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MODULAR TOWED ACOUSTIC SONAR ARRAY

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0002] None.

BACKGROUND OF THE INVENTION

1) Field of the Invention

[0003] The present invention generally relates to towed acoustic sonar arrays in which the array has modular sections.

2) Description of Prior Art

[0004] There are a numerous variations of underwater acoustic sonar arrays towed from submarines, surface ships, and unmanned undersea vehicles. The acoustic sonar arrays detect ships, marine life, geology, and underwater objects. Current sonar towed arrays employ a linear arrangement of individual sonar sensors (acoustic or non-acoustic) that are used to spatially and temporally sample acoustic signals. Typically, an electronic circuit board is connected to between one and eight independent sonar sensors in a hose. These sonar sensors communicate with one another and with an electronic system within the vehicle towing the sonar array.

[0005] Assembly of a typical towed acoustic array begins by determining a mission and a data processing procedure. Assembly parameters are selected based on these determinations. Once complete, the array is pulled into a long hose and the hose ends are terminated with wired connectors. Each hose is approximately 150 feet long. The array is then connected to a number of similar arrays to make a longer array.

[0006] The parameters selected for assembly are static and may not be changed within an assembled array without significant effort. Since the sensors are electronic, changes to the quantity and spacing of the acoustic sensors within the hose may not be made in the field. The process of removing the contents of an array from the hose (called de-booting) involves significant effort and a risk of damaging the electronics.

[0007] In conventional towed acoustic arrays, component failures are endured until the system has degraded below a predetermined threshold. The arrays are of such length and include a significant number of sensors such that repair or replacement of individual components may not be cost effective. Once enough degradation makes the system unreasonably unreliable; the array is removed from service and de-booted to replace damaged components.

[0008] When a mission is complete; the arrays are typically stowed on a reel. A large reel diameter may be necessary to maintain a safe bend radius when spooling long hoses that contain electronics and sensors. These large reels of arrays can be bulky and cumbersome to transport.

SUMMARY OF THE INVENTION

[0009] In one embodiment of the invention, a system comprises a first sensor array module. The sensor array module includes a first submersible hose, a first electrical bus connected between a first and a second end of the submersible hose, a first plurality of sensors spaced apart from one another in relation to a distance “d” along the electrical bus, and a first electrical connector disposed on one of the ends of the hose.

[0010] The system also comprises a second sensor array module. The sensor array module includes a second submersible hose, a second electrical bus connected between a first and a second end of the second submersible hose, a second plurality of sensors spaced from one another in relation to a distance “d/n” along the electrical bus, wherein $n \neq 1$ or 0, and a second electrical connector disposed on at least one of the ends of the second submersible hose and connectable to the first electrical connector of the first submersible hose.

[0011] In another embodiment of the invention, a sensor array module comprises a hose less than 100 feet long; an electrical bus connected between a first and a second end of the hose; at least one hydrophone on the electrical bus; at least one electrical circuit board connected to the at least one hydrophone via the electrical bus; a non-acoustic sensor connected to the circuit board via the electrical bus; and an electrical connector disposed on one of the first and second ends of the hose connectable to a second hose.

[0012] In another embodiment of the invention, a method of changing sensor density in a towed sensor array system comprises the steps of: determining a target frequency for receipt of a signal; determining Sound Navigation and Ranging (SONAR) sensor spacing corresponding to the target frequency; and identifying spacing of a first plurality of SONAR sensors in a first submersible sensor array module. The first array module includes a first hose with connectors at each end. The hose contains a first electronic circuit board; a first bus coupled to the electronic circuit board; and the SONAR sensors disposed along the first bus at a first distance.

[0013] The method further comprises the step of connecting a second submersible sensor array module wherein the second array module includes a second hose with connectors at each end. The hose contains a second electronic circuit board, a second bus coupled to the second electronic circuit board, and a second plurality of SONAR sensors disposed along the second bus at a second distance. The second distance is selected to be different from the first distance to enable an aggregate spacing of the first SONAR sensors and the second SONAR sensors that corresponds to the determined sensor spacing.

