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Attorney Docket No. 85027

DEPLOYMENT SYSTEM FOR FIBER-OPTIC LINE SENSORS

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 RELATED APPLICATION

[0002] None.

BACKGROUND OF INVENTION

1) Field of the Invention

[0003] The present invention is directed to underwater fiber optic sensors and in particular to deployment systems for the fiber optic sensors.

2) Description of Prior Art

[0004] Fiber optics and fiber optic sensors can be used as an alternative or replacement for traditional sensors to measure rotation, acceleration, electric and magnetic field measurement, temperature, pressure, acoustics, vibration, linear and angular position, strain, humidity and viscosity among other measurements. Fiber optic sensors are lightweight, small, passive, low powered, resistant to electromagnetic interference, high sensitivity, wide bandwidth and environmentally rugged. These sensors can be used in harsh environments including underwater environments such as the ocean floor. This compatibility of optical sensors within a harsh marine environment creates opportunities to use fiber optic sensors for tactical or reconnaissance applications.

[0005] For example, a long fiber optic sensor deployed along the ocean floor for several miles can be used to monitor submarine traffic covertly leaving an enemy port. Any submarine that passes over the fiber optic sensor is detected. This presence is communicated through an antenna section to distant command groups. However, a need still exists for a deployment system that can reliably deploy the fiber optic sensor.

SUMMARY OF THE INVENTION

[0006] A system and method in accordance with exemplary embodiments of the present invention are directed to underwater deployment systems for fiber optic line sensors.

[0007] The deployment system of the present invention positions fiber optic line sensors within littoral environments.

Once positioned, the line sensors remain in their deployed positions for extended periods of time.

[0008] The deployment system includes a buoyant antenna section in communication with a control electronics section. The antenna of the antenna section is used to transmit signals from the fiber optic line sensors.

[0009] In one embodiment, the deployment system works in combination with a large Unmanned Underwater Vehicle (UUV) to deliver the fiber optic sensor to the desired location. Once the UUV is positioned in the desired location, the UUV signals a linear actuator to trigger two quick release devices. The first quick release device is on the antenna section and the second quick release device is on the electronic canister section. The electronic canister section includes control electronics and a power supply for the fiber optic line sensor.

[0010] Using the first and second quick release devices, both sections would then separate from the large UUV. As the two sections combined are negatively buoyant, these sections fall away from the large UUV. After the two sections have fallen a safe distance from the UUV (which is equal to the length of a retractable lanyard disposed between the two sections and the UUV); a spring band disposed between the two sections is released. Releasing the spring band allows the buoyant antenna section to separate from the electronics canister. The electronics canister continues falling toward the seafloor and the antenna section rises to the surface.

[0011] The electronics canister eventually comes to rest on the seafloor. The fiber optic line sensor remains disposed between the electronics canister that is now resting on the seafloor and the UUV. The UUV moves away from the electronics canister in accordance with a pre-determined pattern to deploy the fiber optic line sensor along that pattern.

[0012] Once deployed, the system remains in a standby position. When a submarine passes over the sensor, a pressure signal is detected by the deployed fiber optic line sensor. The pressure signal is processed by the electronics in the electronics canister. The resulting information is relayed to a central location via the buoyant antenna section.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] A more complete understanding of the invention and many of the attendant advantages thereto will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein like reference numerals and symbols designate identical or corresponding parts throughout the several views and wherein:

[0014] **FIG. 1** is side view of an embodiment of a deployment system in accordance with the present invention in which the view includes an unmanned undersea vehicle;

[0015] **FIG. 2** is a cross-section view of the three sections of the deployment system;

[0016] **FIG. 3** is a perspective cross-section view of the three sections of the deployment system;

[0017] **FIG. 4** is a front perspective view of an embodiment of a protective cover for use in the deployment system;

[0018] **FIG. 5** is a front perspective view of an embodiment of an end plate for use in the deployment system;

[0019] **FIG. 6** is a front perspective view of an embodiment of an internal plate for use in the deployment system;

[0020] **FIG. 7** is a front perspective view of an embodiment of an end cover for use in the deployment system;

[0021] **FIG. 8** is a top perspective view of an embodiment of a section support band for use in the deployment system;

[0022] **FIG. 9** is a perspective view of an embodiment of a quick release shackle attached to the section support band;

[0023] **FIG. 10** is a perspective view of an embodiment of a quick release shackle;

[0024] **FIG. 11** is a side view illustrating the release of the buoy antenna section and electronics canister section from the launch vehicle;

[0025] **FIG. 12** is a side view illustrating the triggering of the spring band by the retractable lanyard;

[0026] **FIG. 13** is a side view illustrating the separation of the sections and deployment of the fiber optic line sensor; and

[0027] **FIG. 14** is side view illustrating the continued deployment of the fiber optic line sensor.

DETAILED DESCRIPTION OF THE INVENTION

[0028] Referring initially to **FIGS. 1-3**, an exemplary embodiment of a deployment system for a fiber optic line sensor arranged for use with a UUV is illustrated. The deployment system includes three sections, a buoy antenna section **102**, an electronics canister section **104** and a "fishline" spool section **106**. The antenna section **102** contains an antenna **202** that is used to transmit detection signals to a monitoring station, for example, a localized Navy command group. The antenna section **102** is positively buoyant such that the antenna section will float to the surface of a body of water.

[0029] In one embodiment, the antenna section **102** is generally cylindrical and one end of the antenna section is in contact with the electronics canister section **104**. The antenna section **102** in combination with the electronics canister section **104** is negatively buoyant because the electronics canister section is more negatively buoyant than the antenna section is positively buoyant.

[0030] During transport and at initial deployment, the antenna section **102** is securely attached to the electronics canister section **104**. Preferably, a breakaway interface is provided between the antenna section **102** and the electronics canister section **104**. In one embodiment, the breakaway interface is a circumferential spring band **108** that surrounds the interface joint between the cylindrical antenna section **102** and the cylindrical electronics canister section **104**. The spring band **108** secures the two sections together until triggered to spring open.

