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(54) Title: SEISMIC SPREAD TOWING ARRANGEMENT AND METHOD

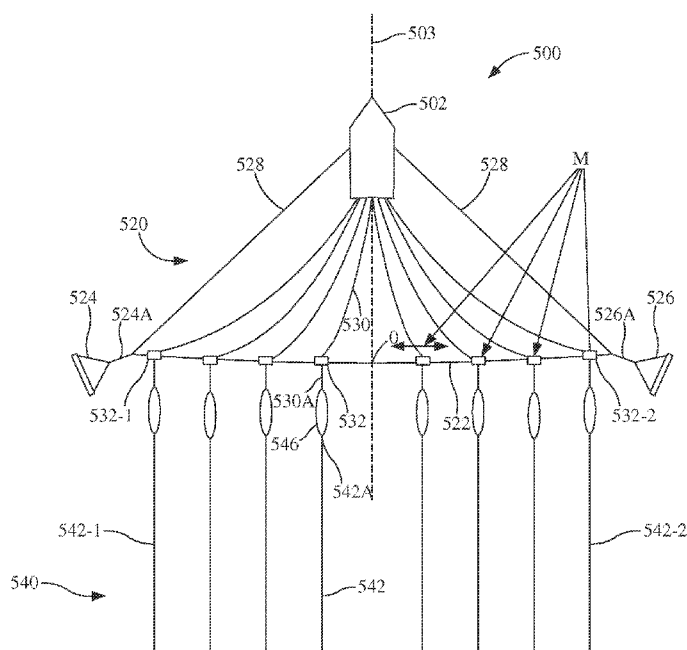


FIG. 5

(57) Abstract: Method and seismic data acquisition System that includes a front-end gear (520) configured to be attached to a vessel, the front-end gear (520) including a spread rope (522), and a streamer spread (540) configured to be attached to the spread rope (522) of the front-end gear (520) and to be towed in water. The streamer spread (540) includes first and second outer streamers (542-1, 542-2). The first outer streamer (542-1) has a moving truck (532-1) that is configured to move in a controlled way along the spread rope (522) while the streamer spread is deployed in water.



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Seismic Spread Towing Arrangement and Method

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority and benefit from U.S. Provisional Patent
5 Application No. 62/299,567, filed on February 25, 2016, entitled "Continuous Spread
Rope," the entire disclosure of which is incorporated herein by reference.

BACKGROUND

TECHNICAL FIELD

10 [0002] Embodiments of the subject matter disclosed herein generally relate to
methods and systems and, more particularly, to mechanisms and techniques for towing
seismic equipment under water.

DISCUSSION OF THE BACKGROUND

15 [0003] Marine seismic data acquisition and processing generate a profile (image)
of the geophysical structure (subsurface) under the seafloor. While this profile does not
provide an accurate location for the oil and gas, it suggests, to those trained in the field,
the presence or absence of oil and/or gas. Thus, providing a high-resolution image of
the subsurface is an ongoing process for the exploration of natural resources, including,
20 among others, oil and/or gas.

[0004] Figure 1 illustrates a marine seismic data acquisition system 100. In this
vertical view, a vessel 110 tows seismic sources 112a and 112b and a streamer spread
114 having plural streamers (only one streamer 115 is shown in the figure) at
predetermined depths under the water surface 111. Although only one streamer 115 is
25 visible in this vertical view, plural streamers are typically spread in a three-dimensional

volume. Streamer 115, which has a tail buoy 118 and likely other positioning devices attached, houses seismic receivers/sensors 116.

[0005] The seismic sources generate seismic waves such as 120a and 120b that propagate through the water layer 30 toward the seafloor 32. At interfaces (e.g., 32 and 36) between layers (e.g., water layer 30, first layer 34, and second layer 38) inside which the seismic waves propagate with different wave propagation velocities, the waves' propagation directions change as the waves are reflected and/or transmitted/refracted/diffracted. Seismic waves 120a and 120b are partially reflected as 122a and 122b and partially transmitted as 124a and 124b at seafloor 32. Transmitted waves 124a and 124b travel through first layer 34, are then reflected as waves 126a and 126b, and transmitted as 128a and 128b at interface 36. At the surface of reservoir 40, waves 128a and 128b are then partially transmitted as waves 130a and 130b and partially reflected as waves 132a and 132b. The waves traveling upward may be detected by receivers 116. Maxima and minima in the amplitude versus time data recorded by receivers carry information about the interfaces and traveling time through layers.

[0006] Streamers 115 are shown in Figure 2 spreading over a predetermined area. This assembly is called the seismic spread 114. In order to maintain the plural streamers 115 substantially parallel and at equal distance from each other, various front-end gears are used.

[0007] An example of a front-end gear 200 is shown in Figure 2. The front-end gear 200 is provided between the vessel 210 and the seismic spread 114 and this gear is configured to achieve the desired positioning for the streamer heads. Figure 2 shows the front-end gear 200 to include cables 232 connected between the vessel 210 and deflectors 234. Deflector 234 is a structure capable of generating the necessary lift

when towed, to keep the streamers deployed in the transverse direction with respect to the sailing line of the towing vessel 210. Spacers 236 are attached to the cables 232 for distributing the lift force among them in order to obtain a substantially linear profile for the position of the streamer heads. Spacers 236 are also part of the streamer spread.

5 **[0008]** To obtain high quality seismic data, the streamers are becoming longer and the number of streamers towed by the vessel is becoming larger. Because the use of the seismic vessel is expensive, it is thus advantageous to make the size of the streamer spread as large as possible so that one vessel pass covers an area as large as possible. In this regard, ultra-wide-tow seismic spread using more than 20
10 streamers, each longer than 10 km is targeted, but is something unfeasible using conventional front-end gear architectures.

[0009] On the other hand, for achieving dense acquisition, smaller separation between streamer heads is required, for example in the range of 25 to 50 meters. This configuration is difficult to achieve using the conventional front-end gears.

15 **[0010]** For very wide and low density acquisitions, a very large separation is to be used for streamers, in the order of 200 to 300 meters. Here too there are difficulties when using the conventional front-end gears.

[0011] The above noted streamer spread configurations make difficult access to the streamer heads, especially to the external streamer heads, for maintenance or
20 partial recovery during deployment. In other words, the current seismic array design has the following problems:

- Many connection points add complexity and increase the deployment/recovery time of the seismic spread;
- It is difficult to access especially the external streamers;

- It has a static design, i.e., once the streamer spread is deployed at sea, the only way to change its geometry is to recover it and replace its elements; and
- It has long spur line/large width due to deployment/recovery constrain, and this can be a limitation in case of numerous obstruction areas.

5 **[0012]** Thus, there is a need for a new and improved streamer spread that can address the above noted problems.

SUMMARY

[0013] According to an embodiment, there is a seismic data acquisition system
10 that includes a front-end gear configured to be attached to a vessel, the front-end gear including a spread rope, and a streamer spread configured to be attached to the spread rope of the front-end gear and to be towed in water. The streamer spread includes first and second outer streamers. The first outer streamer has a moving truck that is configured to move in a controlled way along the spread rope while the streamer spread
15 is deployed in water.

[0014] According to another embodiment, there is a method for deploying a seismic data acquisition system that includes deploying from a back of a vessel first and second deflectors and a spread rope, attaching a truck to the spread rope, attaching a streamer to the truck, releasing the truck in water, and driving the truck in water, along
20 the spread rope, until the streamer arrives at a desired location along the spread rope.

[0015] According to still another embodiment, there is a method of recovering of a target streamer from a streamer spread. The method includes towing with a vessel, along an inline direction, a streamer spread that includes the target streamer; moving with corresponding trucks all streamers of the streamer spread, except the target
25 streamer, away from the target streamer, along a cross-line direction, which is

perpendicular to the inline direction; pulling a lead-in cable, connected to the target streamer, on the vessel; bringing a target truck of the target streamer on the vessel; and disconnecting the target streamer from the target truck and storing the target streamer on the vessel.

5

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate one or more embodiments and, together with the description, explain these embodiments. In the drawings:

10 **[0017]** Figure 1 is a schematic diagram of a conventional marine seismic acquisition configuration;

[0018] Figure 2 is a schematic diagram of another conventional marine seismic acquisition configuration;

15 **[0019]** Figure 3 is a schematic diagram of still another conventional marine seismic acquisition configuration;

[0020] Figure 4 is a schematic diagram of a marine seismic acquisition system having catenary cables;

[0021] Figure 5 is a schematic diagram of a seismic survey acquisition system in which one or more streamers are attached to moving trucks;

20 **[0022]** Figure 6 is a schematic diagram of another seismic survey acquisition system in which one or more streamers are attached to moving trucks;

[0023] Figure 7 is a schematic diagram of still another seismic survey acquisition system in which one or more streamers are attached to moving trucks;

[0024] Figure 8 is a schematic diagram of a moving truck;

25 **[0025]** Figure 9 is a schematic diagram of another moving truck;

[0026] Figure 10 is a schematic diagram of a housing of a moving truck;

[0027] Figures 11A and 11B are schematic diagrams of still another moving truck;

[0028] Figure 12 is a flowchart of a method for deploying a streamer spread using
5 a moving truck;

[0029] Figures 13A and 13B schematically illustrate how a streamer spread is deployed in water;

[0030] Figure 14 is a flowchart of a method for retrieving a streamer from a streamer spread while using a moving truck;

10 [0031] Figures 15A-15C schematically illustrate how a streamer of a streamer spread is retrieved by using a moving truck; and

[0032] Figure 16 is a schematic diagram of a control unit for controlling a moving truck.

15

DETAILED DESCRIPTION

[0033] The following description of the exemplary embodiments refers to the accompanying drawings. The same reference numbers in different drawings identify the same or similar elements. The following detailed description does not limit the invention. Instead, the scope of the invention is defined by the appended claims. The following
20 embodiments are discussed, for simplicity, with regard to the terminology and structure of a front-end gear for towing plural streamers. However, the embodiments to be discussed next are not limited to these structures, but may be applied to other structures that are capable to tow seismic sources or other seismic related equipment.

[0034] Reference throughout the specification to “one embodiment” or “an
25 embodiment” means that a particular feature, structure, or characteristic described in

connection with an embodiment is included in at least one embodiment of the subject matter disclosed. Thus, the appearance of the phrases “in one embodiment” or “in an embodiment” in various places throughout the specification is not necessarily referring to the same embodiment. Further, the particular features, structures or characteristics may be combined in any suitable manner with other features or structures in one or more embodiments.

[0035] According to an embodiment, there is a seismic data acquisition system that includes a front-end gear configured to be attached to a vessel, the front-end gear including a spread rope, and a streamer spread configured to be attached to the spread rope of the front-end gear and to be towed in water. The streamer spread includes first and second outer streamers. The first outer streamer has a moving truck that is configured to move in a controlled way along the spread rope while the streamer spread is deployed in water.

[0036] To appreciate one or more advantages that the novel streamer spread discussed above is bringing to a seismic acquisition system, two traditional systems are discussed with regard to Figures 3 and 4 before introducing in more detail the novel streamer spread.

[0037] A first configuration, which is illustrated in Figure 3, shows a seismic acquisition system 300 that includes a vessel 340 towing two super wide tow ropes 342 provided at respective ends with deflectors 344. Plural lead-in cables 346 are connected to streamers 350 (for simplicity, only a few streamers are illustrated). The plural lead-in cables 346 also connect to the towing vessel 340. Streamers 350 are maintained at desired separations from each other by separation ropes 348. Plural sources 354 are also connected to the vessel 340 through corresponding ropes 352.

[0038] A second configuration, which is illustrated in Figure 4, shows a seismic acquisition system 400 that includes a hybrid front-end gear 460 that is attached to a master vessel 462 and two slave vessels 464a-b. At least one of the vessels is a seismic vessel transporting multiple streamers on board. The second vessel can be
5 either a tug boat or a seismic vessel in cases where a big number of streamers are to be deployed at sea.

[0039] A first cable 466a (called catenary tow line) is provided between the master vessel 462 and slave vessel 464a and a second cable 466b (catenary tow line) is provided between the master vessel 462 and slave vessel 464b. In the following, a
10 cable is considered an element capable of transferring data and/or electrical power and also capable of sustaining a given load, i.e., having a structural role in transferring loads. A rope is considered to be an element that transfers a load but not capable of transmitting data and/or electrical power. The cable and the rope may be made as known in the art.

