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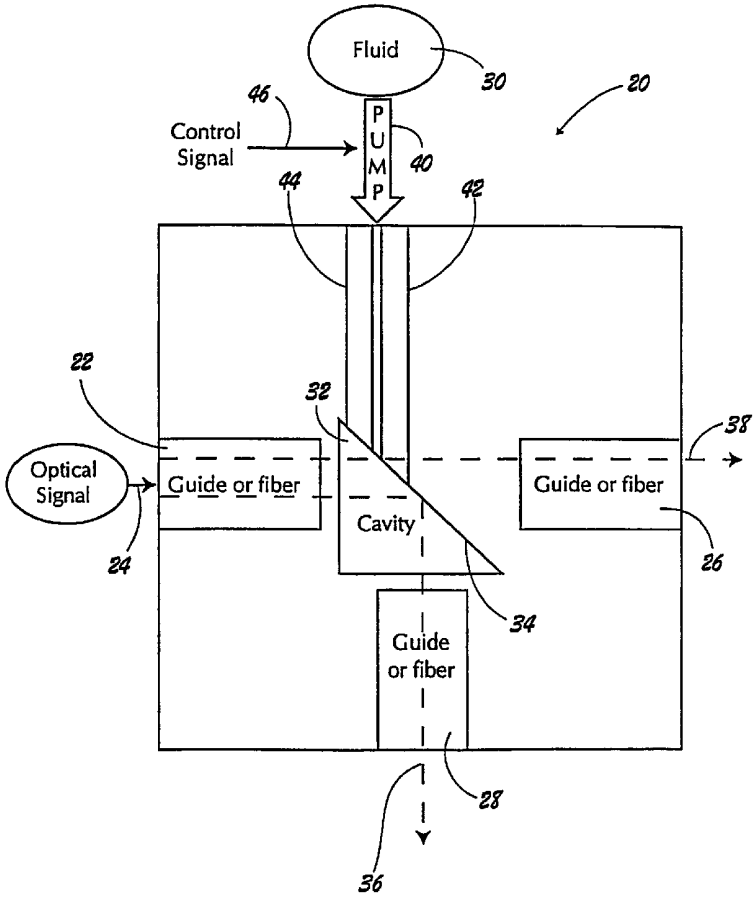

(57) Abstract: An apparatus for switching an optical signal. The optical signal enters an input point of the optical switch and exits through a first exit point. A cavity is connected to the input point and to the first exit point. A fluid is disposed in the cavity for controlling whether the optical signal exits through the first exit point.

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FLUIDIC OPTICAL SWITCHING ELEMENTS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to optical signal components, and more particularly to optical signal switching components.

2. Technical Background

Fiber optic systems use a large number of switches to route signals. Previous optical switches typically rely on moving fibers, prisms, and mirrors to perform the switching operation. However, the moving of a physical component to do the switching gradually deteriorates the physical component over time to the point where the switch no longer can properly function.

A deteriorated component necessitates replacement of the switch. The large number of switches further exacerbates the replacement issue,

and increases the cost of maintaining the operation of the fiber optic system.

SUMMARY OF THE INVENTION

The present invention overcomes this disadvantage as well as other disadvantages. In accordance with the teachings of the present invention, an apparatus for switching an optical signal via an optical switch is disclosed. The optical switch includes an input point through which the optical signal enters the optical switch. The optical signal exits the optical switch through a first exit point. The optical switch includes a cavity that is connected to the input point and to the exit point. A fluid is disposed in the cavity for controlling whether the optical signal exits through the first exit point.

Additional features and advantages of the invention will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled in the art from that description or recognized by practicing the invention as described in the detailed description which follows, the claims, as well as the appended drawings.

It is to be understood that both the foregoing general description and the following detailed description are merely exemplary of the invention, and are intended to provide an overview of framework for understanding the nature and character of the invention as it is claimed.

The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate various features and embodiments of the invention, and together with the description serve to explain the principles and operation of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram depicting a two exit point switching embodiment of the present invention;

Figure 2 is a flow chart depicting the steps associated with operation of the optical switch of the embodiment in Figure 1;

Figure 3 is a block diagram depicting the optical switch of the present invention containing one or more optical signal exit points;

Figure 4 is a block diagram depicting the optical switch of the present invention using multiple fluids for switching an optical signal;

Figure 5 is a block diagram depicting the present invention mixing two or more fluids in order to switch an optical signal; and

Figures 6 and 7 are schematic diagrams depicting the present invention having different cavity geometric configurations that are used to switch multiple input optical signals.

DETAILED DESCRIPTION THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numerals are used throughout the drawings to refer to the same or like parts.

Figure 1 depicts a non-limiting example of an optical switch **20** of the present invention. Optical switch **20** includes an input guide or fiber **22** to allow an optical signal **24** to enter the switch. Optical signal **24** exits optical switch **20** through either a first exit guide or fiber **26** or through a second guide or fiber **28**.

Fluid **30** is pumped into cavity **32** in order to control whether the input optical signal **24** exits through exit point **26** or **28**. When cavity **32** does not contain fluid **30**, the glass/air boundary **34** of cavity **32** reflects optical signal **24** to follow path **36** to second exit point **28**.

However, when cavity **32** is filled with fluid **30**, input optical signal **24** follows path **38** to first exit point **26**. Optical signal **24** travels through cavity **32** to first exit point **26** since the fluid in cavity **32** matches (or at least substantially matches) the refractive index of the material used to form cavity **32**. Accordingly, optical signal **24** passes through cavity **32** without being reflected by boundary **34**. The present invention also functions as a latch since the state of the switch is maintained until it

receives a control signal to change state. Thus, constant energy is not required to maintain the state of the switch.

