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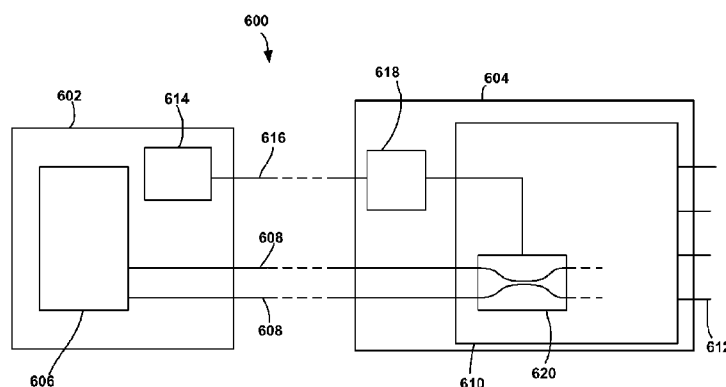


FIG. 6

(57) Abstract: An active optical circuit (216, 300, 610, 810) has a first waveguide (302a, 404, 04) and a second waveguide (302b, 406, 506), with an optical switch (312, 400, 620, 820a) capable of coupling light between the first and second waveguides. A data fiber (608) delivers an optical data signal that passes through the first waveguide (302a, 404, 04) to the optical switch (312, 400, 620, 820a). A fiber channel (608, 616) delivers optical switch power to a switch controller (618). The switch controller (618) comprises an optical-to-electrical energy converter (824) that is coupled to provide electrical power to the optical switch (312, 400, 620, 820a) when optical switch power is transmitted along the fiber channel (608, 616).

REMOTE CONTROL AND POWER SUPPLY FOR OPTICAL NETWORKS**Cross-Reference to Related Application**

This application claims the benefit of U.S. Patent Application Serial No.
5 62/116,784, filed on February 16, 2015, the disclosure of which is incorporated herein
by reference in its entirety.

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
10 the field.

Passive optical networks are becoming prevalent in part because service
providers want to 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
15 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.

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
20 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 that distribute signals to the end
users 105. The various lines of the network 100 can be aerial or housed within
25 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 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 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
10 pigtails that extend from the module. The optical splitter module provides protective packaging for the optical splitter 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.

 The number of end users may change, however, for example through the
15 addition of new customers to the network or by customers dropping out of the network, and so occasions arise where the splitter in the FDH 103 may need to be replaced. In the case where more customers are added to the network, a splitter may need to be replaced by one having more outputs, for example a 1x16 splitter may need replacing by a 1x32 splitter. In other situations, for example where the number of customers
20 drops, it may be useful to replace a splitter with one having fewer outputs. The replacement of a splitter at an FDH 103 requires that a technician travels to the FDH 103 to physically swap out the splitter. This can be costly and time-consuming. Also, a technician visit may be necessary when taking other actions, such as switching over to more OLTs when the number of customers increases, or when switching users between
25 different service levels, such as different bitrates or video channels.

 Furthermore, the splitters that are conventionally used in optical networks are passive devices whose configuration cannot be changed, which can lead to difficulties in monitoring the performance of the optical network. For example, one way of tracking down the cause of a signal loss at one or more end users is to use optical time-
30 domain reflectometry (OTDR), which involves transmitting a pulsed optical signal along the fiber. Breaks, cracks or other issues with the fiber can result in a portion of

the optical pulse being reflected to the source of optical pulses. The arrival times of the reflected pulses can be recorded and the time-of-flight measurement can be correlated with the position in the fiber where the reflection occurred. If there is a problem with transmission of signals to a particular end user, a technician has to set up the OTDR
5 equipment downstream of the splitter output in the FDH 103 in order to isolate the end user's fiber from other fibers. This requires that the technician travels to the FDH 103 and physically disconnects the end user's fiber from the splitter in order to initiate the OTDR measurements. Again, this can be costly and time-consuming.

Therefore, there is a need for remote access to the FDH for changing the
10 configuration of the splitter to add or drop fibers to end users, or to reconfigure the optical network to allow monitoring of one or more end users' fibers. Furthermore, it is desirable to provide remote access in a way that does not require local power, such as a local electrical service or batteries. A local electrical service is subject to power outages, for example because of inclement weather, and batteries require monitoring
15 and maintenance.

Summary of the Invention

An embodiment of the invention is directed to an active optical circuit that has a first waveguide and a second waveguide. A least a first optical switch can couple light between the first waveguide and the second waveguide. The first optical switch is
20 configurable in a plurality of switching states. A data fiber delivers an optical data signal that passes through the first waveguide to the optical switch. A fiber channel delivers optical switch power to a switch controller. The switch controller comprises an optical-to-electrical energy converter that is coupled to provide electrical power to the at least a first optical switch when optical switch power is transmitted along the fiber
25 channel.

Another embodiment of the invention is directed to an optical communication system, that has an optical transmitter station capable of transmitting an optical data signal along a first optical fiber. A fiber distribution hub comprises an optical circuit coupled to receive the optical data signal. The fiber distribution hub also has a plurality
30 of fiber outputs coupled to receive optical data from the optical circuit. The optical

circuit has one or more optical switches. An optical control channel couples an optical switch control signal between the optical transmitter station and an optical switch controller. The optical switch controller is coupled to provide operating power to the one or more optical switches.

- 5 The above summary of the present invention is not intended to describe each illustrated embodiment or every implementation of the present invention. The figures and the detailed description which follow more particularly exemplify these embodiments.

Brief Description of the Drawings

- 10 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;

- 15 FIG. 2 schematically illustrates an embodiment of elements of a fiber distribution hub according to an embodiment of the present invention;

FIGS. 3A-3D schematically illustrate switched optical splitters according to embodiments of the present invention;

- 20 FIGS. 4A-4B schematically illustrate an optical switch according to an embodiment of the present invention;

FIGS. 5A-5D schematically illustrate an optical switch according to another embodiment of the present invention;

- 25 FIG. 6 schematically illustrates a fiber network that incorporates optical transmission of power for optical switches at a fiber distribution hub, according to an embodiment of the present invention;

FIG. 7 schematically illustrates a fiber network that incorporates optical transmission of power for optical switches at a fiber distribution hub, according to another embodiment of the present invention; and

FIG. 8 schematically illustrates a fiber network that incorporates optical transmission of power for optical switches at a fiber distribution hub, according to another 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.

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Detailed Description

The present invention is directed to various optical devices and systems that can provide benefit in optical networks by providing for remote configuration, 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.

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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.

An embodiment of the FDH 103 and cable 110 is illustrated in greater detail in Figure 2. The cable 110 entering the FDH 103 includes an optical data channel 212 and an optical control and power channel 214. The optical data channel typically comprises one or more optical fibers and may include optical data transmission, such as cable television signals which are typically unidirectional in the fiber, and optical communications, for example internet traffic which are typically bidirectional in the fiber. The optical control and power channel 214 provides a power and a control signal to an optical circuit controller 218 located within the FDH 103. The optical circuit 216 contains any optical elements that are used in the FDH 103 to distribute an optical signal to the end users 105. For example, the optical circuit may contain one or more optical splitters, optical switches, amplifiers, optical circulators, multiplexers, and other such elements that are typically used in optical data transmission networks. The optical

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circuit controller 218 may use the optical power received from the optical control and power channel 214 to provide power to the elements of the optical circuit 216 and may also use information received on the optical control and power channel to actively control one or more elements of the optical circuit.

5 In the illustrated embodiment, the optical circuit 216 includes one or more splitters so that the optical signal is split into a number of different output channels 220 that are fed to end users 105. The output channels 220 may be optical channels, such as optical fibers, or may be electrical channels, for example coaxial electrical cables. In the case where the output channels 220 are electrical channels, the optical circuit 216
10 may also include optical-electrical converters for each output channel.

 According to an embodiment of the present invention the optical circuit 216 includes one or more remotely-controlled active optical elements that may be used, for example, to change the configuration of the optical circuit or the ratio of signal split into different output channels. Different approaches may be used to provide active control
15 of the optical signals within the optical circuit 216 including, for example microfluidic, micromechanical (e.g. MEMS), and electro-optic. An advantage of the microfluidic and micromechanical approaches over an electro-optical approach is that a microfluidically-controlled optical circuit can be manufactured on a glass substrate, which is relatively inexpensive, whereas the electro-optical approach typically requires
20 the use of electro-optic crystals that are more expensive than glass. A remotely-controllable optical circuit (RCOC) may, for example include one or more switches that can change a splitter from a configuration having a first number of outputs to a splitter having a second number of outputs. In another example of RCOC, an optical switch is able to provide multiple levels of coupling between two waveguides, thus allowing a
25 user to control the amount of light that is coupled from one waveguide into one or more other waveguides. This is described in greater detail in U.S. Provisional Patent Application Serial No. 62/094,506, filed on December 19, 2014, and incorporated herein by reference.