[0040] One or more transversal ropes 468 are connected from the first cable 466a and from the second cable 466b via links 470. Links 470, which may be ropes or cables or both or other means known in the art, have different lengths depending on their location on the Y axis. For example, link 470 may include a cable part and also a rope part, where the rope part is used to adjust a position of the corresponding streamer
20 and the cable part is configured to transmit data and/or power. Links 470 may be configured to form a single unit with streamers 480. Direct links 472 between the vessels and the transversal ropes 468 are also provided.

[0041] A drawback of the seismic streamer spreads illustrated in Figures 3 and 4 is the lack of capability of adjusting the cross-line position (cross-line direction is along
25 axis Y in the figures and substantially perpendicular to the inline direction, along axis X

in the figures, with the vessels moving along the inline direction) of the streamers while they are deployed in water. This is so because all the existing seismic streamer spreads have fixed lines 468 between two adjacent streamers (or streamer heads).

[0042] To solve the above problem, according to an embodiment illustrated in

5 Figure 5, a seismic acquisition system 500 includes a towing vessel 502, a front-end gear 520 and a streamer spread 540 in which one or more streamers 542 has the capability of moving along the cross-line direction Y while the streamer spread is deployed in water. In one embodiment, the one or more streamers 542 can move along the cross-line direction while the vessel is following a given path and seismic data is
10 being acquired, i.e., there is no need to stop the seismic survey for re-arranging the one or more streamers along the cross-line direction. In other words, according to this embodiment, it is possible to slide a streamer (the entire streamer) along a cross-line direction while the vessel advances along the inline direction, and this capability is achieved by connecting one or more streamers to the front-end gear with corresponding
15 moving trucks.

[0043] The embodiment illustrated in Figure 5 has a continuous spread rope 522

that extends between spur lines 524A and 524B corresponding to deflectors 524 and 526, respectively. Wide tow ropes 528 are shown connecting the deflectors to the towing vessel 502 and lead-in cables 530 (many shown but only one labeled for
20 simplicity) are shown connecting a corresponding truck 532 to the towing vessel 502. Truck 532, which will be discussed in more details later, is a device that attaches to the spread rope 522 and possess a moving system for traveling along the spread rope. Truck 532 is also connected to the lead-in 530 and corresponding streamer 542. Movement M of truck 532 along the spread rope may be controlled from vessel 502, or
25 from a local control device (not shown in this figure) located on or inside truck 532.

[0044] The embodiment shown in Figure 5 illustrates each streamer 542 having a corresponding truck that is capable of traveling along the continuous spread rope 522 (in the cross-line direction). Note that each truck may be controlled independent of the other trucks and thus, only one streamer at a time may be moved along the cross-line direction. In one embodiment, a subset of the streamers has corresponding trucks while the others are directly connected to the corresponding lead-in cables, as in a traditional seismic acquisition system. For example, in one embodiment, only the outer streamers 542-1 and 542-2 have corresponding trucks 532-1 and 532-2 while no other streamer has such a truck. In another embodiment, the subset of streamers having corresponding trucks include the two most outer streamers relative to the position of the towing vessel. In still another embodiment, the most outer and inner streamers have corresponding trucks. In yet another embodiment, only the first two or four most inner streamers have the corresponding trucks. Those skilled in the art would understand that the subset of streamers that may have corresponding trucks varies between 2 and the entire number of streamers.

[0045] The amount of allowable movement M for each truck may vary with the position of the streamer along the cross-line direction. If origin point O in Figure 5 is considered to be located at the intersection of the vessel's travel path 503 and the cross-line direction Y , then, in one embodiment, the amount of movement M for each truck is proportional with the distance between the origin point O and the location y of the truck along the cross-line direction. In another embodiment, the amount of movement M for each truck is invers proportional with the distance between the origin point O and the location y of the truck along the cross-line direction. In still another embodiment, the amount of movement M for each streamer is the same. In yet another embodiment, the amount of movement M for each streamer varies with a given law (for

example, a table that indicates the amount of movement for each streamer). In still another embodiment, the amount of movement M is controlled by the operator of the vessel.

[0046] Figure 5 shows that truck 532 is not directly connected to streamer 542, but rather to a portion 530A of the lead-in cable 530 and this portion 530A connects to the head 542A of the streamer 542. Head 542A may also be connected to a streamer float 546 (which may float to the water surface and maintains the streamer head at a desired depth). In one application, truck 532 may connect to a connection region (not shown) between the lead-in 530 and streamer 542.

[0047] Continuous spread rope 522 may be configured to fulfill one or more of the following functions:

- It acts as a fairing, due to its hydrodynamic shape,
- It allows a robust fastening of the moving truck (by specific locking system acting even when power is off, as will be discussed later),
- A moving path is embedded into the rope to match the truck's moving system (such as wheels, belts, tracks, etc.),
- It is flexible and able to be spooled to allow the deployment seismic operations, and
- It is coded to give an accurate information about the truck's position (this can be achieved with magnetic or optical coding; magnetic coding implies that small magnets are embedded in the spread rope at known locations and they are read with electromagnetic sensor while optical coding implies that marks are made on the spread rope and these marks are read with an optical device, e.g., a camera).

[0048] The spread rope 522 can be combined with a “smart” deflector, i.e., a deflector that can be remote controlled from the vessel to adjust its angle of attack for various phases of the seismic survey, i.e., data acquisition, deployment of the system, retrieval of the system, turning of the streamer spread, etc. This combination allows
5 more flexibility during these phases.

[0049] In another embodiment illustrated in Figure 6, the continuous spread rope 522 is replaced with two spread ropes 622A and 622B, each connected with one end to the towing vessel 502 and with the other end to a corresponding deflector 524 or 526. In other words, the continuous spread rope 522 from the embodiment of Figure 5 is split
10 into two parts, which according to this embodiment, may ease the source deployment as the sources can now be deployed between the two spread ropes 622A and 622B.

[0050] In a related embodiment illustrated in Figure 7, the continuous spread rope 522 is replaced by two spread ropes 722A and 722B that are not directly connected to the towing vessel. For this embodiment, one end of each of the two
15 spread ropes 722A and 722B is connected to a corresponding deflector while the other end is free. In one application, the free end 722B-E of spread rope 722B is terminated with a stopper 734B (a similar stopper may be provided for spread rope 722A). This means that corresponding truck 732 still can move freely along the cross-line in both directions, but is stopped by the stopper at the free end. In still another application, the
20 most inner streamer has no truck and thus, it is fixedly attached to the spread ropes 622A and 622B or 722A and 722B.

[0051] One possible structure of truck 532 is now discussed with regard to Figure 8. Figure 8 is a perspective view of the lead-in cable 530, streamer 542, truck 532, and spread rope 522 (or 622A or 722A). A connector 544 between streamer 542 and lead-
25 in 530 is shown. Truck 532 may be connected directly to lead-in 530, as shown in the

figure, or to connector 544. Note that the X and Y directions (corresponding to the inline and cross-line directions are substantially perpendicular to each other). Truck 532 may include a housing 800 that accommodates various components, e.g., controller, memory, processor, power supply, transmission equipment, motor and other appropriate electronics to be discussed later. An actuation mechanism 802 is connected to the housing 800 and is configured to move along spread rope 522. Actuation mechanism 802 may include at least one of a wheel, belt, track (similar to a tank track), a wheel with spikes, a clamp, a magnetic device, or an electromagnetic device. The actuation mechanism 802 is configured to move along spread rope 522, but also to maintain contact with the spread rope while the towing vessel tows the streamer.

[0052] Spread rope 522 may have a dedicated track 522A that engages the actuation mechanism 802. In one application, the actuation mechanism locks onto the dedicated track 522A and the two elements can slide one relative to the other along the cross-line direction, but are fixed one relative to the other along the inline direction. Dedicated track 522A may be an integral part of spread rope 522, or it may be attached to the spread rope (e.g., with screws).

[0053] Housing 800 may be mechanically connected to streamer 542, or connector 544 or lead-in cable 530 as illustrated in Figure 8. In one application, a bend stiffener element 804 is connected to housing 800 and is configured to allow a bending of the lead-in cable relative to the streamer without damaging the internal wiring (electrical and/or data cables). In one embodiment, the bend stiffener element is articulated. In still another embodiment, the bend stiffener element 804 is configured to connect to head streamer float 546 through a corresponding cable/rope 547. In another

embodiment, the head streamer float 546 connects to the lead-in cable 530 or to connector 544.

[0054] According to the embodiment illustrated in Figure 9, a specific truck 900 is illustrated. Truck 900 has the housing 902 located below the spread rope 522. At least one pair of wheels 920A and 920B is attached to a frame 920 so that one wheel is located above spread rope 522 and the other wheel is located below the spread rope. In one embodiment, frame 920 has a bracket 922 that biases the two wheels toward the spread rope so that a strong contact between the spread rope and the wheels is obtained. Frame 920 is attached to housing 902 and also to bend stiffener element 904. In one application, more than one pair of wheels is attached to frame 920. Figure 9 shows two pairs of wheels for truck 900. Bend stiffener element 904 is rotatably attached to frame 920, so that when the truck moves along the spread rope, the bend stiffener element can rotate along a direction Z substantially perpendicular to the inline and cross-line directions.

[0055] Figure 9 also shows that spread rope 522 has a double track 950A and 950B (grooves) formed along the cross-line direction, so that each of the wheels 920A and 920B engages a corresponding track. The track may be formed in the material from which the spread rope is formed (e.g., plastic, composite, metal, etc.). In one application, the track is made separate than the spread rope and then attached to the spread rope. The spread rope is shown in Figure 9 also having a fairing shape, to more aerodynamically move through water when towed by the towing vessel.

[0056] Wheels 920A and 920B may be motorized, i.e., configured to rotate when a motor (not shown), located inside the housing 902 or inside the wheels, actuates them. The motor (see element 1050 in Figure 10) may be an electrical motor, hydrodynamic motor, magnetic motor, electromagnetic motor, etc. A power supply

source 1052 may supply the power necessary for the motor to actuate the truck. The power supply may be a battery, fuel cell, or a hydro-generator that has a propeller 1053 located outside the housing 902 for generating energy. A local control unit 1054 may be located inside the housing for controlling the motor 1050. The local control unit is also
5 connected to the power supply for receiving power. The local control unit may be also connected to a communication unit 1056 for communicating with the vessel. The vessel may have a global control unit that sends commands to the local control unit. The communication unit 1056 may communicate with the spread rope through induction and the spread rope may be in electrical connection with the global control unit on the
10 vessel. Alternatively, the communication unit 1056 may include an acoustic modem to directly communicate with the vessel. In still another embodiment, the communication unit 1056 may be connected with a transceiver located on the streamer head float, which directly communicates with the vessel through electromagnetic waves. In this embodiment, the streamer head float may also have a GPS system, so that a position of
15 the truck may be calculated.

[0057] Control unit 1054 may be connected to a counter unit 1058, which is configured to determine a position of the truck relative to the spread rope. For example, counter unit 1058 may include an optical element for reading a scale (or other optical markers) present (e.g., printed) on the spread rope. The scale may be in meters and
20 may be starting from reference point O. In this way, the local control unit can calculate the exact cross-line position of the truck. In an alternative embodiment, each assigned position of the streamer is marked (e.g., by painting or similar methods) on the spread rope and a scale starting at this mark is also present on the spread rope so that the counter unit 1058 can measure the truck position relative to the assigned position. The
25 counter unit 1058 may include other type of sensors, for example, an electromagnetic

sensor that determines the rotation of the wheels along the spread rope and calculates the displacement of the truck by multiplying the number of rotations of the wheel by the circumference of the wheel (which can be calculated by knowing the radius of the wheel). Those skilled in the art would know of other methods for determining the position of the truck relative to a given mark on the spread rope. While the marks discussed above with regard to the spread rope may be printed, it is also possible that the marks are formed integrally with the spread rope during a manufacturing process.

[0058] Truck 900 may also include a stop unit 1060, either disposed inside housing 902 as illustrated in Figure 10, or next to the wheels 920A, 920B for locking the wheels so that, during a lock phase, the truck does not move along the cross-line direction. The stop unit may be as simple as a pin that enters a hole in the spread rope for ensuring that the truck is locked. Alternatively, the stop unit may include an electronic component that maintains the motor in a locked position during the lock phase. Other stop unit implementations may be used. The stop unit is configured to lock the truck in absence of any command or power. In order to unlock the truck, the stop unit needs to be activated by, for example, the local and/or global control unit, so that the motor can move the truck. During this unlock phase, the local control unit actuates the motor and moves the truck for a given distance, as instructed, for example, by the global control unit. In the eventuality that power is lost or communication with the local control unit and/or global control unit is interrupted, the stop unit automatically locks the truck and maintains the streamer head at the current cross-line position until a new command is received.

