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**ENHANCED OFFSET/ AZIMUTH DISTRIBUTION FOR MARINE
SEISMIC DATA ACQUISITION**

RELATED APPLICATION

5 The present application is related to and claims priority from US Provisional application N° 62/519 988 filed on June 15, 2017, entitled "Acquisition with multiple differing configurations", the disclosure of which is incorporated herein by reference.

TECHNICAL FIELD

10 Embodiments of the subject matter disclosed herein generally relate to methods and systems for marine seismic data acquisition, and, more particularly, to mechanisms and techniques for improved offset/azimuth distribution in marine seismic data acquisition.

BACKGROUND

15 Marine seismic data acquisition and processing techniques are used to generate a profile (image) of a geophysical structure (subsurface) under the seafloor. This profile does not necessarily provide an accurate location for oil, gas reservoirs and other natural resources, but it may suggest, to those trained in the field, the presence or absence of oil and/or gas reservoirs. In
20 other words, such an image of the subsurface is a necessary tool today for those drilling exploration wells for minimizing the potential of finding a dry well. Thus, providing a better image of the subsurface is an ongoing process.

 For a seismic gathering process, as shown in FIG. 1, a marine seismic data acquisition system 100 includes a survey vessel 102 towing a plurality of
25 streamers 104 (one shown) that may extend over kilometers behind the vessel. One or more sources 106 (or one or more source arrays comprising a plurality of sources) may also be towed by the survey vessel 102 or another survey vessel (not shown) for generating seismic waves 108. Conventionally, the source 106 is placed in front of the streamers 104, considering a traveling

direction of the survey vessel 102. A source may be an air gun, a vibratory element, etc. The seismic waves 108 generated by the source 106 propagate downward and penetrate the seafloor 110, eventually being reflected by a reflecting structure 112, 114, 116, 118 at an interface between different layers of the subsurface, back to the surface 119. The reflected seismic waves 120 propagate upward and are detected by receivers 122 provided on the streamers 104. This process is generally referred to as “shooting” a particular seafloor 110 area, which area is referred to as a cell.

To achieve a good image of the surveyed subsurface, an ideal set of seismic data should correspond to a complete illumination of the subsurface. This requires that each point in the subsurface is illuminated by a complete distribution of source-receiver offsets and source-receiver azimuths, the offset being defined as the distance between a source and a receiver, and the azimuth being defined as the angle made between a line that passes through the source and a recording receiver and the navigation path when viewed from above the source and the recording receiver.

A typical Narrow-Azimuth, NAZ, system 200 includes, as shown in FIG. 2A, only one survey vessel 202 towing at least one source 204 and a set of streamers 206 each comprising a predefined number of seismic receivers 208. Because data are acquired from vessel 202 sailing in a series of adjacent parallel straight lines, conventional marine 3D surveys have a single line direction (providing two opposite survey azimuths, depending on the vessel heading), parallel to sail line 210 in FIG. 2A. With such a NAZ system, data having the same offset range and the same azimuth range are recorded along each sail line. An example of rose diagram representing a narrow offset/azimuth distribution of seismic data achieved with such a NAZ system is illustrated in FIG. 2B. In a rose diagram, offset corresponds to distance from the center of each circle, while azimuth corresponds to the angle within each circle.

An improvement to the above conventional data acquisition method is the use of Multi-Azimuth, MAZ, acquisition, in which multi azimuth surveys are acquired by one vessel sailing in multiple directions (or by multiple vessels

sailing each in one of the multiple directions) and have offset/azimuth distributions clustered around the direction of the sail lines. A MAZ system, as schematically shown in FIG. 3A, includes three NAZ systems, such as NAZ system 200 of FIG. 2A, one of which sails along the sail line 210, while a second system sails along the sail line 212, and a third system sails along the sail line 214. FIG. 3B shows a rose diagram representing a typical offset/azimuth distribution of seismic data achieved with such a MAZ system, which results in the addition of the three narrow offset/azimuth distribution of seismic data achieved corresponding to the three NAZ systems.

Another improvement to the NAZ acquisition method is the use of wide-azimuth, WAZ, acquisition. A typical WAZ survey, such as the one shown in FIG. 4A, comprises two streamer vessels 302 and 308 towing respectively sources 302A and 308A, and streamer spreads 302B and 308B. WAZ system 300 further comprises two source vessels 304 and 306, towing respectively sources 304A and 306A. The two source vessels 304 and 306 are positioned between the streamer vessels 302 and 308, and at the same inline position than the two streamer vessels 302 and 308. WAZ acquisition provides a better illumination of the substructure and, thus, a better final image compared to a NAZ acquisition. Here again, as explained for the NAZ system, multiple adjacent sail lines are performed with the same system, i.e. with the same number of sources and receivers and the same relative position of the sources and receivers. An example of rose diagram representing an offset/azimuth distribution of seismic data achieved with such a WAZ system is illustrated in FIG. 4B.

Still another improvement, developed by the assignee of this application, is illustrated in FIG. 5A (which corresponds to FIG. 4 of U.S. Patent Application US2016/170061, the entire content of which is incorporated by reference herein). This system, called StagSeis, includes two streamer vessels 402 and 410 and three source vessels 404, 406 and 408. The streamer vessels 402 and 410 are towing corresponding streamer spreads 402B and 410B comprising a predefined number of receivers, and optionally, one or more seismic sources 402A and 410A. A streamer vessel necessarily

tows a streamer spread while a source vessel necessarily tows a source or a source array comprising a plurality of sources. However, it is possible that the streamer vessel also tows a source or a source array, as illustrated in FIG. 5A. In the embodiment of FIG. 5A, source vessels 404, 406 and 408 tow only
5 corresponding seismic sources 404A, 406A and 408A. In this configuration, the sources are staggered both along the inline direction X and the cross-line direction Y. The survey of the subsurface is realized by performing multiple sail lines with the same system, i.e. with the same number of sources and receivers and the same relative position of the sources and receivers.
10 Therefore, data having the same offset (or source-receiver offset) range and the same azimuth range are recorded along each sail line. An example of rose diagram obtained with such a system is illustrated in FIG. 5B.

Another possible improvement can be made in the case where data is acquired to complement legacy data, i.e. data acquired in a previous marine
15 seismic survey. As exemplified in FIG. 6A, a second WAZ system 500 may be used to complement legacy data acquired with a first WAZ system 300 illustrated in FIG. 4A. The second WAZ system 500 performs data acquisitions along a second acquisition sail line 510 which has a direction perpendicular to the direction of a first acquisition sail line 310 along which the legacy data
20 were acquired. The second WAZ system 500 comprises two streamer vessels 502 and 508 towing respectively sources 502A and 508A, and streamer spreads 502B and 508B. The second WAZ system 500 further comprises two source vessels 504 and 506, towing respectively sources 504A and 506A, and positioned between the streamer vessels 502 and 508 at the same inline
25 position. The rose diagram obtained by the summations of both legacy data and newly obtained data is illustrated in FIG. 6B. As illustrated in the rose diagram, such a method results in redundancy in the acquired data as some data are acquired by both the legacy survey (using first WAZ system 300) and the new survey (using second system 500).

30 Therefore, there is still a need for collecting data with increased offset/azimuth range for further improving the accuracy of the image of the surveyed subsurface (which is obtained by processing the acquired seismic

data). In addition, it would be desirable to provide cost-effective solutions that further improve the offset and/or azimuth ranges distribution at even cost, or alternatively provide even distributions at reduced cost, particularly through avoiding redundancy in seismic data acquisitions.

5

SUMMARY

According to one exemplary embodiment, a method for generating an enhanced offset/azimuth distribution of acquired seismic data, comprises a step of performing a marine seismic acquisition survey according to at least a
10 first acquisition pattern comprising:

acquiring seismic data, along a first acquisition sail line in a first inline direction, with a first seismic data acquisition system, said first seismic data acquisition system defined by a first set of parameters,

acquiring seismic data, along a second acquisition sail line in a second
15 inline direction, with a second seismic data acquisition system, said second seismic data acquisition system defined by a second set of parameters,
wherein said second acquisition sail line is adjacent to said first acquisition sail line,

wherein said first, respectively second, set of parameters comprises at least:

- 20
- a source parameter representative of a predefined number of sources within the first, respectively second, seismic data acquisition system,
 - a receiver parameter representative of a predefined number of receivers within the first, respectively second, seismic data acquisition system,
and

25

 - configuration parameters representative of predefined relative positions of the sources and receivers within the first, respectively second, data acquisition system,

in order that the receivers of the first, respectively second, seismic data acquisition system acquire seismic data according to a first, respectively
30 second, offset/azimuth distribution in conjunction with actuation of the sources of the first, respectively second, seismic data acquisition system,

wherein the first offset/azimuth distribution is defined by both a first offset range and a first azimuth range, and the second offset/azimuth distribution is defined by both a second offset range and a second azimuth range, and

wherein at least one parameter among the source parameter, the receiver parameter and the configuration parameters within said first set of parameters is different from a corresponding parameter within said second set of parameters, so that the first offset range differs from the second offset range and/or the first azimuth range differs from the second azimuth range.

BRIEF DESCRIPTION OF THE DRAWINGS

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:

FIG. 1 is a schematic illustration of a prior art marine seismic data acquisition system;

FIG. 2A illustrates a prior art narrow azimuth marine seismic data acquisition system;

FIG. 2B illustrates a rose diagram obtained with the marine seismic data acquisition system of FIG. 2A;

FIG. 3A illustrates a prior art multi-azimuth marine seismic data acquisition system;

FIG. 3B illustrates a rose diagram obtained with the marine seismic data acquisition system of FIG. 3A;

FIG. 4A illustrates a prior art wide-azimuth marine seismic data acquisition system;

FIG. 4B illustrates a rose diagram obtained with the marine seismic data acquisition system of FIG. 4A;

FIG. 5A illustrates a prior art StagSeis marine seismic data acquisition system;

FIG. 5B illustrates a rose diagram obtained with the marine seismic data acquisition system of FIG. 5A;

FIG. 6A illustrates a prior art method wherein a WAZ system is used to complement legacy data acquired by the WAZ system of FIG. 4A;

5 FIG. 6B illustrates a rose diagram obtained by the summation of the data acquired with the marine seismic data acquisition systems of FIG. 4A and FIG. 6A;

FIG. 7 is a diagrammatical representation of a vessel towing operating streamers and zones of coverage generated by the passage of the vessel;

10 FIG. 8 illustrates a marine seismic survey with two different acquisition systems according to an embodiment;

FIG. 9A illustrates the offset/azimuth distribution obtained by the first marine acquisition system of FIG. 8, FIG. 9B illustrates the offset/azimuth distribution obtained by the second marine acquisition system of FIG. 8, FIG.
15 9C illustrates the offset/azimuth distribution obtained by the two acquisition systems of FIG. 8, and FIG. 9D illustrates the offset/azimuth distribution of FIG. 9C after applying reciprocity;

FIG. 10 illustrates a marine seismic survey by repeating the acquisition pattern of FIG.8;

20 FIG. 11 illustrates a third acquisition system to perform a marine seismic survey according to another embodiment;

FIG. 12A illustrates the offset/azimuth distribution obtain with the acquisition system of FIG. 11 FIG. 12B illustrates the rose diagram obtained with a marine acquisition survey with systems of FIG. 8 and FIG. 11, and
25 FIG. 12C illustrates the rose diagram of FIG. 12B after applying reciprocity;

FIG. 13 illustrates a marine seismic survey by repeating the acquisition pattern comprising the acquisition systems of FIG. 8 and FIG. 11;

FIG. 14 illustrates a marine acquisition system used to obtain legacy data;

FIG. 15 illustrates the offset/azimuth distribution obtained with the acquisition system of FIG. 14;

FIG. 16 illustrates a marine acquisition survey comprising four different acquisition systems allowing to complement data acquired with acquisition
5 system of FIG. 14;

FIG. 17A-D illustrates the offset/azimuth distribution of each of the four acquisition systems of FIG. 16, FIG. 17E illustrates the combination of offset/azimuth distribution of FIG. 17A-D; FIG. 17F illustrates the offset/azimuth distribution of FIG. 17E after applying reciprocity and FIG. 17G
10 illustrated the offset/azimuth distribution obtained by combining the offset/azimuth distribution of FIG. 15 and FIG. 17F;

FIG. 18 illustrates a marine seismic survey by repeating the acquisition pattern of FIG.16; and

FIG. 19 is a flowchart of a method of marine seismic survey according
15 to an embodiment.

DETAILED DESCRIPTION

The following description of the embodiments refers to the accompanying drawings. The same reference numbers in different drawings
20 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. Some of the following embodiments are discussed, for seismic data acquisition systems (or acquisition systems) comprising determined numbers of streamer vessels, sources vessels, receivers and
25 sources. However, the embodiments to be discussed next are not limited to these acquisition systems, but may be extended to other arrangements that include more or fewer streamer vessels, source vessels, receivers and/or sources. Also, the figures may show a particular order of the streamer and source vessels along inline and cross-line directions. This order is exemplary
30 and not intended to limit the embodiments.

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
5 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.

In order to provide a context for the subsequent exemplary embodiments, a description of aspects and terminology is hereby included. It
10 should be noted in an exemplary embodiment that an individual source can be, for example, an air gun, a vibratory source, or other type of sources known by the skilled person. In another aspect of an exemplary embodiment, a coordinate system for describing the direction of travel of the different vessels can be related to an X-axis, Y-axis system wherein the X-axis is the
15 direction of travel of the vessels or in-line direction and the Y-axis, also known as the cross-line direction, is perpendicular to the X-axis direction.