 A first exemplary embodiment of an RCOC 300 is schematically illustrated in
30 FIG. 3A. The RCOC 300 includes first and second input waveguides 302a and 302b, labeled Input 1 and Input 2 respectively, and has eight outputs 304, labeled Output 1 –

Output 8. Outputs 1-4 are directly connected to Input 1 via a first splitting network 306 and Outputs 5-8 are directly connected to Input 2 via a second splitting network 308. In many cases, the splitting networks 306, 308 may include a number of symmetric splitting nodes 310 that split the input optical power into two equally powered outputs, although this need not be the case and some of the splitting nodes 310 may be asymmetric, with more of the incoming optical power being directed to one of its outputs than the other. A splitting node 310 includes one input waveguide that splits into two output waveguides.

An optical switch 312 is positioned to allow coupling of light between Input 1 and Input 2. The optical switch may be, for example, microfluidic, micromechanical or electro-optical. In some embodiments the optical switch 312 may be adjustable between only two switching states and in other embodiments the optical switch may be adjustable over a number of switching states. The term “switching state” refers to the amount of light coupled between waveguide 302a and 302b in the switch 312. Thus, in a first switching state a first amount of light is coupled between the waveguides 302a, 302b. In a second switching state, a second amount of light is coupled between the waveguides. In some cases, a two-state optical switch will have a “bar state”, in which no light is coupled between the waveguides and a “cross state” in which approximately 100% of the light is coupled between the waveguides. A control signal may be applied to the switch 312 via a control channel 314. The control signal on control channel 314 may be optical or electrical. In the illustrated embodiment the splitting nodes 310 are arranged in two tiers, with the first tier including the nodes 310 immediately following the switch 312, splitting from two to four waveguides and a second tier of nodes 310 splitting from four to eight waveguides.

In one configuration of the RCOC 300, schematically illustrated in FIG. 3B, the switch 312 is in the so-called “bar state,” in which 100% of the light traveling along a waveguide remains in that waveguide and 0% of the light is coupled into the other waveguide. In FIGs. 3B-3D, the two numbers below the switch correspond to the percent amount transmitted along a waveguide without coupling and to the percent amount coupled between the waveguides. Thus, the number 100/0 below the switch means that 100% of the light is transmitted along the respective waveguide and no light

is coupled to the other waveguide. Thus, in the embodiment illustrated in FIG. 3B substantially all the light entering Input 1 is transmitted to Outputs 1-4 and substantially all the light entering Input 2 is directed to Outputs 5-8. In this embodiment it has been assumed that all the splitter nodes 310 are symmetrical, so the light from Input 1 is split
5 equally among outputs 1-4 and the light from Input 2 is split equally among Outputs 5-8. Of course, it will be appreciated that one or more of the splitter nodes 310 may be asymmetrical, in both this embodiment and others discussed below.

In another configuration of the RCOC 300, schematically illustrated in FIG. 3C, the switch 312 is in a so-called “cross-state,” in which 100% of the light travelling
10 along a waveguide is coupled to the other waveguide. This configuration may be referred to as 0/100. Thus, substantially all the light entering Input 1 is coupled over to the second splitting network 308 and transmitted to Outputs 5-8, while substantially all the light entering Input 2 is coupled over to the first splitting network 306 and transmitted to Outputs 1-4.

15 In another configuration of the RCOC 300, schematically illustrated in FIG. 3D, the switch 312 is in an intermediate state, in which some light is transmitted along the waveguide and some is coupled to the other waveguide. In the illustrated embodiment 50% of the light travelling along a waveguide is coupled to the other waveguide. This configuration may be referred to as 50/50. Thus, 50% of the light entering Input 1 is
20 transmitted to the first splitting network 306 and 50% is coupled over to the second splitting network 308 and transmitted to Outputs 5-8. If no signal is applied to Input 2, then Outputs 1-8 all transmit a fraction of the signal applied to Input 1. Where the splitting nodes 310 are all symmetrical, each output contains about 12.5% of the light signal applied at Input 1 (ignoring losses). In this 50/50 configuration, the RCOC 300
25 acts as a 2x8 splitter, whereas the RCOC 300 configurations shown in FIGs. 3B and 3C act as two 1x4 splitters.

Input 2 may also be used to inject a signal into the RCOC 300, for example at a different wavelength from that injected into input 1, as might be used for the simultaneous transmission of a video signal and a data signal or a network test signal.
30 In the illustrated embodiment, with the switch 312 in a 50/50 configuration, light

injected at input 2, as well as light injected at input 1, is spread evenly among all outputs.

Some optical switches can be described as two-state optical switches. In the case where a switch couples light between two waveguides, this means that the optical switch can exist in one of two switching states, namely a state of minimum coupling, and a state of maximum coupling.

Other switches have multiple switching states, meaning that they can exist in more than two switching states. One approach to implementing an optical switch having multiple switching states is to use a microfluidic optical switch. Microfluidic switches are generally based on changing the effective refractive index experienced by light propagating within a waveguide. This can be achieved, for example, by moving a droplet of liquid of a first refractive index liquid surrounded by a liquid of a second refractive index liquid in microfluid channels disposed close to waveguides. Examples of microfluidic switch are described in C. Lerma Arce et al. "Silicon Photonic Sensors Incorporated in a Digital Microfluidic System," Analytical and Bioanalytical Chemistry, 404(10) 2887-94 (2012) and C. Lerma Arce "Novel Microfluidic Platforms Incorporating Photonic Ring Resonator Sensors," Photonics Research Group, INTEC University of Gent, 2014, and U.S. Patent No. 7,283,696, incorporated herein by reference. The microfluidic change in the effective refractive index can affect the coupling coefficient between a waveguide along which the light is propagating and a neighboring waveguide. Thus, it is possible to microfluidically control the coupling coefficient and, therefore, the amount of light propagating along the two waveguides.

One embodiment of a multiple state, microfluidic optical switch is schematically illustrated in FIGs. 4A-B. Such a switch is capable of switching among more than two, i.e. it has a minimum coupling state, a maximum coupling and one or more intermediate coupling states. FIG. 4A schematically shows a microfluidic switch 400 formed on a substrate 402 having a first waveguide 404 and a second waveguide 406. A coupling region 408 is a region where the first and second waveguides 404, 406 are spaced closely together to permit optical coupling between the waveguides 404, 406. In the illustrated embodiment, light propagates along the first waveguide in the direction shown by the arrows, entering the switch at the input and exiting the switch at the

outputs. According to the coordinate system of the figure, the light propagates along the y-direction. In this embodiment, the switch 400 includes four activatable microfluidic droplets 410, labelled 410a, 410b, 410c and 410d, near the coupling region 408. The four droplets 410 are independently movable in the $\pm x$ direction. When a droplet 410 is moved in a position above the waveguides 404 and 406, the coupling coefficient is changed so that a fraction of the light propagating in the first waveguide 404 is coupled into the second waveguide 406. In this embodiment the droplets 410 can have one of two positions, namely i) away from the coupling portion, for example as shown for droplets 410c and 410d, in a position that does not contribute to the coupling coefficient, and ii) over the coupling portion, as is shown for droplets 410a and 410b, in a position that does contribute to the coupling coefficient. Thus, in the droplet configuration illustrated in FIG. 4A, only droplets 410a and 410b affect coupling of light from the first waveguide 404 to the second waveguide 406.

The amount by which a droplet 410 affects the coupling coefficient can depend on a number of different factors including the size of the droplet and the magnitude of the change in the effective refractive index experienced by light in the waveguide. When the droplet is larger, for example when it extends further along the waveguide in the y-direction, the coupling coefficient is increased. The change in the effective refractive index of the waveguide is dependent on the refractive index of the droplet 410. Generally, when the difference between the refractive indices of the droplet 410 and the waveguides is smaller, the coupling coefficient increases.

In one example of the embodiment illustrated in FIG. 4A, each droplet 410 has the same effect on coupling coefficient, and increases the coupling coefficient by 25%. Thus, for each droplet 410 positioned in the coupling region 408 to couple light between the waveguides 404, 406, the amount of light coupled from the first waveguide 404 to the second waveguide 406 is increased by 25%. In the illustrated embodiment two droplets 410a, 410b are positioned in the coupling region 408 to couple light between the waveguides 404, 406, so 50% of the light is coupled from the first waveguide 404 to the second waveguide 406. In another droplet configuration, schematically illustrated in FIG. 4B, three droplets 410a, 410b and 410d are positioned in the coupling region 408 the coupling region to couple light between the waveguides

404, 406. In this case, 75% of the light is coupled from the first waveguide 404 into the second waveguide 406, with 25% of the light propagating in the first waveguide 404 beyond the coupling region.