[0059] The truck shown in Figures 8 and 9 can be considered to be an active interface between the front-end gear (spread rope) and the streamer spread (lead-in cable) and achieves one or more of the following:

- It ensures robust connection between lead-in cable and spread rope;
- It moves along spread rope in both directions at a speed compatible with operational needs, even against the water flow;
- It secures its position relative to the spread rope when not moving, with a stop
5 unit that may include a pin locker or other known mechanisms;
- It is able to communicate with the vessel, through the spread rope (inductive communication) or through an acoustic modem, or through a transceiver located on a streamer head float;
- The truck may be autonomous from an energy point of view when, for example,
10 powered by a hydrogenerator or powered through a wireless energy induction system embedded in the spread rope;
- It protects the lead-in cable by using a bend stiffener/restrictor connected to the truck, allowing rotations of the lead-in cable in three independent directions; and
- In some embodiments, the streamer head float can be connected to the truck. In
15 this case, the truck can be equipped with a winch to tune the depth rope's length or to lift up the streamer head (for maintenance, for example).

[0060] In another embodiment illustrated in Figures 11A and 11B, the motorized truck 1100 may include a cylindrical shape housing 1102 to which four wheels 1104, 1106, 1108 and 1110 are attached. The wheels are symmetrically located on each side
20 of the spread rope to ensure symmetrical forces around the spread rope when moving the truck. Housing 902 and its components illustrated in Figure 10 may be shaped to fit inside the cylindrical housing 1102. Figure 11A shows a transversal view of such a truck when attached to the spread rope while Figure 11B shows an axial view of the same device.

[0061] The truck illustrated in Figures 11A and 11B has a robust and simple design, can have a stop unit in the wheels (stop unit should be passive, no need for power), and one or more electrical motors powering the wheels. In one embodiment, the electrical motors are located inside the wheels instead of the housing. In one application, high friction materials are used between the spread rope and wheels so that the truck does not slide along the cross-line direction. In one embodiment, the wheels could be studded or have sprockets to match the spread rope and achieve good contact.

[0062] The trucks described in one or more of the above embodiments are advantageous to use during operation (deployment, retrieval, and/or maintenance) of a seismic survey system. A deployment method is now discussed with regard to Figure 12. In step 1200, the towing vessel stores on its back deck all the equipment associated with the seismic survey, i.e., the front-end gear and the streamer spread. In step 1202, the deflectors 1324 and 1326 (see Figure 13A) are deployed in water from the vessel 1302. At the same time, the spread rope 1322 is also deployed. This embodiment assumes that the spread rope is a single continuous rope. However, a center point CP of the spread rope is kept onboard. In step 1204, a truck 1332 is attached to the spread rope, in step 1206 a streamer 1342 is attached to the truck and in step 1208 the truck and the streamer are released in water. In step 1210, the truck is controlled through the global control unit 1305 and the local control unit to move to its assigned position. Figure 13 shows streamers 1342-1 and 1342-2 already deployed at their positions while streamer 1342 is in the process of moving (see arrow A) toward its assigned position AP.

[0063] This process may happen simultaneously on each side of the spread rope 1332, or sequentially, on the starboard side and then on the port side. Other

arrangements may be used. After all the streamers have been deployed and moved by truck to their designated positions, the center point CP of the spread rope 1322 is released in step 1212 from the vessel and slowly moved to its designated position with a control rope 1360 so that the spread rope can make a straight line between the two
5 deflectors (see Figure 13B). The control rope 1360 may include power supply wires and/or communication wires for supplying the trucks (if they are not autonomous). The method discussed herein may also be applied to the case of a split spread rope. In case of a split spread rope, two control ropes 1360 may be used, one for each of the split spread rope. If the split ropes from the embodiment illustrated in Figure 6 are
10 used, the control rope is not necessary as one end of each split spread rope remains on the vessel. If the split spread ropes from the embodiment illustrated in Figure 7 are used, then the lead-in cables of the two inner most streamers may be used as the control rope. The control rope (when the embodiment of Figure 5 is used) may be removed from the spread rope and retrieved on the vessel for later use.

15 **[0064]** In step 1214, after all the elements of the front-end gear and streamer spread are in water, the positions of the streamers are finally adjusted with the trucks to match the survey requirements. In case of environmental changes (e.g., lateral current, poor spread stability, barnacle's growth, etc.), the lateral position of one or more streamers can be dynamically adjusted with the trucks. Note that this step of
20 dynamically adjusting the cross-line position of the streamers may be performed while the seismic data is being recorded, i.e., while the streamers are towed by the vessel. In addition, this step may be performed while the towing vessel is turning to follow a different path, so that the streamers are further apart, for example, for preventing tangling, or the streamers are closer to each other for reducing the turning time. In this
25 last case, birds distributed along the streamers may be used for preventing the tangling.

Although this method has been discussed assuming that each streamer has a corresponding truck, the method may be adapted to work when a subset of the streamers has corresponding trucks. For example, it is possible that the outer most streamers (the first, second, third pairs) have trucks while the most inner pairs do not have. In this case, an intermediate step, between steps 1204 and 1212, may be to fixedly attach the inner most streamers, after the outer most streamers have been driven in place, and then to release the center point of the spread rope. In this case, step 1214 adjusts only the positions of the outer most streamers.

[0065] The trucks associated with the streamers may advantageously be used not only to deploy the streamer spread, but also for streamer recovery. As discussed now with regard to Figure 14, a method for recovery of external streamers (other streamers may also be recovered but the external streamers pose the biggest challenges for a seismic survey system) includes a step 1400 in which the streamer spread is towed by a vessel. In step 1402, a decision is made that one external streamer 1542-1 (see Figure 15A) needs to be retrieved on the vessel, and thus, the trucks of all other streamers 1542-i are instructed to move along the spread rope 1522, opposite to the external streamer 1542-1. The deflector positions may be adjusted/controlled during this step (e.g., deflector 1526 is pulled ahead of deflector 1524 along the inline direction) to favor the movement of the streamers. It is noted that the vessel continues to move during this step.

[0066] In step 1404, after all the streamers, except the target external streamer, have been moved to one side of the streamer spread, the lead-in cable 1530 of the target external streamer 1542-1 is pulled on the vessel, as illustrated in Figure 15B. This means that slowly, the target external streamer is brought on the vessel. During this step, or just prior to this step, or both, the corresponding truck 1532 is adjusted to

move away from the closest deflector 1526 but also away from the closest streamer 1542-i. In other words, the target external streamer's truck is driven/controlled to position along the spread rope 1522, away from both the other streamers and from the adjacent deflector. In one embodiment, truck 1532 is driven to be in the middle of the distance between deflector 1526 and the next streamer 1542-i. In still another application, a distance D between the target external streamer 1542-1 and the deflector 1526 is calculated to be larger than a traditional distance between these two elements (i.e., the distance that is used when the streamer spread is fully deployed and towed to record seismic data).

[0067] In step 1406, the corresponding truck 1532 has been brought on the vessel's deck, as illustrated in Figure 15C, and the spread rope 1522 is secured onboard. In step 1408, streamer 1542-1 is disconnected from its lead-in cable and/or truck and rolled onto the vessel's deck. A new streamer may be deployed by attaching it to the lead-in cable and/or truck, releasing the new streamer in water, allowing the spread rope and the corresponding lead-in cable to move away from the vessel, until reaching the designated position in the streamer spread. This position is achieved by controlling a movement of the corresponding truck along the spread rope. After the new streamer has reached its final position, the other trucks are controlled to move their streamers to their original cross-line positions, so that all the streamers are ready to record the seismic data.

[0068] Compared to a current streamer spread, that has no trucks, the novel streamer spread having at least one truck has one or more advantages as now discussed. From a geophysical point of view, the streamer spread with the trucks has the ability to reduce the spur line's length, in order to have the streamers closer to the deflectors. The streamer spread may also has the ability to work with variable

hydrophone distribution (dynamic or static), which can be an advantage for advanced processing.

[0069] From a mechanical point of view, the streamer spread with trucks has no more discontinuity in the strength member between deflectors (when a single continuous spread rope is used as illustrated in Figure 5) and/or less stress is present in the lead-in cables during the deployment/recovery process.

[0070] From an operational point of view, the streamer spread with trucks has the ability to more easily access the external streamers, to control the spread configuration at sea (barnacle's growth, lateral currents, etc.) and/or to make the deployment quicker and easier.

[0072] The above-discussed procedures and methods may be implemented in a global and/or local control unit as already discussed. Hardware, firmware, software or a combination thereof may be used to perform the various steps and operations described herein. A control unit 1600 is illustrated in Figure 16 as an exemplary computing structure that may be used in connection with such a system.

[0073] Control unit 1600 suitable for performing the activities described in the above embodiments may include a server 1601. Such a server 1601 may include a central processor (CPU) 1602 coupled to a random access memory (RAM) 1604 and to a read-only memory (ROM) 1606. ROM 1606 may also be other types of storage media to store programs, such as programmable ROM (PROM), erasable PROM (EPROM), etc. Processor 1602 may communicate with other internal and external components through input/output (I/O) circuitry 1608 and bussing 1610 to provide control signals and the like. Processor 1602 carries out a variety of functions as are known in the art, as dictated by software and/or firmware instructions.

[0074] Server 1601 may also include one or more data storage devices, including hard drives 1612, CD-ROM drives 1614 and other hardware capable of reading and/or storing information, such as DVD, etc. In one embodiment, software for carrying out the above-discussed steps may be stored and distributed on a CD-ROM or DVD 1616, a removable storage device 1618 or other form of media capable of portably storing information. These storage media may be inserted into, and read by, devices such as CD-ROM drive 1614, disk drive 1612, etc. Server 1601 may be coupled to a display 1620, which may be any type of known display or presentation screen, such as LCD, plasma display, cathode ray tube (CRT), etc. A user input interface 1622 is provided, including one or more user interface mechanisms such as a mouse, keyboard, microphone, touchpad, touch screen, voice-recognition system, etc.

[0075] Server 1601 may be coupled to other devices, such as sources, detectors, etc. The server may be part of a larger network configuration as in a global area network (GAN) such as the Internet 1628, which allows ultimate connection to various landline and/or mobile computing devices.

[0076] The disclosed exemplary embodiments provide a system and a method for towing an array of streamers underwater. It should be understood that this description is not intended to limit the invention. On the contrary, the exemplary embodiments are intended to cover alternatives, modifications and equivalents, which are included in the spirit and scope of the invention as defined by the appended claims. Further, in the detailed description of the exemplary embodiments, numerous specific details are set forth in order to provide a comprehensive understanding of the claimed invention. However, one skilled in the art would understand that various embodiments may be practiced without such specific details.

[0077] Although the features and elements of the present exemplary embodiments are described in the embodiments in particular combinations, each feature or element can be used alone without the other features and elements of the embodiments or in various combinations with or without other features and elements disclosed herein.

[0078] This written description uses examples of the subject matter disclosed to enable any person skilled in the art to practice the same, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the subject matter is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims.

WHAT IS CLAIMED IS:

1. A seismic data acquisition system (500) comprising:

a front-end gear (520) configured to be attached to a vessel, the front-end gear (520) including a spread rope (522); and

5 a streamer spread (540) configured to be attached to the spread rope (522) of the front-end gear (520) and to be towed in water, the streamer spread (540) including first and second outer streamers (542-1, 542-2),

wherein the first outer streamer (542-1) has a moving truck (532-1) that is configured to move in a controlled way along the spread rope (522) while the streamer
10 spread is deployed in water.

2. The system of Claim 1, wherein the first outer streamer extends along an inline direction and the spread rope extends along a cross-line direction, which is perpendicular to the inline direction.

15

3. The system of Claim 1, wherein each streamer of the streamer spread has a corresponding moving truck.

4. The system of Claim 1, wherein inner streamers of the streamer spread are
20 fixedly attached to the spread rope.

5. The system of Claim 1, wherein the truck comprises:

a housing (800) that accommodates a local control unit (1054); and

an actuation mechanism (802) attached externally to the housing and configured to move along the spread rope under control of the local control unit.

5

6. The system of Claim 5, wherein the actuation mechanism includes wheels or tracks that move in a corresponding groove (950A) made in the spread rope.

7. The system of Claim 5, further comprising:

10 a bend stiffener element (804) attached to the housing and configured to receive (i) a lead-in cable of a corresponding streamer and (ii) the corresponding streamer.

8. The system of Claim 5, wherein the actuation mechanism includes four wheels distributed symmetrically around the spread rope.

15

9. The system of Claim 1, wherein the spread rope is a single continuous rope extending between first and second deflectors.

10. The system of Claim 1, wherein the spread rope includes two split spread ropes, each split spread rope extending between a corresponding deflector and the vessel.

