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(54) Title: MARINE ACQUISITION USING SUBAQUATIC FLOATING SEISMIC NODES

Figure 4(a)
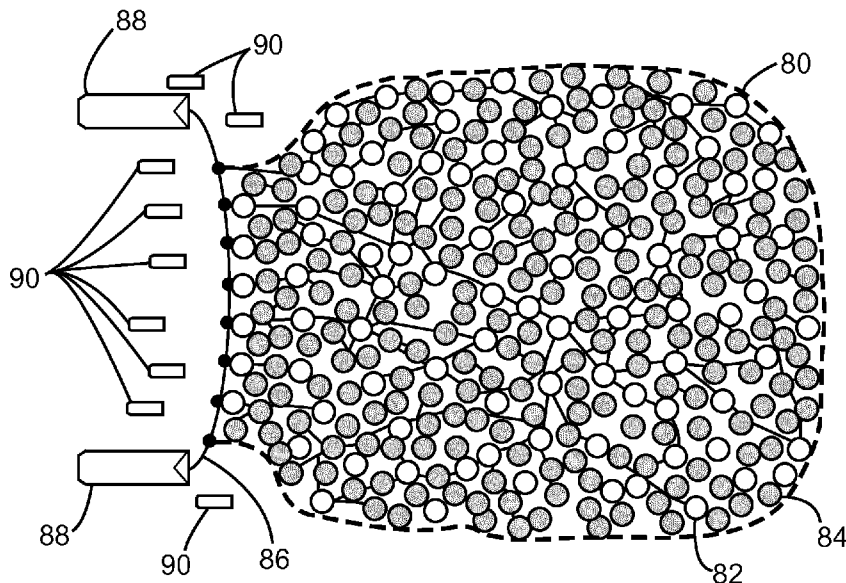
(57) **Abstract**: Methods and systems are presented for generating and performing a seismic data acquisition mission based on an a priori sea current model and a seismic data acquisition operation model and a shooting solution model based on the a priori sea current model. The individual models can be updated based on releasing sample buoys through the survey area both before and during mission execution.

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Marine Acquisition Using Subaquatic Floating Seismic Nodes

Cross-Reference to Related Applications

[0001]   The present application is related to and claims the benefit of priority of

U.S. Provisional Application Serial No. 61/619,007, entitled "Marine Acquisition

Using Subaquatic Floating Seismic Nodes," filed on April 2, 2012 to Risto Siliqi, the

entire contents of which is incorporated herein by reference.

TECHNICAL FIELD

[0002]   Embodiments of the subject matter disclosed herein generally relate to

methods and systems and, more particularly, to mechanisms and techniques for

performing a marine seismic survey using buoys that carry appropriate seismic

sensors.

BACKGROUND

[0003]   Marine seismic data acquisition and processing generates a profile

(image) of geophysical structures under the seafloor. While this profile does not

directly provide a precise location of oil and gas reservoirs, it suggests, to those

trained in the field, the presence or absence of these reservoirs. Thus, providing a

high-resolution image of the geophysical structures under the seafloor is an ongoing

process.

[0004]   Reflection seismology is a method of geophysical exploration for

determining properties of the subsurface of the earth, which is especially helpful in

the oil and gas industry. Marine reflection seismology is based on using a controlled

source of energy that sends the energy into the earth. By measuring the time it

takes for the reflections to come back to plural receivers, it is possible to evaluate the

depth of features causing such reflections. These features may be associated with

subterranean hydrocarbon deposits.

[0005]   A traditional system for generating the seismic waves and recording

their reflections from the geological structures present in the subsurface is illustrated

in Figure 1. A vessel 10 tows an array of seismic receivers 11 provided on

streamers 12. The streamers may be disposed horizontally, i.e., lying at a constant

depth relative to the surface 14 of the ocean or may have other configurations. The

streamers may be disposed to have other than horizontal spatial arrangements. The

vessel 10 also tows a seismic source array 16 configured to generate a seismic

wave 18. The seismic wave 18 propagates downward toward the seafloor 20 and

penetrates the seafloor until eventually a reflecting structure 22 (reflector) reflects the

seismic wave. The reflected seismic wave 24 propagates upward until it is detected

by the receiver 11 on the streamer 12. Based on the data collected by the receiver

11, an image of the subsurface is generated by further analyses of the collected

data.

[0006]   However, this traditional configuration is expensive because of the high

costs associated with operating the towing vessel and the streamers. In addition, the

data produced by the receivers of the streamers can be negatively impacted due to

the flow noise produced by the movement of the streamers in the surrounding water.

Further, the notch diversity of the data recorded with the streamers can be limited.

To overcome some of these problems, new technologies deploy seismic sensors on

the bottom of the ocean (ocean bottom stations, OBS) to achieve a coupling with the

ocean bottom and to reduce the noise. Even so, positioning the seismic sensors remains a challenge for OBS technology.

[0007]   Other technologies use permanent receivers set on the sea bottom, as disclosed in U.S. Patent No. 6,932,185 (herein '185), the entire content of which is incorporated herein by reference. In this case, the seismic sensors 60 are attached, as shown in Figure 2 (which corresponds to Figure 4 of the '185), to a heavy pedestal 62. A station 64 that includes the sensors 60 is launched from a vessel and arrives, due to its gravity, at a desired position. The station 64 remains on the bottom of the ocean permanently. Seismic data recorded by sensors 60 is transferred through a cable 66 to a mobile station 68. When necessary, the mobile station 68 may be brought to the surface to retrieve the seismic data.

[0008]   Although this method provides a good coupling between the ocean bottom and the seismic receivers, the process is still expensive and not flexible because the stations and corresponding sensors are difficult to move around or reuse. Further, positioning the stations is not straightforward. Furthermore, the notch diversity is not greatly improved.

[0009]   An improvement to this method is described, for example, in European Patent No. EP 1 217 390 (herein '390), the entire content of which is incorporated herein by reference. In this document, a receiver 70 is removably attached to a pedestal 72 together with a memory device 74 as illustrated in Figure 3. After recording the seismic signals, the receiver 70 and the memory device 74 are instructed by a vessel 76 to detach from the pedestal 72 and to surface at the ocean surface 78 to be picked up by the vessel 76.

[0010]   However, this configuration is not very reliable because the mechanism

maintaining the receiver 70 connected to the pedestal 72 may fail to release the

receiver 70. Also, the receiver 70 and pedestal 72 may not reach their intended

positions on the seabed. Further, the fact that the pedestals 72 are left behind

increases ocean pollution and the survey price, which is undesirable.

[0011]   Thus, it can be seen from the above approaches that a characteristic of

the existing methods is to record seismic signals either (i) close to the surface, with

streamers, or (ii) at the seabed with OBS. Neither situation offers the desired notch

diversity.

[0012]   Accordingly, it would be desirable to provide systems and methods that

provide an inexpensive and reliable device for recording seismic signals with good

notch diversity.

SUMMARY

[0013] A method of generating and performing a seismic data acquisition mission using a plurality of free-floating subaquatic nodes comprising generating an *a priori* model of sea currents, in a survey area, from available atmospheric and oceanographic data; generating a seismic data acquisition operation model based on said *a priori* model of sea currents; generating a seismic shooting solution to provide illumination and fold of subsurface targets associated with said survey area; launching, from a vessel, a sample portion of said plurality of free-floating subaquatic nodes for collecting preliminary position data associated with said sample portion of said plurality of free-floating subaquatic nodes as they traverse said survey area to confirm sea current drift predicted by said *a priori* model and refining said seismic data acquisition operation model based on said preliminary position data; launching the remainder of said plurality of free-floating subaquatic nodes based on said *a priori* model and said seismic data acquisition operation model; firing said seismic shooting solution based on said seismic data acquisition operation model; and recovering said plurality of free-floating subaquatic nodes, individually, as each free-floating subaquatic node exits said survey area.

[0014] A system for performing a marine-based seismic data acquisition comprising a plurality of free-floating subaquatic nodes; one or more vessels for deploying and retrieving said plurality of free-floating subaquatic nodes; a sea current model component for generating an *a priori* model, based on atmospheric and oceanographic data, of sea currents associated with a survey area; a operation model component for generating a seismic data acquisition operation model based on said *a priori* model; a shooting model component for generating a shooting

solution model based on said seismic data acquisition operation model; and an

update component for analyzing position data collected from said plurality of free-

floating subaquatic nodes and updating said seismic data acquisition operation

model and said shooting solution model.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015]   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:

[0016]   Figure 1 is a schematic diagram of a background art seismic survey system;

[0017]   Figure 2 is a schematic diagram of a background art station that may be positioned on the bottom of the ocean for seismic data recording;

[0018]   Figure 3 is a schematic diagram of another background art station that may be positioned on the bottom of the ocean for seismic data recording;

[0019]   Figures 4a and 4b are schematic diagrams of a seismic survey system that uses buoys for recording seismic data according to an exemplary embodiment;

[0020]   Figure 5 is a schematic diagram of two vessels that determine an underwater position of a buoy according to an exemplary embodiment;

[0021]   Figure 6 is a schematic diagram of a seismic survey system that uses plural buoys distributed at various depths for recording seismic data according to an exemplary embodiment;

[0022]   Figure 7 is a schematic diagram of a seismic survey system that uses plural buoys distributed along a curve for recording seismic data according to an exemplary embodiment;

[0023]   Figure 8 is a schematic diagram of a recovery vessel that instructs various buoys to resurface for recovery according to an exemplary embodiment;

[0024]   Figures 9a and 9b are schematic diagrams of a buoy configured to record seismic signals while traveling underwater according to an exemplary embodiment;

[0025]   Figure 10 is a schematic diagram of a seismic survey system configured to take into consideration lateral currents when recovering buoys according to an exemplary embodiment;

[0026]   Figure 11 is a schematic diagram of a seismic survey system that includes plural launching vessels and plural recovery vessels according to an exemplary embodiment;

[0027]   Figures 12-15 are schematic diagrams of another seismic survey system according to an exemplary embodiment; and

[0028]   Figure 16 is a flowchart of a method for generating and performing a seismic data acquisition mission using a plurality of free-floating subaquatic nodes according to an exemplary embodiment.

DETAILED DESCRIPTION

[0029]   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 embodiments are discussed, for simplicity, with regard to the terminology and structure of a buoy having seismic sensors and being deployed from a deployment vessel. However, the embodiments to be discussed next are not limited to buoys being deployed from a vessel, but may be applied to other devices that may include seismic sensors.

[0030]   Reference throughout the specification to "one embodiment" or "an 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 in one or more embodiments.

[0031]   Looking to Figure 4a, an initial exemplary embodiment shows a top view of a net 80 enclosing a collection of floating receiver buoys 82 and spacer buoys 84. The net 80 is connected to a tow line 86 that is connected to one or more vessels 88. The exemplary embodiment further includes sources 90 for creating the seismic sounding wave.

[0032]   It should be noted in the exemplary embodiment that the spread can be static during the seismic acquisition and seen as a net of floating nodes while the

sources move to different positions. After an exemplary embodiment acquisition is completed, the net can be towed to a different position and another acquisition cycle can be completed. This process can be repeated until the area of interest has been sampled.

[0033]   New technologies in marine seismic surveys need an inexpensive system for deploying and recovering the sea-based seismic receivers. According to an exemplary embodiment, such a seismic system includes multiple buoys, each having one or more seismic sensors. The buoys are initially stored on a launching vessel. The launching vessel launches the buoys at predetermined distances along a course of the vessel. The seismic receivers may be at least one of a hydrophone, geophone, accelerometer, electromagnetic sensor, etc. The buoys are configured to control their own buoyancy so that each buoy is capable of reaching a predetermined depth and then resurfacing on its own, when instructed. After performing the recording, according to an exemplary embodiment, a recovery vessel approaches the buoys, instructs them to resurface and collects them. It should be noted in the exemplary embodiment that a buoy is also known as a free-floating subaquatic node.

[0034]   However, there are certain areas where the underwater currents are strong and, thus, the buoys are not stationary during the seismic survey. For this situation, the new technology takes advantage of the existing underwater currents and allows the buoys to travel underwater to follow the current path. For this reason, the current paths (or trajectories) may be estimated before launching the buoys so it is known where to expect the buoys to arrive after a given time for collection purposes. The launching and recovery vessels may track the position of the buoys

and update the current paths based on real-time measurements. The seismic receivers of the buoys are configured to record seismic signals as a buoy travels from the launching vessel to the recovery vessel. The seismic signals are time-stamped and associated with corresponding three-dimensional (3D) positions (coordinates of the buoy) where the signals were recorded.