[0031] In one embodiment, the spring band **108** is triggered to spring open when the two connected sections drop a safe distance away from a launch vehicle **110**. In another embodiment, the launch vehicle **110** can be considered part of the deployment system.

[0032] In one embodiment, the deployment system includes a triggering mechanism **112** to trigger the spring band **108**. The triggering mechanism **112** can be a retractable lanyard or other suitable rigging that is secured between the launch vehicle **110** and the spring band **108**. The triggering mechanism **112** has a length sufficient to allow the antenna section **102** and the electronics canister section **104** to travel a safe distance from the launch vehicle **110** before the antenna section is separated from the electronics canister section.

[0033] Once the spring band **108** has been released by the triggering mechanism **112**, the buoyant antenna section **102** is free to ascend to the surface of the ocean while the electronics canister section **104** descends to the ocean floor. As the buoyant antenna section **102** ascends away from the electronics canister section **104**, a sufficient length of communications cable **204** or buoyant antenna cable is paid out between the two sections. The communication cable **204** is fixedly secured to both sections and is in communication with both the antenna **202** in the antenna section **102** and the control electronics **206** within the electronics canister section **104**. The antenna section **102** remains connected to the electronics canister section **104** through the communications cable **204**. Therefore, the communication cable **204** also serves as an anchor line for the antenna section **102**. The communication cable **204** has a sufficient length to reach the surface of the ocean when the electronics canister section **104** is on the ocean floor and a sufficient strength to hold the buoyant antenna section **102** in place against the force of wind, waves and ocean currents.

[0034] The electronics canister section **104** contains the control electronics **206** required to power and to operate the fiber optic line sensor **208** and to detect approaching vessels.

These control electronics include, but are not limited to, power supplies such as batteries, electronics, communication interfaces, memory devices, light sources and central processing units. The electronics canister section **104**, once deployed, also functions as an anchor for the buoyant antenna section **102** and the fiber optic line sensor **208**. In one embodiment, the electronics canister section **104** is cylindrical. Initially, one end of the electronics canister section **104** is in contact with an end of the antenna section **102** and is secured to the antenna section by the breakaway mechanism **108**.

[0035] The electronics canister section **104** is initially connected to the antenna section **102**. However, once the launch vehicle **110** releases the two sections, the sections will separate after achieving a safe distance from the large UUV. In one embodiment, separation is achieved by a combination of a mechanical spring band as the breakaway mechanism **108** and a retractable lanyard **112**. The electronics canister section **104** continues a descent until striking the ocean floor. As the electronics canister section **104** falls, the section draws the fiber optic line sensor **208** from a spool **210** located within the spool section **106**.

[0036] The electronics canister section **104** also includes two protective covers **212** located at either end of the electronics canister section. These protective covers include a first protective cover **214** between the electronics canister section **104** and the antenna section **102** and a second protective cover **216** between the electronics canister section **104** and the spool section **106**. The protective covers are visible on the outside and define the rounded shape of the two ends of the electronics canister section **104**.

[0037] Referring now to **FIG. 4**, each protective cover **212** is convex. The protective covers **212** are arranged to protect the delicate control electronics **206** contained inside the electronics canister section **104** as well as the fiber optic line sensor **208** and the buoyant antenna cable **204**. The protective covers **212** are constructed from a thin material (e.g. metal or plastic) which absorbs the shock of impact. The protective covers **212** can dent or deform without damaging any other components of the deployment system. The protective covers **212** are also generally circular to accommodate the cylindrical sections and include a central hole or aperture **402** to accommodate either the communications cable **204** or the fiber optic line sensor **208** - depending on the end of the electronics canister section **104** to which the cover is attached. A well **404** is disposed around the central hole **402** to prevent damage to the communications cable **204** or the fiber optic line sensor **208** when the electronics canister section **104** contacts the seafloor.

[0038] The wells **404** prevent the connectors from being bent if the canister section **104** lands on an end. The wells **404** also protect the fiber optic line sensor **208** and the cable **204** from being pinched or kinked. Each protective cover **212** includes a plurality of openings, apertures or holes **406** to allow water to flow freely through the protective cover. Attachment to the electronics canister section **104** can be provided by fasteners passed through a plurality of apertures or holes **408** in the protective cover **212**.

[0039] Returning to **FIG. 2** and **FIG. 3**, both ends of the electronics canister section **104** include an end plate **218** disposed between the ends of the electronics canister section and the protective covers. The end plates **218** provide the watertight seal for the electronics canister section **104**. The antenna cable **204** and the fiber optic line sensor **208** pass through the end plates **218** while maintaining the watertight seal.

[0040] Referring now to **FIG. 5**, an embodiment of the end plate **218** is illustrated. The end plate **218** is arranged as a circular flange to accommodate the cylindrical sections and includes a plurality of fastener apertures or holes **502** to attach to the end plate **218** of the electronics canister section **104**.

[0041] The spool section **106** can contain up to several miles of the fiber optic line sensor **208**, which is precision wound around a spool **210**. The fiber optic line sensor **208** is loosely wound to minimize the tensile load during deployment. In one embodiment, the spool section **106** is cylindrical.

[0042] The spool section **106** is free-flooded, so that seawater is allowed to flow freely in and out. One end of the spool section **106** is in contact with the electronics canister section **104** and includes an internal plate **220** disposed between the electronics canister section **104** and the spool **210**.

[0043] As illustrated in **FIG. 6**, the internal plate **220** includes a plurality of flow ports or apertures **604** to allow seawater to flow freely into the spool section **106**. In one embodiment, the internal plate **220** is circular and includes a central aperture **602** to allow passage of the fiber optic line sensor **208**.

[0044] The other end of the spool section **106** opposite the end in contact with the electronics canister section **104** includes an end cover **222**. Another end cover **222** is attached to the antenna section **102** on an end opposite the end attached to the electronics canister section **104**. As illustrated in **FIG. 7**, each end plate **222** is arranged as a convex cap on one end of the deployment system and includes a plurality of flange apertures

702 to be used in connecting the end cap to the appropriate sections.