Preferably, fluid **30** is pumped into and out of cavity **32** via pump **40**. Pump **40** utilizes conduits **42** and **44** to pump via electrophoresis the fluid into and out of cavity **32**.

Fluid **30** includes using either liquids or gases that when placed in cavity **32** affect the path of input optical signal **24** so as to perform a predetermined switching function. A low index or high index of refraction fluid (such as a liquid or a gas) is preferably used to maximize the contact with the glass of cavity **32**.

Cavity **32** preferably is formed via chemical etching of glass and includes an AR (anti-reflection) coating at boundary **34**. One example of the size of cavity **32** is a cavity that is approximately 8,000 cubic nanometers in volume (i.e., 20 x 20 x 20 nanometers) for a single mode waveguide. For a multimode waveguide, a non-limiting example of the size of cavity **32** is 100,000 cubic nanometers. It should be understood that these cavity sizes are only examples and vary based upon the optical switching application at hand. Fibers or light guides are preferably aligned with the cavity at an angle appropriate to optimize coupling.

Pump **40** pumps fluid **30** into and out of cavity **32** based upon a control signal **46** that is indicative of whether optical signal **24** should exit through first exit point **26** or second exit point **28**. Pump **40** uses an

electro-osmotic or electro hydrodynamic pump to move the fluid into and out of cavity **32**. In a preferred embodiment, pump **40** fills or empties cavity **32** within a time range of one to fifty milliseconds. However, in the preferred embodiment, pump **40** performs the pumping function within a time range of one to twenty milliseconds.

Figure 2 depicts process steps associated with the operation of the optical switch of Figure 1. With reference to Figure 2, start indication block **60** indicates that at process block **62**, the optical switch receives the optical signal. Decision block **64** determines (preferably via a control signal) which exit point of the switch should receive the input optical signal. If the first exit point is desired, processing continues at decision block **66** which determines whether the cavity of the optical switch is filled with fluid. If the cavity is filled with fluid, then processing continues at process block **68** wherein the optical signal passes through the cavity to the first exit point before processing ends at end block **70**. If decision block **66** determines that the cavity is not filled with fluid, process block **72** fills the cavity with fluid before process block **68** is performed.

If the received optical signal is to pass to the second exit point as determined by decision block **64**, then decision block **80** determines whether the cavity is filled with fluid. If the cavity is not filled with fluid, the received optical signal is routed by the cavity (preferably via reflection) to the second exit point at process block **82**. If the cavity is filled as

determined by decision block **80**, then process block **84** empties the cavity of fluid before process block **82** is performed. Processing terminates at end block **70**.

Figure 3 depicts a block diagram of optical switch **20**. Figure 3 depicts an embodiment of the present invention wherein the present invention contains only a single optical signal exit point **100**. Depending on whether cavity **32** contains fluid, optical signal input either traverses cavity **32** to first optical signal exit point **100** or does not reach exit point **100**. Thus, in this embodiment of the present invention, the present invention operates as an open or closed optical circuit component.

In another embodiment of the present invention, cavity **32** is configured to not only route a received optical signal to first optical signal exit point **100** but also includes routing the signal to one or more additional optical signal exit points as shown by reference numeral **102**. In this manner, the present invention operates as a multiple exit point optical switch. Also, the present invention can accept multiple optical signal input signals as depicted by reference numeral **103**.

In the preferred embodiment, fluid **30** is stored in a fluid storage compartment **104**. Fluid delivery system **106** delivers fluid from compartment **104** to cavity **32**.

Cavity **32** includes a fluid exit point **108** so that fluid **30** may leave the cavity. Upon leaving cavity **32**, fluid **30** can either be disposed of or recycled back into compartment **104**.

Figure 4 depicts another embodiment of the present invention wherein multiple fluids **120** are delivered to cavity **32**. Each of the fluids **120** in this embodiment are pumped separately from the other fluids into cavity **32**. When cavity **32** is to be emptied, the fluid is returned via fluid exit point **108** back to the correct fluid storage compartment.

Through use of multiple fluids within a single optical switching device **20**, different switching functions can be achieved. For example, the fluids can contain different index of refractions in order to pass a received optical signal to a different exit point.

Figure 5 is still another embodiment of the present invention wherein multiple fluids **120** can be mixed with one or more other fluids at mixer **130** before being delivered to cavity **32**. For example, a first fluid and a second fluid can be mixed by mixer **130** in order to achieve a different index of refraction. The mixing of the fluids produces a fluid whose index of refraction is an average of the index of refraction for the first and second fluids. Mixer **130** preferably mixes two or more fluids in various ratios to produce a desired index of refraction. If cavity **32** is to be filled with fluid that is not to be mixed with another fluid, then the fluid is delivered directly to cavity **32** thereby bypassing mixer **130**. The mixed

fluid preferably exits fluid exit point **108** such that it is not recycled back into one of the compartments **120**.

Figure 6 depicts an alternate embodiment of the present invention that uses different cavity geometric configurations to switch multiple input optical signals. For example, switch **20** in this embodiment is a 4x4 switch. Switch **20** can receive input optical signals **160**, **162**, **164**, and **166**, and can route these input signals to different exit points of the switch by filling with fluid the different cavities (**150**, **152**, **154**, and **156**) located within switch **20**.

