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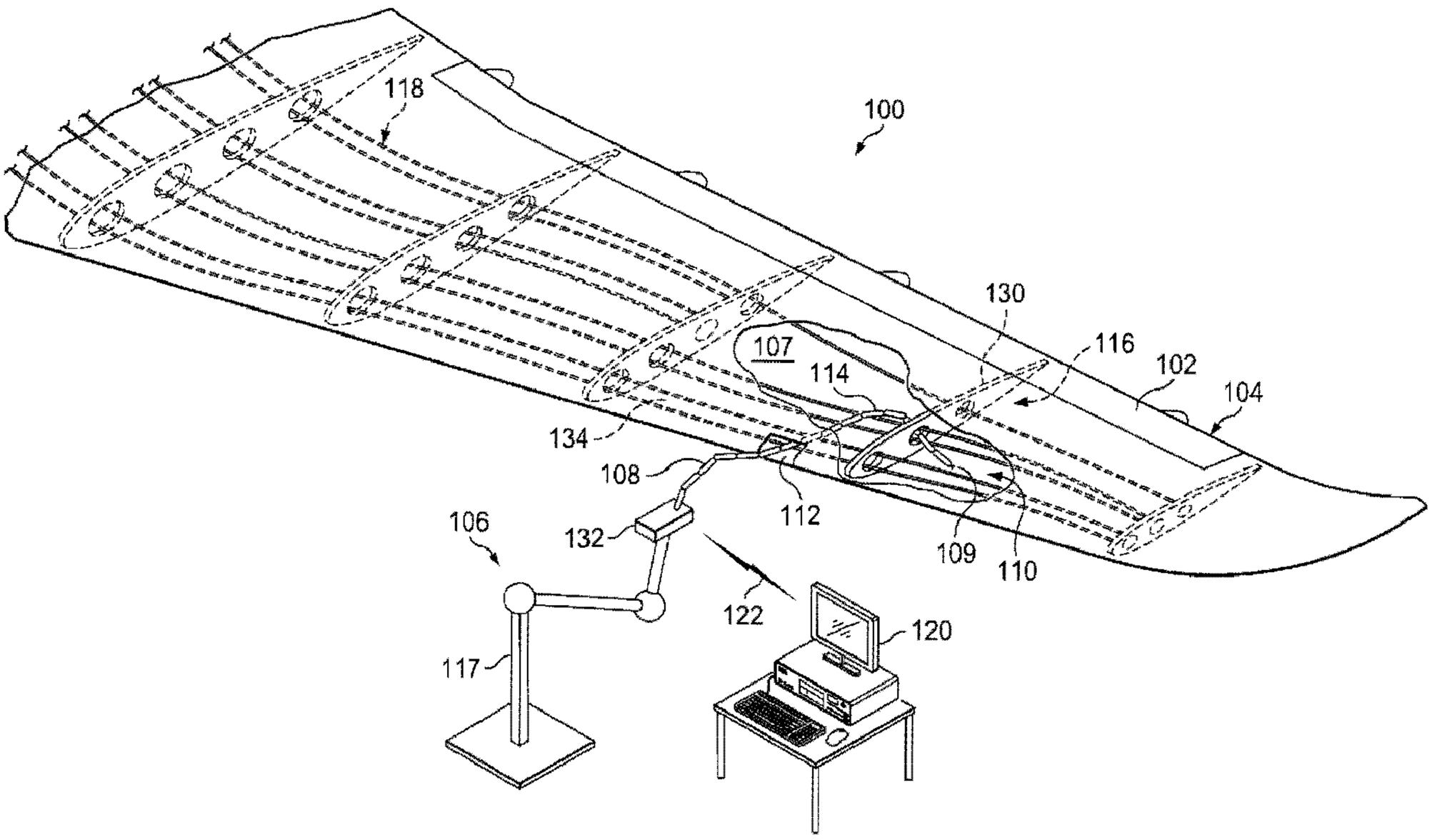


(57) Abrégé/Abstract:
A method for and apparatus for inspecting a location on a test object with a number of obstructions to reaching the location. An elongate optical fiber carrier holding a number of optical fibers is moved to the location on the test object with the number of obstructions to reaching the location. A pattern of light is transmitted from the number of optical fibers onto a surface of the test object at the location. The pattern of the light is configured to cause sound waves in the test object when the pattern of the light encounters the surface of the test object. A response is detected to the sound waves using the number of optical fibers.

ABSTRACT

A method for and apparatus for inspecting a location on a test object with a number of obstructions to reaching the location. An elongate optical fiber carrier holding a number of optical fibers is moved to the location on the test object with the number of obstructions to reaching the location. A pattern of light is transmitted from the number of optical fibers onto a surface of the test object at the location. The pattern of the light is configured to cause sound waves in the test object when the pattern of the light encounters the surface of the test object. A response is detected to the sound waves using the number of optical fibers.

ULTRASOUND INSPECTION SYSTEM OF LIMITED ACCESS COMPOSITE STRUCTURES

BACKGROUND INFORMATION

The present disclosure relates generally to inspecting objects and, in particular, to performing nondestructive inspection of objects using ultrasound inspection. Still more particularly, the present disclosure relates to a method and apparatus for inspecting composite objects with limited access using ultrasound inspection.

In manufacturing aircraft, vehicles, and other structures, inspection of parts used to form these structures is often performed to determine whether the parts will have desired parameters for a desired performance of the part. Additionally, the structures and parts are inspected as part of normal maintenance when the aircraft, vehicles, and other structures are in use.

Nondestructive testing is commonly performed on these parts. Nondestructive testing is used to evaluate the properties of a part without altering the ability to use the part in service.

Ultrasound testing is a type of nondestructive testing. Ultrasound testing is often used to perform inspections on aircraft parts that include or are comprised of composite materials. Ultrasound testing involves transmitting sound waves through a test object, such as an aircraft part or structure.

Ultrasound testing is commonly performed using a transducer. The transducer is configured to send sound waves into a test object and detect a response to the sound waves. The response to these sound waves is analyzed to determine whether inconsistencies are present in the test object.

The transducer is typically coupled to a surface of the test object. This coupling involves physical contact between the transducer and the test object. In most cases, a coupling medium is also employed. For example, water, oil, a water-based gel, or some other liquid may be used. A semi-solid material like rubber can

also be used as a coupling medium. This coupling medium is often used to reduce the acoustic impedance between the transducer and the test object.

In some cases, coupling the transducer to the surface of the test object may be more difficult to perform than desired. These test objects may have various shapes and configurations. These shapes and configurations may make inspection more difficult. For example, curved shapes, corners, fittings, or other non-planar structures may be more difficult to inspect than desired.

Further, some locations within an aircraft may be more difficult to inspect than desired. For example, enclosed spaces within the aircraft are particularly difficult to inspect because other structures may obscure the path of the ultrasound inspection system. These obscured locations may have mechanical and/or electrical structures obscuring the path of the inspection system to the surface of the object under test.

Additionally, some enclosed spaces within an aircraft may limit the type of inspection that may be used to inspect the structures within the enclosed spaces. For example, an enclosed space may be smaller than the transducer array for the ultrasound inspection system.

One example of an enclosed space may be a cavity in a structure such as a fuel tank. Access to the cavity may be through an opening that may not allow access by currently used ultrasound inspection systems.

Moreover, some currently used inspection systems for small spaces are not as accurate as desired. For example, the design of currently used ultrasound inspection systems may not be able to inspect as much of the structure within the space as desired by the operator. For example, when inspecting fuel tanks, wing boxes, electrical boxes, ventilation systems, or other structures, some currently used inspection systems may not be capable of inspecting as much of these structures as desired.

Further, when a selected structure to be inspected in an aircraft is obstructed by other structures, disassembly of one or more of the structures blocking the selected structure may be needed to perform inspection of the selected

structure. During routine maintenance, disassembly of a structure may take more time or manpower than desired. As a result, disassembly of the structure to inspect all surfaces of the structure may be more expensive than desired.

For example, when ultrasound testing is used to inspect the internal surfaces of a wing of an aircraft, the wing may need to be disassembled. This disassembly of the wing may put the aircraft out of service for longer than desired. As a result, these surfaces may not be inspected as often as desired. In some cases, disassembly of some or all of the wing may be infeasible. Thus, inspections require using other techniques other than ultrasound inspection systems. These systems may be more expensive or may not provide a desired level of inspection.

Therefore, it would be desirable to have a method and apparatus that takes into account at least some of the issues discussed above, as well as other possible issues.

SUMMARY

In on embodiment there is provided an apparatus including a platform; an interferometer system connected to the platform; an elongate optical fiber carrier connected to and extending from the interferometer system; a light source in optical communication with the elongate optical fiber carrier, the light source configured to emit a light; and a movement system connected to the elongate optical fiber carrier. The movement system is configured to move the elongate optical fiber carrier through an opening of a test object into an interior cavity of the test object and bypass a plurality of obstructions while moving the elongate optical fiber carrier within the interior cavity to a cavity location obstructed from the opening by the plurality of obstructions, while the interferometer system remains outside the opening. The apparatus further includes a fiber bundle inside the elongate optical fiber carrier. The fiber bundle includes a first plurality of optical fibers and is configured to receive and then transmit light from the light source. The apparatus further includes an end effector disposed on an end of the elongate optical fiber carrier, the end opposite the interferometer system. The end effector includes a

cylinder lens inside a housing and in optical communication with the first plurality of optical fibers. The cylinder lens is configured to cause the light to have a first Gaussian profile in an "X" direction relative to a plane and a second Gaussian profile in a "Y" direction relative to the plane. The cylinder lens is further configured to cause the first Gaussian profile and the second Gaussian profile to be different. The end effector further includes a first mirror inside the housing and in optical communication with the cylinder lens, the first mirror further disposed such that light emitted from the cylinder lens is transmitted in a pattern of light onto the test object. The pattern of light is configured to cause sound waves in the test object and a response light from the test object. The end effector further includes a second mirror inside the housing and is configured to receive the response light; and a plurality of collimators configured to receive the response light from the second mirror. The apparatus further includes a second plurality of optical fibers inside the elongate optical fiber carrier. The second plurality of optical fibers is connected to the plurality of collimators such that each optical fiber of the second plurality of optical fibers is connected to a corresponding collimator of the plurality of collimators. The interferometer system is configured to receive the response light and generate data from the response light, the data used to determine whether an inconsistency is present in the test object at the location.

The platform may include a robotic arm.

The elongate optical fiber carrier may include a hand-held tool.

The movement system may include a plurality of joints.

The light source may include a plurality of lasers. The apparatus may further include a delay line and a delay circuit separating the plurality of lasers. The delay line and the delay circuit may be configured to reduce cross-talk in optical fibers in the elongate optical fiber carrier.

The light source may include a plurality of lasers. The apparatus may further include a mechanism configured to separate the plurality of lasers in the light source and to reduce cross-talk in optical fibers in the elongate optical fiber carrier.

The apparatus may further include a plurality of optical elements configured to modify transmission of the light.

The plurality of optical elements may include at least one of a lens, a mirror, a diffractive optical element, a polarizer, a wave plate, and a periodically poled Lithium niobate crystal.

The elongate optical fiber carrier may include at least one of a deformable sheath, a rigid sheath, a hand-held tool with orientation control, a segmented snake configured to change orientation and move, and a segmented snake configured for attachment to a robotic arm.

The apparatus may further include a third plurality of optical fibers configured to transmit a second pattern of light onto the test object. The second pattern of light may be configured detect a second response to the sound waves in the test object. The apparatus may further include a second elongate optical fiber carrier configured to hold the third plurality of optical fibers and may further include a second movement system configured to move the second elongate optical fiber carrier to through a second opening of the test object into a second interior cavity of the test object and bypass a second plurality of obstructions while moving the second elongate optical fiber within the second interior cavity to a second cavity location obstructed from the second opening by the second plurality of obstructions.

In another embodiment there is provided a method of identifying an inconsistency using a platform, an interferometer system connected to the platform, an elongate optical fiber carrier connected to and extending from the interferometer system, a fiber bundle inside the elongate optical fiber carrier, the fiber bundle including a first plurality of optical fibers, an end effector disposed on an end of the elongate optical fiber carrier opposite the interferometer system, a light source in optical communication with the elongate optical fiber carrier, the light source configured to emit a light wherein the fiber bundle is configured to receive and then transmit the light from the light source, and a movement system connected to the elongate optical fiber carrier. The method involves: moving, using the movement system, the elongate optical fiber carrier into a cavity of a test object through an opening of in the test object; bypassing a plurality of obstructions within the cavity

while moving the elongate optical fiber carrier to a location obstructed from the opening by the plurality of obstructions while the interferometer system remains outside the opening; and causing, using a cylinder lens inside a housing and in optical communication with the first plurality of optical fibers, the light to have a first Gaussian profile in an "X" direction relative to a plane and a second Gaussian profile in a "Y" direction relative to the plane. The method further involves causing, using the cylinder lens, the first Gaussian profile and the second Gaussian profile to be different; and transmitting, using a first mirror inside the housing and in optical communication with the cylinder lens, light emitted from the cylinder lens in a pattern onto a test object. The pattern is configured to cause sound waves in the test object and a response light from the test object. The method further involves receiving, at a second mirror inside the housing, the response light and receiving, at a plurality of collimators, the response light from the second mirror. A second plurality of optical fibers is inside the elongate optical fiber carrier, the second plurality of optical fibers connected to the plurality of collimators such that each optical fiber of the second plurality of optical fibers is connected to a corresponding collimator of the plurality of collimators. The method further involves receiving, at the interferometer system, the response light; generating data from the response light; and determining, using the data, whether an inconsistency is present in the test object at the location.

The platform may include a robotic arm.

The elongate optical fiber carrier may include a hand-held tool.

The movement system may include a plurality of joints and the method may further involve bending the joints.

The light source may include a plurality of lasers. The method may further involve reducing cross-talk in optical fibers in the elongate optical fiber carrier using a delay line and a delay circuit separating the plurality of lasers.

The light source may include a plurality of lasers. The method may further involve reducing cross-talk in optical fibers in the elongate optical fiber carrier using at least one of different phases of light, different wavelengths of light and different timings of light.

The method may further involve modifying transmission of the light using a plurality of optical elements.

The plurality of optical elements may include at least one of a lens, a mirror, a diffractive optical element, a polarizer, a wave plate, and a periodically poled Lithium niobate crystal.

Bypassing the plurality of obstructions within the cavity may involve moving the elongate optical fiber carrier through at least one of the plurality of obstructions.

The plurality of obstructions may include at least one of cables, hardware, systems, wire bundles, pipes, stringers, webbing, another test object, and a wall with an opening.

The elongate optical fiber carrier may include at least one of a deformable sheath, a rigid sheath, a hand held tool with orientation control, a segmented snake configured to change orientation and move, and a segmented snake configured for attachment to a robotic arm.

The method may further involve generating an output indicating whether the inconsistency is present in the test object at the location.

The pattern may include at least one of a line of light, a non-contiguous line of light, a contiguous line of light, contiguous areas of light, and non-contiguous areas of light.

The pattern may include at least one of a pattern of coherent light and a pattern of non-coherent light.

The test object may include a composite test object including at least one of a panel, a fuselage barrel, a stringer, a fuel tank, a spar, a rib, a wing box, a wing, and a stabilizer.

The test object may include a wing of an aircraft.

The test object may include of a plurality of materials including at least one of a composite material, a plastic, and a metal.

The features and functions can be achieved independently in various embodiments of the present disclosure or may be combined in yet other

embodiments in which further details can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments,

however, as well as a preferred mode of use, further objectives and features thereof, will best be understood by reference to the following detailed description of an illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

Figure 1 is an illustration of an inspection environment in accordance with an illustrative embodiment;

Figure 2 is an illustration of a block diagram of an inspection environment in accordance with an illustrative embodiment;

Figure 3 is an illustration of a block diagram of an elongate structure in accordance with an illustrative embodiment;

Figure 4 is an illustration of a block diagram of a sensor in accordance with an illustrative embodiment;

Figure 5 is an illustration of a block diagram of a light source in accordance with an illustrative embodiment;

Figure 6 is an illustration of an elongate optical fiber carrier in accordance with an illustrative embodiment;

Figure 7 is an illustration of an elongate optical fiber carrier in accordance with an illustrative embodiment;

Figure 8 is an illustration of an elongate optical fiber carrier in accordance with an illustrative embodiment;

Figure 9 is an illustration of an elongate optical fiber carrier in accordance with an illustrative embodiment;

Figure 10 is an illustration of an inspection environment in accordance with an illustrative embodiment;

Figure 11 is an illustration of an ultrasound source in accordance with an illustrative embodiment;

Figure 12 is an illustration of an ultrasound source in accordance with an illustrative embodiment;

Figure 13 is an illustration of an ultrasound detector in accordance with an illustrative embodiment;

Figure 14 is an illustration of an ultrasound detector in accordance with an illustrative embodiment.

Figure 15 is an illustration of an ultrasound inspection system in accordance with an illustrative embodiment;

Figure 16 is an illustration of a top view of an ultrasound inspection system in accordance with an illustrative embodiment;

Figure 17 is an illustration of a front view of an ultrasound inspection system in accordance with an illustrative embodiment;

Figure 18 is another illustration of an ultrasound inspection system in accordance with an illustrative embodiment;

Figure 19 is an illustration of a perspective view of an ultrasound inspection system in accordance with an illustrative embodiment;

Figure 20 is an illustration of a flowchart of a process for inspecting a location on a test object with a number of obstructions to reaching the location in accordance with an illustrative embodiment;

Figure 21 is a flowchart of a process for scanning a test object in accordance with an illustrative embodiment;

Figure 22 is an illustration of an aircraft manufacturing and service method in accordance with an illustrative embodiment; and

Figure 23 is an illustration of an aircraft in which an illustrative embodiment may be implemented.

DETAILED DESCRIPTION

The illustrative embodiments recognize and take into account one or more different considerations. For example, the different illustrative embodiments recognize and take into account that currently used ultrasound inspection systems may be unable to inspect test objects in which one or more obstructions are present.

The illustrative embodiments recognize and take into account that an ultrasound testing system may be used to reach locations with obstructions. One or more illustrative embodiments provide a method and apparatus for inspecting a

location on a test object in which a number of obstructions to reaching the desired location are present. A number of optical fibers is moved to the location on the test object in which the number of obstructions to reaching the location are present. A pattern of light is transmitted from the optical fibers onto a surface of the test object at the location. The light is configured to cause sound waves in the test object when the pattern of light encounters the surface of the test object. A response to the sound waves is detected using the number of optical fibers. These optical fibers may be connected to or be a part of sensor systems, such as a system of one or more interferometers.

With reference now to the figures and, in particular, with reference to **Figure 1**, an illustration of an inspection environment is depicted in accordance with an illustrative embodiment. As depicted, inspection environment **100** includes test object **102**. In this illustrative example, test object **102** takes the form of a composite test object. Test object **102** takes the form of composite wing **104**.

Ultrasound inspection system **106** may be used to inspect test object **102**. In particular, ultrasound inspection system **106** may be used to inspect interior **107** of composite wing **104**. As depicted, ultrasound inspection system **106** includes elongate optical fiber carrier **108**, number of optical fibers **109**, interferometer system **132**, platform **117**, and computer **120**.

Elongate optical fiber carrier **108** is configured to hold number of optical fibers **109**. Elongate optical fiber carrier **108** is configured to be moved to inspect location **110** in interior **107** of composite wing **104**.

In these illustrative examples, elongate optical fiber carrier **108** may be configured to move through or around obstructions in composite wing **104**. As depicted, the obstructions may be different sizes of spaces **134** in composite wing **104** as well as different structures located within composite wing **104**.

As depicted, opening **112** is an example of a small space that forms an obstruction to inspecting interior **107** of composite wing **104**. Opening **112** may be, for example, a fastener hole, an access port, or some other suitable opening. With an access port, a panel may be removed from composite wing **104** to expose the

access port. Other obstructions in the way of ultrasound inspection system **106** reaching location **110** in interior **107** of composite wing **104** include lines **118** and rib **130**. Lines **118** may be fuel lines, hydraulic lines, and/or other suitable types of lines in composite wing **104**.

In this illustrative example, elongate optical fiber carrier **108** is configured to enter interior **107** of composite wing **104** through opening **112** in composite wing **104**. The size of opening **112** may result in limited access to interior **107** of composite wing **104**.

Additionally, elongate optical fiber carrier **108** is configured to move around other obstructions, such as lines **118** and rib **130** within interior **107** of composite wing **104** to reach location **110** in interior **107** of composite wing **104**. One or more of these obstructions result in limited access to location **110** in interior **107** of composite wing **104**.

In this illustrative example, movement system **114** is configured to move elongate optical fiber carrier **108** relative to location **110** in interior **107** of composite wing **104**. As depicted, movement system **114** may be comprised of a plurality of motorized joints in elongate optical fiber carrier **108** that move segments in elongate optical fiber carrier **108** within composite wing **104**. For example, movement system **114** may be configured to move elongate optical fiber carrier **108** through composite wing **104** around obstruction **116** to reach test object **102**. As depicted, obstruction **116** within composite wing **104** is a rib **130**.

Elongate optical fiber carrier **108** with movement system **114** may be connected to platform **117**. Platform **117** may be a moveable platform in some illustrative examples. In other illustrative examples, platform **117** may be a stationary platform.

In this illustrative example, computer **120** is configured to control operation of movement system **114**. Computer **120** controls movement system **114** automatically or with input received at an input device connected to computer **120** to control operation of movement system **114**.

