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- (71) **Applicant:** CGG SERVICES SA [FR/FR]; 27, Avenue Carnot, 91300 Massy (FR).
- (72) **Inventors:** PAYEN, Thierry; c/o CGG Services SA, 27, Avenue Carnot, 91300 Massy (FR). BRET, Jean-Louis; c/o CGG Services SA, 27, Avenue Carnot, 91300 Massy (FR).
- (74) **Agents:** PETIT, Maxime et al.; Ipsilon Brema-Loyer, Le Centralis, 63 avenue du Général Leclerc, 92340 Bourg-la-Reine (FR).
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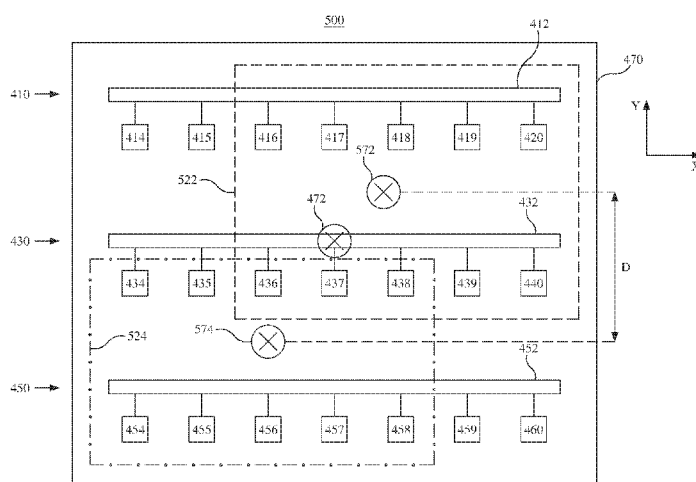


FIG. 5

(57) **Abstract:** Method and marine acoustic composite source array (500) for generating an acoustic wave in a body of water. The composite source array (500) includes a first source array (522) having a first center of source (572) and a second source array (524) having a second center of source (574). The first and second source arrays (522, 524) share a number of source elements (436), and the first center of source (572) is substantially coincident with the second center of source (574). A largest source element of the shared source elements has a volume adapted to be recharged in less time than a desired minimal shooting rate.

Method and Seismic Source with Reduced Shooting Rate

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of priority under 35 U.S.C. § 119(e) to U.S. Provisional Application No. 62/110,697 filed on February 2, 2015, the entire contents of which is hereby incorporated by reference.

BACKGROUND

TECHNICAL FIELD

[0002] Embodiments of the subject matter disclosed herein generally relate to methods and systems related to seismic exploration and, more particularly, to mechanisms and techniques for configuring two or more seismic sources to shoot with a reduced shooting rate.

DISCUSSION OF THE BACKGROUND

[0003] Marine seismic data acquisition and processing generate a profile (image) of a geophysical structure under the seafloor. While this profile does not provide an accurate 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 structures under the seafloor is an ongoing process.

[0004] During a seismic gathering process, as illustrated in Figure 1, a seismic acquisition system 100 includes a vessel 102 that tows a seismic spread 104 (i.e., plural streamers 106 and associated equipment, e.g., float 108). The streamers may be disposed horizontally, i.e., lying at a constant depth relative to a surface of the ocean, slanted or curve. Each streamer 106 includes plural seismic sensors 110 (only two are illustrated for simplicity) for recording seismic data.

[0005] The vessel also tows two seismic source arrays 122 and 124 that are configured to generate seismic waves. Each seismic source array traditionally includes three sub-array 122A-C and each sub-array includes a given number of seismic source elements. A seismic source sub-array 122A is illustrated in Figure 2 having a float 130 to which seven seismic source elements 132 to 144 are attached. The typical seismic source element is an airgun.

[0006] The seismic waves generated by the seismic source arrays propagate downward, toward the seafloor, and penetrate the seafloor until, eventually, a reflecting structure reflects the seismic wave. The reflected seismic wave propagates upward until it is detected by the seismic sensors on the streamers.

5 Based on this data, an image of the subsurface is generated.

[0007] New acquisition methods require that each source array is shoot with a very short shooting rate, e.g., below 4 s. This means, that all the airguns (except the spare or redundant air guns) of the source array need to be shot at a first time t_0 , then at $t_0 + 4$, $t_0 + 8$, and so on. However, the current large airguns that make up a source array cannot be recharged in under 5 s. Figure 3 shows a source array 300 having only two sub-arrays and each sub-array having a given number of source elements. The airguns have the following volumes, from left to right, 45, 60, 150, 100 and 70 cu in (60 cu in are approximately 1 liter). A 150 cu in (about 2.5 l) airgun needs at least 5 s to be recharged with compressed air before being able to shoot again. This means that the traditional source array 300 cannot be used to perform the new short rate acquisition methods.

[0008] To overcome these deficiencies, some operators are reducing the volume of the large airguns, or they completely remove the large airguns. This approach is not desired because removing or reducing the large airguns affects the broadband capability of the source.

[0009] Another solution is to have two different source arrays 122 and 124, as illustrated in Figure 1, and to shot these source arrays in a flip-flop mode. This means that source array 122 is shot first, at t_0 , and while the airguns of this source are recharged, the other source array 124 is shot at $t_0 + 4$. In this way, there is enough time to recharge the large airguns of each source array. However, such a solution requires that the source arrays 122 and 124 are separated by a distance D, usually 50 m for logistical reasons. Having the source arrays separated by such a large distance and shooting them in flip-flop generate gaps in the collected seismic data.

30 **[0010]** Thus, it is desired to produce a new source array that overcomes these problems, has a small footprint, does not require new components and achieves the broadband spectrum desired for the new seismic surveys.

SUMMARY

[0011] According to one embodiment, there is a marine acoustic composite source array for generating an acoustic wave in a body of water. The composite source includes a first source array having a first center of source and a second source array having a second center of source. The first and second source arrays share a number of source elements, and the first center of source is substantially coincident with the second center of source. A largest source element of the shared source elements has a volume adapted to be recharged in less time than a desired minimal shooting rate.

[0012] According to another embodiment, there is a marine acoustic composite source array that includes plural source elements, each configured to generate a sound wave. A first set of the plural source elements forms a first source array, a second set of the plural source elements forms a second source array, a third set of the plural source elements are not part of the first and second source arrays. The first and second source arrays are shot in a flip-flop manner during a seismic survey while the third set is not shot at all.

[0013] According to still another embodiment, there is a method for selecting first and second source arrays that form a composite source array. The method includes deploying in water the composite source array that includes plural source elements, each source element configured to generate a seismic wave; selecting a first set of source elements that form the first source array, wherein the first source array has a first center of source; selecting a second set of source elements that form the second source array, wherein the second source array has a second center of source; and shooting the first and second source arrays in a flip-flop sequence while towing them in water. The steps of selecting the first and second source arrays are performed so that the first and second centers of sources are as close as possible along a cross-line direction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] 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:

5 **[0015]** Figure 1 is a schematic diagram of a conventional seismic survey system;

[0016] Figure 2 is a side view of a sub-array of an array source;

[0017] Figure 3 illustrates the source elements distribution and their volume in a given source array;

10 **[0018]** Figures 4-8 illustrate variations of a composite source array;

[0019] Figures 9A-B illustrate the layouts for two source arrays that make up a composite source array;

[0020] Figure 10 illustrates amplitude spectra for two source array that make up a composite source array;

15 **[0021]** Figure 11 illustrates amplitude spectra for one source array that is part of a composite source array and a traditional source array;

[0022] Figure 12 is another illustration of a composite source array having clusters of source elements;

[0023] Figure 13 is a flowchart of a method for using a composite source array; and

20 **[0024]** Figure 14 illustrates a controller in which the method of Figure 13 may be implemented.

DETAILED DESCRIPTION

25 **[0025]** 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 two seismic source arrays formed with the traditional frame of a single source array. However, the

30 embodiments to be discussed next are not limited to two seismic source arrays, but they may be applied to a higher number of source arrays. Further, the invention may

be applied to a conventional source array in which the source elements are located at a same level or at different levels.

[0026] 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.

[0027] Current technologies in marine seismic surveys need a source array that achieves good gun volume diversity, smooth spectrum, strong low-frequency spectrum, and a superior suppression of notches. Further, such a source array needs to be shot very often, e.g., less than every 5 s (other time intervals may be used for different seismic surveys). In response to this demand, the present inventors have invented a new composite source array that (i) fits in the reduced footprint of a traditional source array, (ii) includes at least two source arrays that are capable to shot with a short shooting rate, (iii) has the center of sources of the two source arrays substantially coincident and (iv) preserves the large guns.

[0028] To better explain the advantage of this composite source array, consider that for a given seismic survey, source array 300 shown in Figure 3 is determined to be the appropriate source. This means, that source array 300 is the array to be towed by a corresponding vessel and the source array needs to be shot in a mono mode with a given shooting time interval. Further, the source array 300 for the given seismic survey has a certain volume, which needs to be preserved. Instead of using the source array 300, which has its shooting time rate limited by the time necessary for firing its largest airgun (i.e., 5 s for the 150 cu in gun), according to an embodiment illustrated in Figure 4, a composite source array 400 having three sub-arrays 410, 430 and 450 is used. Each sub-array includes seven source elements. The actual number of source elements may be larger or smaller. The footprint of composite source array 400 is given by the geometrical contour 470 of the source when looking in the XY plane, which is substantially parallel with the water surface. Composite source array 400 has a center of source 472, located

somewhere inside the geometrical contour 470. The center of source 472 is defined in the seismic art, see for example, U.S. Patent No. 8,547,785, the entire content of which is included herein by reference. The center of source may also be defined as an average of the locations of each source element, a weighted average of the locations of each source element, in which the weights are associated with the volume of each source element, etc.