Figure 7 depicts a non-limiting example of the routing in this embodiment associated with input optical signal **160**. Input optical signal **160** follows exit path **170** when cavities **150** and **152** are filled with fluid. Input optical signal **160** follows exit path **172** when cavities **150** and **154** are filled with fluid but cavity **152** is not filled with fluid. Input optical signal **160** follows exit path **174** when cavities **150** and **156** are filled with fluid but cavities **152** and **154** are not filled with fluid. Input optical signal **160** follows exit path **176** when cavity **150** is filled with fluid but cavities **152**, **154**, and **156** are not filled with fluid.

Switch **20** performs similar routing for the other input optical signals **162**, **164**, and **166**. It should be further understood that the present invention is not limited to the geometric configuration of four inputs and

outputs, but includes other geometric configurations to handle the application at hand.

It will be apparent to those skilled in the art that various modifications and adaptations can be made to the present invention without departing from the spirit and scope of this invention. Thus, it is intended that the present invention covers the modifications and adaptations of this invention, provided that they come within the scope of the appended claims and their equivalents.

Claims

It is Claimed:

1. An optical switch for switching an optical signal, comprising:

an input point through which the optical signal enters the optical switch;

a first exit point through which the optical signal exits the optical switch;

a cavity connected to the input point and to the first exit point; and

a fluid disposed in the cavity for controlling whether the optical signal exits through the first exit point.

2. The switch of Claim 1 further comprising:

a second exit point through which the optical signal exits the optical switch when the cavity is empty of the fluid.

3. The switch of Claim 2 wherein the optical signal exits the first exit point when the cavity contains the fluid.

4. The switch of Claim 1 further comprising:

a plurality of cavities for containing the fluid; and

a plurality of exit points through which the optical signal exits based upon whether the cavities contain the fluid.

5. The switch of Claim 4 further comprising:

a plurality of input points through which the optical signal enters the switch.

6. The switch of Claim 1 further comprising:

a fluid storage compartment for storing the fluid; and

a fluid delivery system for delivering the fluid from the fluid storage compartment to the cavity.

7. The switch of Claim 1 wherein the fluid delivery system delivers the fluid from the fluid storage compartment to the cavity via electrophoresis.

8. The switch of Claim 1 further comprising:

a fluid exit point connected to the cavity through which fluid exit point fluid exits the cavity,

said fluid exit point being connected to a fluid storage compartment for transferring the fluid from the cavity to the fluid storage compartment.

9. The switch of Claim 1 further comprising:

a fluid exit point connected to the cavity through which fluid exit point fluid exits the cavity.

10. The switch of Claim 1 further comprising:

a plurality of fluid storage compartments for storing different fluids, said fluids having different indexes of refraction;

and a mixer connected to at least two of the fluid storage compartments for mixing the fluids from the at least two fluid storage compartments,

said mixed fluid disposed in the cavity for controlling whether the optical signal exits through the first exit point.

11. The switch of Claim 1 further comprising:

a second exit point through which the optical signal exits the optical switch;

a plurality of fluid storage compartments for storing different fluids, said fluids having different indexes of refraction; and

a mixer connected to at least two of the fluid storage compartments for mixing the fluids from the at least two fluid storage compartments,

said mixed fluid disposed in the cavity for controlling whether the optical signal exits through the first exit point or second exit point.

12. The switch of Claim 11 wherein the mixer mixes the fluids in varying ratios in order to produce a mixed fluid with a predetermined index of refraction.

13. The switch of Claim 12 wherein the cavity has material having an index of refraction, said index of refraction of the mixed fluid substantially matching the index of refraction of the material of the cavity.

14. The switch of Claim 1 wherein the cavity has material having an index of refraction, said switch further comprising:

a second exit point through which the optical signal exits the optical switch when the cavity is substantially empty of the fluid, said optical signal exiting the first exit point when the cavity contains the fluid based upon the fluid having an index of refraction that substantially matches the index of refraction of the material of the cavity.

15. The switch of Claim 14 wherein an input control signal determines whether the cavity contains fluid, wherein state of the switch is based upon the presence of fluid in the cavity, said state of the switch being latched until the state is changed by the input control signal.