[0014] These and other features, aspects and advantages of the present invention will become better understood with reference to the following drawings, description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] **FIG. 1** is a block diagram of a sensor array system according to an embodiment of the present invention;

[0016] **FIG. 2** is a flowchart of a method of changing sensor array modules in a towed sensor array system according to another embodiment of the present invention; and

[0017] **FIG. 3** is a cross-sectional view of a connector for use in the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0018] The following detailed description is of the best currently contemplated modes of carrying out the invention. The description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the invention, since the scope of the invention is best defined by the appended claims.

[0019] The present disclosure relates generally to a system that allows assembly of an underwater acoustic towed sensor array from a set of interchangeable modules. This system permits in-field reconfiguration of the array by providing modules that are easy to connect and disconnect.

[0020] Having different modules with varying amounts of sensors allows different sensor spacing along a towed array. The configurable sensor spacing can provide different signal frequency acquisitions for different applications during an array deployment.

[0021] In addition, this modularity facilitates comparatively rapid replacement of malfunctioning components. Some embodiments provide a capability to tailor a towed acoustic array to a particular mission without the need for specialized manufacturing facilities.

[0022] Referring now to **FIG. 1**, a sensor array system **100** along with a plurality of circuit boards **130** is shown according to an embodiment of the present invention. The array system **100** is submersible and configured for towing behind a marine vessel. In an exemplary embodiment, the system **100** includes a plurality of sensor array modules **110a**, **110b**, **110c**, and **110d** (generally referred to as a sensor array module **110**). Although four sensor array modules are shown; it will be understood that any number of sensor array modules can be connected together to form the system **100**.

[0023] The structure of each sensor array module **110** allows one sensor array module to be connectable to another sensor array module. The sensor array modules **110** each include a submersible, flexible waterproof hose **115** configured to encompass electronics within. In an exemplary embodiment, the hose **115** is less than 100 feet long. Typically, the hose **115** is between 5 and 50 feet in length - depending on the application.

[0024] The sensor array modules **110** each include an electrical connector **160** on either or both ends of the hose **115**. Regardless of the length of the system **100**; the end of the last sensor array module **110** away from the towing vessel would be covered with a cap (not shown). The connector **160** is waterproof; thereby, providing a seal that protects the interior of the hose **115**. For example, a glass reinforced epoxy (GRE) underwater dry-mate connector may be used.

[0025] Each pair of connectors **160** mates at an interface **162** with the connector having a male end **164** and a female end **166.** The male end **164** contains male electrical pins **164a** and the female end **166** contains female electrical pins **166a.** O-rings **168** seal where the pins **164a, 166a** meet to prevent fluid from contacting the pins when submerged. There is a locking sleeve **170** that screws into threads on the male end **164.** Once the male end **164** and the female end **166** are mated, the locking sleeve **170** is screwed onto the threads; thereby, providing an effective means of keeping the ends locked together.

[0026] The electrical connector **160** may be universally compatible between sensor array modules. An electrical bus **150** is disposed within the hose **115** for connecting one electrical connector **160** on one end of the hose to another electrical connector on the other end of the hose.

[0027] The sensor array modules **110** include an acoustic sensor(s) **120.** In some embodiments, the acoustic sensor(s) **120** are configured to provide Sound Navigation and Ranging (SONAR) detection. The acoustic sensor **120** is connected to the electrical bus **150.** The acoustic sensor **120** is also connected to the circuit board **130** that is also connected to the electrical bus **150.**

[0028] Signals sent along the electrical bus **150** are connected to one or more inputs of the circuit board **130.** The circuit board **130** amplifies and filters signals from the acoustic sensor(s) **120** by using analog circuitry. The circuit board **130** receives digital values from an ADC (analog to digital conversion) function and broadcasts the values over the electrical bus **150** so that the values can be received by onboard electronics.

[0029] The modularity of the system **100** allows for configuring the sensor array modules **110** to receive various signal frequencies. For example, the module **110** may include one to four acoustic sensors **120** per the circuit board **130**. When the module **110** includes more than one acoustic sensor **120**; adjacent acoustic sensors are spaced apart at a fixed distance "d/n" where wherein n is an integer $\neq 0$. For example, the sensor array module **110b** shows two acoustic sensors **120** spaced apart at distance d. The sensor module **110c**, connected to the sensor array module **110b**, may include four acoustic sensors **120** spaced apart from one another at distance d/n wherein $n \neq 1$ or 0.