[0045] In one embodiment, the fiber optic line sensor **208** may be wound with a weak binder to prevent the fiber optic line sensor from unraveling. Alternatively, the fiber optic line sensor **208** is freely wound. In another embodiment, the fiber optic line sensor **208** is pre-twisted or precision wound to ensure that the fiber optic line sensor pays out straight without tangles and loops along a length once the fiber optic line sensor is deployed on the seafloor.

[0046] In one embodiment, a winding drum is contained inside the spool section **106** to assist with and to contain the loose winding of the fiber optics when a binder is not used. In this situation, finger strips (not shown) are placed inside the winding drum to separate layers or rows of the concentrically coiled line sensor. As the fiber optic line sensor **208** deploys, the fiber optic line sensor pays out from the concentrically-coiled winding drum while moving back and forth similar to the operation of a fishing reel.

[0047] The electronics canister section **104**, the antenna section **102** and the spool section **106** are suspended beneath launch vehicles using at least one section support band **224** attached to each section. As illustrated in **FIG. 8**, each section support band **224** is arranged as a cylindrical sleeve that encircles a section of the deployment system and includes a plurality of fasteners **802** (for example, a plurality of nut and bolt fasteners) to constrict the band around the section and secure the section support band **224**. Supports run from the section support bands **224** to the launch vehicle **110**. These supports include quick release shackles **114** running between the launch vehicle **110** and the antenna section **102** and the electronics canister section **104** and one rigid mount **116** running between the launch vehicle and the spool section **106**.

[0048] Referring now to **FIGs. 9** and **10**, the two mechanical quick release shackles **114** are used to support the weight of the electronics canister section **104** and the antenna section **102** underneath the launch vehicle **110**. In one embodiment, each quick release shackle **114** is attached to one of the bolt fasteners **802**. Once the launch vehicle **110** reaches a designated location, a linear actuator attached to the launch vehicle pulls a cord that is attached to a release mechanism **902** on each one of the quick release shackles **114**. This pulling causes the two quick release shackles **114** to open. The quick release shackles **114** are activated at the same time, such that the assembly is simultaneously released at both points and falls away from the launch vehicle **110** in a generally straight and level fashion.

[0049] The rigid mount **116** is disposed between the spool section **106** and the launch vehicle **110** - for example, attaching to one of the bolt fasteners **802**. The rigid mount **116** does not release the spool section **106** from the launch vehicle **110** when the quick release shackles **114** release the electronics canister section **104** and the antenna section **102**. As the launch vehicle **110** moves away from the electronics canister section **104** that has been released from the launch vehicle and is resting on the ocean bottom, the spool section **106** moves along with the launch vehicle. This relative movement between the electronics canister section **104** and the spool section **106** dispenses the fiber optic line sensor **208**. The launch vehicle **110** travels in a predetermined pattern laying down the fiber optic line sensor **208** in accordance with that predetermined pattern. Once the launch vehicle **110** has traveled the full length of the fiber optic line sensor **208**, the free end of the fiber optic line sensor falls out of the spool section **106**. This disconnects the fiber optic line sensor **208** from the launch vehicle **110**. The launch vehicle **110** returns to the rendezvous point.

[0050] A loose interface is maintained between the electronics canister section **104** and the spool section **106** such that they are not rigidly connected. This allows the electronics canister section **104** and the antenna section **102** to freely separate from the spool section **106** and fall away from the launch vehicle **110** when the quick release shackles **114** are opened.

[0051] The curved shape of the protective cover **216** on the forward end of the electronics canister section **104** has another purpose. The curved shape of the protective cover **216** is used to force the electronics canister section **104** and antenna section **102** away from the spool section **106** as the protective cover falls away from the launch vehicle **110**. Because the protective cover **216** is curved, the cover extends inside of the spool section **106**. As such, the protective cover **216** cannot fall straight down. The protective cover **216** must push back and away as the protective cover falls away from the spool section **106**. By doing so, the fiber optic line sensor **208** is prevented from being sheared off as the electronics canister section **104** slides past the spool section **106**.

[0052] The fiber optic line sensor **208** is used to sense the pressure fluctuations that are created by a passing surface ship or submarine. The fiber optic line sensor **208** has a tensile strength that is strong enough to prevent the fiber optic line sensor from breaking under deployment tensile loads. The fiber optic line sensor **208** is also negatively buoyant such that the fiber optic line sensor will sink and pull out of the spool section **106** as the fiber optic line sensor falls to the seafloor.

[0053] The mechanical spring band **108** is used to connect the antenna section **102** to the electronics canister section **104**. In one embodiment, the mechanical spring band **108** is secured using a safety clip and lock. The spring band **108** is locked in place when the sections are assembled. The locks remain in place while the sections are being handled and loaded underneath the launch vehicle **110**. The locks are removed after the deployment system is prepared for final deployment. At that point, the safety clips prevent the spring bands **108** from releasing. The lanyard **112** removes the safety clips once the electronics canister section **104** and the antenna section **102** have fallen a predetermined distance from the launch vehicle **110**. The spring band **108** is then released. The release allows the antenna section **102** to separate from the electronics canister section **104** and ascend to the surface. The spring band **108** remains attached to the electronics canister section **104** at a hinge point.

[0054] Once the lanyard **112** has reached the end of its length, the lanyard will pull a safety clip (not shown) off the mechanical spring band **108**. Once the safety clip is removed, the lanyard **112** retracts back into a housing to avoid entanglement with the propulsion system of the launch vehicle **110**.

[0055] The launch vehicle **110** is capable of delivering the antenna section **102** and the electronics canister section **104** to a shallow water coastal environment. In addition, the launch vehicle **110** lays down the fiber optic line sensor **208** in a prescribed pattern. In one embodiment, the launch vehicle **110** includes a linear actuator (not shown) that is connected, via a cord, to the quick release shackles **114**. Once in position, the launch vehicle **110** operates the linear actuator and starts deploying the fiber optic line sensor **208**.