[0029] According to an embodiment, instead of shooting all the source elements 414-420, 434-440 and 454-460, which make up source array 400, at the same time, as it is traditionally done in the seismic field, it is possible to divide these source elements into two or more sub-sets and each sub-set to be driven as an independent source array. The two or more sub-sets may be chosen to share the same or substantially the same center of source to avoid the problems experienced by the traditional separated sources when shot in the flip-flop manner. In addition, the two or more sub-sets may be selected to include large airguns, so that a broadband signal is generated.

[0030] For example, as illustrated in Figure 5, the first sub-set, called from now on first source array 522, would include source elements 416-420 from the first sub-array 410, and source elements 436-440 from the second sub-array 140. The second source array 524 would include source elements 434-438 from the second sub-array 430 and source elements 454-458 from the third sub-array 450. In this way, the first and second source arrays 522 and 524 have their centers of sources 572 and 574 substantially coincident with the center of source 472.

[0031] In a practical example, a crossline distance D between the two centers 572 and 574 of sources may be about 8 m along the cross-line direction (y direction) and about 6 m along the inline direction (x direction). In this regard, note that the drawings are not at scale and the exact position of the center of sources depends on the volume of each source element, the distances between the source elements, the distances between the sub-arrays, etc., and thus, the center of source should not be identified to the geometric center of source. In another example, the cross-line distance D may be about 10 m. These values are not arbitrary, but they were determined based on simulations, calculations and the geometry of the composite source array. In this regard, a cross-line distance between two adjacent sub-arrays

(410 and 430 or 430 and 450) is about 8 m. Thus, in one application, the cross-line distance D between the centers of sources 572 and 574 is substantially equal or less than the cross-line distance between two adjacent sub-arrays. In another application, the cross-line D distance between the centers of sources 572 and 574 is substantially equal or less than twice the cross-line distance between the two adjacent sub-arrays.

[0032] If the large volume source elements (large is considered to be any volume larger than 100 cu in and small is considered to be any volume smaller than this value) are selected to be 434, 435, 439 and 440, for example, and the small volume source elements are selected to be 436, 437 and 438 (the shared source elements), then it is possible to shoot the first source array 522 at time t_0 , the second source array 524 at time t_0+4 , again the first source array 522 at time t_0+8 , and so on because the largest volume of any of the shared source element can be refilled in less than 4 s. This means that the first and second source arrays 522 and 524 can be shot with a short shooting rate, e.g., less than 4 s as their respective large volume source elements have enough time to be recharged. Those skilled in the art would understand that the 4 s is just an example and the invention can work with any time interval as long as the shared source elements are selected to have their volume appropriate for refiling in less than the selected time interval. In other words, if a time interval (shooting rate) of 3 s is desired, the source element from the shared source elements is selected to have a volume that can be refilled with compressed air in less than 3 s.

[0033] In addition, because the two source array share substantially the same center of source, it can be considered that the two source arrays 522 and 524 act as a single source array 500 (for this reason, this source is called "composite" source array) that is shot at time intervals of less than 4 s although some of its component source elements take longer than 4 s for being recharged.

[0034] The first and second source arrays 522 and 524 of the embodiment illustrated in Figure 5 can share source elements 436-438 because these source elements have a small volume and can be recharged in a short amount of time, which is less than the time interval between consecutive shots.

[0035] Figure 6 shows another embodiment in which composite source array 600 is made of two source arrays 622 and 624. In this embodiment, source arrays 622 and 624 include source elements from each of the three sub-arrays. Their center of sources 672 and 674 are substantially identical to the center of composite source 600.

[0036] Figure 7 shows another embodiment in which source arrays 722 and 724 act as a single composite source array 700. This embodiment illustrates that the number of source elements selected from each sub-array may vary, i.e., three source elements from each of the first and second sub-arrays and four source elements from the third sub-array for source array 722. Figure 8 shows still another embodiment in which three (not two) source arrays 822, 824, and 826 form the composite source array 800. Those skilled in the art would understand that there are other configurations possible in the same spirit of the invention. One such example is having the source elements from the first source array located at a certain depth and the source elements from the second source array located at another depth or the source elements at different depths relative to each other.

[0037] Returning to the embodiment of Figure 5, the volumes of each air gun of source arrays 522 and 524 are illustrated in Figures 9A-B, with Figure 9A showing the layout for source array 522 and Figure 9B showing the layout for source array 524. Note that the air gun volumes shown in Figures 9A-B are chosen so that the total volume of source arrays 522 and 524 equal the total volume of source array 300. Further, some guns are not selected in the embodiments previously illustrated so that a directivity of the composite source array is similar to the directivity of source array 300. In this regard, the reader is reminded that one premise of the embodiment illustrated in Figure 4 was to replace source array 300 with a new composite source array 400 that would achieve the same results during a seismic survey.

[0038] Figure 10 illustrates the amplitude spectrums 1022 and 1024 for source arrays 522 and 524, respectively. One will note that these spectrums are very close. If the amplitude spectrum 1022 of source array 522 is compared to the amplitude spectrum 1000 of original source array 300, as illustrated in Figure 11, they appear

to look almost identical. This means, that the composite source array has the same qualities as the original source array, and, in addition, a faster shooting time rate.

[0039] The feature of having the center of source arrays coincident, or substantially coincident (where substantially means within 8 or less meters), provides the advantage that although source arrays 522 and 524 are fired in a flip-flop mode, the composite source array 500 acts as being fired in a traditional way (i.e., mono-mode), at time intervals less than 5 s. This is advantageous because when the traditional source arrays are fired in a flip-flop manner, they are separated by large distances (typically around 50 m in a cross-line direction), which negatively affects the binning. However, the composite seismic source has the two or more source arrays with almost no separation (maximum 10 m), which results in a better binning. A separation of 10 m or less between two distinct seismic source arrays is practically impossible for two traditional source arrays because of the space taken by the equipment (e.g., deflectors and other cables) necessary for towing and maintaining the arrays in place. Further, those skilled in the art would understand that 5 s is just an example chosen in relation to a refilling time of a large air gun of about 150 cu in. This shooting time interval may be shorter or longer, depending on the gun composition of each source array. For example, it is possible that the largest volume gun in the source array to be about 100 cu in (about 1.6 l) and then, the charging time may be shorter larger than 5 s. Further, the composite source 400 array has the footprint (or geometry) identical or slightly larger than a traditional source array 300. In one application, if the source array required for a seismic survey needs to have N sub-arrays, the composite source array replacing this source may have N+1 sub-arrays.

[0040] Variations of the composite source array discussed above may also be implemented in a seismic survey system. For example, a composite source array 1200 as illustrated in Figure 12, may have pairs of source elements 1228A-B and 1230A-B at the same location along a sub-array 1222. Composite source array 1200 has three sub-arrays 1202, 1222 and 1242. At least sub-array 1222 includes pairs of guns at given locations on the sub-array. The floats are not shown in the figure for simplicity. With this configuration, the two source arrays 1250 and 1252 do not share any gun, as source array 1250 uses one member of each pair of guns

1228A-B and 1230A-B and the other source array 1252 uses the other member of the pair. In one application, the guns that are mounted in pair (or clustered) need to be small guns, so that they can be refilled quickly. The number of sub-arrays and source elements in Figure 12 is not intended to limit the invention. More or less sub-arrays and/or source elements may be used. In another application, the two source arrays 1250 and 1252 share source elements on different sub-arrays so that the two center of sources coincide. In still another application, the two source arrays share source elements at different depths. In yet another application, there are more than two source arrays forming the composite source array. In one other application, the cluster of source elements may include more than two guns, and these three or more guns may be shared by a corresponding number of source arrays.

[0041] One advantage of a composite source array is the reduced shooting rate with all the guns (especially the biggest one) fully refilled. In one application, the composite source array can have a bigger volume than the traditional sources, i.e., about 6000 cu in (about 98 l) instead of the current 2000 cu in (about 33 l). Increasing the diversity of gun volume will further allow a better source design with smoother amplitude spectrum. The source design is understood herein the process of designing what source elements to be placed in the source array to be used for a given seismic survey, as each seismic survey is unique and has different objectives and operates under different conditions.

[0042] As discussed in the above embodiments, it is desired that the source arrays that form the composite source array have substantially similar cross-line locations, which improve the bins.

[0043] Based on the embodiments discussed one, it is possible, in one application, to have a marine acoustic composite source array for generating an acoustic wave in a body of water, that includes the following elements: a first source array having a first center of source, and a second source array having a second center of source. The first and second source arrays share a number of source elements, and the first center of source is substantially coincident with the second center of source. A largest source element of the shared source elements has a volume less than 2.5 l. Alternatively, the largest source element has a volume less than 1.6 l. Alternatively, a largest source element of the shared source elements has

a volume adapted to be recharged in less time than a desired minimal shooting rate. Those skilled in the art would note that depending of the type of source array, the volumes of the source elements and the required shooting rate, the shared source elements are selected to have a volume that can be charged in a time shorter than that required by the shooting rate.

[0044] In a different embodiment, the marine acoustic composite source array includes plural source elements, each configured to generate a sound wave. The first set of the plural source elements forms a first source array, a second set of the plural source elements forms a second source array, and a third set of the plural source elements do not belong to the first and second source arrays. The first and second source arrays are shot in a flip-flop manner during a seismic survey while the third set is not. A distance between centers of sources of the first and second source arrays is less than 10 m.