16. The switch of Claim 15 wherein the switch is used within a single mode fiber optic waveguide.

17. The switch of Claim 15 wherein the switch is used within a multimode fiber optic waveguide.

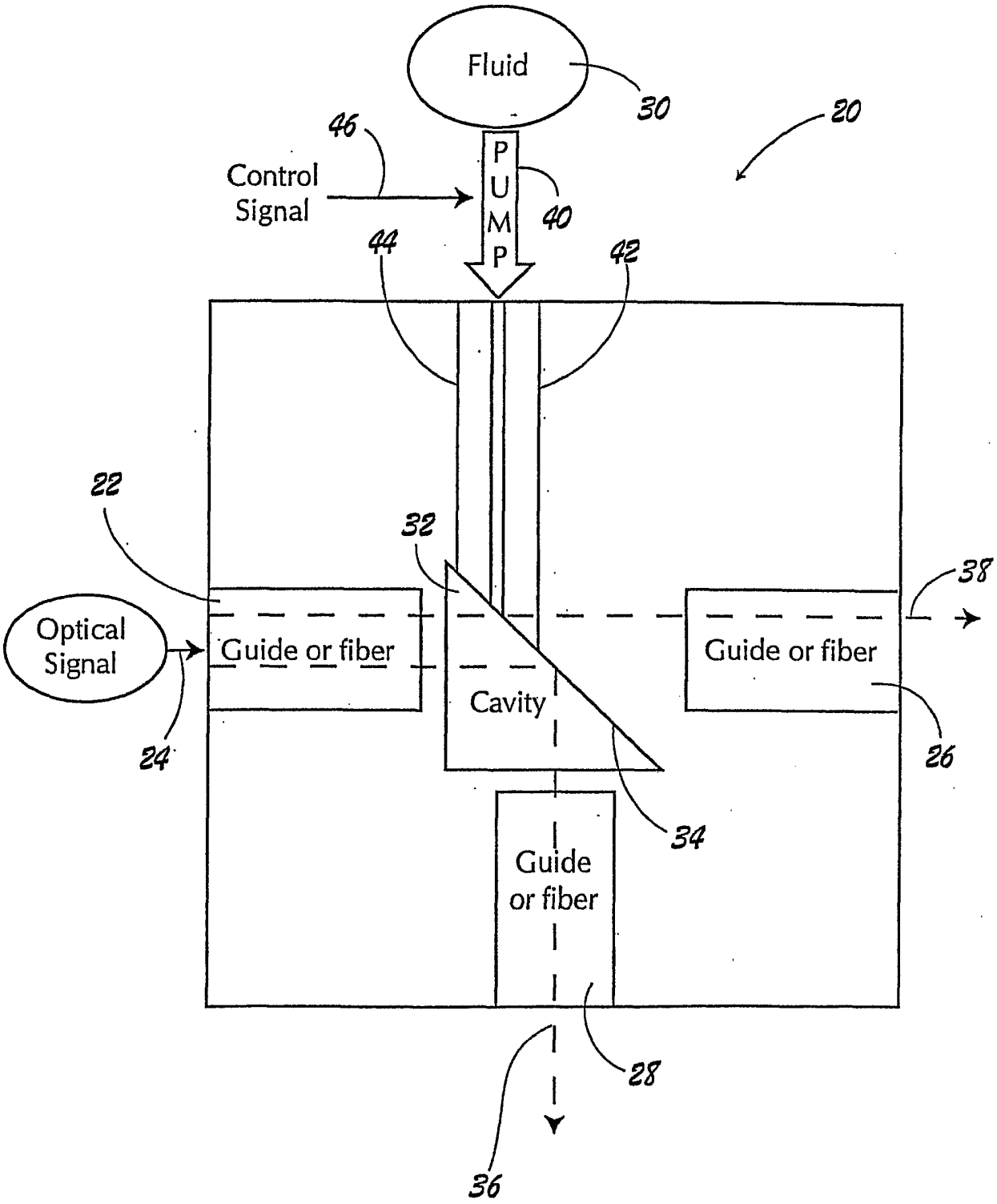
Fluid
30
20
46
Control Signal
PUMP
40
44
42
22
32
38
Optical Signal
Guide or fiber
Cavity
Guide or fiber
24
26
34
Guide or fiber
28
36

FIG. 1

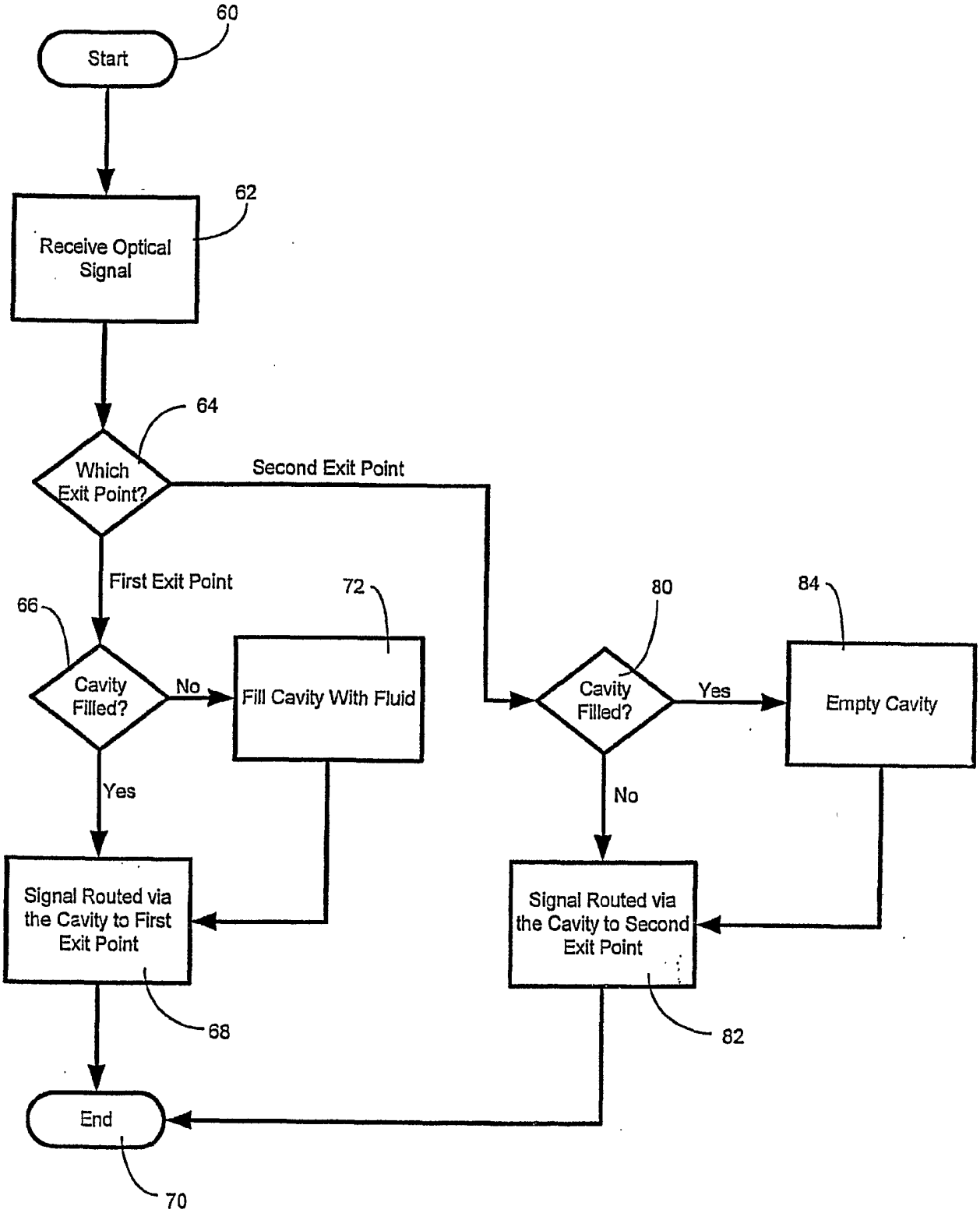
60
Start
62
Receive Optical Signal
64
Which Exit Point?
Second Exit Point
First Exit Point
66
Cavity Filled?
No
72
Fill Cavity With Fluid
Yes
80
Cavity Filled?
Yes
84
Empty Cavity
No
Signal Routed via the Cavity to First Exit Point
68
Signal Routed via the Cavity to Second Exit Point
82
End
70