In these illustrative examples, computer **120** also is configured to receive data from the ultrasound detector in elongate optical fiber carrier **108** over communications link **122**. Communications link **122** may take the form of a wireless communications link in these illustrative examples. In other illustrative examples, interferometer system **132** may generate data in the form of electrical signals that are sent over a number of wires over communications link **122**. As used herein, a "number of" when used with reference to items means one or more items. For example, a number of wires is one or more wires.

Composite wing **104** may be inspected by ultrasound inspection system **106** at various times during the life of composite wing **104**. For example, without limitation, composite wing **104** may be inspected during assembly of composite wing **104**, routine maintenance of composite wing **104** while composite wing **104** is attached to the aircraft, reworking composite wing **104**, and/or some other suitable time during the life of composite wing **104**. Inspection of composite wing **104** using ultrasound inspection system **106** with elongate optical fiber carrier **108** allows structures within interior **107** of composite wing **104** to be inspected without disassembling composite wing **104**. As a result, inspection of composite wing **104** using ultrasound inspection system **106** may be done more quickly and may be more cost effective than inspection using inspection systems that require disassembly of composite wing **104**.

While inspection environment **100** is depicted with ultrasound inspection system **106** used to inspect composite wing **104**, ultrasound inspection system **106** may be used to inspect other test objects. For example, without limitation, ultrasound inspection system **106** with elongate optical fiber carrier **108** may be used to inspect internal structures within an engine, an electrical box, an APU unit, a ventilation system, a stowage system, and/or other suitable structures. Ultrasound inspection system **106** may be used to inspect these and other structures in which obstructions are present. With ultrasound inspection system **106**, the amount of time needed to inspect test objects may be reduced. Further, the amount of disassembly of the structures may be reduced or eliminated.

Turning now to **Figure 2**, an illustration of a block diagram of an inspection environment is depicted in accordance with an illustrative embodiment. Inspection environment **100** in **Figure 1** is one example of an implementation of inspection environment **200** shown in block form in this figure.

As illustrated, inspection environment **200** includes test object **202**. Test object **202** may take any number of forms. For example, test object **202** may be a structure or part in an aircraft. In other illustrative examples, test object **202** may be comprised of multiple structures in the aircraft.

Further, test object **202** may be comprised of different types of materials. For example, without limitation, test object **202** may be comprised of a number of materials selected from at least one of a composite material, a plastic, a metal, and other suitable types of materials.

As used herein, the phrase "at least one of", when used with a list of items, means different combinations of one or more of the listed items may be used and only one of each item in the list may be needed. For example, "at least one of item A, item B, and item C" may include, without limitation, item A or item A and item B. This example also may include item A, item B, and item C, or item B and item C. In other examples, "at least one of" may be, for example, without limitation, two of item A, one of item B, and ten of item C; four of item B and seven of item C; and other suitable combinations.

In these illustrative examples, test object **202** may be a composite part for an aircraft selected from one of a panel, a fuselage barrel, a stringer, a fuel tank, a spar, a rib, a wing box, a wing, a stabilizer, and other suitable types of objects. Test object **202** may be inspected using ultrasound inspection system **204**. In particular, ultrasound inspection system **204** may be used to inspect location **206** for test object **202**. In this illustrative example, test object **202** may have limited access. In particular, access to location **206** in test object **202** may be limited.

In other words, number of obstructions **208** may be present with respect to accessing location **206** in test object **202**. An obstruction in number of obstructions **208** may be selected from at least one of a rib, a spar, a line, a wiring

bundle, a flange, an opening in a structure, a space in an interior of a structure, a channel in a structure, a cable, a pipe, a stringer, a webbing, or other structures that may reduce access to location **206** for inspection. These structures may be structures through which ultrasound inspection system **204** traverses to reach location **206**.

In another illustrative example, number of obstructions **208** may be test object **202**, itself. For example, test object **202** may be a cavity in test object **202** accessed by an opening. In particular, test object **202** may be a fuel tank with an opening. The opening may be smaller than feasible for currently available ultrasound systems to traverse and reach a location within the interior of the fuel tank for inspection. These openings may be, for example, without limitation, fastener holes, small access panels, a temporary hole, an opening created by an impact or other source, or other suitable openings.

In these illustrative examples, ultrasound inspection system **204** is configured to reach location **206** taking into account number of obstructions **208** to perform inspection of test object **202**. In other words, ultrasound inspection system **204** is configured to bypass number of obstructions **208**. For example, ultrasound inspection system **204** may pass through, move around, move between, or move in other ways to bypass number of obstructions **208**.

As depicted, ultrasound inspection system **204** includes number of optical fibers **210**, elongate optical fiber carrier **212**, light source **214**, measurement system **216**, movement system **218**, and controller **220**.

As depicted, number of optical fibers **210** is configured to reach location **206** by moving through or around number of obstructions **208**. In these illustrative examples, number of optical fibers **210** is associated with elongate optical fiber carrier **212**.

When one component is “associated” with another component, the association is a physical association in these depicted examples. For example, a first component, number of optical fibers **210**, may be considered to be associated with a second component, elongate optical fiber carrier **212**, by being secured to the

second component, bonded to the second component, mounted to the second component, welded to the second component, fastened to the second component, and/or connected to the second component in some other suitable manner. The first component also may be connected to the second component using a third component. The first component may also be considered to be associated with the second component by being formed as part of and/or an extension of the second component.

In this illustrative example, elongate optical fiber carrier **212** is configured to hold number of optical fibers **210**. Further, elongate optical fiber carrier **212** is configured bypass a number of obstructions **208** to reach location **206**. For example, elongate optical fiber carrier **212** may be configured to move between obstructions in number of obstructions **208** such as cables, hardware, systems, wire bundles, pipes, stringers, webbing, or other structures to reach location **206**. In another example, elongate optical fiber carrier **212** may be configured to move through an obstruction in number of obstructions **208**, such as an opening in test object **202**, to reach location **206** within the interior of test object **202**. For example, test object **202** may be a wall with an opening.

Movement system **218** is configured to move elongate optical fiber carrier **212** to location **206** in test object **202**. Movement system **218** may include various types of movement devices. For example, movement system **218** may include hydraulic actuators, motors, electromechanical actuators, and other suitable types of devices.

Light source **214** is connected to number of optical fibers **210**. In this illustrative example, light source **214** is configured to generate first light **222**. Number of optical fibers **210** is configured to transmit first light **222** toward location **206**. First light **222** is configured to cause first pattern **224** of first light **222** on surface **226** at location **206** of test object **202**. In this illustrative example, first pattern **224** of first light **222** on surface **226** is configured to cause sound waves **228** in test object **202**.

In this illustrative example, first pattern **224** may take various forms. For example, first pattern **224** may be a single area when number of optical fibers **210** is one optical fiber. In other illustrative examples, first pattern **224** may be areas that may or may not overlap each other. These areas may be arranged in the form of a line or some other suitable shape. The line may be contiguous or non-contiguous depending on whether the areas overlap.

First response **230** occurs as a result of sound waves **228** traveling within test object **202**. First response **230** is comprised of sound waves **231**. First response **230** includes sound waves **231** that may occur as a result of scattering, reflection, modulation, and other changes to sound waves **228** traveling within test object **202**.

Number of optical fibers **210** is configured to detect first response **230** to sound waves **228**. In these illustrative examples, first response **230** may be detected by number of optical fibers **210** transmitting second light **232** onto surface **226** of test object **202**. Second light **232** has second pattern **234** when transmitted onto surface **226** of test object **202**.

As depicted, second pattern **234** also may be comprised of areas of light on surface **226** in response to second light **232** transmitted by number of optical fibers **210**. In these illustrative examples, second pattern **234** of second light **232** may be the same or may be different from first pattern **224** of first light **222**. Number of optical fibers **210** is configured to detect second response **236**. The areas of light may be contiguous or non-contiguous.

Second response **236** is second light **232** that has been deflected by first response **230** in this illustrative example. First response **230** caused by sound waves **228** traveling within test object **202** may reach surface **226** and cause changes in the index of refraction of the air at surface **226**. The change in the index of refraction in the air causes light in second response **236** to travel differently.

Additionally, sound waves **231** in first response **230** may cause changes in surface **226** that result in scattering, reflection, and modulation of second

light **232** transmitted as areas in second pattern **234** onto surface **226** of test object **202**. The change is used to identify first response **230**.

Second response **236** provides information about first response **230**. Thus, second response **236** may be used to generate data **238** about first response **230**.

In this illustrative example, measurement system **216** is configured to generate data **238** using second response **236**. Measurement system **216** may be, for example, one or more interferometers in these illustrative examples. In these illustrative examples, number of optical fibers **210** and measurement system **216** may form sensor **239**. In some illustrative examples, sensor **239** also may include elongate optical fiber carrier **212**.

In this illustrative example, controller **220** is configured to receive and process data **238** from measurement system **216**. Further, controller **220** is configured to control the operation of light source **214**, measurement system **216**, and movement system **218**.

In these illustrative examples, controller **220** controls the operation of ultrasound inspection system **204**. Controller **220** may be implemented using hardware, software, or a combination of the two. When software is used, the operations performed by the components may be implemented in the program code configured to be run on a processor unit. When hardware is employed, the hardware may include circuits that operate to perform the operations in the components.

In the illustrative examples, the hardware may take the form of a circuit system, an integrated circuit, an application specific integrated circuit (ASIC), a programmable logic device, or some other suitable type of hardware configured to perform a number of operations. With a programmable logic device, the device is configured to perform the number of operations. The device may be reconfigured at a later time or may be permanently configured to perform the number of operations. Examples of programmable logic devices include, for example, a programmable logic array, a programmable array logic, a field programmable logic array, a field

programmable gate array, and other suitable hardware devices. Additionally, the processes may be implemented in organic components integrated with inorganic components and/or may be comprised entirely of organic components excluding a human being. For example, the processes may be implemented as circuits in organic semiconductors.

In these illustrative examples, controller **220** may be implemented within computer system **240**. Computer system **240** may be one or more computers. When more than one computer is present in computer system **240**, those computers may be in communication with each other through a communications medium such as a network.

In this illustrative example, controller **220** may use data **238** to generate output **242**. Output **242** may indicate whether inconsistency **244** is present in test object **202**. Inconsistency **244** may be, for example, without limitation, an undesired level of porosity, delamination, and other undesired features or properties of test object **202**.

Output **242** may take a number of different forms. For example, output **242** may take the form of alert **246**. Alert **246** may indicate whether inconsistency **244** is present. Alert **246** may be displayed on display device **248** within computer system **240**.

In another illustrative example, output **242** may be image **250**. Image **250** may be displayed on display device **248**. Image **250** also may be an image of a portion or all of test object **202,** including graphical indicator **252** when inconsistency **244** is present in test object **202**. Graphical indicator **252** may be displayed in a location in image **250** corresponding to a location in test object **202** where inconsistency **244** is detected. In other illustrative examples, if inconsistency **244** is absent, graphical indicator **252** may be displayed to indicate an absence of inconsistency **244**.

As another illustrative example, output **242** may take the form of report **254**. Report **254** may identify any inconsistencies for test object **202**. Report **254** also may include other information such as locations of inconsistencies, types of

inconsistencies, sizes of inconsistencies, and other suitable types of information. Thus, output **242** may be at least one of alert **246**, image **250** with graphical indicator **252**, report **254**, and other suitable types of output. As a result, ultrasound inspection system **204** provides for more efficient inspection of test object **202** when number of obstructions **208** is present as compared to currently available ultrasound inspection systems.

Further, ultrasound inspection system **204** uses first light **222** and second light **232** that are transmitted through number of optical fibers **210**. Elongate optical fiber carrier **212** may be configured to move to location **206** when number of obstructions **208** is present. In these illustrative examples, elongate optical fiber carrier **212** may be moved through or around number of obstructions **208** to location **206** to perform inspection of test object **202** at location **206**.

In this manner, ultrasound inspection system **204** may be used to inspect test objects such as fuel tanks, wing boxes, and other structures that may have locations that are difficult to access due to number of obstructions **208** to ultrasound inspection system **204** reaching location **206** to perform an inspection of test object **202**. In this manner, less disassembly and less time may be needed to inspect these and other types of test objects.

Turning now to **Figure 3**, an illustration of a block diagram of an elongate structure is depicted in accordance with an illustrative embodiment. In this depicted example, examples of elongate optical fiber carrier **212** in **Figure 2** are depicted.

In this illustrative example, elongate optical fiber carrier **212** comprises elongate structure **300**. Elongate structure **300** defines channel **302**. Channel **302** is a channel in which number of optical fibers **210** may be held within elongate structure **300** for elongate optical fiber carrier **212**.

In this illustrative example, elongate structure **300** may have, for example, rigid configuration **304** or deformable configuration **306**. When elongate structure **300** has deformable configuration **306**, elongate structure **300** may stay in the shape after the deformation of elongate structure **300**. In other illustrative

examples, elongate structure **300** may return to its original shape after being deformed.

Further, elongate structure **300** may be comprised of number of segments **308**. In this illustrative example, number of segments **308** may be a single segment in which channel **302** is continuous through the segment. For example, when a single segment is present in number of segments **308**, the single segment may be a sheath, a rigid sheath, a deformable sheath, a mesh, or some other suitable form.

When more than one segment is present in number of segments **308**, channel **302** may be defined within the different segments and may not be continuous. When more than one segment is present in number of segments **308**, those segments may be connected to each other by number of joints **310**. Number of joints **310** may allow number of segments **308** to be moved to different positions and orientations. In this form, elongate structure **300** may be a segmented snake configured to change orientation and move. In other illustrative examples, the segmented snake may be configured for attachment to a robotic arm or other platform. In still other illustrative examples, elongate structure **300** may be a hand held tool with orientation control.

When more than one joint is present in number of joints **310**, movement system **218** in **Figure 2** may be configured to move and position number of segments **308** relative to each other. The movement of number of segments **308** may involve moving number of segments **308** on test object **202**. In other illustrative examples, movement of number of segments **308** may involve changing the position of number of segments **308** with respect to each other.

With reference now to **Figure 4,** an illustration of a block diagram of a sensor is depicted in accordance with an illustrative embodiment. Examples of components in sensor **239** are shown in this figure.

As depicted, sensor **239** includes sensor structure **400**, ultrasound source **402**, and ultrasound detector **404**. Sensor structure **400** may take a number of different forms. For example, sensor structure **400** may be a housing, a frame, or

some other suitable type of physical structure. In one illustrative example, sensor structure **400** may take the form of elongate optical fiber carrier **108** in **Figure 1** and elongate optical fiber carrier **212** in **Figure 2**.

In these illustrative examples, ultrasound source **402** and ultrasound detector **404** are associated with sensor structure **400**. Ultrasound source **402** is configured to transmit first light **222**, while ultrasound detector **404** is configured to detect sound waves **231** in first response **230** in response to sound waves **228**.

Ultrasound source **402** is comprised of first array of optical fibers **406**. First array of optical fibers **406** is configured to receive first light **222** from light source **214** and transmit first light **222** in the form of first pattern **224** onto surface **226** of test object **202**. First light **222** from first array of optical fibers **406** is configured to cause excitation in test object **202**. In other words, first light **222** from first array of optical fibers **406** is configured to generate sound waves **228** within test object **202**.

As depicted, ultrasound detector **404** is comprised of second array of optical fibers **408**. Second array of optical fibers **408** is configured to transmit second light **232** and detect second response **236** to second light **232**. Second light **232** is not configured to generate sound waves **228** within test object **202**. Instead, second light **232** is configured to reflect, scatter, or otherwise interact with surface **226** of test object **202,** the air around surface **226** of test object **202,** or both in a manner such that the portion of second light **232** that is received by second array of optical fibers **408** may be affected by sound waves in first response **230** that reach surface **226** of test object **202**.

In some illustrative examples, if overlap is present in the time between the two patterns of light, first pattern **224** and second pattern **234** being transmitted onto surface **226**. With this overlap, second array of optical fibers **408** may be used to monitor for first response **230** at the same time or prior to the generation of sound waves **228**.

In other illustrative examples, each optical fiber in first array of optical fibers **406** may transmit first light **222** sequentially rather than at the same time.

Additionally, groupings of optical fibers in number of optical fibers **210** may sequentially transmit first light **222**. Second light **232** may be transmitted in a similar fashion by second array of optical fibers **408**.

In still other illustrative examples, first light **222** may be transmitted using different phases, wavelengths, or both in addition to transmitting first light **222** through optical fibers in first array of optical fibers **406**, second array of optical fibers **408,** or both at different times.

Mechanisms such as delay lines and delay circuits separate lasers in light source **214**. These mechanisms may reduce cross-talk in the optical fibers that results in first light **222** in first array of optical fibers **406** and second light **232** in second array of optical fibers **408** from exiting one optical fiber and entering another optical fiber. In other words, different phases, wavelengths, timings or some combination thereof may be used to reduce cross-talk between optical fibers within first array of optical fibers **406** and second array of optical fibers **408**.

In these illustrative examples, sensor **239** also may include optics system **410**. Optics system **410** is associated with sensor structure **400**. As depicted, optics system **410** is a hardware system and may include components such as number of optical elements **412**, number of movement devices **416**, and other suitable components.

Optics system **410** is configured to direct the transmission of first light **222** and second light **232** to surface **226** of test object **202**. Further, optics system **410** also may direct second response **236** to second array of optical fibers **408**.

Number of optical elements **412** is configured to modify the transmission of first light **222** and second light **232** in these illustrative examples. Number of optical elements **412** may include at least one of a lens, a mirror, a diffractive optical element, a polarizer, a wave plate, a periodically poled Lithium niobate crystal, or other suitable optical elements.

For example, number of optical elements **412** may be configured to shape first light **222** transmitted from first array of optical fibers **406** to form first pattern **224**. In a similar fashion, number of optical elements **412** may be used to

shape second light **232** transmitted from second array of optical fibers **408** to form areas in second pattern **234** with a desired size. Number of optical elements **412** also may be used to change the polarization of first light **222** and second light **232**, the color of first light **222** and second light **232**, and other parameters of first light **222** and second light **232**.

In these illustrative examples, number of movement devices **416** may be used to move one or more of number of optical elements **412** to cause movement of first pattern **224** of first light **222** and second pattern **234** of second light **232**. This movement may occur without moving sensor structure **400** in this illustrative example. Number of movement devices **416** may include, for example, at least one of a motor, an actuator, and other suitable types of devices that may be configured to move number of optical elements **412**.

Sensor **239** also may include interferometer system **418**. Interferometer system **418** is a hardware device and is configured to identify information from the light forming second response **236**. Interferometer system **418** may include one or more interferometers in these illustrative examples. The information identified by interferometer system **418** may include, for example, displacements, deflections, surface velocity, and other information that may be used to identify second response **236** as detected by second array of optical fibers **408** receiving the light in second response **236**.

In some illustrative examples, interferometer system **418** may be considered part of ultrasound detector **404** even though interferometer system **418** may not be located in sensor structure **400**. Interferometer system **418** may be associated with optics system **410** or may be in a separate location.

Turning now to **Figure 5**, an illustration of a block diagram of a light source is depicted in accordance with an illustrative embodiment. In these illustrative examples, light source **214** in **Figure 2** may be, for example, at least one of a coherent light source **500** and non-coherent light source **502**. Coherent light source **500** may be, for example, a laser, an array of laser diodes, or some other suitable source of coherent light. Non-coherent light source **502** may be, for

example, an array of light emitting diodes, xenon light, or some other suitable source of non-coherent light.

As depicted, light source **214** is configured to generate, first light, first light **222**, and second light, second light **232** with properties **504**. Properties **504** include wavelength **506**, pulse length **508**, and intensity **510**. Properties **504** may be different for first light **222** and second light **232.**

Wavelength **506** may be selected based on the material forming test object **202**, the thickness of test object **202,** and other suitable factors. Wavelength **506** may be selected for first light **222** in a manner that increases absorption of energy from first light **222** when first light **222** and second light **232** are transmitted onto surface **226** of test object **202**. For example, when test object **202** is comprised of one or more composite materials, wavelength **506** selected for first light **222** may be from about **300** millimeters to about **30,000** millimeters. Wavelength **506** may be the same for generating both sound waves **228** and first response **230**.

Pulse length **508** may be selected for first light **222** to generate a desired frequency for sound waves **228**. For example, a pulse duration of about 1 nanosecond to about 200 nanoseconds may be used. Pulse length **508** may be selected to have a duration of about 50 microseconds to about 100 microseconds for second light **232** to be used to detect sound waves **231** in first response **230**.

Intensity **510** is selected based on the amount of energy that is desired to be transmitted into test object **202** by first light **222** encountering surface **226** of test object **202**. Intensity **510** may be selected for first light **222** to provide a desired level of sound waves **228** when first light **222** is transmitted onto surface **226** of test object **202**. Intensity **510** may be selected for first light **222** and second light **232** to reduce or avoid damage to surface **226** of test object **202**. Of course, the intensity also may vary depending on the values selected for pulse length **508**.

Although specific values have been specified for properties **504**, these values are only presented for purposes of illustration and not meant to limit other values that may be used. The selection of properties **504** may vary depending on light source **214**, materials in test object **202**, and other factors.

The illustration of inspection environment **200** and the different components in inspection environment **200** in **Figures 2-5** are not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be unnecessary. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined, divided, or combined and divided into different blocks when implemented in an illustrative embodiment.

For example, in some illustrative embodiments, ultrasound source **402** and ultrasound detector **404** may be placed in separate sensor structures. In other illustrative examples, sensor **239** may be moved by a human operator rather than a robot or other type of machine. In other words, movement system **218** may take the form of a human operator.