[0035]   A seismic system assumed to operate underwater with low or no water currents is now discussed in more detail according to an exemplary embodiment illustrated in Figure 4b. Figure 4b illustrates a seismic survey system 100 that may include a launching vessel 102, a recovery vessel 104 and plural buoys 106. Both vessels 102 and 104 may act as (i) recovery or (ii) launching or (iii) recovery and launching vessels. These vessels may be small boats with a low cost of operation.

[0036]   The launching vessel initially stores the plural buoys 106. When the survey is started, the launching vessel 102 launches the buoys 106 with a certain space interval d. The space interval d may be, for example, between 10 and 200 m. However, the value of the space interval may vary according to the goals of the seismic survey. The system 100 may also include one or more source vessels 120 that are configured to tow a seismic source 122. The seismic source 122 is configured to generate a seismic wave 124. A reflected seismic wave 126 is recorded by the seismic receiver of the buoy 106.

[0037]   The buoys 106 are configured to sink to a predetermined depth H and then to maintain that depth until instructed to the contrary. The depth may, for example, be between 200 and 300 m. However, other depths may be used according to the goals of the seismic survey.

[0038]   The launching vessel launches the buoys while moving along a

predetermined path. The buoys, assuming that there is low or no underwater

current, tend to maintain their absolute position. Seismic sources are deployed to

generate seismic waves. Reflections of the seismic waves from the subsea surfaces

are recorded by the seismic receivers of the buoys. While recording the seismic

waves, the buoys also listen for an acoustic signal from the recovery vessel that

indicates that the buoy needs to resurface. Upon receiving that acoustic signal, the

buoy resurfaces and it is then collected by the recovery vessel.

[0039]   A distance D between the launching and recovery vessels may be in

the order of kilometers, for example, 10 km. Under this scenario, as illustrated in

Figure 5, the launching vessel 102 may have two acoustic pingers 202 and 204 (that

form an acoustic system) and the recovery vessel 104 may have two acoustic

pingers 206 and 208. The acoustic pingers may be provided on sides of the vessels

and may be configured to use their own frequencies (f1 to f4) so that a buoy 210

receives four different frequencies from the acoustic pingers. The acoustic pingers

may be configured to transmit a signal, for example, every 5 seconds, with a range

of 5 km.

[0040]   The buoy may have an oscillator (to be discussed later) that keeps a

copy of the 5-second transmitting clock. Thus, the buoy is configured to record the

time of arrival of the acoustic signals from the pingers. Combining that information

with the depth information given by its pressure gauge and the positions of the

pingers (provided, for example, by a differential global positioning system (DGPS),

and optionally by the pitch and roll of the boats), it is possible to reconstitute the

absolute position of each buoy at any desired time so that the time-stamped

recorded signals may be mapped to the positions of the buoy when the seismic signals were recorded. Figure 5 shows DGPS units 220A and 220B mounted on each vessel. Other GPS-type units may be used.

[0041]   Thus, the buoys shown in figures 4b and 5 may be imagined as the equivalent of one or more streamers (in terms of seismic data collection), but with the advantage that there is no drag on the vessels, a depth range of the buoys is much enlarged comparative with a real streamer, and a distance d between the receivers may be adjusted as desired. Also, the buoys may be instructed before being launched from the launching vessel 204 to have various depths as illustrated in Figures 6 and 7.

[0042]   In this respect, Figure 6 is a side view showing a system 300 that includes a launching vessel 302, a recovery vessel 304 and plural buoys 306. Some buoys form a first layer 308, which is provided at a first depth H1, and other buoys form a second layer 310, which is provided at a second depth H2, different from H1. Although Figure 6 shows the buoys provided at only two depths, those skilled in the art would appreciate that the buoys may be provided at more than two depths.

[0043]   Figure 7 is a side view showing a system 400 that includes a launching vessel 402, a recovery vessel 404, and plural buoys 406. The buoys are arranged in this embodiment along a curve 408. The curve 408 may be a straight line, a parabola, a hyperbola, an exponential, etc., or a combination of these types of functions. In the embodiment illustrated in Figure 7, the curve 408 has a curved portion 410 and a straight line portion 412. It is noted that the buoys not distributed on the curve 408 are travelling to either reach their final underwater position (those

closer to the launching vessel 402) or their surface position (those closer to the recovery vessel 404) for being recovered by the recovery vessel 404.

[0044]   The recovery phase of the buoys is now discussed with regard to Figure 8. Figure 8 shows a system 500 that includes a launching vessel (not shown), a recovery vessel 502 and plural buoys 504. A set of buoys 506 is shown having a predetermined depth, while another set of buoys 508 are in the process of surfacing, and still another set of buoys 510 are already at the water surface 512 waiting to be recovered by the recovery vessel 502.

[0045]   The recovery vessel generates an acoustic signal 514 with an appropriate acoustic signal generator 516. The acoustic signal 514 may have a frequency f5 different from the frequencies used by the pingers of the launching and recovery vessels. The acoustic signal 514 may be a short-range acoustic signal and constitutes a command for the buoy to surface. When a buoy receives the acoustic signal 514, the buoy activates its buoyancy system (to be discussed later) to resurface. The set of buoys 508 are in the middle of the resurfacing process. Once at the water surface, each buoy of the set of buoys 510 activates a radio-frequency (RF) beacon (transmitter) for sending a signal 520 to the RF goniometer 522 of the recovery vessel 502. Thus, each buoy may have an RF transmitter 524.

[0046]   Based on this information, the recovery vessel 502 determines the position of each buoy and recovers them. The recovery process may include bringing the buoys on a deck of the vessel. The structure of a buoy is now discussed with regard to Figure 9.

[0047]   Figure 9a illustrates an exemplary buoy 900. The buoy 900 may have a body 901 that includes a buoyancy system 902 configured to control the buoyancy

of the buoy. For example, the buoyancy system 902 may change the effective density of the buoy. The density of any object is determined by its mass divided by its volume. The buoy 900 may keep its mass constant, but altering its volume changes its density. To achieve this, for example, a hydraulic piston may be used to push, e.g., mineral oil out of the buoy and expand a rubber bladder at the bottom end of the buoy. As the bladder expands, the buoy becomes less dense than the seawater and rises to the surface. Upon being launched from the launching vessel, the buoy withdraws the piston and descends to the desired depth to record seismic signals.

[0048]　　　This is one example for controlling the buoyancy of the buoy. Those skilled in the art would appreciate that other systems may be employed for controlling the buoyancy of the buoy. In one application, the buoyancy system may include a motor and a propeller to further control the speed and direction of the buoy.

[0049]　　　Further, the buoy 900 may include one or more sensors 904, e.g., a pressure gauge, for determining the pressure and/or temperature of the ambient of the buoy, etc. A processor 906 may be connected to the sensors 904 and the buoyancy system 902 for coordinating the up and down movement of the buoy. The processor 906 may also be configured to control the vertical speed of the buoy by controlling the buoyancy of the buoy. For example, the processor may be configured to achieve a first speed for a shallow depth and a second speed for higher depths. Also, the processor 906 may calculate the depth of the buoy based on the pressure readings from the sensor 904.

[0050]　　　The processor 906 may also be connected to a battery 908, a high-accuracy oscillator or clock module 910, e.g., a temperature-controlled crystal

oscillator (TCXO), a data storage device 912, an inertial device 914, a GPS 916 and

a corresponding antenna 916a, and an RF beacon 918 and a corresponding antenna

918a, etc. The battery 908 may be any known battery. The module 910 is

configured to provide an accurate time to the processor 906 for correctly time-

stamping the recorded seismic data. In one application, the module 910 is

configured to sample every 2 ms the acoustic signal and time-stamp it. The module

910 may also record a compass direction. Based on the temperature sensor, the

module 910 may adjust/correct its oscillating time to provide an accurate time as the

water temperature is changing.

[0051]   The optional inertial device 914 may be an inexpensive inertial

navigation system (INS). An inertial navigation system includes at least a module

containing accelerometers, gyroscopes or other motion-sensing devices. The INS is

initially provided with the position and velocity of the buoy from another source, for

example, a human operator, the GPS 916, etc., and thereafter the INS may compute

its own updated position and velocity by integrating information received from its

motion sensors. The advantage of an INS is that it requires no external references

in order to determine its position, orientation or velocity once it has been initialized.

Further, usage of the INS is inexpensive. However, in the exemplary embodiment

discussed herein, the position of the buoy is determined using the pingers of the

vessels discussed above.

[0052]   The buoy 900 may also include the RF beacon 918, which is

configured to send RF signals such that a vessel can locate the buoy. The

processor 906 is configured to activate the RF beacon 918 when the buoy is at the

surface of the water, or the antenna 918a is capable of transmitting the RF signals to

a vessel. Those skilled in the art would recognize that the buoy may include other equipment that helps the navigation. However, it is desirable to provide an inexpensive buoy and, for this reason, it may be desirable that the equipment added to the buoy be kept to a minimum.

[0053]   In terms of seismic equipment, the buoy 900 may include one or more seismic sensors 920. Such a sensor may be at least one of a hydrophone, geophone, accelerometer, electromagnetic sensor, etc. In one application, the seismic sensor includes only a hydrophone. In another application, the seismic sensor includes a hydrophone and three geophones. Once the buoy has reached the desired depth, the buoy stabilizes its position by performing, for example, a control loop between the buoyancy control system and the pressure gauge. Additionally, the buoy 900 may include an acoustic signal conditioning module 922. This module is configured to process the acquired seismic signals, for example, to apply various filters to the recorded seismic signals.

[0054]   Looking to figure 9b, another exemplary buoy is illustrated. The exemplary buoy comprises a float 950, a top stabilizer 952, an underwater buoy 954, a bottom stabilizer 956 and an anchor 958. It should be noted in the exemplary embodiment that the float 950 and the anchor 958 are not necessarily attached to anything above or below the exemplary buoy, allowing the buoy to drift with the current while maintaining a stable orientation at a configured depth.

[0055]   The embodiments discussed above have assumed that the water currents are minimal or non-existing. However, if there are some underwater currents (not strong currents) that need to be taken into account, the next exemplary embodiments explain how to address this matter. Figure 10 shows a top view of a

system 1000 in which the launching vessel 1002 launches buoys 1004a-e along a

predetermined path 1006. A real-time map of the buoys may be achieved by using

the pingers of the vessels. Thus, a controller 1007 provided on the recovery vessel

1008, or on the launching vessel 1002, or distributed on both vessels, may calculate

how strong the underwater currents 1010 are and may instruct the recovery vessel

1008 to take a path 1012 to correctly intercept the resurfacing buoys.

[0056]   The buoys may also be used to perform a 3D seismic survey as shown

in Figure 11. The system 1100 may include plural launching vessels 1102a-e and

corresponding plural recovery vessels 1106a-e. Buoys 1104 are launched by each

launching vessel and recovered by the corresponding recovery vessel as explained

in the previous embodiments. Source vessels may be used to obtain a wide azimuth

seismic survey. Thus, such a system may work similarly to a conventional system in

which a vessel tows multiple streamers. In this case, a "streamer" is formed by the

buoys between the launching vessel and the recovery vessel.

[0057]   However, the system shown in Figure 11 is cheaper than the

conventional streamer system because the vessels used to launch and recover the

buoys are not as sophisticated as the vessel that tows the streamers, there is no

drag produced by the buoys on the vessel, and the buoys themselves are cheaper

than the streamers. In addition, the present system obtains more diversified data,

the seismic receivers on the buoys reach a greater depth than the current depths

achieved by the streamers, and the flow noise is minimized or entirely suppressed

because the speed of the buoy during data acquisition is substantially zero.

[0058]   In addition, because the flow noise present in the case of the real

streamers is absent in the present design, the speed of the launching and recovery

vessels may be increased above the conventional 5 knots per hour used in

streamer-based seismic surveys. This decreases the time necessary for completing

the survey, which results in a reduced cost for renting and operating the equipment,

and also reduces personnel expenses. Further, the present system may be

deployed near obstructed areas, e.g., next to drilling platforms, etc. Not the least,

the data recorded with the present system achieves the highest notch diversity,

which is desirable for data deghosting.