FIG. 2

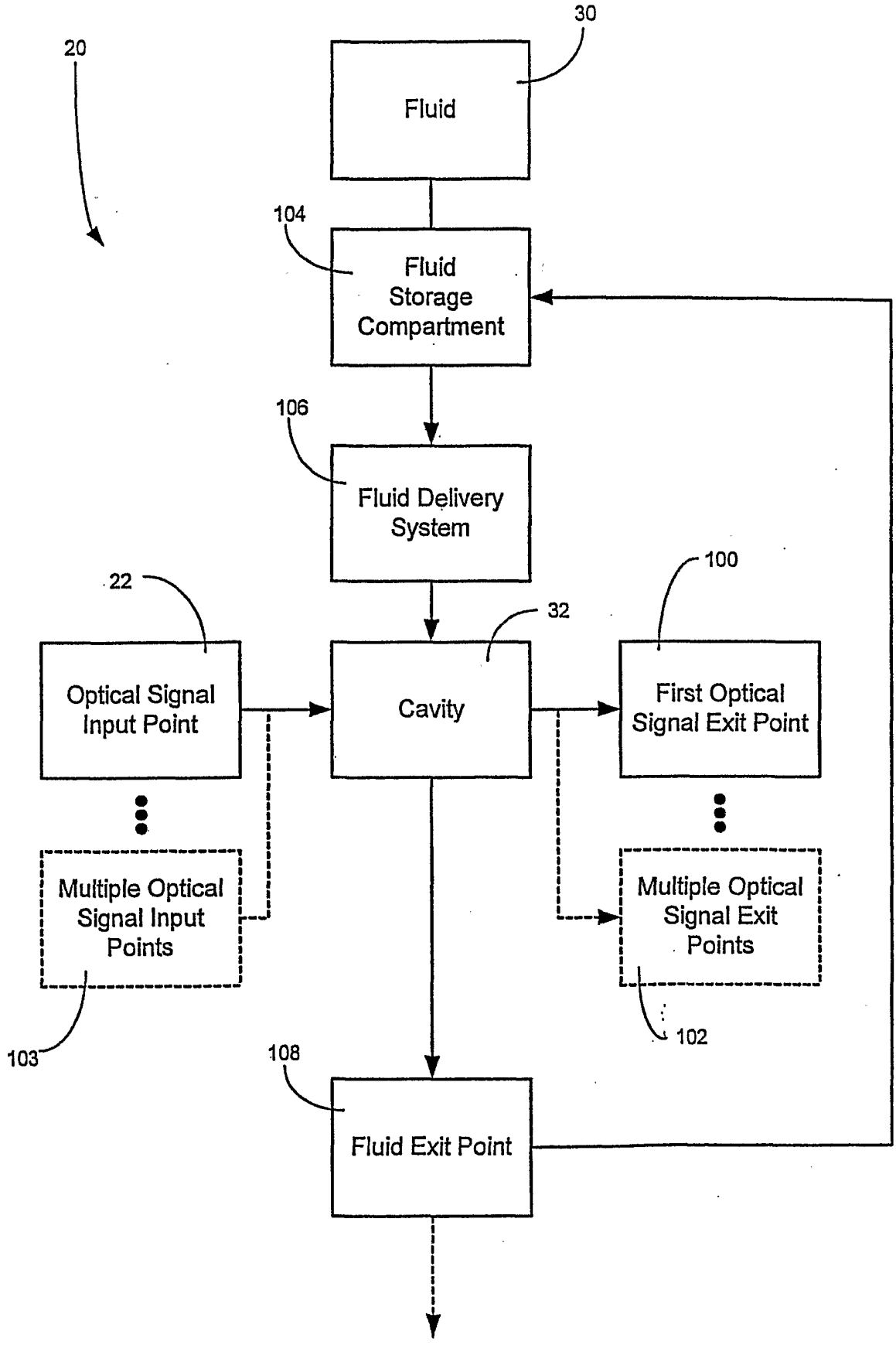
20
30
Fluid
104
Fluid Storage Compartment
106
Fluid Delivery System
22
Optical Signal Input Point
32
Cavity
100
First Optical Signal Exit Point
Multiple Optical Signal Input Points
103
Multiple Optical Signal Exit Points
102
108
Fluid Exit Point