[0056] The deployment system of the present invention minimizes the tensile load placed on the fiber optic line sensor **208** by loosely winding the sensor and by using a weak binder. Other methods, which make use of a capstan, place much greater loads on the sensor. By deploying the fiber optic line sensor **208** from a loose winding, the tensile loads are limited to the strength of the binder and the comparatively small inertial loads created by the weight of the sensor **208**. The only other loads that are experienced by the sensor **208** are friction loads and water resistance loads.

[0057] Another operational advantage of the fiber optic deployment system is coastal accessibility. The fiber optic deployment system does not have to be deployed from surface ships or submarines that do not have access to shallow water coastal areas. The deployment system of the present invention can be used in areas as shallow as fifteen feet. The deployment system of the present invention can include a reflective coating on the exterior of sections to mirror the surroundings of the deployment system.

[0058] The deployment system of the present invention can be used with various launch vehicle platforms. The deployment system can be deployed from surface ships, small boats, helicopters, and planes, in addition to being deployed from a large UUV.

[0059] The ends of the electronic canister section **104** are arranged with protective covers. The protective covers act as a damage avoidance system and minimize shock loads during bottom impact. The protective covers also prevent the electronics canister section **104** from landing upright and vertical after deployment. In addition, the protective sections prevent the fiber optic line sensor **208** and the buoyant antenna cable from being pinched or damaged when the electronics canister section hits the seafloor.

[0060] When the launch vehicle is a large UUV, the quick release shackles **114** are actuated by a linear actuator and the lanyard **112** releases the spring band. A slight modification to these features may be necessary for some of the alternative deployment options. If the launch vehicle is a surface ship or craft, the quick release shackles **114** and lanyard **112** would not be necessary as the electronics canister section and buoy antenna section could be tossed over the side of the surface ship. The fishline spool section may be hung over the side. The ship would then pay out the fiber optic line sensor **208** in much the same way as the large UUV.

[0061] If the launch vehicle is an aircraft, the quick release shackles **114** and lanyard **112** would not be necessary. The electronics canister section **104** and the antenna section **102** could be thrown from the aircraft. The spool section **106** would remain with the aircraft in an analogous way as the large UUV.

[0062] The fiber optic sensor deployment system is arranged for containment inside a cylinder, which is compatible with all submarine torpedo tubes. In the submarine deployment application, no quick release shackles or lanyards would be necessary. The sections are deployed using the same weapon ejection system used for torpedoes. The spool section **106** would remain inside the torpedo tube while the antenna section **102** and electronics canister section **104** is ejected.

[0063] Referring to **FIGs. 11-14**, an embodiment of a deployment system in accordance with the present invention including an UUV is illustrated deploying the fiber optic line sensor **208**. Initially, the quick release shackles attached to the buoyant antenna section **102** and the electronics canister section **104** are triggered and these two sections fall away from the UUV. The lanyard attached to the UUV and the spring band extends and the electronics canister section **104** begins to pull the fiber optic line sensor **208** from the spool section **106**. The spool section **106** remains attached to the UUV by a fixed mount.

[0064] As shown in **FIG. 12**, when the lanyard **112** extends to a full length, the spring band **108** is opened. This allows the positively buoyant antenna section **102** to separate from the negatively buoyant electronics canister section **104**. The electronics canister section **104** falls to the ocean floor and the antenna section **102** continues to rise to the surface; thereby, extending a communication cable between the two sections (**FIG. 13**). The fiber optic line sensor **208** continues to dispense from the spool section **106** as the UUV moves away in accordance with a predefined path. The antenna section **102** reaches the surface where the antenna section can broadcast to a receiving station and the UUV follows the prescribed path until the length of the fiber optic line sensor **208** is dispensed (**FIG. 14**).

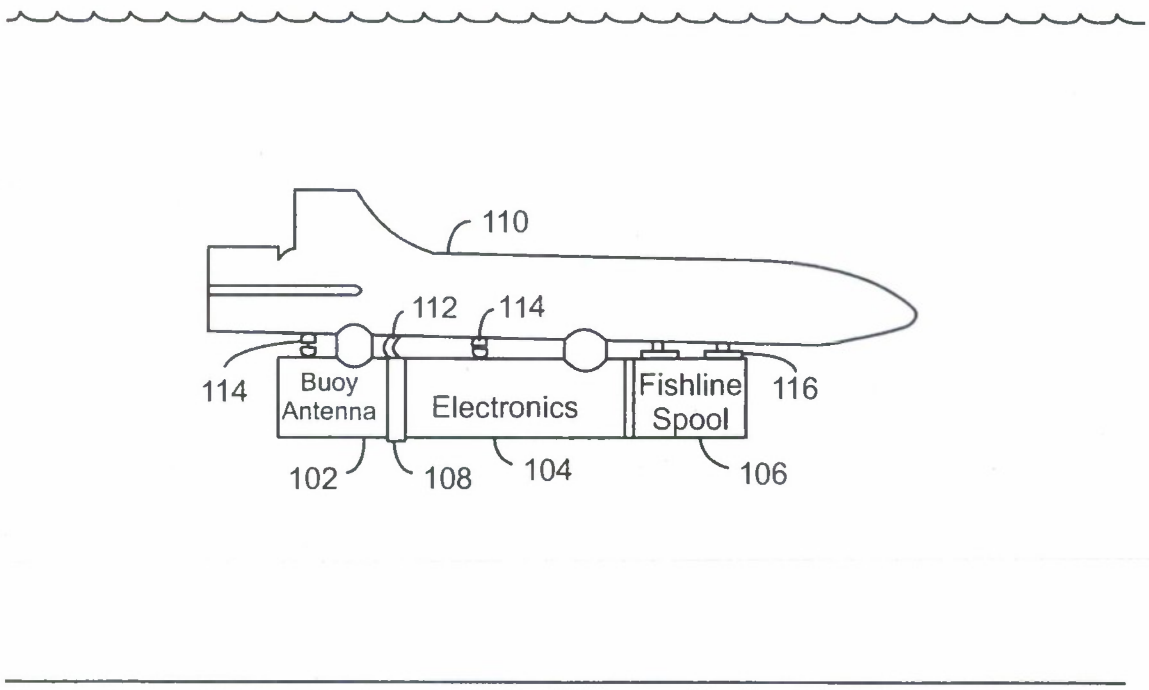
[0065] It will be understood that many additional changes in details, materials, steps, and arrangements of parts which have been described herein and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

