



DEPARTMENT OF THE NAVY

OFFICE OF COUNSEL
NAVAL UNDERSEA WARFARE CENTER DIVISION
1176 HOWELL STREET NEWPORT RI 02841-1708

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TECHNOLOGY PARTNERSHIP OFFICE
NAVAL UNDERSEA WARFARE CENTER
1176 HOWELL ST.
CODE 00T2, BLDG. 102T
NEWPORT, RI 02841

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Inventor Jeffrey S. Hanson

Address any questions concerning this matter to the Technology Partnership Office at (401) 832-3339.

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TETHERED RECHARGING OF AUTONOMOUS UNDERWATER VEHICLES

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 is directed to autonomous underwater vehicles (AUVs) and is further directed to AUVs that recharge their battery using ocean currents.

(2) DESCRIPTION OF THE PRIOR ART

[0004] Autonomous Underwater Vehicles (AUVs) are well known and used in numerous subsea applications, most notably collecting bathymetric data and ocean bottom imaging by means of sensors carried aboard the AUV. As the name implies, these vehicles operate autonomously without pilots, unlike Remotely Operated Vehicles (ROVs), which typically include a coupled tether management system (TMS), as known in the art. Although AUVs may

have an acoustic communication mechanism for communication with a remote platform, essentially a mission plan is loaded into an onboard computer, the vehicle is lowered into the water, and it follows that mission plan to collect, utilize, and share bathymetric, geo-acoustic, and other oceanographic (chemical, biological, geological, and physical) data of interest.

[0005] In general, AUVs carry their own onboard power source such as batteries or fuel cells. The onboard power source powers the vehicle's propulsion, as well as onboard processors and instrumentation. For example, an AUV may operate energy demanding mechanical propulsion systems and guidance systems requiring high precision-high accuracy inertial measurement units (IMU), depth sensors, GPS, and altimeters. To minimize the power used for propulsion and maximize battery life, most AUVs are shaped like a torpedo, which minimizes the vehicle's drag in the water.

[0006] Once the AUV has been launched, there are limited options for charging the AUV. The most popular system for self-charging involves solar panels mounted on the AUV. Solar panel recharging requires the AUV to stay at the surface of the ocean until the charging is complete. Having to stay at the surface can cause issues for the vehicle, such as drift and theft. Solar AUVs (SAUVs) can use an anchor to avoid drift but that limits the operational area for the SAUV to shallow water and

does not eliminate the possibility of theft. Operating time is currently limited by the power resources.

[0007] There remains a need for a system that allows the AUV to recharge when deployed while remaining under the surface and not adrift.

SUMMARY OF INVENTION

[0008] It is a first object to provide a charging system for an underwater vehicle.

[0009] It is a second object that the charging system allow the vehicle to remain underwater in a fixed area while charging.

[0010] An autonomous underwater vehicle includes a device made up of a vehicle body including a bow region and a stern region. The vehicle body defines a cavity between the bow region and the stern region, and an anchor is disposed in the cavity. The anchor is attached to the vehicle body. Control surfaces are disposed between the bow region and the stern region and attached external to the vehicle. A turbine is disposed external to the vehicle at the stern region. A propulsion unit is disposed within the vehicle body. The propulsion unit is connected to the turbine. The propulsion unit and turbine generate a thrust force to propel the vehicle through an aquatic environment. A processor within the vehicle body controls the propulsion unit and the control surfaces. A power source in the

vehicle body provides power to the processor and the propulsion unit. When the processor detects that a power condition of the power source is below a threshold value, the propulsion unit is stopped, and the anchor is deployed. Movement of the vehicle is constrained by the tether. Interaction between the control surfaces and the environmental fluid flow allow the vehicle to be moved in a predetermined trajectory through the aquatic environment causing the turbine to rotate and recharge the power source.

[0011] According to another embodiment, an underwater system includes an autonomous underwater vehicle (AUV). The AUV has a body with a cavity. A deployable anchor is disposed in the cavity. The AUV also has a processor and a power source disposed in the vehicle body. The processor is connected to the power source. A propulsion unit is disposed in the vehicle body and also connected to the power source. A turbine is connected to the propulsion unit. The turbine is external to the vehicle body. Control surfaces are attached to the exterior of the vehicle body. The processor controls operation and navigation of the AUV through an aquatic environment. The propulsion unit generates a thrust force by the turbine to propel the AUV through the aquatic environment. The processor monitors charge status of the power source. Responsive to the processor detecting a power condition of the power source below a

threshold value, the processor deploys the anchor and controls the AUV in a predetermined trajectory through a fluid stream of the aquatic environment to recharge the power source.