While the waveguides 404, 406 are shown in FIGs. 4A-B are shown sitting on top of the substrate 402, this is not intended that this be a limitation of the invention herein. The waveguides of this and other embodiments may be formed in any conventional manner, including growing the waveguides on a substrate or in the substrate via diffusion or implantation or other suitable technique. Thus, waveguides may be formed on and/or in a substrate.

10 An advantage of optical microfluidic switched optical circuits discussed herein is that a control signal need only be applied to change a switch state, to move the droplet from one position to another but need not be continually applied to maintain the switch in that state. The microfluidic switches can persist in a selected state after being switched to that state without continued application of the control signal, since an
15 activation signal is only required to move a droplet from one position to another. Once a droplet has reached a desired position, it remains in that position until another activation signal is applied to move it. Microfluidic droplets can typically be moved using electrostatic or hydrostatic forces.

It will be understood that the droplets need not all contribute the same amount of
20 coupling, and different droplets may contribute respectively different amounts of coupling. The amount of coupling contributed by each droplet may be selected so that the user can select a number of different coupling values. For example, in a variation of the optical switch 400 shown in FIGs. 4A and 4B, a first droplet may provide 6.25% coupling between the waveguides, while a second droplet provides 12.5% coupling, a
25 third droplet provides 25% coupling and a fourth droplet provides 50% coupling. Various arrangements of these four droplets will provide up to 16 different values of coupling. It will be appreciated that other configurations will result in different amounts of light being coupled from the first waveguide 404 to the second waveguide 406. It will further be appreciated that different numbers of droplets may be
30 incorporated in a multi-state switch and that amount of coupling attributable to each

droplet may be selected to have different values from those discussed in the example above.

The description of optical switches herein ignores optical losses due to, for example, impurities, fabrication errors and the like. Accordingly, values of light transmission, coupling etc. given as a percentage or fraction should be understood to cover an ideal embodiment, while actual devices may not operate with the same values are exemplified herein. In illustration, the droplets in a real device of the above embodiment may not produce the exact same values of coupling as described, which are provided for illustration purposes only, but may operate within an approximate range of these values.

In another approach to a multi-state optical switch, a microfluidic droplet may be controllably moved to one of several different positions relative to the coupling region between two waveguides, resulting in respectively different levels of coupling when the droplet is in the different positions. One embodiment of such an optical switch is schematically illustrated in FIGs. 5A-5D. The switch includes a first waveguide 504 and a second waveguide 506. Portions of the first and second waveguides 504, 506 are positioned closely together to form a coupling portion 508 where light is coupled between the waveguides 504, 506. In this embodiment, the droplet 510 is moved in a transverse direction across the waveguides 504, 506. In FIG. 5A the droplet 510 is in a first position removed from the coupling portion 508 so that no coupling takes place between the waveguides 504, 506. In FIG. 5B the droplet 510 is in a second position closer to the coupling portion 508 than the first position to couple a first amount of light from the first waveguide 504 to the second waveguide 506. In the illustration, 30% of the light in the first waveguide 504 is coupled to the second waveguide 506 when the droplet 510 is in the second position. In FIG. 5C the droplet 510 is in a third position closer to the coupling portion 508 than the second position to couple a second amount of light from the first waveguide 504 to the second waveguide 506, that is larger than the first amount of light. In the illustration, 60% of the light in the first waveguide 504 is coupled to the second waveguide 506 when the droplet 510 is in the third position, leaving 40% of the light in the first waveguide 504. In FIG. 5D the droplet 510 is in a fourth position closer to the coupling portion 508 than the third

position to couple a third amount of light from the first waveguide 504 to the second waveguide 506. In the illustration, 100% of the light in the first waveguide 504 is coupled to the second waveguide 506 when the droplet 510 is in the fourth position, leaving no light in the first waveguide 504.

- 5 In a variation of the embodiment shown in FIGs. 5A-5D, the droplet 510 may have a refractive index that is non-uniform over the range of light wavelengths that pass along the waveguides. For example, the refractive index of the fluid may be tailored using an additive such as semiconductor quantum dots or the like. Thus, the switch may be able to demonstrate a wavelength-dependent switching ability, and be able to
- 10 couple light at a first wavelength relatively strongly while coupling light at a second wavelength either relatively weakly, if not at a zero level. Such a switch is referred to as a wavelength-dependent microfluidic switch. It will be appreciated that such wavelength dependence may be included into the other embodiments of microfluidic switch, and optical circuits including such switches, described herein.
- 15 Other types of active optical circuits and active optical switches, including optical switches having multiple switching states, are described in greater detail in U.S. Patent Application Serial No. 62/094,506, filed on December 19, 2014, incorporated herein by reference.

- Active optical circuits require power to activate the optical switches and control
- 20 signals to control the switching state of the optical signals. According to an embodiment of the present invention, power for a remote optical switch, for example in an FDH, can be transmitted to the location of the optical switch optically. One example of remote powering of an optical switch is schematically illustrated in FIG. 6. A fiber network 600 includes a transmitter station 602 and a receiver station 604, for example a
- 25 FDH. The transmitter station includes a transmitter unit 606 that provides an optical data or optical communication signal to one or more data transmission fibers 608. The transmitter unit 606 may, for example, provide optical CATV signals or optical communications from an internet service provider. The one or more data transmission fibers 608 are coupled to an optical circuit 610 at the receiver station 604 that provides
- 30 any desired switching, amplifying, splitting etc. operations to the incoming optical data and/or communication signal. The receiver station 604 may have a number of different

outputs 612 from the optical circuit 610, for example for distributing signals to various end users.

The optical power for activating the active optical switches in the receiver station 604 is provided over a fiber channel. In this embodiment, the fiber channel for transmitting the optical power is separate from the data transmission fibers 608. The transmission station 602 may include an optical switch power transmission unit 614 that produces an optical power signal that is transmitted along an optical power and control fiber 616. The optical power and control fiber 616 is coupled to an optical switch controller 618 at the receiver station 604. The optical switch controller 618 may include an optical-to-electrical converter, such as a photodiode and related circuitry, that converts the optical power received at the optical switch controller to electrical power. The optical switch controller 618 is coupled to one or more active optical switches 620 in the optical circuit 610. The optical switch controller 618 controls the switching state of the one or more active optical switches 620 in order to configure the optical circuit 610 as desired.

In another embodiment of fiber network 700, schematically illustrated in FIG. 7, the fiber channel that carries the optical power used to activate the optical switches is a data transmission fiber 608. The optical switch power transmission unit 614 produces an optical power signal that is multiplexed with a data signal produced by the transmitter unit 606 in a multiplexer unit 622. For example, the optical power signal may be carried by light having a wavelength different from the light carrying the optical data signal, in which case the multiplexer unit 622 is a wavelength multiplexer unit. The receiver station 604 includes a demultiplexer 624 that demultiplexes the multiplexed signal carried by the fiber 608 and directs an optical control/power signal to the optical switch controller via a switch waveguide 626. The demultiplexed data signal is transmitted on to the optical circuit 610 and the demultiplexed optical power signal is transmitted to the optical switch controller 618. In the illustrated embodiment where the multiplexer 622 is a wavelength multiplexer, the demultiplexer 624 may be a wavelength demultiplexer. It will be appreciated that other types of multiplexing/demultiplexing may be used to combine the data signal and optical power

signal in the fiber 608 and separate the data signal from the optical power signal at the receiver station 604.

The optical power signal may also carry information, for example, to direct the optical switch controller as to which optical switch is to be activated and the selected switching state for that optical switch. Thus, the operator may encode the optical power signal at the transmitter station with information to remotely operate the optical switches at the receiver station. One embodiment for achieving this is schematically illustrated in FIG. 8. An optical circuit 810 has a number of active optical switches 820, of which two are shown in the illustrative example, 820a, 820b. Data waveguides or fibers 808 transmit optical data, received from the transmitter station via data transmission fibers, to the optical circuit 810. An optical switch controller 818 is coupled to control the optical switches 820a, 820b. A modulated optical power signal 822 is input to the optical switch controller 818. The modulated optical power signal 822 may be transmitted to the optical switch controller from the transmitter station via any of the methods described above.