Attorney Docket No. 85027

DEPLOYMENT SYSTEM FOR FIBER-OPTIC LINE SENSORS

ABSTRACT

A system for deploying a fiber optic line sensor is provided that includes a launch vehicle to which three sections are attached. The first section is a buoy antenna section. The second section is an electronics canister section having control electronics. These sections are releasably attached to the launch vehicle. The electronics canister section is in contact with the antenna section and secured to the antenna section by a spring band. A communications cable is attached between the antenna and the control electronics. The third section is a spool section containing a spool of a fiber optic line sensor. This third section is attached to the launch vehicle by a rigid mount and is in contact with the electronics canister section. The fiber optic line sensor extends from the spool section into the electronics canister section to the control electronics.


110
112
114
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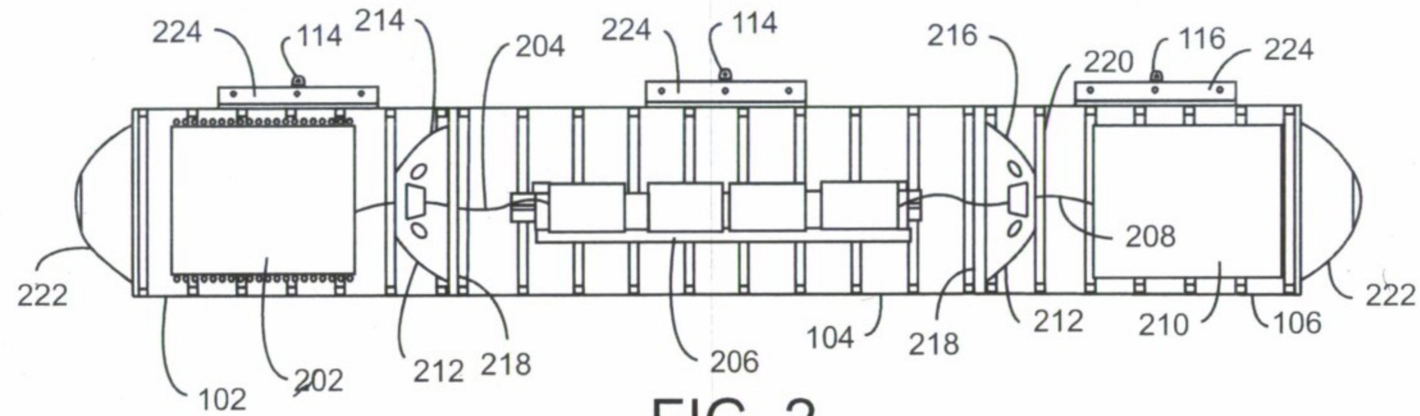
Buoy Antenna
Electronics
Fishline Spool
116
102
108
104
106

FIG. 1


224
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214
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FIG. 2

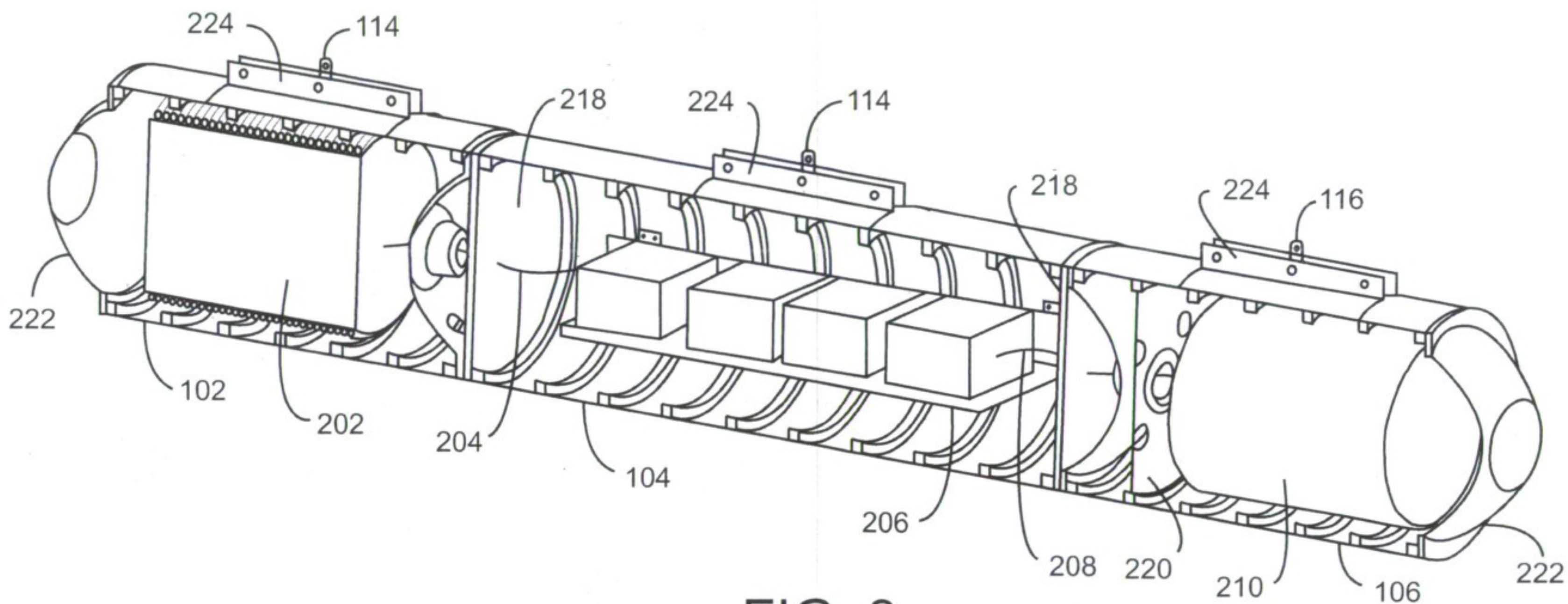
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FIG. 3