In still another illustrative example, optics system **410** may be implemented using more than one block. For example, optics system **410** may be part of ultrasound source **402**, ultrasound detector **404**, or both rather than being a separate block.

In another illustrative example, test object **202** may be an object for other types of platforms other than an aircraft. The platform in which the test object may be located may be, for example, a mobile platform, a stationary platform, a land-based structure, an aquatic-based structure, and a space-based structure. More specifically, the platform may be a surface ship, a tank, a personnel carrier, a train, a spacecraft, a space station, a satellite, a submarine, an automobile, a power plant, a bridge, a dam, a manufacturing facility, a building, and other suitable platforms.

In another illustrative example, movement system **218** is shown as a separate block from elongate optical fiber carrier **212**. These components, however, may be combined in some illustrative examples. In other words, movement system **218** may be part of elongate optical fiber carrier **212** in some illustrative examples.

In another illustrative example, a portion of light source **214** may be implemented as part of measurement system **216**. For example, when measurement system **216** takes the form of an interferometer, measurement system **216** may also generate second light **232** in addition to detecting second response **236**.

In still another illustrative example, number of optical fibers **210** and sensor **239** may be distributed in two or more elongate optical fiber carriers. For example, a first portion of number of optical fibers **210** may be held in elongate optical fiber carrier **212** and a second portion of optical fibers **210** may be held in a second optical fiber carrier. In this example, the first portion of number of optical fibers **210** may transmit first light **222**. The second portion of number of optical fibers **210** may transmit second light **232** and detect second response **236**.

Turning now to **Figure 6**, an illustration of an elongate optical fiber carrier is depicted in accordance with an illustrative embodiment. In this depicted example, elongate optical fiber carrier **600** is an example of one implementation of elongate optical fiber carrier **212** shown in block form in **Figure 2**.

In this depicted example, elongate optical fiber carrier **600** includes elongate structure **602**, which has first end **604** and second end **606**. Elongate structure **602** for elongate optical fiber carrier **600** is configured to carry number of optical fibers **608** within channel **610** of elongate structure **602**. In this illustrative example, elongate structure **602** is deformable and may be bent to different orientations.

As depicted, light **612** may be emitted from number of optical fibers **608** at first end **604**. Second end **606** may be connected to a movement system such as movement system **218** in **Figure 2**.

With reference now to **Figure 7**, an illustration of an elongate optical fiber carrier is depicted in accordance with an illustrative embodiment. In this depicted example, elongate optical fiber carrier **700** is an example of an implementation for elongate optical fiber carrier **212** shown in block form in **Figure 2**.

In this illustrative example, elongate optical fiber carrier **700** has elongate structure **702.** Elongate structure **702** has first end **704** and second end **706**. As depicted, number of optical fibers **708** within channel **710** may be carried by elongate structure **702**.

As depicted, elongate structure **702** is comprised of segments **712**. Segments **712** are connected to each other through joints **714**. In this illustrative example, segments **712** are rigid segments. Segments **712** may be positioned relative to each other at joints **714**. Changing the position of segments **712** relative to each other may change the shape of channel **710** and the number of optical fibers **708**.

In this illustrative example, elongate optical fiber carrier **700** includes handle **716** at second end **706** of elongate structure **702**. Handle **716** is configured to be held by a human operator. Additionally, handle **716** also may include control **718** that may be manipulated to change the position of segments **712** relative to each other. For example, movement of segments **712** may be controlled by cables running around pulleys at each joint in joints **714**. The cables may be attached to handle **716**. In another example, each joint in joints **714** may be controlled by geared stepper motors in joints **714.** In this illustrative example, light **720** may be emitted from number of optical fibers **708** at first end **704** of elongate optical fiber carrier **700**.

Turning now to **Figure 8**, an illustration of an elongate optical fiber carrier is depicted in accordance with an illustrative embodiment. In this depicted example, elongate optical fiber carrier **800** is an example of an implementation for elongate optical fiber carrier **212** shown in block form in **Figure 2**.

In this illustrative example, elongate optical fiber carrier **800** has elongate structure **802**. Elongate structure **802** has first end **804** and second end **806**. Number of optical fibers **808** may be located within channel **810** of elongate structure **802**.

As depicted, elongate structure **802** is comprised of segments **812**. These segments are connected to each other by joints **814**. Joints **814** allow positioning of segments **812** relative to each other.

Second end **806** of elongate structure **802** is connected to pedestal robot **816**. Pedestal robot **816** may move elongate optical fiber carrier **800** to different locations relative to a test object. In this illustrative example, light **818** may be emitted by number of optical fibers **808** at first end **804** of elongate structure **802**.

Turning now to **Figure 9**, an illustration of an elongate optical fiber carrier is depicted in accordance with an illustrative embodiment. In this depicted example, elongate optical fiber carrier **900** is an example of an implementation of elongate optical fiber carrier **212** shown in block form in **Figure 2**.

In this illustrative example, elongate optical fiber carrier **900** includes elongate structure **902**. Elongate structure **902** has first end **904** and second end **906**. Elongate structure **902** has channel **908** which holds number of optical fibers **910**.

Elongate structure **902** is comprised of segments **912** that are joined to each other by joints **914**. In this illustrative example, segments **912** may move relative to each other to change positions. Additionally, segments **912** also may be motorized such that elongate optical fiber carrier **900** may move on a test object or other structure without requiring a human operator or a robot. In these illustrative examples, light **916** may be transmitted by number of optical fibers **910** at first end **904** of elongate structure **902**.

Turning now to **Figure 10**, an illustration of an inspection environment is depicted in accordance with an illustrative embodiment. In this depicted example, inspection environment **1000** is an example of an implementation for inspection environment **200** in **Figure 2**.

As depicted, ultrasound inspection system **1002** and ultrasound inspection system **1004** may be used to inspect test object **1006**. In this illustrative example, test object **1006** takes the form of wing box **1008**.

Ultrasound inspection system **1002** includes computer **1010**, measurement system **1011**, light source **1012**, number of optical fibers **1014**, and elongate optical fiber carrier **1016**. Ultrasound inspection system **1004** comprises computer **1018**, measurement system **1019**, light source **1020**, number of optical fibers **1022**, and elongate optical fiber carrier **1024**. In this illustrative example, obstructions **1030** are present with respect to testing locations in test object **1006**. In this illustrative example, obstructions **1030** include obstruction **1032**, obstruction **1034**, obstruction **1036**, and obstruction **1038**.

Obstructions **1030** reduce accessibility to locations such as location **1040** and location **1042** in interior **1044** of test object **1006** in these illustrative examples. For example, space available for access to interior **1044** of test object **1006** may be limited by obstructions **1030**. Obstruction **1032** is an example of one of obstructions **103**0 in interior **1044**. Obstruction **1032** is an access port.

In this illustrative example, obstruction **1034** and obstruction **1036** may be spars, ribs, or other structures within test object **1006**. As can be seen, obstruction **1034** and obstruction **1036** form restricted space **1050** within interior **1044** of test object **1006**.

As can be seen, elongate optical fiber carrier **1024** may be moved through access port **1060** and restricted space **1050** to reach location **1040** within interior **1044** of test object **1006**. In this illustrative example, elongate optical fiber carrier **1024** may be changed in configuration to reach location **1040**. When positioned within interior **1044**, light **1061** may be emitted from number of optical fibers **1022** toward location **1040**.

Ultrasound inspection system **1002** is configured to inspect location **1042** in interior **1044** of test object **1006**. In this illustrative example, elongate optical fiber carrier **1016** may be moved through obstruction **1038** which takes the form of a fastener hole in this illustrative example.

Elongate optical fiber carrier **1016** may be moved into interior **1044** through obstruction **1038** to perform inspection of location **1042** within interior **1044**

of test object **1006**. When in a desired position, light **1062** may be emitted from number of optical fibers **1014** toward location **1042**.

In this manner, ultrasound inspection system **1002** and ultrasound inspection system **1004** may be operated to inspect test object **1006**. In particular, the inspection may be made for locations such as location **1040** and location **1042** in interior **1044** of test object **1006**. As depicted, elongate optical fiber carrier **1016** and elongate optical fiber carrier **1024** may be moved to bypass obstructions **1030** as described above. In particular, the movement may move these elongate optical fiber carriers through, around, or between obstructions **1030**.

In yet another illustrative example, ultrasound inspection system **1002** may emit light **1062** to cause sounds waves to travel in wing box **1008**. Ultrasound inspection system **1004** may emit light **1061** to detect responses to the vibrations in wing box **1008** caused by ultrasound inspection system **1002** emitting light **1062**.

With this implementation, number of optical fibers **1014** may be an example of first array of optical fibers **406** and number of optical fibers **1022** may be second array of optical fibers **408**.

Turning now to **Figure 11**, an illustration of an ultrasound source is depicted in accordance with an illustrative embodiment. Ultrasound source **1100** is an example of one implementation for ultrasound source **402** shown in block form in **Figure 4**.

In this illustrative example, optical fibers **1102** are arranged in array **1104**. Optical fibers **1102** may be implemented using any type of optical fiber that is configured to carry light within the optical fibers.

In this illustrative example, six optical fibers are present in optical fibers **1102**. Array **1104** is a 1x6 array in this illustrative example. Of course, other numbers of optical fibers and other types of arrays may be used. For example, optical fibers **1102** may include three fibers, fifteen fibers, twenty-seven fibers, or some other suitable number of fibers. Further, in some illustrative examples, the array may have two or more rows instead of a single row of optical fibers.

Ultrasound source **1100** also includes cylinder lens **1106**. Cylinder lens **1106** is configured to cause light **1108** transmitted by array **1104** of optical fibers **1102** to form beams **1110** which has a linear shape. Cylinder lens **1106** is configured to shape light **1108**. In particular, cylinder lens **1106** is configured to cause light **1108** to form pattern **1112** on surface **1114** of test object **1116** as a contiguous line. In this illustrative example, cylinder lens **1106** may function to cause pattern **1112** of light **1108** to have an intensity with a Gaussian profile. In this illustrative example, the Gaussian profile is in an X and Y direction relative to a plane on surface **1114** of test object **1116**.

In these illustrative examples, if optical fibers **1102** in array **1104** are spaced far enough apart, then a pattern of individual areas is formed on surface **1114** of test object **1116**. Each area is "approximately a Gaussian profile" in both X and Y directions. Cylinder lens **1106** causes the Gaussian profiles to be different in the X and Y directions.

In particular, cylinder lens **1106** is configured to reduce divergence in a manner such that beams **1110** are focused in one direction and form pattern **1112** when reaching surface **1114** of test object **1116**. In these illustrative examples, pattern **1112** takes the form of line **1118**. Line **1118** may be formed from the intersection or overlapping of beams **1110** on surface **1114** of test object **1116**. Without cylinder lens **1106**, the divergence of beams **1110** may be in two dimensions resulting in an oval or circular shape rather than a line.

In this example, mirror **1120** is an example of a component that may be used to implement optics system **410** in **Figure 4.** Mirror **1120** is configured to manage the direction in which beams **1110** of light **1108** travel to reach surface **1114** of test object **1116**.

As depicted, optical fibers **1102** may be grouped and covered to form fiber bundle **1122**. In this illustrative example, end **1124** of fiber bundle **1122** is connected to collimator **1126**.

Collimator **1126** is connected to laser **1128**. Laser **1128** is the source of light **1108**. As depicted, light **1108** is sent through collimator **1126**. Collimator **1126** is configured to make light **1108** coherent in these illustrative examples.

Turning now to **Figure 12**, an illustration of an ultrasound source is depicted in accordance with an illustrative embodiment. In this depicted example, ultrasound source **1100** is shown in a perspective view.

Turning now to **Figure 13**, an illustration of an ultrasound detector is depicted in accordance with an illustrative embodiment. Ultrasound detector **1300** is an example of one implementation for ultrasound detector **404** shown in block form in **Figure 4**. As depicted, ultrasound detector **1300** includes optical fibers **1302**. Optical fibers **1302** are arranged as array **1304**. Array **1304** of optical fibers **1302** is configured to emit beams **1306** of light **1308**.

In this illustrative example, six optical fibers are present in optical fibers **1302**. Additionally, array **1304** is a 1X6 array. Of course, other numbers of optical fibers and other configurations for array **1304** may be present depending on the particular implementation.

In this illustrative example, ultrasound detector **1300** also includes collimators **1310**. As depicted, each optical fiber in optical fibers **1302** is associated with a collimator in collimators **1310**.

In these illustrative examples, collimators **1310** may be implemented using different types of collimators. For example, without limitation, collimators **1310** may be selected from at least one of an aspherical lens collimator, a spherical lens collimator, a grin lens collimator, or some other suitable type of collimator. Collimators **1310** are used to change light **1308** into coherent light in these illustrative examples.

Light **1308** is comprised of light waves that are in phase with each other. With light **1308**, the phases of the electromagnetic waves at each point on a line normal to the direction of which the beams **1306** are traveling is identical.

In this illustrative example, beams **1306** of light **1308** form pattern **1312** on surface **1114** of test object **1116**. In this illustrative example, pattern **1312** is in

the form of line **1313**. Line **1313** of pattern **1312** is a non-contiguous line in this illustrative example. In other illustrative examples, line **1313** of pattern **1312** may be a contiguous line.

In this illustrative example, light **1308** transmitted by optical fibers **1302** onto surface **1114** of test object **1116** results in response **1318**. Response **1318** is comprised of light. The light in response **1318** is caused by interaction with surface **1114**. For example, light **1308** may reflect, scatter, or reflect and scatter off of surface **1114**.

Response **1318** is detected at end **1319** of optical fibers **1302** and may be transmitted through optical fibers **1302** in a direction opposite to the transmission of light **1308**. In this illustrative example, end **1320** of optical fibers **1302** in array **1304** is connected to interferometer system **1322**. Interferometer system **1322** is the source of light **1308** and receives response **1318**.

In this illustrative example, mirror **1326** is an example of a component that may be used to implement optics system **410** in **Figure 4**. Mirror **1326** is configured to control the direction in which light **1308** and response **1318** travel.

Turning now to **Figure 14,** an illustration of an ultrasound detector is depicted in accordance with an illustrative embodiment. In this illustrative example, a perspective view of ultrasound detector **1300** is shown. Turning now to **Figure 15**, an illustration of an ultrasound inspection system is depicted in accordance with an illustrative embodiment. In this depicted example, a perspective view of ultrasound inspection system **1500** is shown. In this example, ultrasound inspection system **1500** includes ultrasound source **1100**, ultrasound detector **1300**, and sensor structure **1502**. Sensor structure **1502** is an example of a sensor structure that may be located on an end of an elongate optical fiber carrier, such as on first end **604** of elongate optical fiber carrier **600** in **Figure 6**, first end **704** on elongate optical fiber carrier **700 in Figure 7,** first end **804** on elongate optical fiber carrier **800** in **Figure 8**, and first end **904** on elongate optical fiber carrier **900** in **Figure 9.**

Sensor structure **1502** takes the form of a housing for an end effector in this illustrative example. As depicted, components for ultrasound source **1100**

and ultrasound detector **1300** are located inside of sensor structure **1502** but not seen in this example.

Turning next to **Figure 16**, an illustration of a top view of an ultrasound inspection system is depicted in accordance with an illustrative embodiment. In this view, sensor structure **1502** may be positioned over surface **1114** of test object **1116** to perform inspection of test object **1116**.

In this illustrative example, pattern **1112** and pattern **1312** are aligned with each other on surface **1114** of test object **1116**. In other words, pattern **1112** is transmitted onto the same location as pattern **1312** in this illustrative example. As a result, these two patterns substantially overlap each other.

Pattern **1112** of light **1108** is configured to generate sound waves within test object **1116**. Responses to sound waves may cause vibrations in surface **1114** of test object **1116**. Pattern **1312** of light **1308** is configured to generate response **1318** which includes variations or changes in surface **1114** due to vibrations caused by the response to the sound waves. Response **1318** is detected by optical fibers **1302**.

In these illustrative examples, laser **1128** generates light **1108**. Light **1108** is collimated by collimator **1126** in this illustrative example. This collimated light is then transmitted through optical fibers **1102** in the manner described with respect to **Figure 11** and **Figure 12**.

In these illustrative examples, light **1308** may be generated by interferometer system **1322**. Response **1318** to light **1308** may travel through optical fibers **1302** back to interferometer system **1322**. Interferometer system **1322** may use response **1318** to generate data used to determine whether an inconsistency is present in test object **1116**.

Turning now to **Figure 17**, an illustration of a front view of an ultrasound inspection system is depicted in accordance with an illustrative embodiment. In this illustrative example, another cross-sectional view of ultrasound inspection system **1500** is shown.

Turning now to **Figure 18**, another illustration of an ultrasound inspection system is depicted in accordance with an illustrative embodiment. As depicted, ultrasound inspection system **1800** is another example of an implementation for ultrasound inspection system **204** shown in block form in **Figure 2**.

In this illustrative example, ultrasound inspection system **1800** includes optical fibers **1804**. Optical fibers **1804** comprise optical fibers **1806**, **1808**, **1810**, **1812**, **1814**, **1816**, and **1818**. Optical fibers **1806**, **1808**, and **1810** form first array of optical fibers **1820**. Optical fibers **1812**, **1814**, **1816**, and **1818** form second array of optical fibers **1822**.

In this illustrative example, optical fibers **1804** are associated with collimators **1824**. Collimators **1824** comprise collimators **1826**, **1828**, **1830**, **1832**, **1834**, 1836, and **1838**. Collimators **1826**, **1828**, and **1830** are associated with optical fibers **1806**, **1808**, and **1810**, respectively. Collimators **1832**, **1834**, **1836**, and **1838** are associated with optical fibers **1812**, **1814**, **1816**, and **1818**, respectively. In this illustrative example, optical fibers **1806**, **1808**, and **1810**, in first array of optical fibers **1820**, are interspersed with optical fibers **1812**, **1814**, **1816**, and **1818** in second array of optical fibers **1822**.

In this illustrative example, first array of optical fibers **1820** is connected to laser **1840**. Second array of optical fibers **1822** is connected to interferometer system **1842**. In this illustrative example, light **1844** from first array of optical fibers **1820** is emitted in the form of pattern **1846** onto surface **1848** of test object **1850**. Light **1852** from second array of optical fibers **1822** forms pattern **1856** on surface **1848** of test object **1850**.

In this illustrative example, pattern **1846** of light **1844** and pattern **1856** of light **1852** are non-contiguous lines. As depicted, pattern **1846** of light **1844** takes the form of line **1858**, and pattern **1856** of light **1852** takes the form of line **1859**. These two patterns of light encounter surface **1848** at substantially the same location. In other words, these two patterns of light would overlap each other if transmitted at the same time.

In this illustrative example, mirror **1860** is an example of an optical system that may be used to control the direction in which light **1844** and light **1852** travel. Mirror **1860** may be one implementation for optics system **410** shown in block form in **Figure 4**.

Turning now to **Figure 19**, an illustration of a perspective view of an ultrasound inspection system is depicted in accordance with an illustrative embodiment. In this perspective view, sensor structure **1900** is shown in phantom with some of the components in ultrasound inspection system **1800** being located within sensor structure **1900**.

The illustration of the different embodiments of an ultrasound inspection system in **Figures 11-19** is not meant to imply limitations in the way in which other illustrative embodiments may be implemented. For example, other numbers of optical fibers may be used other than those depicted. In still other illustrative examples, the light source for the first array of optical fibers and the second array of optical fibers may be a single light source.

In yet another illustrative example, a diffractive diffuser may be used to shape light **1108** emitted from array **1104** of optical fibers **1102**. The diffractive diffuser may be used in addition to or in place of cylinder lens **1106**.

The different components shown in **Figure 1** and **Figure 6-13** may be combined with components in **Figures 2-5**, used with components in **Figures 2-5**, or a combination of the two. Additionally, some of the components in **Figure 1** and **Figures 6-13** may be illustrative examples of how components shown in block form in **Figures 2-5** can be implemented as physical structures.

Turning now to **Figure 20**, an illustration of a flowchart of a process for inspecting a location on a test object with a number of obstructions to reaching the location is depicted in accordance with an illustrative embodiment. The process illustrated in **Figure 20** may be implemented in inspection environment **200** in **Figure 2**. In particular, the process may be implemented using ultrasound inspection system **204** to inspect test object **202**.

The process begins by identifying locations on a test object for inspection (operation **2000**). Next, the process selects an uninspected location with a number of obstructions for inspection (operation **2002**).

The process then moves a number of optical fibers to the location with the number of obstructions to reaching the location (operation **2004**). In these illustrative examples, the number of optical fibers may be moved to the location using an elongate optical fiber carrier. This elongate optical fiber carrier is configured to be moved in a manner that bypasses the obstructions to reaching the location where the inspection is desired. In this manner, the optical fibers held by the optical fiber carrier are moved to the location in operation **2004**.

A pattern of light is transmitted from the optical fibers onto a surface of the test object at the location (operation **2006**). The light is configured to cause sound waves in the test objects when the pattern of light encounters the surface of the test object.

A response to sound waves is detected using the number of optical fibers (operation **2008**). In some illustrative examples, the optical fibers may be connected to, or part of, one or more interferometers. These devices may be used to detect the sound waves.

Next, data is generated using the response (operation **2010**). This data may be used to determine whether an inconsistency is present at the location. The data may include information about the response as well as an identification of the information. This identification may be based on coordinates. The coordinates may use a coordinate system for the test object.