FIG. 3

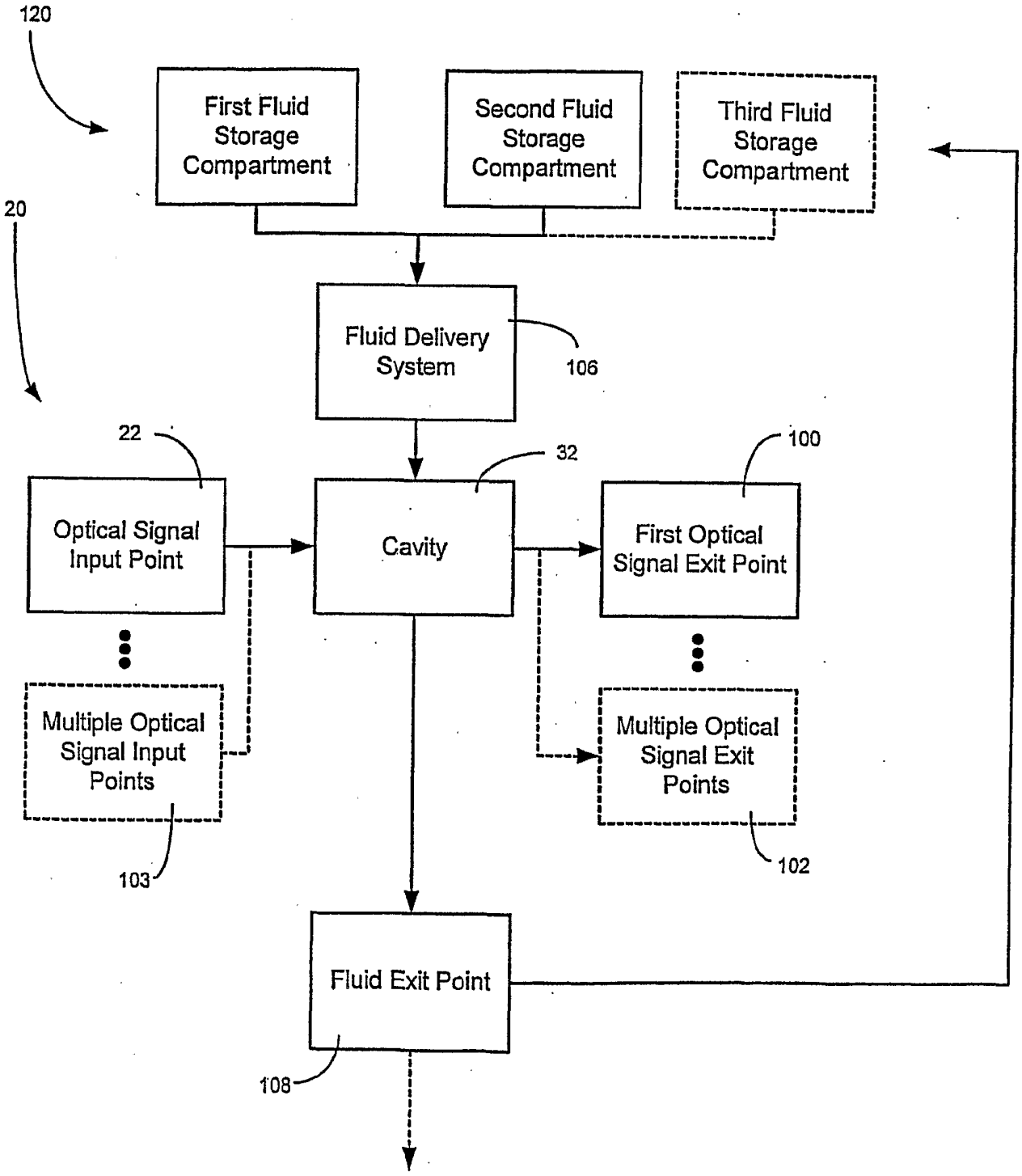
120
First Fluid Storage Compartment
Second Fluid Storage Compartment
Third Fluid Storage Compartment
20
Fluid Delivery System
106
22
32
100
Optical Signal Input Point
Cavity
First Optical Signal Exit Point
Multiple Optical Signal Input Points
Multiple Optical Signal Exit Points
103
102
Fluid Exit Point
108