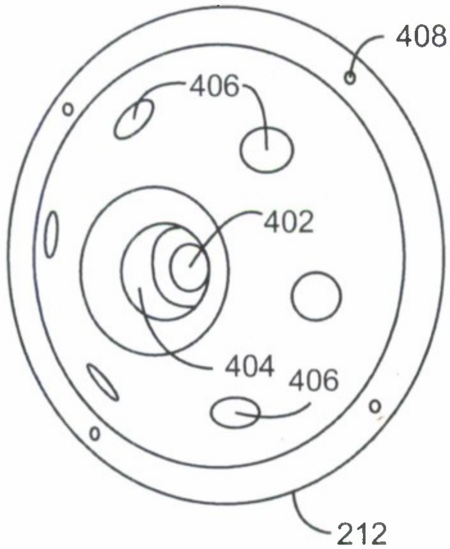


FIG. 4

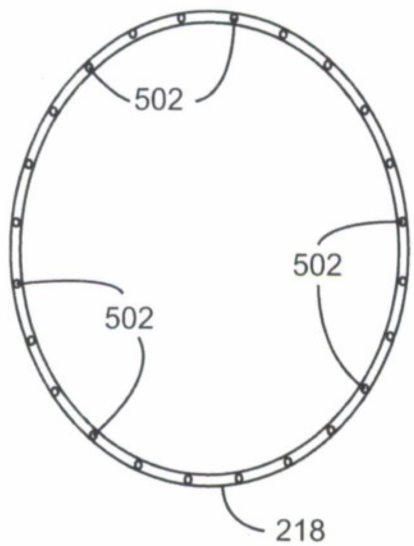


FIG. 5

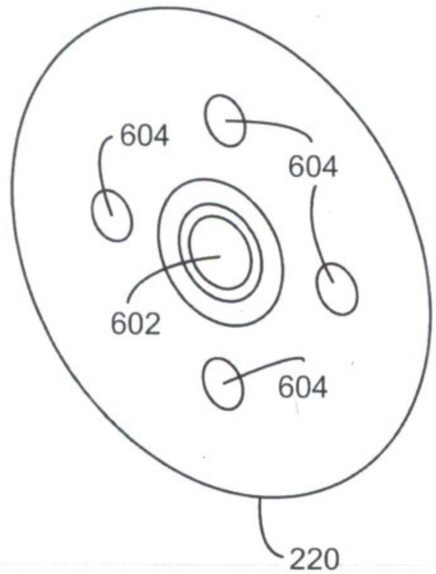


FIG. 6

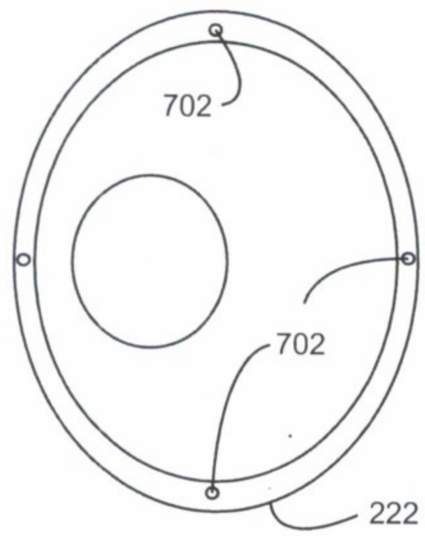


FIG. 7

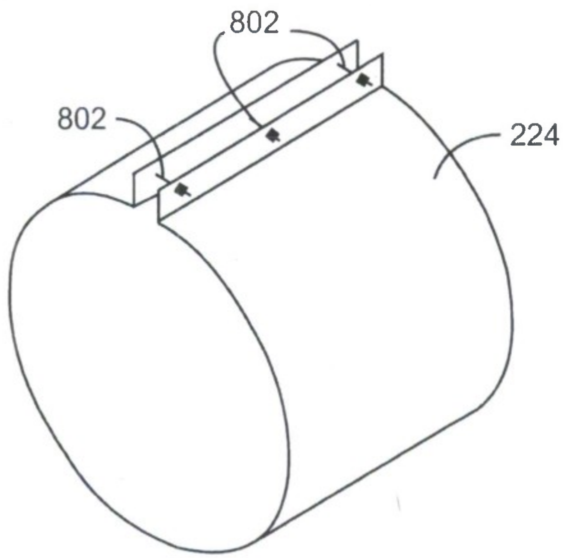


FIG. 8

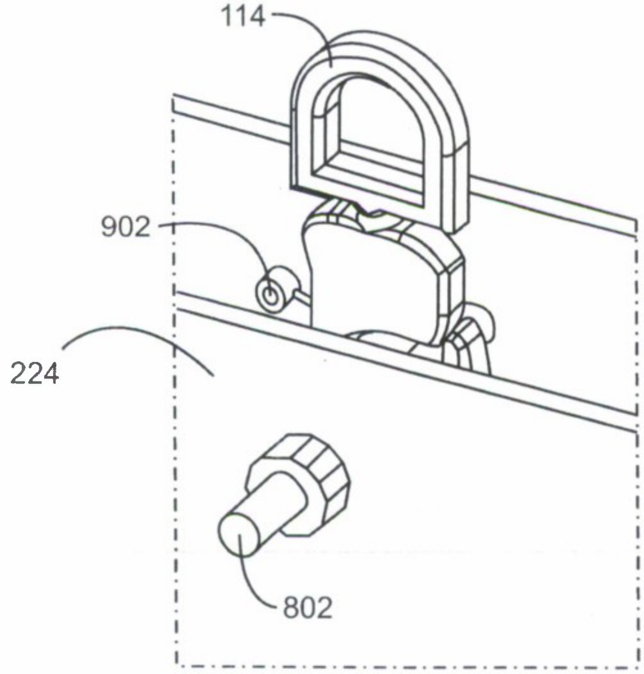


FIG. 9