The modulation of the modulated optical power signal 822 contains information that may be used by the optical switch controller 818 to control the optical switches 820a, 820b in a desired manner. In an exemplary embodiment of the optical switch controller 818, an optical-to-electrical converter (OE) 824 receives the modulated optical power signal 822 and converts a substantial amount of the incoming optical power to electrical power. The OE 824 passes electrical power to the power supply and switching unit (PS&S) 826. The OE 824 also passes a signal to the controller (C) 828 that detects the information contained in the incoming modulated optical power signal 822 and uses the information to control which optical switch 820a, 820b is activated by the PS&S 826, and which switching state is selected for the optical switch 820a, 820b. The optical switch controller may be implemented using conventional electronic components, preferably electronic components that have low power requirements.

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 specifically described herein.

As noted above, the present invention is applicable to fiber optical communication and 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

5 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 review of the present specification. The claims are intended to cover such modifications and devices.

Parts List

- 100 – network
- 101 – central office
- 102 – break-out location
- 5 103 – fiber distribution hub
- 104 – drop terminal
- 105 – end user
- 110 – fiber cable
- 212 – optical data channel
- 10 214 - optical control and power channel
- 216 – optical circuit
- 218 – optical circuit controller
- 220 – output channels
- 300 – remotely-controllable optical circuit
- 15 302a, 302b – input waveguides
- 304 – output
- 306 – splitting network
- 308 – splitting network
- 310 – splitting node
- 20 312 – optical switch
- 314 – control channel
- 400 – microfluidic optical switch
- 402 – substrate
- 404 – first waveguide
- 25 406 – second waveguide
- 408 – coupling region
- 410a, 410b, 410c, 410d - microfluidic droplet
- 504 – first waveguide
- 506 – second waveguide
- 30 508 – coupling portion
- 510 – droplet

- 600 – fiber network
- 602 – transmitter station
- 604 – Receiver station
- 606 – transmitter unit
- 5 608 – data transmission fiber
- 610 – optical circuit
- 612 – optical circuit output
- 614 – optical switch power transmission unit
- 616 – optical power and control fiber
- 10 618 – optical switch controller
- 620 – optical switch
- 622 – multiplexer unit
- 624 – demultiplexer
- 626 – switch waveguide
- 15 700 – fiber network
- 810 – optical circuit
- 820a, 820b – optical switch
- 822 – modulated optical power signal
- 824 – optical-to-electrical converter
- 20 826 – power supply and switching unit
- 828 – controller

Claims

1. An active optical circuit (216, 300, 610, 810), comprising:
 - a first waveguide (302a, 404, 504);
 - a second waveguide (302b, 406, 506);
 - at least a first optical switch (312, 400, 620, 820a) for coupling light between the first waveguide and the second waveguide, the first optical switch being configurable in a plurality of switching states;
 - a data fiber (608) delivering an optical data signal that passes through the first waveguide to the optical switch;
 - a fiber channel (608, 616) for delivering optical switch power to a switch controller (618), the switch controller comprising an optical-to-electrical energy converter (824), the optical-to-electrical energy converter (824) being coupled to provide electrical power to the at least a first optical switch when optical switch power is transmitted along the fiber channel (608, 616).
2. The device as recited in claim 1, wherein the first optical switch (312, 400, 620, 820a) is configurable in more than two switching states.
3. The device as recited in claim 1, wherein the first optical switch (312, 400, 620, 820a, 820b) is configurable in at least two switching states, the at least two switching states being persistent, un-powered switching states.
4. The device as recited in claim 1, wherein the data fiber (608) comprises the fiber channel, wherein the optical data signal comprises light at a first wavelength and the optical switch-controlling signal comprises light at a second wavelength different from the first wavelength, and further comprising a wavelength demultiplexer (624) disposed to receive light from the data fiber (608) to separate the optical-switch controlling signal from optical data signal and to direct the optical switch-controlling signal to the optical-to-electrical energy converter (824).

5. The device as recited in claim 4, wherein the optical switch (312, 400, 620, 820a, 820b) is supported on a substrate (402) and the wavelength demultiplexer (624) is supported on the substrate (402).

6. The device as recited in claim 4, wherein the wavelength demultiplexer (624) is a fiber wavelength demultiplexer that separates the optical switch-controlling signal from the optical data signal and transmits the optical switch controlling signal to the optical switch (312, 400, 620, 820a) via a switch waveguide (626).

7. The device as recited in claim 1, wherein the fiber channel comprises a power and control fiber (616) separate from the data fiber (608), the power and control fiber being coupled to transmit the optical switch-controlling signal to the optical-to-electrical energy converter.

8. The device as recited in claim 1, wherein the optical-to-electrical converter (824) comprises a photodiode.

9. The device as recited in claim 1, wherein the optical switch controller (618) is configured to decode control information transmitted along the fiber channel (608, 616) and to control the at least one optical switch (312, 400, 620, 820a) according to the control information.

10. The device as recited in claim 9, wherein the optical switch controller is configured to control the at least a first optical switch (312, 400, 620, 820a) among at least two switching states.

11. The device as recited in claim 10, wherein the at least a first optical switch (312, 400, 620, 820a) further comprises a second optical switch (312, 400, 620, 820b), and the optical switch controller (616) is further configured to control the second optical switch (312, 400, 620, 820b) among at least two switching states.

12. A optical communication system, comprising:
an optical transmitter station (602) capable of transmitting an optical data signal along a first optical fiber (608, 808);
an optical receiver station (604) having an optical circuit (610) coupled to receive the optical data signal, the fiber distribution hub also comprising a plurality of fiber outputs (612) coupled to receive optical data from the optical circuit (610), the optical circuit (610) comprising one or more optical switches (312, 400, 620, 820a, 820b); and
an optical control channel (608, 616) coupling an optical switch control signal between the optical transmitter station (602) and an optical switch controller (618), the optical switch controller (618, 818) being coupled to provide operating power to the one or more optical switches (312, 400, 620, 820a, 820b).
13. A system as recited in claim 12, wherein the first optical fiber (608, 808) comprises the optical control channel, and further comprising a demultiplexer (624) that separates the optical switch control signal from the optical data signal and that directs the optical switch control signal to the optical switch controller (618, 818).
14. A system as recited in claim 13, wherein the optical transmitter station (602) further comprises an optical switch power transmission unit (614) to generate the optical switch control signal and a multiplexer (622) coupled to receive the optical switch control signal from the optical switch power transmission unit (614) and to transmit the optical switch control signal along the first optical fiber (608).
15. A system as recited in claim 12, wherein the optical control channel comprises a second optical fiber (616) coupled between the optical transmitter station (602) and the optical receiver station (604), an optical switch power transmission unit (614) in the optical transmitter station (602) generating the optical switch control signal transmitted along the second optical fiber (616), the optical switch control signal being coupled between the second optical fiber (616) and the optical switch controller (618, 818).

16. A system as recited in claim 12, wherein the optical switch controller (618, 818) is configured to operate a selected optical switch (820a, 820b) of the one or more optical switches based on information received via the optical switch control signal.

