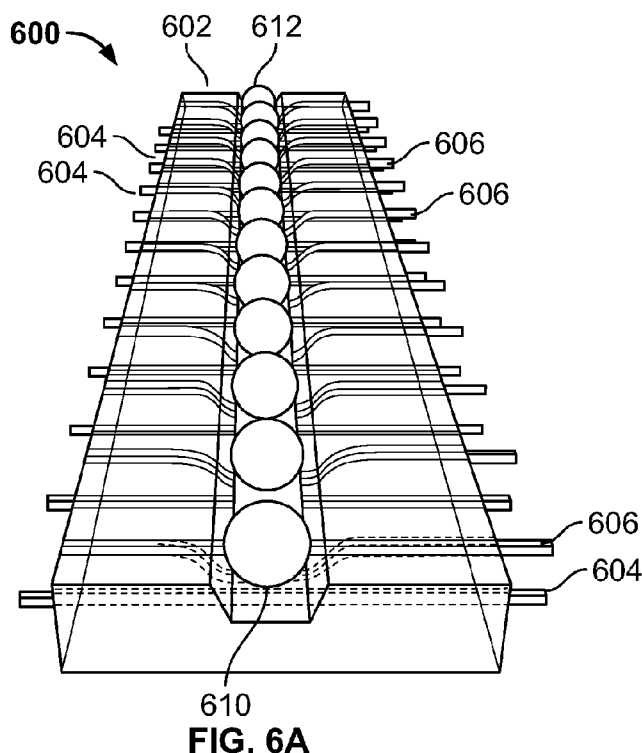




- (51) International Patent Classification:
G02B 6/35 (2006.01)
- (21) International Application Number:
PCT/EP2017/052476
- (22) International Filing Date:
3 February 2017 (03.02.2017)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
62/291,322 4 February 2016 (04.02.2016) US
- (71) Applicant: COMMSCOPE CONNECTIVITY BELGI-
UM BVBA [BE/BE]; Diestsesteenweg 692, B-3010 Kes-
sel-Lo (BE).
- (72) Inventors: LERMA ARCE, Cristina; Louis van Hout-
testraat 12, 9050 Gentbrugge (BE). WATTÉ, Jan; Molen-
straat 168, 1851 Grimbergen (BE). HUYBRECHTS,
Koen; Naamsesteenweg 74/0031, 3001 Heverlee (BE).
- (74) Agent: KEANE, David; Murgitroyd & Company, Scot-
land House, 165-169 Scotland Street, Glasgow Strathclyde
G5 8PL (GB).
- (81) Designated States (*unless otherwise indicated, for every
kind of national protection available*): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN,
KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA,
MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG,
NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS,
RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY,
TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN,
ZA, ZM, ZW.
- (84) Designated States (*unless otherwise indicated, for every
kind of regional protection available*): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,

[Continued on next page]

(54) Title: ACTIVE OPTICAL WAVEGUIDE DEVICE



(57) Abstract: The invention is directed to an active optical device that has a plurality of transmission waveguides in a substrate and is used for indexing. Each transmission waveguide has an input end and an output end. The substrate also includes either a single channel drop waveguide or a channel drop waveguide for each transmission waveguide. Coupling regions are formed between the transmission waveguides and the channel drop waveguides. Droplets of optical fluid are associated with the coupling regions, and selected movement of the droplets relative to the coupling regions either promotes or denies the ability to couple light in the coupling region, between the transmission waveguide and its channel drop waveguide. Any one of the active optical switches is activatable to couple light from its respective transmission waveguide into the channel drop waveguide.

WO 2017/134286 A1



SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, **Published:**
GW, KM, ML, MR, NE, SN, TD, TG).

— *with international search report (Art. 21(3))*

ACTIVE OPTICAL WAVEGUIDE DEVICE

Cross-Reference to Related Application

5 This application claims the benefit of U.S. Patent Application Serial No. 62/291,322, filed on February 4, 2016, the disclosure of which is incorporated herein by reference in its entirety.

Field of the Invention

The invention relates to optical data networks, and particularly to devices for splitting
10 fibers from a fiber bundle.

Background of the Invention

The present invention is generally directed to optical transmission networks, and more particularly to systems that permit flexible configuration of optical components in the field. Passive optical networks are becoming prevalent in part because service providers want to
15 deliver high bandwidth communication capabilities to customers. Passive optical networks are a desirable choice for delivering high-speed communication data because they may not employ active electronic devices, such as amplifiers and repeaters, between a central office and a subscriber termination. The absence of active electronic devices may decrease network complexity and/or cost and may increase network reliability.

20 FIG. 1 illustrates one embodiment of a network 100 deploying fiber optic lines. In the illustrated embodiment, the network 100 can include a central office 101 that connects a number of end subscribers 105 (also called end users 105 herein) in a network. The central office 101 can additionally connect to a larger network such as the Internet (not shown) and a public switched telephone network (PSTN). The network 100 can also include fiber distribution hubs (FDHs) 103
25 that distribute signals to the end users 105. The various lines of the network 100 can be aerial or housed within underground conduits.

The portion of the network 100 that is closest to central office 101 is generally referred to as the F1 region, where F1 is the "feeder fiber" from the central office 101. The portion of the network 100 closest to the end users 105 can be referred to as an F2 portion of network 100. The
30 network 100 includes a plurality of break-out locations 102 at which branch cables are separated

out from the main cable lines. Branch cables are often connected to drop terminals 104 that include connector interfaces for facilitating coupling of the fibers of the branch cables to a plurality of different subscriber locations 105.

5 An incoming signal is received from the central office 101, and is then typically split at a break-out location 102 or the FDH 103, using one or more optical splitters (e.g., 1x8 splitters, 1x16 splitters, or 1x32 splitters) to generate different user signals that are directed to the individual end users 105. In typical applications, an optical splitter is provided prepackaged in an optical splitter module housing and provided with a splitter output in pigtails that extend from the module. The optical splitter module provides protective packaging for the optical splitter
10 components in the housing and thus provides for easy handling for otherwise fragile splitter components. This modular approach allows optical splitter modules to be added incrementally to FDHs 103 as required.

An important factor in maintaining such fiber networks is the reduction of complexity for the technician. Fibers are typically “indexed” so that there is uniformity between each break-out
15 location 102 or FDH 103 as to which fiber(s) is split out from the bundle. For example, if a single fiber is split out from the fiber bundle at each FDH 103, it may be useful for the fiber that is being split out at each FDH 103 is at the same position on each bundle connector. This makes connection to the split fiber less complicated, and reduces a source of error in maintenance of the network. Current indexing methods are passive and static, so changing the indexing protocol at a
20 break-out location 102 or FDH 103 requires the technician to travel the break-out location 102 or FDH 103 in question.