[0059]   However, if the underwater currents are significant, for example, having

a speed equal to or greater than 200 or 300 meters per hour (m/h), the above-

discussed embodiments pose a challenge to the recovery vessel when recovering

the buoys because the buoys may spread beyond a desired range. Thus, according

to another exemplary embodiment, the high underwater currents may be used to the

advantage of the seismic survey as now discussed.

[0060]   As illustrated in Figure 12, a system 1200 includes a launching vessel

1202, a recovery vessel 1204, and plural buoys 1206. The vessels may be equipped

with an acoustic system 1210 for tracking the position of the buoys when

underwater. An exemplary acoustic system is described next, and this system can

track the buoy with an accuracy of approximately five meters at a distance on the

order of kilometers.

[0061]   The acoustic system 1210 may be an Ultra-short baseline (USBL)

system, also sometimes known as Super Short Base Line (SSBL). This system uses

a method of underwater acoustic positioning. A complete USBL system includes a

transceiver, which is mounted on a pole under a vessel, and a

transponder/responder on the buoy. A processor is used to calculate a position from

the ranges and bearings measured by the transceiver. For example, an acoustic

pulse is transmitted by the transceiver and detected by the subsea transponder,

which replies with its own acoustic pulse. This return pulse is detected by the

transceiver on the vessel. The time from the transmission of the initial acoustic pulse

until the reply is detected is measured by the USBL system and is converted into a

range. To calculate a subsea position, the USBL calculates both a range and an

angle from the transceiver to the subsea buoy. Angles are measured by the

transceiver, which contains an array of transducers. The transceiver head normally

contains three or more transducers separated by a baseline of, e.g., 10 cm or less.

[0062]   Figure 12 also shows a seismic survey area 1220 that is desired to be

surveyed with the buoys 1206. Based on various data (e.g., historic data) available

for the underwater currents corresponding to the area 1220, a current model is

developed through computer calculations in a computer system 1222. The output of

these computer calculations is a number of current paths/trajectories 1224. Thus, a

current map 1226 may be developed for the area 1220 of interest. With this

information, the survey is designed so that the buoys are launched at a side (line)

1220A of the area 1220 of interest such that the underwater current 1224 would take

the buoys to the opposite side (line) 1220B of the area 1220. Thus, a

course/trajectory of the launching and/or recovery vessels may be substantially

perpendicular on the trajectories of the underwater currents.

[0063]   A distance 1220C travelled by the buoys may be in the order of

kilometers, e.g., 20 to 30 km. In other words, the buoys are expected in this

embodiment to travel along the current 1224, from one side 1220A of the survey

area 1220 to an opposite side 1220B of the survey area 1220.

[0064]   Thus, for such an arrangement, the launching vessel is instructed to travel back and forth along the first side 1220A and to launch a first set of buoys 1206A at a first pass, a second set of buoys 1206B at a second pass (later in time) as shown in Figure 13, and so on until a desired number of buoys has been launched as shown in Figure 14. It is noted in these figures the path 1230 followed by the launching vessel and how the buoys are spaced along an X direction at a desired first distance and along a Y direction at a desired second distance. Figure 14 also shows how the first set of buoys 1220A reach the recovery vessel 1204. It is noted that the buoys 1220 are distributed underwater similar to the embodiment shown in Figure 4, with the exception that in that embodiment the buoys are almost stationary, while in Figures 12-14 the buoys travel underwater, up to tens of kilometers as required by the survey. For example, for a current of 700 m/h as might be in the Gulf of Mexico, a buoy may travel along the current 1224 for 84 km in five days.

[0065]   If there is a desire to limit the spread of the buoys over the X axis, the survey may be divided into smaller areas (rectangles or other shapes) 1220-1 to 1220-3 as shown in Figure 15, and each smaller area may be surveyed as shown in Figures 12-14. Once the survey of one area is finalized, the recovery vessel may become the launching vessel and the former launching vessel moves to the end of the second area to restart the recovery for the survey.

[0066]   Continuing with an exemplary embodiment, pre-study and planning of a survey mission, accomplished with a sea current model component, is based on an a priori model of the currents in the survey area. It should be noted in the exemplary embodiment that the information and measurements used for the initial model are

available from sources such as but not limited to Argos, weather forecasts, national government administrations, etc. It should further be noted in the exemplary embodiment that this phase of the planning can include the launching of a sample number of buoys at sea in the area of interest to validate obtained data, collect data in areas where data is not obtainable or refine data based on changing conditions. The exemplary embodiment initial model can be iterative updated as new data becomes available. Further in the exemplary embodiment, data can be collected from the sample buoys while they are drifting at sea and the model can be re-computed and updated in quasi real-time or with delays associated with data transmission time.

[0067]   Next in the exemplary embodiment, a complete seismic acquisition plan and operational model is prepared by an operation model component using the previously defined a priori model of the currents associated with the survey area of interest. The exemplary embodiment seismic acquisition plan will provide an initial deployment plan of the course of the buoys as they drift with the currents through the survey area of interest. Further in the exemplary embodiment, the seismic shooting scenario is defined by a shooting model component to guarantee the expected illumination and fold of the subsurface targets. Similar to the a priori model described above, the exemplary embodiment operational model is refined in situ before starting operations. In the exemplary embodiment operational model refinement, sample buoys can again be launched in the area of interest to verify that the exhibited buoy drift path is consistent with the operational model current predictions. If the sample buoys indicated a divergence from the exemplary

embodiment operational model prediction greater than a predetermined error amount then the operational model is updated before beginning operations.

[0068]   Further, in the exemplary embodiment, launching and positioning based on the operational model is implemented. The exemplary embodiment subaquatic seismic nodes can be launched from either a flying vessel, e.g. a helicopter, or a navigation vessel. It should be noted in the exemplary embodiment that the launch of the buoys is based on the operation model developed for the currents and the mission planning results. It should further be noted in the exemplary embodiment that seismic buoys can be launched individually or in clusters. It should be noted in the exemplary embodiment that an update component handles processing the real-time data collected from the buoys for modifying the generated operation model, shooting solution and the initial *a priori* model.

[0069]   Positioning of the buoys in the exemplary embodiment can be based on techniques such as but not limited to 1) using the USBL of the vessels involved in the survey to track the buoys through a TDMA protocol capable of dealing with the large number of buoys; and 2) having two families of seismic buoys, i.e., master buoys and slave buoys, wherein the master buoys will communicate with the slave buoys to determine their position before firing each seismic shot. Further in the exemplary embodiment, the positions of the buoys are calculated in real-time using surface located radio frequency (RF) buoys. It should be noted in the exemplary embodiment that after the buoys are launched, the school of buoys drift freely following the currents associated with the survey area of interest but the general theoretical behavior of the school of buoys is known and anticipated based on the operational model. It should further be noted that the operational model and the

deployment characteristics are updated in real-time based on data received from the buoys already deployed.

[0070]   The patch geometry of the exemplary embodiment seismic buoys is not controllable after the buoys have been dropped into the sea and will change based on the current experienced by the individual buoy and the capability of the recovery ship to collect the buoys once they have exited the limits of the survey area but the drop timing and location of succeeding buoys can change based on data received from previously dropped buoys or other data inputs. Further in the exemplary embodiment, the navigation of the shooting vessels associated with this data acquisition survey are guided according to the ongoing operational model and mission plan and can be adjusted in real-time as information is received from deployed buoys or other data inputs.

[0071]   In one aspect of the exemplary embodiment, buoys automatically return to the surface based on a dedicated resurfacing acoustic signal when they exit the predetermined survey area. A variety of techniques are available for recover the surfaced buoys, i.e., a large net or a catamaran type vessel with a recover device attached between the twin hulls. In both cases, acoustic devices are located on the recovery system to send the surface command to the buoys. In another aspect of the exemplary embodiment, the buoys upload their data to a collection device on the recovery vessel and are re-conditioned for re-deployment on the next sweep of another grid of the survey area. It should be noted in the exemplary embodiment that the positioning characteristics of the buoys can be updated/changed before the buoys are redeployed, based on data received from the buoys or mission changes.

[0072]   The above-discussed embodiments may be implemented as methods as now discussed. According to an exemplary method embodiment 1600 illustrated in Figure 16, there is a method for generating and performing a seismic data acquisition mission using a plurality of free-floating subaquatic nodes. The method includes a step 1602 of generating an *a priori* model of sea currents, in a survey area, from available atmospheric and oceanographic data; a step 1604 of generating a seismic data acquisition operation model based on the *a priori* model of sea currents; a step 1606 of generating a seismic shooting solution to provide illumination and fold of subsurface targets associated with the survey area; a step 1608 of launching, from a vessel, a sample portion of the plurality of free-floating subaquatic nodes for collecting preliminary position data associated with the sample portion of the plurality of free-floating subaquatic nodes as they traverse the survey area to confirm sea current drift predicted by the *a priori* model and refining the seismic data acquisition operation model based on the preliminary position data; a step 1610 of launching the remainder of the plurality of free-floating subaquatic nodes based on the *a priori* model and the seismic data acquisition operation model; a step 1612 of firing the seismic shooting solution based on the seismic data acquisition operation model; and a step 1614 of recovering the plurality of free-floating subaquatic nodes, individually, as each free-floating subaquatic node exits the survey area.

[0073]   Note that, as used herein, the phrase "seismic shooting solution" is intended to include any of a variety of marine acquisition approaches including, but not limited to, so-called compressive sensing. For embodiments wherein a

compressive sensing acquisition approach is used, the seismic shooting solution will then operate with the needed irregularity to preserve the sparseness of subsurface targets associated with the survey area.

[0074]   The systems and processes discussed above are just some examples for illustrating the novel concepts of generating and performing a seismic data acquisition mission based on free-floating subaquatic nodes. Those skilled in the art would appreciate that these systems and/or processes may be changed, adjusted or modified to fit various needs.

[0075]   One or more of the exemplary embodiments discussed above disclose a buoy configured to perform seismic recordings. 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.

[0076]   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.

[0077]   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 method of generating and performing a seismic data acquisition mission using a plurality of free-floating subaquatic nodes, said method comprising:

generating an *a priori* model of sea currents, in a survey area, from available atmospheric and oceanographic data;

generating a seismic data acquisition operation model based on said *a priori* model of sea currents;

generating a seismic shooting solution to provide illumination and fold of subsurface targets associated with said survey area;

launching, from a vessel, a sample portion of said plurality of free-floating subaquatic nodes for collecting preliminary position data associated with said sample portion of said plurality of free-floating subaquatic nodes as they traverse said survey area to confirm sea current drift predicted by said *a priori* model and refining said seismic data acquisition operation model based on said preliminary position data;

launching the remainder of said plurality of free-floating subaquatic nodes based on said *a priori* model and said seismic data acquisition operation model;

firing said seismic shooting solution based on said seismic data acquisition operation model; and

recovering said plurality of free-floating subaquatic nodes, individually, as each free-floating subaquatic node exits said survey area.

2.   The method of claim 1, wherein the seismic shooting solution is an irregular acquisition approach wherein the illumination and fold are provided so as to preserve a sparseness associated with subsurface targets in the survey area.

3.   The method of claim 1, wherein said generating an *a priori* model further comprises launching a portion of said plurality of free-floating subaquatic nodes and collecting position data to confirm current predictions associated with said *a priori* model.

4.   The method of claim 3, wherein said a priori model is updated based on said position data.

5.   The method of claim 1, wherein said available atmospheric and oceanographic data comprises satellite based environmental monitoring data, local and regional weather forecast data and national government administration provided data.

6.   The method of claim 1, wherein said vessel is an airborne vessel.

7.   The method of claim 1, wherein said vessel is a seaborne vessel.

8.   The method of claim 1, wherein said plurality of free-floating subaquatic nodes are launched in clusters.

9.   The method of claim 1, wherein said plurality of free-floating subaquatic nodes are launched individually.

10.   The method of claim 1, wherein said plurality of free-floating subaquatic nodes comprise radio frequency (RF) surface nodes, master nodes and slave nodes and said master nodes collect position data from said slave nodes, said RF surface nodes collect said position data from said master nodes and said vessel collects said position data from said RF surface nodes.

11.   The method of claim 1, wherein said vessel collects position data from said plurality of free-floating subaquatic nodes.

12.   The method of claim 1, wherein said launching the remainder of free-floating subaquatic nodes further comprises collecting operational launch position data as free-floating subaquatic nodes are launched and updating said seismic data acquisition operation model in real-time as said launching continues.