Continuing with the general context description of an exemplary embodiment, the individual sources (or sources) can be fired based on various schemes. One scheme in an exemplary embodiment can shoot the sources
20 sequentially. It should further be noted in the exemplary embodiment that a firing sequence includes the sequential one-time firing of each source. In another exemplary embodiment firing sequence, the sources are fired either simultaneously or almost simultaneously with random time delays between firings. It should be noted in the exemplary embodiment that for a twenty
25 kilometer offset the tail sources must be shot until the end of the full-fold boundary. Further, it should be noted in an exemplary embodiment that a large offset between a source and a traveling distance is considered by the industry to be equal to or larger than two thousand meters.

In the following embodiments, the streamers may be conventionally
30 towed at the same depth below the water surface or slanted to the water surface with a straight or curved profile. In the following embodiments, the source may be part of a source array that includes three sub-arrays. Each sub-

array includes a float to which an individual source is attached. Thus, all the individual sources are located at a same depth. In another possible arrangement, each source may be at a different depth.

The distances given in the description are indicated without taking into
5 account the sea current. These distances can thus vary substantially depending on the sea current.

In an embodiment, during an acquisition survey, the ship follows a set of lines that ideally are parallel to one another, the distance between two adjacent acquisition sail lines L_i and L_{i+1} as shown in FIG. 7 are chosen so as
10 to obtain a desired coverage continuity of the measurements of the streamer S_2 when the ship passes on the line L_i with the measurement of the streamer S_1 during the following pass of the same ship or a different ship on the line L_{i+1} .

Thus, when the ship passes along the acquisition sail line L_i , the
15 streamers have covered an elementary zone Z_i , and when the ship passes along the acquisition sail line L_{i+1} , the streamers have covered an elementary zone Z_{i+1} . The two elementary zones Z_i and Z_{i+1} are continuous. This desired continuity of the coverages is shown in the upper part of FIG. 7. However, in the invention two elementary zones Z_i and Z_{i+1} may partially
20 overlap, for example to increase the density of data acquired.

In the following, the position of the source arrays (comprising a plurality of sources) will be given relative to the position of the streamer spreads, in particular relative to the position of a point of the streamer spread placed at the same cross-line position of the streamer vessel towing said
25 streamer spread and at the head of the streamer spread.

In the following, the number of sources corresponds to the number of sources which are activated during the survey performed by a given system and the number of receivers corresponds to the number of receivers which are activated during the survey performed by a given system.

30 In the following, configurations parameters are representative of predefined relative positions of the source and receivers, these positions may

depend on various parameters such as the depth of the sources, the depth of the streamers and the crossline distance between two adjacent streamers in a streamer spread.

In an exemplary embodiment illustrated at FIG. 8, a marine seismic acquisition survey is performed using a first seismic data acquisition system (or first acquisition system) 700 and a second seismic data acquisition system 800 (or second acquisition system). An acquisition pattern of the marine seismic acquisition survey comprises acquiring seismic data, along a first acquisition sail line 710 and in a first direction, with the first acquisition system 700, and then acquiring seismic data, along a second acquisition sail line 810 and in a second direction parallel and opposite to the first direction, with the second acquisition system 800. In another exemplary embodiment, the second acquisition system 800 may travel along a second acquisition sail line in the same direction as the first acquisition sail line.

First acquisition system 700 is defined by a first set of parameters comprising a source parameter representative of a predefined number of sources, a receiver parameter representative of a predefined number of sources and configuration parameters representative of a predefined relative positions of the sources and receivers. In FIG. 8, the first acquisition system 700 comprises a first streamer vessel 702, a second streamer vessel 704, a first source vessel 706 and a second source vessel 708. The four vessels are staggered along the inline direction X, i.e. none of the vessels has the same inline position (on X axis) at a given instant and all navigate according to direction X. The first streamer vessel 702 is positioned at coordinate (0,0), the second streamer vessel 704 is positioned at coordinate (4594, -4320), the first source vessel 706 is positioned at coordinate (1530, -1440) and the second source vessel 708 is positioned at coordinate (3063, -2880).

The first and second streamer vessels 702 and 704 tow each an identical first and second streamer spread 702B and 704B respectively. Streamers spread 702A comprises 12 streamers of a length of 9450 meters, the streamers being parallel to each other and two consecutive streamers being separated by a distance of 120 meters. Each streamer comprises 757

receivers placed regularly along the streamer, therefore streamers spreads 702B and 704B comprises each 9084 receivers. The first and second streamer vessels 702 and 704 also tow respectively a first source array 702A and a second source array 704A respectively, each source array comprising 48
5 sources which are air-guns in this exemplary embodiment. The first and second source vessels 706 and 708 tow each an identical third and fourth source array 706A and 708A respectively, each source array being identical to source arrays 702A and 704A. Therefore, the first acquisition system 700 comprises 18168 receivers placed on two identical streamer spreads and 192
10 sources placed on four identical source arrays. The first set of parameters associated to the first acquisition system comprises thus a source parameter equal to 192 and a receiver parameter equal to 18168 (assuming that all the sources and receivers of the first system are activated during the survey).

Accordingly, the first source array 702A is positioned at the same
15 cross-line position of the first streamer spread 702B and at an inline distance of 200 meters in front of it. The first source array 702A is also positioned at a cross-line distance of 4320 meters on the port side of the second streamer spread 704B and at an inline distance of 4394 meters behind it.

The second source array 704A is positioned at the same cross-line
20 position of the second streamer spread 704B and at an inline distance of 200 meters in front of it. The second source array 704A is also positioned at a cross-line distance of 4320 meters on the starboard side of the first streamer spread 702B and at an inline distance of 4594 meters in front of it.

The third source array 706A is positioned at an inline distance
25 of 1730 meters in front of the first streamer spread 702B and at a cross-line distance of 1440 meters on the starboard side thereof. The third source array 706A is also positioned at an inline distance of 2862 meters behind the second streamer spread 704B and at a cross-line distance of 2880 meters on the port side thereof it.

30 The fourth source array 708A is positioned at an inline distance of 3262 meters in front of the first streamer spread 702B and at a cross-line

distance of 2880 meters on the starboard side thereof. The fourth source array 708A is also positioned at an inline distance of 1331 meters behind the second streamer spread 704B and at a cross-line distance of 1440 meters on the port side thereof.

5 The first acquisition sail line 710 of first acquisition system 700 is a straight line which is parallel to the navigation sail lines of the first and second streamer vessels 702 and 704 and at the same distance from each streamer vessel. Therefore, first acquisition system 700 acquires seismic data along acquisition sail line 710, the first set of parameters described above being
10 constant along the sail line, which corresponds to the trajectory performed by the first acquisition system 700 over the subsurface to be surveyed, in particular the trajectory performed between two turns of the acquisition system 700. With the first set of parameters described above and defined by its associated source parameter, receiver parameter and configuration
15 parameters, receivers of the first acquisition system 700 can acquire seismic data over a first source-receiver offset range and a first azimuth range in conjunction with actuation of the sources of the first acquisition system 700. A first offset/azimuth distribution corresponding to the acquisition performed by first acquisition system 700 is represented on the rose diagram illustrated in
20 FIG. 9A.

 Second acquisition system 800 is defined by a second set of parameters comprising a source parameter representative of a predefined number of sources, a receiver parameter representative of a predefined number of sources and configuration parameters representative of predefined
25 relative positions of the sources and receivers.

 As illustrated in FIG. 8, second acquisition system 800 comprises a first streamer vessel 802, a second streamer vessel 804, a first source vessel 806 and a second source vessel 808. The two streamers vessels 802 and 804 are placed between the two source vessels 806 and 808 and all navigate
30 according to a direction opposite to direction X. In acquisition system 800, none of the vessels has the same inline position (on X axis) at a given instant. The first streamer vessel 802 is positioned at coordinate (0, 0), the second

streamer vessel 804 is positioned at coordinate (6125, -5760), the first source vessel 806 is positioned at coordinate (3063, 1440) and the second source vessel 808 is positioned at coordinate (3375, -7200).

The first and second streamer vessels 802 and 804 tow each an
5 identical first and second streamer spread 802B and 804B respectively which are identical to the streamer spreads 702B and 704B. . The first and second streamer vessels 802 and 804 also comprise a first source array 802A and a second source array 804A respectively, which are identical to source arrays 702A and 704A.

10 Accordingly, the first source array 802A is positioned at the same cross-line position of the first streamer spread 802B and at an inline distance of 200 meters in front of it. The first source array 802A is also positioned at a cross-line distance of 5760 meters on the starboard side of the second streamer spread 804B and at an inline distance of 6325 meters in front of it.

15 The second source array 804A is positioned at the same cross-line position of the second streamer spread 804B and at an inline distance of 200 meters in front of it. The second source array 804A is also positioned at a cross-line distance of 5760 meters on the port side of the first streamer spread 802B and at an inline distance of 6325 meters behind it.

20 The third source array 806A is positioned at an inline distance of 2863 meters behind the first streamer spread 802B and at a cross-line distance of 1440 meters on the starboard side thereof. The third source array 806A is also positioned at an inline distance of 3262 meters in front of the second streamer spread 804B and at a cross-line distance of 7200 meters on
25 the starboard side thereof.

The fourth source array 808A is positioned at an inline distance of 3175 meters behind the first streamer spread 802B and at a cross-line distance of 7200 meters on the port side thereof. The fourth source array 808A is also positioned at an inline distance of 2950 meters in front of the
30 second streamer spread 804B and at a cross-line distance of 1440 meters on the port side thereof.

The second acquisition sail line 810 of second acquisition system 800 is a straight line which is parallel to the navigation sail lines of the first and second streamer vessels 802 and 804 and at the same distance from each streamer vessel. Therefore, second acquisition system 800 acquires seismic data along acquisition sail line 810, the set of parameters described above being constant along the sail line, which corresponds to the distance performed by the acquisition system 800 over the subsurface to be surveyed, in particular the trajectory performed between two turns of the acquisition system 800. With the second set of parameters described above and defined by its associated source parameter, receiver parameter and configuration parameters, receivers of second acquisition system 800 can acquire seismic data over a second source-receiver offset range and a second azimuth range in conjunction with actuation of the sources of second acquisition system 800. A second offset/azimuth distribution corresponding to the acquisition performed by second acquisition system 800 is represented on the rose diagram illustrated in FIG. 9B.

In this embodiment, the first and the second acquisition system, respectively 700 and 800, comprise the same source parameter, i.e. a number of sources equal to 192, and the same receiver parameter, i.e. a number of receivers equal to 18168. Therefore, in this embodiment, the two systems differ only by their configuration parameters, i.e. by the relative positions of the sources and receivers, the source arrays and the streamer spreads being identical.

According to other embodiments, both systems may differ by, for example, the number of sources, the number of receivers, the streamer spread (in particular the length of the streamers and spacing between two adjacent streamers), and/or the source array.

As illustrated on FIG. 9A and 9B, the first and second acquisition systems have been designed so that the first offset/azimuth distribution (FIG. 9A) is optimally complementary to the second offset/azimuth distribution (FIG. 9B), i.e. the first offset/azimuth distribution only partially overlap the second offset/azimuth distribution. In other words, according to this embodiment, the

difference in the configuration parameters between the first acquisition system 700 and the second acquisition system 800, due in particular to the difference in the position of streamer vessels and source vessels relative to each other between, allows to obtain two different offset/azimuth distributions on the rose diagram with no (or little) overlapping (FIG. 9C). Hence, there is by construction optimal complementarity (with no or little redundancy) in the data acquired by both systems.

This embodiment may allow to take advantage of Green's reciprocity principle. In this context and within current seismic processing approximations, reciprocity implies that the seismic trace from a given source and a given receiver can be deduced from the reciprocal trace measured with inverted positions of said source and receiver. On a rose diagram, the reciprocal traces are disposed symmetrically with respect to the center. For embodiments which exploit this reciprocity principle, it is thus possible to provide more complete azimuth coverage in the rose diagram without doubling the fold. By applying reciprocity of the data represented on rose diagram of FIG. 9C, rose diagram of FIG. 9D is obtained.

In this exemplary embodiment, the first acquisition sail line 710 and the second acquisition sail line 810 are parallel to each other and separated by a distance of 720 meters. However, in other exemplary embodiments, the two adjacent sail lines may be separated by a distance higher or smaller than 720 meters.

In this exemplary embodiment, the vessels of acquisition system 800 travel in a direction opposite to the traveling direction of the vessels of acquisition system 700. In another possible embodiment, the vessels of acquisition system 800 may travel in the same direction than the traveling direction of the vessels of acquisition system 700.

The acquisition of seismic data along the first acquisition sail line 710 by the acquisition system 700 and the acquisition of seismic data along the second acquisition sail line 810 by the acquisition system 800, the first and the second sail line being adjacent to each other, define the first acquisition pattern of the survey. According to an embodiment illustrated on FIG. 10, the

first acquisition pattern (n) may be repeated one or more times. In such an embodiment, the first acquisition sail line 710 of a subsequent acquisition pattern (n+1 or n+2) is adjacent to the second acquisition sail line 810 of the previous acquisition pattern respectively (n or n+1). In such an embodiment, the vessels of the first acquisition system 700 of the subsequent acquisition pattern (n+1 or n+2) may travel in the same direction as the vessels of the first seismic acquisition system 700 of the previous acquisition pattern (n or n+1) as illustrated on FIG.10, or in the opposite direction.