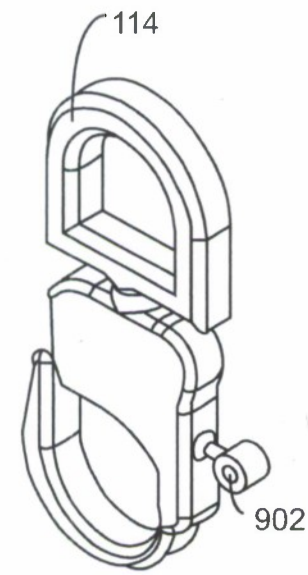
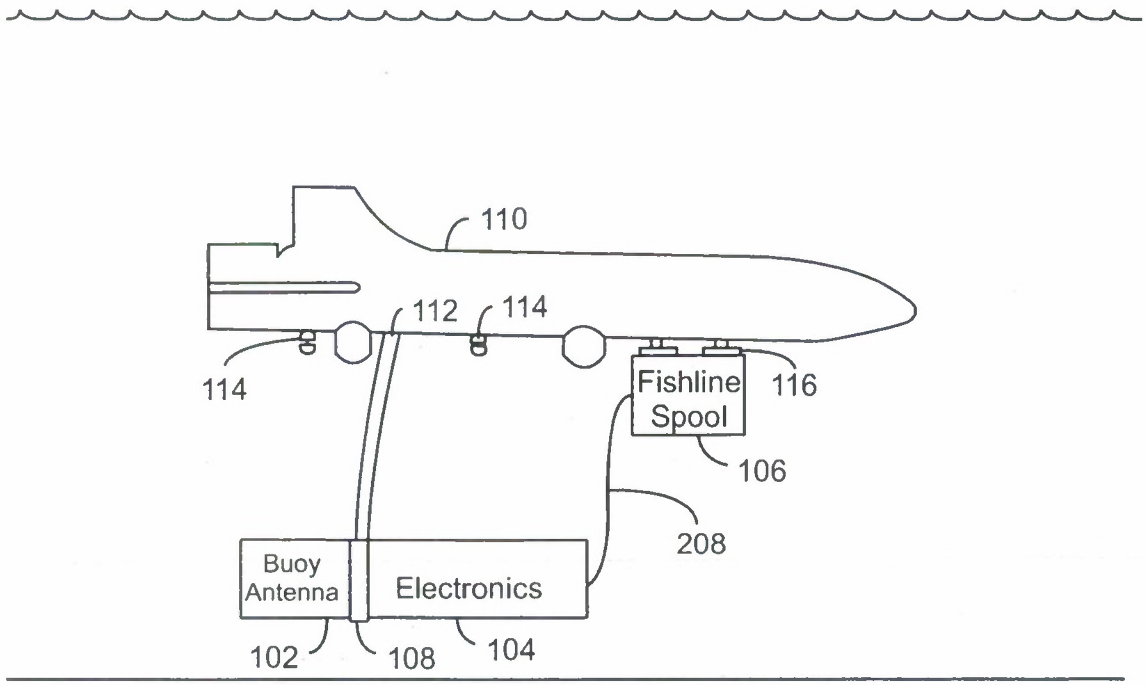


FIG. 10


110
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Fishline
Spool
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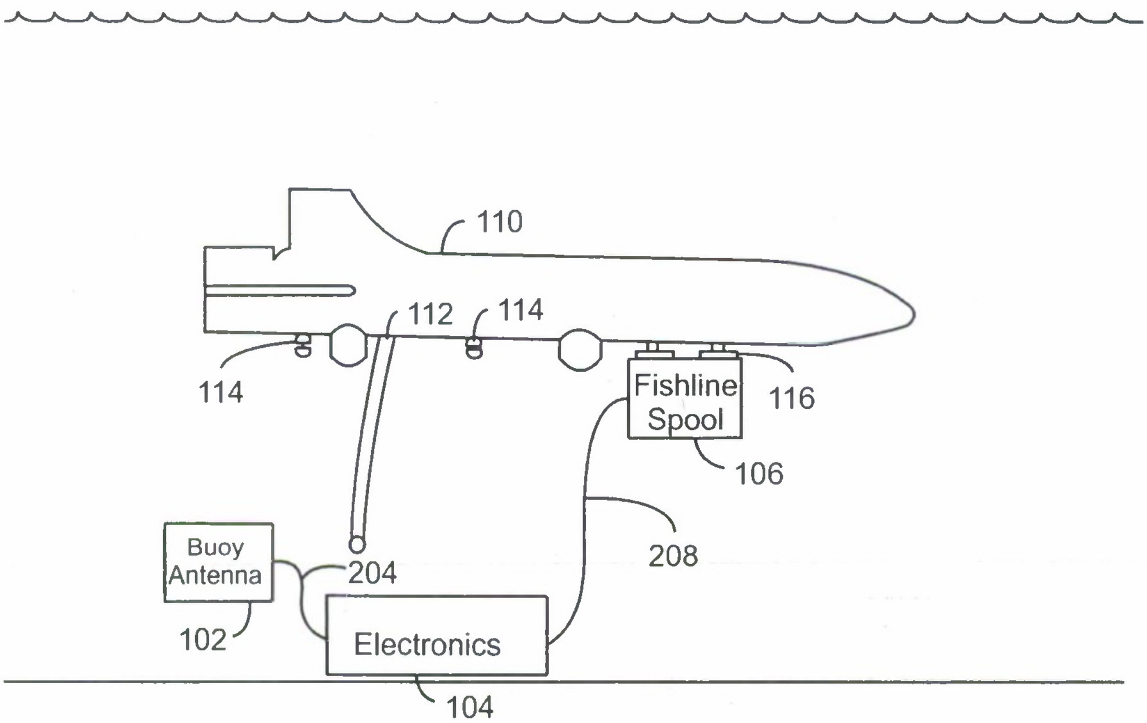
208
Buoy
Antenna
Electronics
102
108
104