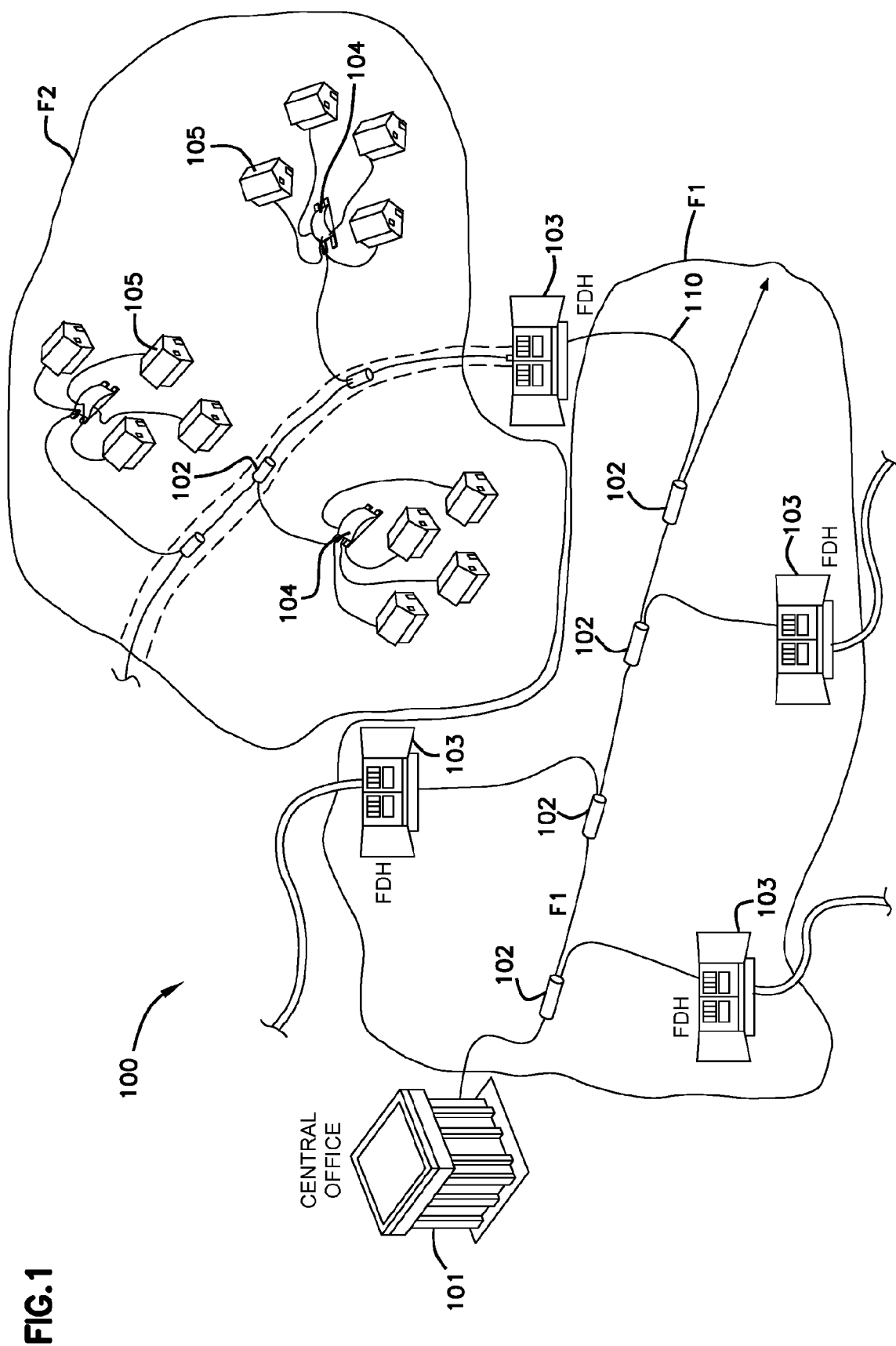


FIG.1

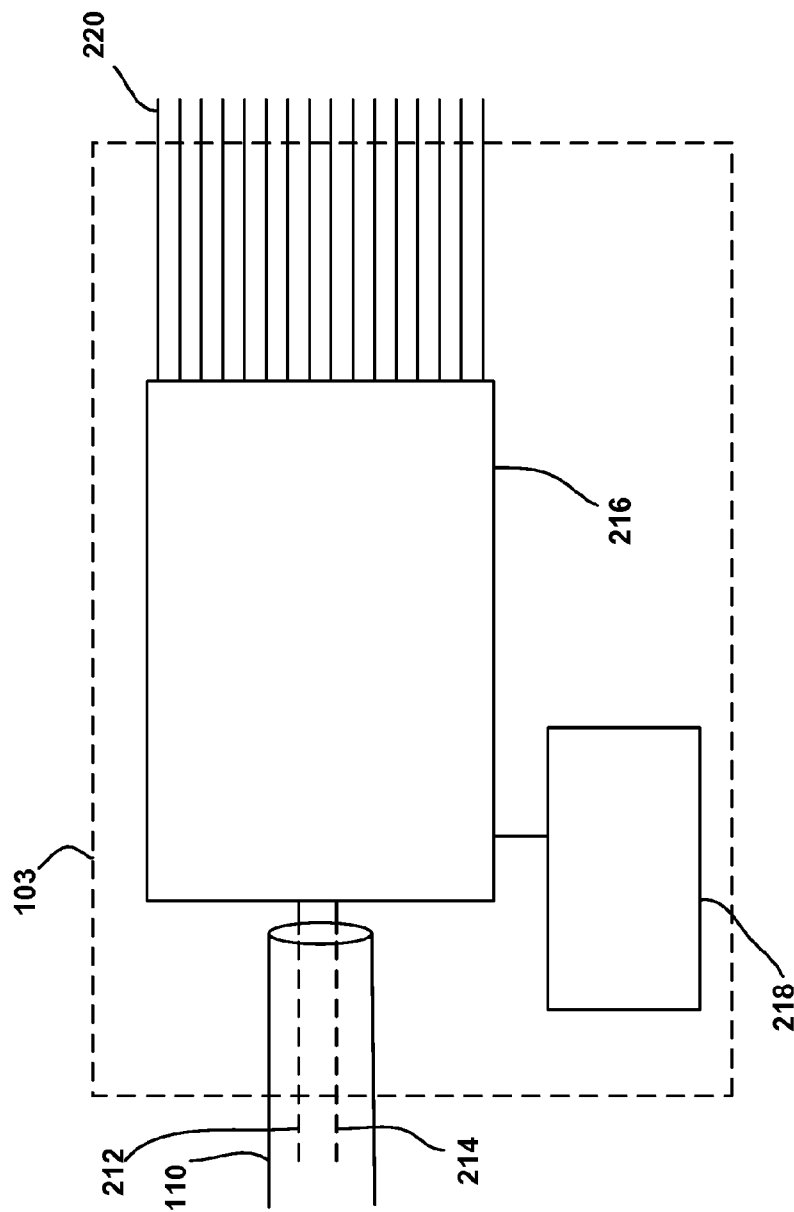


FIG. 2

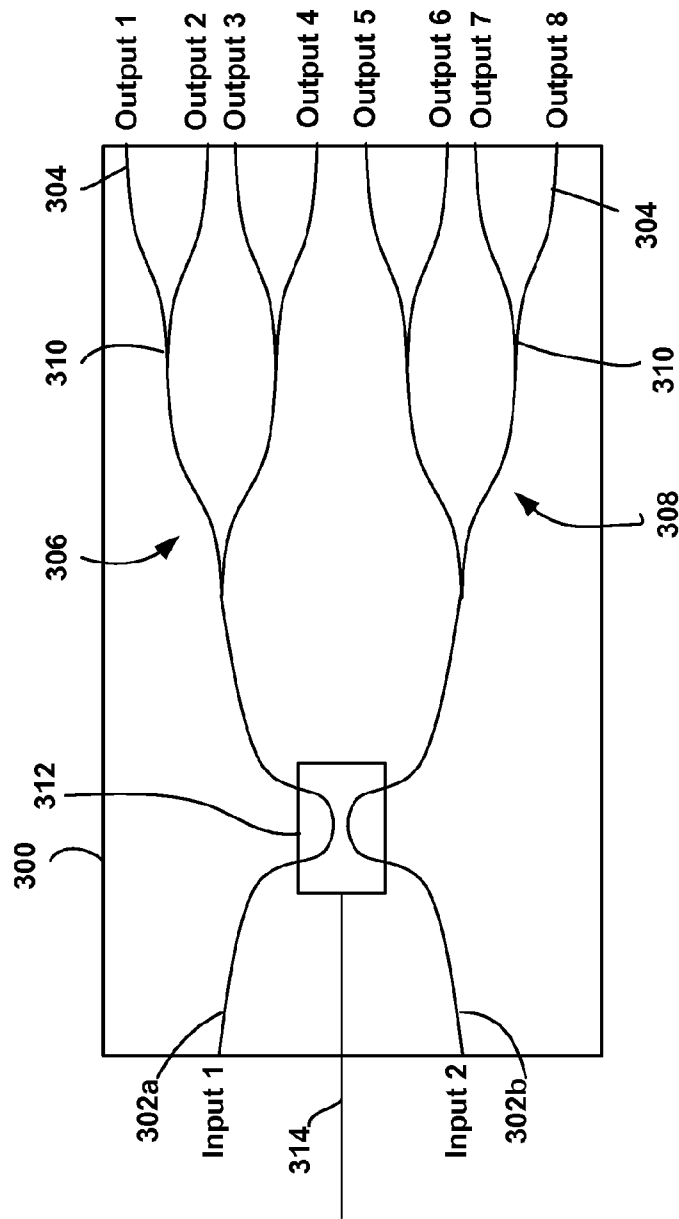


FIG. 3A

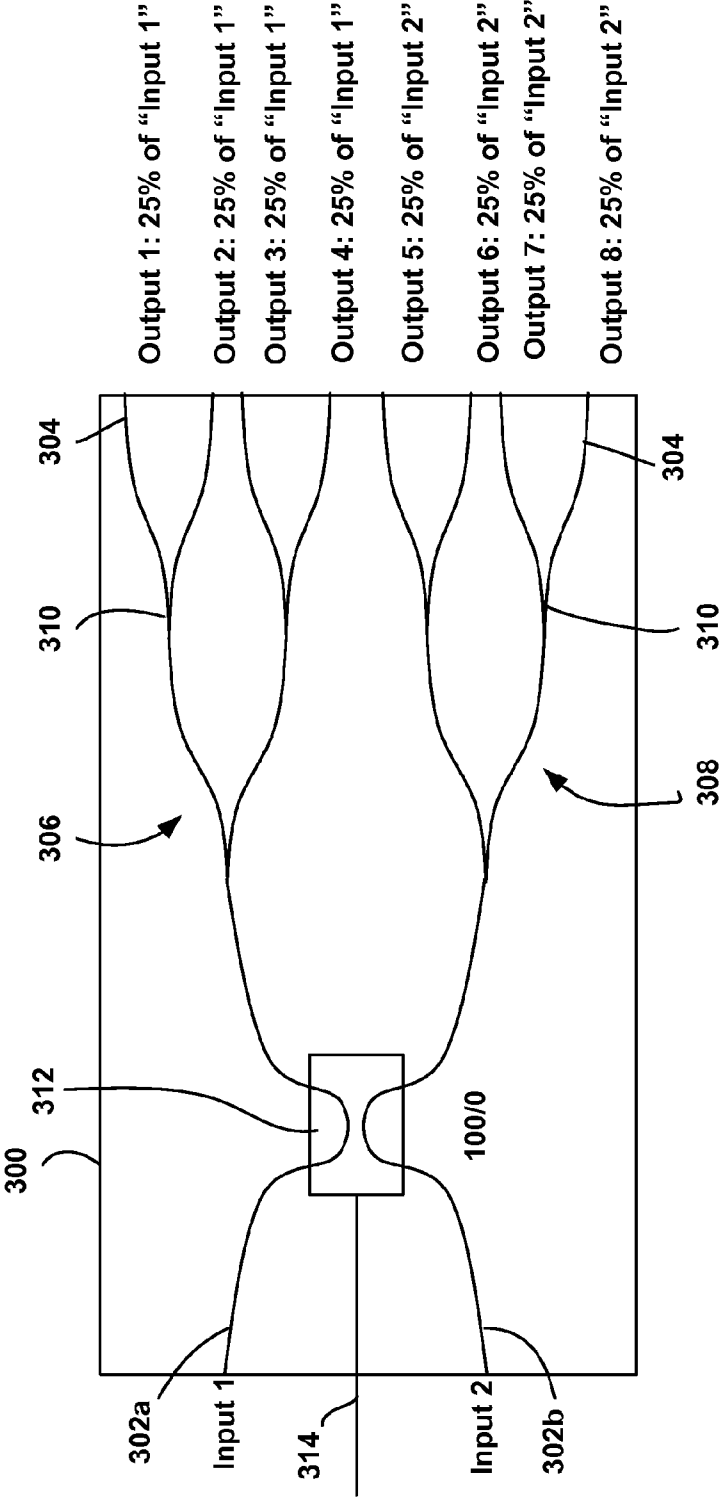


FIG. 3B