13.   The method of claim 12, wherein said shooting solution is updated based on said launch position data.

14.   A system for performing a marine-based seismic data acquisition, said system comprising:

a plurality of free-floating subaquatic nodes;

one or more vessels for deploying and retrieving said plurality of free-floating subaquatic nodes;

a sea current model component for generating an *a priori* model, based on atmospheric and oceanographic data, of sea currents associated with a survey area;

a operation model component for generating a seismic data acquisition operation model based on said *a priori* model;

a shooting model component for generating a shooting solution model based on said seismic data acquisition operation model; and

an update component for analyzing position data collected from said plurality of free-floating subaquatic nodes and updating said seismic data acquisition operation model and said shooting solution model.

15.   The system of claim 14, wherein the seismic shooting solution is an irregular acquisition approach wherein the illumination and fold are provided so as to preserve a sparseness associated with subsurface targets in the survey area.

16.   The system of claim 14, wherein said atmospheric and oceanographic data further comprises satellite based environmental monitoring data, local and regional weather forecast data and national government administration provided data.

17.   The system of claim 14, wherein said update component analyzes position data from previously launched free-floating subaquatic nodes and updates said seismic data acquisition operation model for subsequently launched free-floating subaquatic nodes.

18.   The system of claim 14, wherein said plurality of free-floating subaquatic nodes further comprise master free-floating subaquatic nodes and slave free floating subaquatic nodes wherein said master free-floating subaquatic nodes collect position data from said slave free-floating subaquatic nodes.

19.   The system of claim 18, wherein radio frequency (RF) floating nodes collect said position data from said master free-floating subaquatic and said one or more vessels collect said position data from said RF floating nodes.

20.   The system of claim 14, wherein said one or more vessels collect position data from said plurality of free-floating subaquatic nodes.
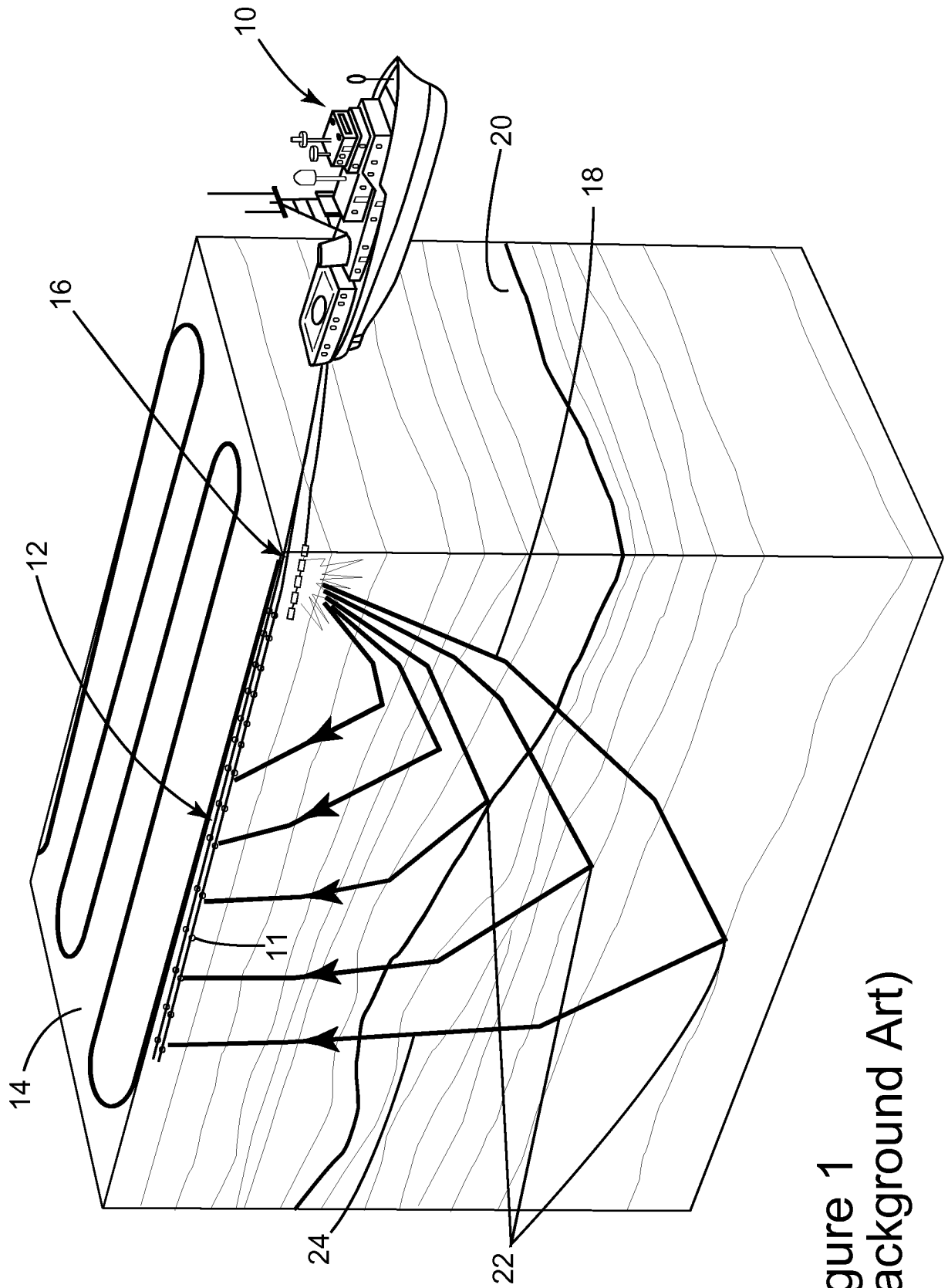
Figure 1
(Background Art)

