging optics (relay lenses **550***a, b* and ATO lens **560**), enables to achieve a low loss optical switch.

[0059] The ATO principle is described in further detail in Canadian Patent Application No. 2,326,362, the disclosure of which is herein incorporated by reference.

[0060] Optical switch **500** is scalable to 4000×4000 switch based on arrays **522** of two-dimensional tilt mirrors **524** and ATO lens **560**.

[0061] Each array **522***a, b* includes micro-mirrors **524** disposed on a MEMS chip and transmissive points **518***a, b* at respective optical bypasses **520***a, b* through which light beams can enter/exit the switch core **510**. In accordance with the embodiment presented in **FIG. 5**, optical bypasses **520***a, b* are provided in the form of an optically transparent region, for example a region on the MEMS substrate that is unobstructed by a micro-mirror, associated mirror control circuitry or any other optical element or a window. The optical arrays **522***a, b* are preferably positioned to lie in respective opposite focal planes of the ATO lens **560**. As is seen from **FIG. 5**, each optical array **522** has an axis of symmetry that substantially coincides with an optical axis of the ATO lens **560** and the optical axis OA of switch **500**.

[0062] Each MEMS mirror **524** is preferably provided as a two-dimensionally tiltable micro-mirror which can be selectively oriented, as described heretofore, to deflect a light beam received from any optical element **520, 524** of the opposite array **522** to any other optical element **520, 524** of the opposite array **522**. In this manner, each MEMS mirror **524** is selectively positioned to define an optical path between any two optical elements **520, 524** of the opposite optical array **522**.

[0063] Optical switch **500** further comprises an input fiber bundle **512** including a plurality of waveguides **514***a* having an input micro-lens array **516***a* placed at an end face of input fiber bundle **512** with one micro-lens centered on an optical axis of each fiber. An input relay lens **550***a* is provided between the micro-lens array **516***a* and a first array **522***a* that includes the two-dimensional tilt mirrors/micro mirrors **524**. The input microlens array **516***a* and the first array **522***a* are separated from the input relay lens **550***a* by a distance that corresponds approximately to the focal length f_1 of the input relay lens **550***a.* This input relay lens **550***a* directs a beam of light incident thereon through a transmissive point **518***a* at bypass **520***a* of the first array **522***a.* The first array **522***a* is followed by an ATO lens **560**, and a second array **522***b* having an array of two-dimensional tilt mirrors/micro mirrors **524** and a bypass **520***b* comprising a transmissive point **518***b* disposed thereon. Both, the first array **522***a* and the second array **522***b* are arranged at a distance from the ATO lens **560** which corresponds approximately to the focal length f_{ATO} of ATO lens **560**. The second array **522***b* is followed by an output relay lens **550***b* which focuses the light beams to an output micro-lens array **516***b* provided at an end face of an output fiber bundle **514***b* having one micro-lens centered on an optical axis of each fiber. The second array **522***b* and the output micro-lens array **516***b* are separated from the output relay lens **550***b* by a distance that corresponds approximately to the focal length f_2 of the output relay lens **550**_b_. In accordance with a preferred embodiment of the present invention, the input relay lens **550**_a_ and the output relay lens **550**_b_ have a same focal length, $f_1=f_2$, for maintaining a high degree of symmetry and compactness of optical cross-connect **500**.

[**0064**] All optical components of cross-connect **500** are arranged about the optical axis OA. Such an arrangement provides for an even more compact design of an optical switch in accordance with the present invention, and lessens aberration effects of the lens.

[**0065**] In order to demonstrate more clearly how optical cross-connect **500** functions, an exemplary input beam of light IB is traced along an optical path A to H through cross-connect **500**. The input beam IB exits input fiber bundle **512**_a_ at point A, i.e. from an end face of fiber **514**_a_ having a micro-lens disposed thereon. Beam IB propagates parallel to the optical axis OA until it reaches point B on the input relay lens **550**_a_. Input relay lens **550**_a_ directs beam IB at an angle to the optical axis OA to point C on the ATO lens **560** through the transmissive point **518**_a_ at the bypass **520**_a_ in the first array **522**_a_. The ATO lens **560** directs the beam parallel to the optical axis OA to point D on one of the micro-mirrors **524** on the second array **522**_b_. From this point on, i.e. point D, there are two possible pathways shown in **FIG. 5** for the beam to yield a switched output beam SOB**1**, as indicated by a dash-dot line, or a switched output beam SOB**2**, as indicated by the dashed line, in dependence upon a tilting of the respective micro-mirror **524**. However, for illustrative purposes only the propagation path following the dash-dot line is described hereinafter.

[**0066**] The respective micro-mirror **524** on the second array **522**_b_ switches the light beam to point E on one of the micro-mirrors on the first array **522**_a_ after passing through the ATO lens **560**. The respective micro-mirror **524** on the first array **522**_a_ directs the light beam back to point F on the ATO lens **560** parallel to the optical axis OA and then at an angle to the optical axis OA to point G on the output relay lens **550**_b_ through transmissive point **518**_b_ at bypass **520**_b_ of the second array **522**_b_. The output relay lens **550**_b_ collects the beam of light beam coming from bypass **520**_b_ and images it on the output micro-lens array **516**_b_ at point H. An output fiber **514**_b_ of the output fiber bundle **512**_b_ collects the beam from the output micro-lens array **516**_b_ to yield SOB**2**.

[**0067**] It is appreciated that cross-connect **500** also functions in reverse, i.e. the output fiber bundle **512**_b_ then functions as the input fiber bundle and so forth.