[0045] A method for selecting first and second source arrays of a composite source is now discussed with regard to Figure 13. The method includes a step 1300 of deploying in water the composite source array that includes plural source elements, each source element configured to generate a seismic wave, a step 1302 of selecting a first set of source elements that form the first source array, wherein the first source array has a first center of source, a step 1304 of selecting a second set of source elements that form the second source array, wherein the second source array has a second center of source, and a step 1306 of shooting the first and second source arrays in a flip-flop sequence while towing them in water. The steps of selecting the first and second source arrays are performed so that the first and second centers of sources are as close as possible along a cross-line direction.

[0046] In order to be able to select a desired number of source elements to form a source array and to shoot them, for example, simultaneously for each source element, a control system that drives the source elements needs to communicate with each source element. In this way, irrespective of the source element selection, those source elements that form one of the source arrays can be simultaneously shot.

[0047] The above-discussed composite source arrays may be driven with a computing device as illustrated in Figure 14. Hardware, firmware, software or a

combination thereof may be used to perform the various steps and operations described herein.

[0048] Exemplary computing device 1400 suitable for performing the activities described in the above embodiments may include a server 1401. Such a server 1401 may include a central processor (CPU) 1402 coupled to a random access memory (RAM) 1404 and to a read-only memory (ROM) 1406. ROM 1406 may also be other types of storage media to store programs, such as programmable ROM (PROM), erasable PROM (EPROM), etc. Processor 1402 may communicate with other internal and external components through input/output (I/O) circuitry 1408 and bussing 1410 to provide control signals and the like. Processor 1402 carries out a variety of functions as are known in the art, as dictated by software and/or firmware instructions.

[0049] Server 1401 may also include one or more data storage devices, including hard drives 1412, CD-ROM drives 1414 and other hardware capable of reading and/or storing information, such as DVD, etc. In one embodiment, software for carrying out the above-discussed steps may be stored and distributed on a CD-ROM or DVD 1416, a removable media 1418 or other form of media capable of portably storing information. These storage media may be inserted into, and read by, devices such as CD-ROM drive 1414, disk drive 1412, etc. Server 1401 may be coupled to a display 1420, which may be any type of known display or presentation screen, such as LCD, plasma display, cathode ray tube (CRT), etc. A user input interface 1422 is provided, including one or more user interface mechanisms such as a mouse, keyboard, microphone, touchpad, touch screen, voice-recognition system, etc.

[0050] Server 1401 may be coupled to other systems, such as a navigation system, GPS, and/or streamers. The server may be part of a larger network configuration as in a global area network (GAN) such as the Internet 1428, which allows ultimate connection to various landline and/or mobile computing devices.

[0051] The disclosed exemplary embodiments provide a system and a method for providing a composite source array that can be quickly and fully recharged and shoot, as necessary, for a high-density seismic survey. 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

5 comprehensive understanding of the claimed invention. However, one skilled in the art would understand that various embodiments may be practiced without such specific details.

[0052] Although the features and elements of the present exemplary embodiments are described in the embodiments in particular combinations, each
10 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.

[0053] 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
15 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 marine acoustic composite source array (500) for generating an acoustic wave in a body of water, the composite source array (500) comprising:

a first source array (522) having a first center of source (572); and

5 a second source array (524) having a second center of source (574),

wherein the first and second source arrays (522, 524) share a number of source elements (436),

the first center of source (572) is substantially coincident with the second center of source (574), and

10 a largest source element of the shared source elements has a volume adapted to be recharged in less time than a desired minimal shooting rate.

2. The composite source array of Claim 1, wherein the largest source element of the shared source elements has the volume less than 2.5 l.

15 3. The composite source array of Claim 1, wherein the source elements are air guns.

4. The composite source array of Claim 1, wherein source elements making
20 up the composite source array are distributed on only three sub-arrays.

5. The composite source array of Claim 4, wherein the first source array includes source elements from first and second sub-arrays and the second source array includes source elements from second and third sub-arrays.

25 6. The composite source array of Claim 5, wherein a sub-set of the source elements do not belong to the first and second source arrays.

7. The composite source array of Claim 4, wherein a cross-line distance between the first and second centers of sources is less than a distance between two
30 adjacent sub-arrays of the three sub-arrays.

8. The composite source array of Claim 1, wherein the first and second source arrays are shot in a flip-flop sequence.

9. The composite source array of Claim 1, wherein the second source array is shot after a given time interval after the first source array is shot, and the given time interval is shorter than a time necessary for filling up with compressed air a source element, having the largest volume, of the second source array.

10. The composite source array of Claim 1, wherein a cross-line distance between the first and second centers of sources is less than 10 m.

11. A marine acoustic composite source array (500) comprising:
plural source elements (414-460), each configured to generate a sound wave, wherein a first set (416-420, 436-438) of the plural source elements forms a first source array (522);
a second set (434, 435, 454-458) of the plural source elements forms a second source array (524);
a third set (414, 415, 439, 440) of the plural source elements are not part of the first and second source arrays; and
the first and second source arrays are shot in a flip-flop manner during a seismic survey while the third set is not shot at all.

12. The composite source array of Claim 11, wherein a distance between centers of sources of the first and second source arrays is less than 10 m.

13. The composite source array of Claim 11, wherein a first center of source of the first source array is substantially coincident with a second center of source of the second source array.

14. The composite source array of Claim 11, wherein a largest source element of the shared source elements has a volume less than 2.5 l.

15. The composite source array of Claim 11, wherein the source elements are distributed to three sub-arrays, and a cross-line distance between first and second centers of sources of the first and second source arrays, respectively, is less than a distance between two adjacent sub-arrays of the three sub-arrays.

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16. The composite source array of Claim 11, wherein the source elements are distributed to three sub-arrays, and a cross-line distance between first and second centers of sources of the first and second source arrays, respectively, is less than twice a distance between two adjacent sub-arrays of the three sub-arrays.

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17. The composite source array of Claim 11, wherein the second source array is shot after a given time interval after the first source array is shot, and the given time interval is shorter than a time necessary for filling up with compressed air a source element, having the largest volume, of the second source array.

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18. A method for selecting first and second source arrays that form a composite source array (500), the method comprising:

deploying (1300) in water the composite source array (500) that includes plural source elements, each source element configured to generate a seismic wave;

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selecting (1302) a first set of source elements that form the first source array (522), wherein the first source array has a first center of source (572);

selecting (1304) a second set of source elements that form the second source array (524), wherein the second source array has a second center of source (572); and

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shooting the first and second source arrays in a flip-flop sequence while towing them in water,

wherein the steps of selecting the first and second source arrays are performed so that the first and second centers of sources are as close as possible along a cross-line direction.

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19. The method of Claim 18, wherein a cross-line offset of the first and second centers of sources is less than 10 m.

20. The method of Claim 18, wherein a cross-line offset of the first and second centers of sources is less than a cross-line distance between two adjacent sub-arrays that form the composite source array.

5

10

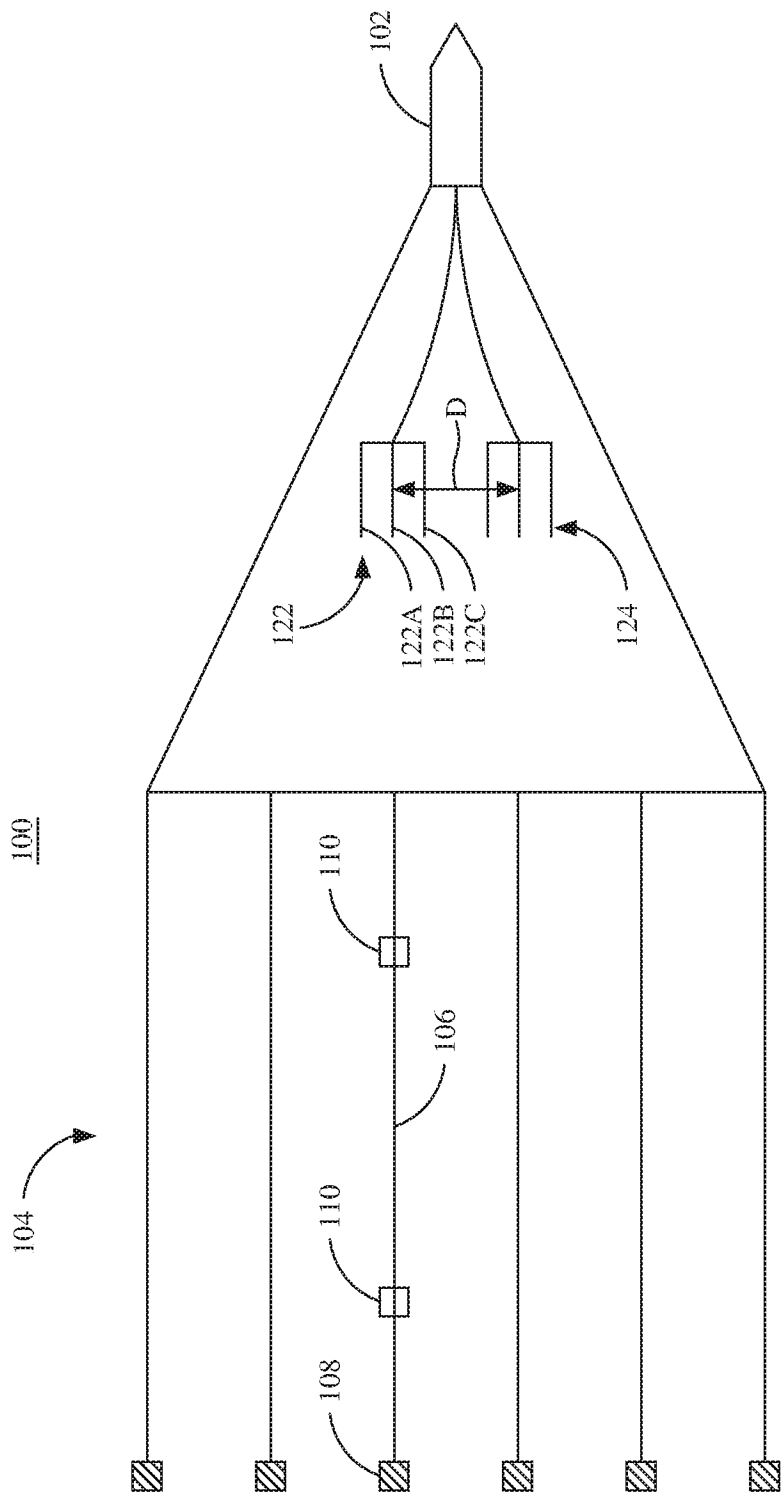


FIG. 1
(Background Art)

