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(54) **RECONFIGURABLE OPTICAL SWITCH**

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(58) **Field of Search** 385/16, 17, 18, 385/24, 31, 33, 47; 359/131, 196, 212, 127, 124

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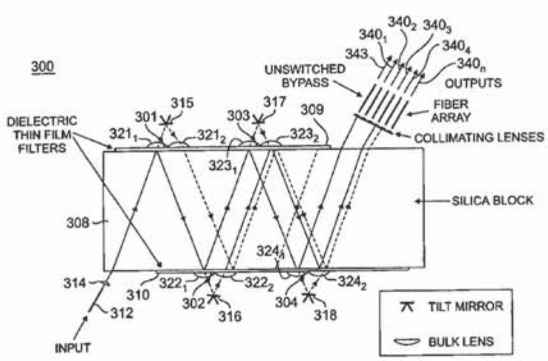
(57) **ABSTRACT**

An optical switch includes at least one input port for receiving a WDM optical signal having a plurality of wavelength components, at least three output ports, and a plurality of wavelength selective elements each selecting one of the wavelength components from among the plurality of wavelength components. A plurality of optical elements are also provided, each of which are associated with one of the wavelength selective elements. Each of the optical elements direct the selected wavelength component that is selected by its associated selected element to a given one of the output ports independently of every other wavelength component. The given output port is variably selectable from among all the output ports.

88 Claims, 3 Drawing Sheets



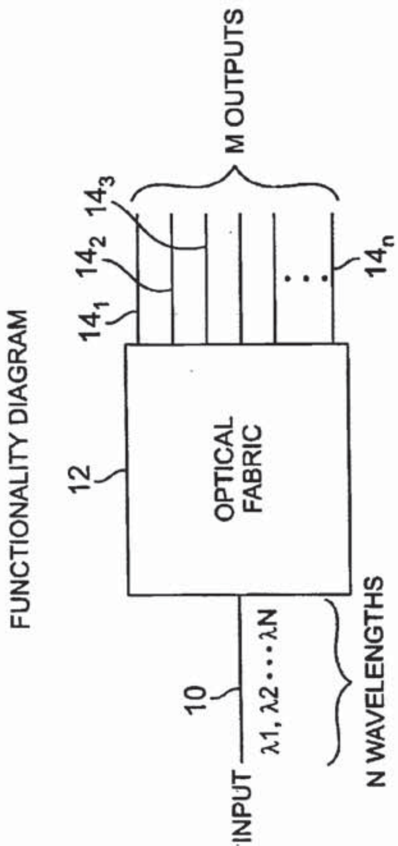

FUNCTIONALITY DIAGRAM
12
OPTICAL FABRIC
14_1
14_2
14_3
14_n
M OUTPUTS
10
INPUT
$\lambda 1, \lambda 2 \cdots \lambda N$
N WAVELENGTHS