A determination is made as to whether an additional location is present in the locations that has not been inspected (operation **2012**). If an additional location is present that has not been inspected, the process returns to operation **2002**. Otherwise, the process terminates.

Turning now to **Figure 21**, a flowchart of a process for scanning a test object is depicted in accordance with an illustrative embodiment. In this illustrative

example, the process in **Figure 21** may be implemented using ultrasound inspection system **204** in **Figure 2**.

The process begins by identifying the portion of the test object for inspection (operation **2100**). This portion of the test object may be some or the entire surface of the test object. For example, the portion of the test object may be a side, an edge, a radius, or some other portion of the test object.

A sensor is then moved to a location in the portion of the test object (operation **2101**). In operation **2101**, an orientation of the sensor may be adjusted to take into account a non-planar feature on the test object.

For example, the sensor may be positioned such that the pattern of light encompasses a non-planar feature not easily scanned by currently available laser ultrasound inspection systems. The non-planar feature may be, for example, a radius. The sensor may be moved in a linear direction along the length the radius.

In another illustrative example, the sensor may be positioned such that the pattern of light encompasses the margin of a part close to an edge where ultrasound coupling is difficult to achieve using currently available laser ultrasound inspection systems.

The process transmits a first pattern of light onto a surface of the test object at the location from a first array of optical fibers (operation **2102**). In this illustrative example, the ray of light is transmitted in pulses and in a manner configured to cause sound waves in the test object. The location is a location in the portion of the test object that is to be inspected.

The process transmits a second pattern of light onto the same location on the surface of the test object as the first pattern of light from a second array of optical fibers (operation **2104**). A response to the second pattern of light is detected (operation **2106**). The response to the second pattern of light may be analyzed to identify a response to the sound waves that reach the surface of the test object.

A determination is made as to whether an inconsistency is detected (operation **2108**). If an inconsistency is detected, the location of the inconsistency is identified (operation **2110**). This location may be identified based on the response to

sound waves detected using the response to the second pattern of light. The location of the inconsistency is stored (operation **2112**).

A determination is made as to whether all of the portion of the test object has been scanned using the patterns of light (operation **2114**). If all of the test object has not been scanned, the process moves the sensor to another location in the portion of the test object (operation **2116**), with the process then returning to operation **2102** as described above.

If all of the portion of the test object has been scanned in operation **2114**, an output is generated (operation **2118**) with the process terminating thereafter. In operation **2118**, the output may depend on whether one or more inconsistencies has been identified in the test object. If an inconsistency has been identified, at least one of an alert, an image with one or more graphical images identifying inconsistencies, a report, and other suitable types of output may be generated. Turning back to operation **2108**, if an inconsistency is not detected, the process proceeds to operation **2114** as described above.

The different operations performed in **Figure 20** and **Figure 21** may be applied to test objects with planar and non-planar surfaces. These different operations may be performed for test objects that have non-planar features such as a radius, an edge, a groove, a ramp, a ply drop, a filler noodle, and other non-planar features.

Additionally, the different operations in **Figure 20** and **Figure 21** may be performed to inspect test objects more quickly than currently available laser ultrasound inspection systems that use a laser beam in the form of a point. Further, these operations may be performed without contact to the surface of a test object in contrast to laser ultrasound inspection systems that use piezoelectric transducers.

The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture, functionality, and operation of some possible implementations of apparatuses and methods in an illustrative embodiment. In this regard, each block in the flowcharts or block diagrams may represent a module, segment, function, and/or a portion of an operation or step. For example, one or

more of the blocks may be implemented as program code, in hardware, or a combination of the program code and hardware. When implemented in hardware, the hardware may, for example, take the form of integrated circuits that are manufactured or configured to perform one or more operations in the flowcharts or block diagrams.

In some alternative implementations of an illustrative embodiment, the function or functions noted in the blocks may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be performed in the reverse order, depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram.

Illustrative embodiments of the present disclosure may be described in the context of aircraft manufacturing and service method **2200** as shown in **Figure 22** and aircraft **2300** as shown in **Figure 23**. Turning first to **Figure 22**, an illustration of an aircraft manufacturing and service method is depicted in accordance with an illustrative embodiment. During pre-production, aircraft manufacturing and service method **2200** may include specification and design **2202** of aircraft **2300** in **Figure 23** and material procurement **2204**.

During production, component and subassembly manufacturing **2206** and system integration **2208** of aircraft **2300** in **Figure 23** takes place. Thereafter, aircraft **2300** in **Figure 23** may go through certification and delivery **2210** in order to be placed in service **2212**. While in service **2212** by a customer, aircraft **2300** in **Figure 23** is scheduled for routine maintenance and service **2214**, which may include modification, reconfiguration, refurbishment, and other maintenance or service.

Each of the processes of aircraft manufacturing and service method **2200** may be performed or carried out by a system integrator, a third party, and/or an operator. In these examples, the operator may be a customer. For the purposes of this description, a system integrator may include, without limitation, any number of aircraft manufacturers and major-system subcontractors; a third party may include,

without limitation, any number of vendors, subcontractors, and suppliers; and an operator may be an airline, a leasing company, a military entity, a service organization, and so on.

With reference now to **Figure 23**, an illustration of an aircraft is depicted in which an illustrative embodiment may be implemented. In this example, aircraft **2300** is produced by aircraft manufacturing and service method **2200** in **Figure 22** and may include airframe **2302** with plurality of systems **2304** and interior **2306**. Examples of systems **2304** include one or more of propulsion system **2308**, electrical system **2310**, hydraulic system **2312**, and environmental system **2314**. Any number of other systems may be included. Although an aerospace example is shown, different illustrative embodiments may be applied to other industries, such as the automotive industry.

Apparatus and methods embodied herein may be employed during at least one of the stages of aircraft manufacturing and service method **2200** in **Figure 22**.

One or more illustrative embodiments may be used during component and subassembly manufacturing **2206**. For example, ultrasound inspection system **204** in **Figure 2** may be used to test different components generated during component and subassembly manufacturing **2206**. In particular, ultrasound inspection system **204** may be used to test composite objects that form different parts for aircraft **2300**. Further, ultrasound inspection system **204** also may be used to perform inspections during maintenance and service **2214**. For example, aircraft **2300** may be inspected during scheduled maintenance for aircraft **2300**. Further, ultrasound inspection system **204** also may be used to inspect composite parts used during maintenance and service **2214**.

Thus, one or more illustrative embodiments may be used to perform inspections of test objects. In particular, inspections may be performed on test objects that may have obstructions to reaching locations at which inspections are desired. The illustrative embodiments use a light-based ultrasound inspection system in which optical fibers may be carried on an elongate optical fiber carrier.

The elongate optical fiber carrier is configured to move in a manner that bypasses the obstructions. In other words, the elongate optical fiber carrier may be deformed or changed in shape to move around or through obstructions.

With an ultrasound inspection system in accordance with an illustrative embodiment, inspections of test objects may be made with less expense and time. In some illustrative embodiments, disassembly of structures in the test object may be reduced or avoided to perform desired inspections of different locations that may have obstructions to reaching those locations.

The description of the different illustrative embodiments has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different illustrative embodiments may provide different features as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An apparatus comprising:

a platform;

an interferometer system connected to the platform;

an elongate optical fiber carrier connected to and extending from the interferometer system;

a light source in optical communication with the elongate optical fiber carrier, the light source configured to emit a light;

a movement system connected to the elongate optical fiber carrier, the movement system configured to:

move the elongate optical fiber carrier through an opening of a test object into an interior cavity of the test object;

bypass a plurality of obstructions while moving the elongate optical fiber carrier within the interior cavity to a cavity location obstructed from the opening by the plurality of obstructions, while the interferometer system remains outside the opening;

a fiber bundle inside the elongate optical fiber carrier, the fiber bundle comprising a first plurality of optical fibers, the fiber bundle configured to receive and then transmit the light from the light source;

an end effector disposed on an end of the elongate optical fiber carrier, the end opposite the interferometer system, the end effector comprising:

a cylinder lens inside a housing and in optical communication with the first plurality of optical fibers, wherein the cylinder lens is configured to cause the light to have a first Gaussian profile in an "X" direction relative to a plane and a second Gaussian profile in a "Y" direction relative to the plane, and wherein the cylinder lens is further configured to cause the first Gaussian profile and the second Gaussian profile to be different;

a first mirror inside the housing and in optical communication with the cylinder lens, the first mirror further disposed such that light emitted from the cylinder lens is transmitted in a pattern of light onto the test object, wherein the pattern of light is configured to cause sound waves in the test object and a response light from the test object;

a second mirror inside the housing and configured to receive the response light; and

a plurality of collimators configured to receive the response light from the second mirror;

a second plurality of optical fibers inside the elongate optical fiber carrier, the second plurality of optical fibers connected to the plurality of collimators such that each optical fiber of the second plurality of optical fibers is connected to a corresponding collimator of the plurality of collimators; and

wherein the interferometer system is configured to receive the response light and generate data from the response light, the data used to determine whether an inconsistency is present in the test object at the location.

2. The apparatus of claim **1**, wherein the platform comprises a robotic arm.

3. The apparatus of claim **1** or **2**, wherein the elongate optical fiber carrier comprises a hand-held tool.

4. The apparatus of any one of claims **1** to **3**, wherein the movement system comprises a plurality of joints.

5. The apparatus of any one of claims **1** to **4**, wherein the light source comprises a plurality of lasers, the apparatus further comprising:

a delay line and a delay circuit separating the plurality of lasers, the delay line and the delay circuit configured to reduce cross-talk in optical fibers in the elongate optical fiber carrier.

6. The apparatus of any one of claims **1** to **5**, wherein the light source comprises a plurality of lasers, the apparatus further comprising:

a mechanism configured to separate the plurality of lasers in the light source and to reduce cross-talk in optical fibers in the elongate optical fiber carrier.

7. The apparatus of any one of claims **1** to **6**, further comprising:

a plurality of optical elements configured to modify transmission of the light.

8. The apparatus of claim **7**, wherein the plurality of optical elements comprises at least one of a lens, a mirror, a diffractive optical element, a polarizer, a wave plate, and a periodically poled Lithium niobate crystal.

9. The apparatus of any one of claims **1**, **4** to **8**, wherein the elongate optical fiber carrier comprises at least one of a deformable sheath, a rigid sheath, a hand-held tool with orientation control, a segmented snake configured to change orientation and move, and a segmented snake configured for attachment to a robotic arm.

10. The apparatus of any one of claims **1** to **9**, further comprising:

a third plurality of optical fibers configured to transmit a second pattern of light onto the test object, wherein the second pattern of light is configured detect a second response to the sound waves in the test object;

a second elongate optical fiber carrier configured to hold the third plurality of optical fibers; and

a second movement system configured to:

move the second elongate optical fiber carrier to through a second opening of the test object into a second interior cavity of the test object;

bypass a second plurality of obstructions while moving the second elongate optical fiber within the second interior cavity to a second cavity location obstructed from the second opening by the second plurality of obstructions.

11. A method of identifying an inconsistency using a platform, an interferometer system connected to the platform, an elongate optical fiber carrier connected to and extending from the interferometer system, a fiber bundle inside the elongate optical fiber carrier, the fiber bundle comprising a first plurality of optical fibers, an end effector disposed on an end of the elongate optical fiber carrier opposite the interferometer system, a light source in optical communication with the elongate optical fiber carrier, the light source configured to emit a light wherein the fiber bundle is configured to receive and then transmit the light from the light source, and a movement system connected to the elongate optical fiber carrier, the method comprising:

moving, using the movement system, the elongate optical fiber carrier into a cavity of a test object through an opening of in the test object;

bypassing a plurality of obstructions within the cavity while moving the elongate optical fiber carrier to a location obstructed from the opening by the plurality of obstructions while the interferometer system remains outside the opening;

causing, using a cylinder lens inside a housing and in optical communication with the first plurality of optical fibers, the light to have a first Gaussian profile in an "X" direction relative to a plane and a second Gaussian profile in a "Y" direction relative to the plane;

causing, using the cylinder lens, the first Gaussian profile and the second Gaussian profile to be different;

transmitting, using a first mirror inside the housing and in optical communication with the cylinder lens, light emitted from the cylinder lens in a pattern onto a test object, wherein the pattern is configured to cause sound waves in the test object and a response light from the test object;

receiving, at a second mirror inside the housing, the response light;

receiving, at a plurality of collimators, the response light from the second mirror, wherein a second plurality of optical fibers is inside the elongate optical fiber carrier, the second plurality of optical fibers connected to the plurality of collimators such that each optical fiber of the second plurality of optical fibers is connected to a corresponding collimator of the plurality of collimators;

receiving, at the interferometer system, the response light;

generating data from the response light; and

determining, using the data, whether an inconsistency is present in the test object at the location.

12. The method of claim **11**, wherein the platform comprises a robotic arm.

13. The method of claim **11** or **12**, wherein the elongate optical fiber carrier comprises a hand-held tool.

14. The method of any one of claims **11** to **13**, wherein the movement system comprises a plurality of joints and the method further comprises:

bending the joints.

15. The method of any one of claims **11** to **14**, wherein the light source comprises a plurality of lasers, the method further comprising:

reducing cross-talk in optical fibers in the elongate optical fiber carrier using a delay line and a delay circuit separating the plurality of lasers.

16. The method of any one of claims **11** to **14**, wherein the light source comprises a plurality of lasers, the method further comprising:

reducing cross-talk in optical fibers in the elongate optical fiber carrier using at least one of different phases of light, different wavelengths of light and different timings of light.

17. The method of any one of claims **11** to **16** further comprising:

modifying transmission of the light using a plurality of optical elements.

18. The method of claim **17**, wherein the plurality of optical elements comprises at least one of a lens, a mirror, a diffractive optical element, a polarizer, a wave plate, and a periodically poled Lithium niobate crystal.

19. The method of any one of claims **11** to **18**, wherein bypassing the plurality of obstructions within the cavity comprises:

moving the elongate optical fiber carrier through at least one of the plurality of obstructions.

20. The method of any one of claims **11** to **19**, wherein the plurality of obstructions comprises at least one of cables, hardware, systems, wire bundles, pipes, stringers, webbing, another test object, and a wall with an opening.

21. The method of any one of claims **11, 14** to **20**, wherein the elongate optical fiber carrier comprises at least one of a deformable sheath, a rigid sheath, a hand held tool with orientation control, a segmented snake configured to change orientation and move, and a segmented snake configured for attachment to a robotic arm.

22. The method of any one of claims **11** to **21** further comprising:

generating an output indicating whether the inconsistency is present in the test object at the location.

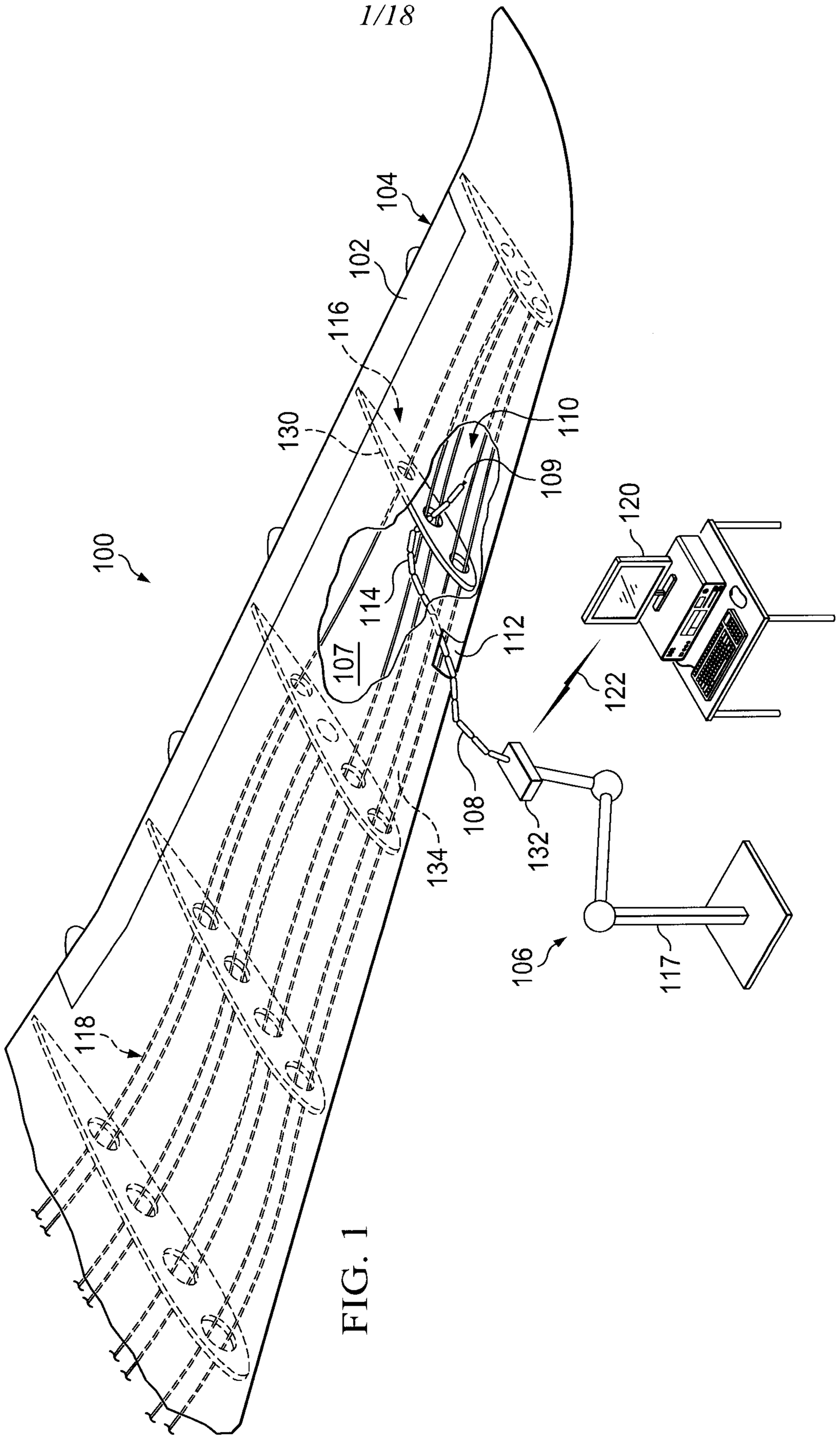
23. The method of any one of claims **11** to **22**, wherein the pattern comprises at least one of a line of light, a non-contiguous line of light, a contiguous line of light, contiguous areas of light, and non-contiguous areas of light.

24. The method of any one of claims **11** to **23**, wherein the pattern comprises at least one of a pattern of coherent light and a pattern of non-coherent light.

25. The method of any one of claims **11** to **24**, wherein the test object comprises a composite test object including at least one of a panel, a fuselage barrel, a stringer, a fuel tank, a spar, a rib, a wing box, a wing, and a stabilizer.