FIG. 11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Fishline
Spool
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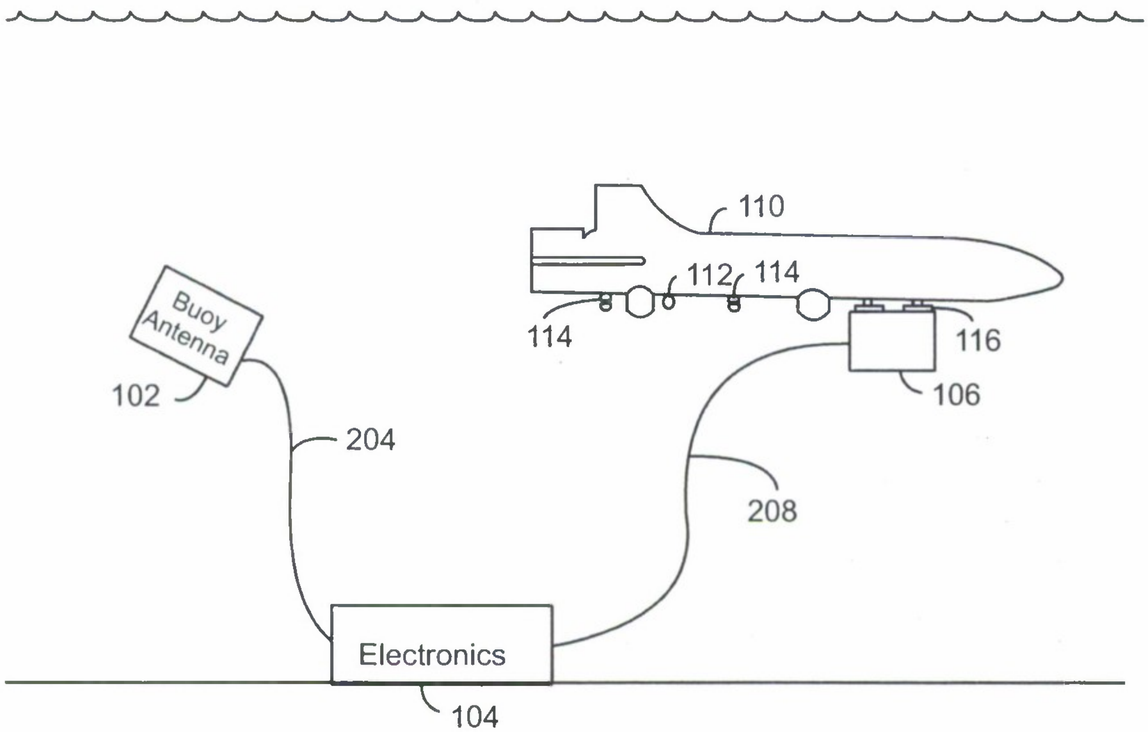
106
Buoy
Antenna
204
208
102
Electronics
104

FIG. 12


110
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Electronics
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FIG. 13

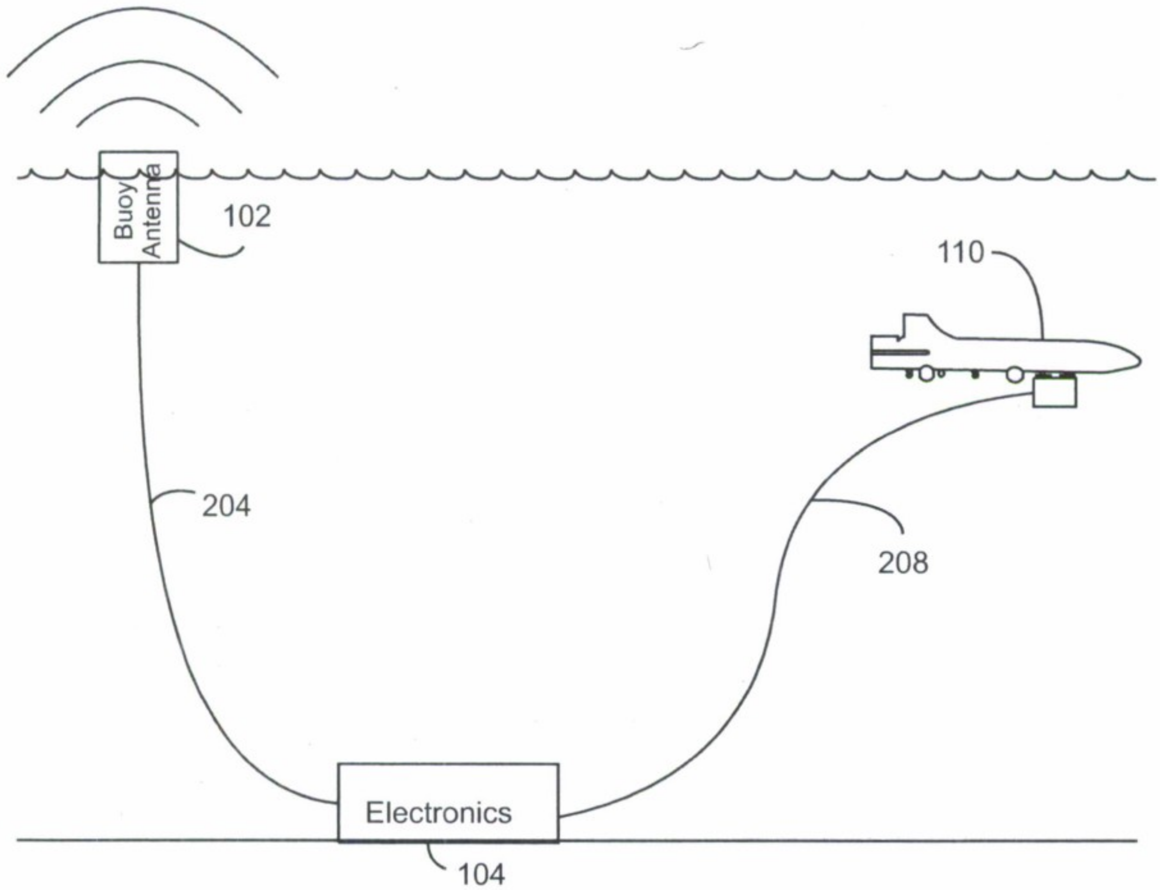

FIG. 14