[0030] In the exemplary embodiment shown for the sensor array module **110c**; the four acoustic sensors **120** are spaced apart from one another at distance d/3. Thus, within the same system **100**, signals from various sources are detected by different sensor array modules **110**.

[0031] Embodiments of the present invention thus provide a sensor array system **100** that may be divided into regions of differing sensor spacing (also known as nested arrays). An exemplary embodiment of a sensor array system **100** may have thirty-two channels at a first spacing followed by thirty-two channels at a second spacing.

[0032] While the foregoing has been described in terms of fixed sensor spacing, it will be understood that other configurations may be assembled. For example, the modularity of the system **100** allows for some sensor array modules **110** in the system to include acoustic sensors **120** positioned with unequal spacing or with spacing biased to one end of the hose **115.**

[0033] In another exemplary embodiment, the sensor array module **110** is configured to maintain acoustic sensor spacing between adjacent hoses **115.** For example, the width of two mated electrical connectors **160** may be adapted so that distance of an acoustic sensor **120** closest to one of the electrical connectors is spaced at distance d/2. As shown, the array module **110a** is mated to the array module **110b** at an interface **162.**

[0034] Acoustic sensor **120′** of the sensor array module **110a** is closest to the interface **162.** In the module **110b,** acoustic sensor **120′′** is closest to the interface **162.** Acoustic sensors **120′** and **120′′** are each spaced at a distance d/2 from the interface **162.** Thus, when the sensor array modules **110a** and

110b are mated; the distance between the acoustic sensor **120′** and the acoustic sensor **120′′** is d. For applications benefitting from fixed sensor spacing; the sensor spacing remains the same when swapping in new sensor array modules **110.**

[0035] The sensor array modules **110** may include non-acoustic sensors **140.** The non-acoustic sensors **140** may be for geographic heading, depth, temperature, vibration, and to measure pitch and roll. The non-acoustic sensors **140** are connected to the circuit board **130** via the electrical bus **150.** In some embodiments, the non-acoustic sensors **140** are connected to one or more of the acoustic sensors **120.** Some sensor array modules **110** include the non-acoustic sensors **140** without the acoustic sensors **120** present (for example: sensor array module **110d**).

[0036] In some embodiments, the non-acoustic sensors **140** may be positioned at differing points in the hose **115.** For example, the non-acoustic sensor **140** in the sensor array module **110c** may be positioned at a first distance from the electrical connector **160′′** while the non-acoustic sensor **140** (nearest electrical connector **160′**) in the sensor array module **110b** may be positioned at a second distance from the electrical connector **160′.**

[0037] The modularity configuration of the non-acoustic sensors **140** allows non-acoustic sensor positions to be determined and adjusted. This configuration is useful when evaluating new processing algorithms by comparing performance between varying quantities and positions of the non-acoustic sensors **140**. For example, array shape estimation capability versus the number of heading and depth sensors used can be determined by swapping out sensor array modules **110** of differing acoustic sensor **120** and non-acoustic sensor **140** configurations.

[0038] In operation, the system **100** provides versatility and ease of re-configuration. Sensor configurations can be selected and modified by disconnecting and connecting compatible sensor array modules **110** at universally compatible connectors outside of specialized towed array assembly facilities. Spare array modules **110** can be inserted into the system **100** without the need to open up and repair individual internal components.

[0039] Referring to **FIG. 2**, a method **200** of swapping sensor array modules in a towed sensor array system is shown. In the method, a target SONAR frequency is determined **(210)**. As an example, the target SONAR frequency may be up to 1 kHz. The SONAR sensor spacing needed for acquiring the target frequency is determined **(220)**. The spacing is set [for example: to one-half of the wavelength of the target frequency wherein the wavelength = (speed of sound in water)/(frequency in Hz)]. For example, a sound speed of 4500 ft/sec and a 1 kHz signal has a 4.5 foot wavelength and therefore 2.25 foot sensor spacing.

[0040] The spacing of acoustic sensors in a first sensor array module is identified **(230)**. In some embodiments, the spacing of the acoustic sensors is known (e.g., either by a reference chart or labeling on the hose). The position of non-acoustic sensors in the first sensor array module is identified **(240)** (e.g., either by a reference chart or labeling on the hose).