FIG. 1

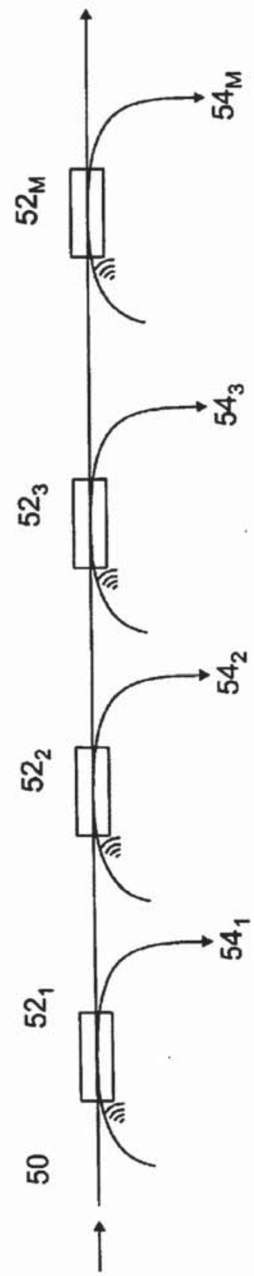

50
52_1
52_2
52_3
52_M
54_1
54_2
54_3
54_M

FIG. 3

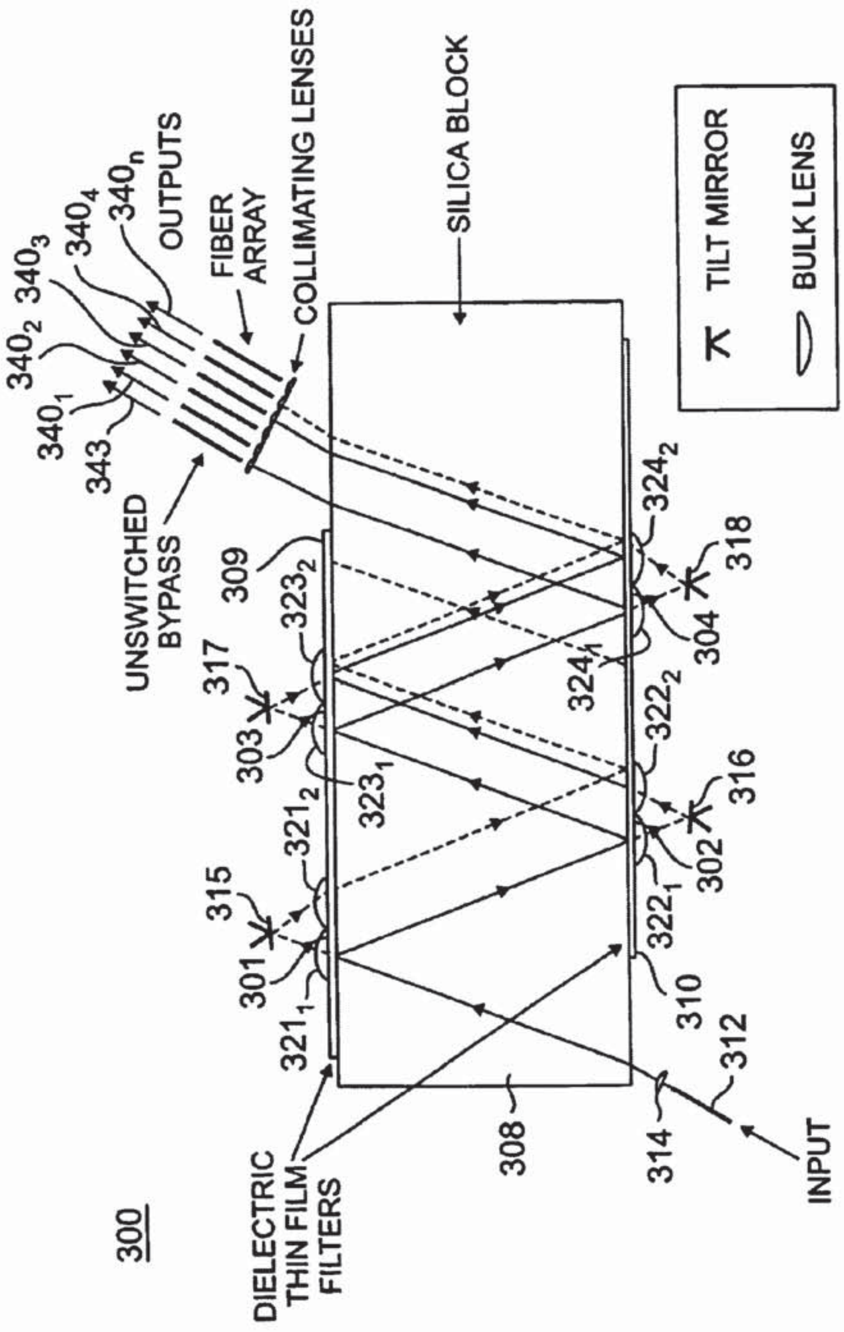

300
DIELECTRIC THIN FILM FILTERS
308
314
INPUT
312
310
321_1
301
315
321_2
322_1
302
316
322_2
323_1
303
317
323_2
309
324_1
304
318
324_2
UNSWITCHED BYPASS
343
340_1
340_2
340_3
340_4
340_n
OUTPUTS
FIBER ARRAY
COLLIMATING LENSES
SILICA BLOCK
TILT MIRROR
BULK LENS