FIG. 4

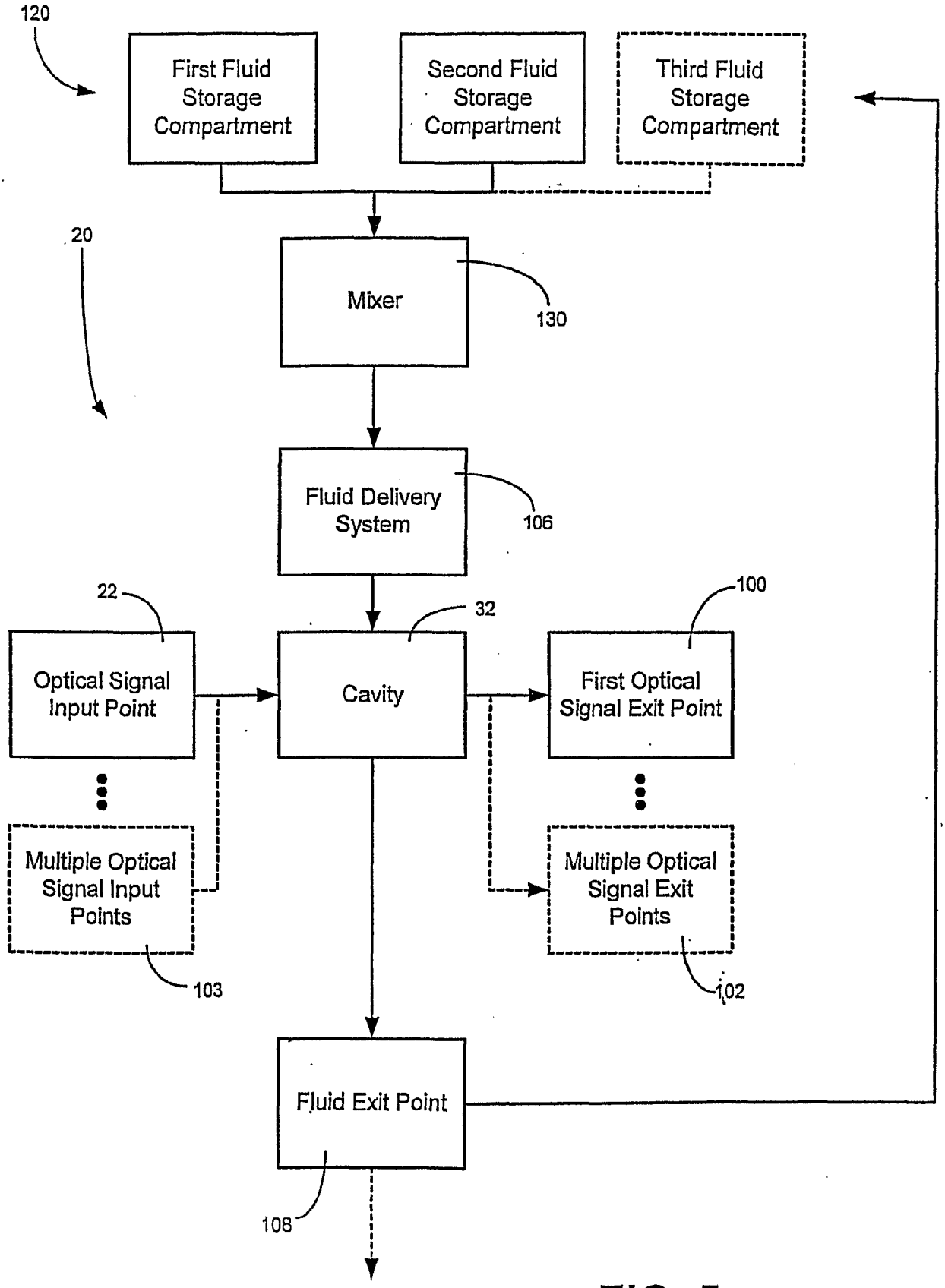
120
First Fluid Storage Compartment
Second Fluid Storage Compartment
Third Fluid Storage Compartment
20
Mixer
130
Fluid Delivery System
106
22
32
100
Optical Signal Input Point
Cavity
First Optical Signal Exit Point
Multiple Optical Signal Input Points
103
Multiple Optical Signal Exit Points
102
Fluid Exit Point
108