In another exemplary embodiment, a marine seismic acquisition survey is performed using seismic data acquisition system 700 (described above), seismic data acquisition system 800 (described above) and seismic acquisition system 900 illustrated on FIG. 11. An acquisition pattern of the marine seismic acquisition survey according to this embodiment comprises acquiring seismic data, along a first acquisition sail line and in a first direction, with first acquisition system 700, acquiring seismic data, along a second acquisition sail line and in a second direction parallel and opposite to the first direction, with second acquisition system 800, and acquiring seismic data, along a third acquisition sail line and in a third direction identical to the first direction, with third acquisition system 900. In other exemplary embodiments, acquisition systems 800 and 900 may each travel along an acquisition sail line in the same direction as the first acquisition sail line or in an opposite direction.

As for the first and second acquisition systems, acquisition system 900 is defined by a third set of parameters comprising a source parameter representative of a predefined number of sources, a receiver parameter representative of a predefined number of sources and configuration parameters representative of predefined relative positions of the sources and receivers. As illustrated in FIG. 11, third acquisition system 900 comprises a first streamer vessel 902, a second streamer vessel 904, a first source vessel 906 and a second source vessel 908. In this exemplary embodiment, none of the vessels has the same inline position (on X axis) at a given instant and all navigate according to direction X. The first streamer vessel 902 is positioned

at coordinate (0,0), the second streamer vessel 904 is positioned at coordinate (4500, -8640), the first source vessel 906 is positioned at coordinate (7000, -3540) and the second source vessel 908 is positioned at coordinate (7500, -5700).

5 The first and second streamer vessels 902 and 904 tow each an identical first and second streamer spread 902B and 904B respectively which are identical to the streamer spreads 702B, 704B, 802B and 804B. The first and second streamer vessels 902 and 904 also comprise respectively a first source array 902A and a second source array 904A respectively, which are
10 identical to source arrays 702A, 704A, 802A and 804A.

 Accordingly, the first source array 902A is positioned at the same cross-line position of the first streamer spread 902B and at an inline distance of 200 meters in front of it. The first source array 902A is also positioned at a cross-line distance of 8640 meters on the port side of the second streamer
15 spread 904B and at an inline distance of 4300 meters behind it.

 The second source array 904A is positioned at the same cross-line position of the second streamer spread 904B and at an inline distance of 200 meters in front of it. The second source array 904A is also positioned at a cross-line distance of 8640 meters on the starboard side of the first streamer
20 spread 902B and at an inline distance of 4700 meters in front of it.

 The third source array 906A is positioned at an inline distance of 7200 meters in front of the first streamer spread 902B and at a cross-line distance of 3540 meters on the starboard side thereof. The third source array 906A is also positioned at an inline distance of 2700 meters in front of the
25 second streamer spread 904B and at a cross-line distance of 5100 meters on the port side thereof.

 The fourth source array 908A is positioned at an inline distance of 7700 meters in front of the first streamer spread 902B and at a cross-line distance of 5700 meters on the starboard side thereof. The fourth source array
30 908A is also positioned at an inline distance of 3200 meters in front of the second streamer spread 904B and at a cross-line distance of 2940 meters on

the port side thereof.

The third acquisition sail line 910 of third acquisition system 900 is a straight line which is parallel to the navigation sail lines of the first and second streamer vessels 902 and 904 and at the same distance from each streamer vessel. Therefore, third acquisition system 900 acquires seismic data along acquisition sail line 910, the third set of parameters described above being constant along the sail line, which corresponds to the trajectory performed by the acquisition system 900 over the subsurface to be surveyed, in particular the trajectory performed between two turns of the acquisition system 900.

10 With the third set of parameters described above comprising and defined by it associated source parameter, receiver parameter and configuration parameters, receivers of third acquisition system 900 can acquire seismic data over a third source-receiver offset range and a third azimuth range in conjunction with actuation of the sources of third acquisition system 900. A

15 third offset/azimuth distribution corresponding to the acquisition performed by third acquisition system 900 is represented on the rose diagram illustrated in FIG. 12A.

In this embodiment, the first, the second and the third acquisition systems, respectively 700, 800 and 900 comprise the same source parameter, i.e. a number of sources equal to 192, and the same receiver parameter, i.e. a number of receivers equal to 18168. Therefore, in this embodiment, the three systems differ only by the configuration parameters, i.e. by the relative positions of the sources and receivers.

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According to other embodiments, the three systems may differ by, for example, the number of sources, the number of receivers, the streamer spread (in particular the length of the streamers and spacing between two adjacent streamers), and/or the source array.

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As illustrated on FIG. 12A and 12B, the third offset/azimuth distribution corresponding to the third acquisition system 900 (FIG. 12A) complements optimally the first and second offset/azimuth distributions corresponding respectively to the first and second acquisition systems 700 and

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800 (FIG. 9A and 9B). In other words, the third offset/azimuth distribution only partially overlaps the first and second offset/azimuth distribution. The resulting offset/azimuth distribution of the data acquired by the acquisition pattern according to this embodiment is illustrated on FIG. 12B. Therefore, according to this embodiment, the difference in the configuration parameters between the first acquisition system 700, the second acquisition system 800, and the third acquisition system 900, due to the difference in the position of streamer vessels and source vessels relative to each other between the two systems, allows to obtain three different offset/azimuth distributions on the rose diagram with no (or little) overlapping. In other words, there is by construction optimal complementarity (with no or little redundancy) in the data acquired by the three systems.

Here again, it is possible to take advantage of the reciprocity principle. By applying reciprocity on data represented on rose diagram of FIG. 12B, rose diagram of FIG. 12C is obtained. According to this embodiment, after applying reciprocity, a full azimuth coverage is obtained up to a 10 km offset.

In this exemplary embodiment, the first acquisition sail line 810, the second acquisition sail line 810 and the third acquisition sail line 910 are parallel to each other and separated by a distance of 720 meters. However, in other exemplary embodiments, the two adjacent sail lines may be separated by a distance higher or smaller than 720 meters.

In this exemplary embodiment, the vessels of second acquisition system 800 travel in a direction opposite to the traveling direction of the vessels of first acquisition system 700, and the vessels of the third acquisition system 900 travel in the same direction as the traveling direction of the vessels of first acquisition system 700. In another possible embodiment, the vessels of second acquisition system 800 may travel in the same direction than the traveling direction of the vessels of acquisition system 700. In another possible embodiment, the vessels of the third acquisition system 900 may travel in a direction opposite to the direction of the vessels of the first acquisition system 700. According to another embodiment, the vessels of the three acquisition systems 700, 800 and 900 travel in the same direction.

The acquisition of seismic data along the first acquisition sail line 710 by the first acquisition system 700, the acquisition of seismic data along the second acquisition sail line 810 by the second acquisition system 800, and the acquisition of seismic data along the third acquisition sail line 910 by the third acquisition system 900, the first, the second and the third sail line being adjacent to each other, define the first acquisition pattern of the survey. According to an embodiment illustrated on FIG. 13, the first acquisition pattern (n) may be repeated one or more times. In such an embodiment, the first acquisition sail line 710 of a subsequent acquisition pattern (n+1 or n+2) is adjacent to the third acquisition sail line 910 of the previous acquisition pattern respectively (n or n+1). In such an embodiment, the vessels of the first acquisition system 700 of the subsequent acquisition pattern (n+1 or n+2) may travel in the same direction as the vessels of the first seismic acquisition system 700 of the previous acquisition pattern (n or n+1) as illustrated on FIG.13, or in the opposite direction.

In another exemplary embodiment, the method is used to complement legacy data, i.e. previously acquired data.

In this embodiment, it is assumed that the legacy data have been obtained with a system such as the acquisition system 1000 illustrated on FIG. 14. The acquisition system 1000 comprises two streamer vessels 1002 and 1004 each towing a source array 1002A and 1004A respectively, and a streamer spread 1002B and 1004B respectively, each streamer spread comprising 10 streamers having a length of 8100 meters. Two sources vessels 1006 and 1008 towing a source array 1006A and 1006B respectively are placed between the two streamer vessels 1002 and 1004. The four sources 1002A, 1004A, 1006A and 1008A are staggered both along the inline direction X and the cross-line direction Y. The inline distance between two sources (which is the same distance than the distance between two vessels) is 37 meters and the cross-line distance between two sources (which is the same distance than the distance between two vessels) is 1200 meters. The seismic survey is performed by acquiring seismic data along successive antiparallel passes with the same system configuration (i.e. the same number of

receivers, the same number of sources and the same configuration parameters). The legacy data acquired by system 1000 are shown in the rose diagram of FIG. 15.

The method of the invention is used to acquire seismic data having an offset/azimuth distribution which is complementary to the legacy data, i.e. preferably with almost no overlapping between the newly acquired seismic data and the legacy data.

In this embodiment, a first acquisition pattern comprises acquiring data along four acquisitions sail lines with four acquisition systems, each acquisition system being defined by its own set of parameters comprising the source parameter, the receiver parameter and the configuration parameters as defined above. As for the first and second embodiments, each system differs from one another by at least one parameter among the source parameter, the receiver parameter and the configuration parameters.

Each system comprises two streamer vessels each towing a streamer spread, and two source vessels towing a source array. The streamer spreads each comprise 10 streamers having a length of 8100 meters, separated to each other by a distance of 120 meters. Each streamer comprises 649 receivers and a streamer spread therefore comprises 6490 receivers, and each source array comprises about 48 sources which are air-guns in this embodiment. Therefore each of the four acquisition system 1100, 1200, 1300 and 1400 comprises 12980 receivers placed on two identical streamer spreads and 144 sources placed on three identical source arrays.

The marine seismic acquisition survey allowing to complete the legacy data acquired with acquisition system 1000 is performed using a first acquisition system 1100, a second acquisition system 1200, a third acquisition system 1300 and a fourth acquisition system 1400 illustrated on FIG. 16. The first acquisition pattern of the marine seismic acquisition survey according to this embodiment comprises acquiring seismic data, along a first acquisition sail line 1110 and in a first direction, with first acquisition system 1100, acquiring seismic data, along a second acquisition sail line 1210 and in a second

direction parallel and opposite to the first direction, with second acquisition system 1200, acquiring seismic data, along a third acquisition sail line 1310 and in the first direction, with third acquisition system 1300, and acquiring seismic data, along a fourth acquisition sail line 1410 and in the second
5 direction, with fourth acquisition system 1400. In other exemplary embodiments, acquisition systems 1200, 1300 and 1400 may each travel along an acquisition sail line in the same direction as the first acquisition sail line or in an opposite direction.

In FIG. 16, acquisition system 1100 comprises a first streamer vessel
10 1102 and a second streamer vessel 1104 and also comprises a first source vessel 1106, a second source vessel 1108 and a third source vessel 1109. In this exemplary embodiment, none of the vessels has the same inline position (on X axis) at a given instant and all navigate according to a first direction which opposite to direction X. The source array 1106A of the first source
15 vessel 1106 is positioned at coordinate (0,0), the source array 1108A of the second source vessel 1108 is positioned at coordinate (1200, 1200) and the source array 1109A of the third source vessel 1109 is positioned at coordinate (2400, 2400). The streamer spread 1102B of the first streamer vessel 1102 is positioned at coordinate (5420, 0) and the streamer spread 1104B of the
20 second streamer vessel 1104 is positioned at coordinate (1820, -3600).

Accordingly, the first source array 1106A is positioned at the same cross-line position of the first streamer spread 1102B and at an inline distance of 5420 meters in front of it. The first source array 1106A is also positioned at a cross-line distance of 3600 meters on the starboard side of the second
25 streamer spread 1104B and at an inline distance of 1820 meters in front of it.

The second source array 1108A is positioned at a cross-line distance of 1200 meters on the starboard side of the first streamer spread 1102B and at an inline distance of 4220 meters in front of it. The second source array 1108A is also positioned at a cross-line distance of 4800 meters on the starboard side
30 of the second streamer spread 1104B and at an inline distance of 620 meters in front of it.

The third source array 1109A is positioned at a cross-line distance of 2400 meters on the starboard side of the first streamer spread 1102B and at an inline distance of 3020 meters in front of it. The third source array 1109A is also positioned at a cross-line distance of 6000 meters on the starboard side
5 of the second streamer spread 1104B and at an inline distance of 580 meters behind it.

The first acquisition sail line 1110 of acquisition system 1100 is a straight line which corresponds to the traveling direction of the first source vessel 1106. Therefore, acquisition system 1100 acquires seismic data along
10 acquisition sail line 1110, the set of parameters described above being constant along the sail line, which corresponds to the trajectory performed by the acquisition system 1100 over the subsurface to be surveyed, in particular the trajectory performed between two turns of the acquisition system 1100. With the first set of parameters described above and defined by its associate
15 source parameter, receiver parameter and configuration parameters, receivers of acquisition system 1100 can acquire seismic data over a first source-receiver offset range and a first azimuth range in conjunction with actuation of the sources of first acquisition system 1100. A first offset/azimuth distribution corresponding to the acquisition performed by first acquisition system 1100 is
20 represented on the rose diagram illustrated in FIG. 17A.