Therefore, there is a need to remotely control indexing of fibers which will reduce the need for technician visits, thus reducing the costs of maintaining the fiber system.

Summary of the Invention

25 One embodiment of the invention is directed to a first active optical device that has a plurality of transmission waveguides in a substrate. Each transmission waveguide has an input end and an output end. The substrate also includes a channel drop waveguide that has a channel drop output. Portions of the channel drop waveguide respectively forming coupling regions with the transmission waveguides. Droplets of optical fluid are respectively associated with the
30 coupling regions, and the positions of the droplets of the optical fluid relative to the respective coupling regions are adjustable - the respective droplets of optical fluid and coupling regions

form active optical switches. Any one of the active optical switches is activatable to couple light from its respective transmission waveguide into the channel drop waveguide.

In some embodiments of the invention, the first active optical device is located in a first terminal incorporated in an optical communications system. The system has an optical
5 transmitter system, a first multi-fiber cable coupled to receive optical signals from the optical transmitter system, and the first terminal is coupled to the first multi-fiber cable. A second multi-fiber cable is coupled to an output of the first terminal. A splitter is coupled to receive light from the channel drop output.

Another embodiment of the invention is directed to a second active optical device that
10 includes a plurality of transmission waveguides in a substrate, each transmission waveguide having an input end and an output end. The substrate also contains a plurality of channel drop waveguides, each channel drop waveguide forming a coupling region with a respective transmission wavelength of the plurality of transmission waveguides. The channel drop waveguides have channel drop outputs. Droplets of optical fluid are respectively associated with
15 the coupling regions, and positions of the droplets of the optical fluid relative to the respective coupling regions are adjustable - the respective droplets of optical fluid and coupling regions form active optical switches. Any one of the active optical switches is activatable to couple light from its respective transmission waveguide into its respective channel drop waveguide.

In some embodiments, the second active device is included in a first terminal in an
20 optical communications system that has an optical transmitter system, a first multi-fiber cable is coupled at one end to receive optical signals from the optical transmitter system and at another end to the first terminal coupled. A second multi-fiber cable is coupled to the first terminal. A splitter is optically coupled to receive optical signals from the channel drop output.

Brief Description of the Drawings

25 The invention may be more completely understood in consideration of the following detailed description of various embodiments of the invention in connection with the accompanying drawings, in which:

FIG. 1 schematically illustrates various elements of an optical data distribution and communication network that can include the optical devices of the present invention;

30 FIG. 2 schematically illustrates an embodiment of a cascaded optical network that can incorporate the optical devices of the present invention;

FIG. 3 schematically illustrates a prior art approach to indexing optical fibers;

FIGs. 4A and 4B schematically illustrate an embodiment of an electro-wetting optical device (EWOD) optical switch used in embodiments of the present invention;

FIGs. 5A and 5B schematically illustrate an embodiment of an optically integrated, actively switched, channel-dropping device according to an embodiment of the present invention; and

FIGs. 6A and 6B schematically illustrate another embodiment of an optically integrated, actively switched, channel-dropping device according to an embodiment of the present invention.

While the invention is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the invention to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

Detailed Description

The present invention is directed to various optical devices and systems that can provide benefit in optical networks by providing for the management of optical signals in a way that permits identical components to be used at different stages along the fiber network, thus reducing the need for technician visits to a fiber distribution hub (FDH) and allowing various operations to be carried out more quickly than using conventional passive optical components.

The terms “input” and “output” are used herein to help understand various optical elements, and are typically used with reference to light signals propagating in a direction from the central office to the user. Thus, the “input” side of an optical element typically receives optical signals from the central office and the signals leave the “output” side of the optical element to propagate on to the user. There is no intention to imply any limitation on the direction of propagation of the light signals through the use of the terms “input” and “output,” and it is understood that in many systems light signals propagate both from the central office to the user and from the user to the central office.

In an illustrated embodiment of the invention, the optical network 100 includes a cable 110 that connects to an FDH 103. The cable 110 includes at least an optical data transmission

fiber and an optical control and power channel. The following describes a strategy of building a fiber network that is enabled by hardened, multiple fiber connectivity and plug-and-play indexed patch terminal concept that, in a repeated manner, can be used at different nodes of the network. Ruggedized connectors are considered important components in enabling connectivity products because they allow fast connectivity jobs by eliminating the need for highly skilled labor. A ruggedized connector is used for coupling multiple fibers in a single operation. For example, a ruggedized MPO connector may connect 12 fibers. Fig. 2 schematically illustrates an embodiment of a fiber network 200 that includes a central office 202 connected via a multi-fiber cable 204 to a first indexed terminal 206. The multi-fiber cable 204 is coupled to the indexed terminal 206 via a ruggedized connector 208, such as a ruggedized MPO connector or the like. In the illustrated embodiment, the multi-fiber cable carries 12 fibers, although it may carry a different number of fibers. The indexed terminal 206 may be located at a break-out location or at a FDH. Subsequent indexed terminals 206 are coupled in series via intermediate multi-fiber cables 204.

A cascaded approach to splitting optical signals in a passive optical network (PON) is schematically illustrated in FIG. 2. The PON 200 is connected at the central office 202. A multi-fiber cable 204 is connected at one end to the central office 202 via a multi-fiber optical connector 206. The other end of the multi-fiber cable 204 is connected via another multi-fiber optical connector 206 to an indexed terminal 208. The indexed terminal 208 may be located at any suitable point along the PON 200 where it is desired to split an optical fiber off from the multi-fiber cable 204, such as an FDH. Multiple indexed terminals 208 are connected in series using a repeated building block of a multi-fiber cable 204 connected to an indexed terminal 208 using multi-fiber optical connectors 206.

At each indexed terminal 208, one or more fibers are split off from the multi-fiber cable 204, and each split fiber may be directed through an optical splitter 210 at the indexed terminal to produce indexed terminal outputs 212. In the illustrated embodiment, the indexed terminals 208 are provided with 1 x 4 splitters, so each indexed terminal 208 provides four terminal outputs 212. It will be appreciated that the indexed terminal need not include a splitter, and may just provide a single output or may include other sizes of splitters, such as 1 x 8 splitters or the like.