26. The method of any one of claims **11** to **24**, wherein the test object comprises a wing of an aircraft.

27. The method of any one of claims **11** to **26**, wherein the test object comprises of a plurality of materials including at least one of a composite material, a plastic, and a metal.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134

FIG. 1

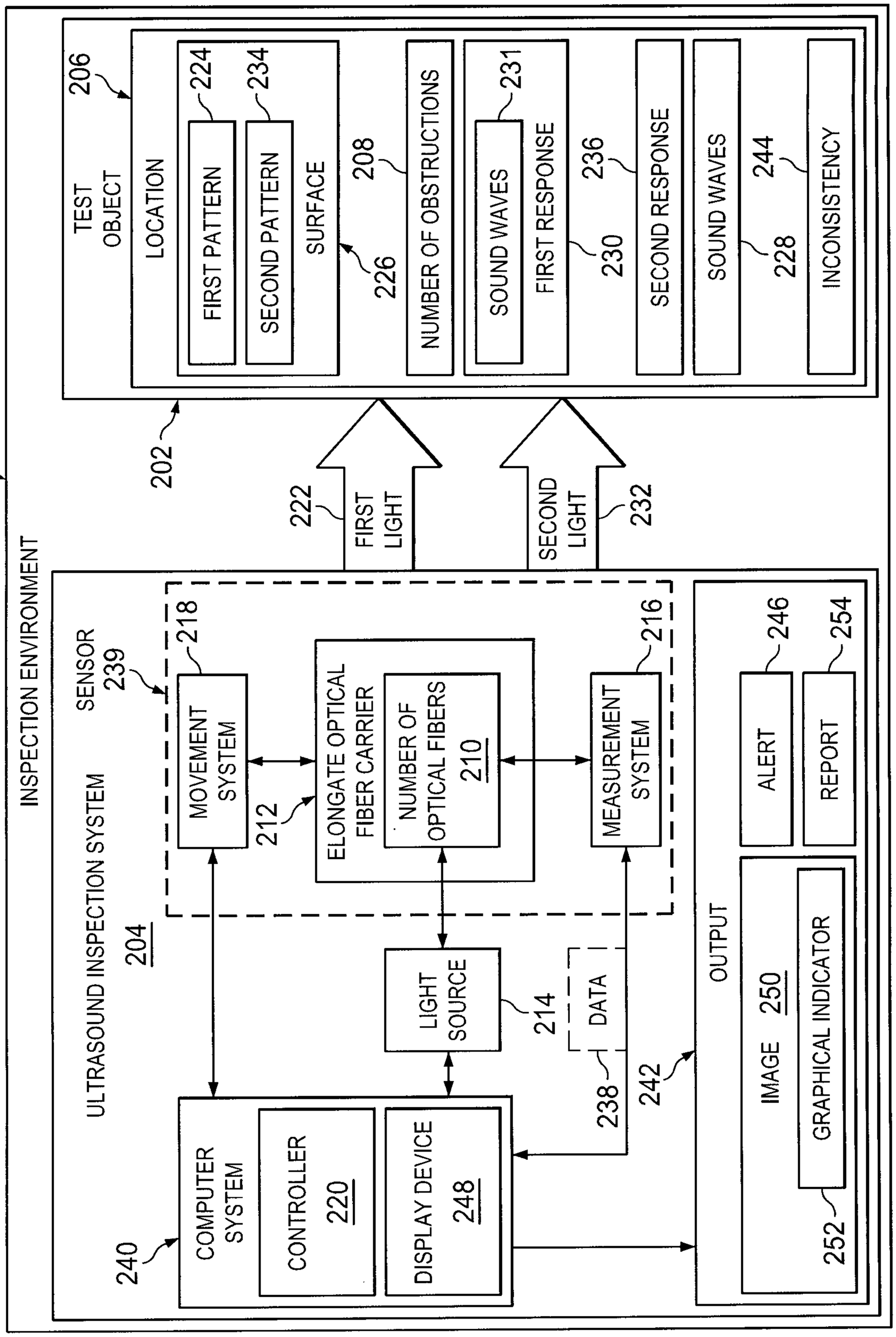

200
INSPECTION ENVIRONMENT
ULTRASOUND INSPECTION SYSTEM
202
TEST OBJECT
206
LOCATION
224
FIRST PATTERN
234
SECOND PATTERN
SURFACE
226
208
NUMBER OF OBSTRUCTIONS
231
SOUND WAVES
FIRST RESPONSE
230
236
SECOND RESPONSE
SOUND WAVES
228
244
INCONSISTENCY
222
FIRST LIGHT
SECOND LIGHT
232
SENSOR
239
204
MOVEMENT SYSTEM
218
212
ELONGATE OPTICAL FIBER CARRIER
NUMBER OF OPTICAL FIBERS
210
MEASUREMENT SYSTEM
216
LIGHT SOURCE
214
DATA
238
242
OUTPUT
ALERT
246
REPORT
254
IMAGE
250
GRAPHICAL INDICATOR
252
240
COMPUTER SYSTEM
CONTROLLER
220
DISPLAY DEVICE
248

FIG. 2

FIG. 3

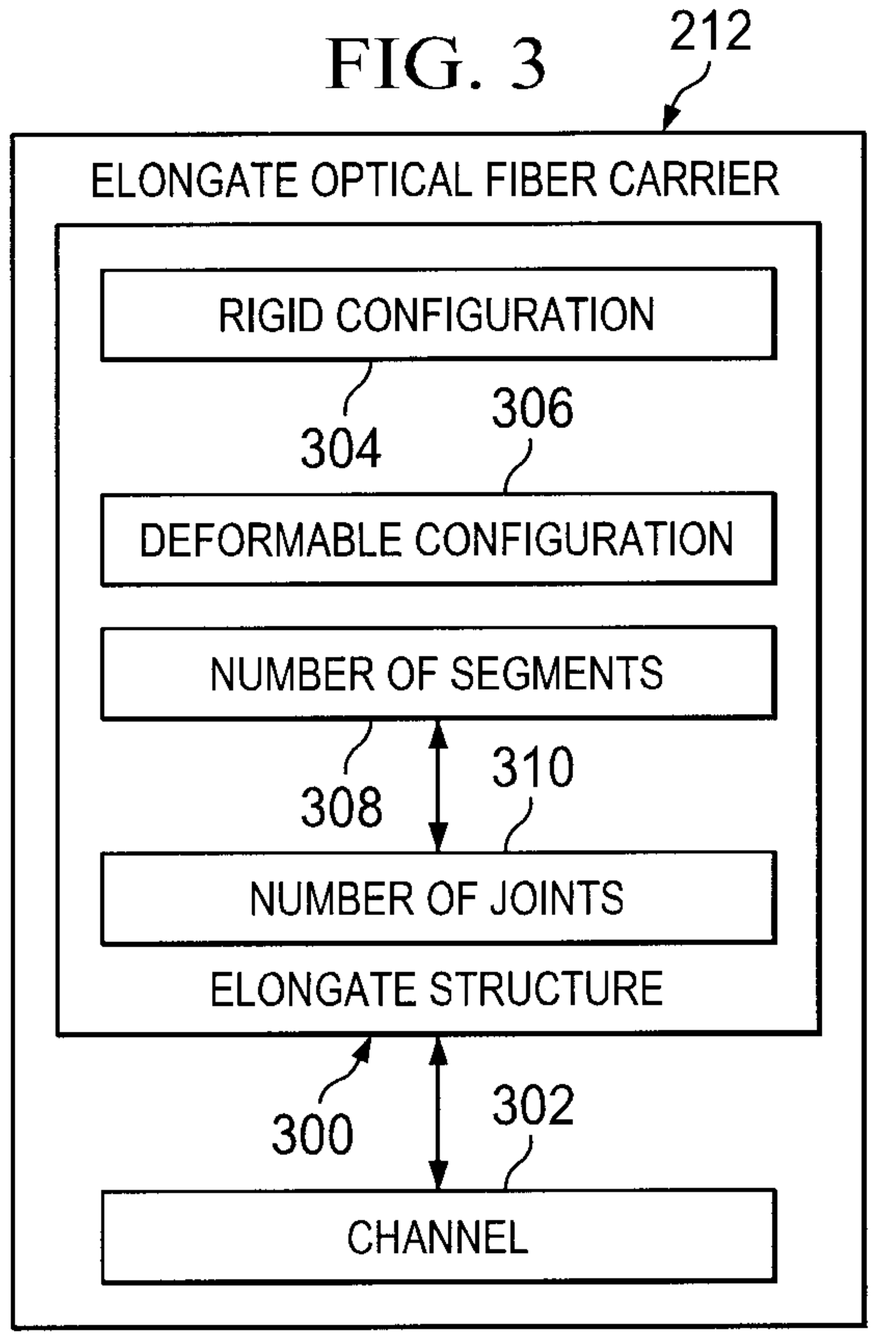
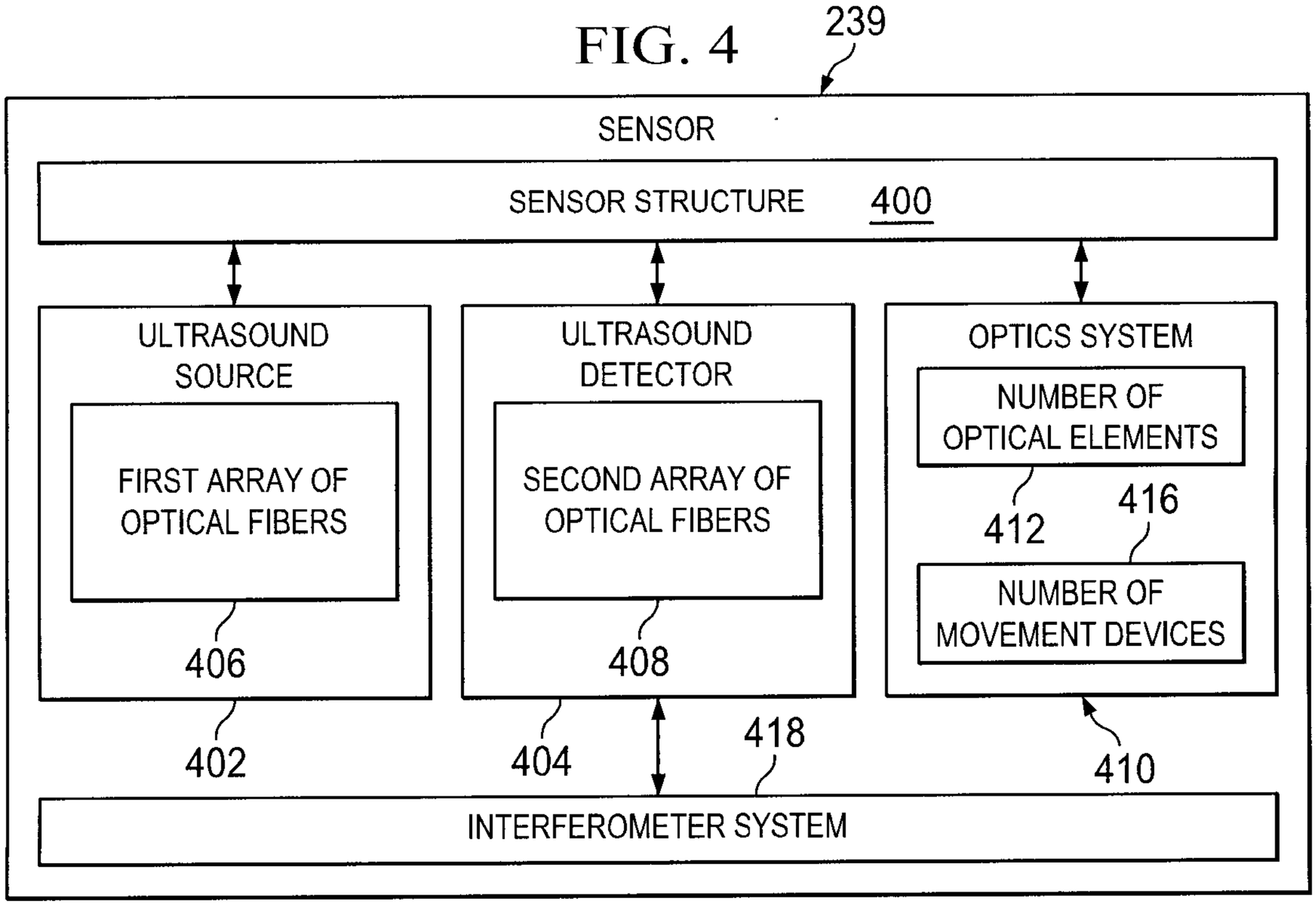

212
ELONGATE OPTICAL FIBER CARRIER
RIGID CONFIGURATION
304
306
DEFORMABLE CONFIGURATION
NUMBER OF SEGMENTS
308
310
NUMBER OF JOINTS
ELONGATE STRUCTURE
300
302
CHANNEL

FIG. 4


239
SENSOR
SENSOR STRUCTURE 400
ULTRASOUND SOURCE
FIRST ARRAY OF OPTICAL FIBERS
406
402
ULTRASOUND DETECTOR
SECOND ARRAY OF OPTICAL FIBERS
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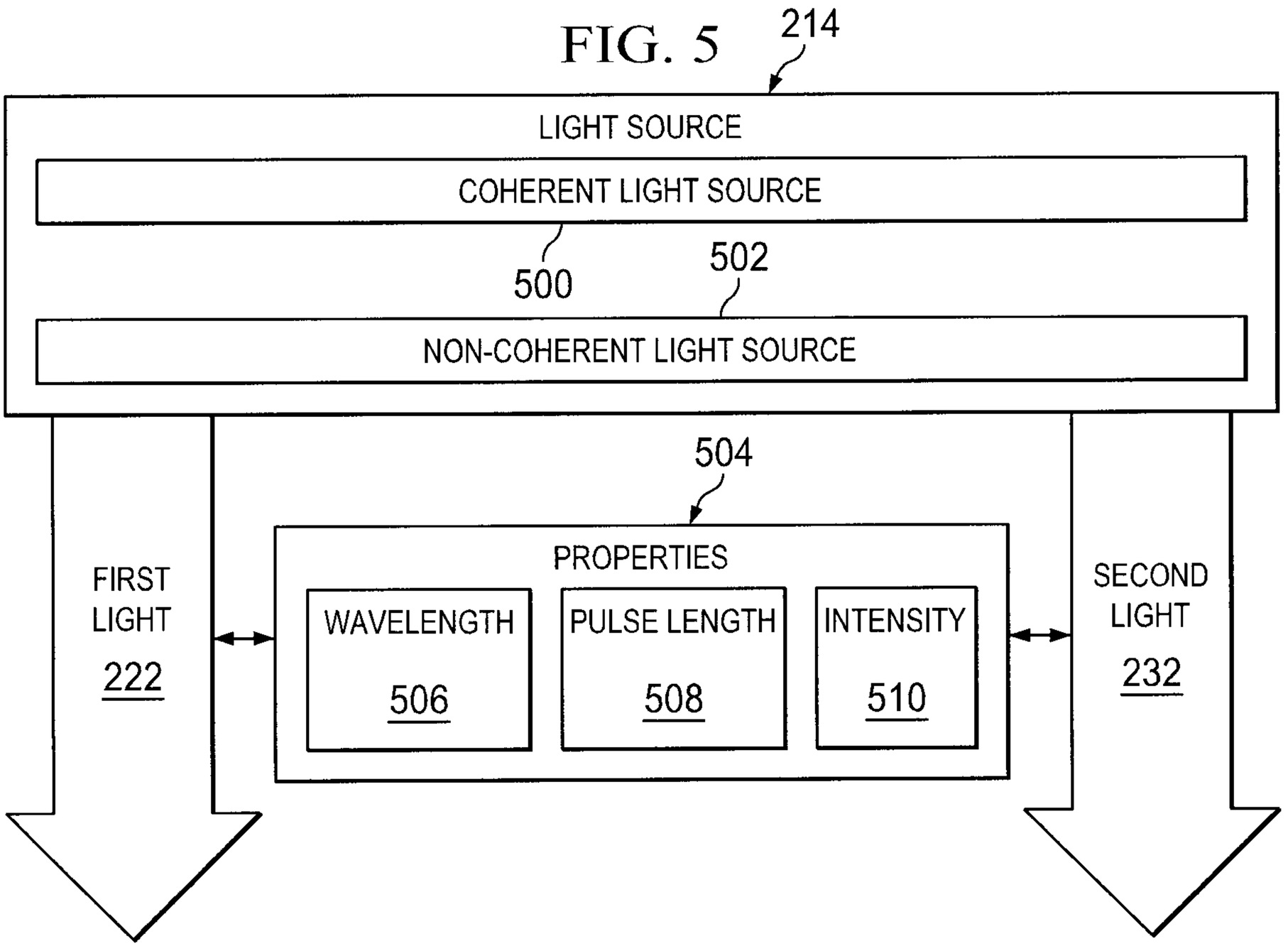
404
418
OPTICS SYSTEM
NUMBER OF OPTICAL ELEMENTS
412
416
NUMBER OF MOVEMENT DEVICES
410
INTERFEROMETER SYSTEM

FIG. 5


214
LIGHT SOURCE
COHERENT LIGHT SOURCE
500
502
NON-COHERENT LIGHT SOURCE
504
PROPERTIES
WAVELENGTH
506
PULSE LENGTH
508
INTENSITY
510
FIRST LIGHT
222
SECOND LIGHT
232