In FIG. 16, acquisition system 1200 comprises a first streamer vessel 1202 and a second streamer vessel 1204 and also comprises a first source vessel 1206, a second source vessel 1208 and a third source vessel 1209. In this exemplary embodiment, none of the vessels has the same inline position
25 (on X axis) at a given instant and all navigate according to a second direction X. The source array 1206A of the first source vessel 1206 is positioned at coordinate (0,0), the source array 1208A of the second source vessel 1208 is positioned at coordinate (-1200, 1200) and the source array 1209A of the third source vessel 1209 is positioned at coordinate
30 (-2400, 2400). The streamer spread 1202B of the first streamer vessel 1202 is positioned at coordinate (-7220, -4620) and the streamer spread 1204B of the second streamer vessel 1204 is positioned at coordinate (-3620, -8220).

Accordingly, the first source array 1206A is positioned at a cross-line distance of 4620 meters on the port side of the first streamer spread 1202B and at an inline distance of 7220 meters in front of it. The first source array 1206A is also positioned at a cross-line distance of 8220 meters on the port side of the second streamer spread 1204B and at an inline distance of 3620 meters in front of it.

The second source array 1208A is positioned at a cross-line distance of 5820 meters on the port side of the first streamer spread 1202B and at an inline distance of 6020 meters in front of it. The second source array 1208A is also positioned at a cross-line distance of 9420 meters on the port side of the second streamer spread 1204B and at an inline distance of 2420 meters in front of it.

The third source array 1209A is positioned at a cross-line distance of 7020 meters on the port side of the first streamer spread 1202B and at an inline distance of 4820 meters in front of it. The third source array 1209A is also positioned at a cross-line distance of 10620 meters on the port side of the second streamer spread 1204B and at an inline distance of 1220 meters behind it.

The second acquisition sail line 1210 of acquisition system 1200 is a straight line which corresponds to the traveling direction of the first source vessel 1206. Therefore, acquisition system 1200 acquires seismic data along acquisition sail line 1210, the set of parameters described above being constant along the sail line, which corresponds to the trajectory performed by the acquisition system 1200 over the subsurface to be surveyed, in particular the trajectory performed between two turns of the acquisition system 1100. With the first set of parameters described above, receivers of second acquisition system 1200 can acquire seismic data over a second source-receiver offset range and a second azimuth range in conjunction with actuation of the sources of acquisition system 1200. A second offset/azimuth distribution corresponding to the acquisition performed by second acquisition system 1200 is represented on the rose diagram illustrated in FIG. 17B.

In FIG. 16, a third acquisition system 1300 comprises a first streamer vessel 1302 and a second streamer vessel 1304 and also comprises a first source vessel 1306, a second source vessel 1308 and a third source vessel 1309. In this exemplary embodiment, none of the vessels has the same inline position (on X axis) at a given instant and all navigate according to the first direction which is opposite to direction X. The source array 1306A of the first source vessel 1306 is positioned at coordinate (0,0), the source array 1308A of the second source vessel 1308 is positioned at coordinate (-1200, -1200) and the source array 1309A of the third source vessel 1309 is positioned at coordinate (1200, 1200). The streamer spread of the first streamer vessel 1302 is positioned at coordinate (-2980, -8820) and the streamer spread of the second streamer vessel 1304 is positioned at coordinate (7820, 1980).

Accordingly, the first source array 1306A is positioned at a cross-line distance of 8820 meters on the starboard side of the first streamer spread 1302B and at an inline distance of 2980 meters behind it. The first source array 1306A is also positioned at a cross-line distance of 1980 meters on the port side of the second streamer spread 1304B and at an inline distance of 7820 meters in front of it.

The second source array 1308A is positioned at a cross-line distance of 7620 meters on the starboard side of the first streamer spread 1302B and at an inline distance of 1780 meters behind it. The second source array 1308A is also positioned at a cross-line distance of 3180 meters on the port side of the second streamer spread 1304B and at an inline distance of 9020 meters in front of it.

The third source array 1309A is positioned at a cross-line distance of 10020 meters on the starboard side of the first streamer spread 1302B and at an inline distance of 4180 meters behind it. The third source array 1309A is also positioned at a cross-line distance of 780 meters on the port side of the second streamer spread 1304B and at an inline distance of 6620 meters in front of it.

The third acquisition sail line 1310 of acquisition system 1300 is a

straight line which corresponds to the traveling direction of the first source vessel 1306. Therefore, acquisition system 1300 acquires seismic data along acquisition sail line 1310, the set of parameters described above being constant along the sail line, which corresponds to the trajectory performed by the acquisition system 1300 over the subsurface to be surveyed, in particular the trajectory performed between two turns of the acquisition system 1100. With the third set of parameters described above, receivers of acquisition system 1300 can acquire seismic data over a third source-receiver offset range and a third azimuth range in conjunction with actuation of the sources of acquisition system 1300. A third offset/azimuth distribution corresponding to the acquisition performed by third acquisition system 1300 is represented on the rose diagram illustrated in FIG. 17C.

In FIG. 16, a fourth acquisition system 1400 comprises a first streamer vessel 1402 and a second streamer vessel 1404 and also comprises a first source vessel 1406, a second source vessel 1408 and a third source vessel 1409. In this exemplary embodiment, none of the vessels has the same inline position (on X axis) at a given instant and all navigate according to the second direction which corresponds to direction X. The source array 1406A of the first source vessel 1406 is positioned at coordinate (0,0), the source array 1408A of the second source vessel 1408 is positioned at coordinate (1200, -1200) and the source array 1309A of the third source vessel 1309 is positioned at coordinate (-1200, 1200). The streamer spread 1402B of the first streamer vessel 1402 is positioned at coordinate (-10520, 780) and the streamer spread 1404B of the second streamer vessel 1404 is positioned at coordinate (-14120, -2820).

Accordingly, the first source array 1406A is positioned at a cross-line distance of 2820 meters on the port side of the first streamer spread 1402B and at an inline distance of 14120 m in front of it. The first source array 1406A is also positioned at a cross-line distance of 780 meters on the starboard side of the second streamer spread 1404B and at an inline distance of 10520 meters in front of it.

The second source array 1408A is positioned at a cross-line distance of

1620 meters on the port side of the first streamer spread 1402B and at an inline distance of 15320 meters in front of it. The second source array 1408A is also positioned at a cross-line distance of 1980 meters on the starboard side of the second streamer spread 1404B and at an inline distance of 11720
5 meters in front of it.

The third source array 1409A is positioned at a cross-line distance of 4020 meters on the port side of the first streamer spread 1402B and at an inline distance of 12920 meters behind it. The third source array 1409A is also positioned at a cross-line distance of 420 meters on the port side of the
10 second streamer spread 1404B and at an inline distance of 9320 meters in front of it.

The fourth acquisition sail line 1410 of acquisition system 1400 is a straight line which corresponds to the traveling direction of the first source vessel 1406. Therefore, acquisition system 1400 acquires seismic data along
15 acquisition sail line 1410, the set of parameters described above being constant along the sail line, which corresponds to the trajectory performed by the acquisition system 1400 over the subsurface to be surveyed, in particular the trajectory performed between two turns of the acquisition system 1400. With the fourth set of parameters described above, receivers of acquisition
20 system 1400 can acquire seismic data over a fourth source-receiver offset range and a fourth azimuth range in conjunction with actuation of the sources of acquisition system 1400. A fourth offset/azimuth distribution corresponding to the fourth acquisition performed by acquisition system 1400 is represented on the rose diagram illustrated in FIG. 17D.

25 In this embodiment, the first, the second, the third and the fourth acquisition system, respectively 1100, 1200, 1300 and 1400 comprise the same source parameter, i.e. a number of sources equal to 144, and the same receiver parameter, i.e. a number of receivers equal to 12980. Therefore, in this embodiment, the four systems differ only by the configuration
30 parameters, i.e. by the relative positions of the sources and receivers, the source arrays and the streamer spreads being identical.

According to other embodiments, the four systems may differ by, for example, the number of sources, the number of receivers, the streamer spread (in particular the length of the streamers and spacing between two adjacent streamers), and/or the source array.

5 As illustrated on FIG. 19A to 19D, the offset/azimuth distributions of the data acquired by the four acquisition systems 1100, 1200, 1300 and 1400 (FIG. 16) have each a different offset/azimuth distribution which only partially overlap the offset/azimuth distribution of the other systems. The resulting offset/azimuth distribution of the data acquired by the acquisition pattern
10 according to this embodiment is illustrated on FIG. 17E. Therefore, according to this embodiment, the difference in the configuration parameters between the first acquisition system 1100, the second acquisition system 1200, the third acquisition system 1300 and the fourth acquisition system 1400, due to the difference in the position of streamer vessels and source vessels relative to
15 each other between the four systems, allows to obtain four different and complementary offset/azimuth distributions on the rose diagram with almost no overlapping. In other words, there is almost no redundancy in the data acquired by the four systems, allowing optimal usage of the vessels fleet to reach out for more offset/azimuths ranges.

20 By applying reciprocity of the data represented on rose diagram of FIG. 17E, rose diagram of FIG. 17F is obtained.

As stated above, the data acquired by the acquisition systems 1100, 1200, 1300 and 1400 are used to complement data previously acquired by acquisition system 1000. In such a case, the first acquisition system 1100
25 travels along acquisition sail line 1410 in a direction which makes an angle of 45° with the direction of sail line 1010 corresponding to the traveling direction of acquisition system 1000. FIG. 17G illustrates the rose diagram obtained by the summation of the offset/azimuth distribution acquired by acquisition systems 1100, 1200, 1300 and 1400 (after applying reciprocity, i.e. FIG. 17F)
30 and the offset/azimuth distribution acquired by acquisition system 1000 (FIG. 15). One advantage of this embodiment is that the newly acquired data (i.e. data acquired by systems 1100, 1200, 1300 and 1400) have an

offset/azimuth distribution different than the offset/azimuth distribution of the legacy data, more specifically, the offset/azimuth distribution of the newly acquired data overlap only partially the offset/azimuth distribution of the data previously acquired.

- 5 According to another embodiment, the offset/azimuth distribution of newly acquired data may overlap the offset/azimuth distribution of previously acquired data.

 In this exemplary embodiment, the first, second, third and fourth acquisition sail lines 1110, 1210, 1310 and 1410 are parallel to each other and
10 separated by a distance of 600 meters. However, in other exemplary embodiments, the two sail lines may be separated by a distance higher or smaller than 600 meters.

 In this exemplary embodiment, the vessels of acquisition systems 1100 and 1300 travel in a direction opposite to the traveling direction of the
15 vessels of acquisition systems 1200 and 1400. In another possible embodiment, the vessel of each acquisition system 1200, 1300 and 1400 may travel in a direction which is identical or opposite to the traveling direction of the vessels of acquisition system 1100.

 The acquisition of seismic data along the first acquisition sail line 1110
20 by the first acquisition system 1100, the acquisition of seismic data along the second acquisition sail line 1210 by the second acquisition system 1200, the acquisition of seismic data along the third acquisition sail line 1310 by the third acquisition system 1300 and the acquisition of seismic data along the fourth acquisition sail line 1410 by the fourth acquisition system 1400, the
25 first, the second, the third and the fourth sail line being adjacent to each other, define the first acquisition pattern of the survey. According to an embodiment illustrated on FIG. 18, the first acquisition pattern (n) may be repeated one or more times. In such an embodiment, the first acquisition sail line 1110 of a subsequent acquisition pattern (n+1 or n+2) is adjacent to the
30 fourth acquisition sail line 1410 of the previous acquisition pattern respectively (n or n+1). In such an embodiment, the vessels of the first acquisition system

1100 of the subsequent acquisition pattern ($n+1$ or $n+2$) may travel in the same direction as the vessels of the first seismic acquisition system 1100 of the previous acquisition pattern (n or $n+1$) as illustrated on FIG.20, or in the opposite direction.

5 A method 1500 for acquiring seismic data based on one of the embodiments discussed above is now discussed with regard to FIG.19. The method comprises a step 1501 of acquiring seismic data, along a first acquisition sail line and according to a first inline direction, with a first seismic data acquisition system, said first seismic data acquisition system being
10 defined by a first set of parameters.

The method also comprises a step 1502 of acquiring seismic data, along a second acquisition sail line (adjacent to the first acquisition sail line) and according to the first inline direction or according to a direction opposite to the first inline direction, with a second seismic data acquisition system, said
15 second seismic data acquisition system being defined by a second set of parameters.

The first set of parameters comprises at least a source parameter representative of a predefined number of sources within the first seismic data acquisition system, a receiver parameter representative of a predefined
20 number of receivers within the first seismic data acquisition system, and configuration parameters representative of predefined relative positions of the sources and receivers within the first data acquisition system. Thanks to this first set of parameters, the receivers of the first seismic data acquisition system acquire seismic data over both a first offset range and a first azimuth
25 range, in conjunction with actuation of the sources of the first seismic data acquisition system, thus defining a first offset/azimuth distribution.

Similarly, the second set of parameters comprises at least a source parameter representative of a predefined number of sources within the second seismic data acquisition system, a receiver parameter representative of a
30 predefined number of receivers within the second seismic data acquisition system, and configuration parameters representative of predefined relative

positions of the sources and receivers within the second data acquisition system. Thanks to this second set of parameters, the receivers of the second seismic data acquisition system acquire seismic data over both a second offset range and a second azimuth range, in conjunction with actuation of the
5 sources of the second seismic data acquisition system, thus defining a second offset/azimuth distribution.