In one particular embodiment of a PON 200, the multi-fiber cable 204 contains 12 optical fibers and is terminated at each end with a hardened MPO-type multi-fiber optical connector 206. However, it will be appreciated that other types of multi-fiber cable 204 and other types of multi-fiber optical connectors 206 may be used in the invention. An advantage of this approach to constructing a PON 200 is that identical components can be used at each stage.

Current methods of indexing are hard-wired, as is discussed with reference to FIG. 3, which shows two indexed terminals 308 connected by a multi-fiber cable 304 and multi-fiber optical connectors 306. The multi-fiber cable 304 carries 12 optical fibers, and one of the fibers is split off from the others in the terminal 308. The fibers 314 on the input side of the indexed terminal are numbered 1-12, depending on their relative position at the multi-fiber optical connector 306. Likewise, the fibers 316 on the output side of the terminal are numbered 1-12. The number 1 fiber position for the fiber connector 306 at the input side of the indexed terminal 308 corresponds to the number 1 fiber position for the fiber connector at the output side of the indexed terminal 308.

If all the terminals 308 split off the fiber 302 at the number 1 position, as is the case where each terminal 308 is the same as the preceding one, then the terminal has to index the fibers, i.e. change their positions for the next terminal. In the illustrated embodiment, in the terminal 308 on the left of the figure, terminal 308a, input fiber 302 number 1 is split off to a splitter 310, to produce four terminal outputs 312. The indexing operation within terminal 308a connects input fiber 302 number 2 with output fiber 304 number 1, so that output fiber 304 number 1 is at the number 1 position of the output connector 306 of the first terminal 308a and the number 1 position at the input connector 306 of the second terminal 308b. Likewise, all the other input fibers 314 in the first terminal 308a are connected to respectively different output fibers 316.

This approach is simple but inflexible in its design: a change in the configuration of the indexing element requires that a technician has to travel to the indexing terminal to swap out the old indexing element for the new one. The present invention is directed to a reconfigurable indexing element that can be addressed remotely and, therefore is less expensive to maintain. The present invention still preserves the advantage of indexed systems in that identical components can be used in the same arrangement in different terminals, which reduces

installation and maintenance costs, and reduces the chances of mistakes in aligning a particular fiber to a particular set of users.

A building block for a configurable indexing element is schematically illustrated in FIGs. 4A and 4B. In this embodiment, based on an electro-wetting optical device (EWOD) integrated in an optical circuit, an optical switch 400 is formed using two waveguides 402, 404 disposed within a substrate 406. The waveguides 402, 404 are preferably disposed in vertical relation to each other, although this is not a requirement. The first waveguide 402 and the second waveguide 404 are, for a substantial part of their lengths, reasonably far apart that optical coupling does not take place between them. A coupling region 408 is formed where the first and second waveguides 402, 404 are spaced by a sufficiently small distance that, under certain conditions, light can couple between them. In the illustrated embodiment, the second waveguide 404 shaped so that a portion of the second waveguide 404 lies close to the first waveguide 402 at the coupling region 408, but it will be understood that the first waveguide 402 may also be shaped to approach the second waveguide 404 to form the coupling region 408. The second waveguide 404 approaches the upper surface 410 of the substrate 406 at the coupling region 408. In the illustrated embodiment, a groove 412 is formed in the upper surface 410 of the substrate 406.

In EWOD optical switches, the effective refractive index experienced by light propagating along one of the waveguides changed by moving, using an electro-wetting force, a droplet of liquid. The movement of the droplet of electro-wetting fluid results in the replacement of the fluid above the coupling region 408 of the substrate 406, either liquid or gas, by a second fluid having a different refractive index. Generally, a liquid having a relatively low refractive index is replaced by a liquid having a relatively high refractive index. Thus, the refractive index of the environment around the coupling region is changed, which results in a change in the propagation constant of light propagating along the waveguides 402, 404 in the coupling region. The changing propagation constant results in a change in the coupling constant between the two waveguides. Thus, movement of the liquid droplet can change the switch from a bar state, in which light propagating along either waveguide 402, 404 remains in that waveguide 402, 404 without coupling to the other waveguide 404, 402, to a cross state, in which light propagating along one of the waveguides 402, 404 is coupled into the other of the waveguides 404, 402. The use and control of EWOD optical switches is described further in U.S. Provisional Patent

Application No. 62/094,506, “Integrated Optical Switching and Splitting for Optical Networks,” filed December 19, 2014, and U.S. Provisional Patent Application No. 62/116,784, entitled “Remote Control and Power Supply for optical Networks,” filed on February 16, 2015, both of which are incorporated herein by reference.

5 Thus, the liquid droplet 414 in the EWOD optical switch can be controlled to move and thus switch light from one waveguide 402, 404 to the other 404, 402.

 An embodiment of an optically integrated channel-dropping device 500 is schematically illustrated in FIG. 5A. The indexing device 500 comprises a substrate 502 and a number of transmission waveguides 504 having an input end 506 and an output end 508. The input ends
10 506 may be coupled to the input from a multi-fiber cable, with each fiber of the multi-fiber cable being optically coupled to a respective transmission waveguide 504. Likewise, the output ends 508 may be coupled to output fibers to a subsequent multi-fiber cable, with each output 508 being optically coupled to a fiber of the output multi-fiber cable.

 A channel drop waveguide 510 forms coupling regions 512 with each of the transmission
15 waveguides 504. In the illustrated embodiment, the channel drop waveguide 510 snakes its way across the substrate 502, as it curves to meet a neighboring waveguide and forms a straight section to form the coupling region with the transmission waveguide 504 below. In other embodiments, the transmission waveguides 504 may include curved regions to align the transmission waveguides to the channel drop waveguide 510. An EWOD switch 514 is located
20 at each coupling region 512, shown as a liquid droplet 516 in a respective groove 518. A single EWOD switch 514 is selected to operate in the cross state such that light from the transmission waveguide 504 that forms the cross state EWOD switch 514 is coupled into the channel drop waveguide 510. The light coupled into the channel drop waveguide 510 is delivered via a drop output 520 to a splitter 522 that has a desired number of splitter outputs 524. The splitter 522
25 may be located separately from the device 500, or may be integrated on the substrate 502. The light in the dropped channel therefore exits the splitter outputs 522. The splitter 522 may have any number of splits and may be, for example, a 1 x 2 splitter, a 1 x 4 splitter a 1 x 8 splitter or the like. Detail of an embodiment of the EWOD switch 514 is shown in the expanded view of FIG. 5B.

30 As is discussed in U.S. Provisional Patent Application No. 62/094,506, “Integrated Optical Switching and Splitting for Optical Networks,” filed December 19, 2014, and U.S.