FIG. 2

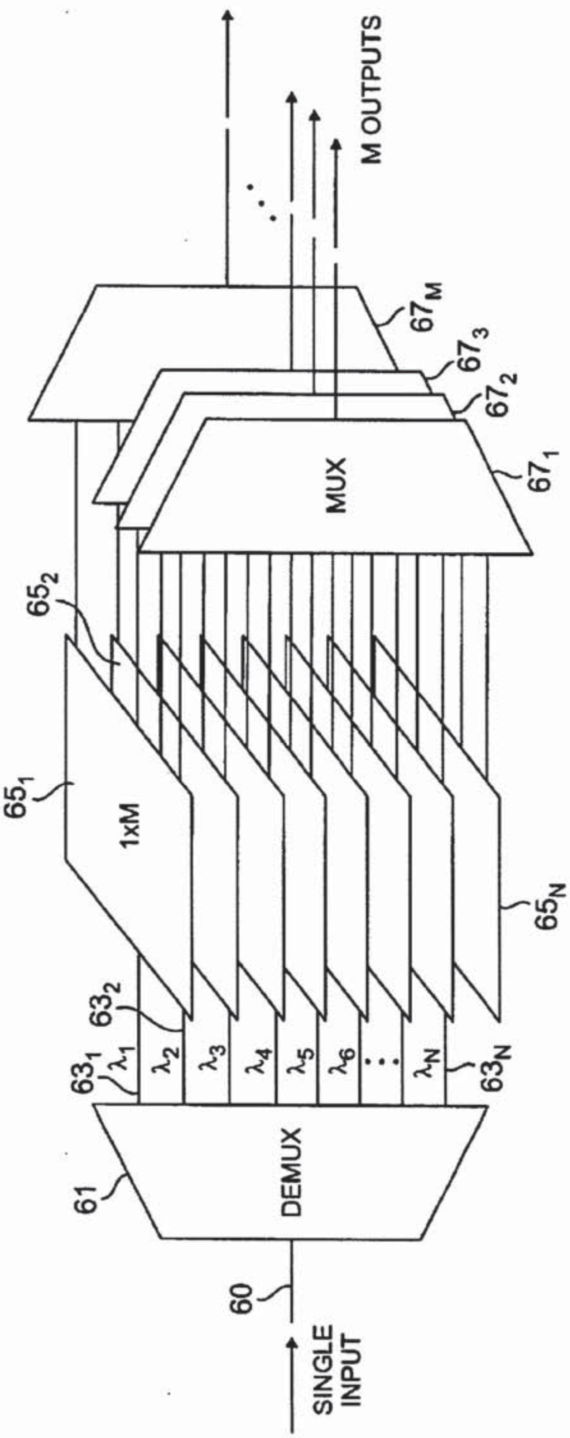

M OUTPUTS
67_M
67_3
67_2
67_1
MUX
65_2
65_1
1xM
65_N
63_1
63_2
λ_1
λ_2
λ_3
λ_4
λ_5
λ_6
λ_N
63_N
61
DEMUX
60
SINGLE INPUT

FIG. 4

RECONFIGURABLE OPTICAL SWITCH

STATEMENT OF RELATED APPLICATIONS

This application claims the benefit of priority to U.S. Provisional Patent Application Ser. No. 60/182,289, filed Feb. 14, 2000, entitled "An all Optical Router With Petabyte Per Second Switching Capability. "

FIELD OF THE INVENTION

The invention relates generally to an optical communications system and more particularly to an optical switch for flexibly routing light in a wavelength-selective manner.

BACKGROUND OF THE INVENTION

Significant interest exists in multi-wavelength communication systems, which are typically referred to as Wavelength Division Multiplexed (WDM) systems. These systems use a WDM optical signal having different wavelength components that support different streams of information. While WDM systems were initially investigated to increase the information capacity that a fiber could transmit between two points, recent improvements in optical filtering technology, among other things, has led to the development of switching elements which allow a complex network of paths to be constructed that differ from wavelength to wavelength. Furthermore, in addition to the availability of wavelength dependent switching elements in which a given wavelength is routed along a given path, reconfigurable optical elements have become available. Such reconfigurable optical elements can dynamically change the path along which a given wavelength is routed to effectively reconstruct the topology of the network as necessary to accommodate a change in demand or to restore services around a network failure.

Examples of reconfigurable optical elements include optical Add/Drop Multiplexers (OADM) and Optical Cross-Connects (OXC). OADMs are used to separate or drop one or more wavelength components from a WDM signal, which is then directed onto a different path. In some cases the dropped wavelengths are directed onto a common fiber path and in other cases each dropped wavelength is directed onto its own fiber path. OXCs are more flexible devices than OADMs, which can redistribute in virtually any arrangement the components of multiple WDM input signals onto any number of output paths.