The first and second acquisition systems differ in that at least one parameter among the source parameter, the receiver parameter and the configuration parameters within said first set of parameters is different from a
10 corresponding parameter within said second set of parameters, so that the first offset range differs from the second offset range and/or the first azimuth range differs from the second azimuth range.

The invention does not aim to cover a first and a second acquisition system wherein the second acquisition system is a mirrored configuration of
15 the first acquisition system. The second acquisition system would be a mirrored configuration of the first acquisition system in the case where the second acquisition system is symmetric to the first acquisition system according to an axis perpendicular to the acquisition sail line of the first acquisition system.

20 According to an embodiment, the parameters of the first acquisition system and of the second acquisition system are chosen so that the first offset/azimuth distribution and the second offset/azimuth distribution overlap only partially, for instance to complement optimally (with no to little overlap).

In a general manner, regardless of the number of receivers and
25 sources, the first and the second system may comprise the same number of vessels or a different number of vessels. According to an embodiment, the first seismic system may comprise only one vessel towing both a source array and a seismic spread and the second seismic system may differ from the first system only by the number of sources in the source array and/or by the
30 number of receivers on the streamer spread.

In another embodiment, the first seismic system may comprise only one vessel towing both a source array and a seismic spread and the second seismic system may comprising one or more streamer vessels and one or more source vessels.

- 5 According to an embodiment, the first seismic data acquisition system and the second seismic data acquisition system may comprise the same predefined number of sources and/or the same predefined number of receivers.

10 According to an embodiment, the predefined number of sources can be equal or greater to 1.

 According to another embodiment, the first seismic data acquisition system and the second seismic data acquisition system may comprise the same predefined number of sources and the same predefined number of receivers and differ by the number of streamer vessels and source vessels.

- 15 According to another embodiment, the first seismic data acquisition system and the second seismic data acquisition system may comprise the same predefined number of sources and the same predefined number of receivers, the source and receiver being towed by the same number of streamer vessel and source vessel, and both system differ by the position of
20 the vessels relative to each other.

 According to another embodiment, a streamer vessel within an acquisition system may tow a different streamer spread compared to another streamer vessel within the same acquisition system, i.e. a streamer spread having a different number of streamers and/or different distances between the
25 streamers when the streamers are parallel to each other and/or a different configuration of streamers (parallel, dovetail, horizontal or slanted for example).

 According to another embodiment, a source vessel within an acquisition system may tow a different source array compared to another source vessel
30 within the same acquisition system, i.e. a source array having a different

number of sources and/or a different configuration of the source array (horizontal or slanted for example).

According to an embodiment, the method comprises a processing step 1503 of generating an enhanced offset/azimuth distribution by summing
5 seismic data acquired according to the first offset/azimuth distribution and seismic data acquired according to the second offset/azimuth distribution.

According to an embodiment, the processing step further comprises generating a new offset/azimuth distribution by summing seismic data acquired according to the enhanced offset/azimuth distribution and seismic
10 data acquired according to a previous offset/azimuth distribution, wherein the enhanced offset/azimuth distribution and the previous offset/azimuth distribution overlap only partially.

The above-disclosed embodiments provide a method for generating an enhancing offset/azimuth distribution of acquired seismic data. It should be
15 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
20 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.

Although the features and elements of the present embodiments are described in the embodiments in particular combinations, each feature or
25 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.

This written description uses examples of the subject matter disclosed to enable any person skilled in the art to practice the same, including making
30 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.

CLAIMS

1. A method for generating an enhanced offset/azimuth distribution of acquired seismic data, the method comprising a step of performing a marine
5 seismic acquisition survey according to at least a first acquisition pattern comprising:

acquiring seismic data, along a first acquisition sail line in a first inline direction, with a first seismic data acquisition system, said first seismic data acquisition system defined by a first set of parameters,

10 acquiring seismic data, along a second acquisition sail line in a second inline direction, with a second seismic data acquisition system, said second seismic data acquisition system defined by a second set of parameters,
wherein said second acquisition sail line is adjacent to said first acquisition sail line,

15 wherein said first, respectively second, set of parameters comprises at least:

- a source parameter representative of a predefined number of sources within the first, respectively second, seismic data acquisition system,
- a receiver parameter representative of a predefined number of receivers within the first, respectively second, seismic data acquisition system,
20 and
- configuration parameters representative of predefined relative positions of the sources and receivers within the first, respectively second, data acquisition system,

in order that the receivers of the first, respectively second, seismic data
25 acquisition system acquire seismic data according to a first, respectively second, offset/azimuth distribution in conjunction with actuation of the sources of the first, respectively second, seismic data acquisition system,

wherein the first offset/azimuth distribution is defined by both a first offset range and a first azimuth range, and the second offset/azimuth distribution is
30 defined by both a second offset range and a second azimuth range, and

wherein at least one parameter among the source parameter, the receiver parameter and the configuration parameters within said first set of parameters is different from a corresponding parameter within said second set of parameters, so that the first offset range differs from the second offset range
5 and/or the first azimuth range differs from the second azimuth range.

2. The method according to claim 1, wherein the first set of parameters and the second set of parameters are chosen so that the first and the second offset/azimuth distributions overlap only partially.

3. The method according to anyone of the preceding claims, wherein the
10 second inline direction corresponds to the first inline direction or to a direction opposite to the first inline direction.

4. The method according to anyone of the preceding claims, wherein said first acquisition pattern is repeated at least one time in a second acquisition pattern during said marine seismic acquisition survey.

15 5. The method according to claim 4, wherein said second acquisition pattern is adjacent to said first acquisition pattern.

6. The method according to claim 4 or 5, wherein said second acquisition pattern is performed according to the first inline direction or according to a direction opposite to the first inline direction.

20

7. The method according to anyone of the preceding claims, further comprising a processing step generating the enhanced offset/azimuth distribution by summing seismic data acquired according to the first offset/azimuth distribution and seismic data acquired according to the second
25 offset/azimuth distribution.

8. The method according to claim 7, wherein the processing step comprises obtaining additional seismic data by applying a reciprocity principle on seismic data acquired according to the first offset/azimuth distribution and/or to the second offset/azimuth distribution.

9. The method according to anyone of claim 7 or 8, wherein the processing step further comprises generating a new offset/azimuth distribution by summing seismic data acquired according to the enhanced offset/azimuth distribution and seismic data acquired according to a previous offset/azimuth distribution, wherein the enhanced offset/azimuth distribution and the previous offset/azimuth distribution overlap only partially.

10. The method according to anyone of the preceding claims, wherein said predefined number of receivers within the first and/or the second seismic data acquisition system, are carried by one or more streamers towed by one or more streamer vessels.

11. The method according to claim 10, wherein said predefined number of sources within the first and/or the second seismic data acquisition system, are towed by said one or more streamer vessels and/or by another vessel.

12. The method according to anyone of claims 1 to 10, wherein the first seismic data acquisition system and the second seismic data acquisition system comprise the same predefined number of sources and/or the same predefined number of receivers.

13. The method according to claim 12, wherein the sources and receivers of the first acquisition system are towed by a first predefined number of streamer vessel(s) and source vessel(s) and wherein the sources and receivers of the second acquisition system are towed by a second predefined number of streamer vessel(s) and source vessel(s), first predefined number of streamer vessel(s) and source vessel(s) being the same as the second predefined number of streamer vessel(s) and source vessel(s).

14. The method according to claim 12, wherein the sources and receivers of the first acquisition system are towed by a first predefined number of streamer vessel(s) and source vessel(s) and wherein the sources and receivers of the second acquisition system are towed by a second predefined number of streamer vessel(s) and source vessel(s), first predefined number of streamer

vessel(s) and source vessel(s) being different than the second predefined number of streamer vessel(s) and source vessel(s).

15. The method according to claim 13, wherein the first and second acquisition systems each comprises two streamer vessels and two source
5 vessels.

16. The method according to claim 13, wherein the first and second acquisition systems each comprises two streamer vessels and three source vessels.

17. The method according to claim 1, wherein the step of performing a
10 marine seismic acquisition survey according to at least a first acquisition pattern comprising:

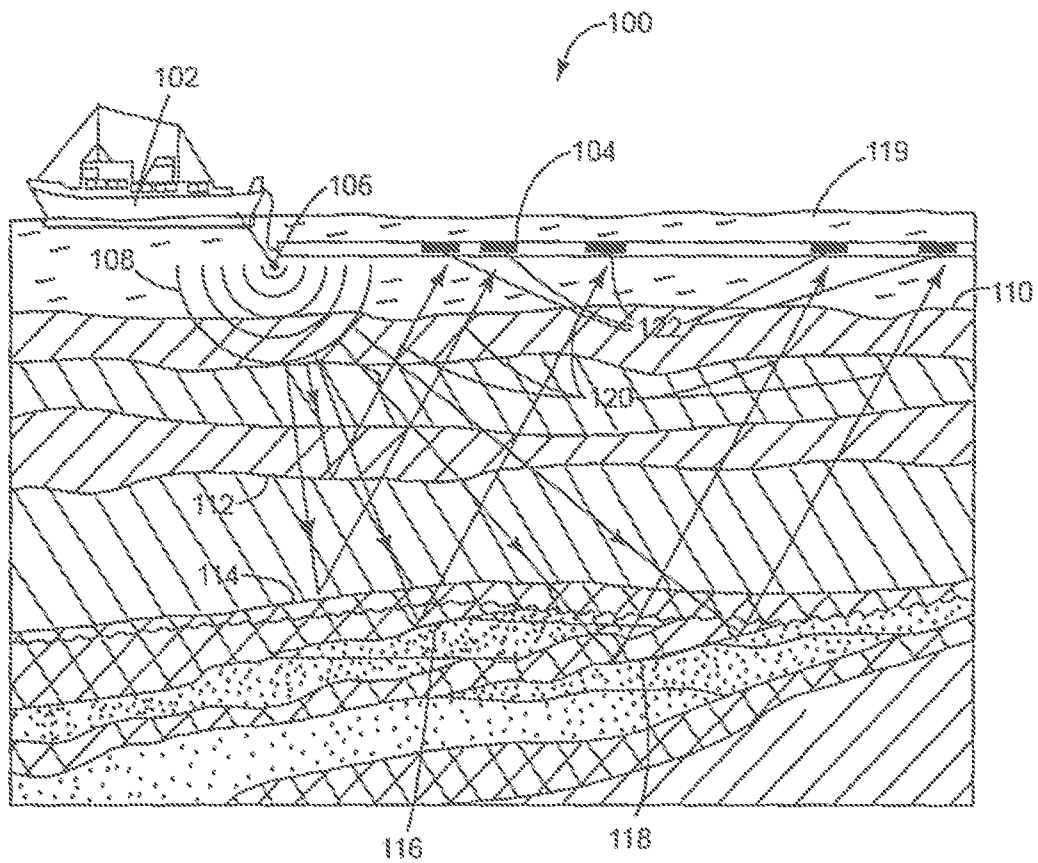
acquiring seismic data, along a third acquisition sail line adjacent to the second acquisition sail line, with a third seismic data acquisition system defined by a third set of parameters comprising at least:

- 15 • a source parameter representative of a predefined number of sources within the third seismic data acquisition system,
- a receiver parameter representative of a predefined number of receivers within the third seismic data acquisition system, and
- configuration parameters representative of predefined relative positions
20 of the sources and receivers within the third data acquisition system,

in order that the receivers of the third seismic data acquisition system acquire seismic data according to a third offset/azimuth distribution in conjunction with actuation of the sources of the third seismic data acquisition system, wherein the third offset/azimuth distribution is defined by both a third offset
25 range and a third azimuth range, and

wherein at least one parameter among the source parameter, the receiver parameter and the configuration parameters within said third set of parameters is different from a corresponding parameter within said first and second set of parameters, so that the third offset range differs from the first

and second offset ranges and/or the third azimuth range differs from the first and second azimuth ranges.