Provisional Patent Application No. 62/116,784, entitled “Remote Control and Power Supply for optical Networks,” filed on February 16, 2015, the EWOD switches can be operated, and powered, remotely. Thus, an indexing device as discussed herein can be dropped into position in the terminal, and configured by the technician present at that time or it can be configured
5 remotely. Remote configuration can take place at any subsequent time, for example if channels are being added or dropped, or new customers added.

An embodiment of another optically integrated channel-dropping device 600 is schematically illustrated in FIG. 6A. The device 600 is formed in a substrate 602 that has a number of transmission waveguides 604 and associated channel drop waveguides 606. Each pair
10 of transmission and channel drop waveguides 604, 606 has an EWOD switch formed with a waveguide coupling region 608 and fluid droplet 610 in a channel 612.

Selective activation of an EWOD switch by movement of one of the fluid droplets 610 results in the light propagating along the associated transmission waveguide 604 being coupled to the respective channel drop waveguide 606. The light signals in the remaining transmission
15 waveguides 604 can then be transferred to a multi-fiber coupler and on to another terminal via a multi-fiber cable. The light signal coupled into the channel drop waveguide 606 may be sent to a splitter for distribution to subsequent users.

The device 600 may be integrated with other optical elements, such as combiners and splitters, for example in the integrated optical chip element 650 as shown in FIG. 6B. In this
20 embodiment, there are eight transmission waveguides 604, shown as dashed lines, extending from an input side 652 to an output side 654 of the chip element 650.

The channel drop waveguides 606 are shown as solid lines. The channel drop waveguides 606 from the switching device 600 combine via a passive splitter/combiner element 656 to a single waveguide 658, which may be referred to as a single output. The single
25 waveguide 658 is then split in a second passive splitter/combiner element 660. In the illustrated embodiment, the second passive splitter/combiner element 660 has four splitter outputs 662.

In the illustrated embodiment, the device 600 is configured so that the EWOD closest to the bottom of the figure is in the cross state: liquid droplet 612a is positioned over transmission waveguide 604a. Thus, the optical signals entering the device 600 along the transmission
30 waveguide 604a are coupled into channel drop waveguide 606a, shown by the arrows. The coupled signals pass through the first and second passive splitter elements 656, 660, and exit the

chip element 650 via the splitter outputs 662. The splitter outputs 662 may be connected to a multi-fiber connector or to individual fiber connectors so that the signals in the dropped channel can be passed on to the users.

Using this approach, identical components can be used in each indexing terminal, which
5 preserves the advantages of an indexed, cascaded system, but greater flexibility is provided than in the prior art, fixed system.

While various examples were provided above, the present invention is not limited to the specifics of the examples. For example, various combinations of elements shown in different figures may be combined together in various ways to form additional optical circuits not
10 specifically described herein. In illustration, the embodiments described above are not intended to provide any limits on the number of inputs and outputs from the various optical elements. An integrated optical device as described herein may have any reasonable number of inputs and outputs. Likewise, although the splitter used after an indexing device has been described to have four outputs, this is not a limit, and a splitter that follows an indexing device may be provided
15 with any other number of outputs. Furthermore, any passive splitting element discussed herein may be substituted using an active splitter element, for example, as described in greater detail in U.S. Provisional Patent Application No. 62/094,506, "Integrated Optical Switching and Splitting for Optical Networks," filed December 19, 2014.

As noted above, the present invention is applicable to fiber optical communication and
20 data transmission systems. Accordingly, the present invention should not be considered limited to the particular examples described above, but rather should be understood to cover all aspects of the invention as fairly set out in the attached claims. Various modifications, equivalent processes, as well as numerous structures to which the present invention may be applicable will be readily apparent to those of skill in the art to which the present invention is directed upon
25 review of the present specification. The claims are intended to cover such modifications and devices.

Claims

1. An active optical device, comprising:
 - a substrate,
 - a plurality of transmission waveguides in the substrate, each transmission waveguide having an input end and an output end;
 - a channel drop waveguide in the substrate, the channel drop waveguide having a channel drop output, portions of the channel drop waveguide respectively forming coupling regions with the transmission waveguides of the plurality of transmission waveguides; and
 - droplets of optical fluid respectively associated with the coupling regions, positions of the droplets of the optical fluid relative to the respective coupling regions being adjustable, the respective droplets of optical fluid and coupling regions forming active optical switches;
 - wherein any one of the active optical switches is activatable to couple light from its respective transmission waveguide into the channel drop waveguide.
2. The device as recited in claim 1, further comprising a splitter coupled to the channel drop output, the splitter having a plurality of splitter outputs, light signals coupled into the channel drop waveguide being split at the splitter to propagate to the plurality of splitter outputs.
3. The device as recited in claim 2, wherein the splitter is selected from a 1 x 2 splitter, a 1 x 4 splitter and a 1 x 8 splitter.
4. The device as recited in claim 1, wherein the droplets of optical fluid are positioned within respective recesses on a surface of the substrate.
5. The device as recited in claim 1, further comprising a first, hardened multi-fiber connector containing optical fibers respectively optically coupled to the plurality of transmission waveguides.

6. An active optical device, comprising:
 - a substrate,
 - a plurality of transmission waveguides in the substrate, each transmission waveguide having an input end and an output end;
 - a plurality of channel drop waveguides, each channel drop waveguide forming a coupling region with a respective transmission wavelength of the plurality of transmission waveguides, the channel drop waveguides having channel drop outputs;
 - and
 - droplets of optical fluid respectively associated with the coupling regions, positions of the droplets of the optical fluid relative to the respective coupling regions being adjustable, the respective droplets of optical fluid and coupling regions forming active optical switches;
 - wherein any one of the active optical switches is activatable to couple light from its respective transmission waveguide into its respective channel drop waveguide.
7. A device as recited in claim 6, further comprising a first splitter/combiner coupled to receive light from the channel drop outputs and to form a single output signal.
8. A device as recited in claim 7, further comprising a second splitter/combiner having a plurality of splitter outputs, the second splitter/combiner being coupled to receive the single output signal and to split the received single output signal into a plurality of output signals at the splitter outputs.
9. A device as recited in claim 6, wherein the first splitter/combiner is passive.
10. A device as recited in claim 6, wherein the first splitter/combiner is active.
11. A device as recited in claim 6, wherein the droplets of optical fluid are positioned within a single recess on the surface of the substrate.