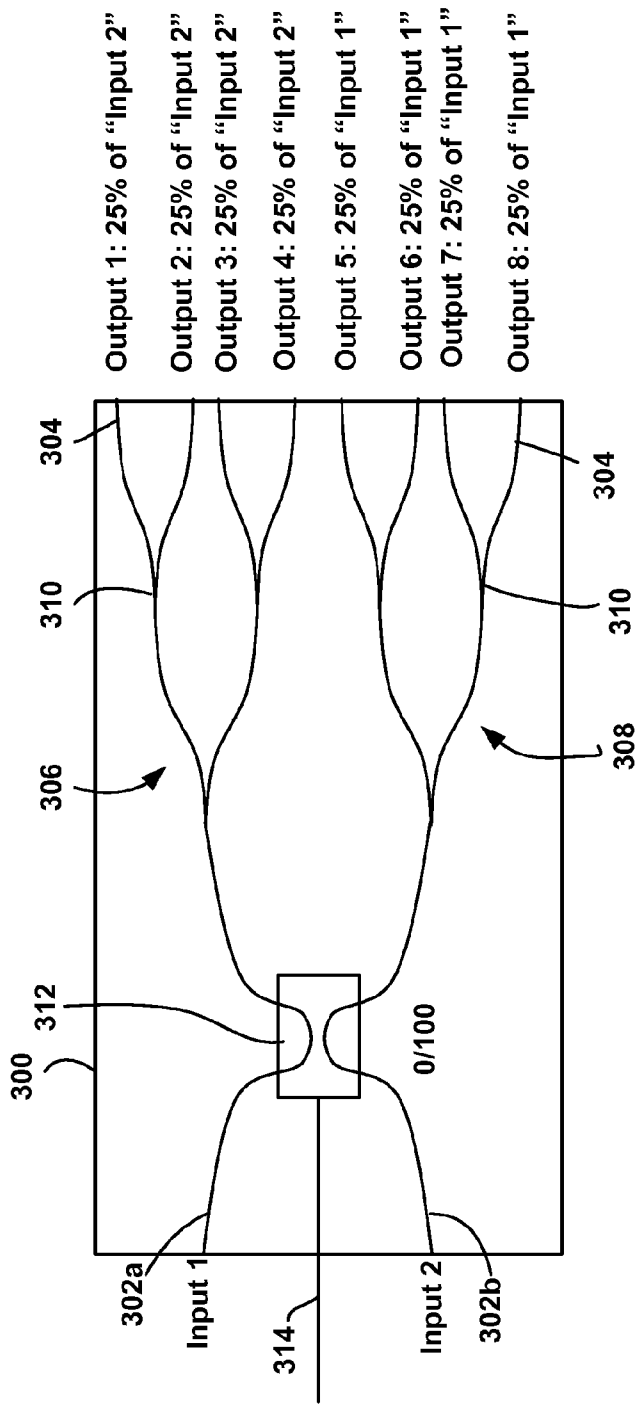


FIG. 3C

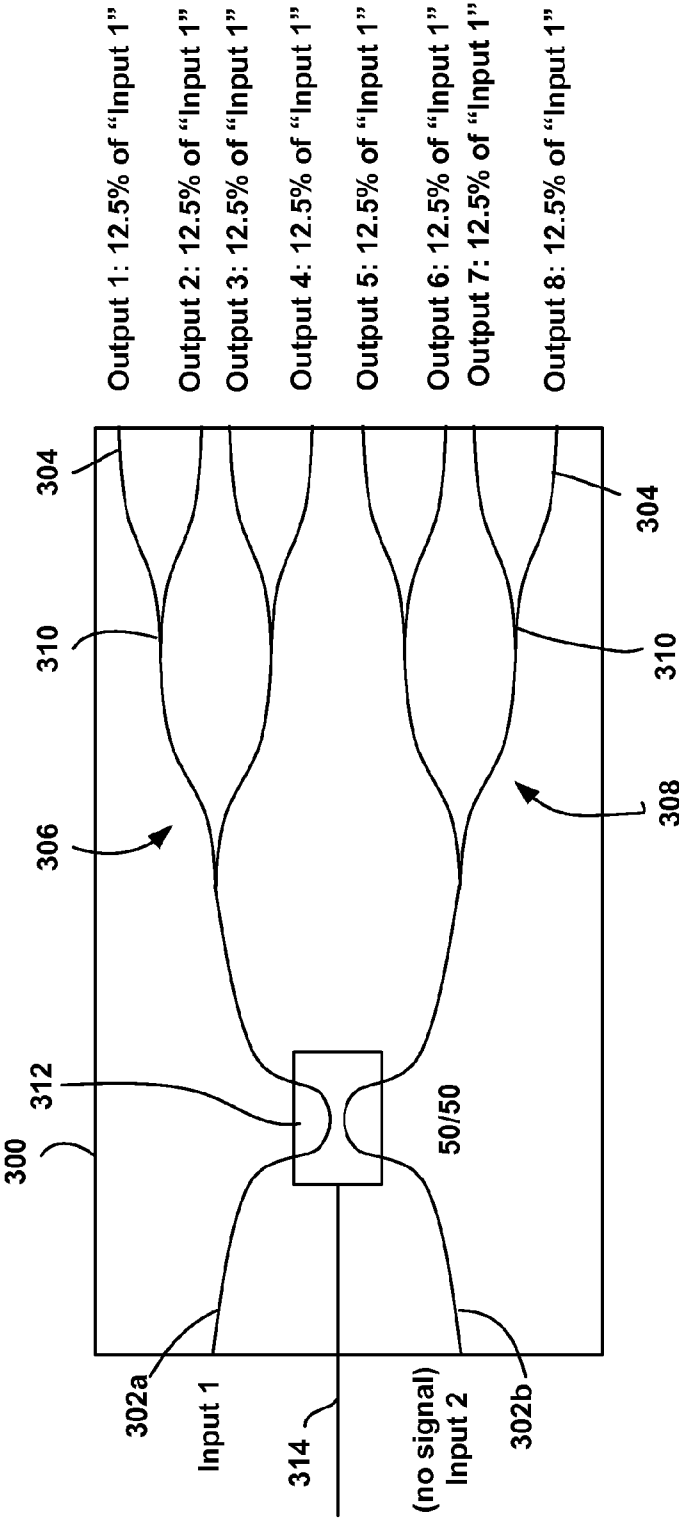


FIG. 3D

FIG. 4A

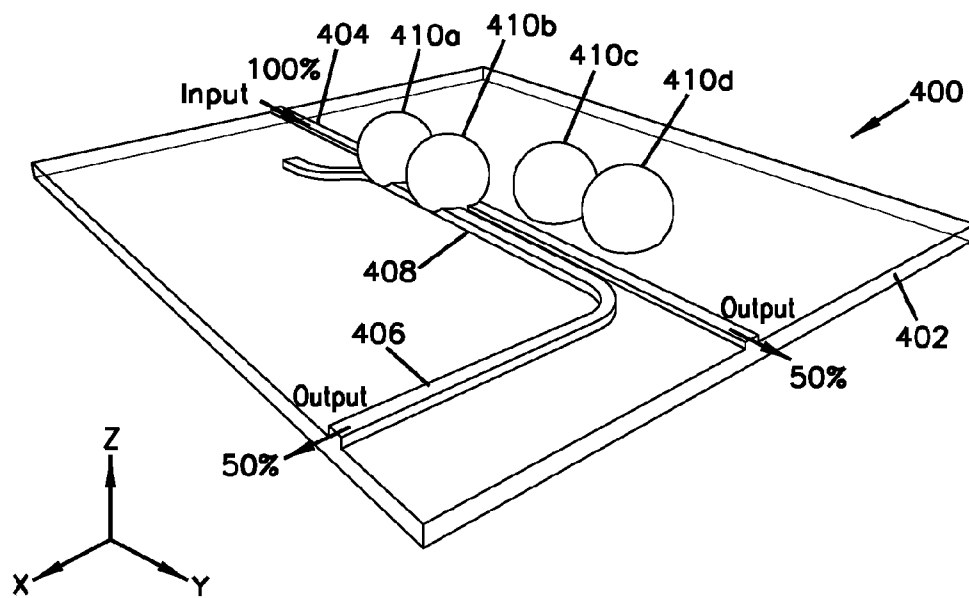


FIG. 4B

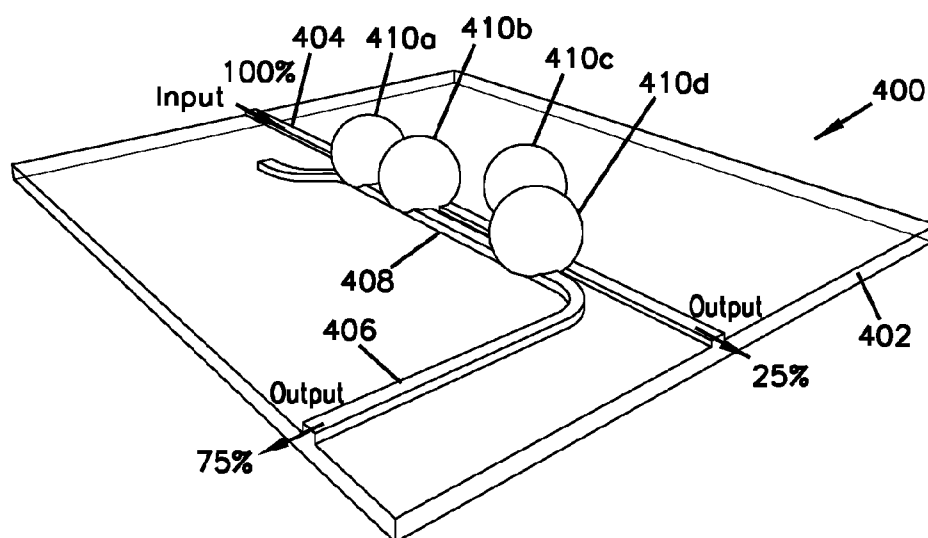