[0041] A second sensor array module is identified **(250)**. The second sensor array module has acoustic sensor spacing (a second distance) that complements the spacing of the acoustic sensors in the first sensor array module so that an aggregate spacing of the first acoustic sensors and the second acoustic sensors corresponds to the determined acoustic sensor spacing. The position of non-acoustic sensors in the second sensor array module is identified **(260)** (e.g., either by a reference chart or labeling on the hose). The first and second sensor array modules are connected **(270)** so that the aggregate spacing corresponds to the sensor spacing needed for the target frequency.

[0042] **FIG. 3** is a cross-sectional view of the interface **162** of the array modules **110a, 110b**. In the figure, the male electrical pins **164a** connect to the female electrical pins **166a**. A connector insert **180** can be added to protect the electrical pins **164a, 166a**. The insert **180** is a cylindrical piece of plastic or another non-conductive material that can be customized to the number of electrical pins needed for a particular application. The electrical pins **164a**, **166a** connect to the electrical bus **150**.

[0043] It will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

[0044] The foregoing description of the preferred embodiments of the invention has been presented for purposes of illustration and description only. It is not intended to be exhaustive nor to limit the invention to the precise form disclosed; and obviously many modifications and variations are possible in light of the above teaching. Such modifications and variations that may be apparent to a person skilled in the art are intended to be included within the scope of this invention as defined by the accompanying claims.

ABSTRACT OF THE DISCLOSURE

A sensor system and method of use is provided with at least one sensor array module in which the at least one sensor array can be removed and reinstalled for maintenance ad reconfiguration of components within the module. Each array module includes a submersible hose, an electrical bus connected between ends of the hose, acoustic sensors spaced apart from one another at a distance along the electrical bus, and an electrical connector on each end of the hose. Each array module can also contain non-acoustic sensors and other supporting electronic components.

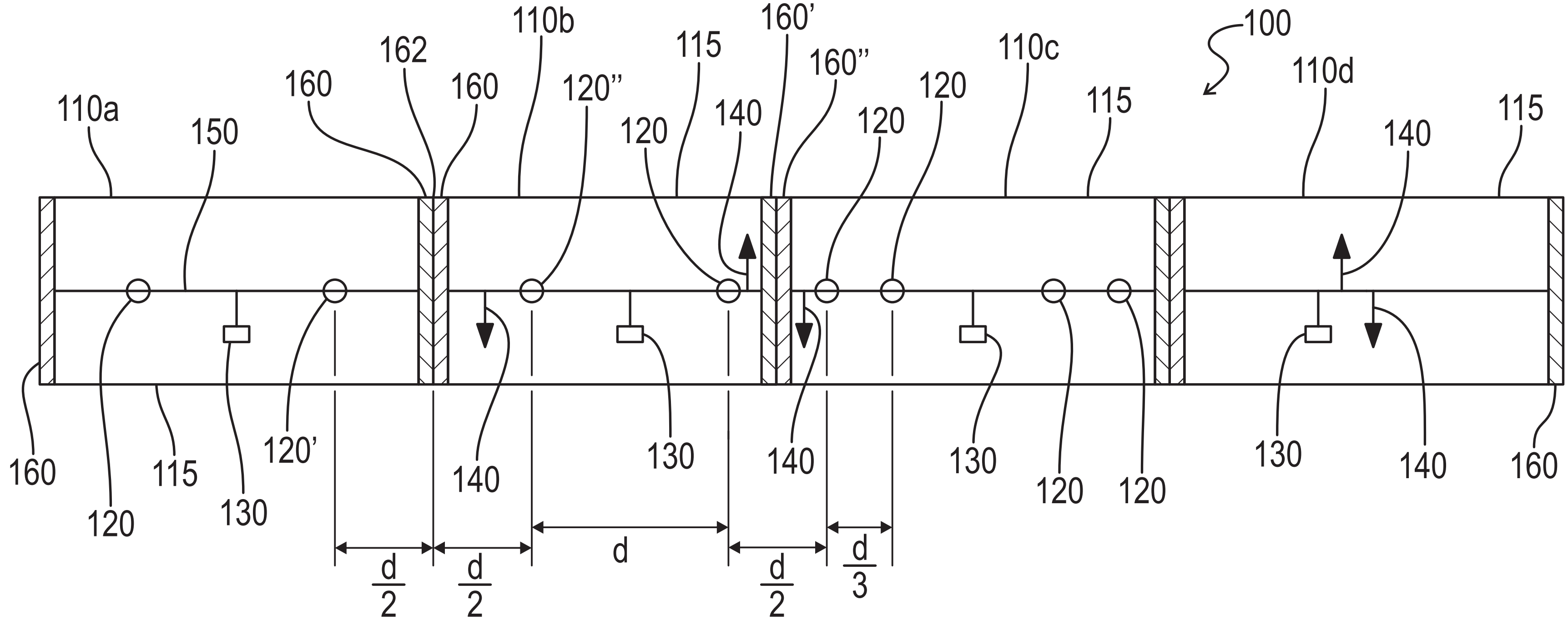
100
110a
110b
110c
110d
115
115
115
115
115
150
160
162
160
160'
160''
160
160
120
120'
120''
120
120
120
120
120
130
130
130
130
140
140
140
140
140
d/2
d/2
d
d/2
d/3