[**0068**] Advantageously, this embodiment of an optical cross-connect **500** in accordance with the present invention provides for the use of high fill factor arrays of two-dimensionally tiltable micro-mirrors **524** to redirect light beams while providing a very compact switch core **510** which lessens aberration effects of the ATO lens **560**. The linear arrangement of all components along the optical axis OA affords a very compact design of cross-connect **500**. A further factor in affording a compact cross-connect **500** is that small optical components can be used in this switch because of the beam geometry.

[**0069**] Numerous other embodiments can be envisaged without departing from the spirit and scope of the invention. For example, multiple optical bypasses can be provided on any one MEMS array. In this case, a plurality of symmetry axes exist that are parallel to the optical axis OA.

What is claimed is:

1. An optical switch comprising:

at least one input port for launching a beam of light into the optical switch;

at least two output ports for selectively receiving a beam of light;

a switch core in optical communication with the at least one input port and the at least two output ports;

at least a first optical bypass, disposed at the switch core, comprising a first transmissive point through which output beams pass out of the switch core, said output beams substantially overlap each other at the first optical bypass; and

a plurality of beam deflectors disposed in the switch core for switching the beam of light from the at least one input port to a selected one of the at least two output ports through the transmissive point of the at least first optical bypass.

2. The optical switch as defined in claim 1 wherein the at least first optical bypass is in optical communication with the at least one input port for allowing input beams to pass into the switch core via the first transmissive point.

3. The optical switch as defined in claim 2 wherein at least one of the plurality of beam deflectors is an independently moveable beam deflector.

4. The optical switch as defined in claim 3 wherein the plurality of beam deflectors includes a first plurality of independently moveable beam deflectors, said first plurality of independently moveable beam deflectors being disposed on a first surface comprising the at least first optical bypass.

5. The optical switch as defined in claim 1 further including an at least second optical bypass for allowing at least one of input and output beams to pass into and out of the switch core.

6. The optical switch as defined in claim 5 wherein the plurality of beam deflectors includes a second plurality of independently moveable beam deflectors, said second plurality of independently moveable beam deflectors being disposed on a second surface opposed to the first surface comprising the at least second optical bypass.

7. The optical switch as defined in claim 6 wherein at least one of the first and second surface is one of a planar and a spherical surface.

8. The optical switch as defined in claim 7 wherein the at least first optical bypass and the at least second optical bypass are disposed along an axis of symmetry.

9. The optical switch as defined in claim 8 wherein the first plurality of independently moveable beam deflectors is disposed about the at least first optical bypass and the second plurality of independently moveable beam deflectors is disposed about the at least second optical bypass, said at least first optical bypass being in optical communication with the at least one input port and said at least second optical bypass being in optical communication with the at least two output ports.

10. The optical switch as defined in claim 9 further including a first relay lens disposed about the axis of symmetry between the at least one input port and the first plurality of independently moveable beam deflectors, said first relay lens for receiving a beam of light from the at least one input port and for directing a beam of light to the first optical bypass.

11. The optical switch as defined in claim 10 wherein the at least one input port and the first plurality of independently moveable beam deflectors are disposed near or at a focal plane of the first relay lens.

12. The optical switch as defined in claim 10 further including a second relay lens disposed about the axis of symmetry between the second plurality of independently moveable beam deflectors and the at least two output ports, said second relay lens for receiving a beam of light from the at least second optical bypass and for directing a beam of light to a selected one of the at least two output ports.

13. The optical switch as defined in claim 12 wherein the second plurality of independently moveable beam deflectors and the at least two output ports are disposed near or at a focal plane of the second relay lens.

14. The optical switch as defined in claim 13 wherein a focal length of the first relay lens is approximately equal to a focal length of the second relay lens.

15. The optical switch as defined in claim 8 further comprising an ATO element, said ATO element being disposed between the first and the second plurality of independently moveable beam deflectors along the axis of symmetry, said axis of symmetry being an optical axis of the ATO element.

16. The optical switch as defined in claim 15 wherein the ATO element is for passing a beam of light three times therethrough along an optical path between the at least one input port and a selected one of the at least two output ports.

17. The optical switch as defined in claim 15 wherein the first and the second plurality of independently moveable beam deflectors are disposed near or at a focal plane of the ATO element.

18. The optical switch as defined in claim 17 wherein the ATO element has a focal length approximately equal to a near zone length or Rayleigh range of a beam of light incident thereon.

19. The optical switch as defined in claim 17 wherein the ATO element is one of a lens and a mirror.

20. The optical switch as defined in claim 8 wherein the first plurality of independently moveable beam deflectors and the second plurality of independently moveable beam deflectors comprise an array of micro-mirrors.

21. The optical switch as defined in claim 20 wherein the array of micro-mirrors is one of a linear, rectangular, and radial array.

22. The optical switch as defined in claim 9 further including at least one micro-lens disposed at at least one of the at least one input port and the at least two output ports.

23. The optical switch as defined in claim 22 wherein the at least one input port and the at least two output ports are parallel to the optical axis or radially disposed about the optical axis.

24. An optical switch comprising:

at least one input port for launching a beam of light into the optical switch;

at least two output ports for selectively receiving the beam of light;

a first plurality of independently moveable deflectors disposed about a first optical bypass for allowing a beam of light launched from the at least one input port to pass therethrough, and wherein input beams passing through the first optical bypass are substantially overlapping at the first optical bypass; and

a second plurality of independently moveable deflectors disposed about a second optical bypass for allowing a beam of light to pass therethrough to any one of the at least two output ports, said second plurality of independently moveable deflectors being disposed so as to receive a beam of light that has passed through the first optical bypass, and wherein the first and second plurality of independently moveable deflectors are adapted to switch a beam of light, and wherein output beams passing through the second optical bypass are substantially overlapping at the second optical bypass.

25. The optical switch as defined in claim 24 wherein the first and second optical bypasses comprise a transmissive point through which input and output beams pass into and out of the optical switch.

* * * * *