FIG. 5A

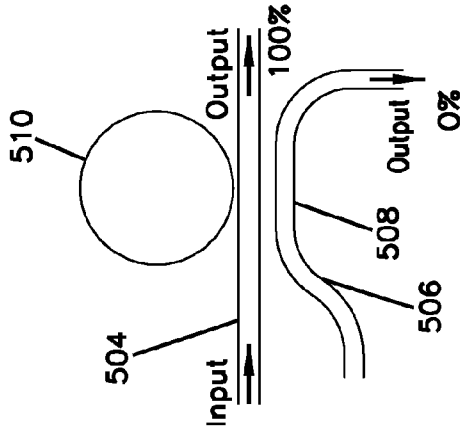


FIG. 5B

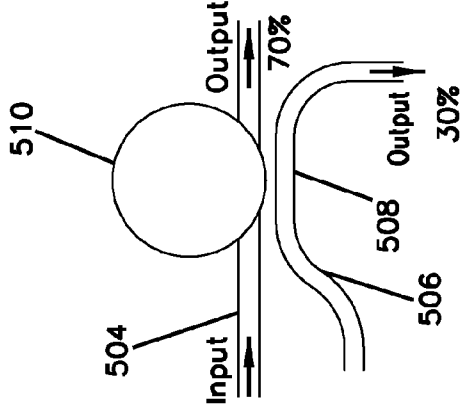


FIG. 5C

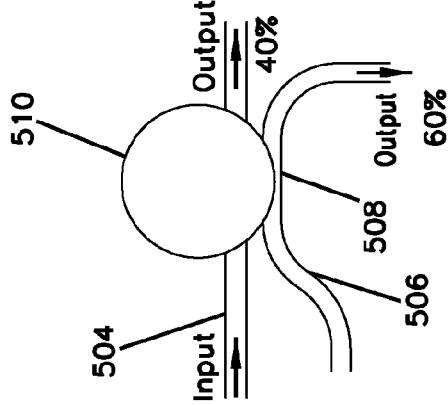
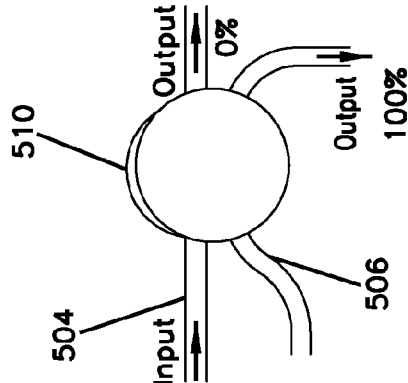