FIG. 5

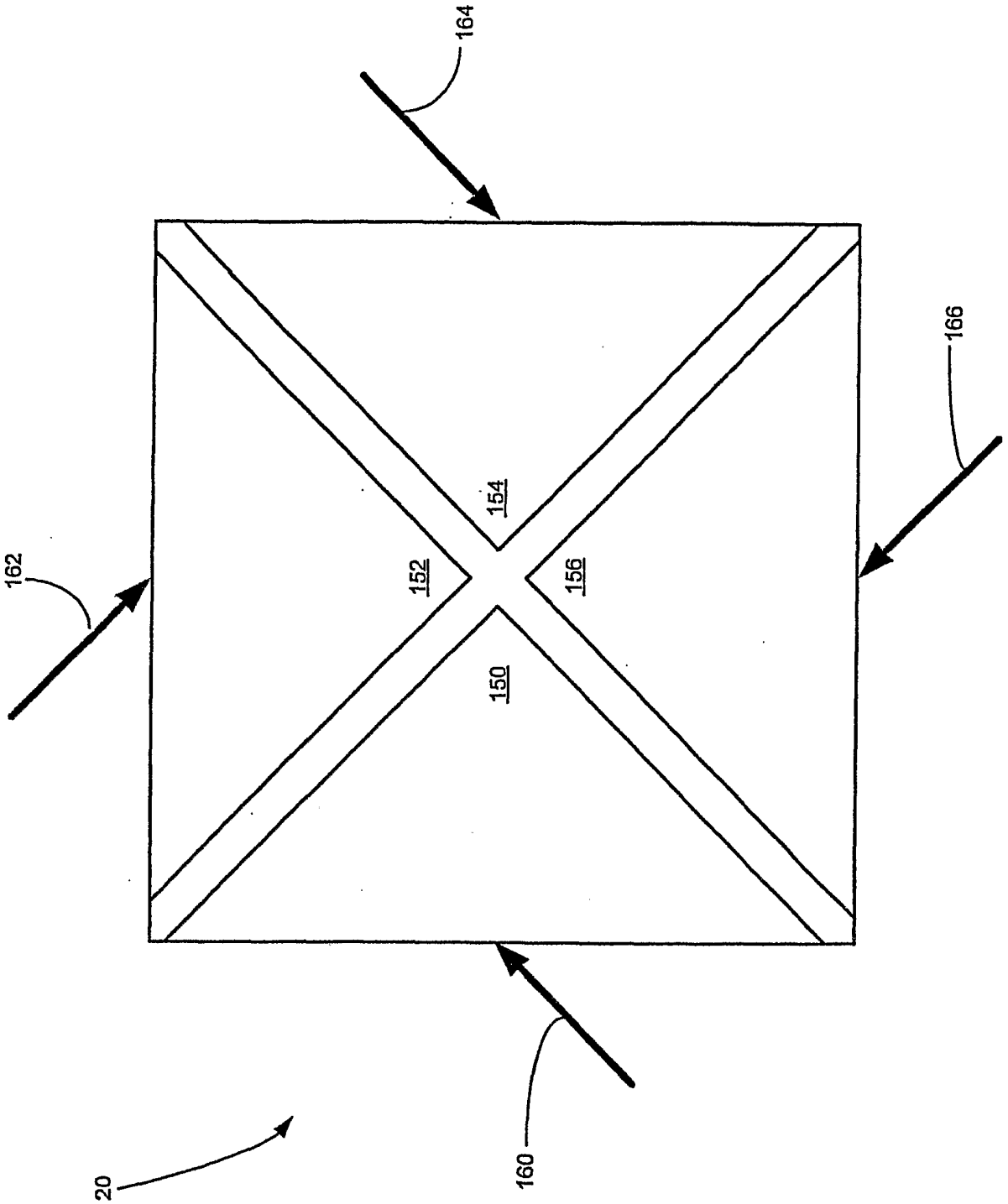

FIG. 6

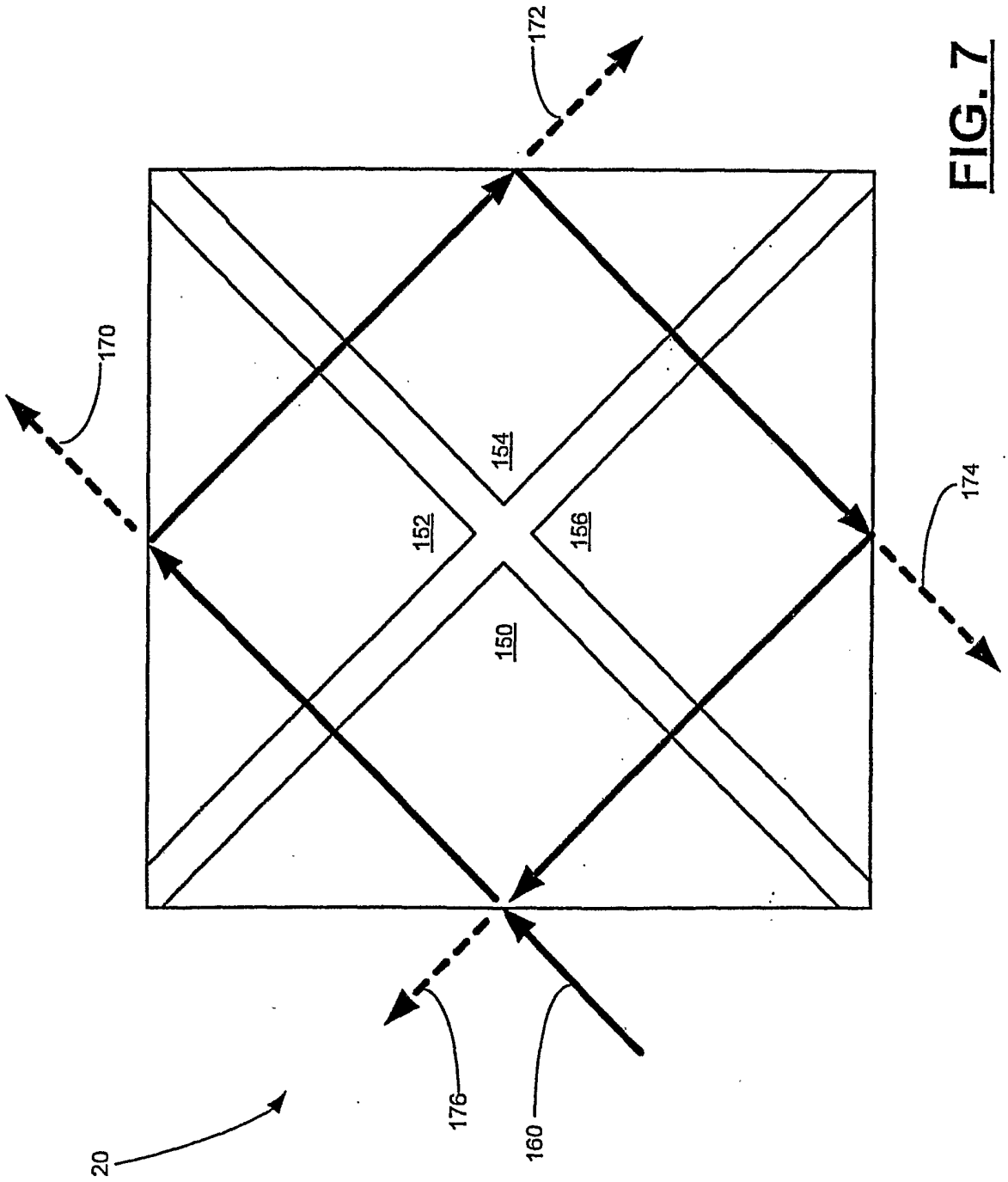

FIG. 7