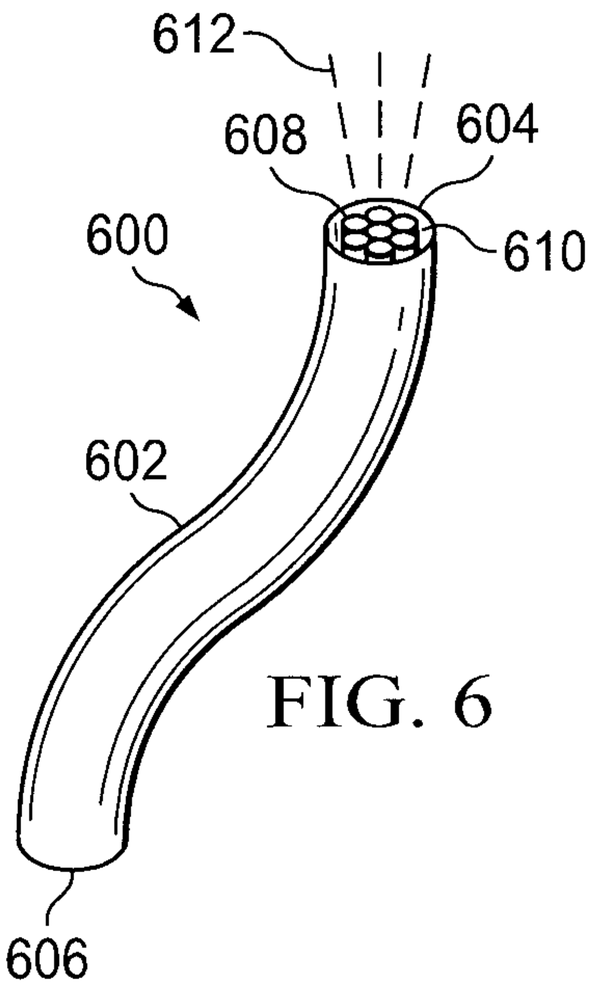


FIG. 6

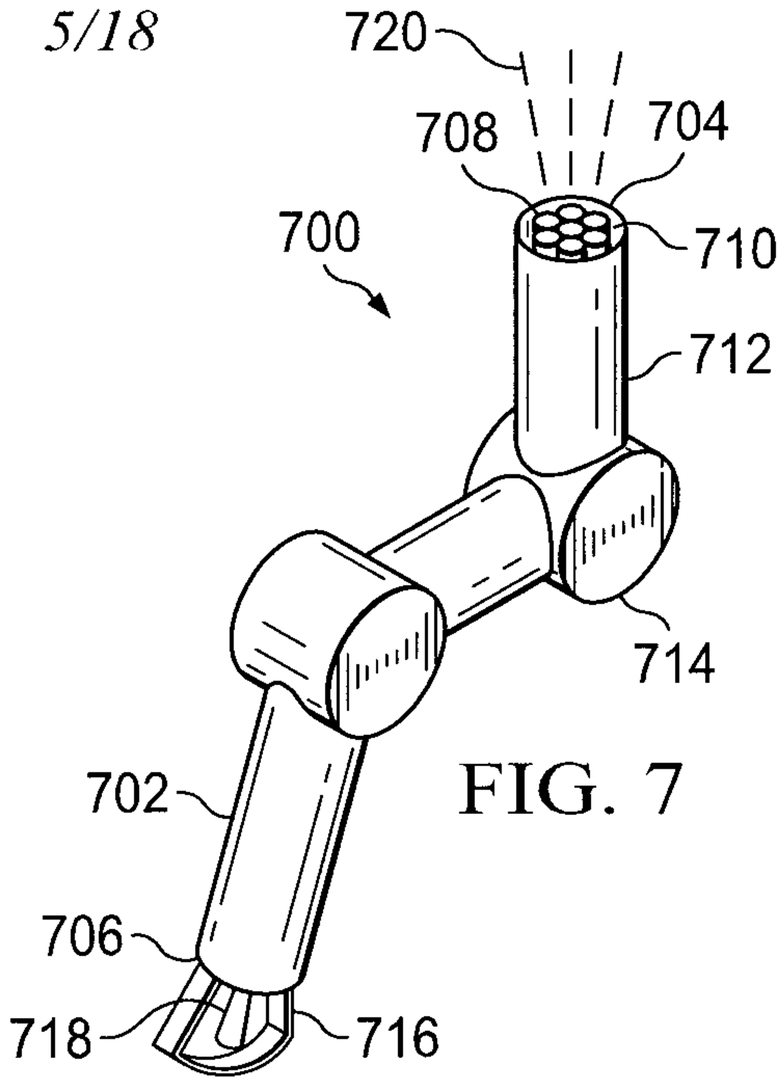


FIG. 7

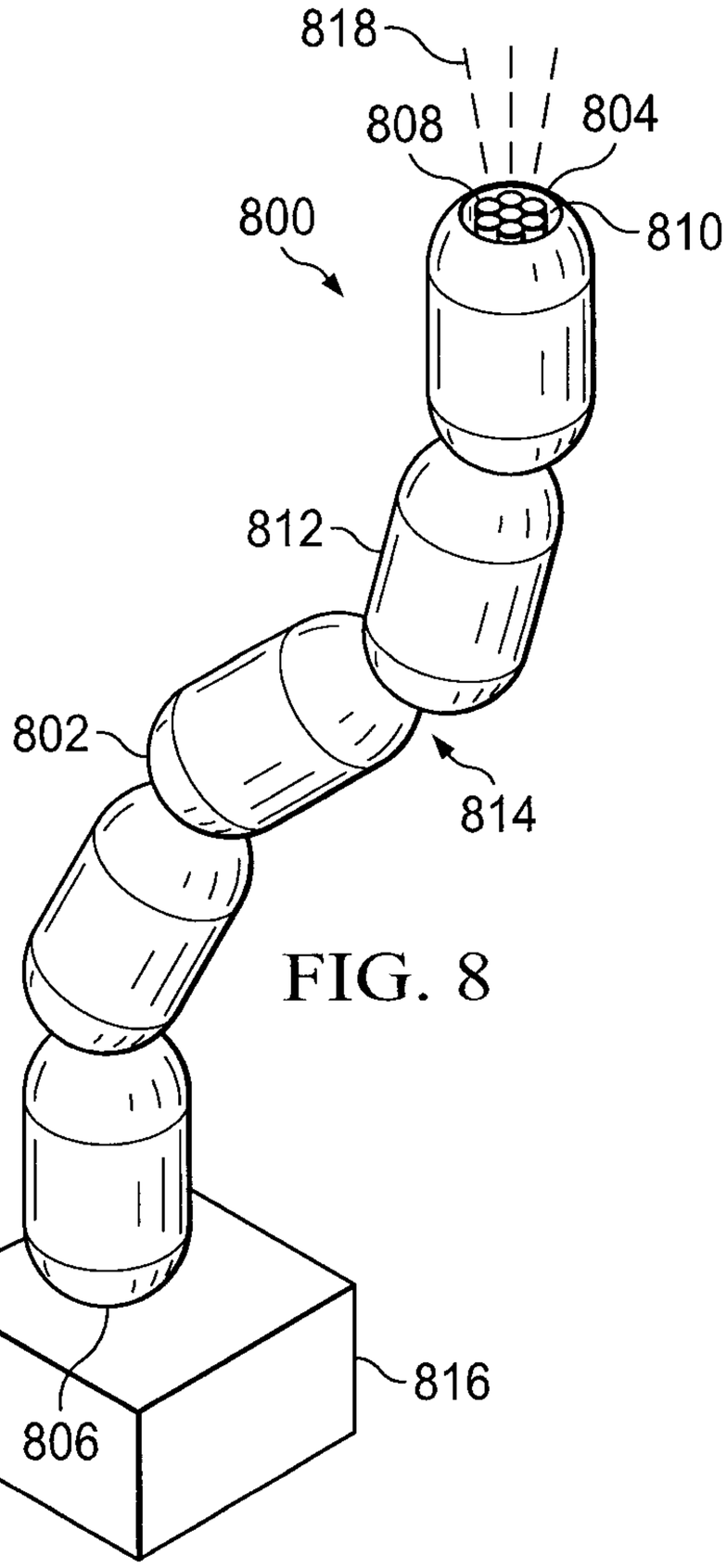


FIG. 8

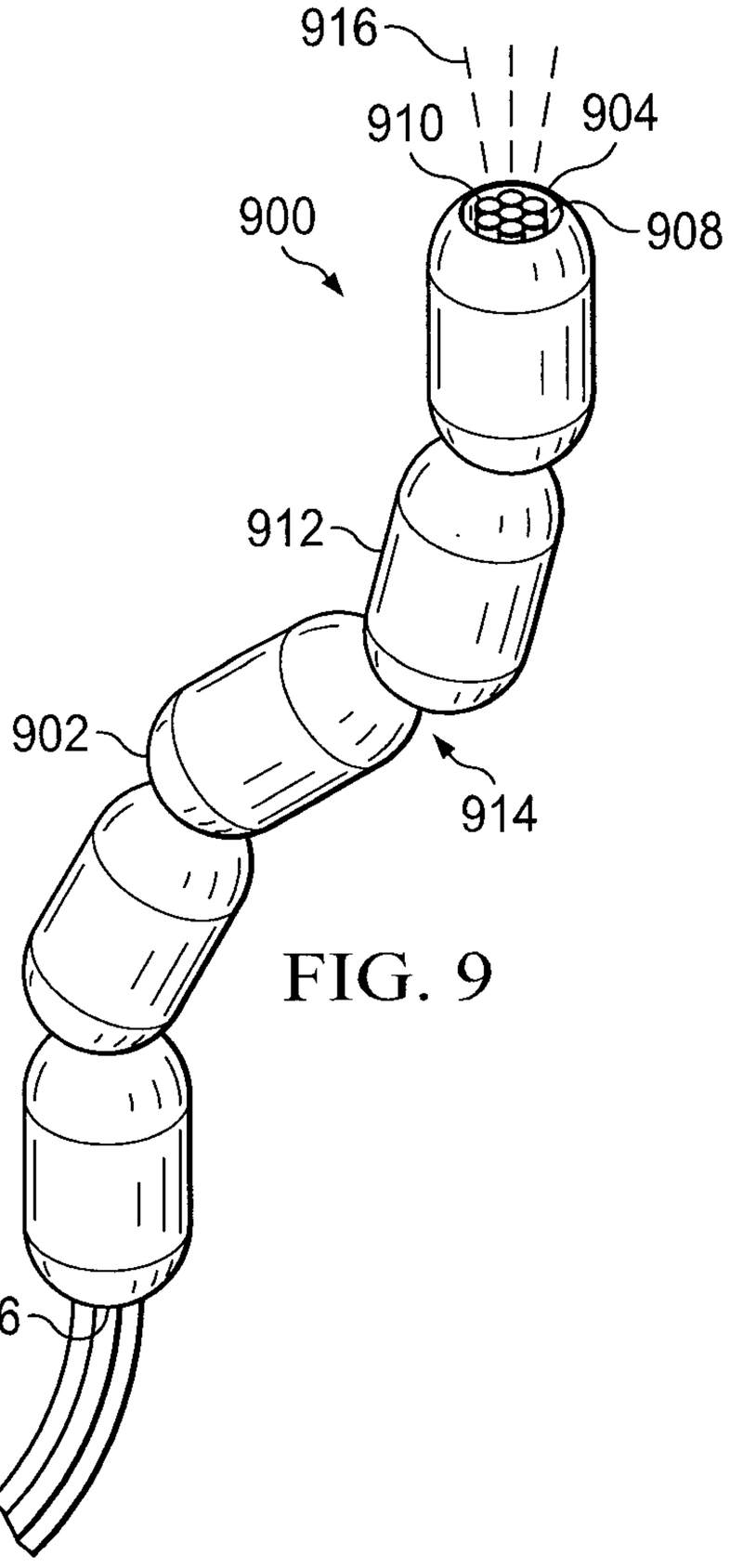


FIG. 9

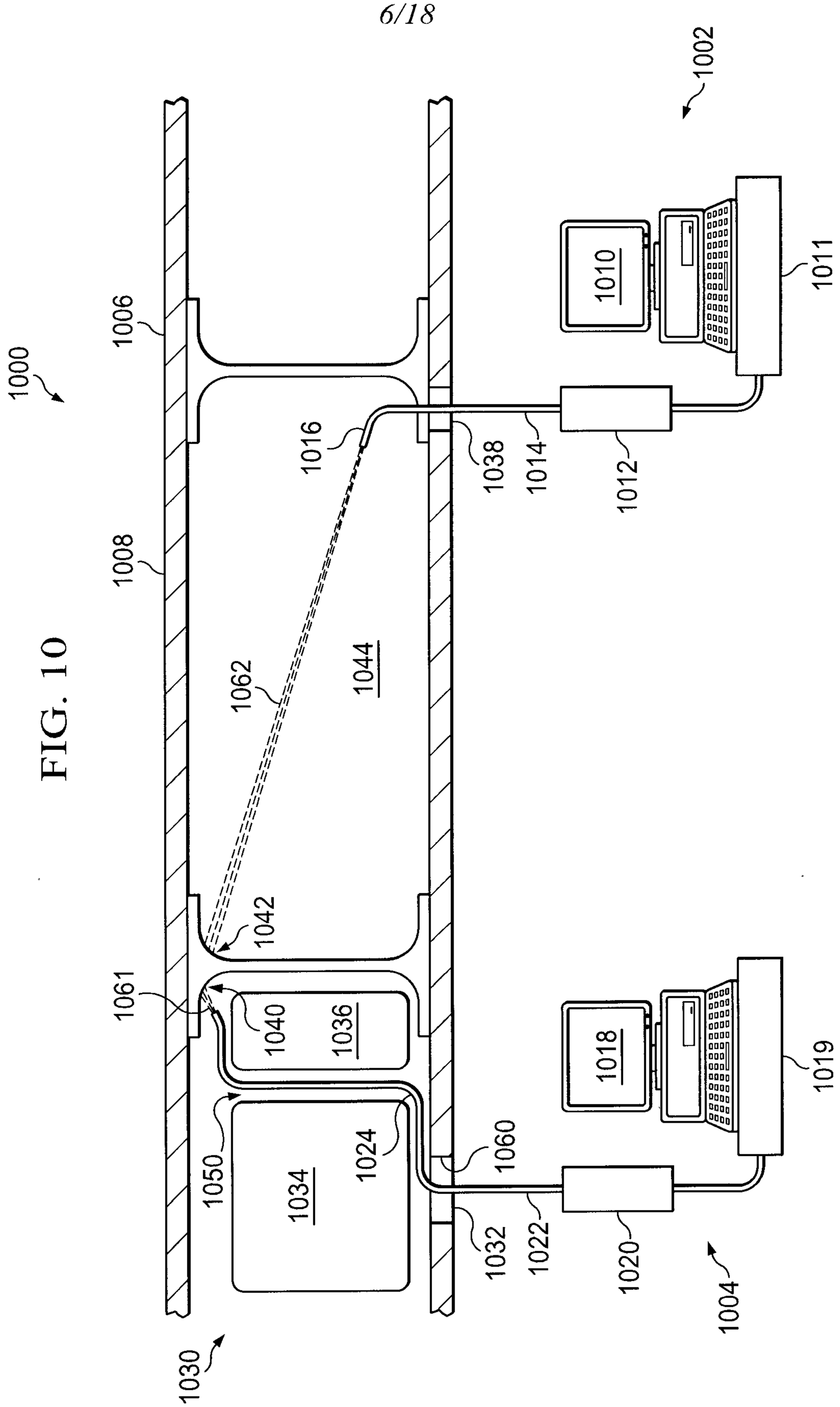

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FIG. 10

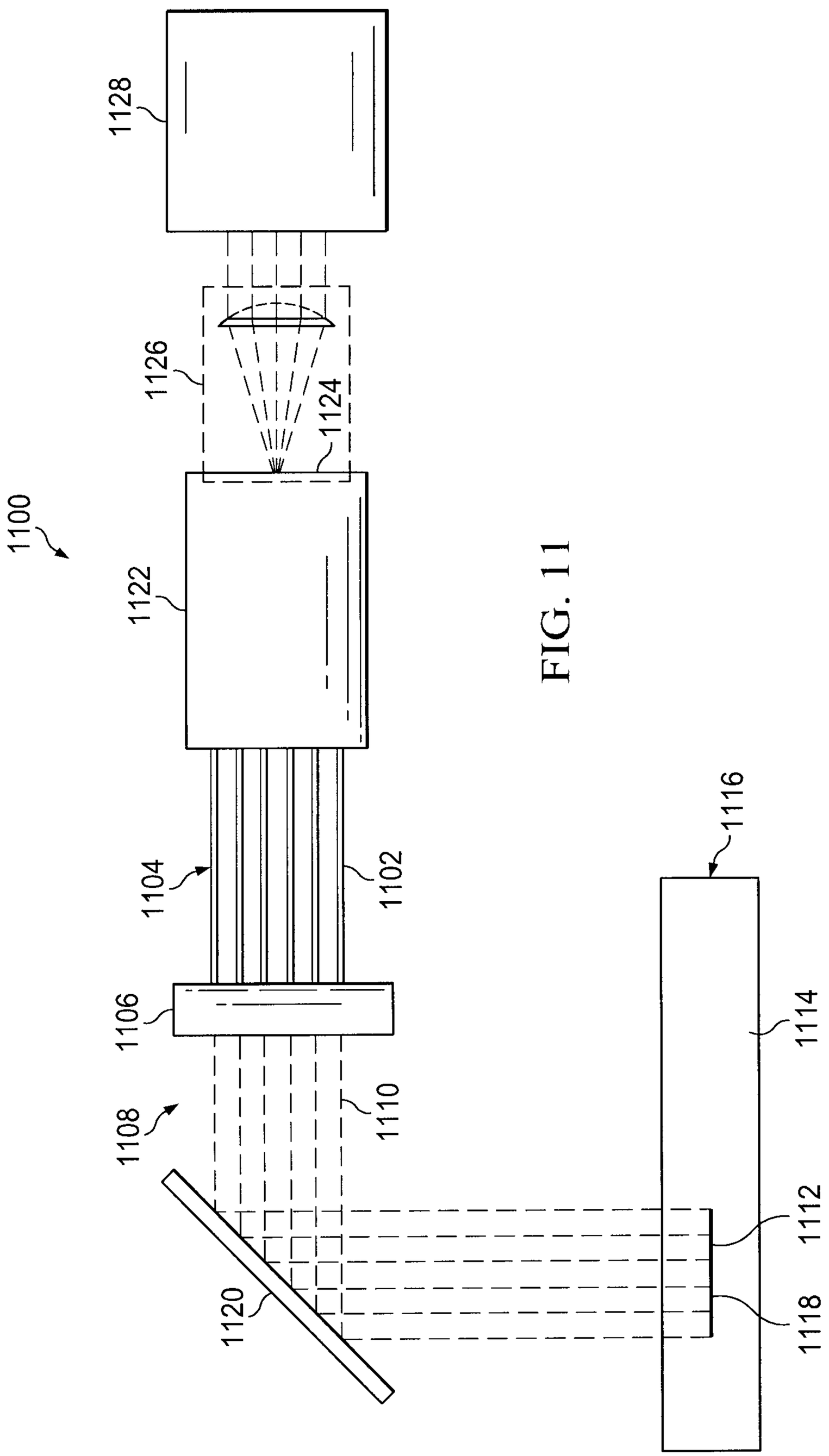
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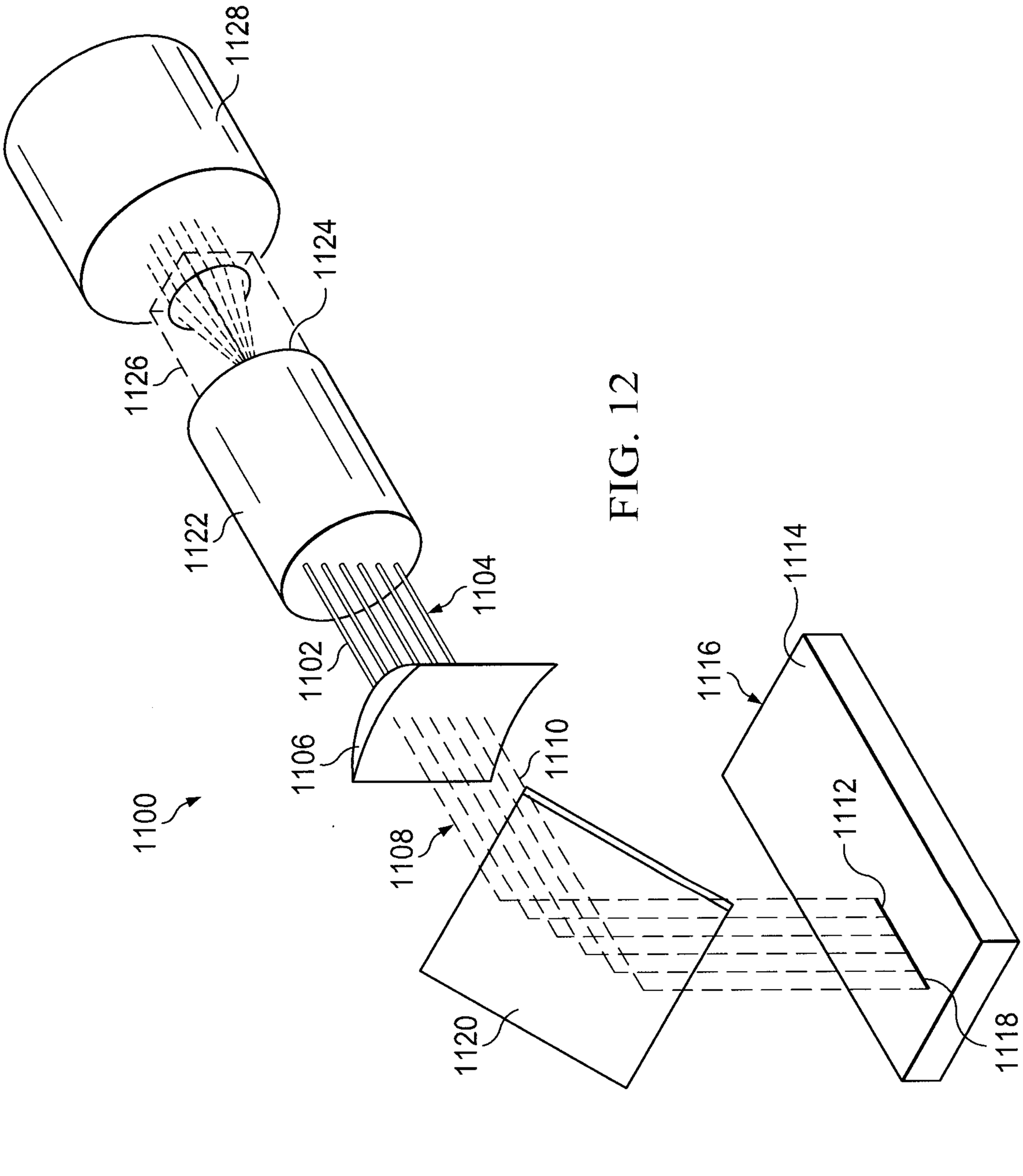
FIG. 11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1126
1128

FIG. 12

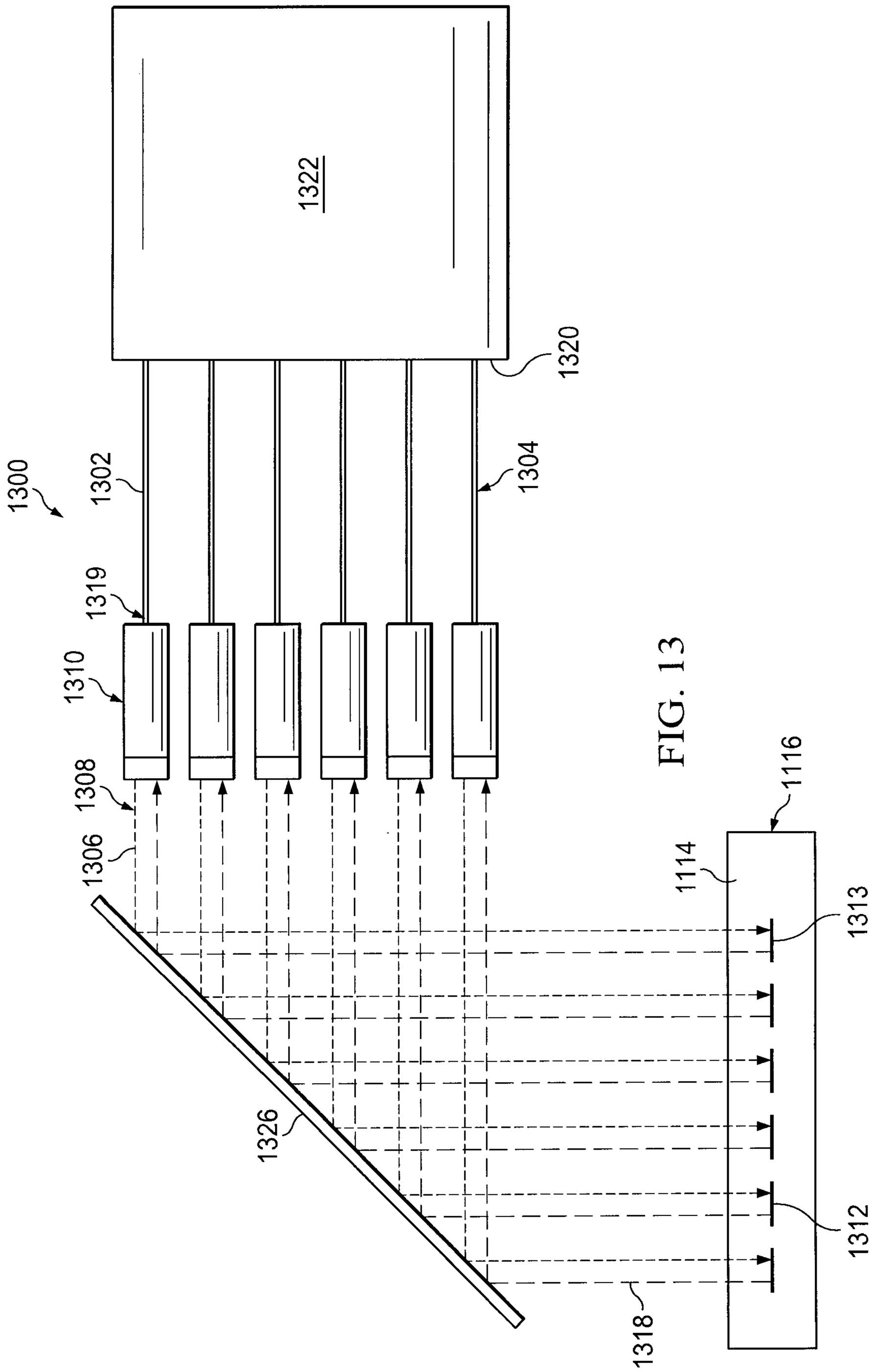
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FIG. 13