FIG. 1

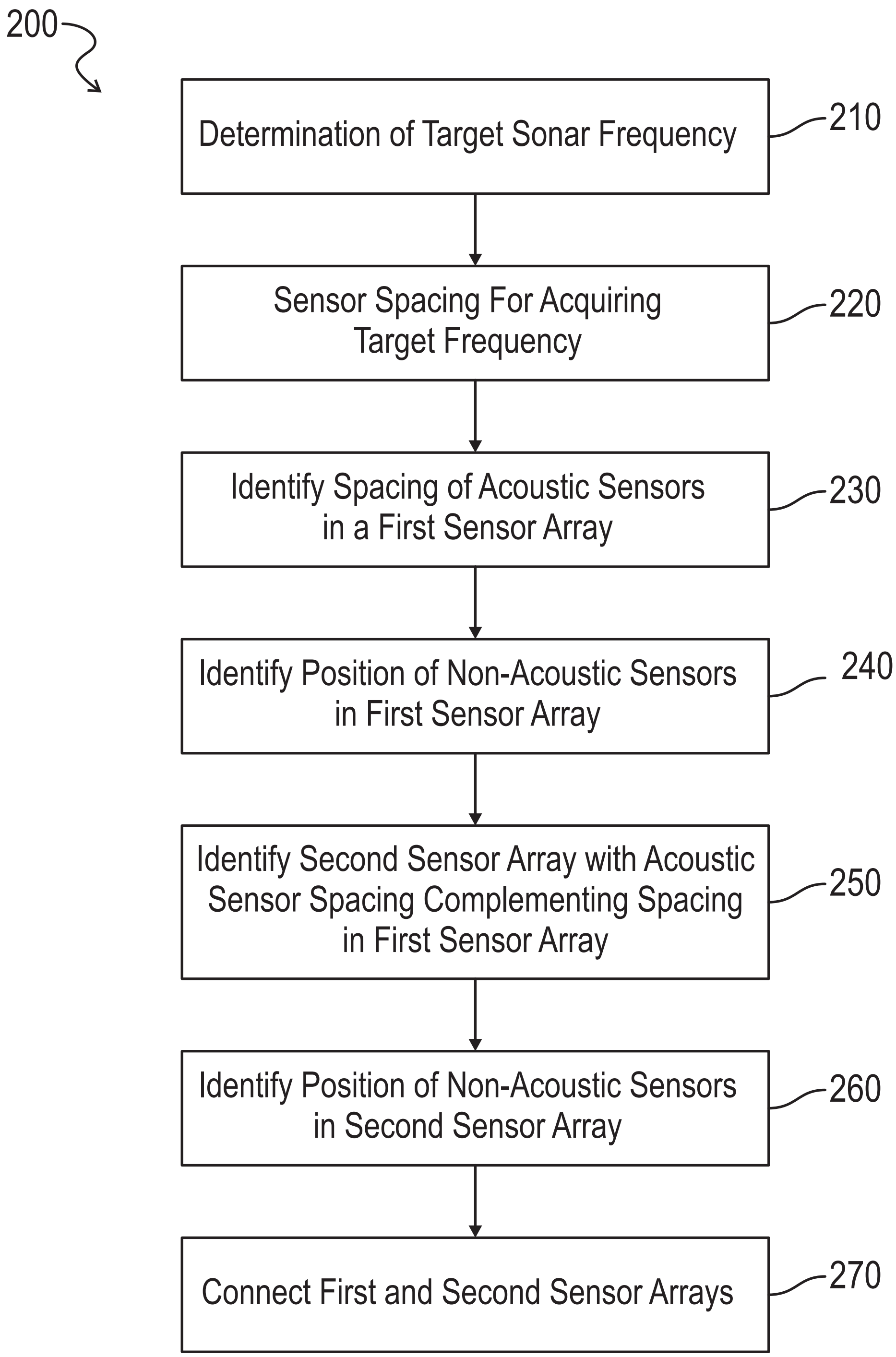
200
Determination of Target Sonar Frequency
210
Sensor Spacing For Acquiring Target Frequency
220
Identify Spacing of Acoustic Sensors in a First Sensor Array
230
Identify Position of Non-Acoustic Sensors in First Sensor Array
240
Identify Second Sensor Array with Acoustic Sensor Spacing Complementing Spacing in First Sensor Array
250
Identify Position of Non-Acoustic Sensors in Second Sensor Array
260
Connect First and Second Sensor Arrays
270