Figure 2
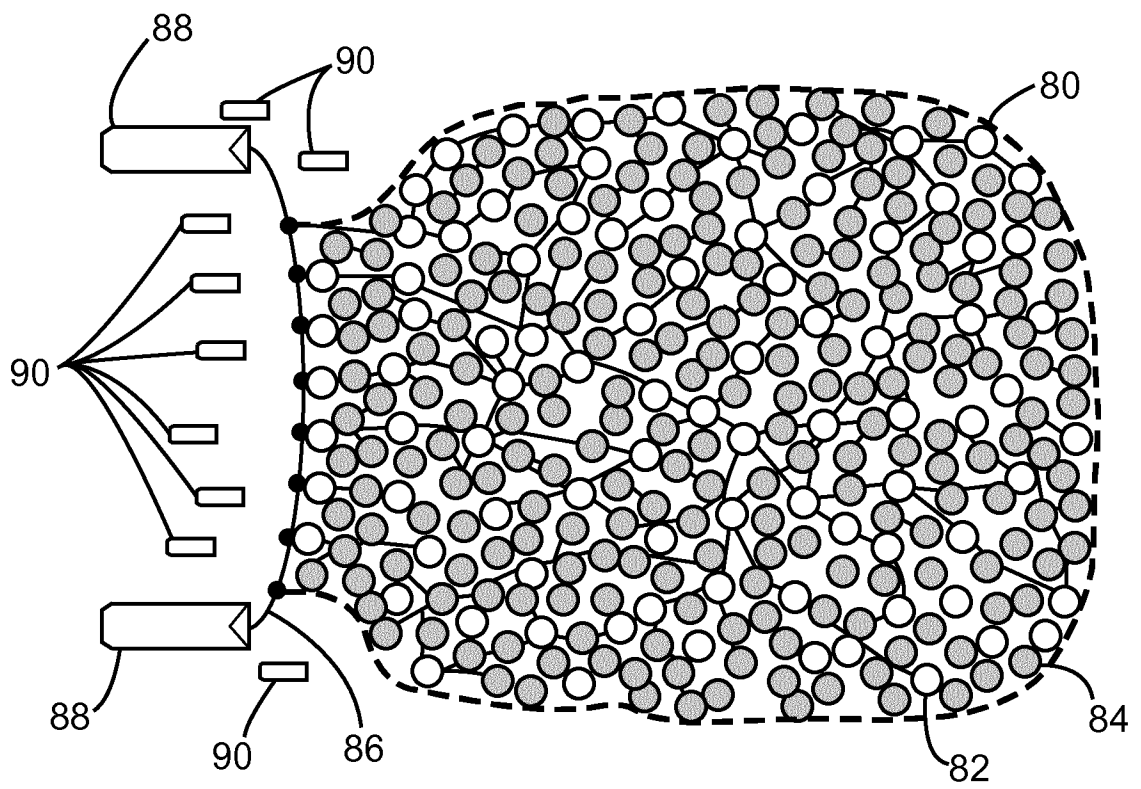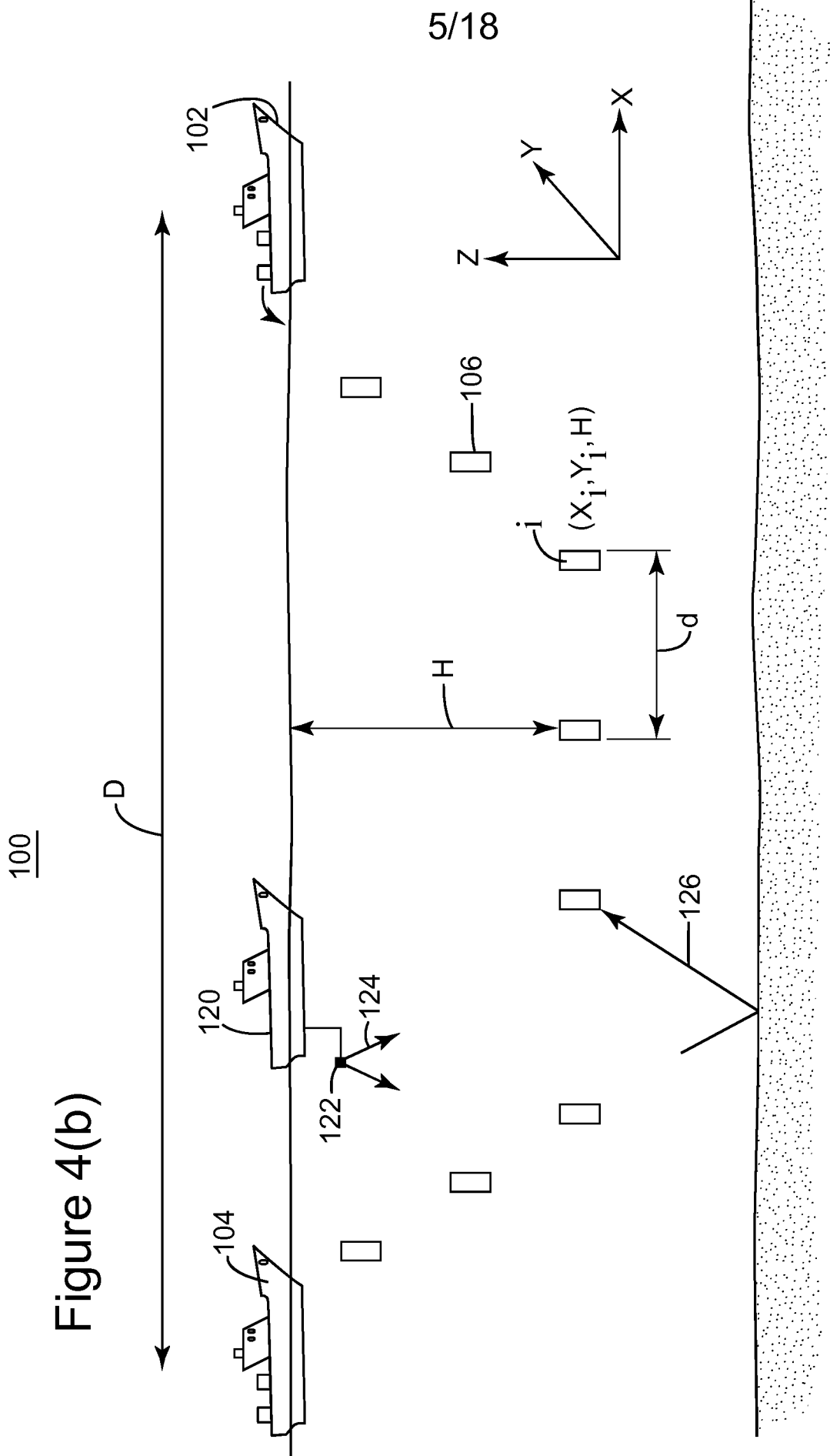(Background Art)
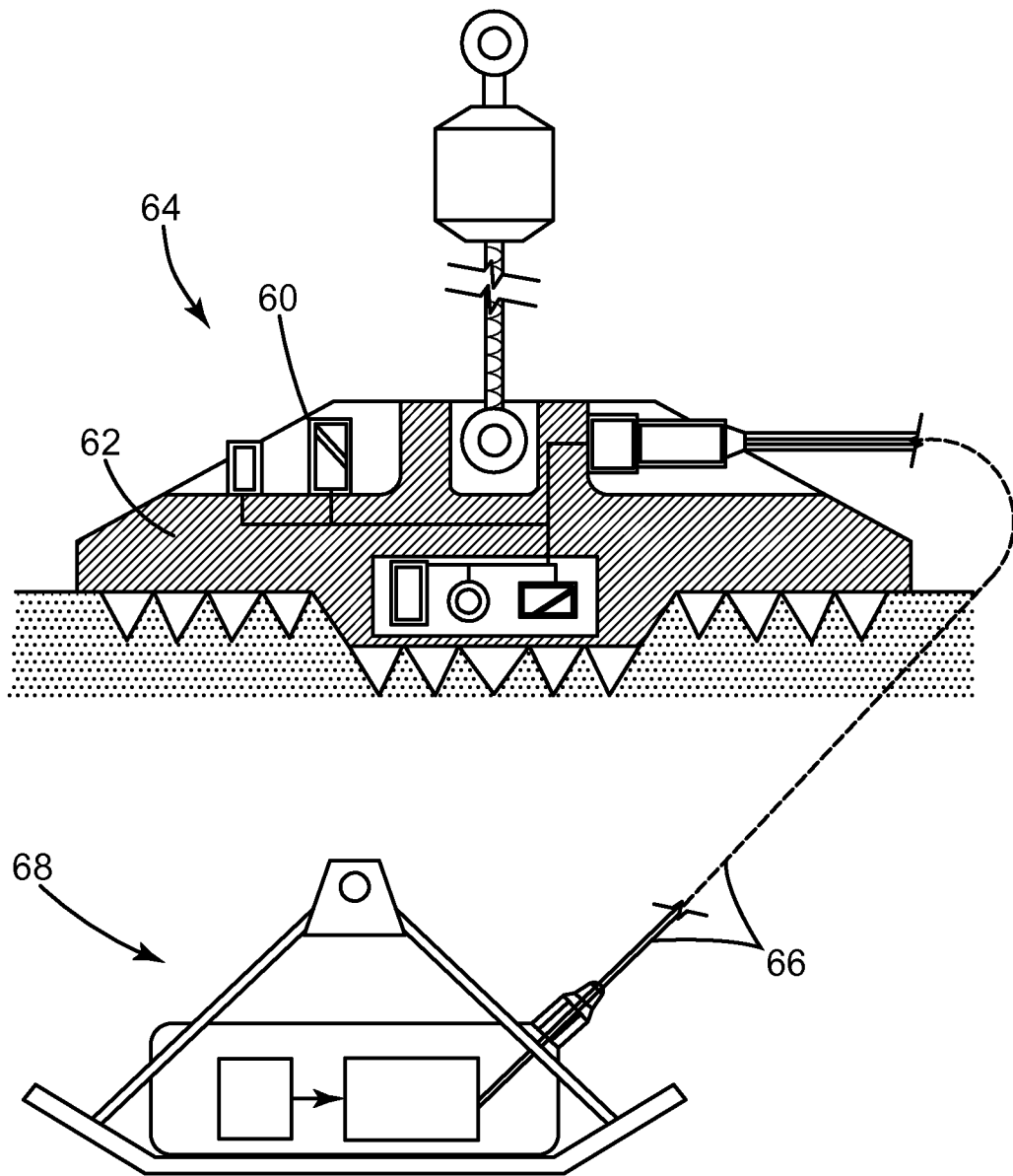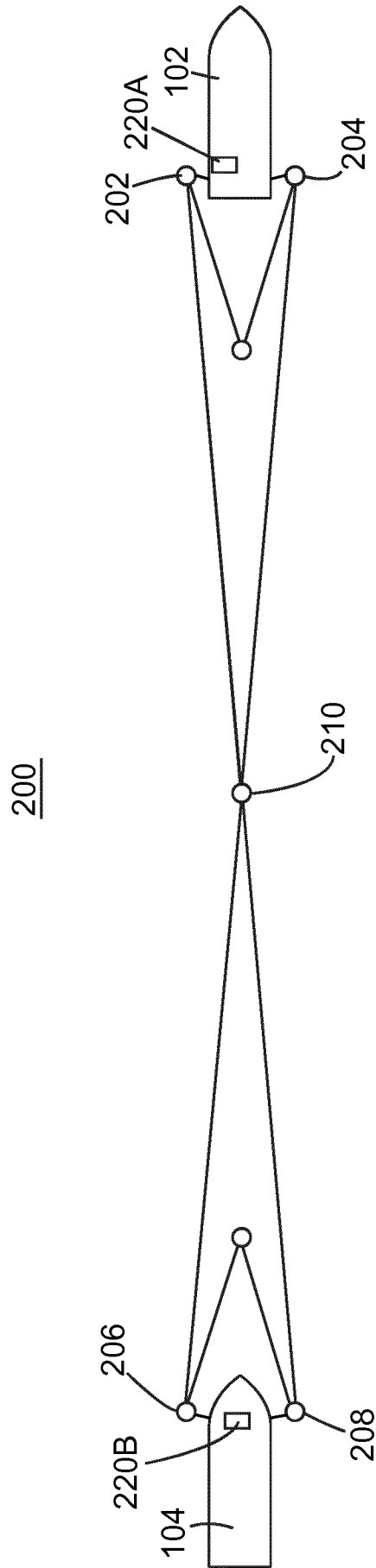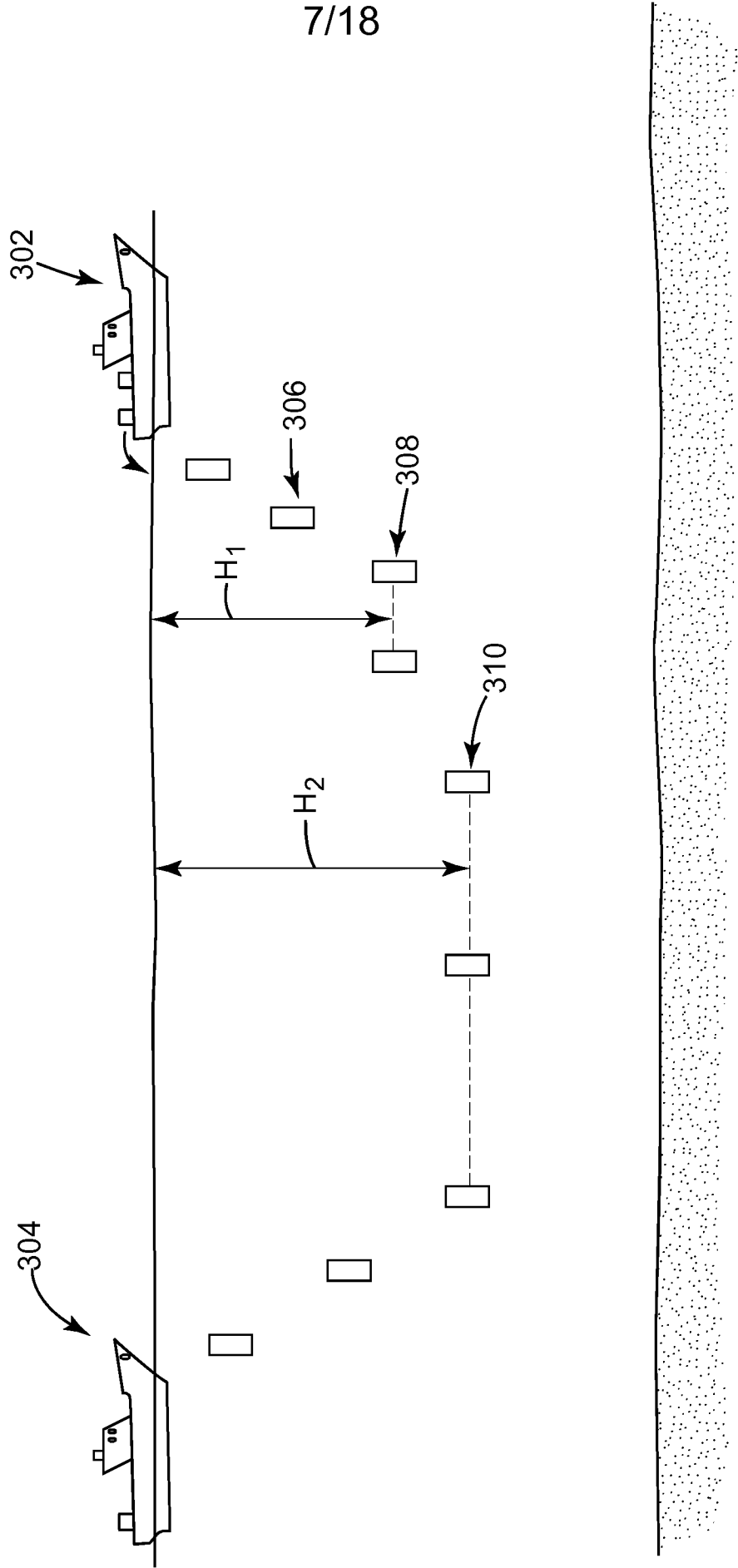