**FIG.1**

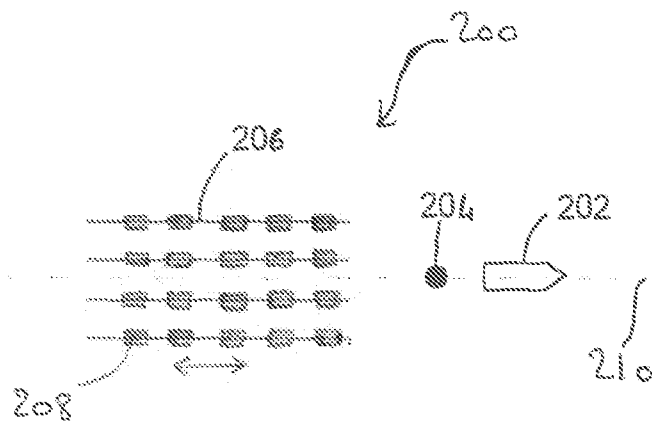


FIG. 2A

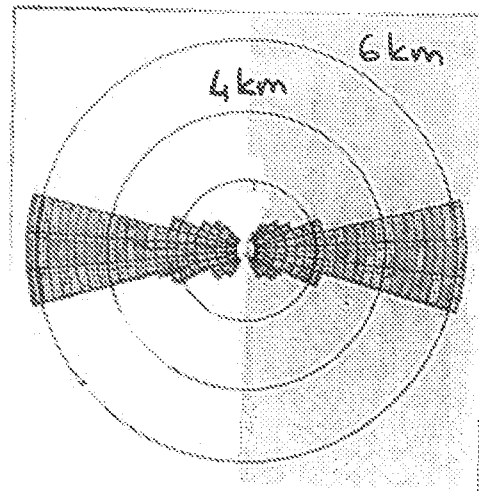


Fig. 2B

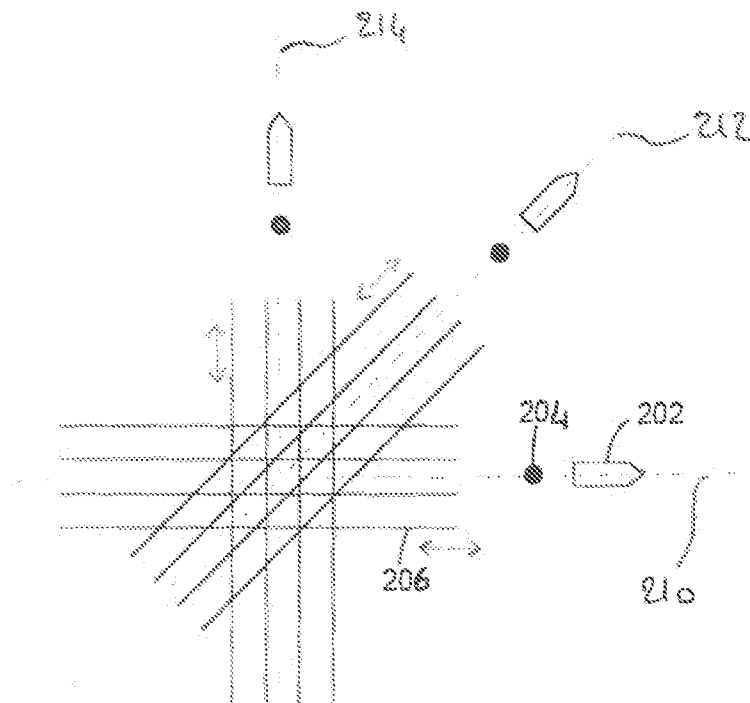


FIG. 3A

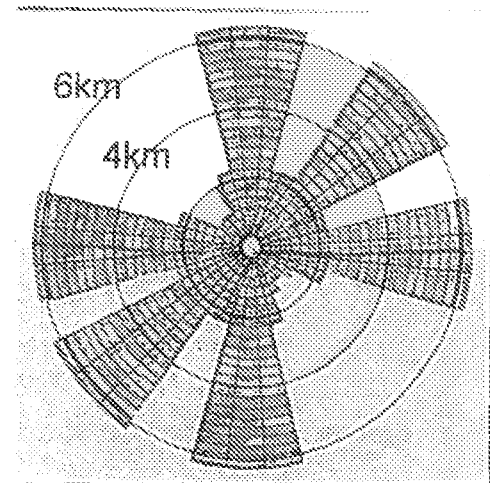


Fig. 3B

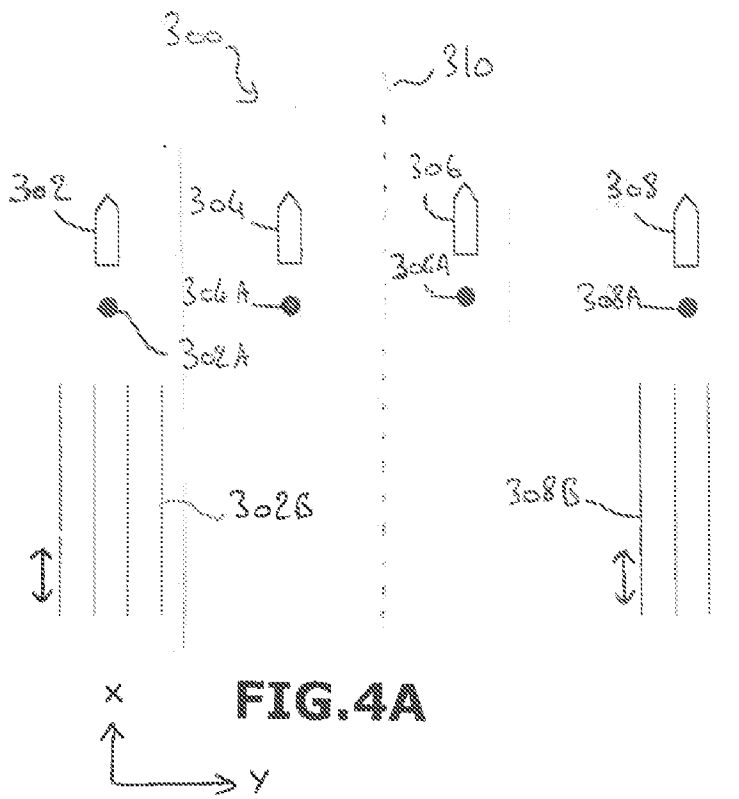
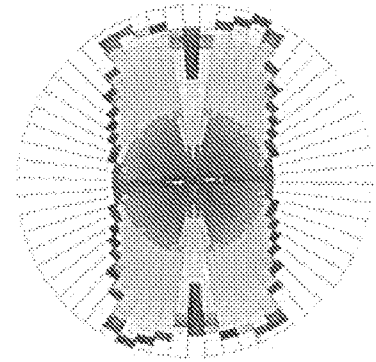


Fig. 4B

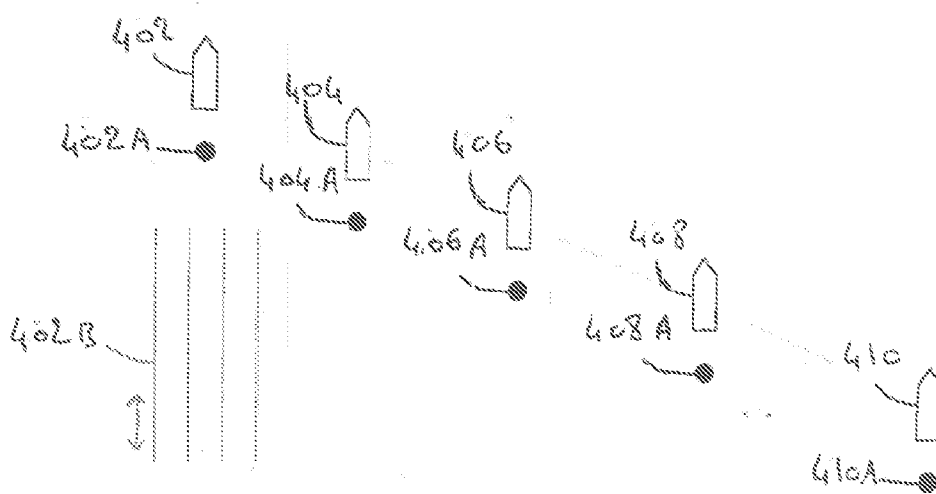


Fig. 5A

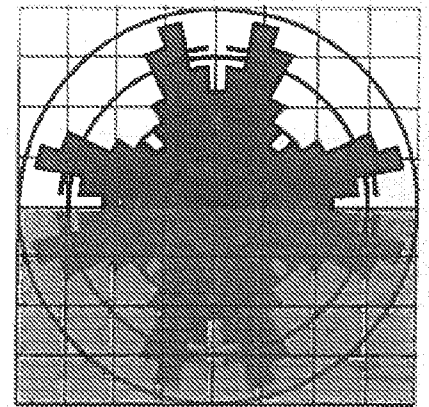


Fig. 5B

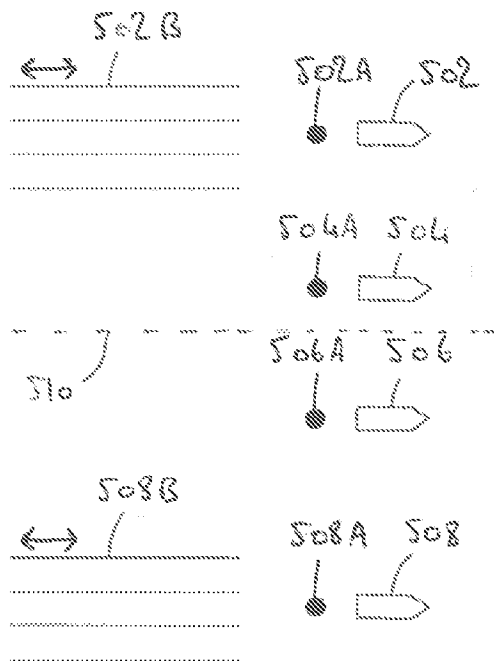


Fig. 6A

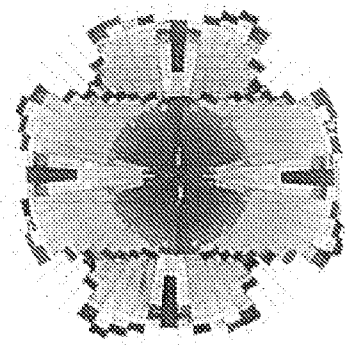


Fig. 6B

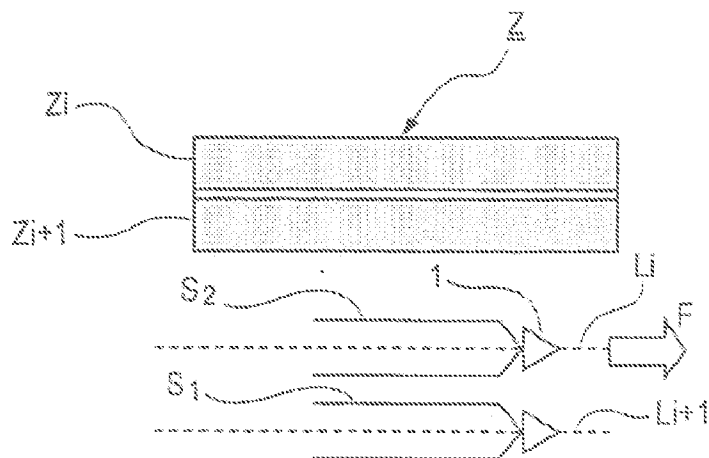
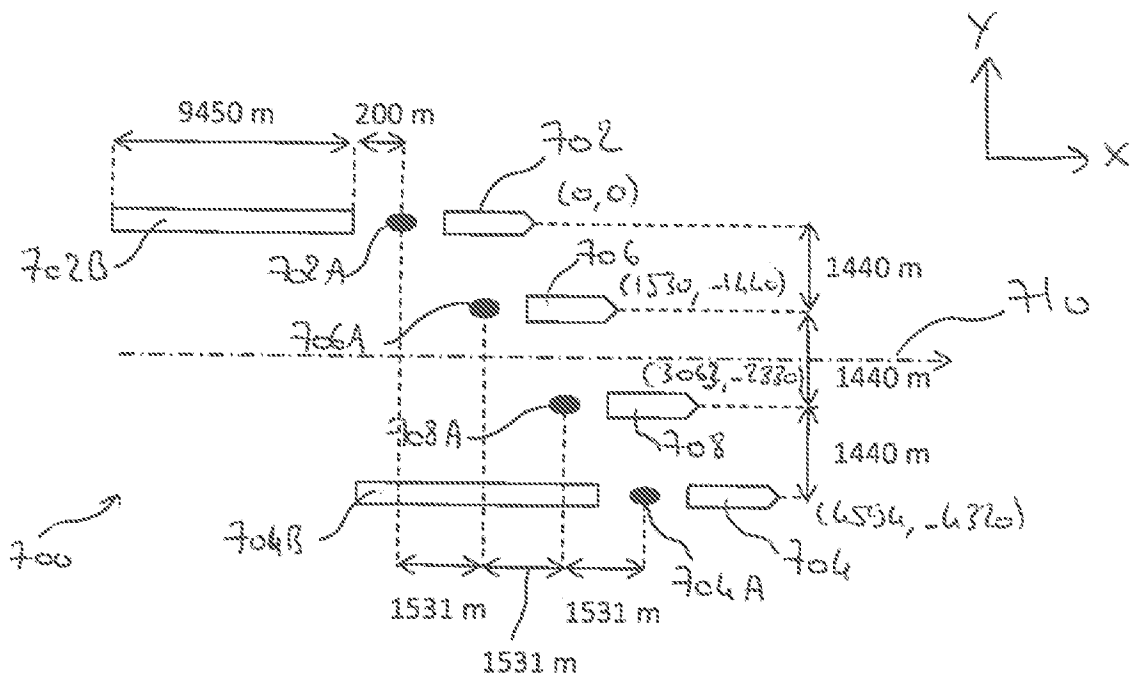