FIG. 2

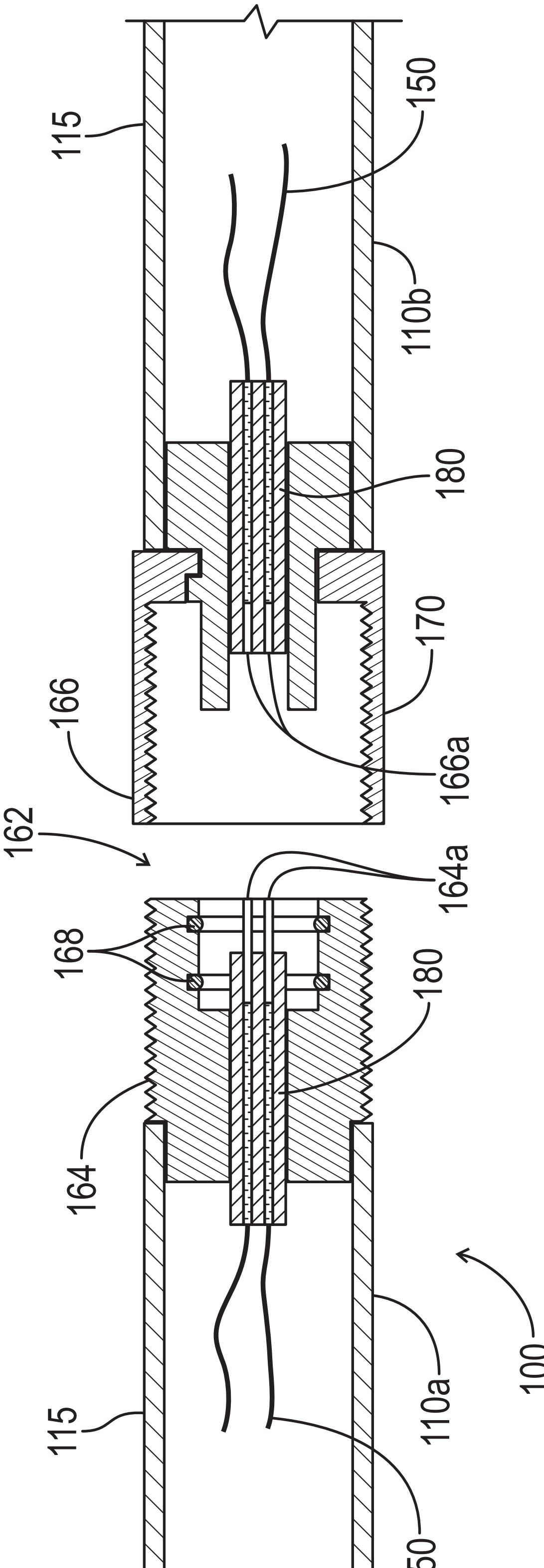
115
150
110b
180
170
166
166a
162
164a
168
180
164
100
110a
115
150

FIG. 3