[0012] According to a method of controlling an autonomous underwater vehicle, an autonomous underwater vehicle (AUV) is provided. The AUV includes a processor, a power source, a propulsion unit having a turbine external to the AUV, control surfaces, and a deployable anchor. The propulsion unit generates a thrust force by the turbine to propel the AUV through an aquatic environment. Responsive to the processor detecting a power condition of the power source below a threshold value, the speed of the AUV is reduced. The anchor is deployed. The control surfaces are operated to move the AUV in a predetermined trajectory through an environmental fluid stream wherein the turbine rotates and recharges the power source.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Other objects, features and advantages of the present invention will become apparent upon reference to the following description of the preferred embodiments and to the drawings, wherein corresponding reference characters indicate corresponding parts throughout the several views of the drawings and wherein:

[0014] **FIG. 1** illustrates an autonomous underwater vehicle (AUV) according to devices and methods herein;

[0015] **FIG. 2** shows a cut-away diagram of an aft portion of the autonomous underwater vehicle of **FIG. 1**;

[0016] **FIG. 3** illustrates an autonomous underwater vehicle at anchor according to devices and methods herein; and

[0017] **FIG. 4** illustrates a trajectory pattern for recharging an autonomous underwater vehicle according to devices and methods herein.

DETAILED DESCRIPTION OF THE INVENTION

[0018] A Tethered Undersea Kite (TUSK) self-charging AUV is disclosed that can recharge its battery using environmental currents. The TUSK AUV includes anchors, control surfaces, alternators (or other mechanical to electrical energy conversion devices), and control software to allow it to use the cross current motion of environmental currents to generate power that will recharge the battery. Using the cross current motion, the TUSK AUV can travel 2 to 16 times faster than the ocean current and generate electricity at a faster rate than if it were stationary.

[0019] Currently, AUV technology focuses on increased battery capacity or increased AUV efficiency to lengthen the assigned mission of the AUV. As presently enabled, all AUVs need to be

retrieved after use or need to reduce their functional range in order to return to home. The technology described herein allows the AUV to travel further, do more, and operate without human intervention for much longer.

[0020] Referring to the drawings, **FIG. 1** shows autonomous underwater vehicle (AUV), indicated generally as **100**. The AUV **100** is made up of a vehicle body **102** including a bow region **104** and a stern region **106**. Control surfaces **108** are disposed between the bow region **104** and the stern region **106** and located on opposite sides, external to the vehicle body **102**. The control surfaces **108** may include a rudder, fins, and/or wings that may interact with hydrodynamic flow to direct the movement of the AUV **100**. The AUV **100** may be shaped like a torpedo and, depending on the mission and depth rating, its length, girth, and weight can range quite broadly.

[0021] As shown in **FIG. 2**, a turbine **110** is disposed external to the vehicle body **102** at the stern region **106**. The turbine **110** may be any of a variety of propeller type devices or fan-like structures for efficiently moving a body through an aquatic environment. In some embodiments, the turbine may be a variable speed propeller and may be shrouded or unshrouded, as is known in the art. A propulsion unit **112** is disposed within the vehicle body **102**. The propulsion unit **112** is connected to the turbine **110** by a shaft **114**. In general, the propulsion unit **112**

may be an electric motor. The propulsion unit **112** and turbine **110** generate a thrust force to propel the AUV **100** through the environment. As described in further detail below, a charging device, such as an alternator **116**, may be operationally attached to the shaft **114**. Instead of using a separate propulsion unit **112** and alternator **116**, a combined motor/generator unit can be used. Alternator **116** can be mechanically coupled and uncoupled from shaft **114** by a clutch **117** joined to processor **118** so that it is not coupled to shaft **114** when not in use.

[0022] A processor **118** is disposed within the vehicle body **102** and controls the propulsion unit **112** and the control surfaces **108**. Any of the control surfaces **108** may be controlled independently by the processor **118**. In operation, a mission plan may be loaded to the processor **118**, and the processor **118** operates the control surfaces **108** to direct the movement of the AUV **100** so that the AUV **100** follows that mission plan through the environment, as controlled by the processor **118**. That is, the processor **118** uses hydrostatic forces of water moving over the control surfaces **108** to adjust the heading and/or depth of the AUV **100**.