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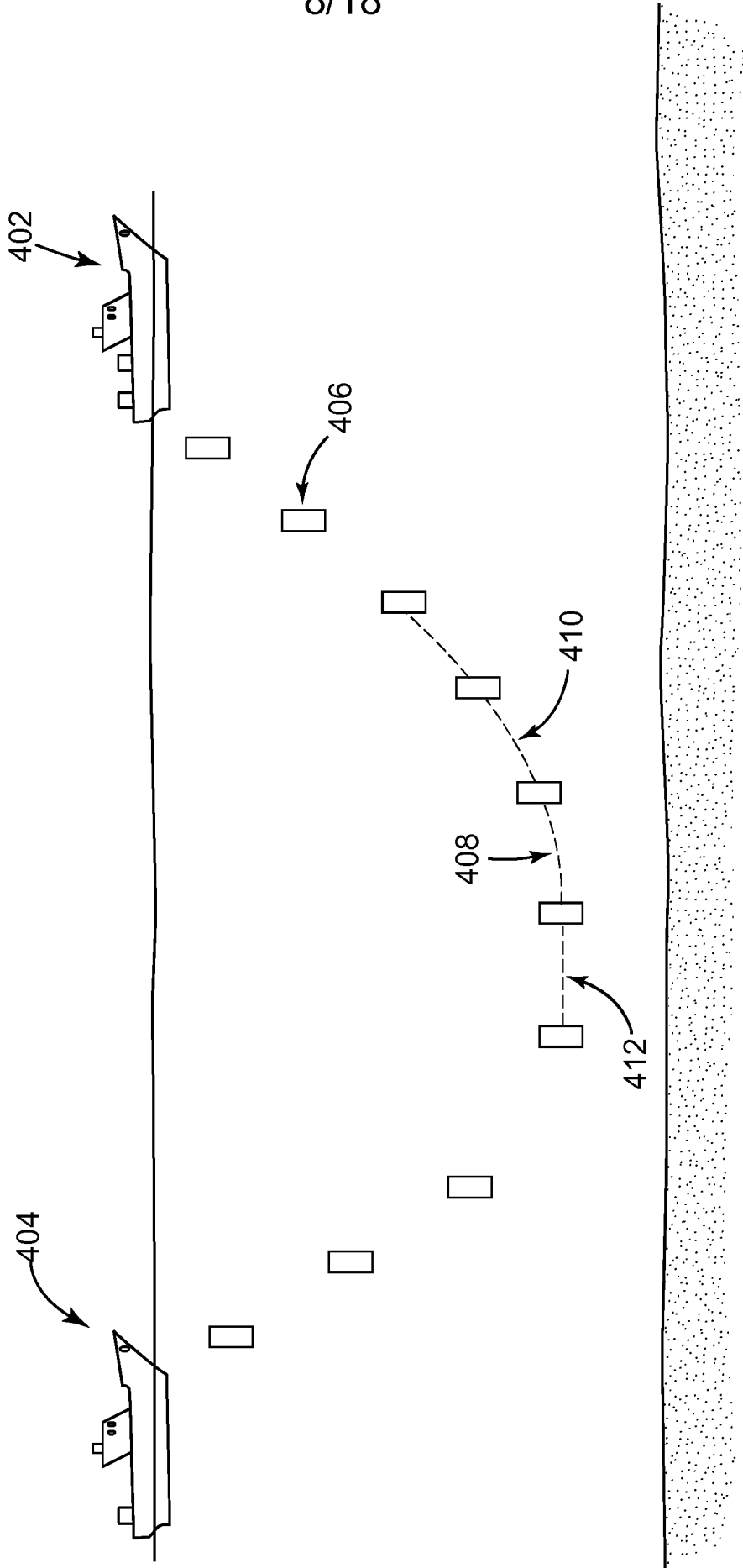# Background Art
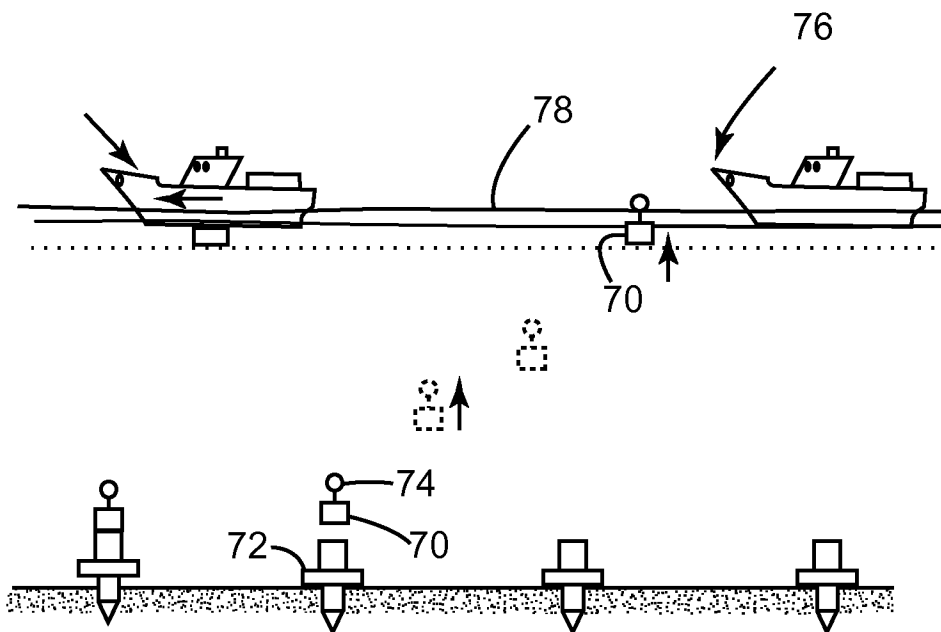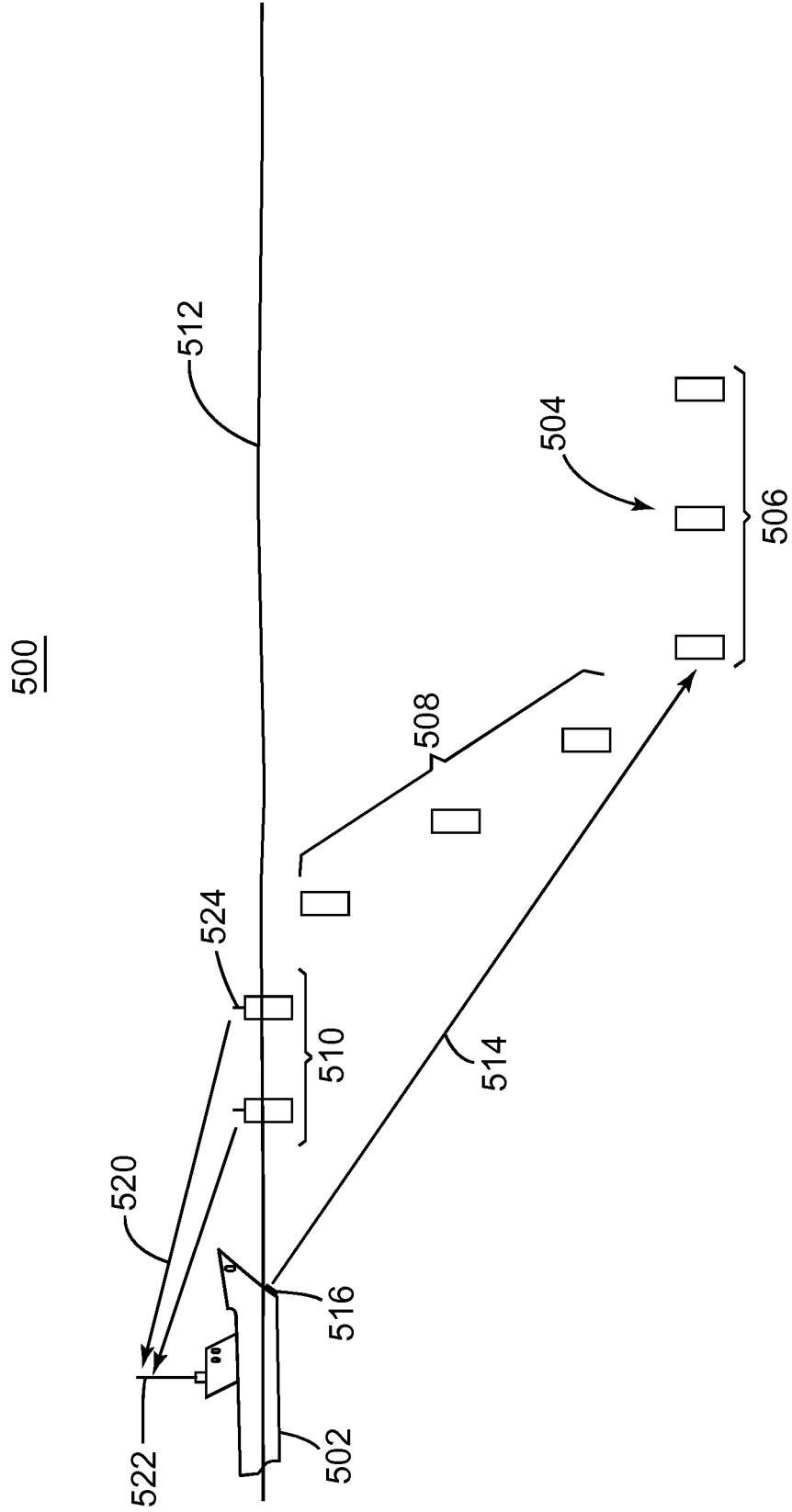
Figure 4(a)

