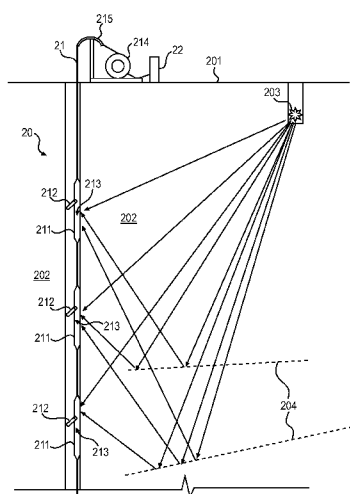




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[Continued on next page]

(54) **Title:** DOWNHOLE SENSOR AND METHOD OF COUPLING SAME TO A BOREHOLE WALL**FIG. 1**

(57) **Abstract:** Devices and methods for borehole seismic investigation are provided. The devices are a downhole tool having gripping devices which may improve contact between the downhole tool and the borehole wall (or casing of the borehole wall) and reduce slippage as compared to downhole tools without the gripping devices. The methods involve lowering a downhole tool having the gripping devices into a borehole and applying force to cause the gripping devices to penetrate or create an indentation in the borehole wall (or casing of the borehole wall). The methods and devices may improve the coupling between the downhole tool and surface to be monitored and/or may enhance the frequency range due to higher coupling frequency as compared to downhole tools without the gripping devices.





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DOWNHOLE SENSOR AND METHOD OF COUPLING SAME TO A BOREHOLE WALL

FIELD

The present disclosure relates to the study of underground formations and structures, for example as it relates to oil and gas exploration. The present disclosure relates more specifically to downhole sensors and methods of coupling sensors to borehole walls.

BACKGROUND

Borehole seismic investigation is among the tools that oil and gas professionals use to assist them in understanding formation properties. The quality of information derived from seismic data is related to the quality of the monitoring process, and in the case of sensors this can depend on how well the sensors reproduce the particle motion of the borehole wall. Specifically, monitoring of acoustic events, whether natural as in the case of some microseismic events, or induced, such as in the case of firing a controlled source or hydraulic fracturing, may be achieved using several sensors mounted in a common enclosure. The resulting sensor package is brought into contact with the surface to be monitored. However, the ability of a sensor package to reproduce the motion of the surface can be limited by the coupling frequency, above which the motion of the sensor package differs from that of the surface being monitored.

SUMMARY

The present disclosure relates to devices and methods for coupling sensors to borehole walls. In some embodiments, the devices and methods result in improved coupling between the sensor and the formation to be monitored as compared to conventional devices and methods. In some embodiments, the devices and methods enhance the frequency that can be monitored as compared to conventional devices and methods. In some embodiments, the devices and methods improve the coupling between the sensor and formation and enhance the frequency that can be monitored as compared to conventional devices and methods.

In some embodiments, the device is a downhole tool equipped with at least one gripping device adapted to puncture, or create an indentation in, a borehole wall (or casing of a borehole wall if the borehole wall is cased) when the at least one gripping device contacts the borehole wall and sufficient force is applied to the downhole tool. The downhole tool can be a bare

sensor, a shuttle which at least one sensor is mounted on or within and which has a housing carrying at least one gripping device, or a measurement-while-drilling (or logging-while-drilling) tool which at least one sensor is mounted on or within and which carries at least one gripping device. In some embodiments, the gripping devices are protruding spikes. In some
5 embodiments, the gripping devices (for example the protruding spikes) are three gripping devices mounted in a triangular geometry relative to one another. The gripping devices may be made of a material that is harder than the borehole wall or casing, such as tungsten carbide. The sensors may be any sensors that are desirably coupled to the borehole wall, such as geophones or accelerometers. In some embodiments, the devices have a coupling frequency of
10 at least 1000 Hz.