[0023] A power source **120** is disposed within the vehicle body **102** and provides power to the processor **118**, the propulsion unit **112**, and instrumentation and controls for the AUV **100**. The power source **120** may be a battery, fuel cell, or other

rechargeable device having sufficient power and reserve for the duration of the mission plan. Further, in addition to controlling the operation of the AUV **100**, the processor **118** keeps track of the position of the AUV **100** and the condition of the power source **120** (i.e., charge level of the battery).

[0024] Referring to **FIG. 3**, the vehicle body **102** includes a cavity **122** disposed between the bow region **104** and the stern region **106**. An anchor **124** is disposed in the cavity **122**. The anchor **124** is attached to the vehicle body **102** by a tether **126**. Tether **126** is joined to a deployment and retrieval equipment **127** such as a winch controlled by processor **118**.

[0025] When the processor **118** determines that the power condition of the power source **120** is below a threshold value, the processor **118** operates the AUV **100** to recharge the power source **120**. The threshold value may be a voltage output level or a power output level of the power source **120**. It is known to measure a battery's charge state by knowing the battery voltage output and temperature. Processor **118** can compare the known capacity against a voltage curve to estimate the battery charge state. To recharge the power source **120**, the processor **118** may stop the propulsion unit **112** and deploy the anchor **124** using the deployment and retrieval equipment **127**. The processor **118** can then operate the control surfaces **108** to move the AUV **100** in a predetermined trajectory through a fluid stream of the

environment causing the turbine **110** to rotate, which rotates the shaft **114**. The alternator **116** rotates with the shaft **114**, passing conductors through a magnetic field, and generating alternating current (AC). The AC is then converted to DC to charge the power source **120** (e.g., battery). The operation of alternators is well known in the art and is not described further herein to maintain focus on the salient points.

[0026] During a mission, an AUV **100** may be expected to be operated in coastal seas where tidal currents and ocean currents are typically greater than those of the open ocean. For example, an energetic, tidally-driven current in the coastal ocean may have a power density of approximately 200 W/m. According to devices and methods herein, the energy of these currents can be harvested for recharging the AUV **100**, whereby the AUV **100** is temporarily tethered to the seafloor **128**. The resulting flow of fluid over the vehicle body **102** and through the turbine **110** drives the turbine **110** in reverse, spinning the alternator **116**, and generating energy to charge the onboard power source **120**. That is, while the AUV **100** travels through the water by motion of the ocean current, fluid flows through the turbine **110**, which causes the shaft **114** to rotate. The rotating shaft **114** causes the alternator **116** to generate electricity, which is used to power the power source **120**. The

AUV **100** may be held above the seafloor **128** using buoyancy or lift from the control surfaces **108**.

[0027] It has been determined that for a given turbine, greater power generation can be achieved by allowing the vehicle to undergo controlled motion. This leads to an increase in the relative (apparent) water speed over that of freestream speed and, when harnessed, can lead to greater rates of energy extraction when compared with a stationary vehicle. According to devices and methods herein, a dynamically tethered AUV **100** uses a drag-based approach for self-charging. That is, the power generation is integrated with the AUV **100** in the form of a turbine **110**. The AUV **100**, which contains a turbine **110**, is then operated in a trajectory that maximizes the apparent velocity to optimize power generation by the onboard turbine **110**. A common closed trajectory utilized in dynamically tethered kites is the figure eight pattern **130**, shown in **FIG. 4**. In other words, to increase the fluid flow traveling across the turbine **110**, the processor **118** operates the control surfaces **108** to perform a predetermined trajectory (e.g., figure eight pattern **130**) in the ocean. Academic research suggests that fluid flow can be increased by a factor of approximately 2 to 16 times ocean current speed.

[0028] Once the processor **118** determines that the power source **120** has been sufficiently recharged. The processor **118**

activates the retrieval equipment **127** to reel in the tether **126** and restore the anchor **124** to cavity **122**. In an alternative embodiment, the retrieval equipment **127** can detach the tether **126** from connection between the vehicle body **102** and the anchor **124**, abandoning the anchor **124** and tether **126**. Upon completion of the charging operation, the AUV **100** can then continue on its programmed mission.

[0029] 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.