Figure 4(b)

Figure 5

7/18

Figure 6

Figure 7

Figure 8

Figure 9(a)

900

916a   918a

916 — DGPS   RF Beacon — 918

914 — Inertial Device   940

912 — Data Storage

910

906 — CPU   TCXO   Batteries — 908
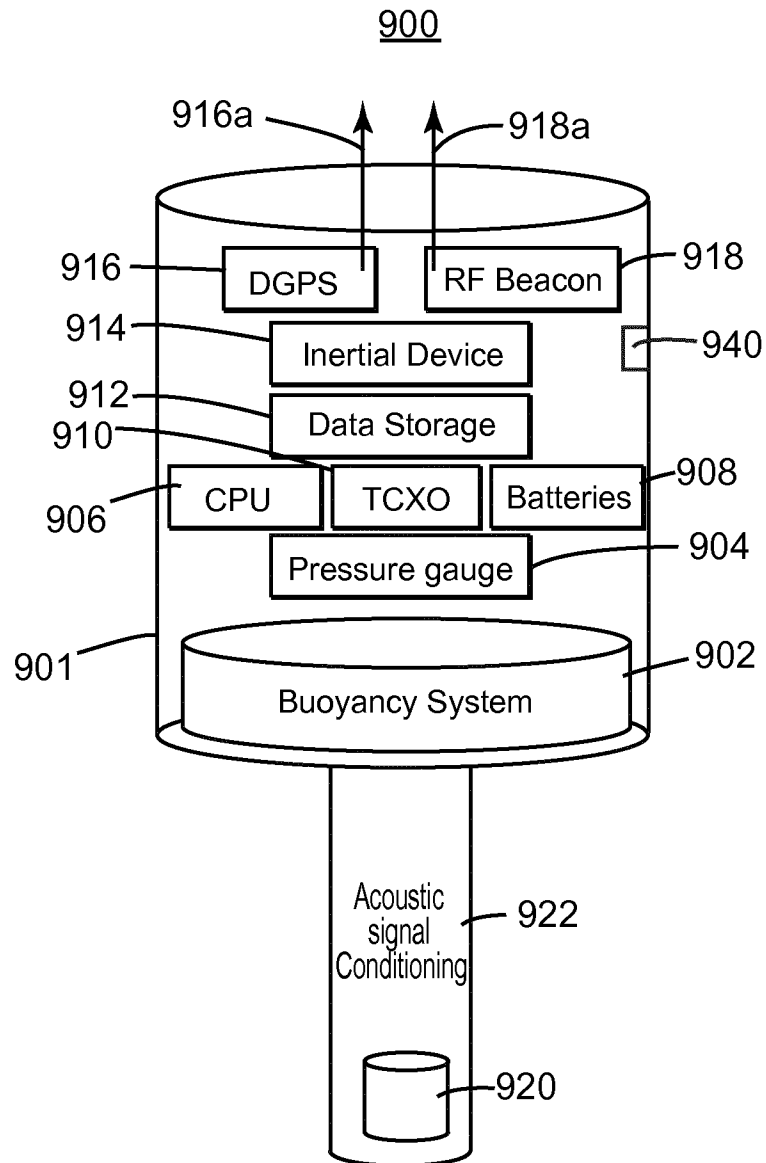
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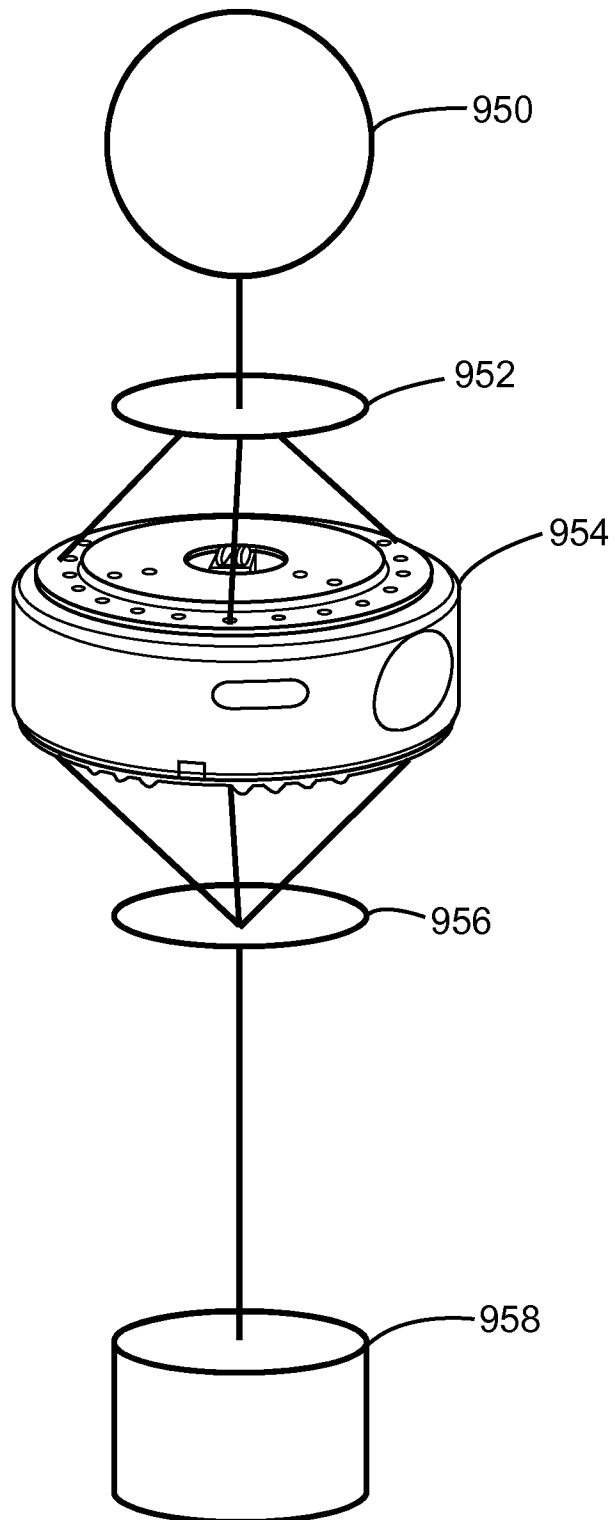901   Buoyancy System — 902
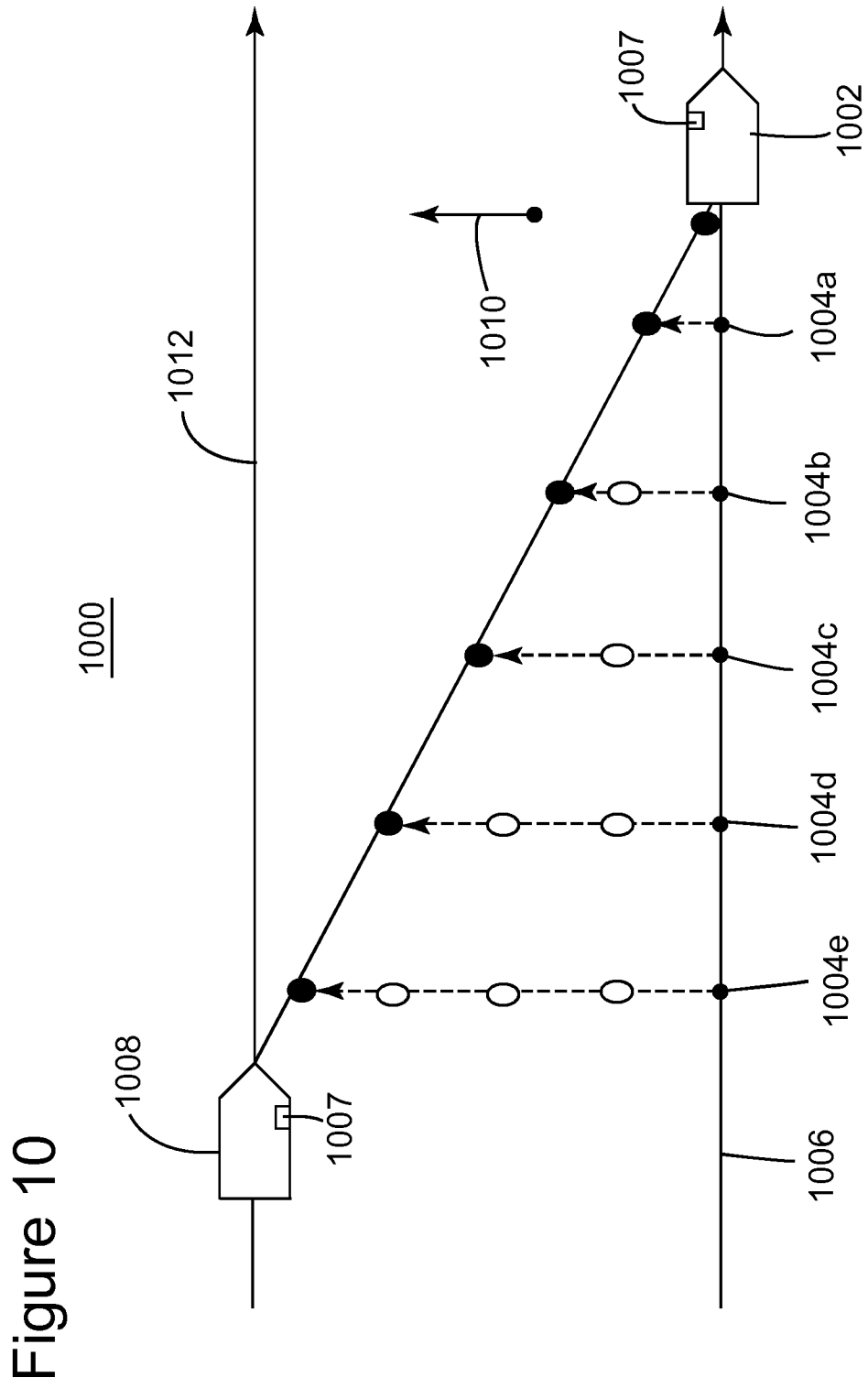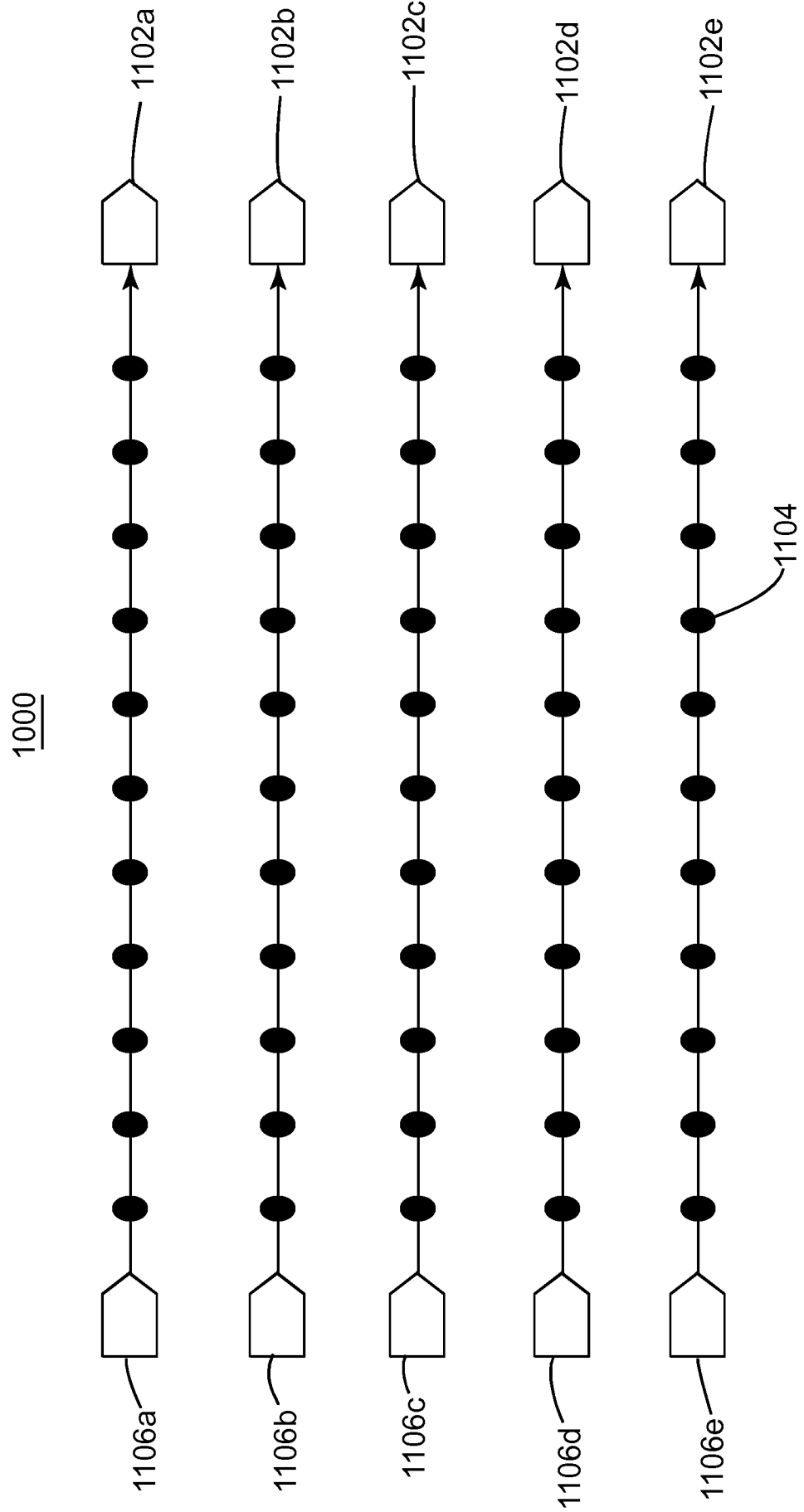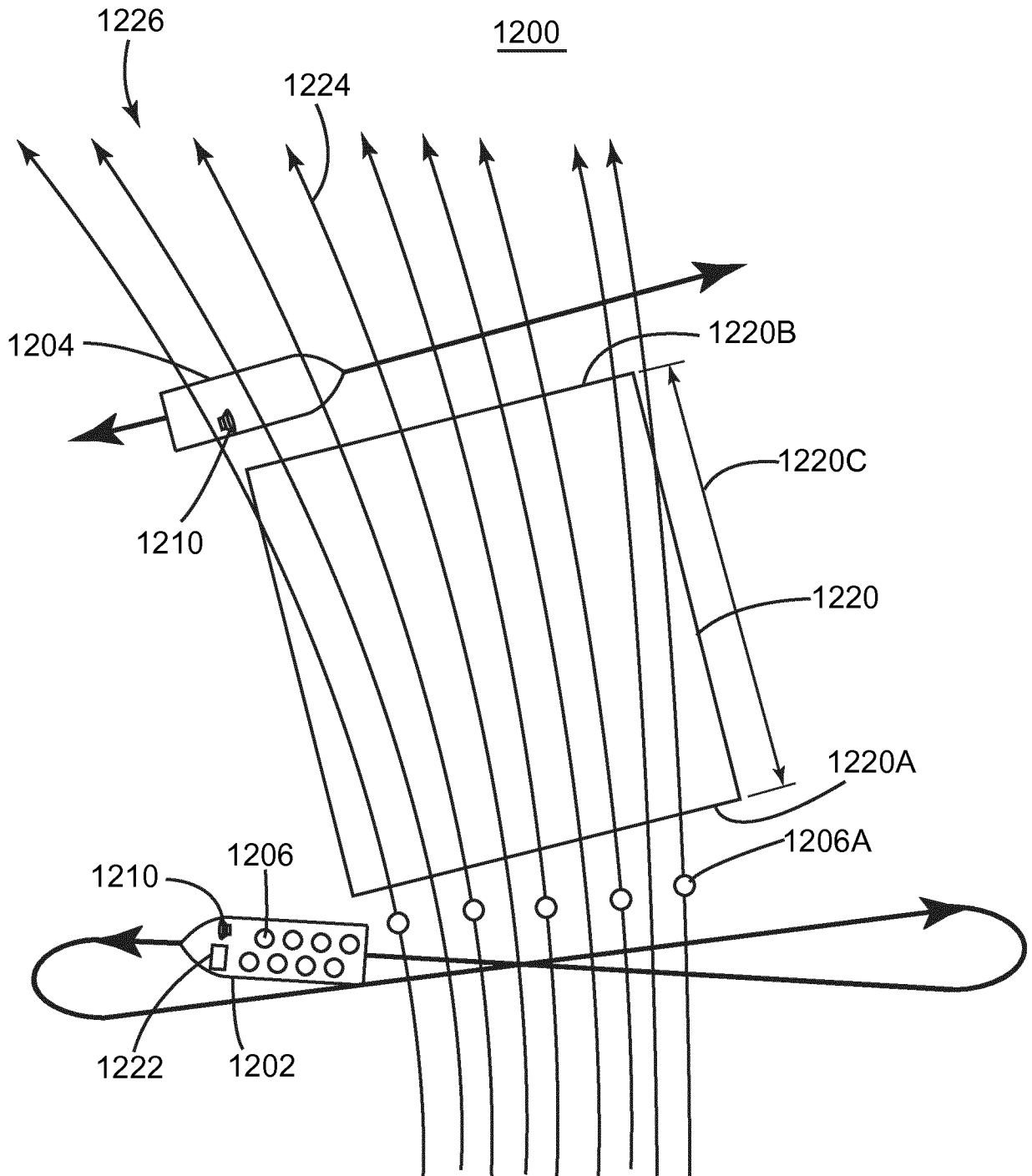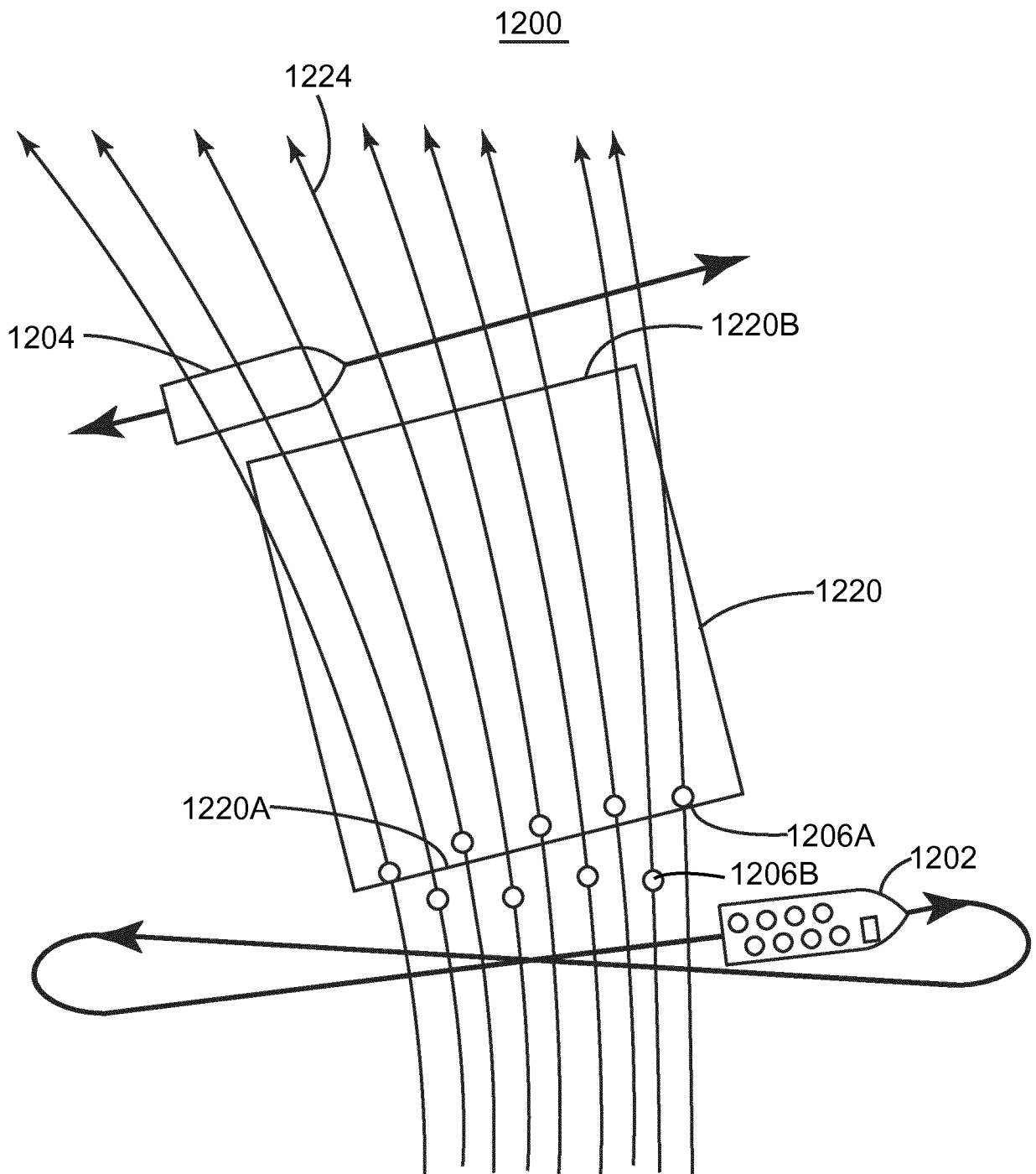
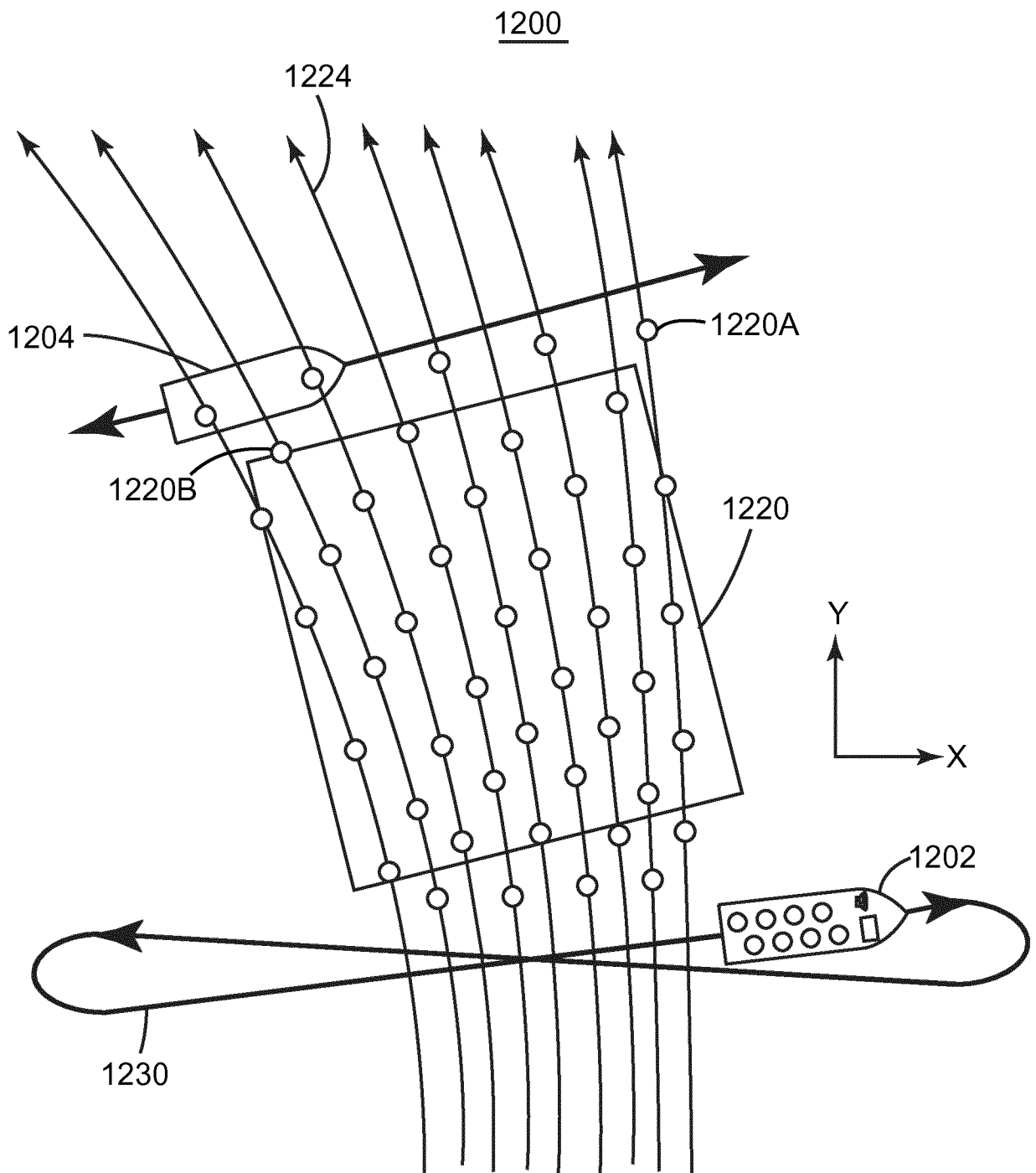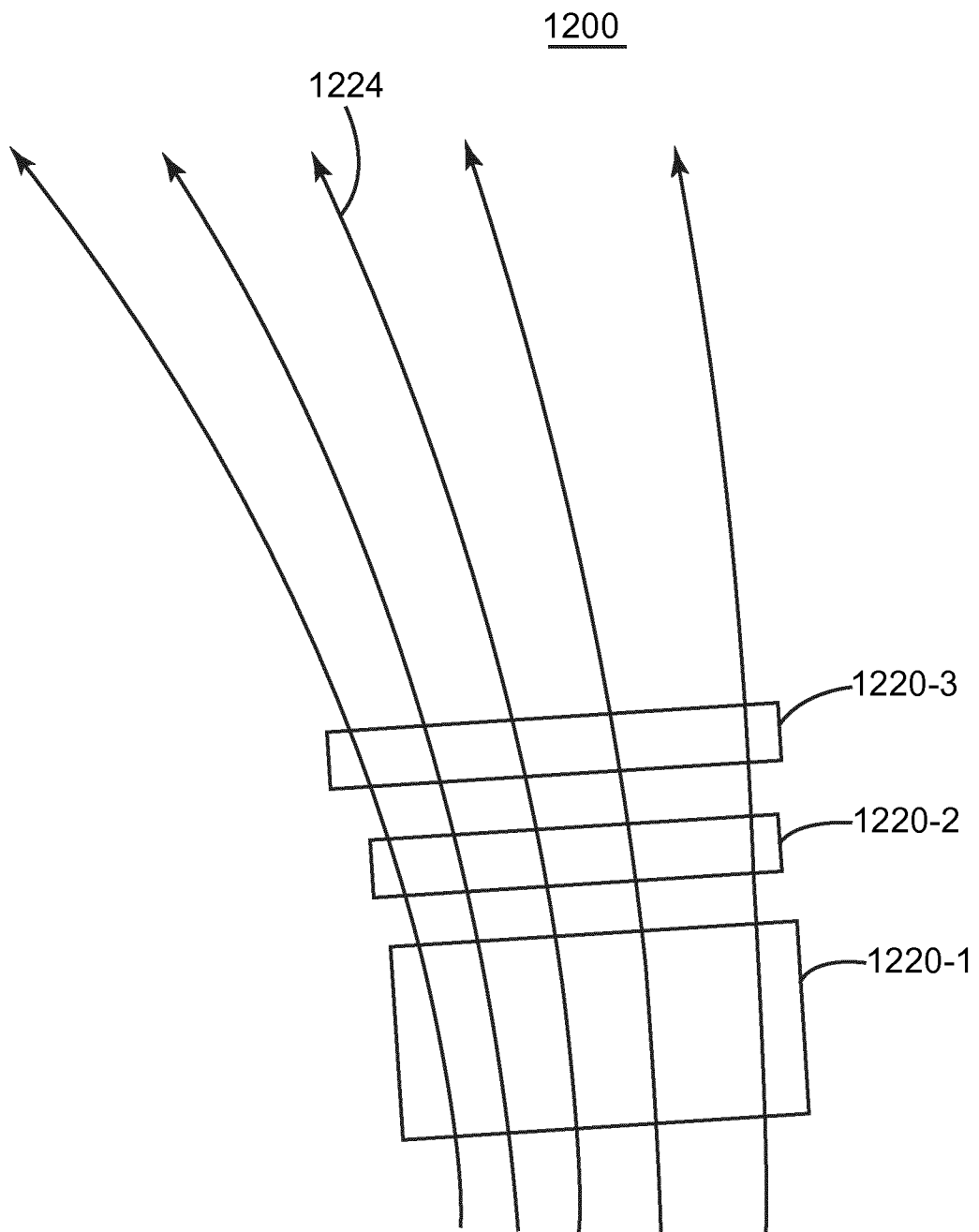Acoustic signal Conditioning — 922

920

Figure 9(b)

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

1602

Generating an a priori model of sea currents,
in a survey area, from available
atmospheric and oceanographic data

1604

Generating a seismic data acquisition
operation model based on the
a priori model of sea currents

1606

Generating a seismic shooting solution to
provide illumination and fold of subsurface
targets associated with the survey area

1608

Launching, from a vessel, a sample portion
of the plurality of free-floating subaquatic nodes
for collecting preliminary position data associated
with the sample portion of the plurality of free-floating
subaquatic nodes as they traverse the survey area to
confirm sea current drift predicted by the a priori model
and refining the seismic data acquisition operation model
based on the preliminary position data

1610

Launching the remainder of the plurality of free-floating
subaquatic nodes based on the a priori model and the
seismic data acquisition operation model

1612

Firing the seismic shooting solution based on the
seismic data acquisition operation model

1614

Recovering the plurality of free-floating sub aquatic
nodes, individually, as each free-floating
subaquatic node exits the survey area