122A

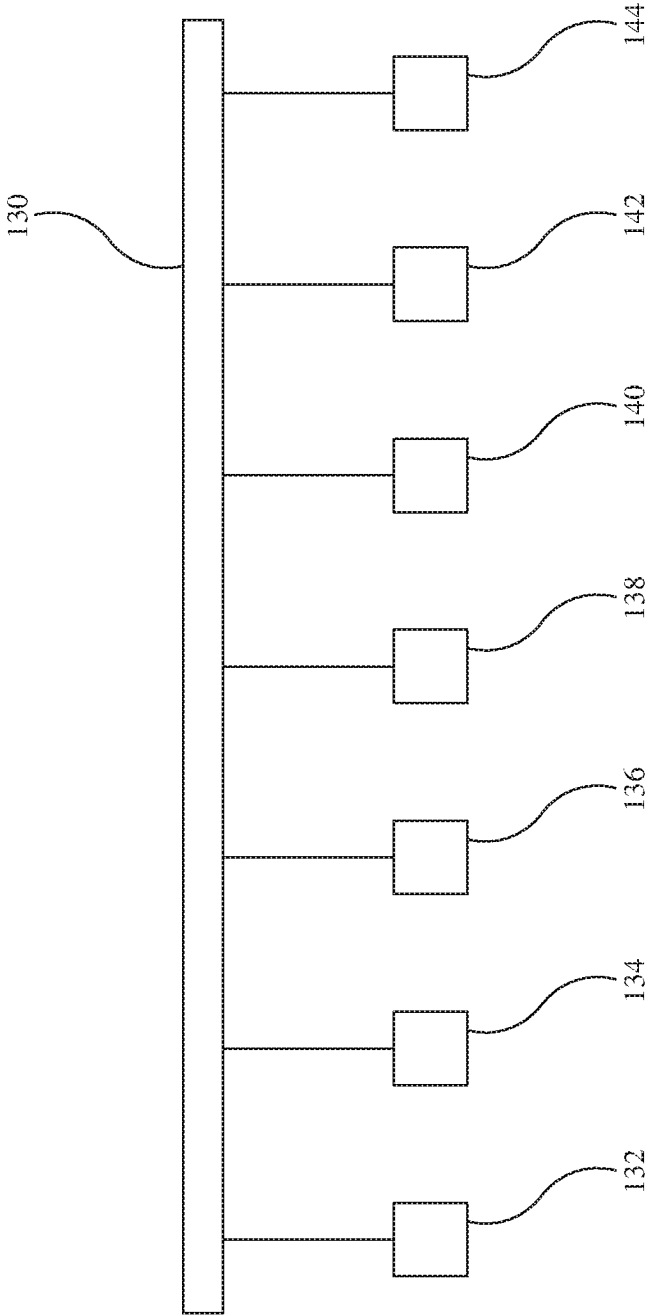


FIG. 2

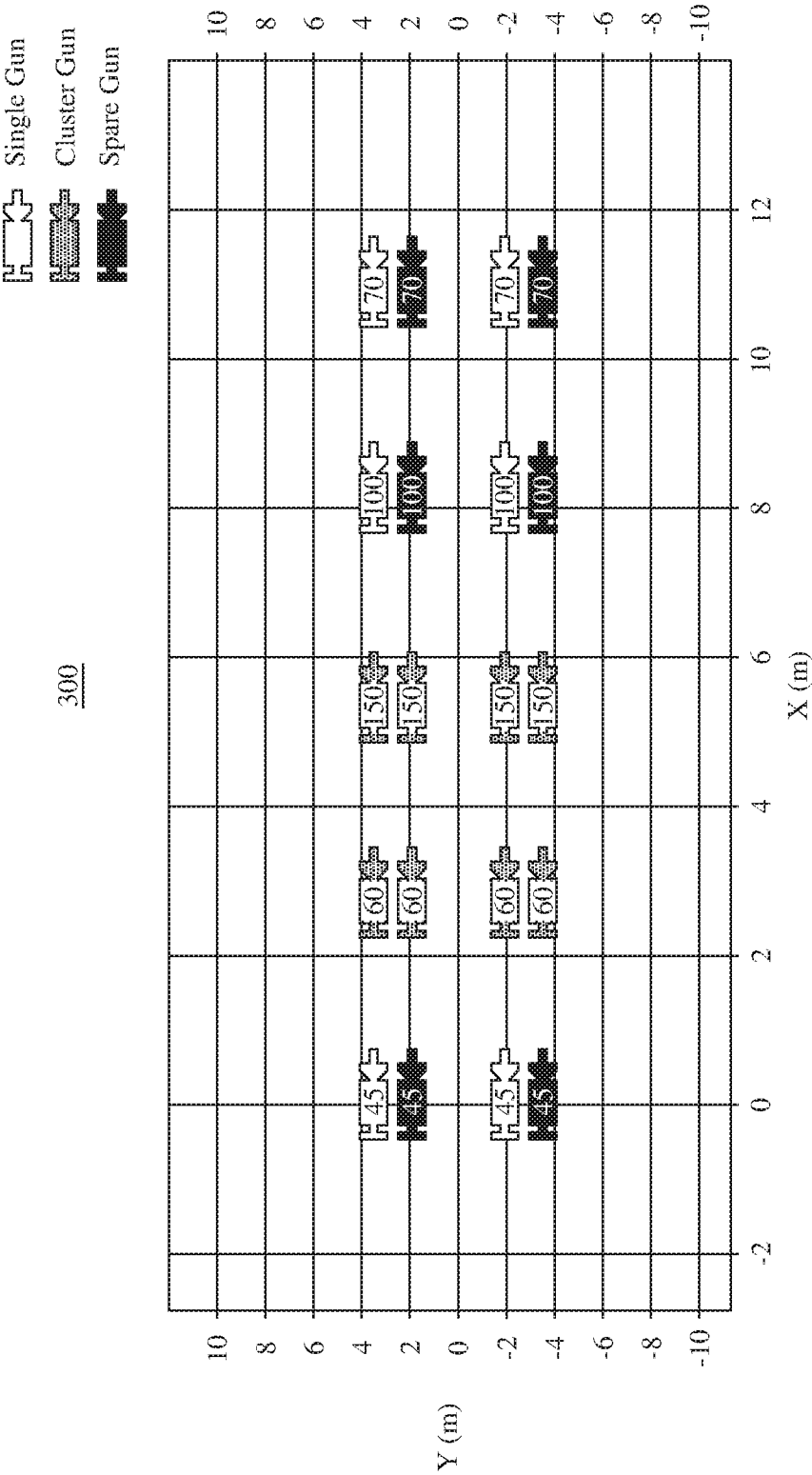


FIG. 3