12. An optical communications system, comprising:
an optical transmitter system;
a first multi-fiber cable coupled to receive optical signals from the optical transmitter system;
a first terminal coupled to the first multi-fiber cable;
a second multi-fiber cable coupled to the first terminal;
an integrated optical device in the first terminal, the integrated optical device comprising
a substrate,
a plurality of transmission waveguides in the substrate, each transmission waveguide having an input end optically coupled to respective fibers of the first multi-fiber cable and an output end optically coupled to respective fibers of the second multi-fiber cable;
a channel drop waveguide in the substrate, the channel drop waveguide having a channel drop output, portions of the channel drop waveguide respectively forming coupling regions with the transmission waveguides of the plurality of transmission waveguides; and
droplets of optical fluid respectively associated with the coupling regions, positions of the droplets of the optical fluid relative to the respective coupling regions being adjustable, the respective droplets of optical fluid and coupling regions forming active optical switches, wherein any one of the active optical switches is activatable to couple light from its respective transmission waveguide into the channel drop waveguide; and
a splitter optically coupled to receive optical signals from the channel drop output.
13. An optical communications system, comprising:
an optical transmitter system;
a first multi-fiber cable coupled to receive optical signals from the optical transmitter system;
a first terminal coupled to the first multi-fiber cable;

a second multi-fiber cable coupled to the first terminal;
an integrated optical device in the first terminal, the integrated optical device comprising

a substrate,

a plurality of transmission waveguides in the substrate, each transmission waveguide having an input end optically coupled to respective fibers of the first multi-fiber cable and an output end optically coupled to respective fibers of the second multi-fiber cable;

a plurality of channel drop waveguides, each channel drop waveguide forming a coupling region with a respective transmission waveguide of the plurality of transmission waveguides, the channel drop waveguides having channel drop outputs;
and

droplets of optical fluid respectively associated with the coupling regions, positions of the droplets of the optical fluid relative to the respective coupling regions being adjustable, the respective droplets of optical fluid and coupling regions forming active optical switches;

wherein any one of the active optical switches is activatable to couple light from its respective transmission waveguide into the channel drop waveguide; and

a splitter optically coupled to receive optical signals from the channel drop output.