Fig. 7



F5 8

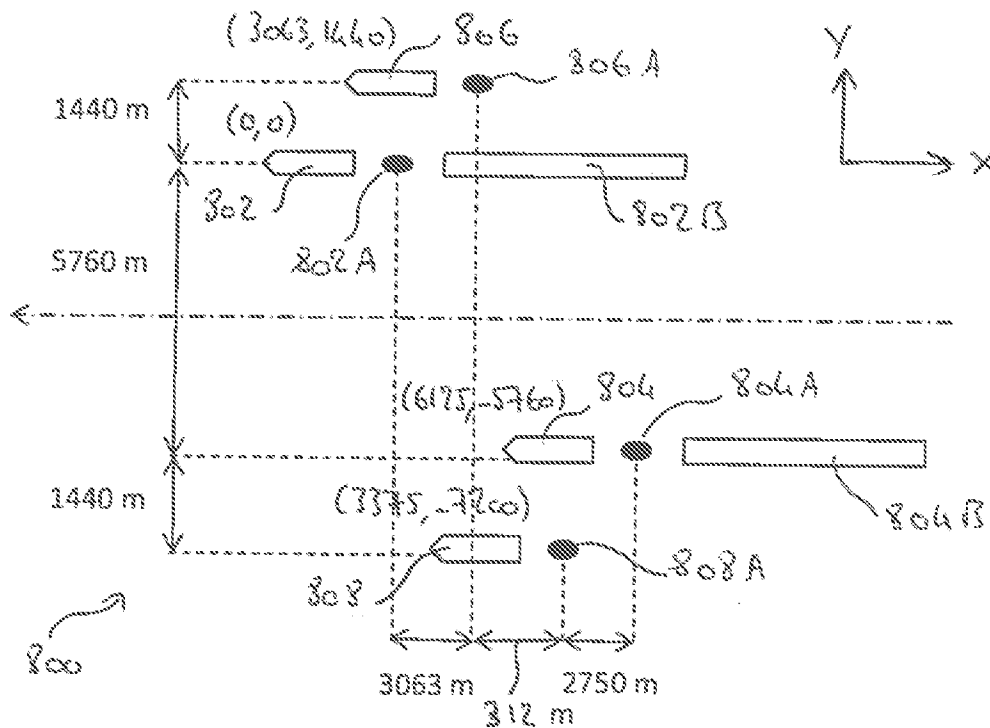
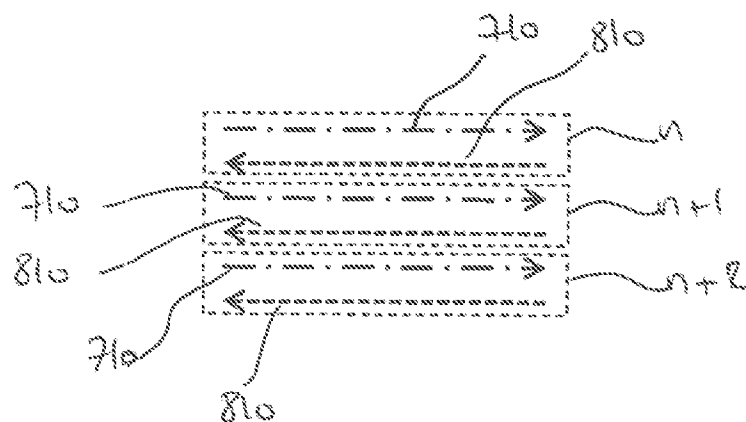