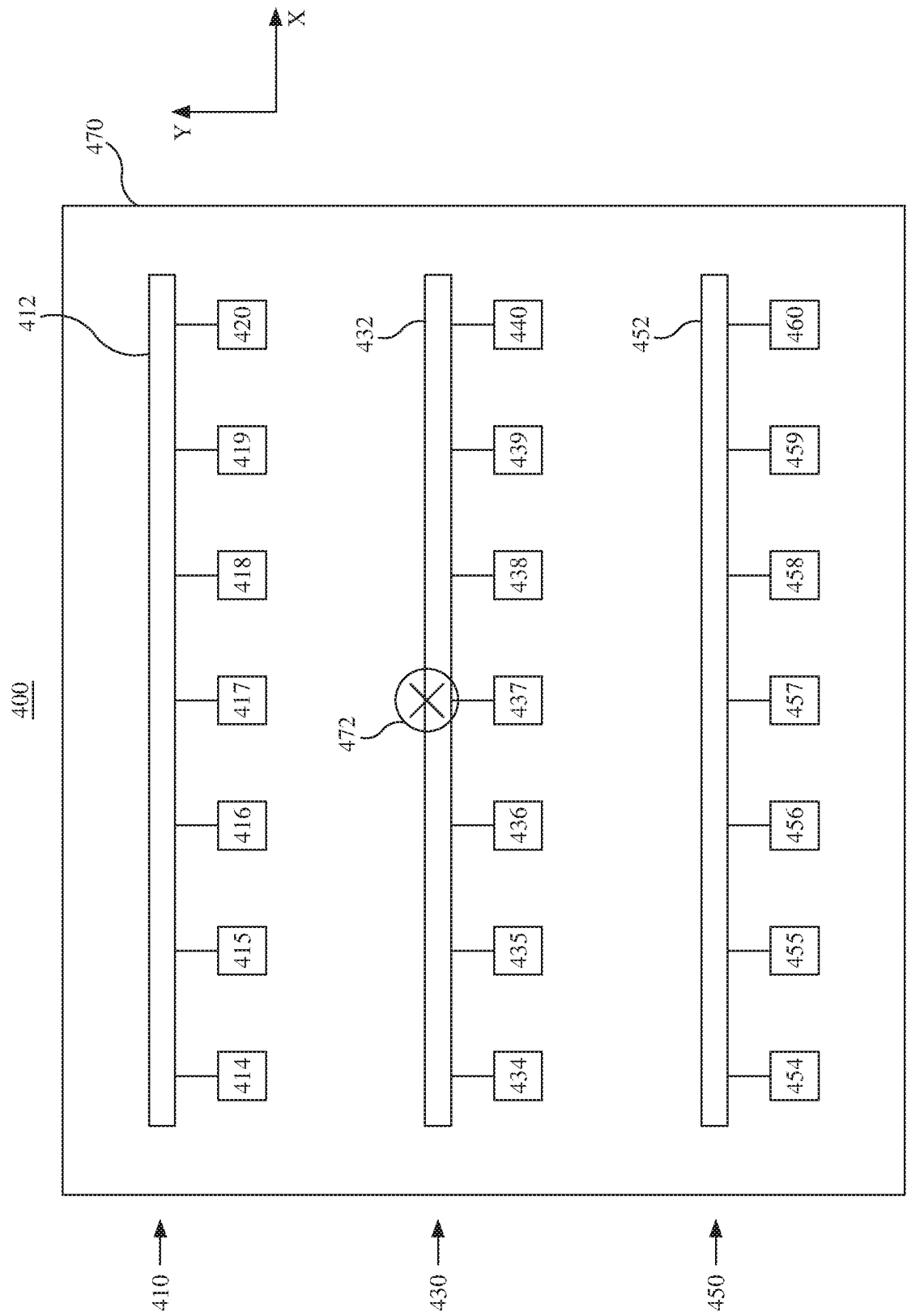


FIG. 4

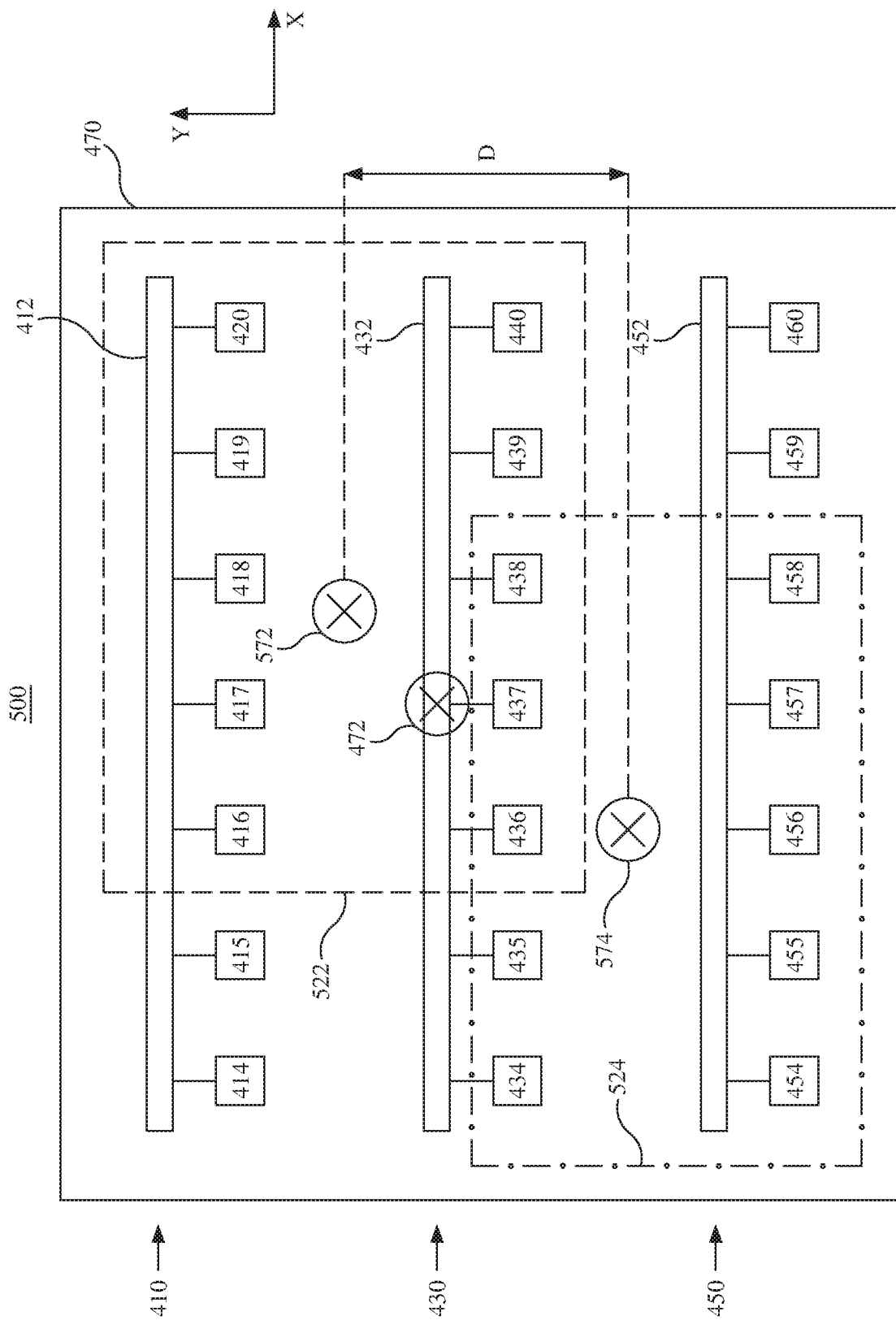


FIG. 5.