[0030] The invention has been described with references to specific embodiments. While particular values, relationships, materials, and steps have been set forth for purposes of describing concepts of the present disclosure, it will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the disclosed embodiments without departing from the spirit or scope of the basic concepts and operating principles of the invention as broadly described. It should be recognized that, in the light of the above teachings, those skilled in the art could modify those specifics without departing from the

invention taught herein. Having now fully set forth certain embodiments and modifications of the concept underlying the present disclosure, various other embodiments as well as potential variations and modifications of the embodiments shown and described herein will obviously occur to those skilled in the art upon becoming familiar with such underlying concept. It is intended to include all such modifications, alternatives, and other embodiments insofar as they come within the scope of the appended claims or equivalents thereof. It should be understood, therefore, that the invention might be practiced otherwise than as specifically set forth herein. Consequently, the present embodiments are to be considered in all respects as illustrative and not restrictive.

TETHERED RECHARGING OF AUTONOMOUS UNDERWATER VEHICLES

ABSTRACT OF THE DISCLOSURE

An autonomous underwater vehicle includes a vehicle body controlled by a processor. An anchor joined to a tether is disposed in the vehicle. The vehicle has control surfaces for maneuvering, a propulsion unit, and a turbine. The propulsion unit and turbine generate thrust to propel the vehicle. A power source provides power to the vehicle. The turbine is further joined to a generator. When the processor detects that the power source is below a threshold value, the propulsion unit is stopped, the anchor is deployed, and the control surfaces are operated to move the vehicle in a predetermined trajectory through a fluid stream of the environment restrained by the tether. The fluid stream causes rotation of the turbine and generator to recharge the power source.