The functionality of the previously mentioned reconfigurable optical elements can be achieved with a variety of different devices. For example, a common approach employs any of a number of different broadband switching fabrics inserted between a pair of demultiplexers/multiplexers. Examples of OADM elements are disclosed in U.S. Pat. Nos. 5,504,827, 5,612,805, and 5,959,749, and general OXC switching architecture is reviewed by E. Murphy in chapter 10 of *Optical Fiber Telecommunications IIIB*, edited by T. Koch and I. Kaminow. As shown in these references, these approaches sequentially demultiplex the wavelengths, perform the necessary switching and then remultiplex, where the OXC can direct a given wavelength onto any output because a conventional OXC uses a relatively complex MxM device for the switching fabric, while OADMs are less flexible due to their use of an array of 2×2 optical switches that can only direct between one of two outputs. Two alternate approaches to OADMs employ switchable mirrors effectively inserted between a device that simultaneously performs wavelength demultiplexing and multiplexing. The first of these approaches uses a thin film dielectric demultiplexer/multiplexer that is traversed twice by the wavelengths (e.g., U.S. Pat. No. 5,974,207), while the second approach uses dispersion from a bulk diffraction grating to demultiplex (separate) the wavelength channels before they reflect off an array of tiltable mirrors (U.S. Pat. No. 5,960,133). Another set of OADM technologies employ 4-port devices that drop multiple wavelengths onto a single fiber output in a reconfigurable manner, and thus require an additional demultiplexer if the channels need to undergo broadband optoelectronic conversion at the receiver. One realization of such functionality uses fiber optic circulators added to a two-port version of the previously-described diffraction grating demultiplexer and tilt mirror array (Ford et al., Postdeadline papers LEOS '97, IEEE Lasers and Electro-Optics Society). A second realization uses integrated silica waveguide technology (e.g., Doerr, IEEE Phot. Tech. Lett '98) with thermo-optic phase shifters to switch between the add and drop states for each wavelength. Another four-port OADM employs a fiber optic circulator and an optional tunable fiber grating reflector to route the dropped channels (e.g., C. R. Giles, IOOC '95, JDS 2000 catalog)

All of the aforementioned conventional optical switching technologies have shortcomings. These devices generally fall into two classes with respect to their shortcomings: very flexible devices with high cost and high optical loss, and lower flexibility devices, which are less expensive and have lower optical loss. The most flexible OXCs can be programmed to switch the path of any of a large number of wavelengths, each onto its own fiber (e.g. demux/mux with switches), however these devices may have up to 20 dB of insertion loss and therefore require an optical amplifier to compensate for the loss. This substantially adds to the cost of an already expensive device. Because these devices are so costly, less flexible alternatives such as fiber gratings and thin film filters are often used. While these devices have a significantly lower cost and insertion loss (2-5 dB/node), they are typically less flexible because they are implemented as fixed wavelength OADMs that cannot be reconfigured. These devices are also inflexible because as you scale them so that they drop more wavelengths their loss, cost, size and/or complexity increase to the point that the more flexible OXC alternatives become more attractive. Recently, as shown in U.S. Pat. No. 5,479,082, some flexibility has been added to these lowest cost OADM devices so that they can selectively drop or pass a predetermined subset of wavelengths that was previously designated as fixed. In addition, the previously described reconfigurable OADM devices offer somewhat enhanced flexibility, but typically at the expense of higher insertion loss (for Demux/switches), limited wavelength resolution (for bulk grating approaches), and/or higher cost for additional Mux/Demux equipment used in connection with four-port devices.

One particular limitation of the conventional OXC and OADM approaches, which demultiplex the incoming signal before optical switching is performed, is that each output port can only drop a particular fixed wavelength that cannot be altered. In this configuration each switch is arranged so that it only receives a preselected wavelength component from the demultiplexer, and therefore can only output that particular wavelength. Unless subsequent optical switching is used, the flexibility of these devices is limited since it is not possible to redirect a given wavelength from one output port to another output port or to redirect multiple wavelengths to a given output port, should that become necessary. This functionality is desirable when a unique element within the network is accessible through a particular port, and it is

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