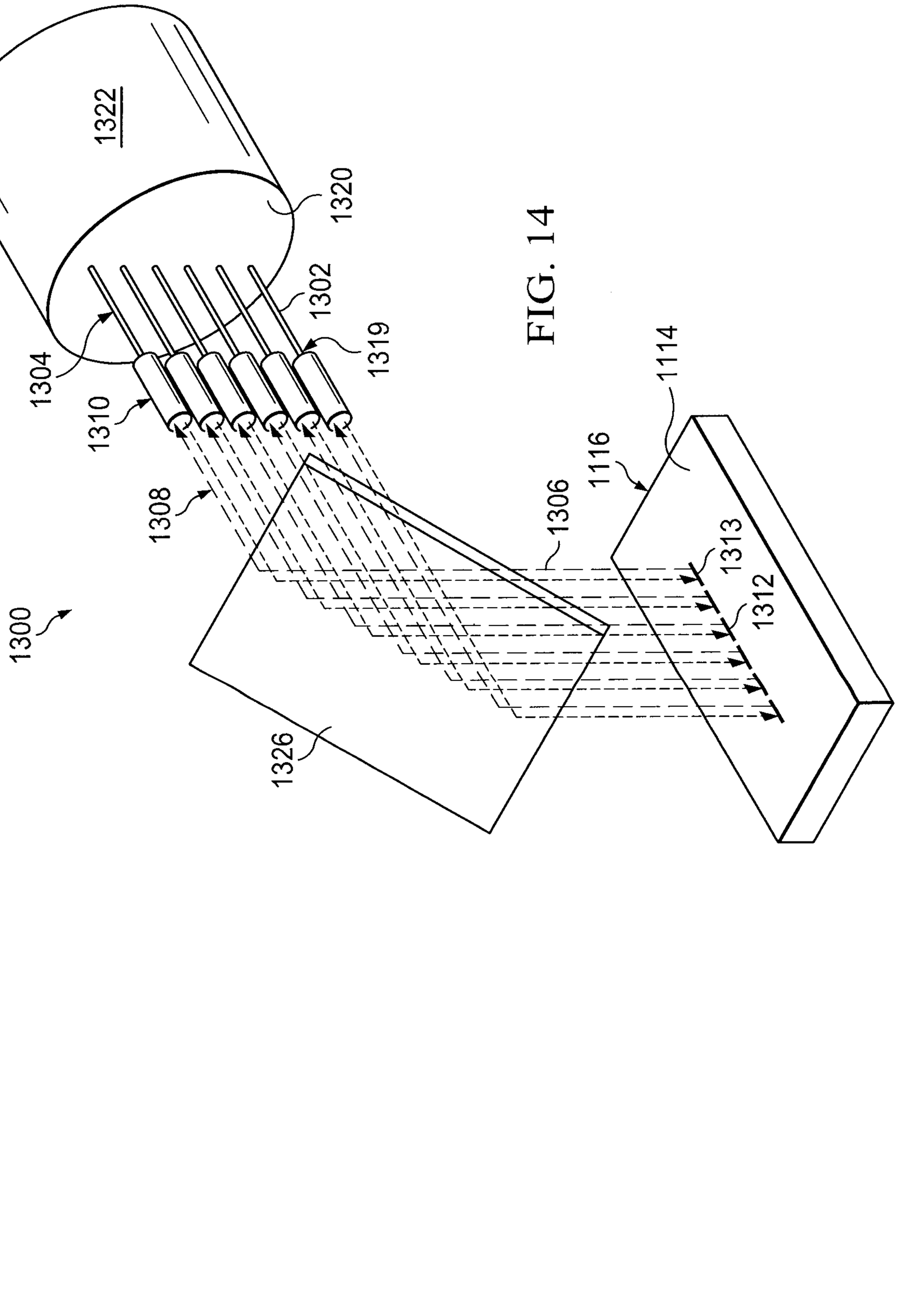
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FIG. 14

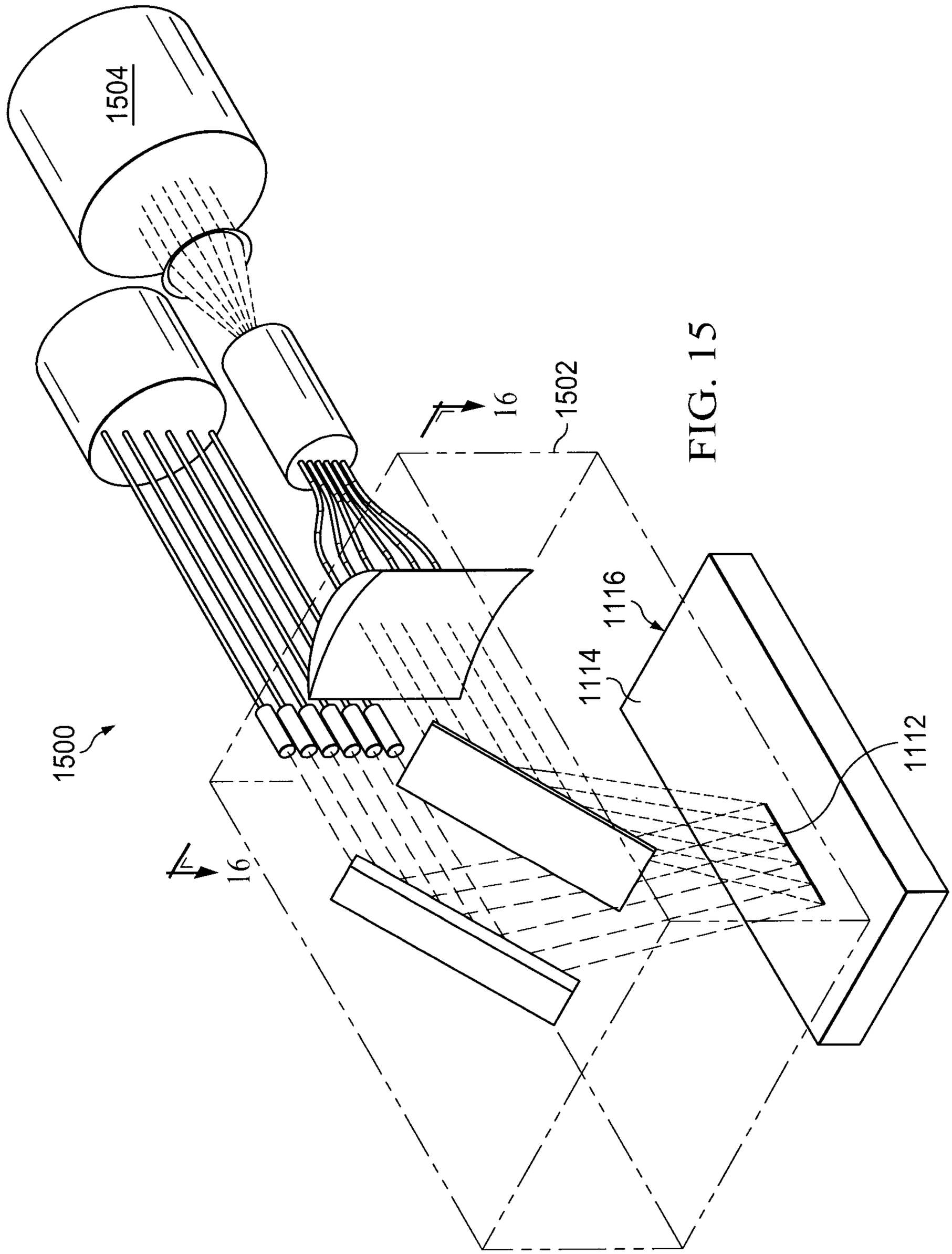

FIG. 15

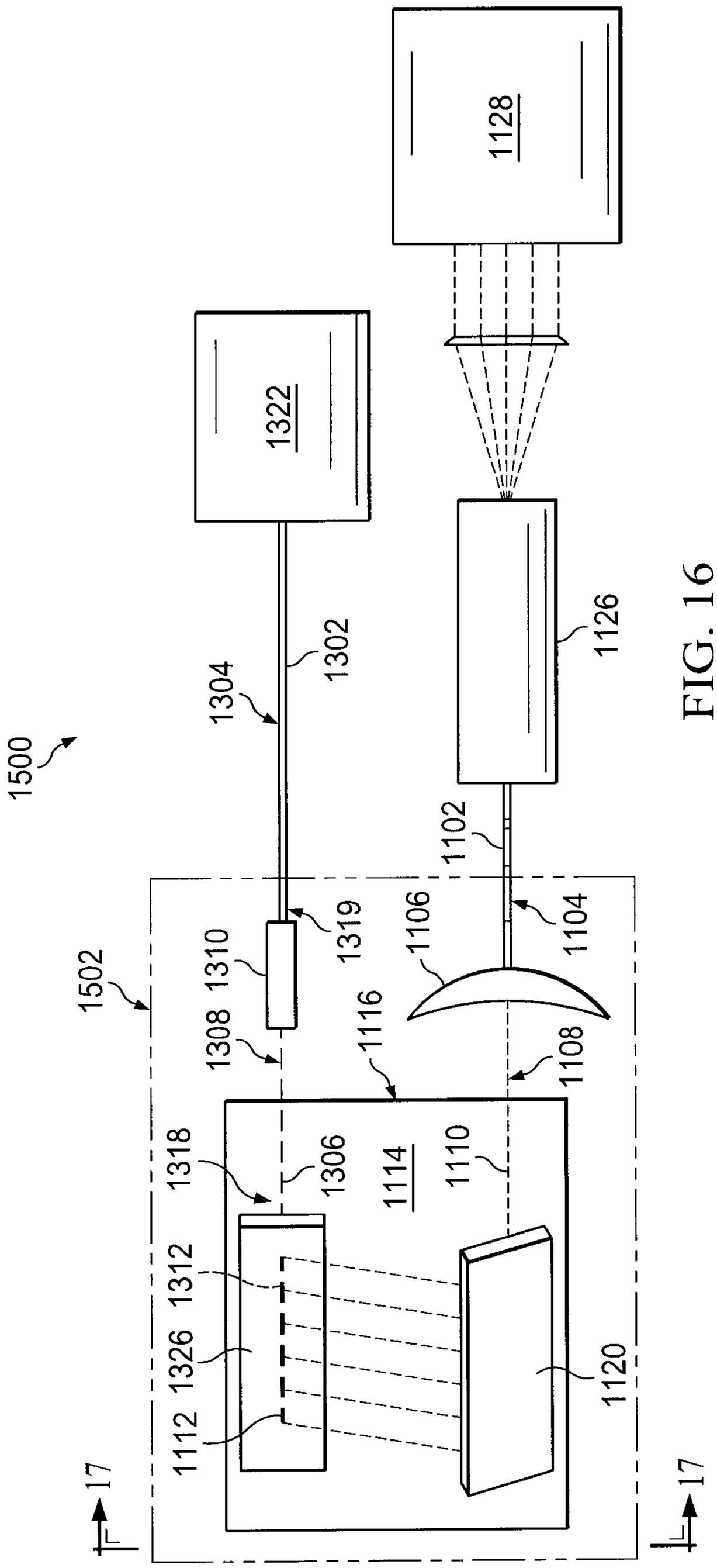
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FIG. 16

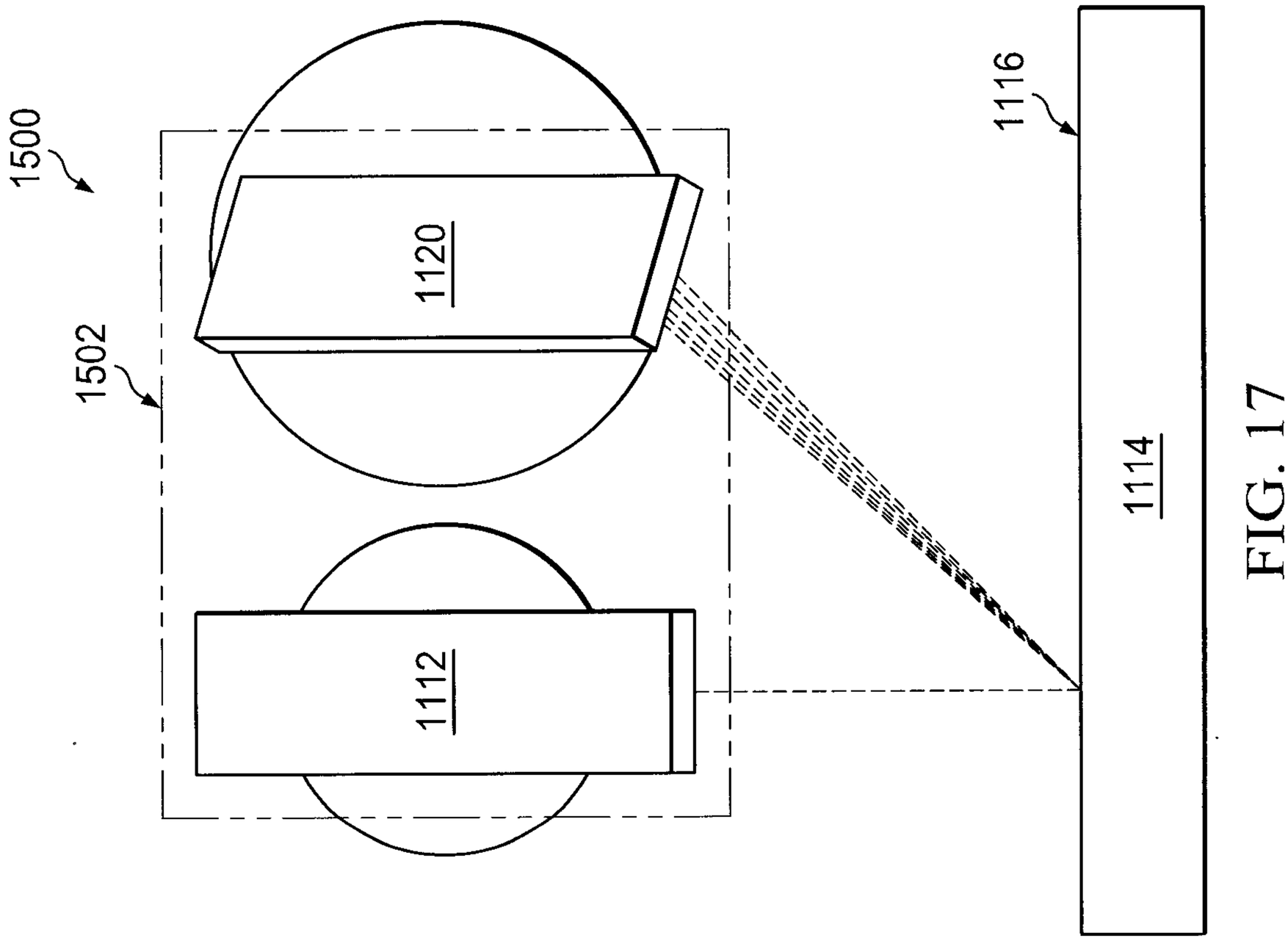

FIG. 17

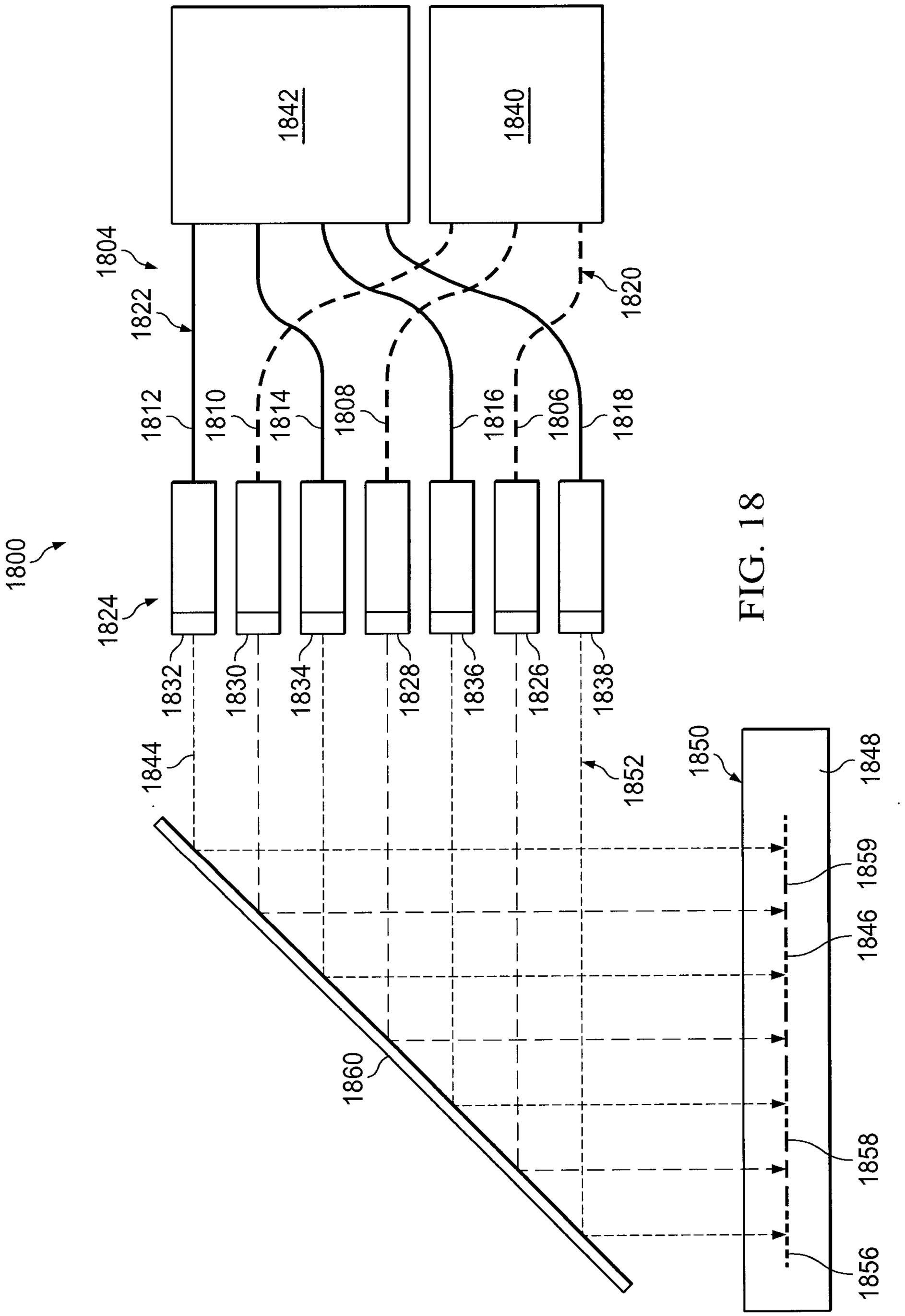
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FIG. 18

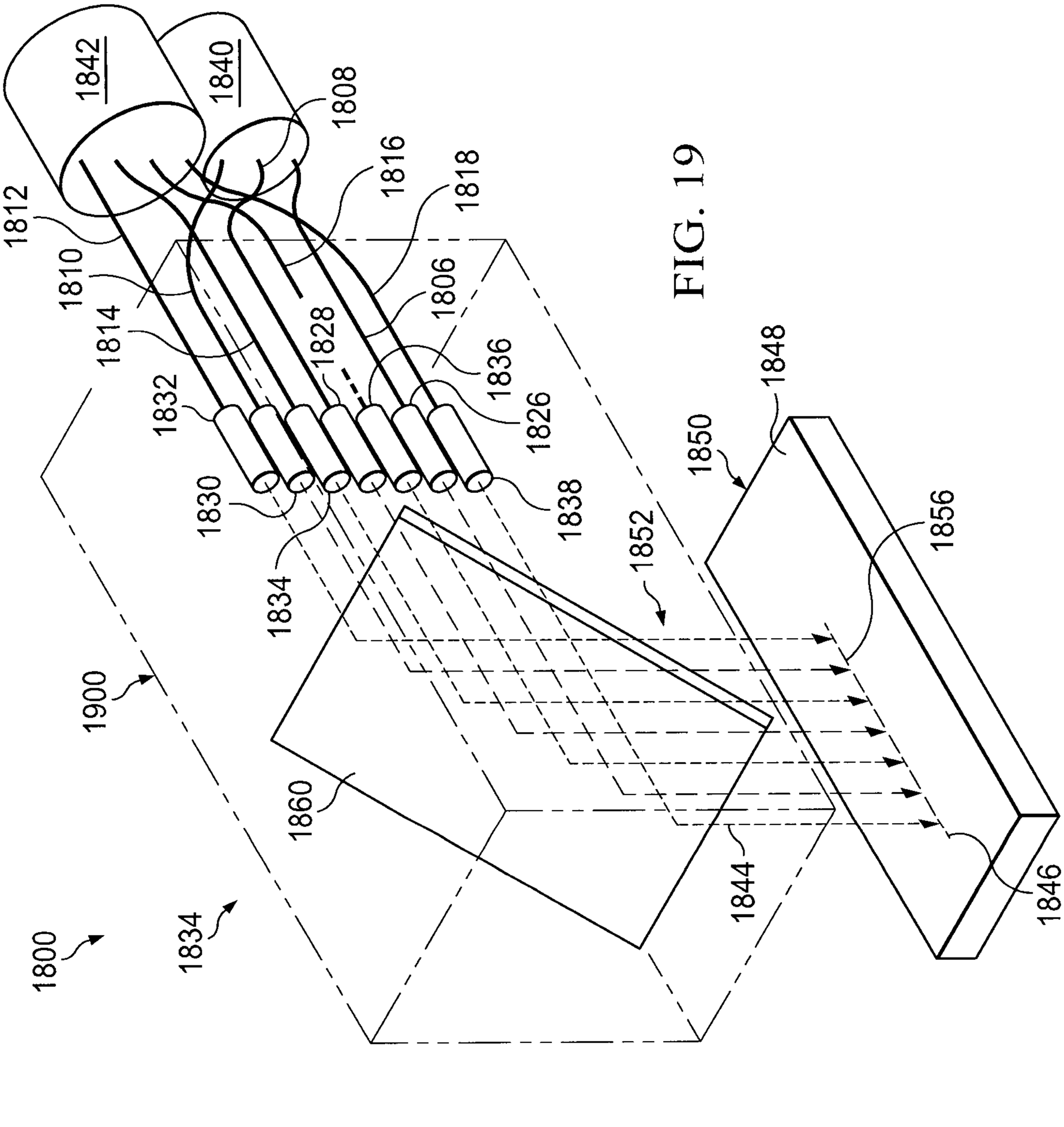
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FIG. 19