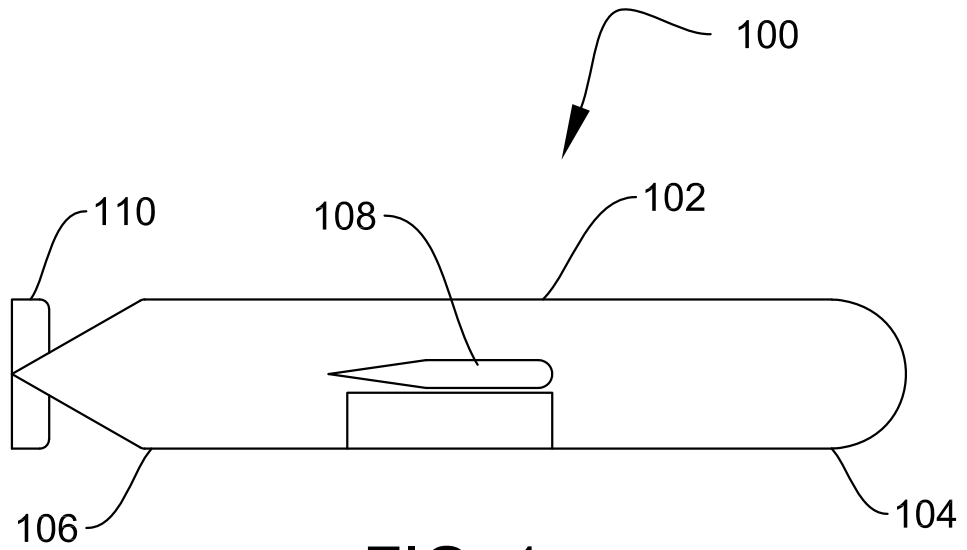


FIG. 1

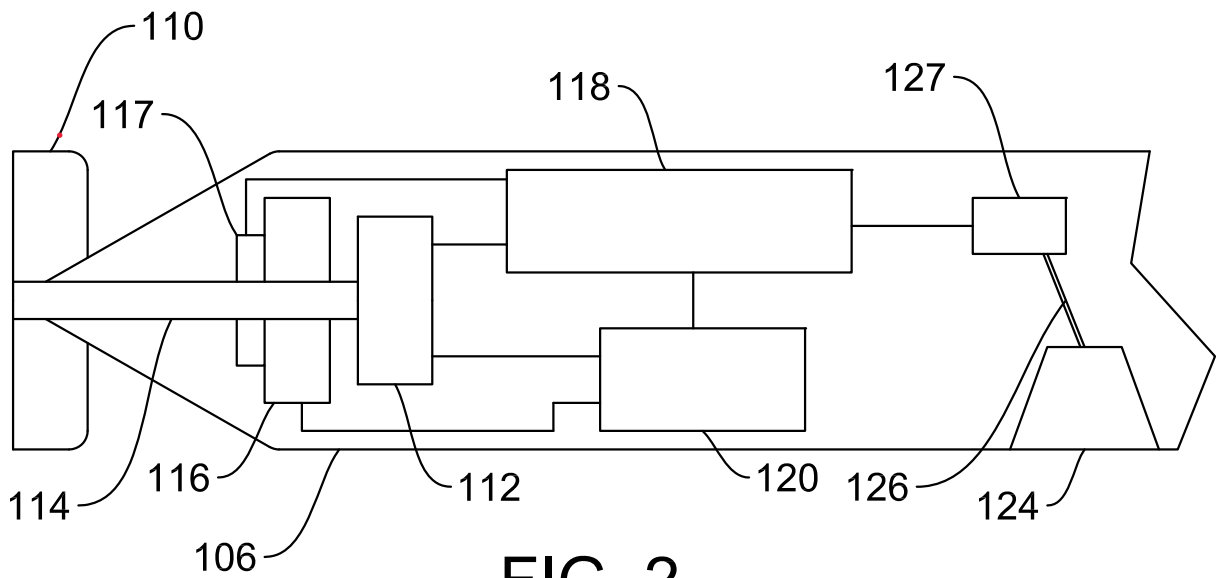


FIG. 2