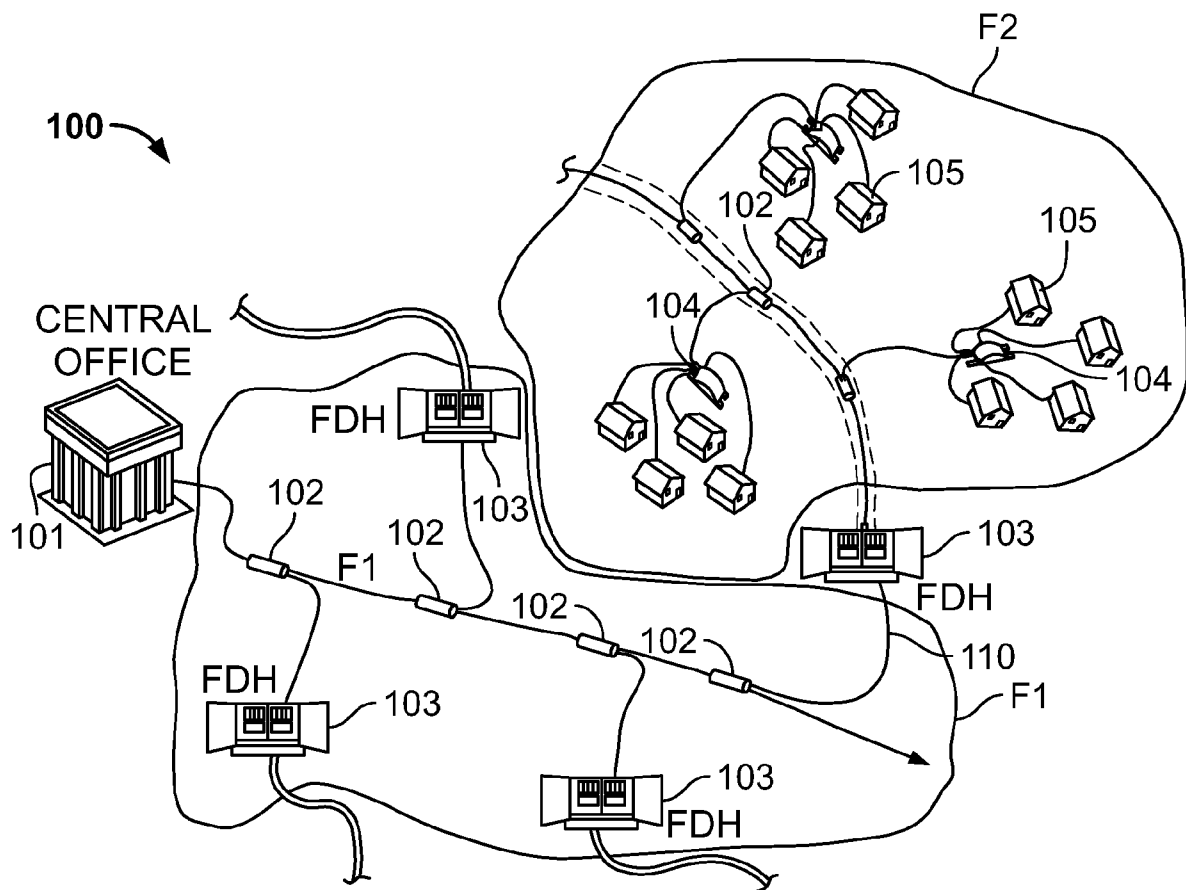


FIG. 1

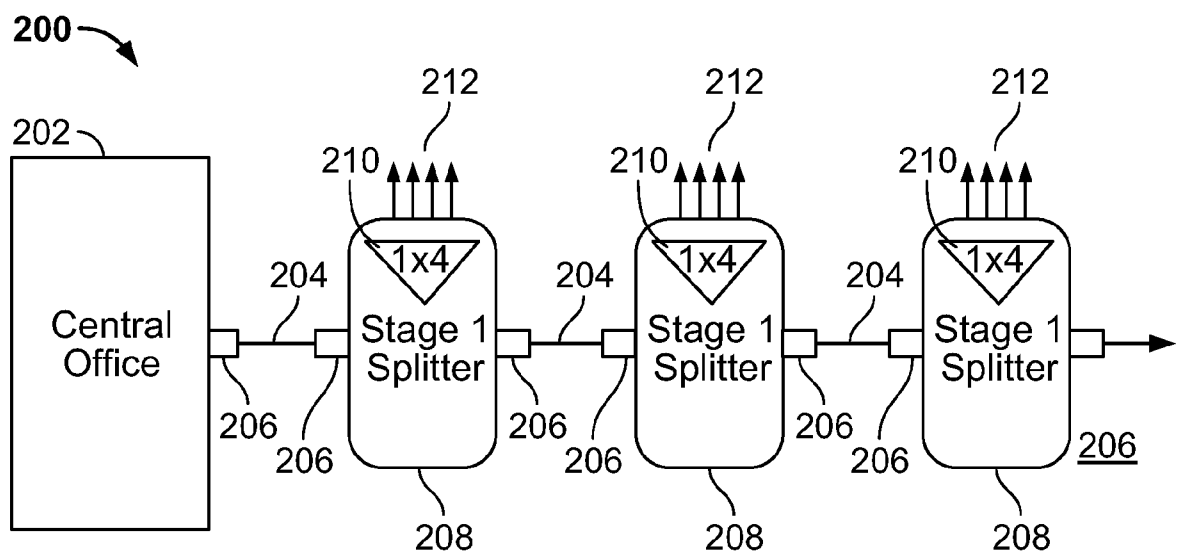


FIG. 2

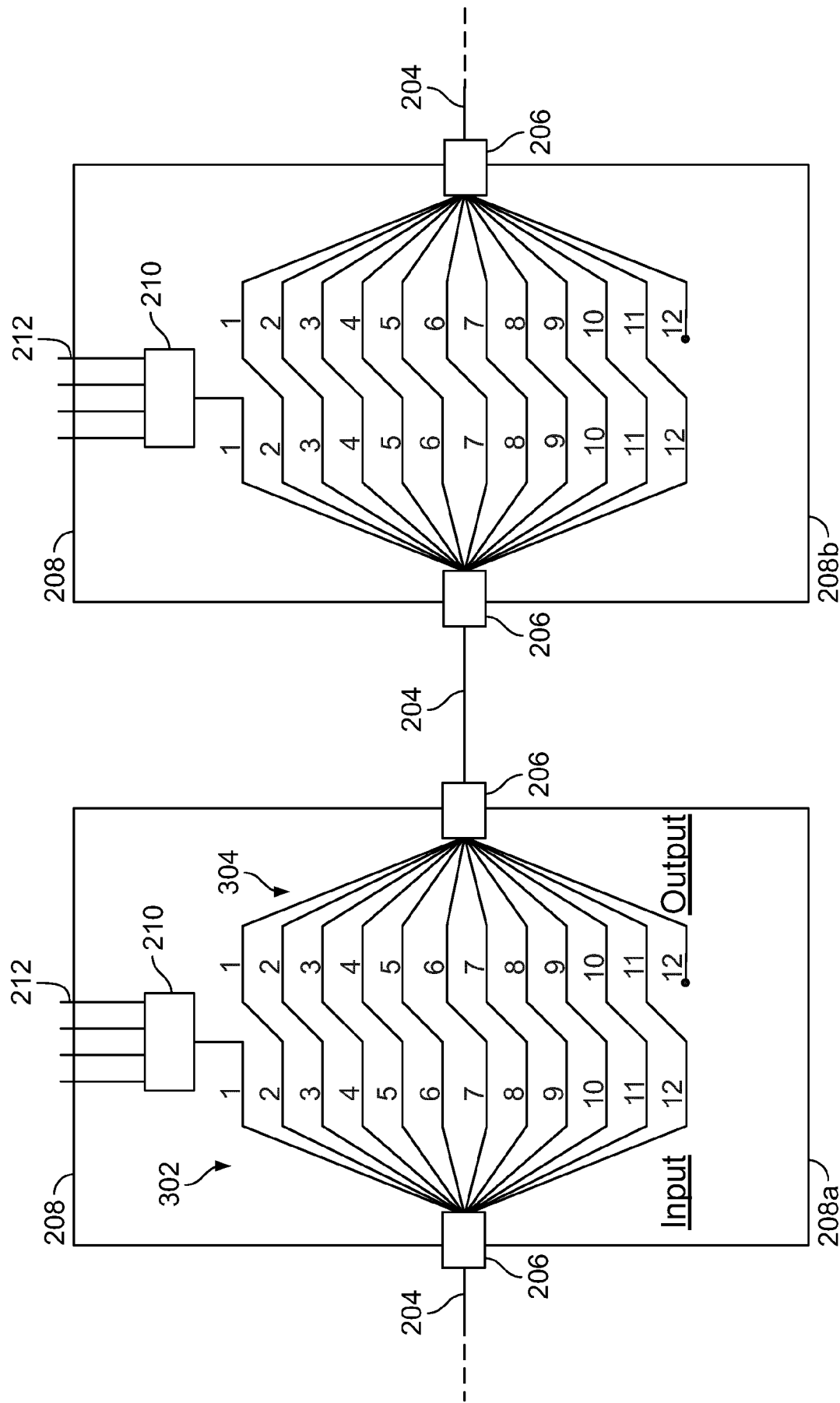


FIG. 3

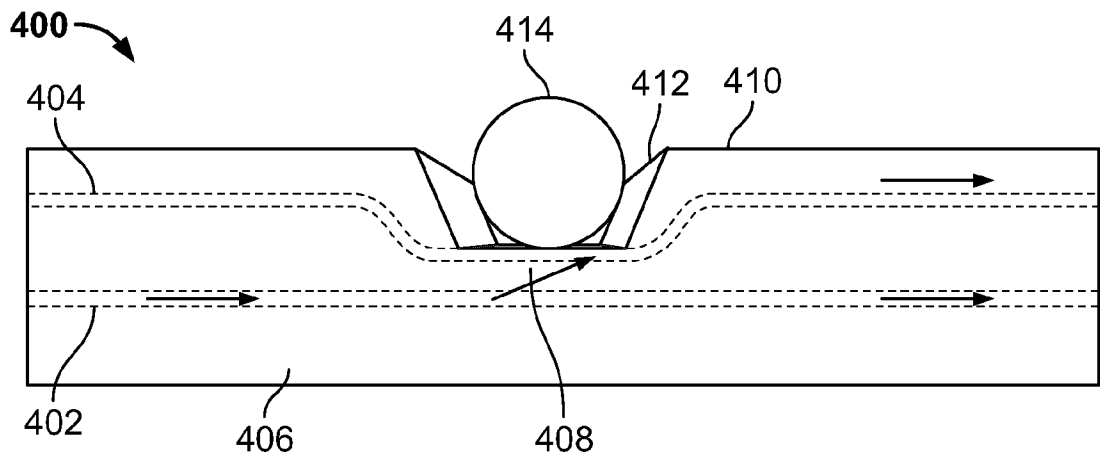


FIG. 4A

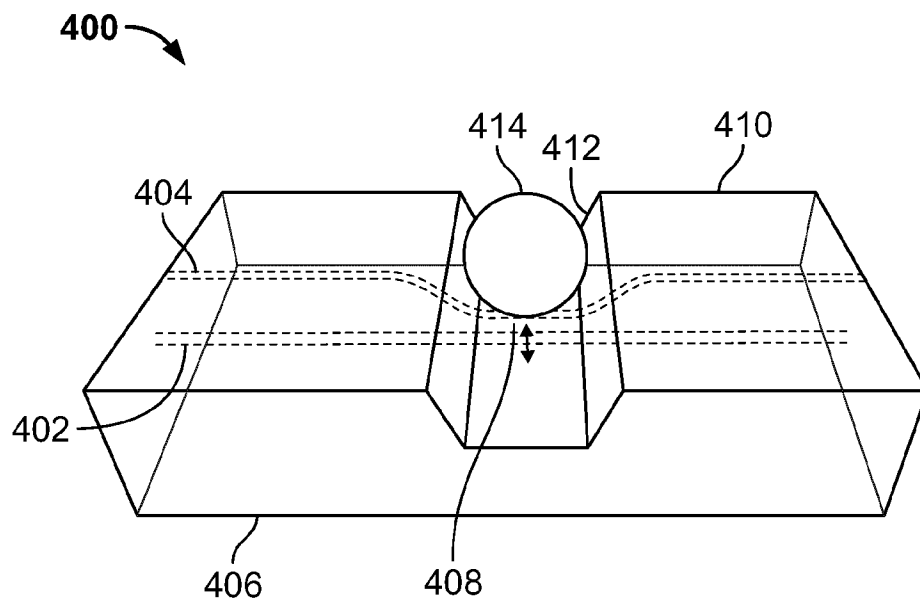


FIG. 4B

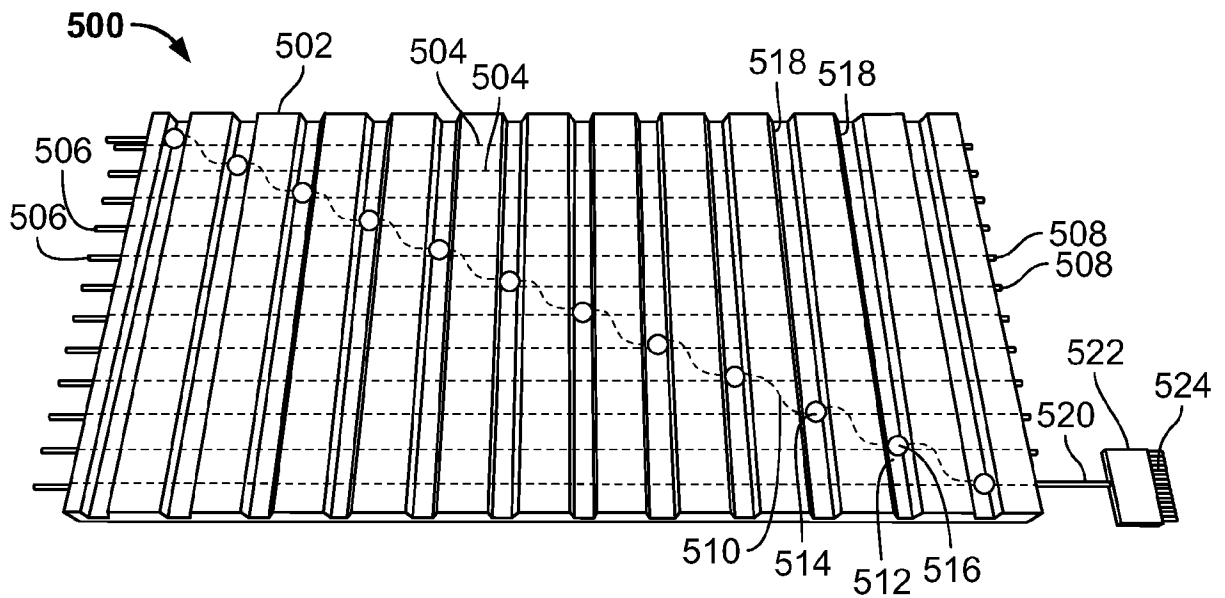


FIG. 5A

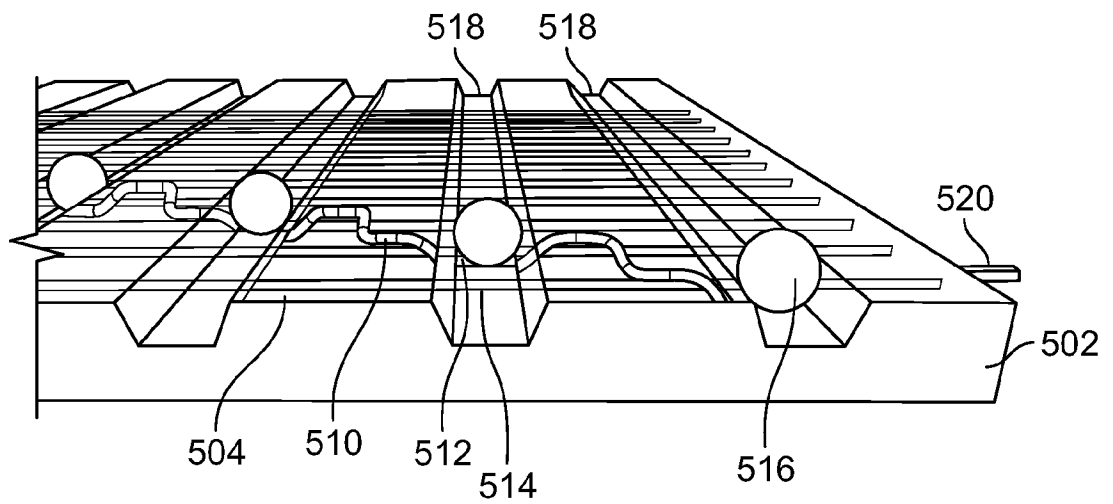


FIG. 5B

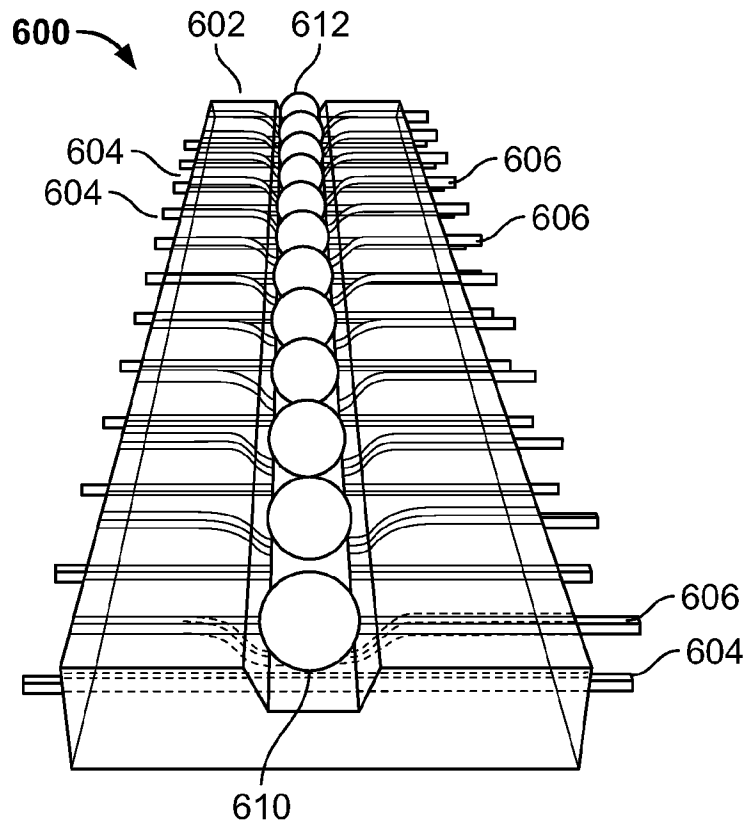


FIG. 6A

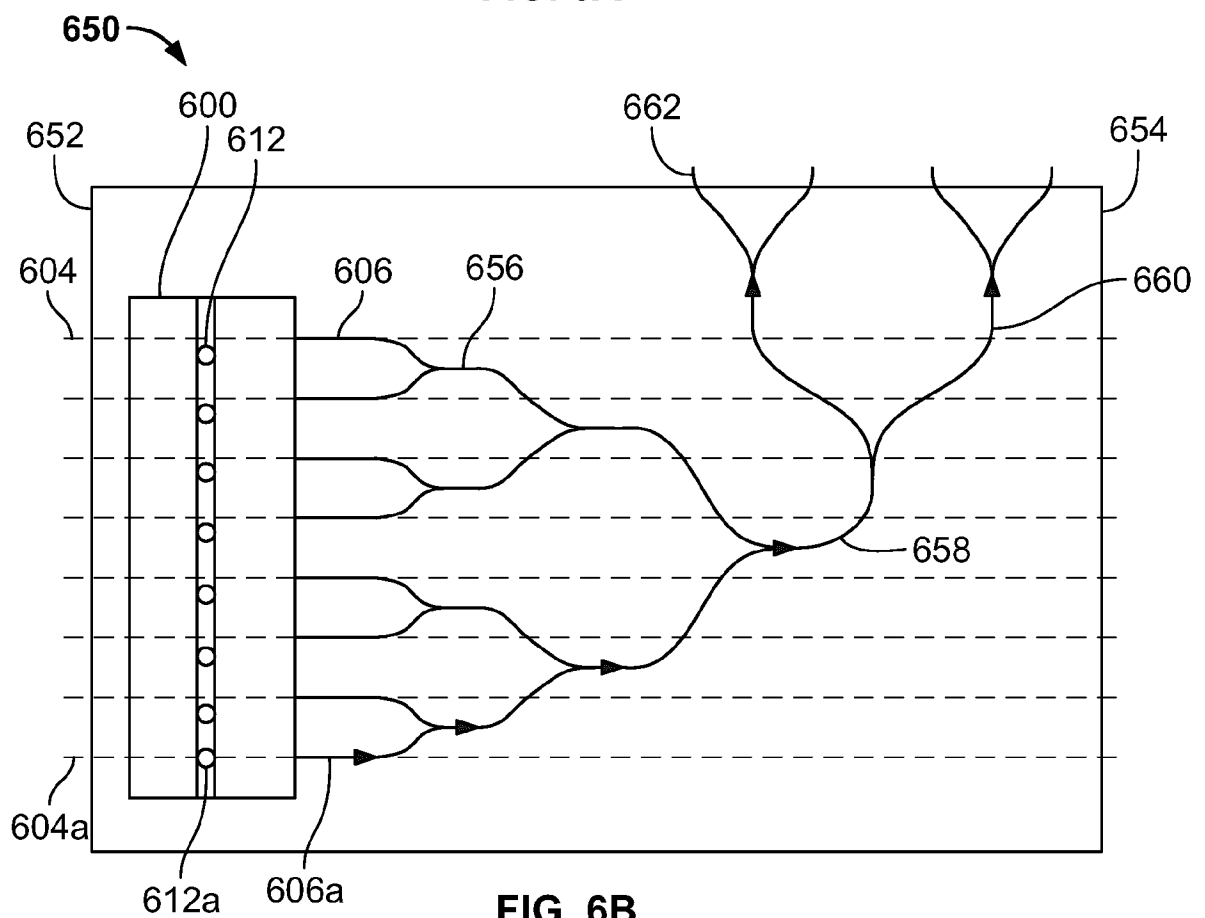


FIG. 6B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/052476

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B6/35
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 699 462 A (FOUQUET JULIE E [US] ET AL) 16 December 1997 (1997-12-16) column 7, line 13 - column 10, line 5; figures 1-3	1-10,12, 13
X	US 6 408 112 B1 (BARTELS FRANK [DE]) 18 June 2002 (2002-06-18) column 8, lines 23-52; figures 5a,5b column 13, lines 45-63 column 16, lines 5-53; figure 11 column 18, line 66 - column 19, line 3; figure 14	1-10,12, 13
A	US 2003/012483 A1 (TICKNOR ANTHONY J [US] ET AL) 16 January 2003 (2003-01-16) paragraph [0203]; figure 47	1-13
	-/--	



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

5 May 2017

Date of mailing of the international search report

16/05/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Ciarrocca, Marco

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2017/052476

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2 207 522 A (GEN ELECTRIC CO PLC) 1 February 1989 (1989-02-01) page 1, last paragraph - page 2, paragraph 1; figure 4 -----	1-13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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			JP 3945595 B2 18-07-2007
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GB 2207522	A	01-02-1989	NONE