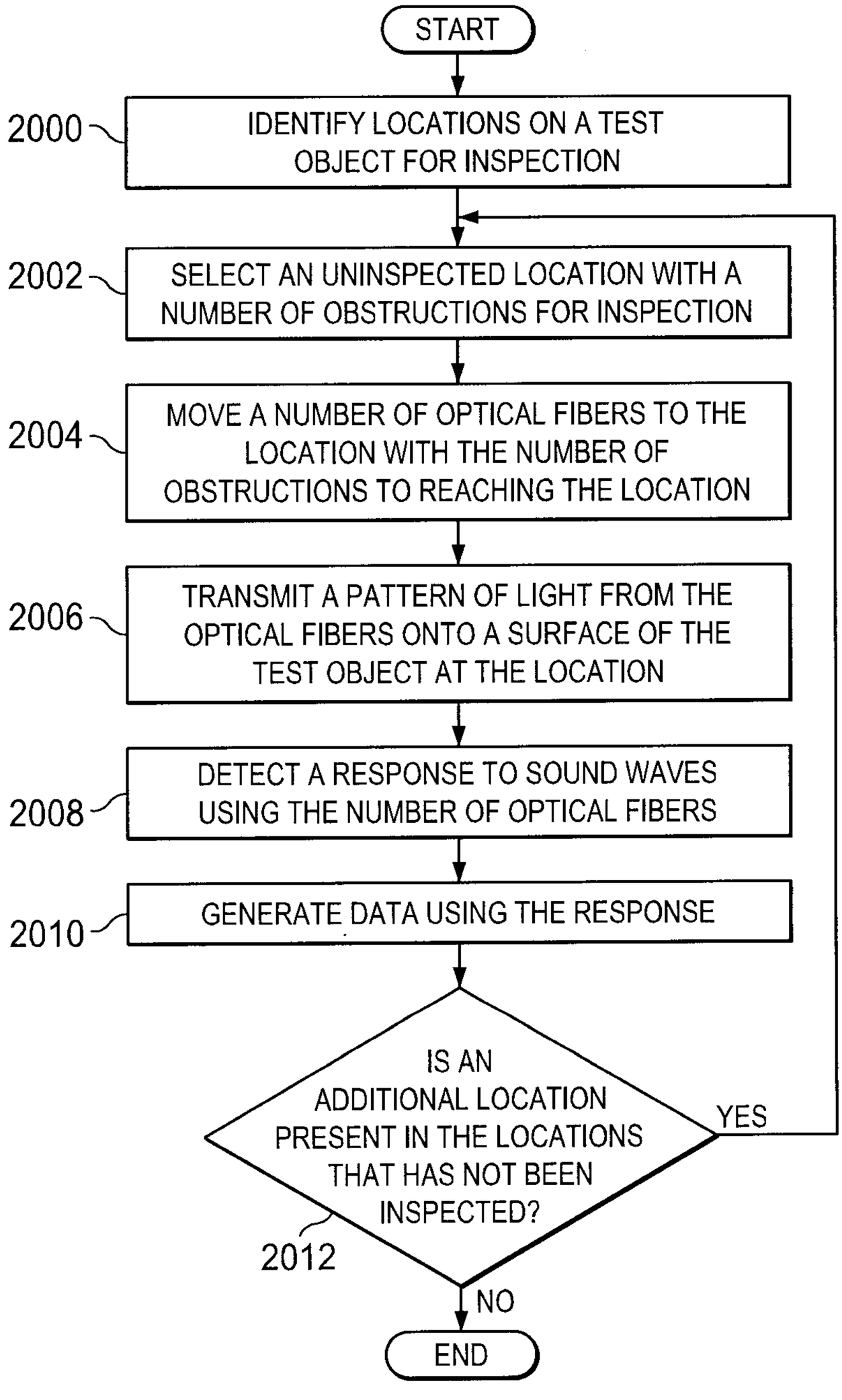

START
2000
IDENTIFY LOCATIONS ON A TEST OBJECT FOR INSPECTION
2002
SELECT AN UNINSPECTED LOCATION WITH A NUMBER OF OBSTRUCTIONS FOR INSPECTION
2004
MOVE A NUMBER OF OPTICAL FIBERS TO THE LOCATION WITH THE NUMBER OF OBSTRUCTIONS TO REACHING THE LOCATION
2006
TRANSMIT A PATTERN OF LIGHT FROM THE OPTICAL FIBERS ONTO A SURFACE OF THE TEST OBJECT AT THE LOCATION
2008
DETECT A RESPONSE TO SOUND WAVES USING THE NUMBER OF OPTICAL FIBERS
2010
GENERATE DATA USING THE RESPONSE
IS AN ADDITIONAL LOCATION PRESENT IN THE LOCATIONS THAT HAS NOT BEEN INSPECTED?
2012
YES
NO
END

FIG. 20

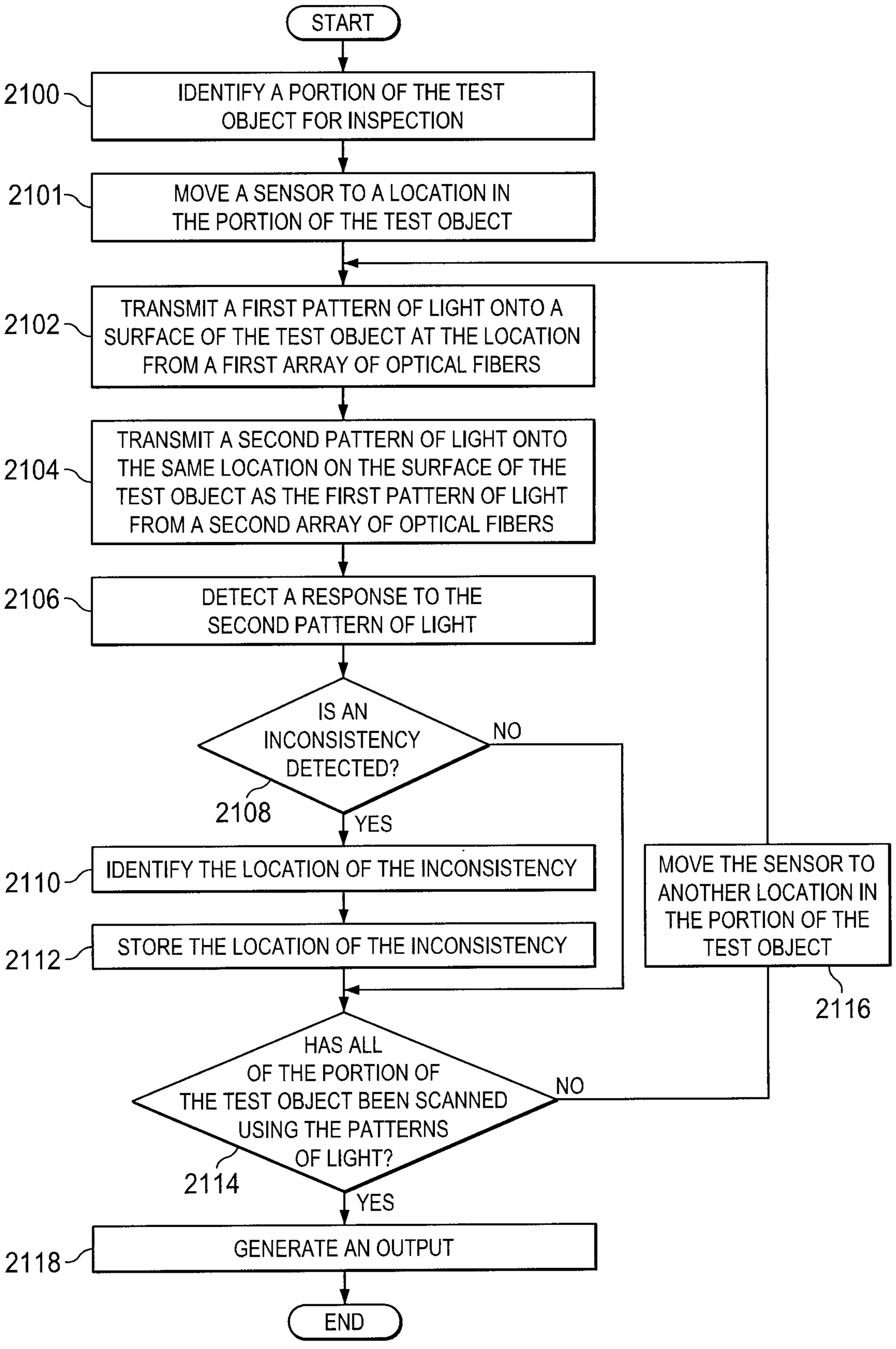

START
2100
IDENTIFY A PORTION OF THE TEST OBJECT FOR INSPECTION
2101
MOVE A SENSOR TO A LOCATION IN THE PORTION OF THE TEST OBJECT
2102
TRANSMIT A FIRST PATTERN OF LIGHT ONTO A SURFACE OF THE TEST OBJECT AT THE LOCATION FROM A FIRST ARRAY OF OPTICAL FIBERS
2104
TRANSMIT A SECOND PATTERN OF LIGHT ONTO THE SAME LOCATION ON THE SURFACE OF THE TEST OBJECT AS THE FIRST PATTERN OF LIGHT FROM A SECOND ARRAY OF OPTICAL FIBERS
2106
DETECT A RESPONSE TO THE SECOND PATTERN OF LIGHT
IS AN INCONSISTENCY DETECTED?
2108
NO
YES
2110
IDENTIFY THE LOCATION OF THE INCONSISTENCY
2112
STORE THE LOCATION OF THE INCONSISTENCY
HAS ALL OF THE PORTION OF THE TEST OBJECT BEEN SCANNED USING THE PATTERNS OF LIGHT?
2114
NO
YES
MOVE THE SENSOR TO ANOTHER LOCATION IN THE PORTION OF THE TEST OBJECT
2116
2118
GENERATE AN OUTPUT
END

FIG. 21

FIG. 22

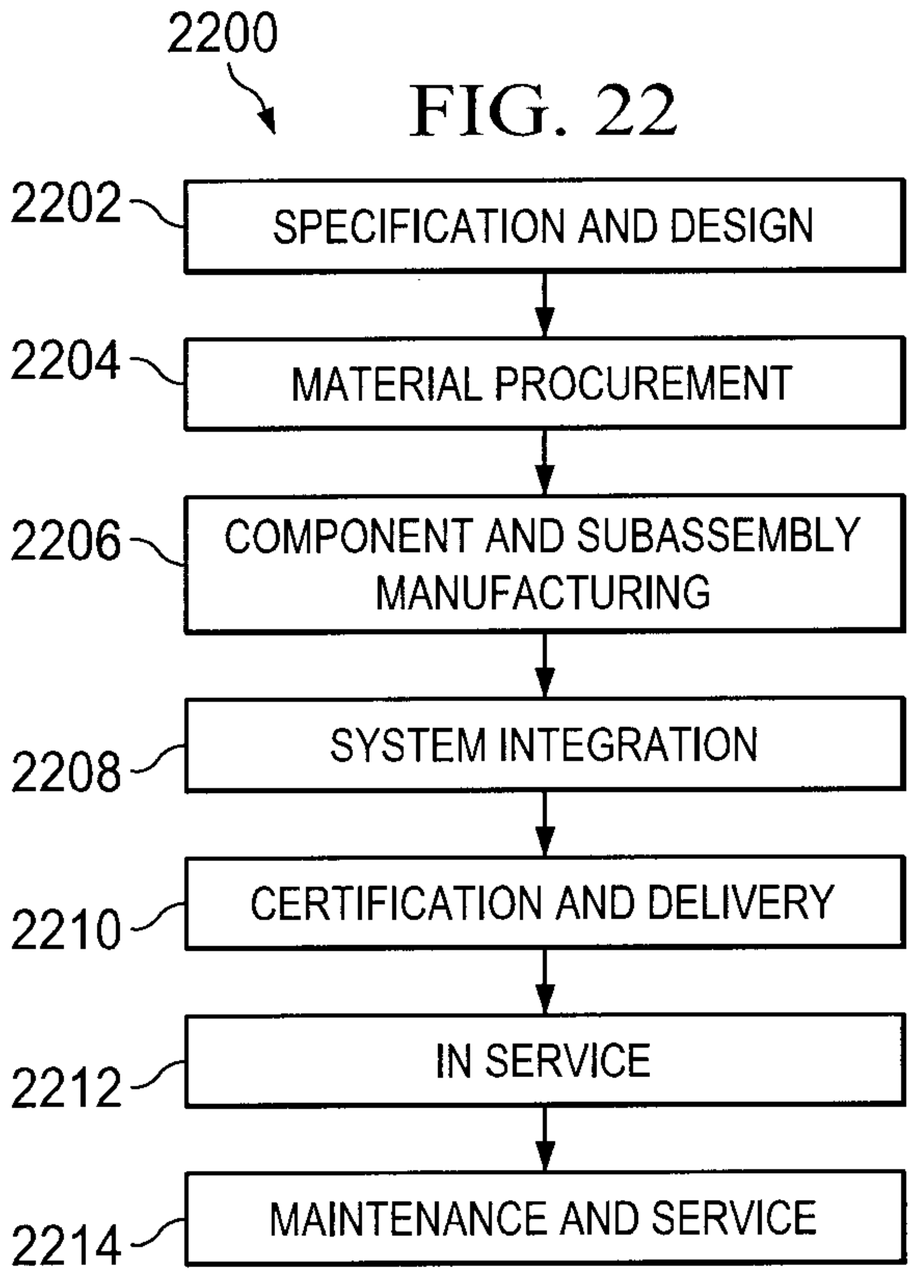
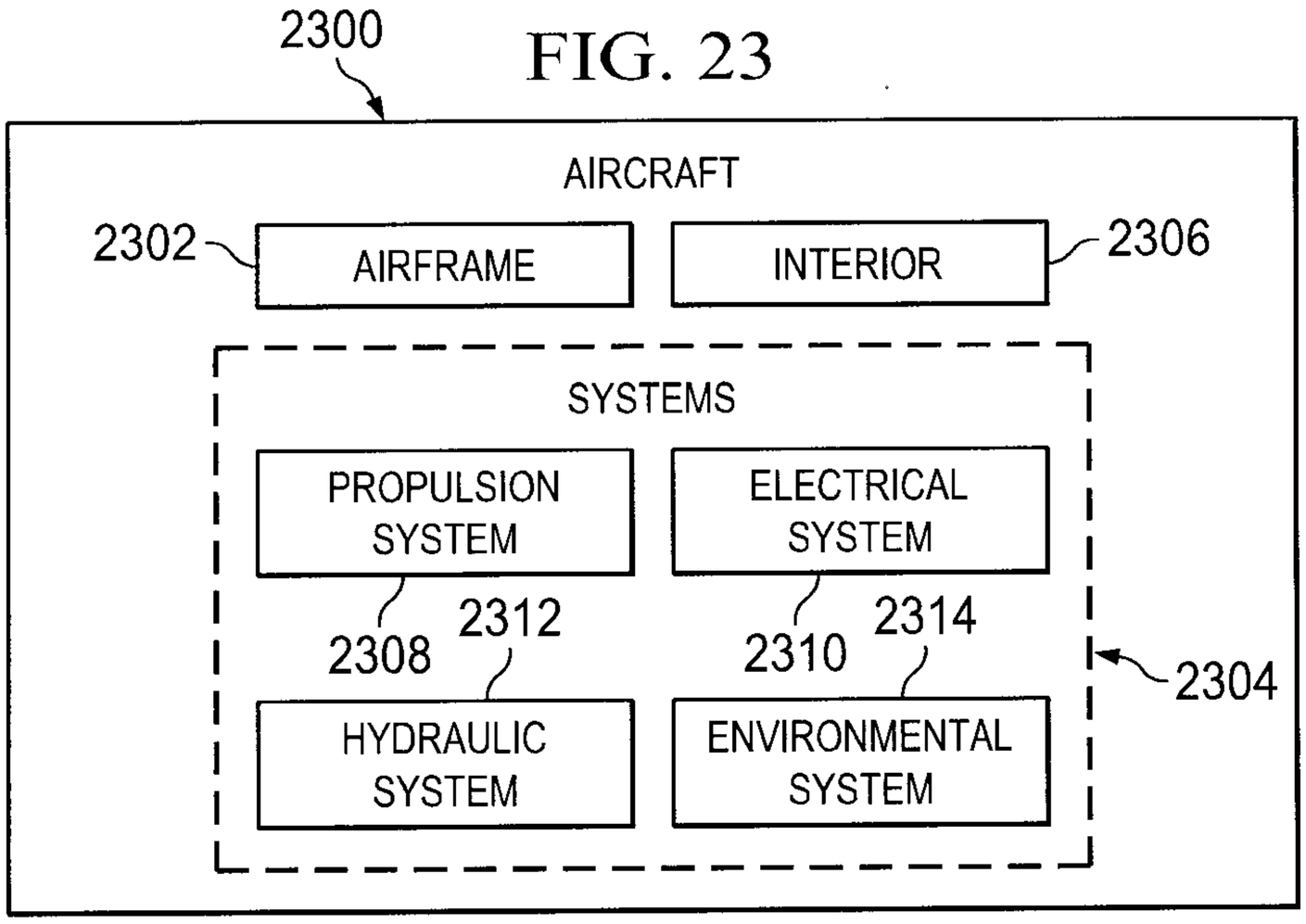

2200
2202
SPECIFICATION AND DESIGN
2204
MATERIAL PROCUREMENT
2206
COMPONENT AND SUBASSEMBLY MANUFACTURING
2208
SYSTEM INTEGRATION
2210
CERTIFICATION AND DELIVERY
2212
IN SERVICE
2214
MAINTENANCE AND SERVICE

FIG. 23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AIRFRAME
INTERIOR
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SYSTEMS
PROPULSION SYSTEM
ELECTRICAL SYSTEM
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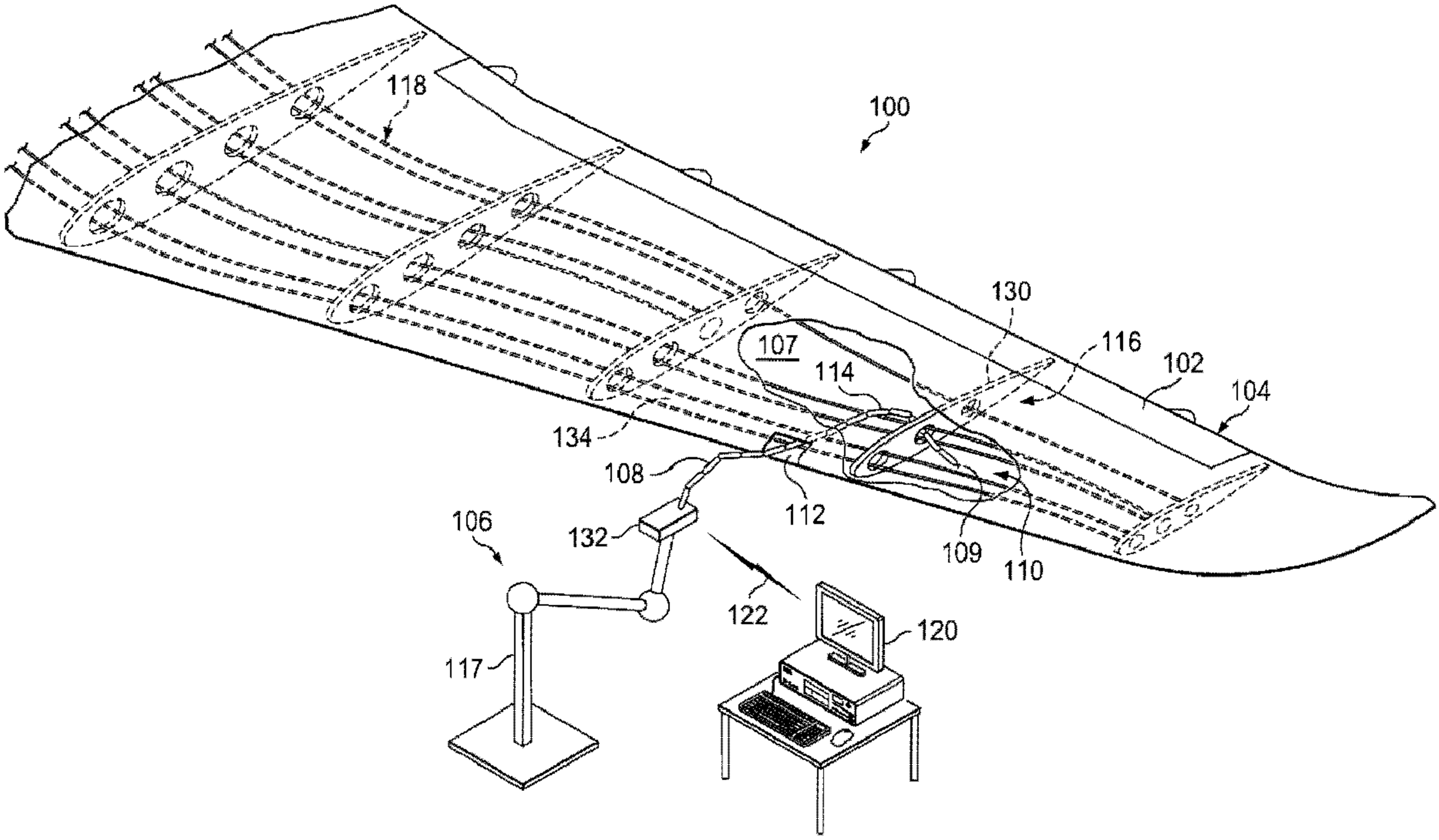
2314
HYDRAULIC SYSTEM
ENVIRONMENTAL SYSTEM
2304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