20

11. The system of Claim 1, wherein the spread rope includes two split spread ropes, each split spread rope being attached with one end to a corresponding deflector and with another end being free.

25

12. The system of Claim 1, further comprising:

a streamer head float attached to the moving truck with a rope for maintaining the moving truck to a given depth below the water.

5

13. A method for deploying a seismic data acquisition system, the method comprising:

deploying (1202) from a back of a vessel first and second deflectors (524, 526) and a spread rope (522);

10 attaching (1204) a truck (532-1) to the spread rope (522);

attaching (1206) a streamer (542-1) to the truck (532-1);

releasing (1208) the truck (532-1) in water; and

driving (1210) the truck (532-1), in water, along the spread rope (522), until the streamer (542-1) arrives at a desired location along the spread rope (522).

15

14. The method of Claim 13, wherein a center point of the spread rope is kept on the vessel during the step of releasing the truck.

15. The method of Claim 14, further comprising:

20 releasing the center point of the spread rope (522) from the vessel after the step of releasing the truck.

16. The method of Claim 13, further comprising:

25 adjusting a cross-line position of the truck along the spread rope after all streamers have been released in water.

17. A method for recovering a target streamer from a streamer spread, the method comprising:

5 towing (1400) with a vessel, along an inline direction, a streamer spread that includes the target streamer;

moving (1402) with corresponding trucks all streamers of the streamer spread, except the target streamer, away from the target streamer, along a cross-line direction, which is perpendicular to the inline direction;

pulling (1404) a lead-in cable, connected to the target streamer, on the vessel;

10 bringing (1406) a target truck of the target streamer on the vessel; and

disconnecting (1408) the target streamer from the target truck and storing the target streamer on the vessel.

18. The method of Claim 17, wherein the target streamer is a most outer
15 streamer of the streamer spread.

19. The method of Claim 17, wherein the corresponding trucks are configured to move along a spread rope that extends in the cross-line direction.

20 20. The method of Claim 17, further comprising:

connecting a new streamer to the target truck and releasing the target truck and the new streamer in water.

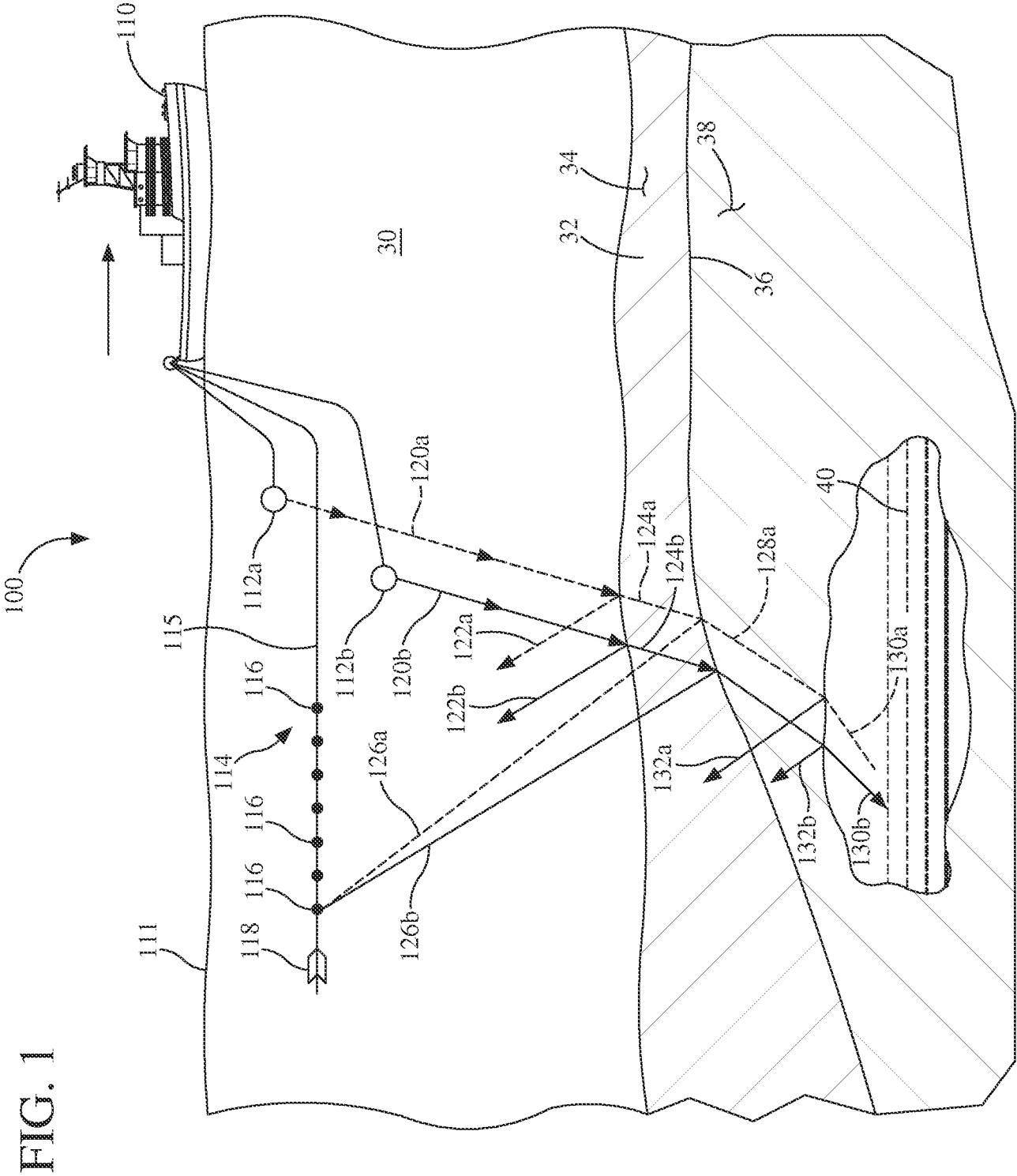
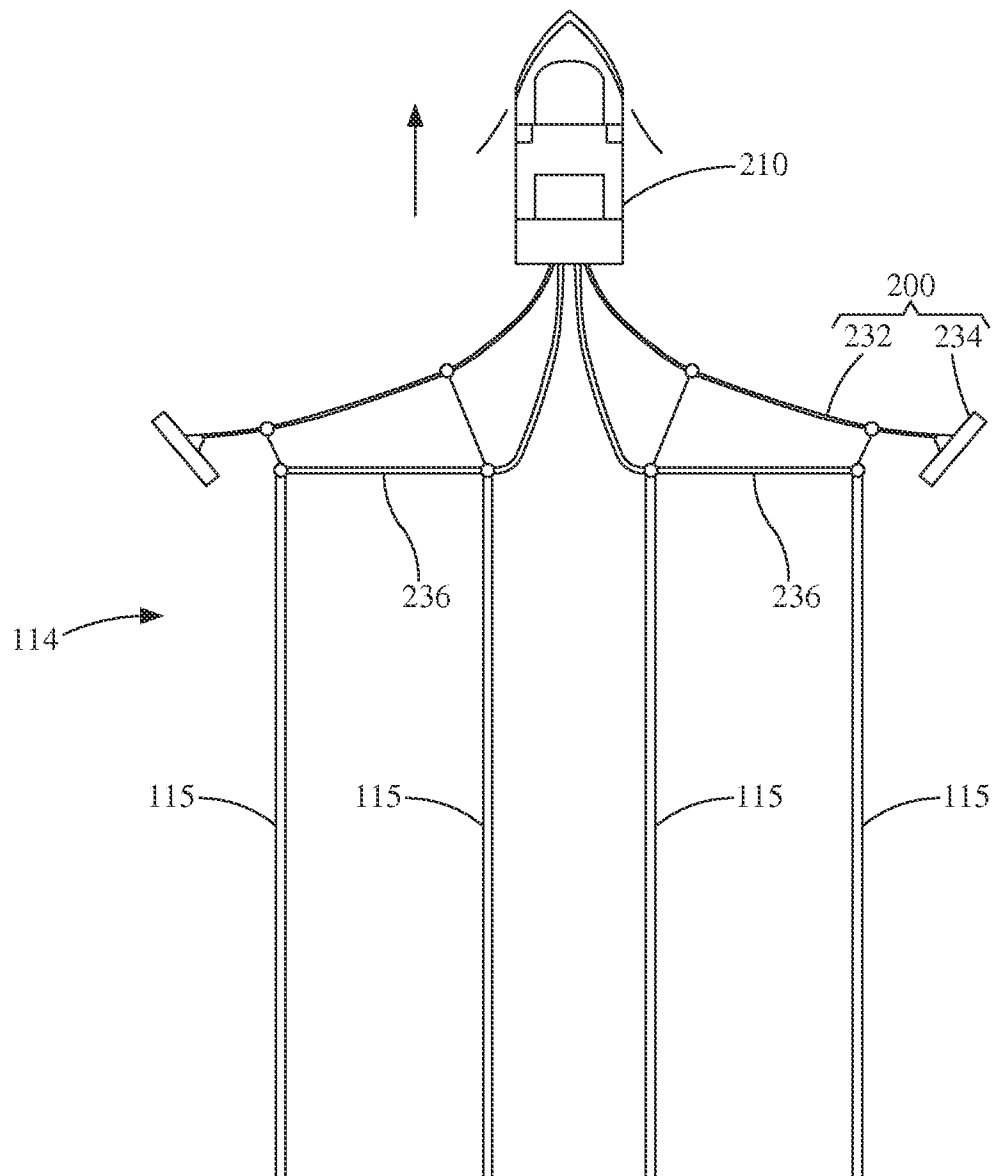


FIG. 2
(Background Art)