Fig 10

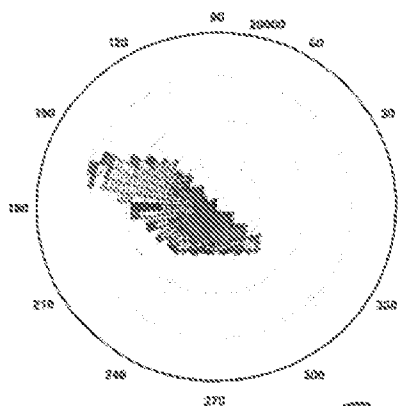


Fig. 9A

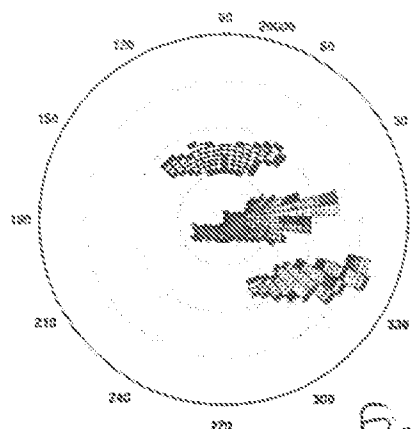


Fig. 9B

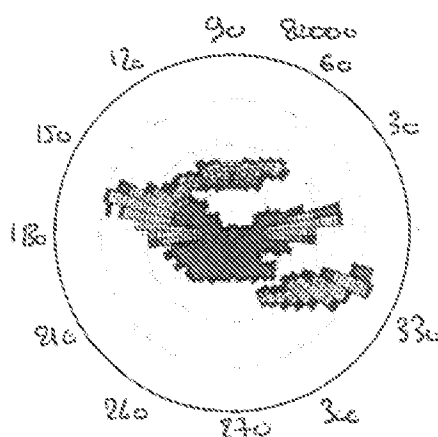


Fig. 9C

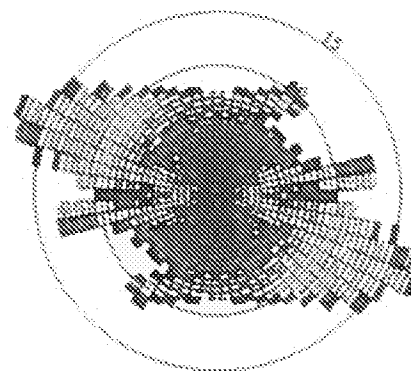


Fig. 9D

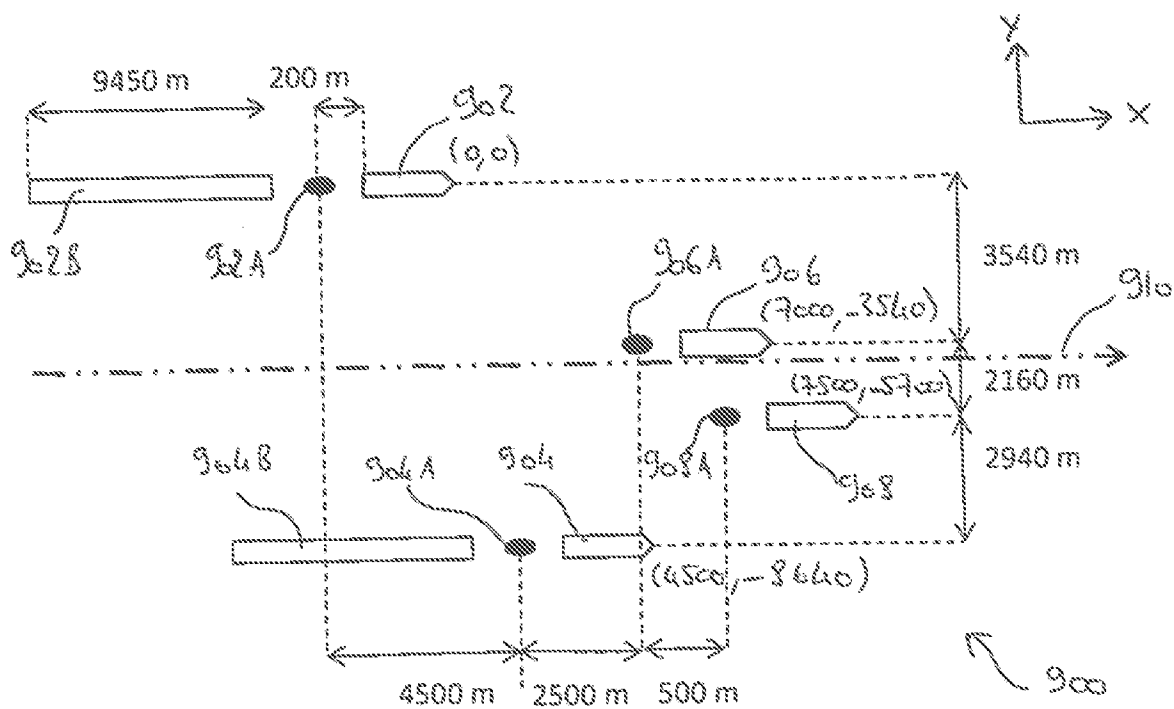


Fig. 11

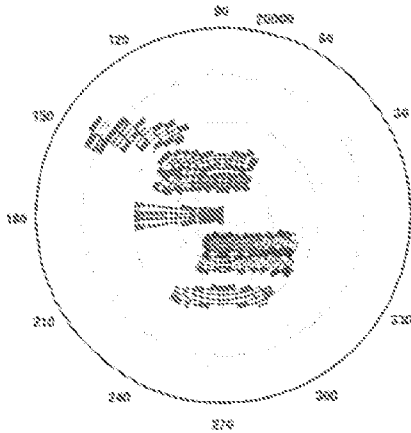


Fig. 12A

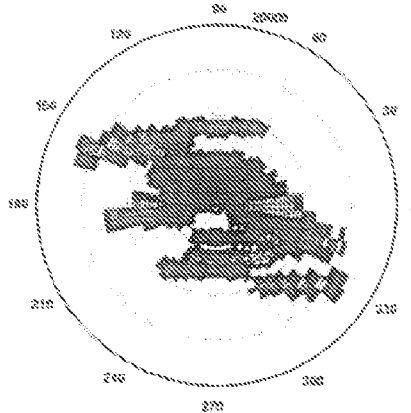


Fig. 12B

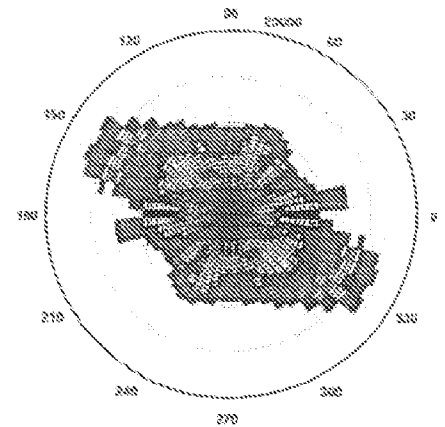


Fig. 12C

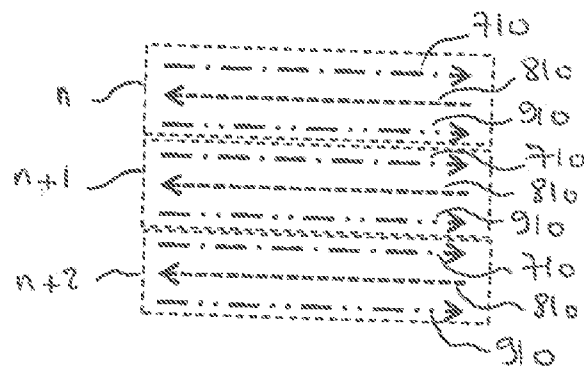


Fig. 13

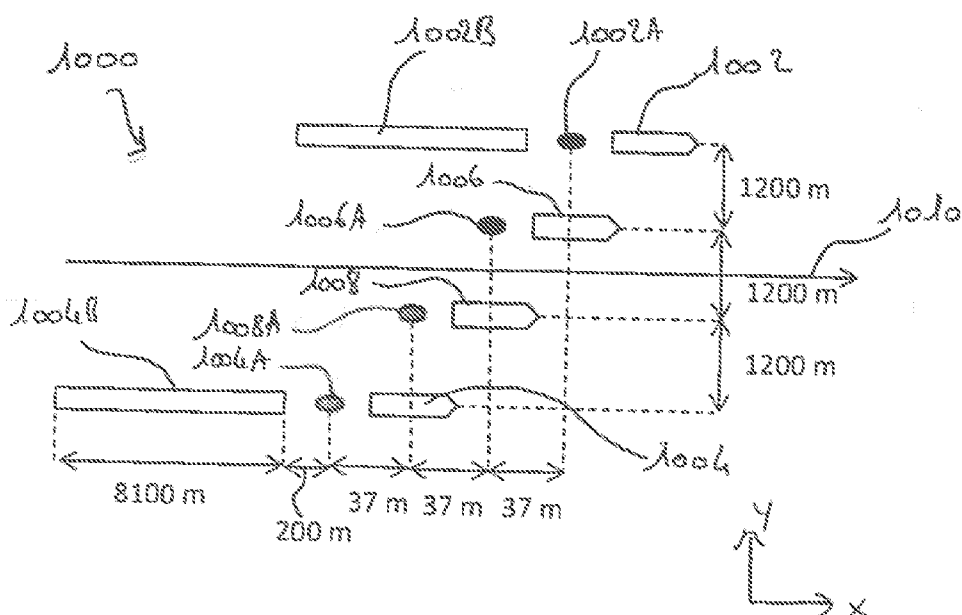


Fig. 14

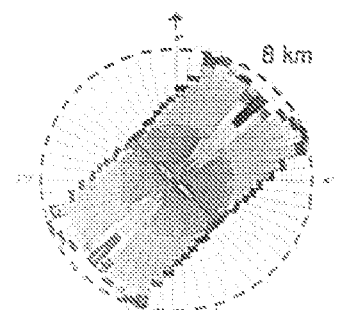


Fig. 15

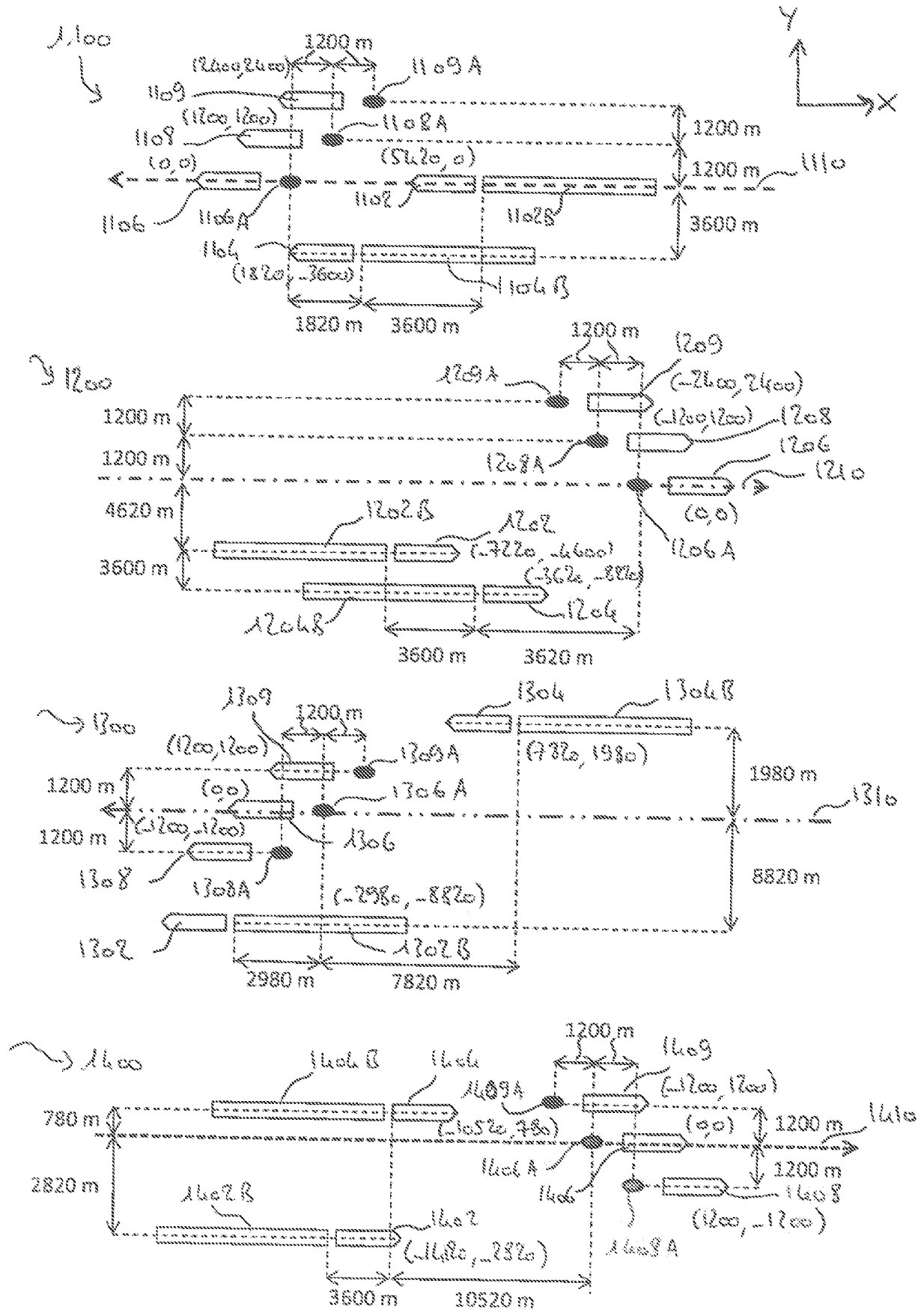


Fig. 16

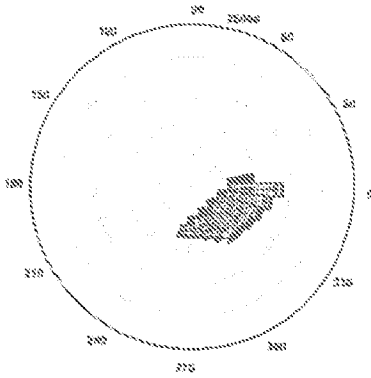


Fig. 17A

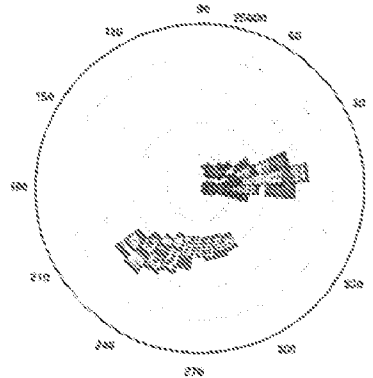


Fig. 17B

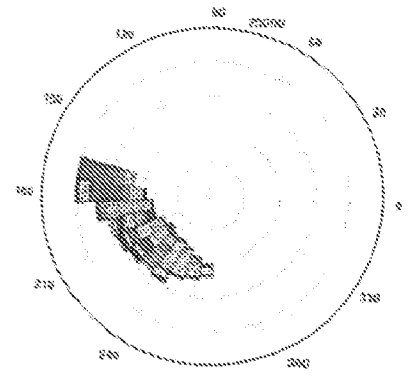


Fig. 17C

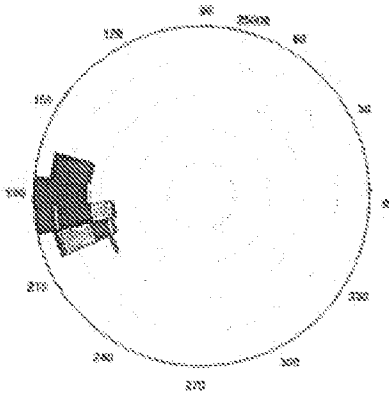


Fig. 17D

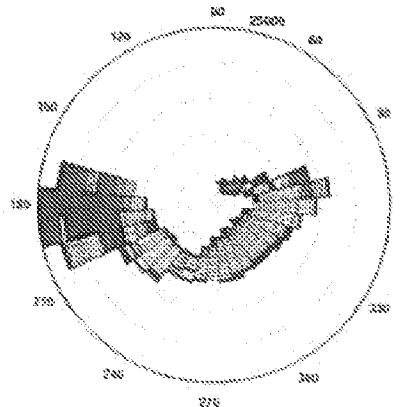


Fig. 17E

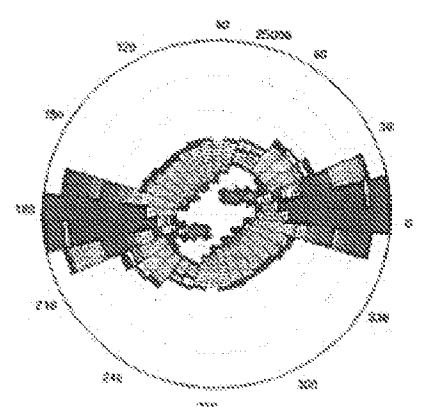


Fig. 17F

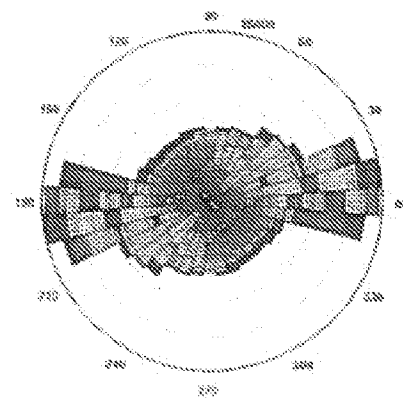


Fig. 17G

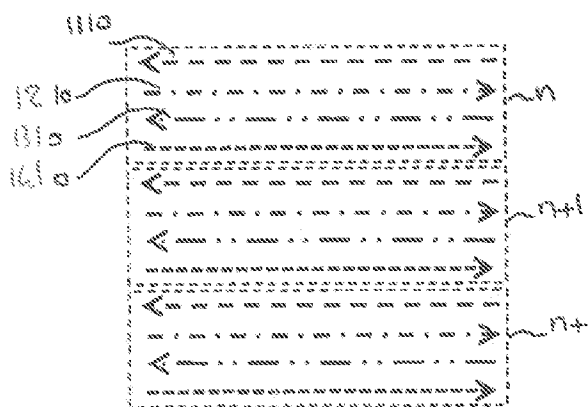


Fig. 18

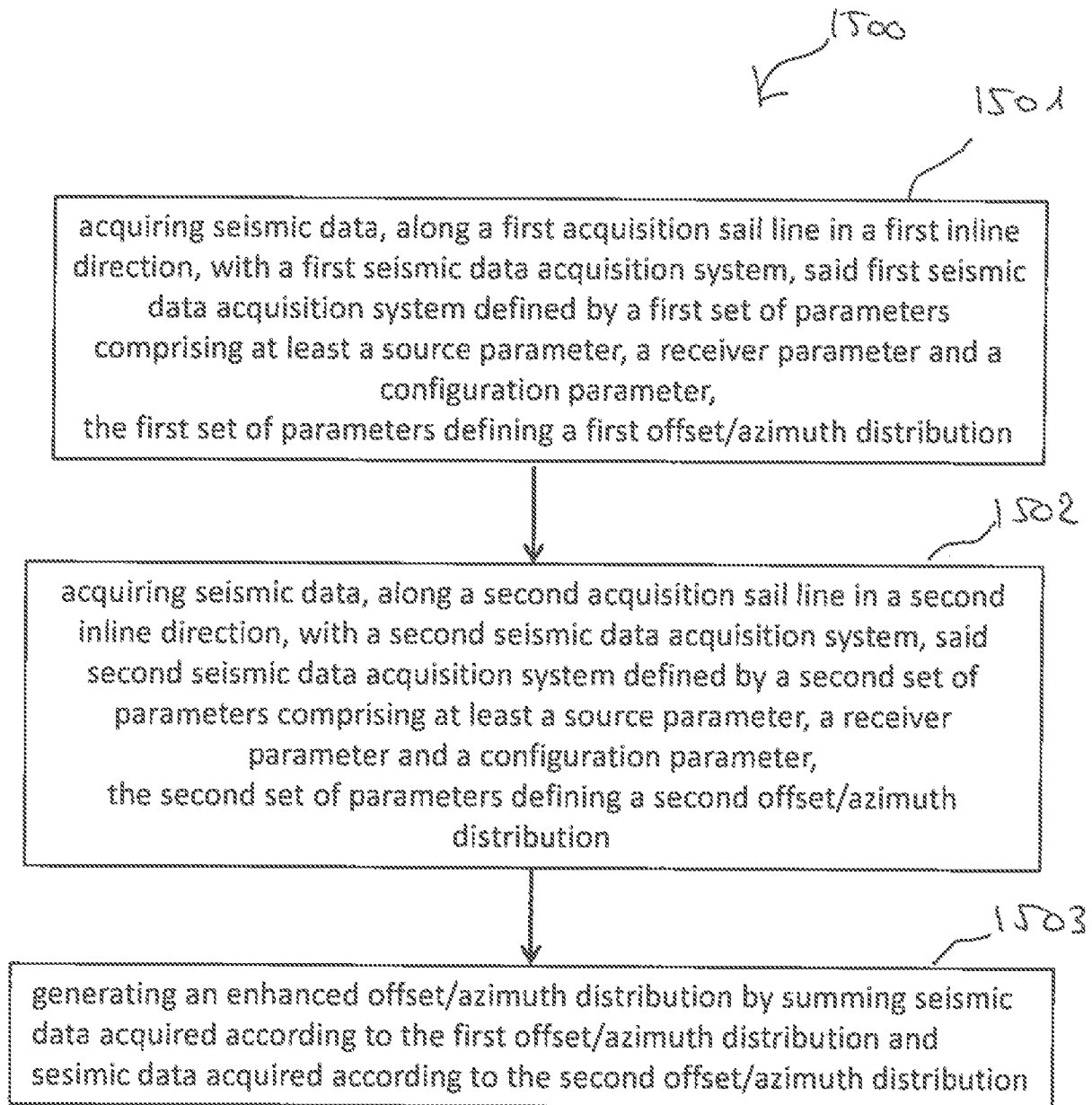


Fig. 19

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2018/000973

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

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)

EPO-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 2016/363682 A1 (GRENIE DAMIEN [FR] ET AL) 15 December 2016 (2016-12-15)	1,2,4,5, 7,9-11
Y	claim 1; figures 2,4,6A,6B -----	3,6,8,17
X	US 2014/241118 A1 (LANDAIS MICKAEL [FR] ET AL) 28 August 2014 (2014-08-28) paragraph [0045] - paragraph [0049]; figures 8-12 -----	1,3-6, 12-17
Y	EP 3 088 919 A1 (CGG SERVICES SA [FR]) 2 November 2016 (2016-11-02) claim 1; figures 9D,10D,11D -----	3,6,17
Y	EP 2 613 179 A2 (CGGVERITAS SERVICES SA [FR]) 10 July 2013 (2013-07-10) paragraph [0048]; claim 1 -----	8



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

21 November 2018

Date of mailing of the international search report

03/12/2018

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Authorized officer

Lorne, Benoît

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2018/000973

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EP 2613179	A2	10-07-2013	AU 2013200010 A1 18-07-2013 BR 102013000163 A2 12-05-2015 CN 103185895 A 03-07-2013 EP 2613179 A2 10-07-2013 RU 2012158355 A 10-07-2014 US 2013170316 A1 04-07-2013 US 2016245944 A1 25-08-2016 US 2017075010 A1 16-03-2017