FIG. 5D



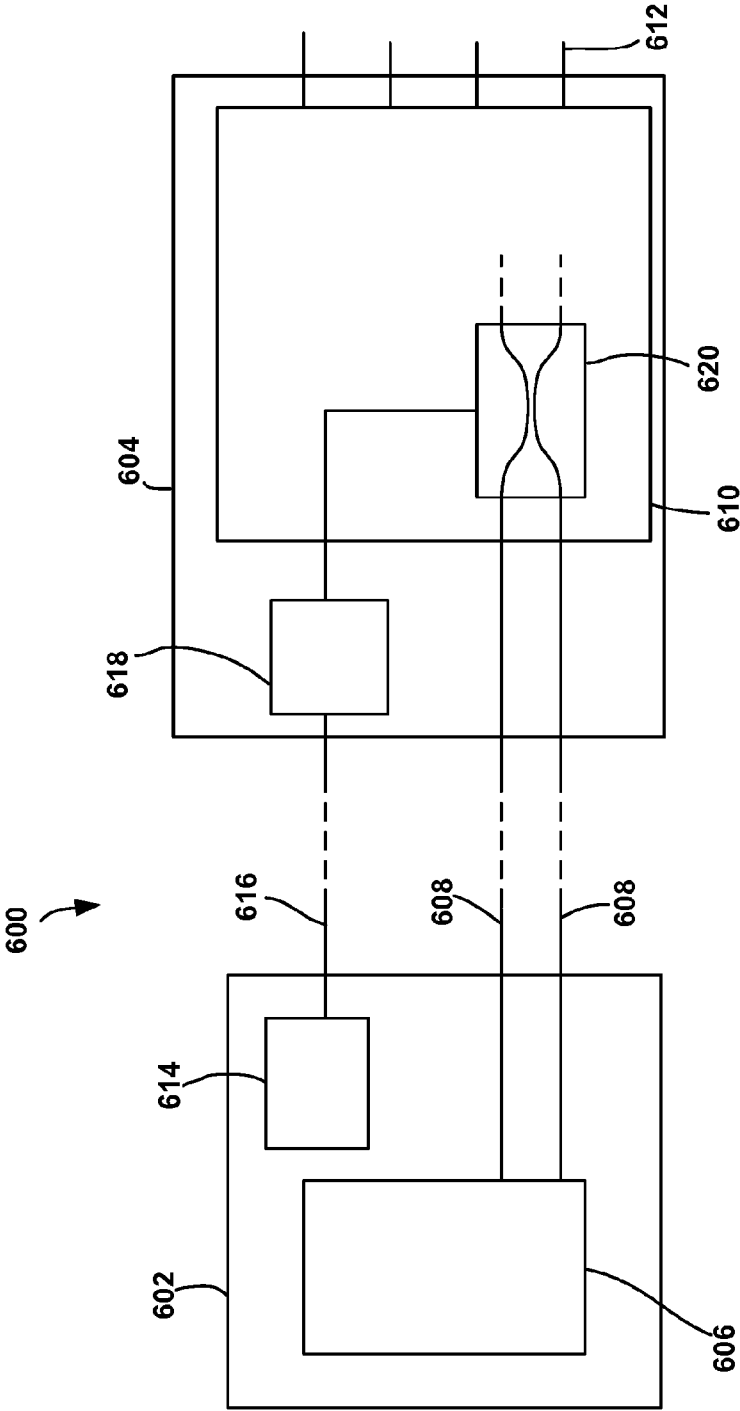


FIG. 6

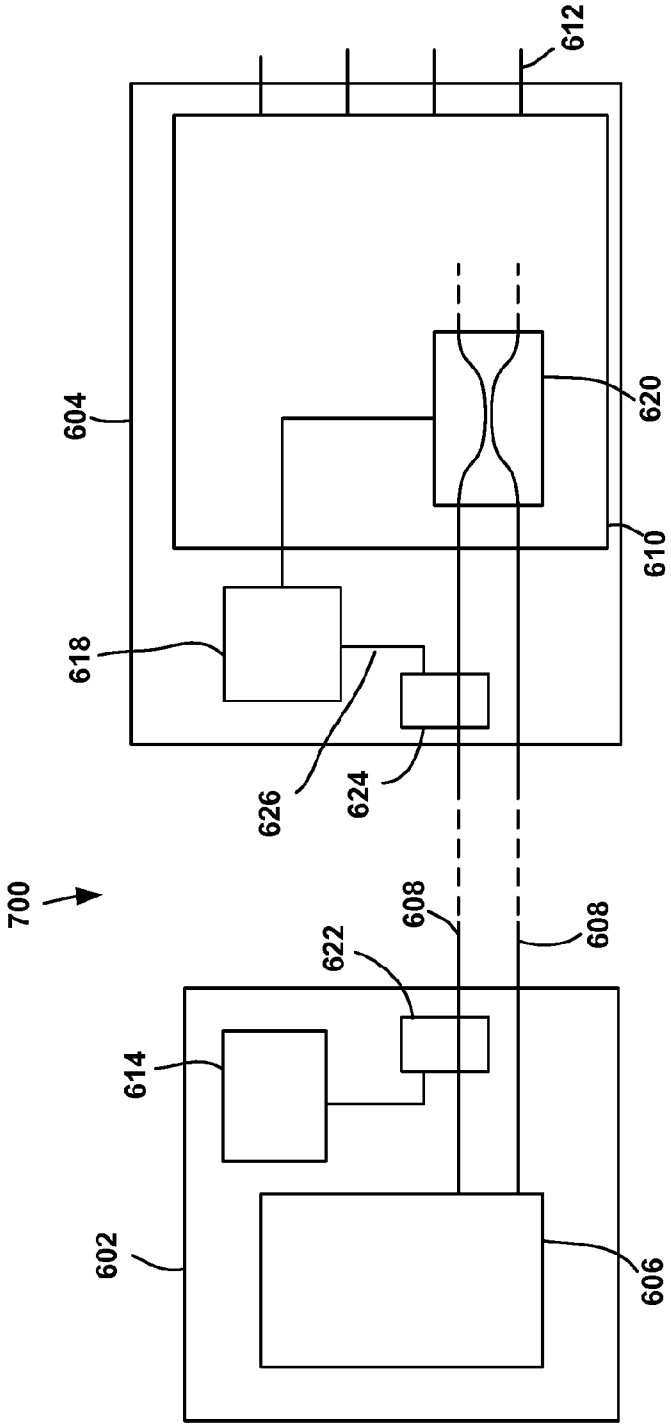


FIG. 7

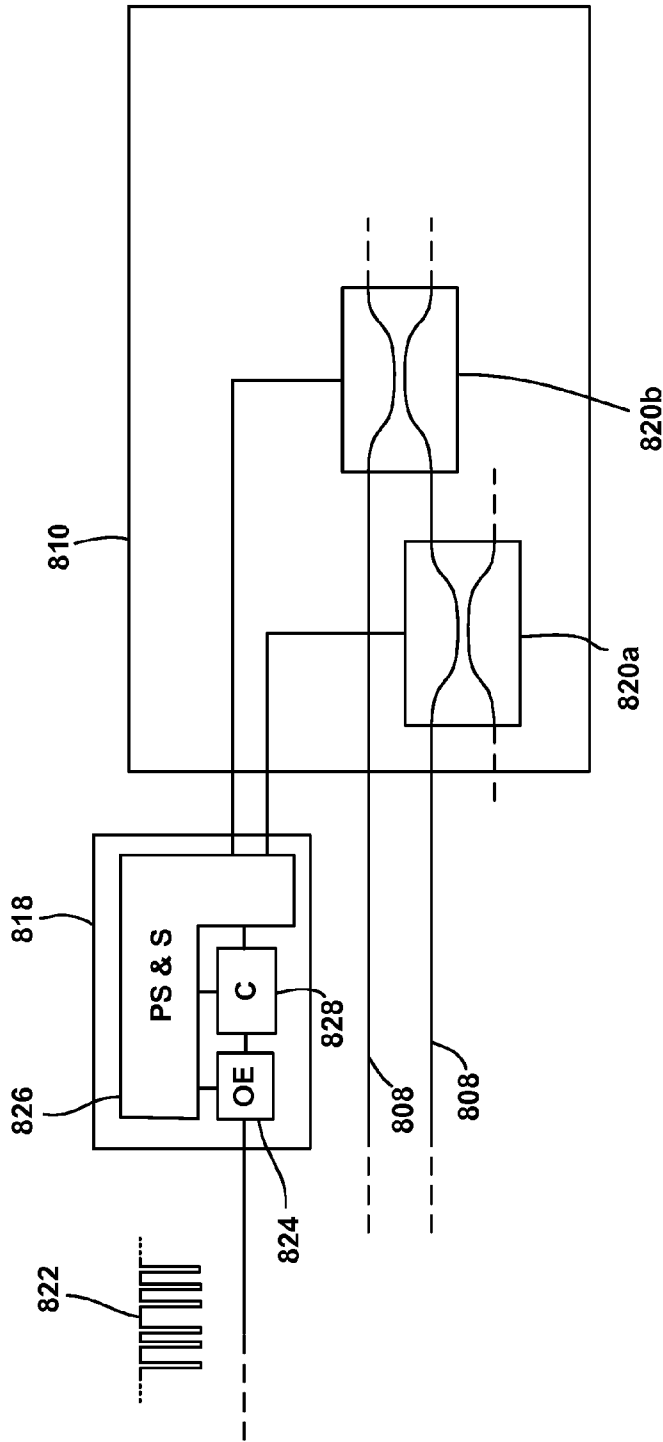


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/053265

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B10/80
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)
H04B

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	WO 2009/044948 A1 (KOREA ADVANCED INST SCI & TECH [KR]; LEE CHANG-HEE [KR]; LEE JONG-HOON) 9 April 2009 (2009-04-09) paragraphs [0001], [0015], [0016], [0052], [0058] - [0061] figures 1,2 -----	1-16
X	FR 2 890 508 A1 (FRANCE TELECOM [FR]) 9 March 2007 (2007-03-09) page 7, line 25 - page 8, line 2 page 9, lines 1-27 page 11, lines 1-4 page 11, lines 17-28 page 12, line 17 - page 13, line 2 page 13, lines 15-21 page 15, lines 5-12 figures 1,4 -----	1-16



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

3 May 2016

Date of mailing of the international search report

18/05/2016

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Authorized officer

Petitit, Nicolas

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/053265

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