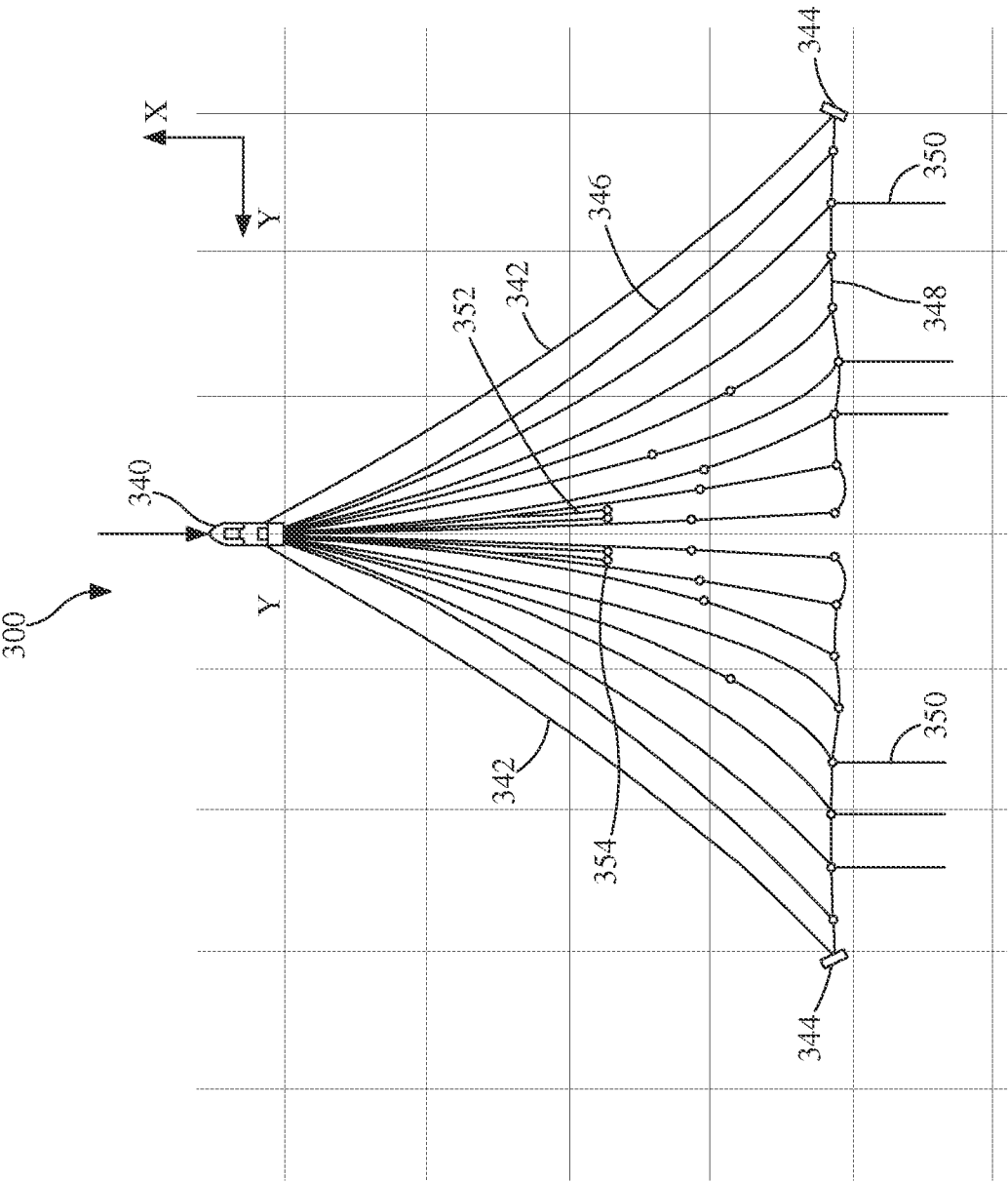


FIG. 3

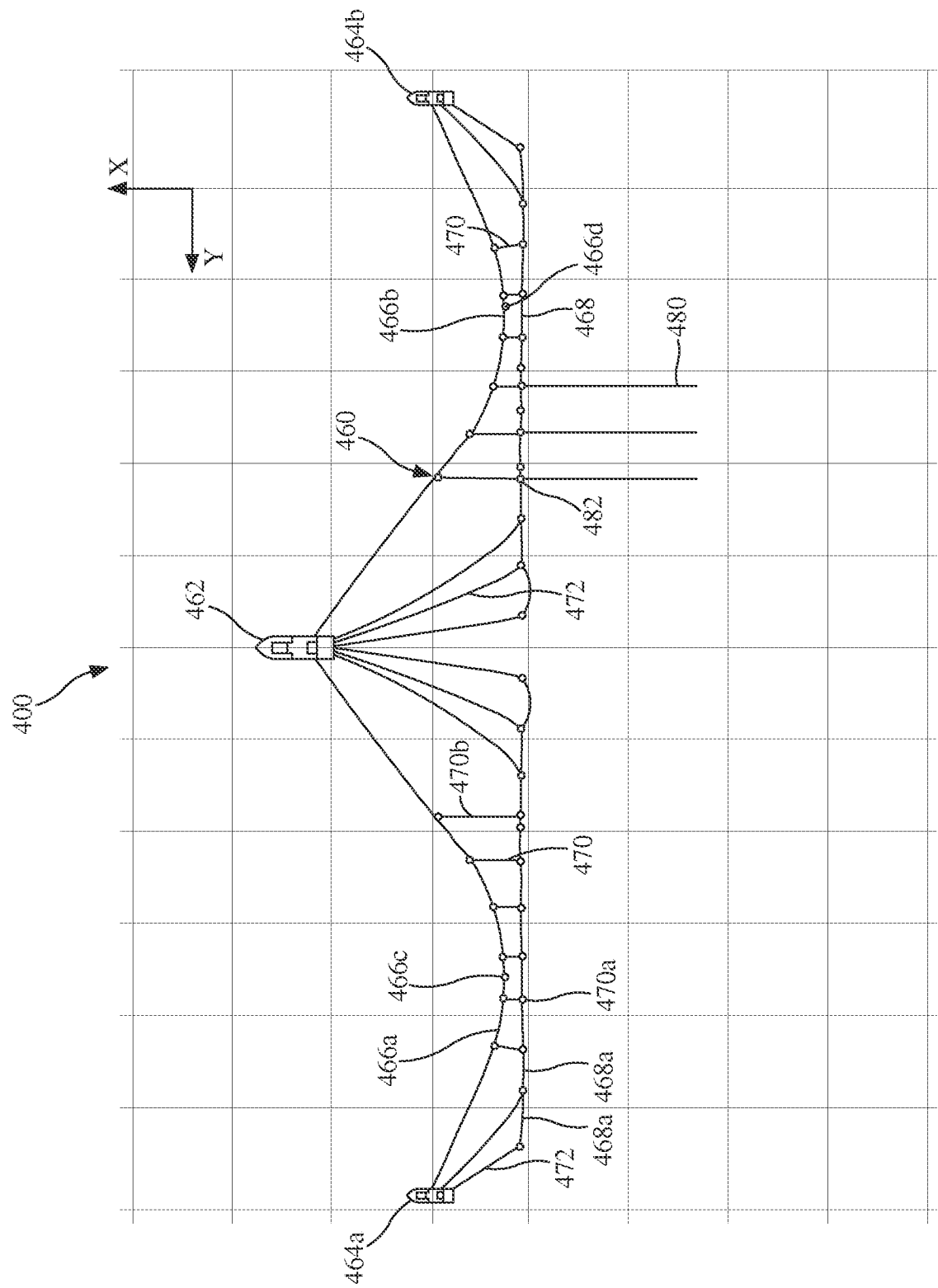


FIG. 4

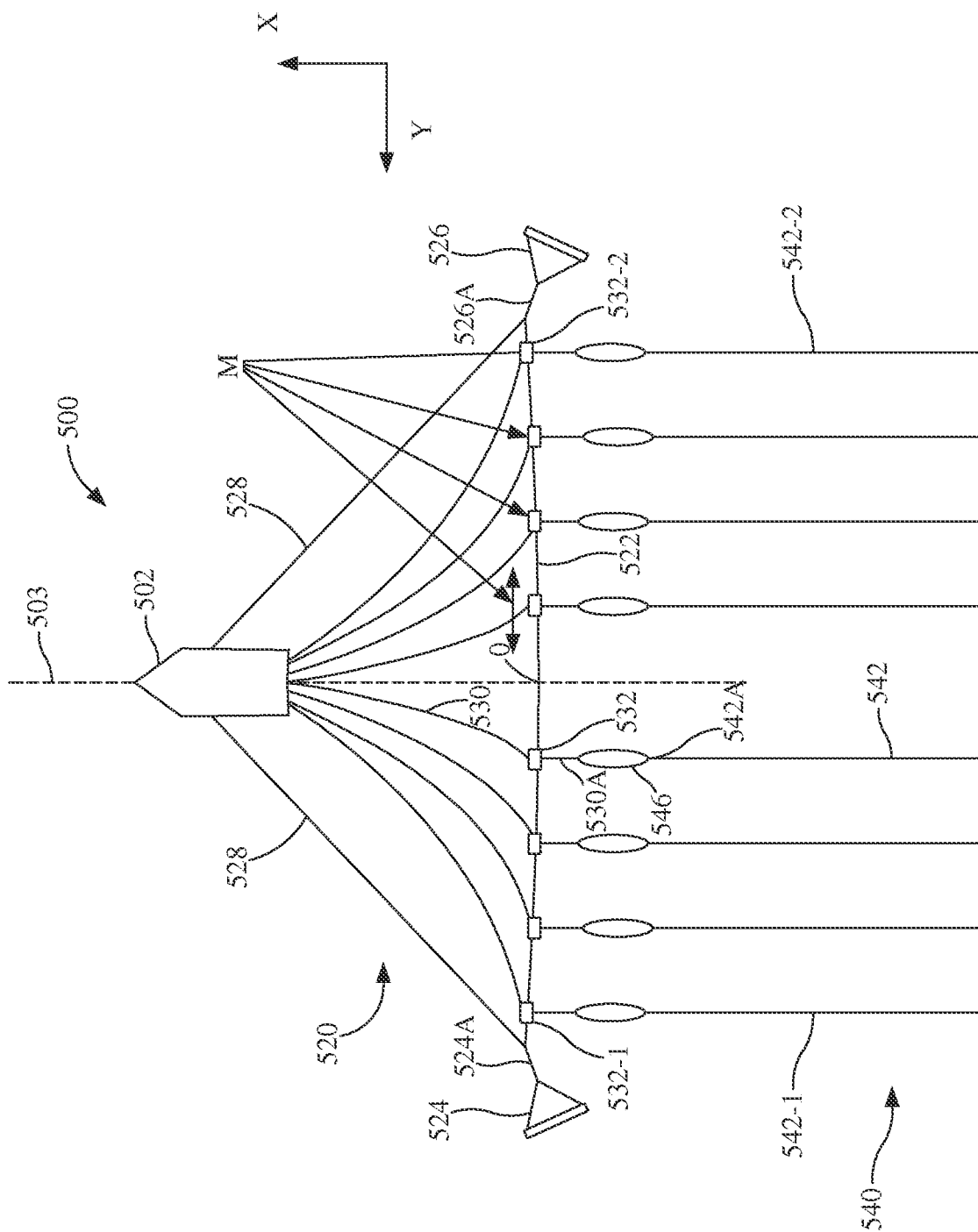


Fig. 5

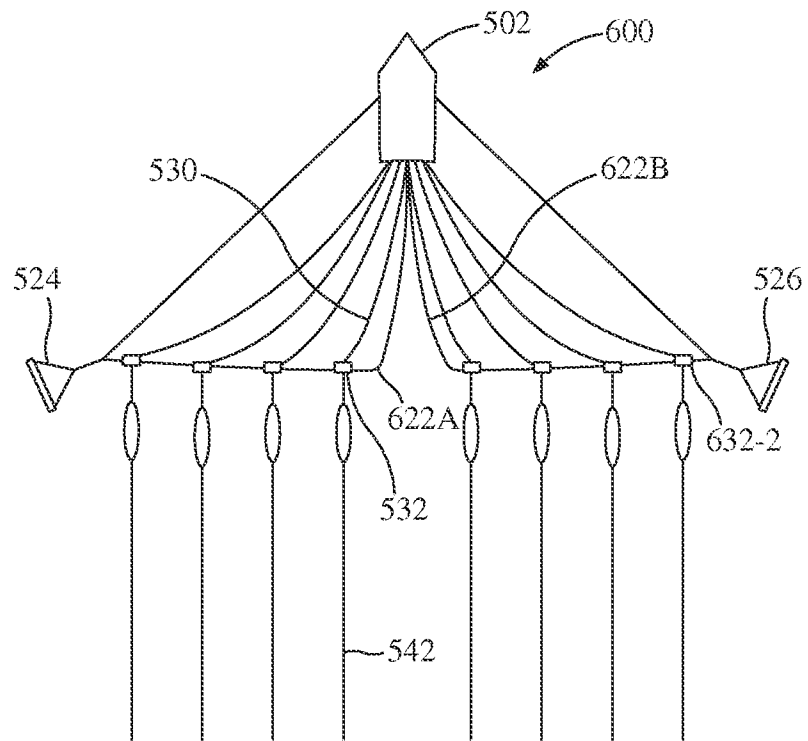


FIG. 6

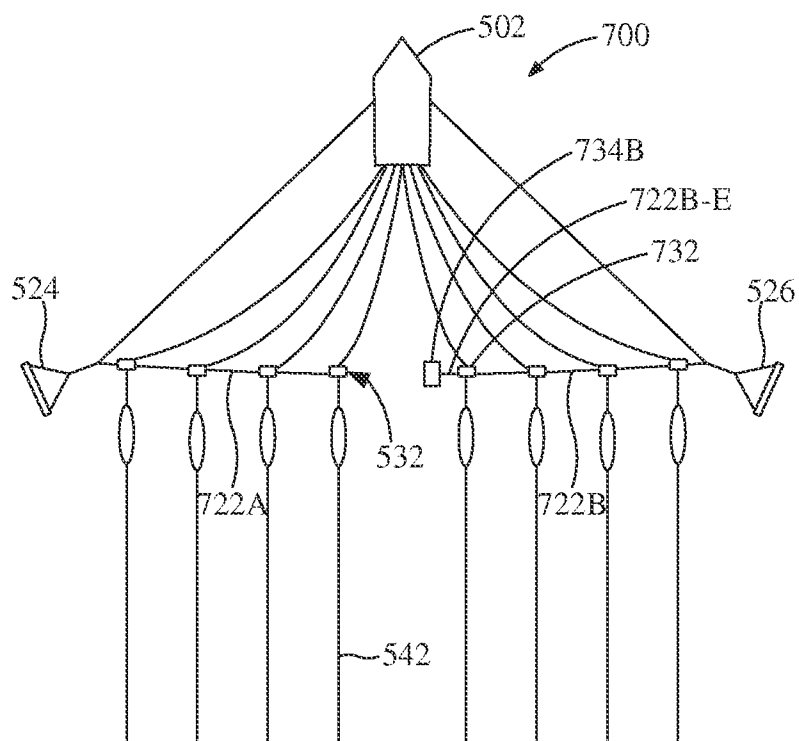


FIG. 7

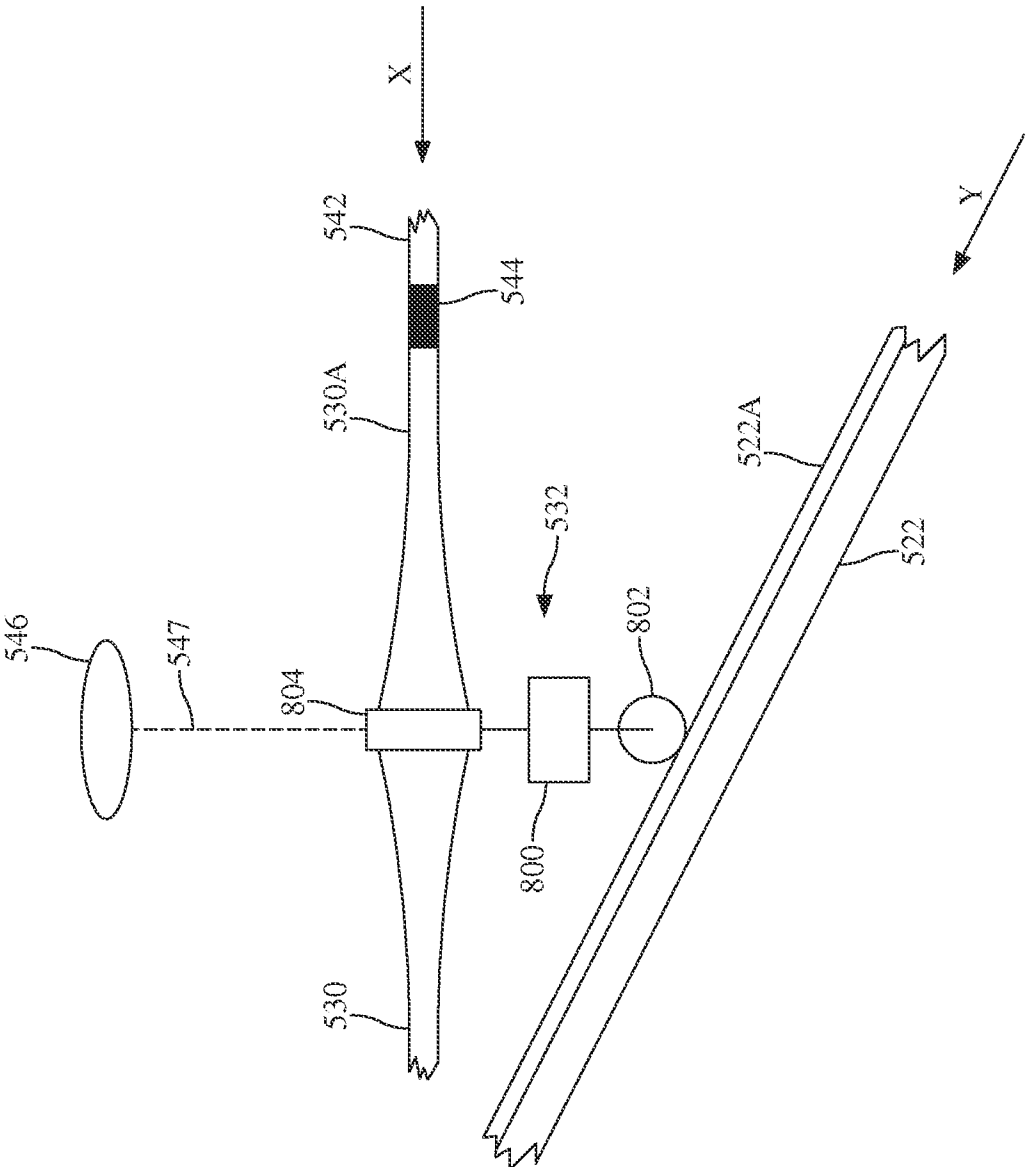


FIG. 8

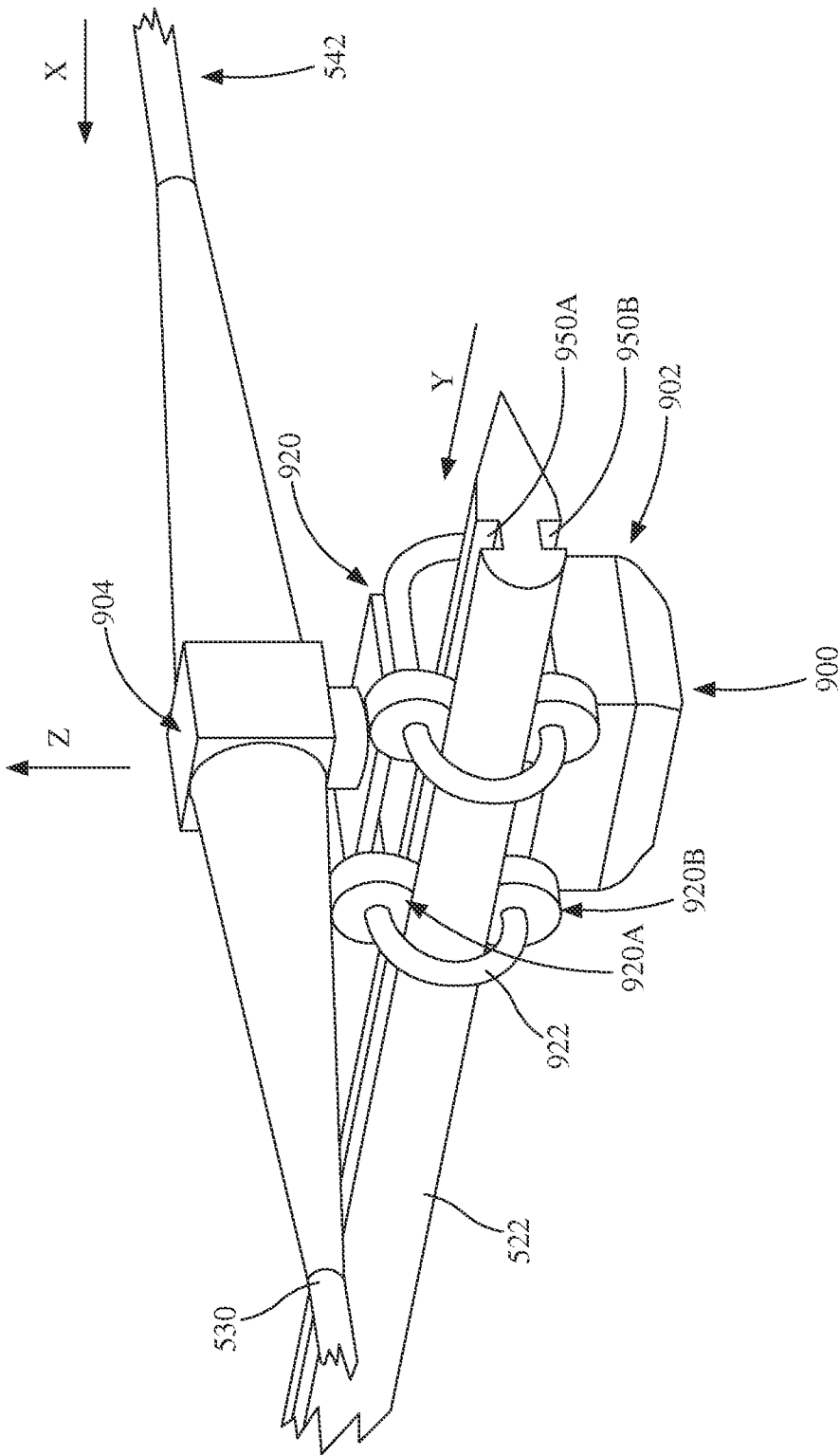


FIG. 9

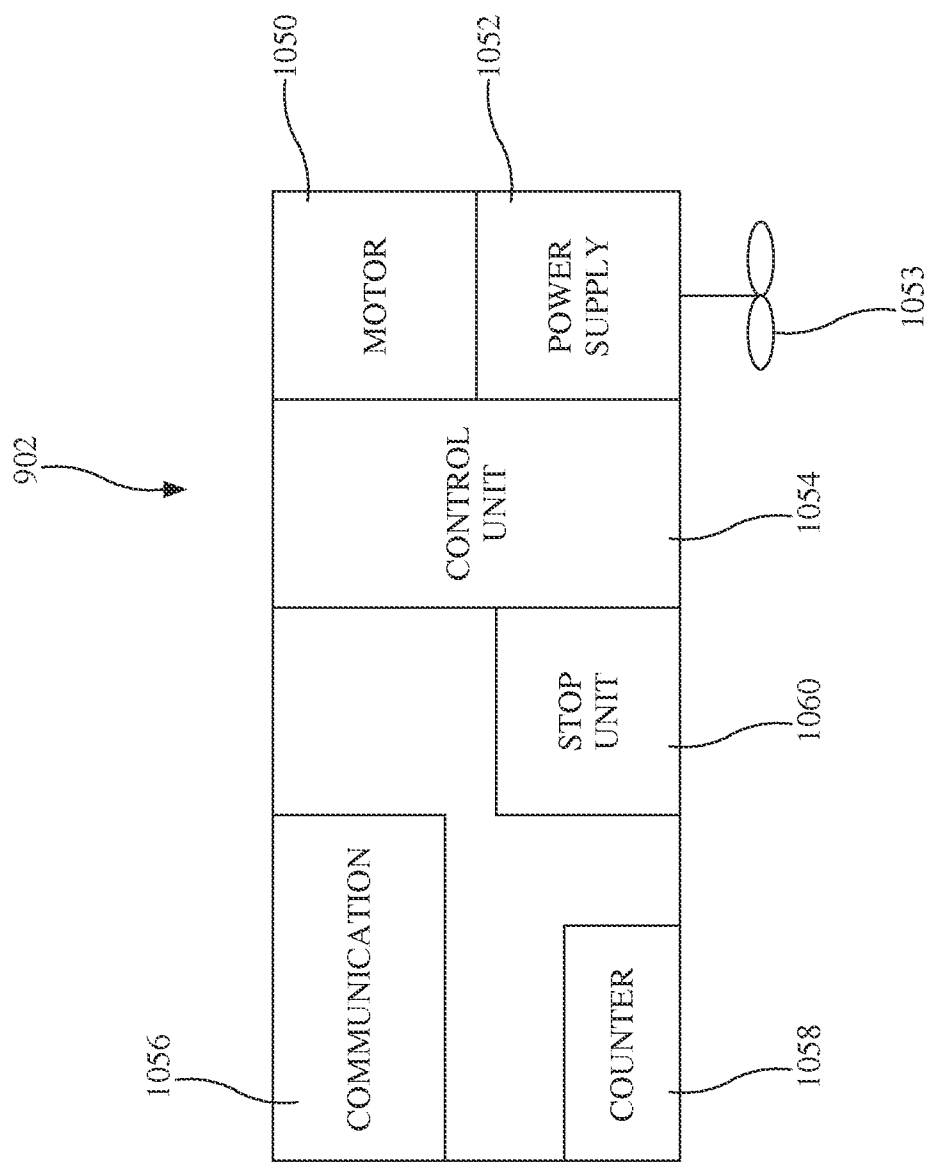


FIG. 10

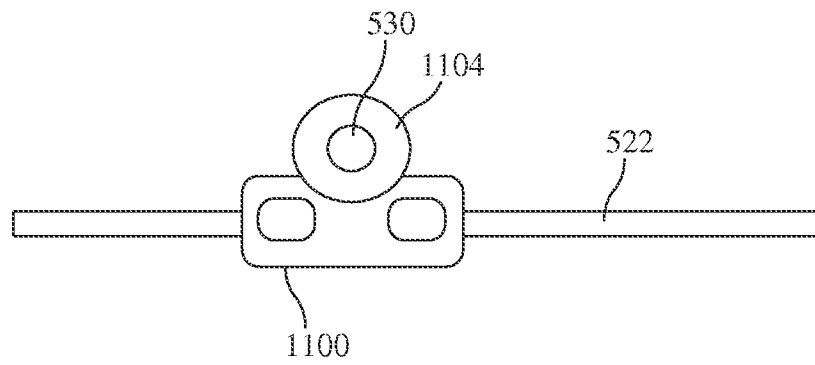


FIG. 11A

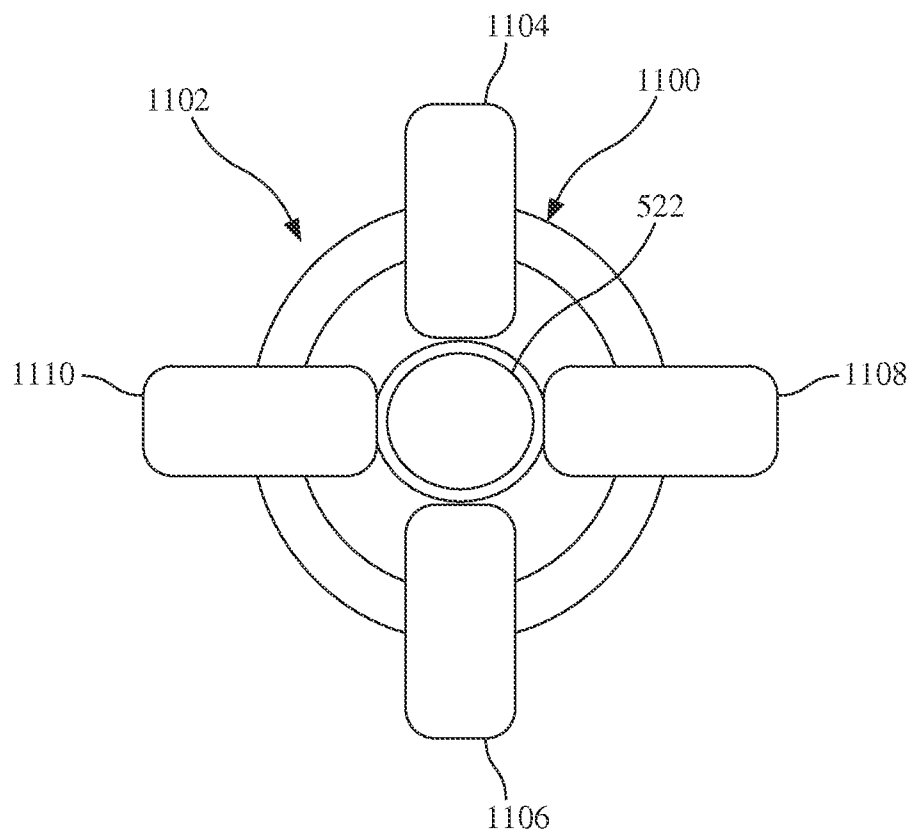


FIG. 11B