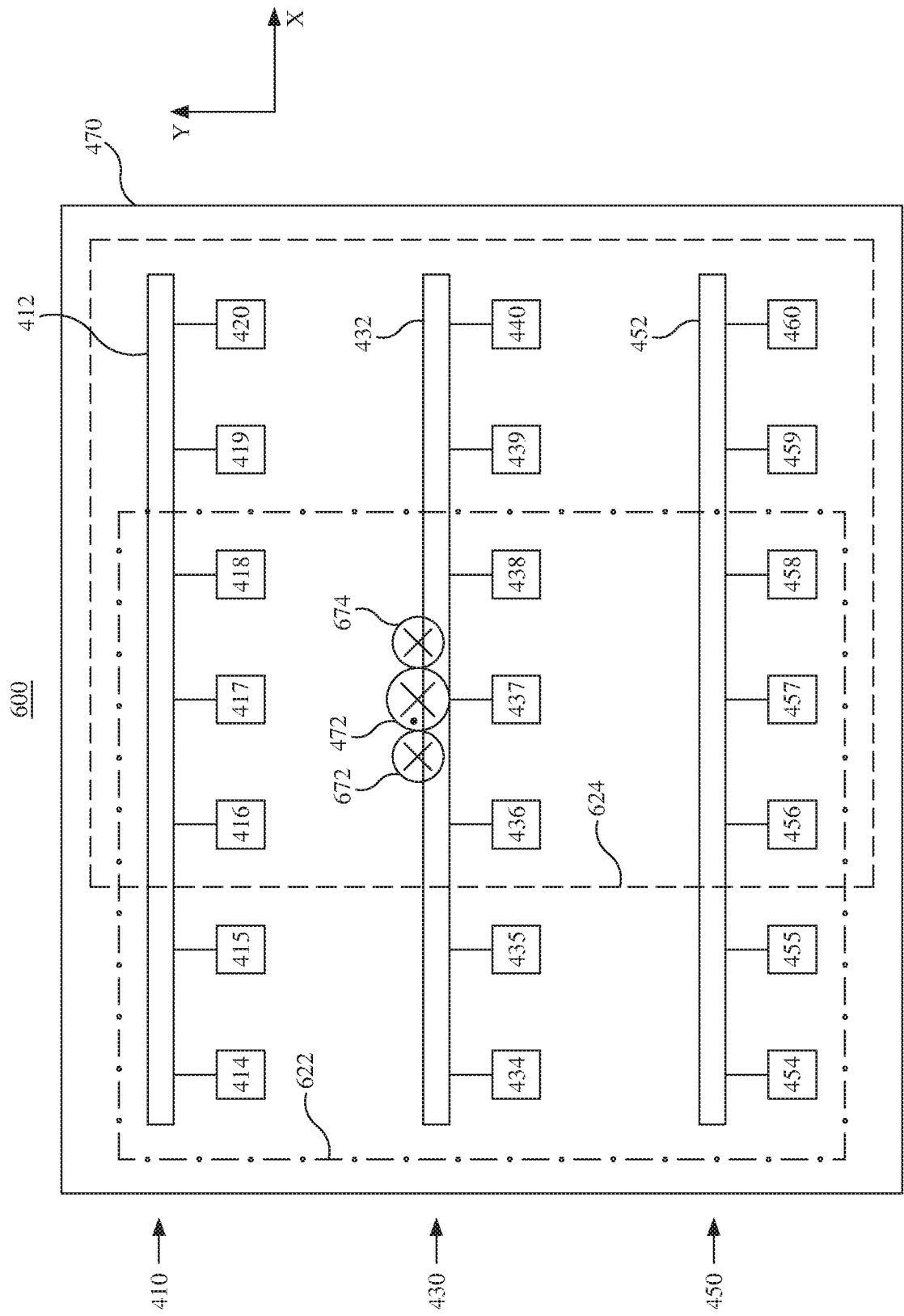


FIG. 6

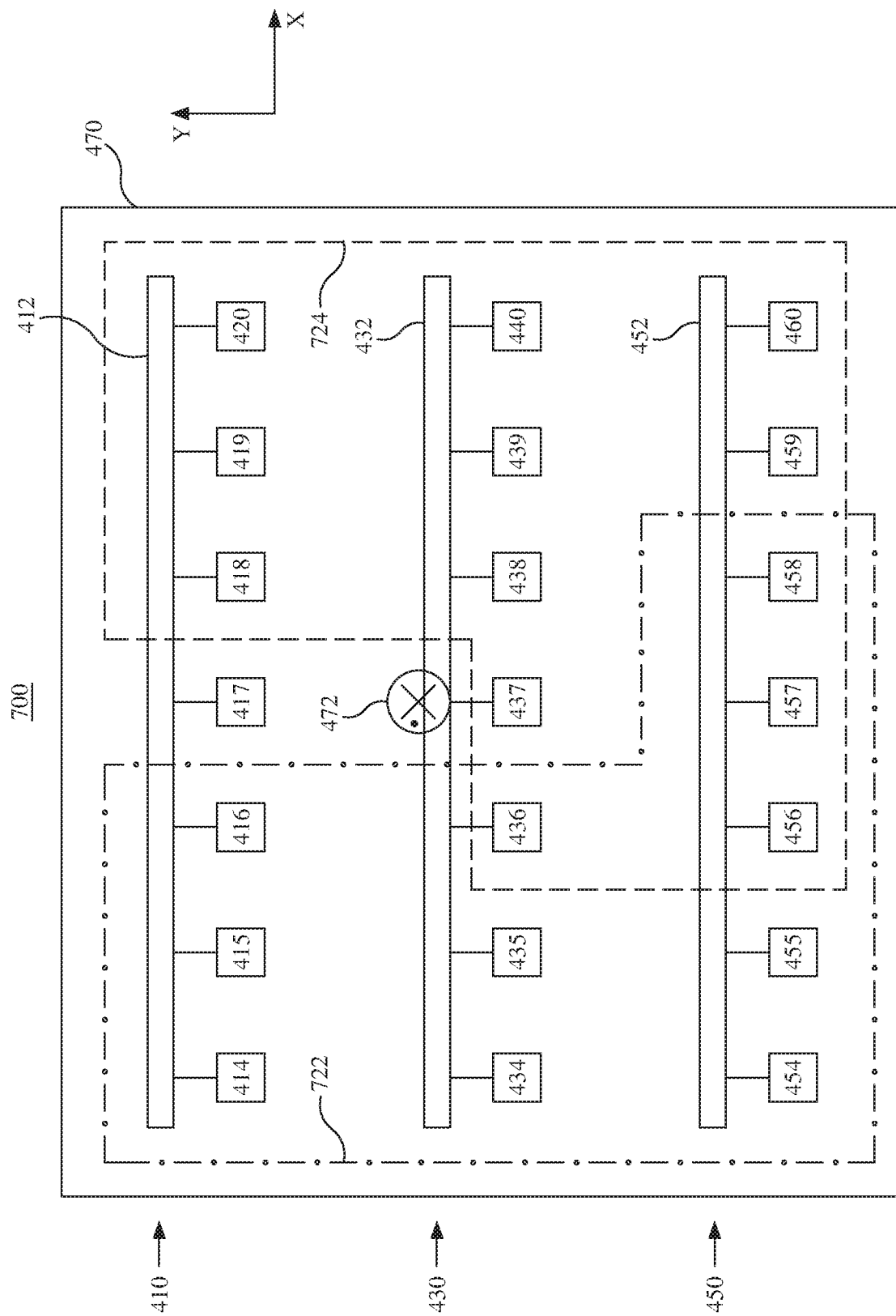


FIG. 7

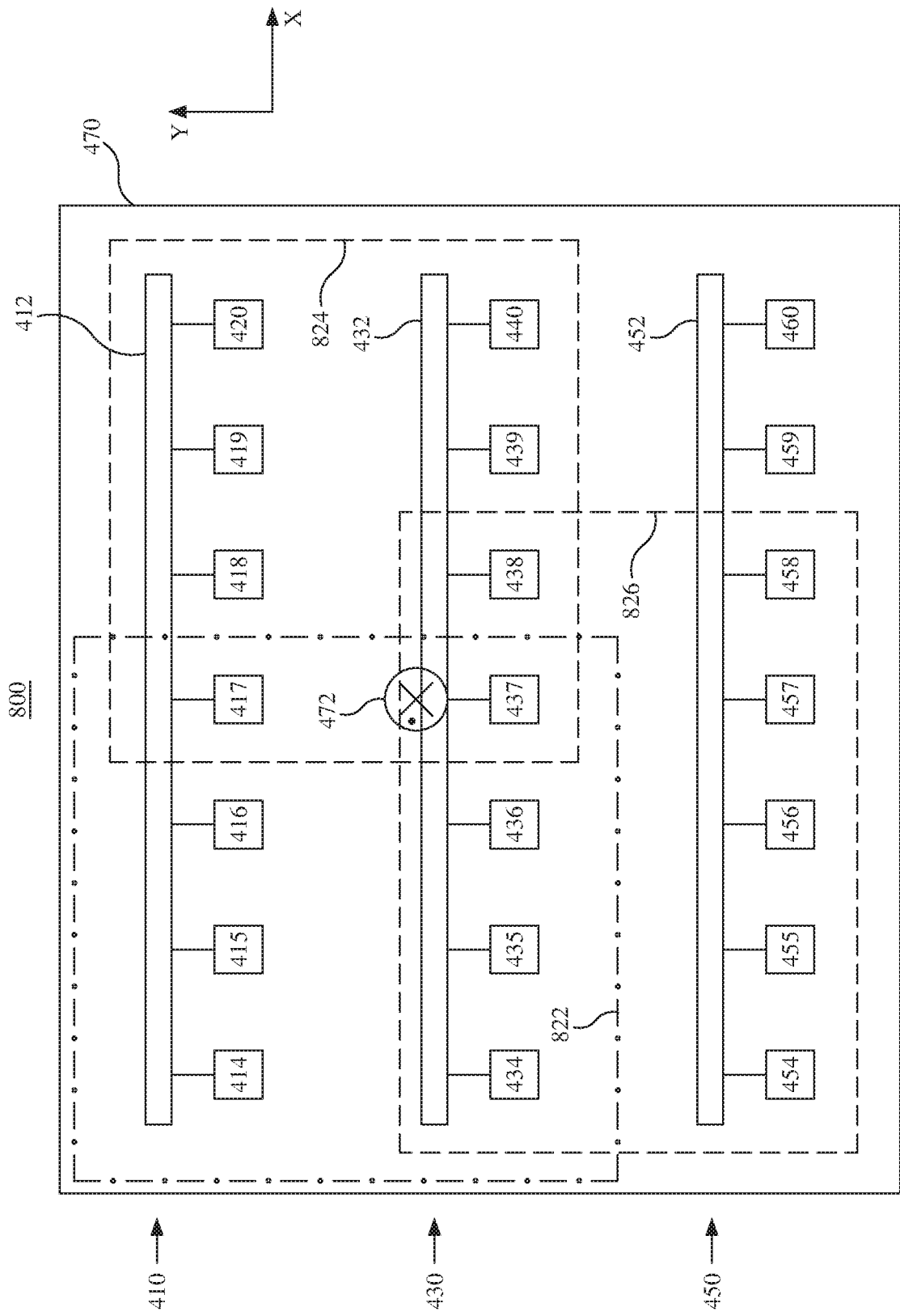


FIG. 8

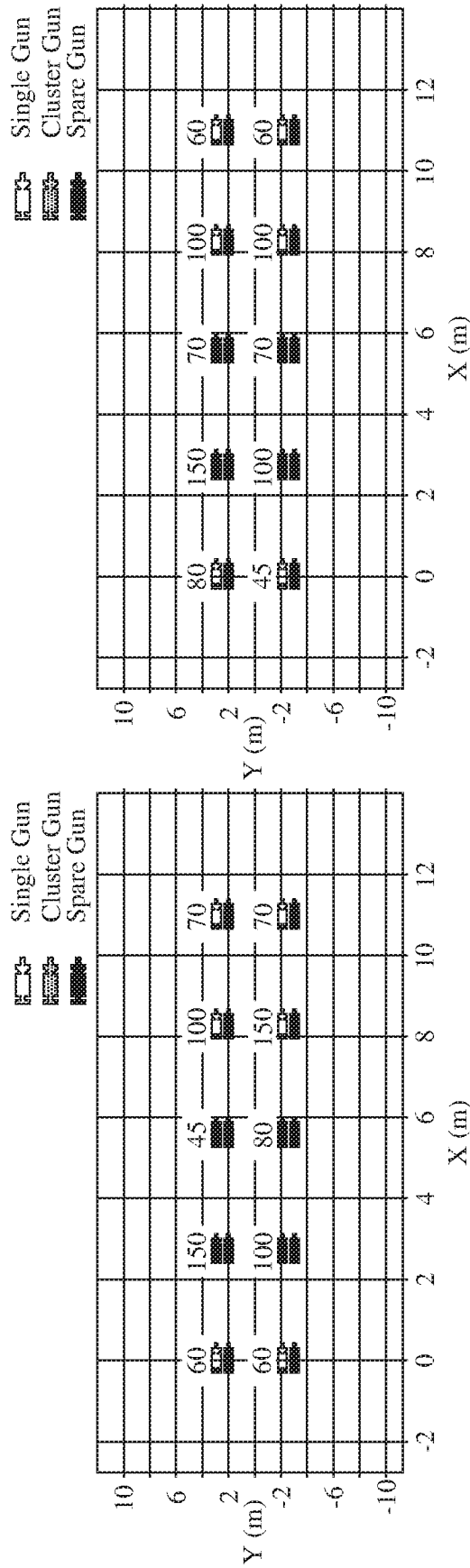


FIG. 9A

FIG. 9B

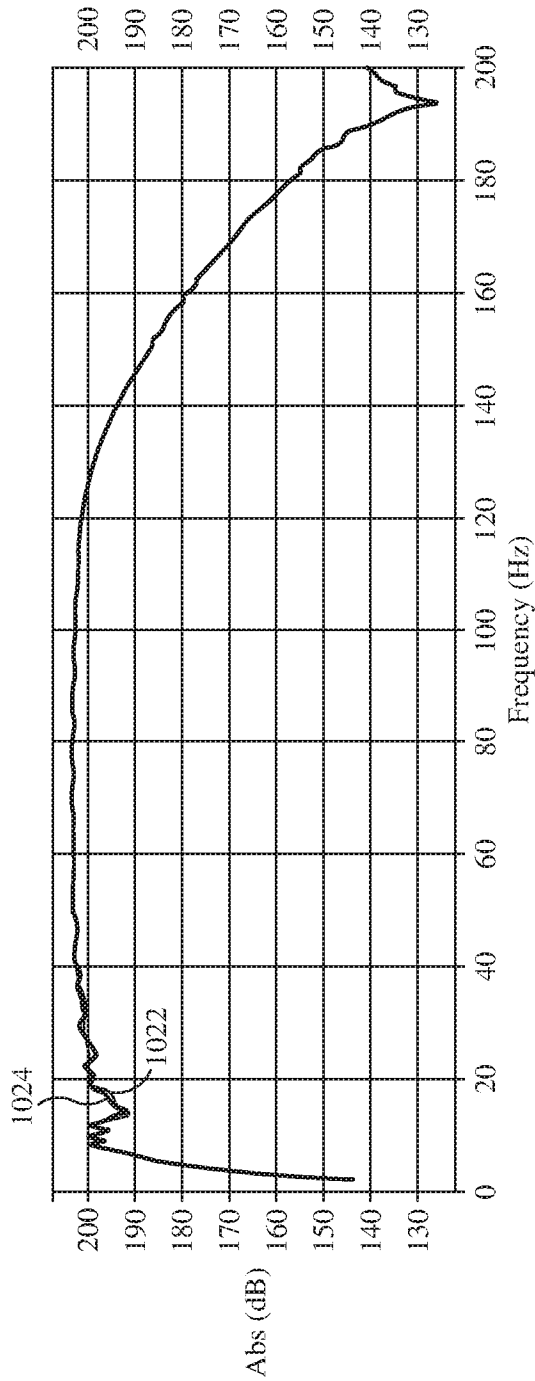


FIG. 10

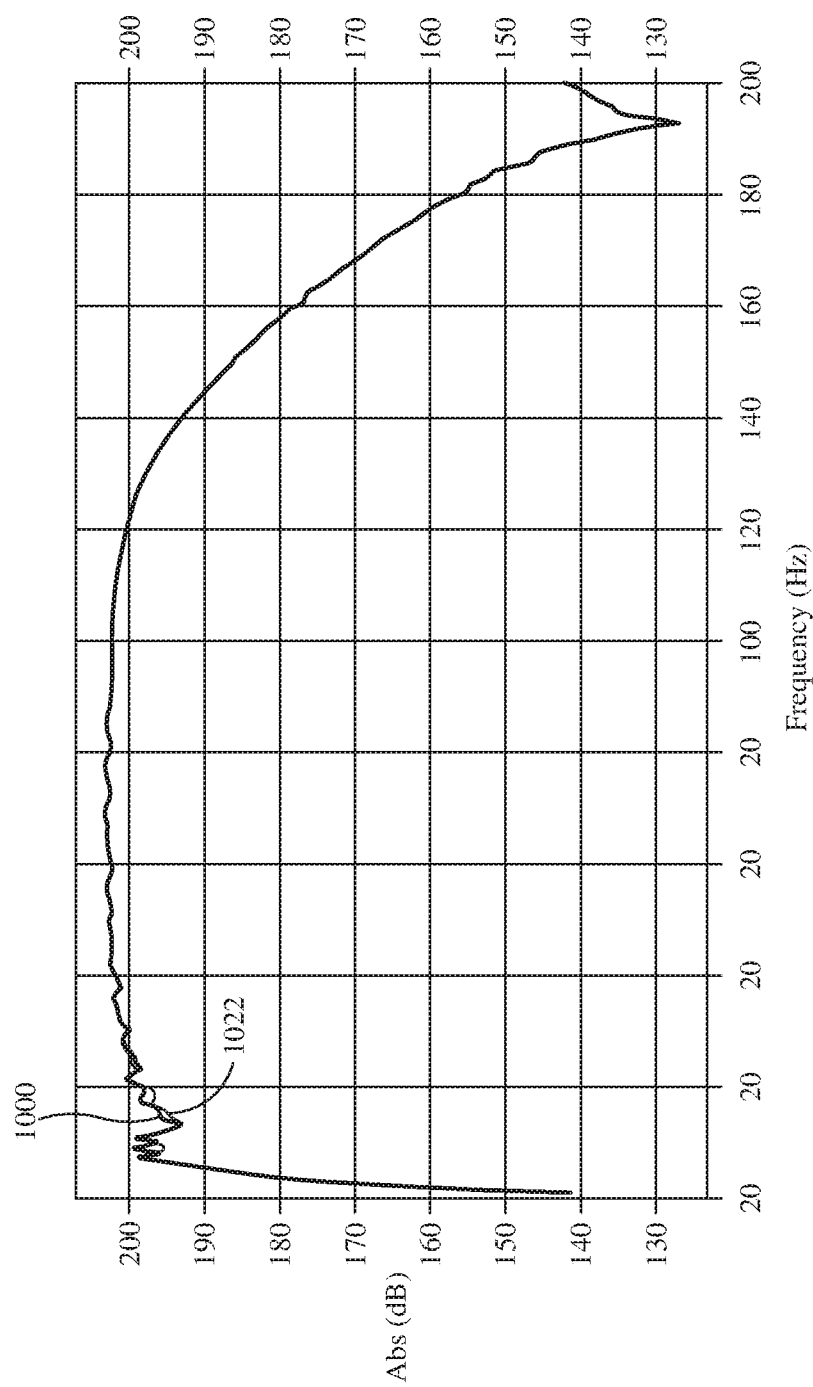


FIG. 11

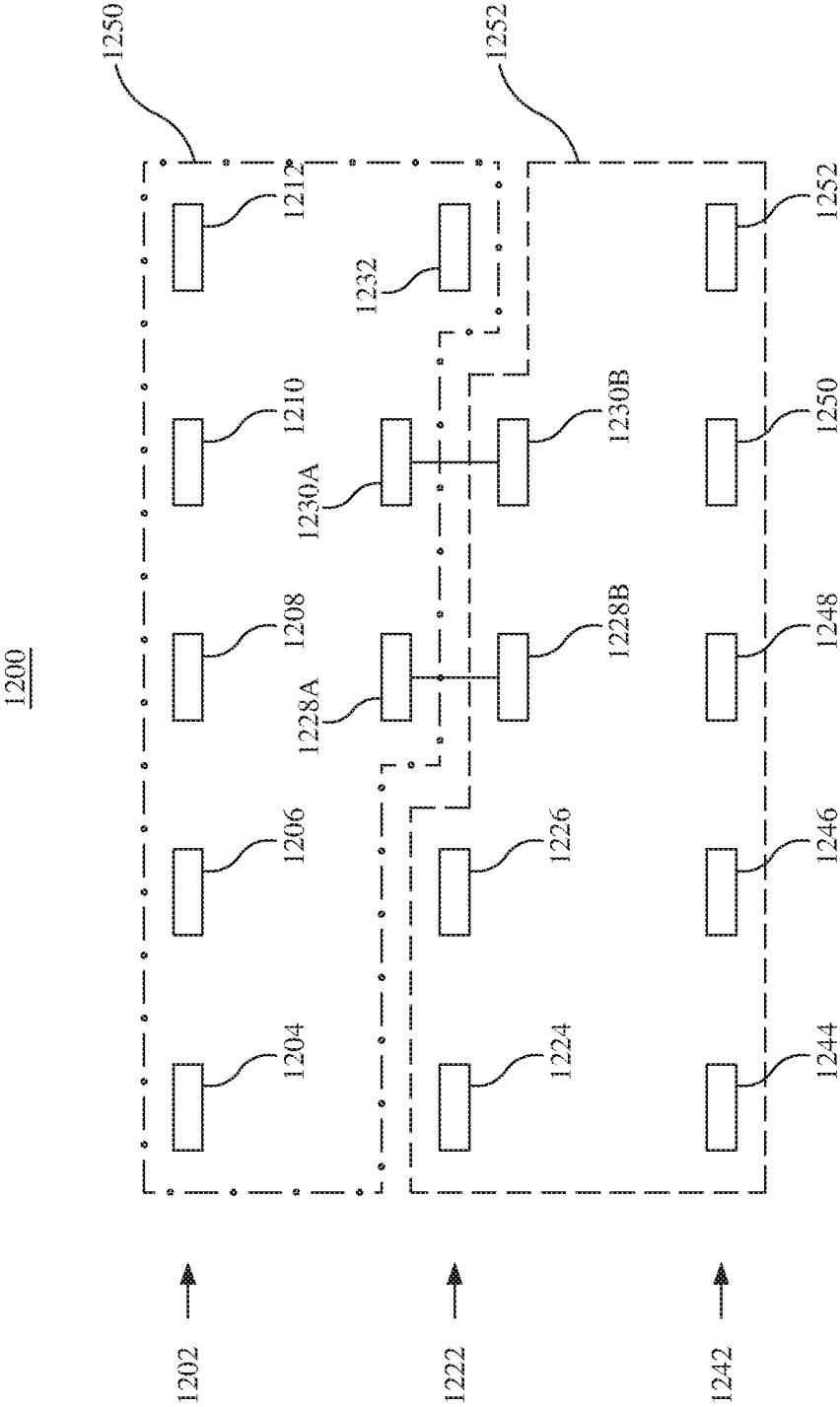


FIG. 12

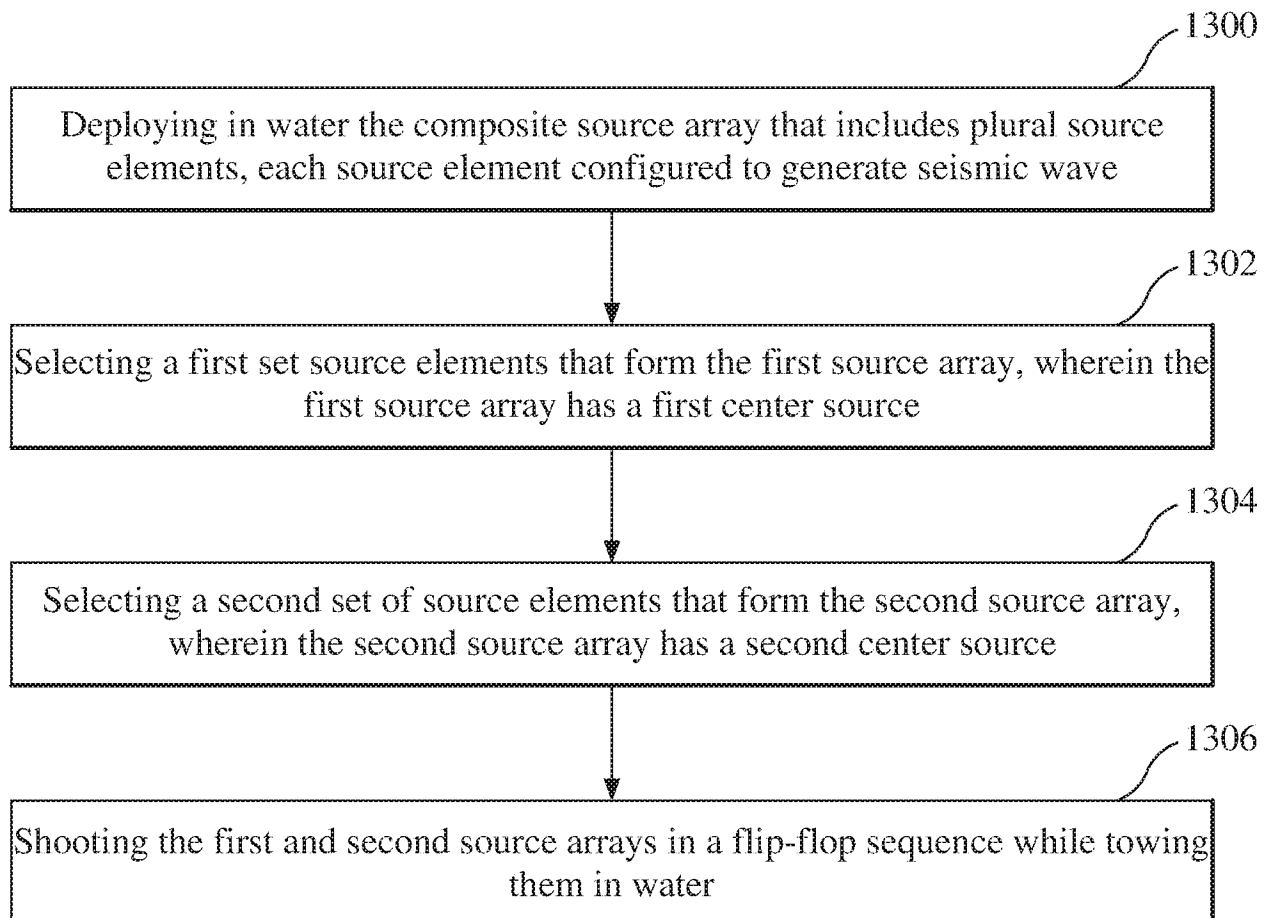


FIG. 13

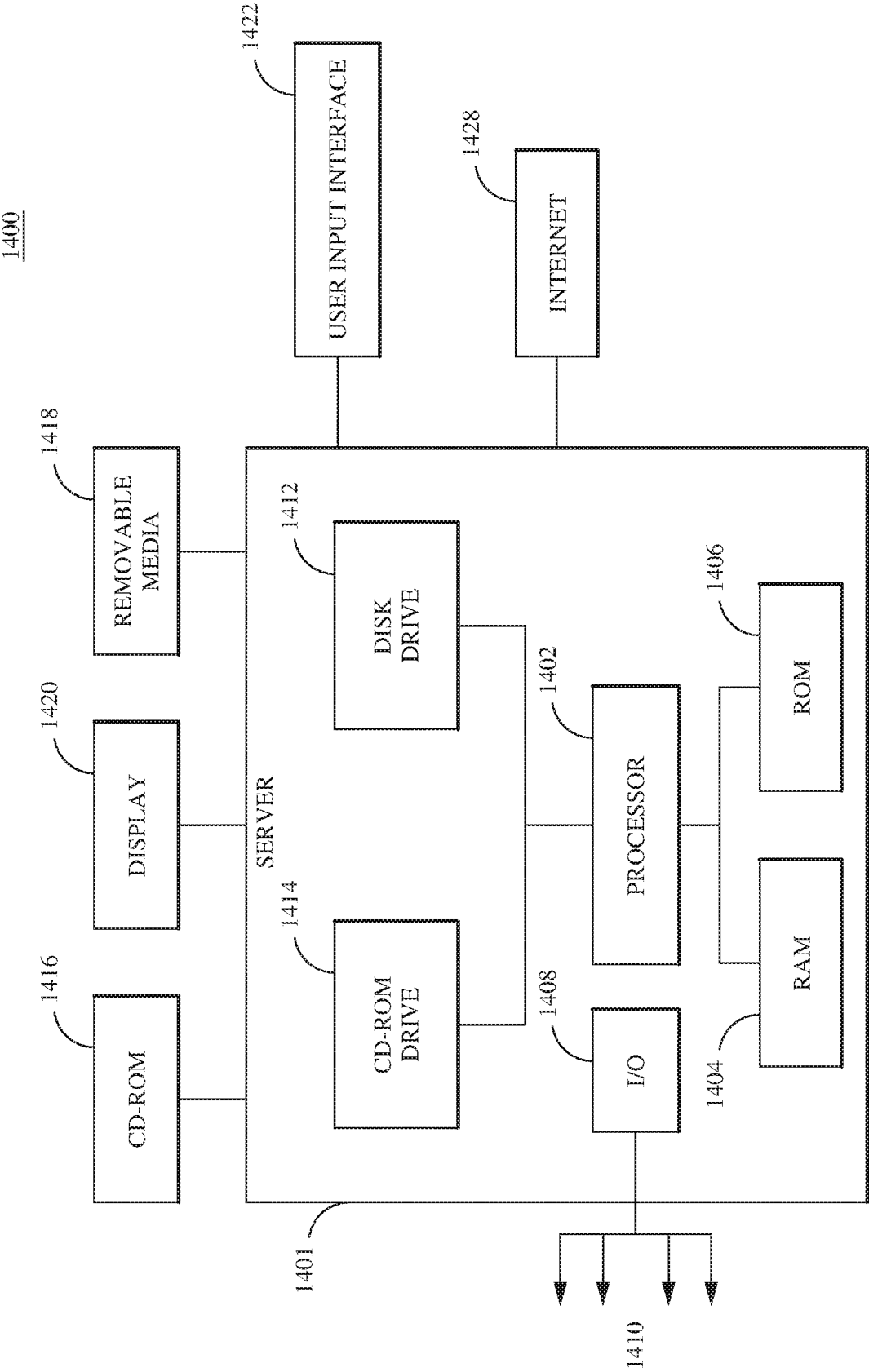


FIG. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/002258

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01V1/38 G01V1/00
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)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 460 073 A (STATOILHYDRO ASA [NO]) 18 November 2009 (2009-11-18) page 2, paragraph 4 page 3, paragraph 5 page 4, paragraph 1-2 page 7, paragraph 3-6 page 8, paragraph 5 figure 2	1-3,8,9, 18
A	----- US 2011/211422 A1 (MOLDOVEANU NICOLAE [US]) 1 September 2011 (2011-09-01) paragraphs [0009], [0024] - [0025], [0040] - [0042]	1-3,8,9, 18