In some embodiments, the methods involve: lowering a downhole tool carrying at least one gripping device into a borehole, where the downhole tool may be a bare sensor, a shuttle including at least one sensor, or a measurement-while-drilling (or logging-while-drilling) tool including at least one sensor; contacting the at least one gripping device with the borehole wall
15 (or casing of the borehole wall if the borehole wall is cased); and applying a sufficient force to the downhole tool to cause the at least one gripping device to penetrate or create an indentation in the borehole wall (or casing if the borehole wall is cased). In some embodiments, the at least one gripping device has at least one protruding spike, which may be three protruding spikes arranged in a triangular geometry relative to one another. In some embodiments, the sufficient
20 force is applied by extendible mechanical arms, an inflatable bladder, bow springs, a clamping device, a locking device, or combinations thereof.

The identified embodiments are exemplary only and are therefore non-limiting. The details of one or more non-limiting embodiments of the present disclosure are set forth in the accompanying drawings and the descriptions below. Other embodiments should be apparent to
25 those of ordinary skill in the art after consideration of the present disclosure.

DESCRIPTION OF THE DRAWINGS

Certain embodiments of the present disclosure will hereafter be described with reference to the accompanying drawings, wherein like reference numerals denote like elements.
30 It should be understood, however, that the accompanying drawings illustrate only the various implementations described herein and are not meant to limit the scope of various technologies described herein. The drawings are as follows:

Figure 1 is a schematic illustration of a vertical seismic profiling (“VSP”) operation suitable for use with embodiments of devices and methods of the present disclosure.

Figure 2 is a schematic illustration of a well logging data acquisition and logging system suitable for use with embodiments of devices and methods of the present disclosure.

5 Figures 3a, 3b, 3c, and 3d are schematic representations of several VSP survey configurations.

Figure 4 is a schematic illustration of an embodiment of a sensor module in accordance with an embodiment of the present disclosure in contact with a borehole wall, shown in perspective partial plan view.

10

DETAILED DESCRIPTION

Illustrative embodiments and aspects are described below. It will be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions can be made to achieve the developers’ specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such development effort might be complex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of the present disclosure.

15

20

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as is commonly understood by one of ordinary skill in the art to which the present disclosure belongs. In the event that there is a plurality of definitions for a term herein, those in this section prevail unless stated otherwise.

25

Wherever the phrases “for example,” “such as,” “including” and the like are used herein, the phrase “and without limitation” is understood to follow unless explicitly stated otherwise.

30

The terms “comprising” and “including” and “involving” (and similarly “comprises” and “includes” and “involves”) are used interchangeably and mean the same thing. Specifically, each of the terms is defined consistent with the common United States patent law definition of “comprising” and is therefore interpreted to be an open term meaning “at least the following” and is also interpreted not to exclude additional features, limitations, aspects, etc.

The term “about” is meant to account for variations due to experimental error. All measurements or numbers are implicitly understood to be modified by the word about, even if the measurement or number is not explicitly modified by the word about.

5 The term “substantially” (or alternatively “effectively”) is meant to permit deviations from descriptor that don’t negatively impact the intended purpose. Descriptive terms are implicitly understood to be modified by the word substantially, even if the term is not explicitly modified by the word substantially.

The terms “wellbore” and “borehole” are used interchangeably.

10 “Measurement While Drilling” (“MWD”) can refer to devices for measuring downhole conditions including the movement and location of the drilling assembly contemporaneously with the drilling of the well. “Logging While Drilling” (“LWD”) can refer to devices concentrating more on the measurement of formation parameters. While distinctions may exist between these terms, they are also often used interchangeably. For purposes of the present disclosure MWD and LWD are used interchangeably and have the same meaning. That is, both
15 terms are understood as related to the collection of downhole information generally, to include, for example, both the collection of information relating to the movement and position of the drilling assembly and the collection of formation parameters.

A “downhole tool” can be any instrumentation used in a borehole such as a bare sensor, or a sensor deployed on a shuttle, or a sensor deployed on a MWD drill string.