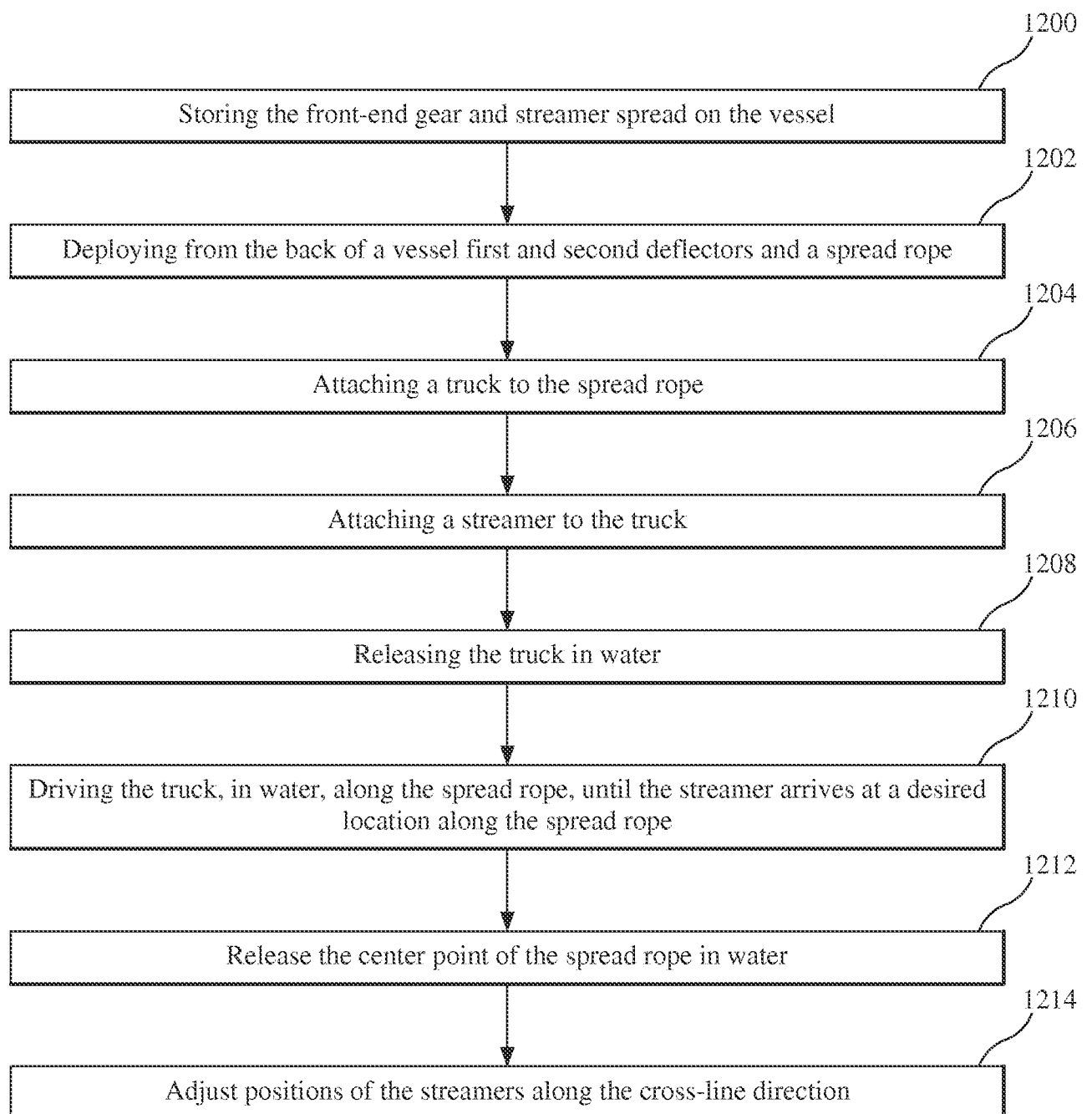


FIG. 12

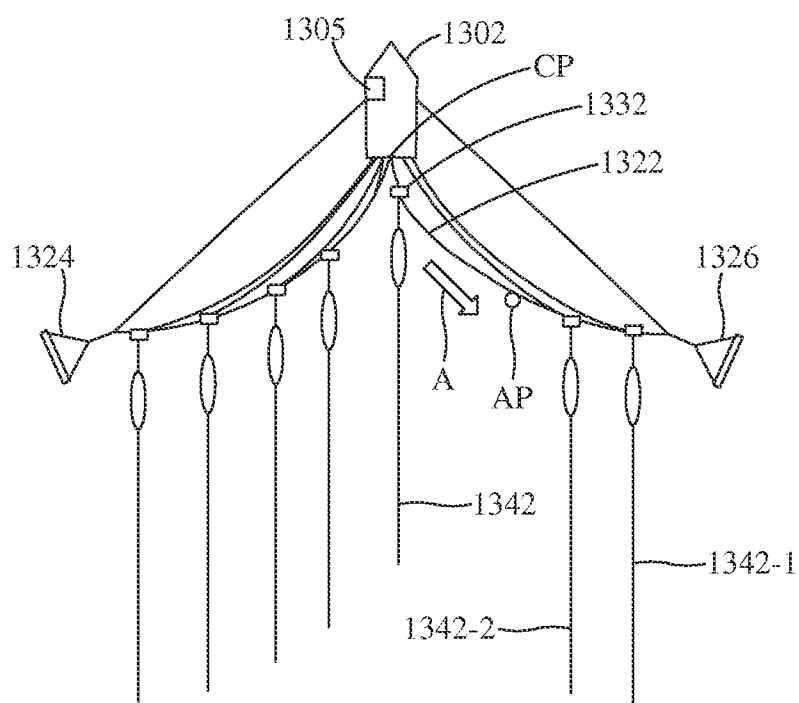


FIG. 13A

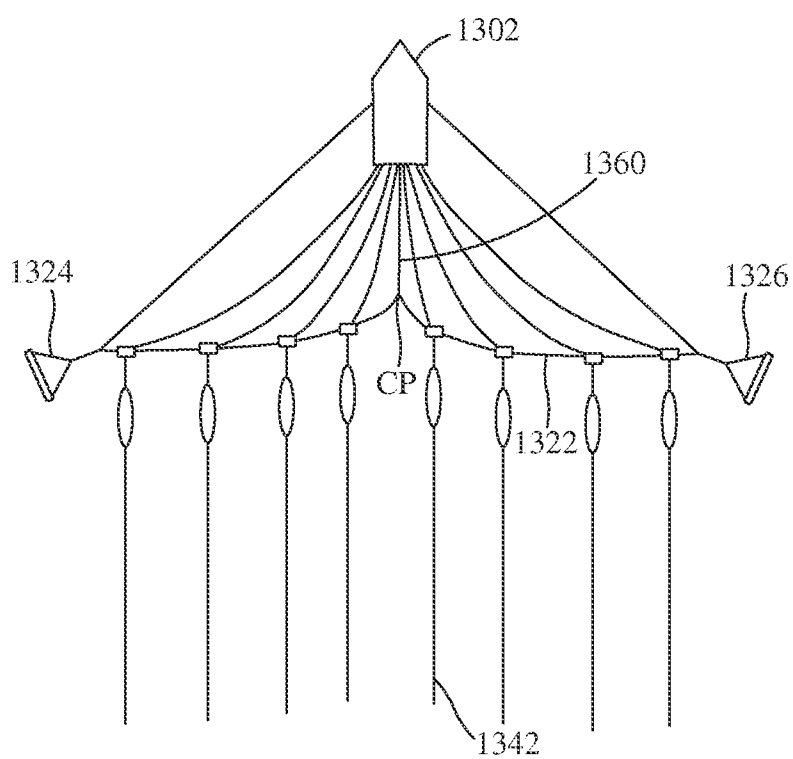


FIG. 13B

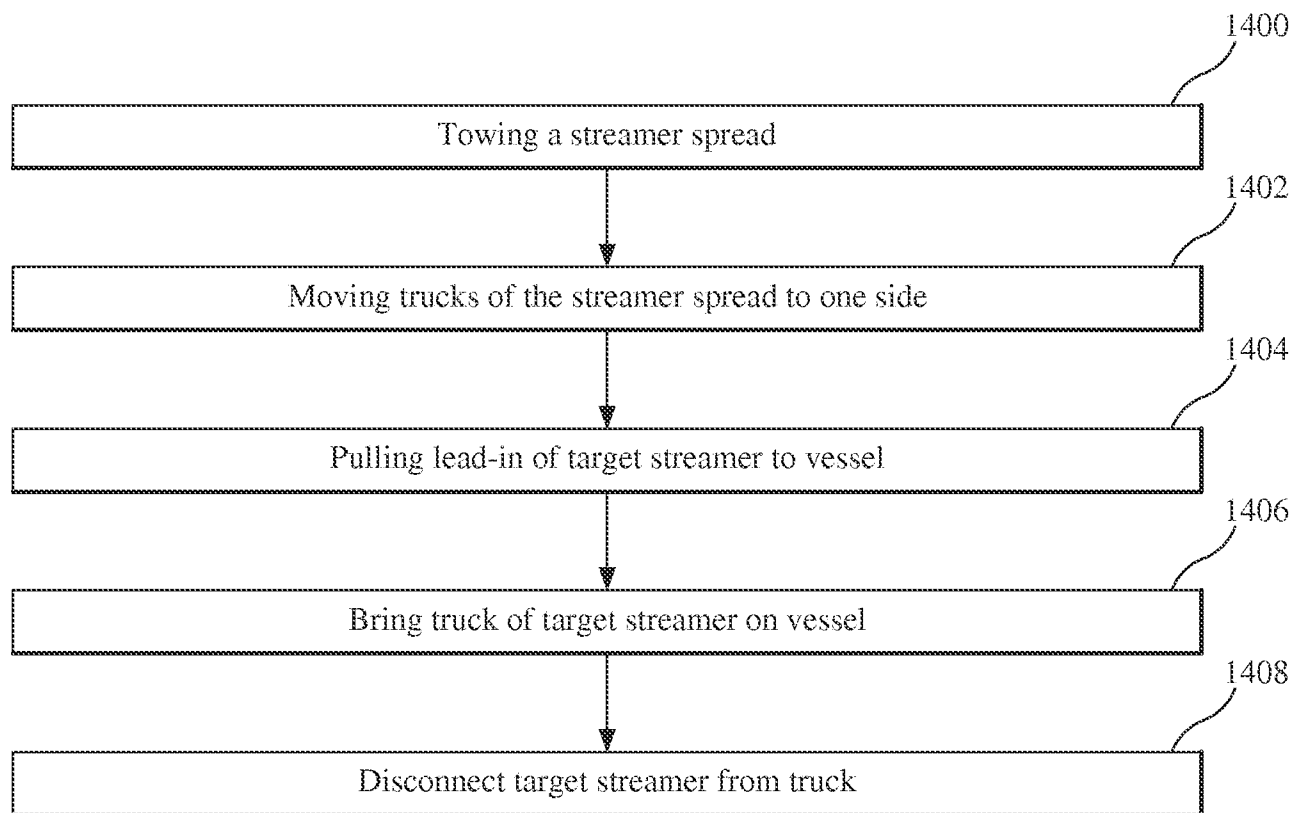


FIG. 14

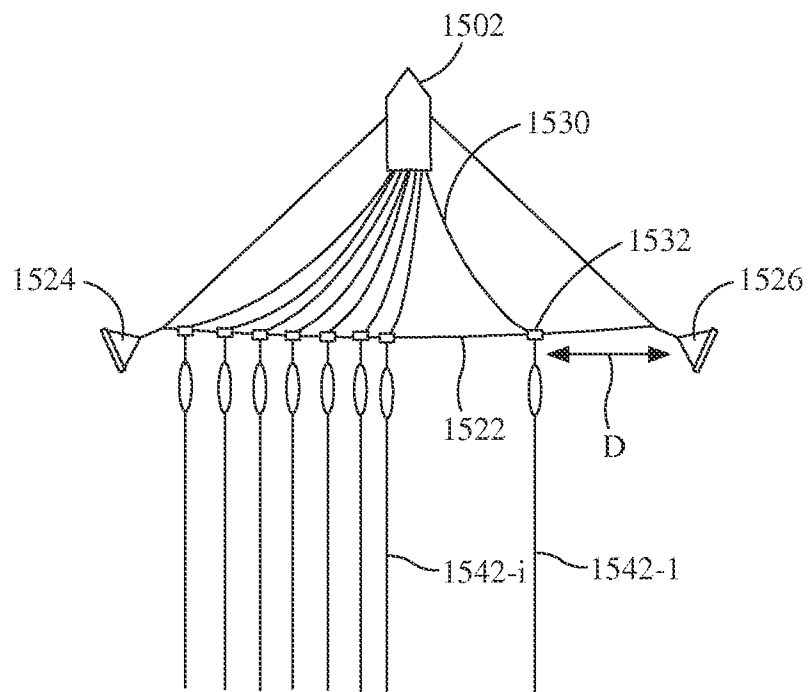


FIG. 15A

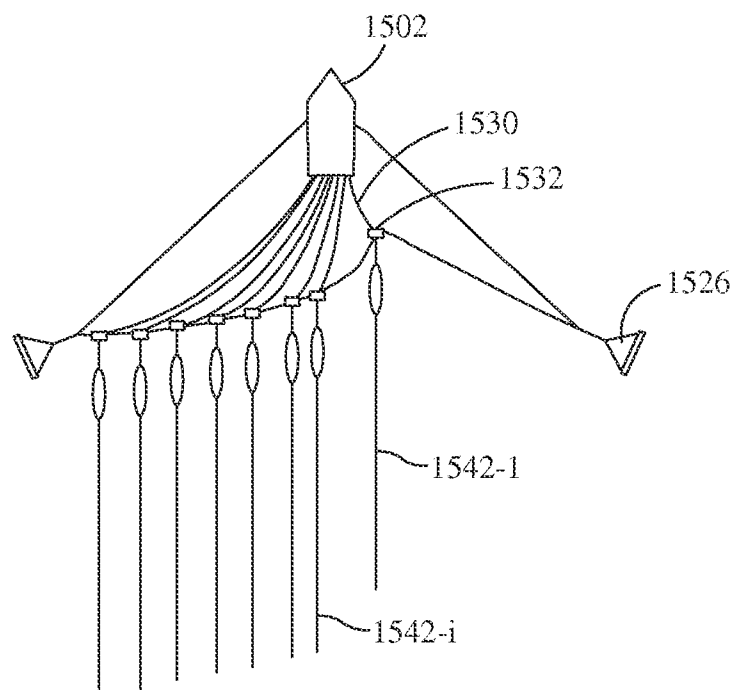


FIG. 15B

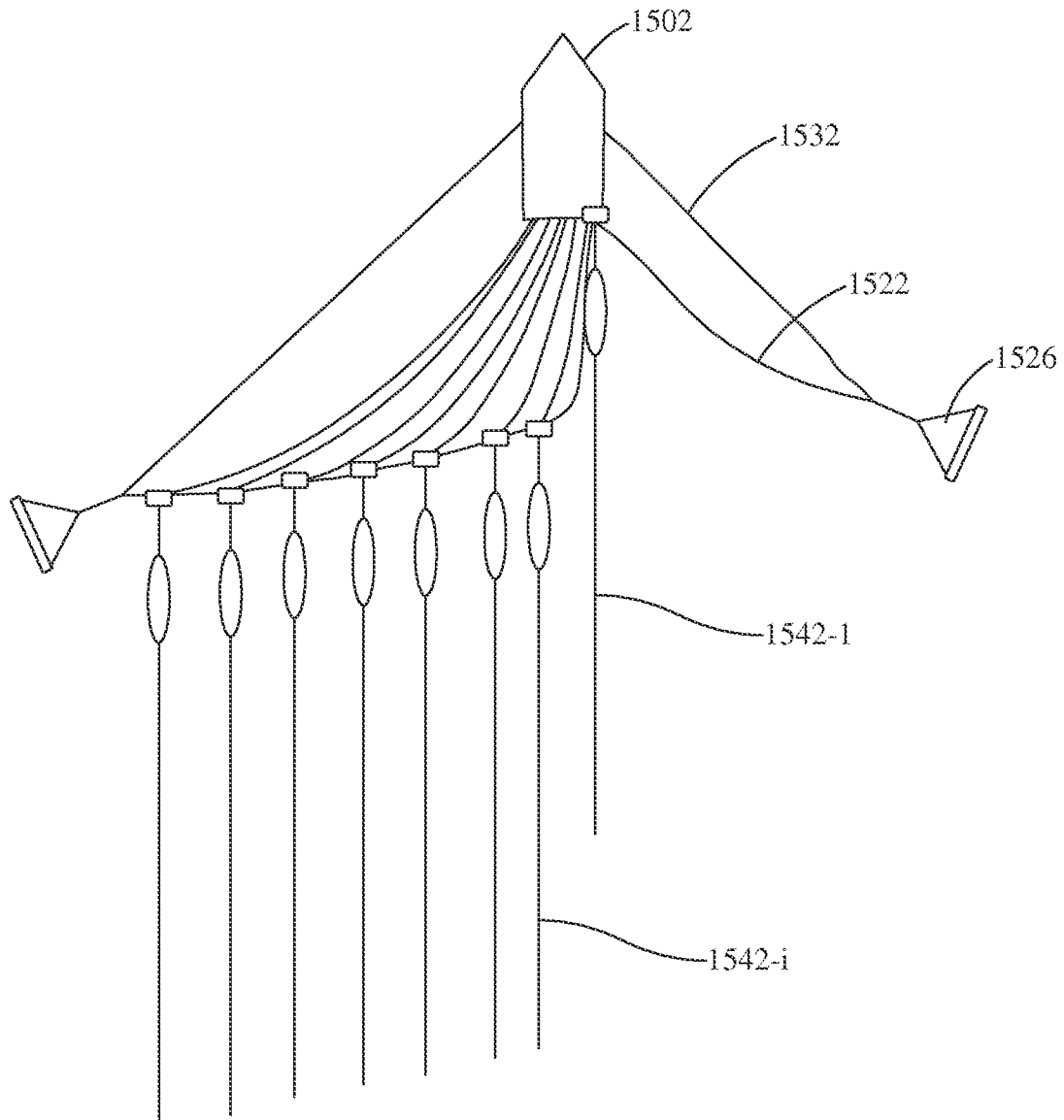


FIG. 15C

1600

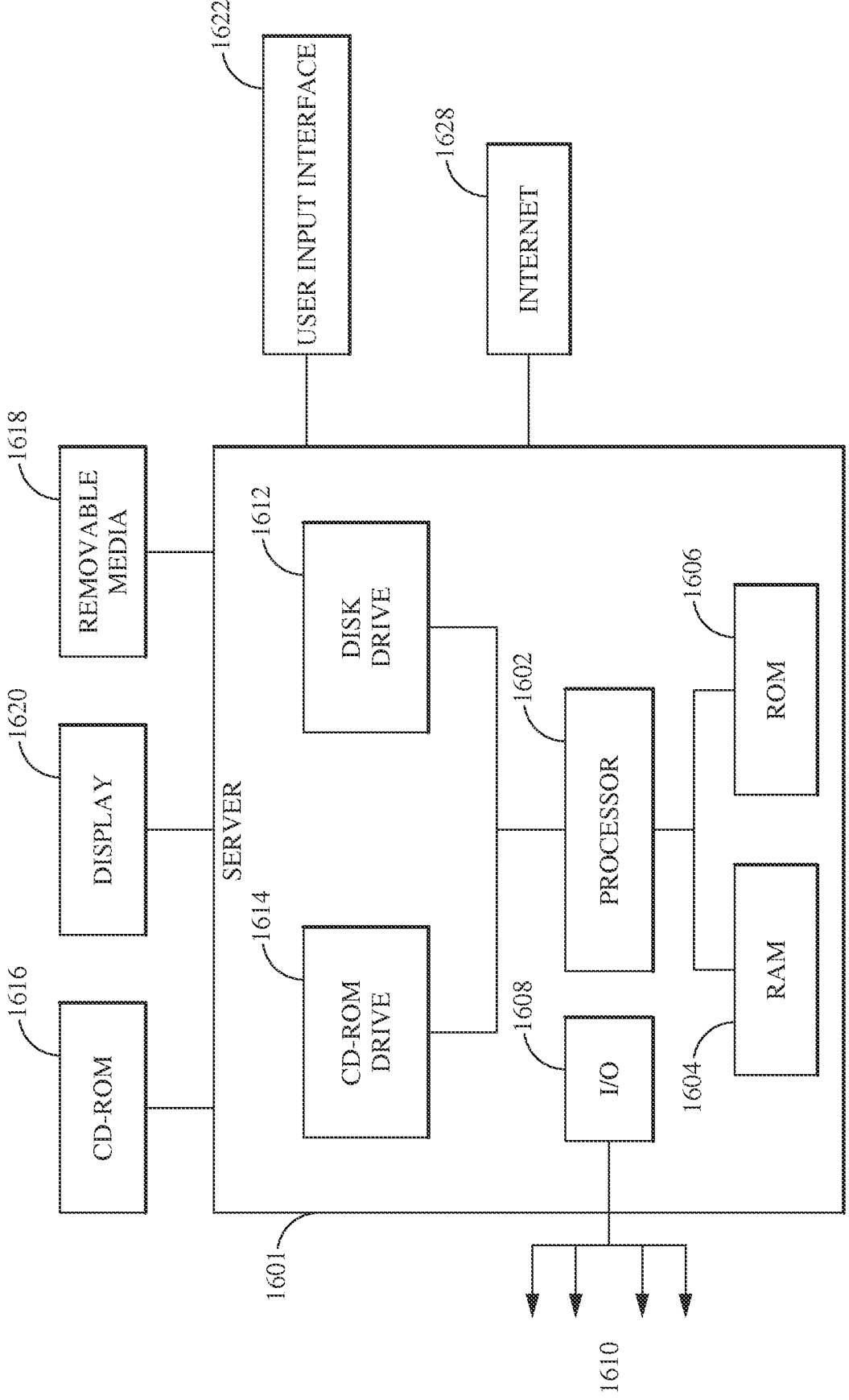


FIG. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2017/000291

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01V1/38
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01V B63B A01K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/195162 A1 (BORGES LARS [NO] ET AL) 2 August 2012 (2012-08-02)	1-10, 12-14, 16-20
Y	figures 1,2,5-7 paragraphs [0025], [0026], [0028], [0033] - [0036], [0041], [0042] -----	11,15
Y	US 2013/155805 A1 (TONCHIA HELENE [FR]) 20 June 2013 (2013-06-20) figures 4-9 paragraphs [0036], [0039] -----	11,15
A	US 2012/300581 A1 (VAHIDA BEHZAD [FR]) 29 November 2012 (2012-11-29) abstract figures 8,9,15 ----- -/--	1-20

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

6 June 2017

Date of mailing of the international search report

21/06/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Authorized officer

Meyer, Matthias

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2017/000291

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 504 792 B2 (BARKER GLEN P [US]) 7 January 2003 (2003-01-07) figures 1-4 abstract -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2017/000291

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