A	----- US 2013/250720 A1 (MONK DAVID J [US] ET AL) 26 September 2013 (2013-09-26) paragraphs [0017], [0035] - [0042]; figure 6 ----- -/-	1-3,8,9, 18



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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

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

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

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

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

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

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

"Z" document member of the same patent family

Date of the actual completion of the international search

24 March 2016

Date of mailing of the international search report

16/06/2016

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Naujoks, Marco

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2015/002258

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2014/029381 A1 (SOERLI JON MAGNUS [NO]) 30 January 2014 (2014-01-30) paragraphs [0025] - [0027]; figures 1-3 -----	1-3,8,9, 18

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2015/002258

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-3, 8, 9, 18

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-3, 8, 9, 18

How to acquire low frequencies in broadband data with a fast shooting rate?

2. claims: 4-7, 11-17

How to keep operating when source elements fail?

3. claims: 10, 19, 20

How to maintain a single composite shooting position when firing with different source arrays?

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2015/002258

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
GB 2460073	A	18-11-2009	GB 2460073 A	18-11-2009
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			BR P10418776 A	09-10-2007
			CN 1954239 A	25-04-2007
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			GB 2429290 A	21-02-2007
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			US 2008011540 A1	17-01-2008
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			US 2011211422 A1	01-09-2011
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			US 2008304363 A1	11-12-2008
			US 2009175124 A1	09-07-2009
			US 2014029381 A1	30-01-2014