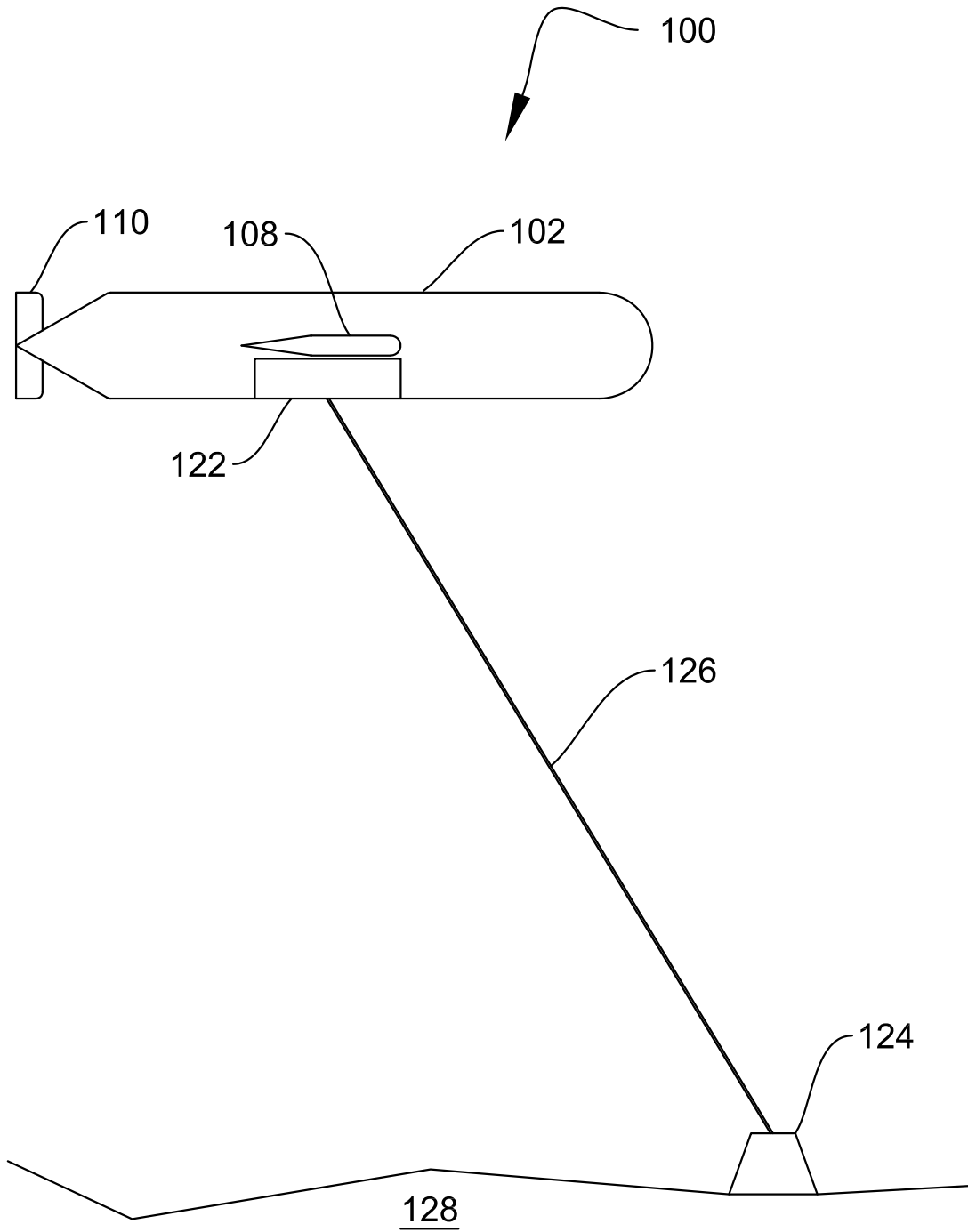


FIG. 3

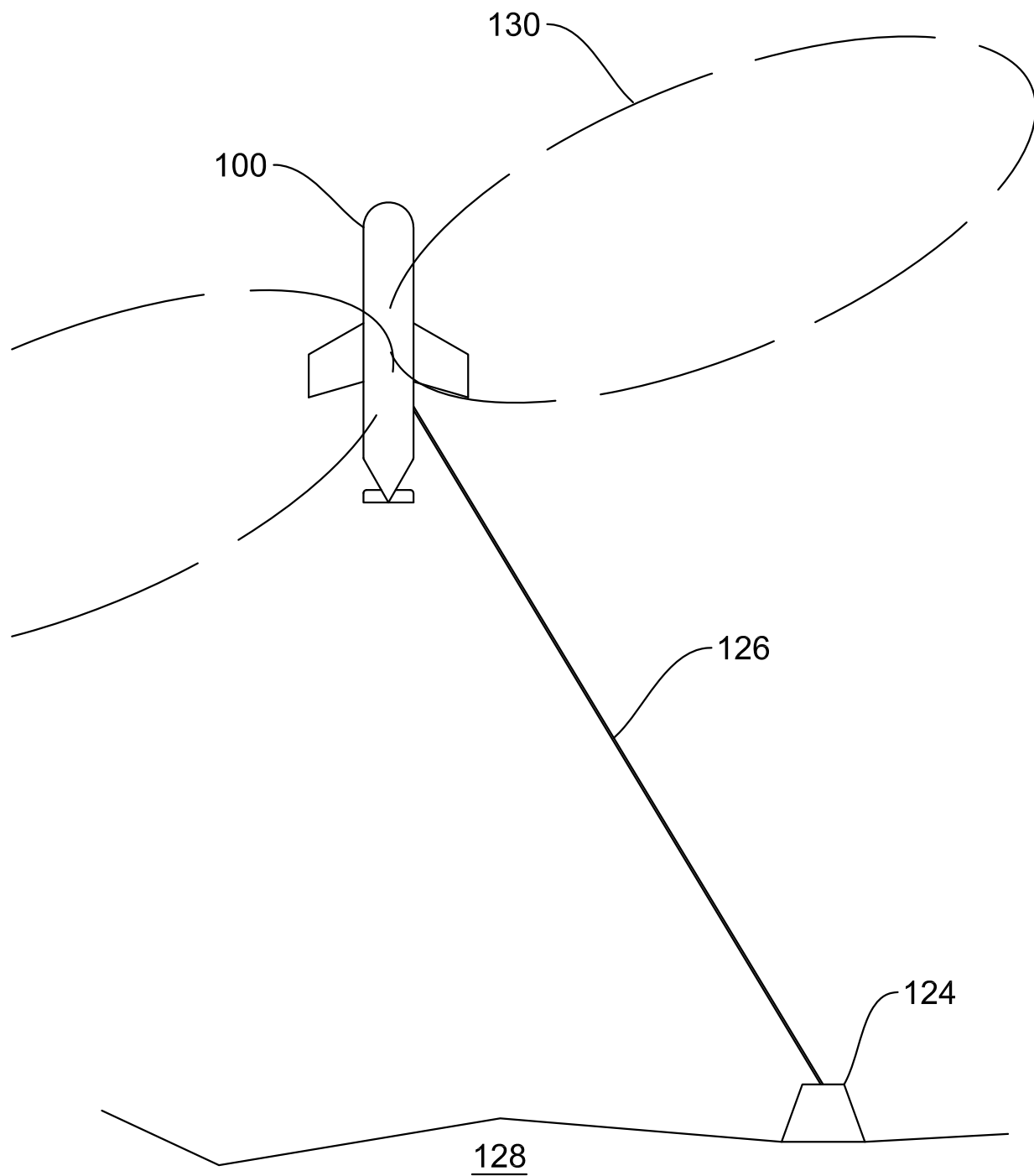


FIG. 4