20 A vertical seismic acquisition in a borehole is illustrated in Figure 1. A cable 21 carrying a plurality of VSP shuttles 211 is suspended from the surface 201 of a borehole 20 into the borehole 20. System noise is alleviated or avoided by pushing or wedging the shuttles against the formation 202 or any casing surrounding the wellbore 20 using any means known in the art, including inflatable bellows, or as shown, a clamping or locking mechanism 212.

25 The clamping or locking mechanism 212 can be based on the use of springs, telescopic rams or pivoting arms as shown. The shuttles 211 can carry transducer elements 213 to measure the velocity or acceleration in one of three independent directions. The clamping mechanism 212 couples the transducers 213 to the borehole wall. In a VSP operation, a significant decrease in the signal-to-noise ratio can be observed when the geophone loses
30 contact with the wall of the borehole 20.

On the surface, a cable reel 214 and feed 215 supports the cable 21. Measurement signals or data are transmitted through the cable 21 to a base station 22 on the surface for further processing. The cable can be an armored cable as used for wireline operations.

In operation a source 203 as shown is activated generating seismic waves which travel through the formation 202. Where there are changes in formation impedance (as indicated by dashed lines 204), part of the seismic energy may be reflected and/or refracted. The transducers 213 register movements of the earth and the measurements are transmitted directly or after in-line digitization and/or signal processing to the surface base station 22 for storage, transmission and/or further processing. The subsequent data processing steps are known and well established in the field of hydrocarbon exploration and production.

Figure 2 illustrates another embodiment of a wellsite system in which the present disclosure can be employed. Here again, the wellsite can be onshore or offshore. In this exemplary system, a borehole 11 is formed in subsurface formations by rotary drilling in a manner that is well known. Various embodiments can also use directional drilling.

A drill string 12 is suspended within the borehole 11 and has a bottom hole assembly 100 which includes a drill bit 105 at its lower end. The surface system includes platform and derrick assembly 10 positioned over the borehole 11, the assembly 10 including a rotary table 16, kelly 17, hook 18 and rotary swivel 19. The drill string 12 is rotated by the rotary table 16, energized by means not shown, which engages the kelly 17 at the upper end of the drill string. The drill string 12 is suspended from a hook 18, attached to a traveling block (also not shown), through the kelly 17 and a rotary swivel 19 which permits rotation of the drill string relative to the hook. As is well known, a top drive system could alternatively be used.

In the example of this embodiment, the surface system further includes drilling fluid or mud 26 stored in a pit 27 formed at the well site. A pump 29 delivers the drilling fluid 26 to the interior of the drill string 12 via a port in the swivel 19, causing the drilling fluid to flow downwardly through the drill string 12 as indicated by the directional arrow 8. The drilling fluid exits the drill string 12 via ports in the drill bit 105, and then circulates upwardly through the annulus region between the outside of the drill string and the wall of the borehole, as indicated by the directional arrows 9. In this well known manner, the drilling fluid lubricates the drill bit 105 and carries formation cuttings up to the surface as it is returned to the pit 27 for recirculation.

The bottom hole assembly 100 of the illustrated embodiment includes a logging-while-drilling (LWD) module 120, a measuring-while-drilling (MWD) module 130, a roto-steerable system and motor 150, and drill bit 105.

The LWD module 120 can be housed in a drill collar, as is known in the art, and may contain one or more logging tools. It will also be understood that more than one LWD and/or MWD module can be employed, e.g. as represented at 120A. (References, throughout, to a module at the position of 120 can alternatively mean a module at the position of 120A as well.) The LWD module includes capabilities for measuring, processing, and storing information, as well as for communicating with the surface equipment. In some embodiments, the LWD module includes a seismic measuring device.

The MWD module 130 can also be housed in a drill collar, as is known in the art, and may contain one or more devices for measuring characteristics of the drill string and drill bit. For example, the MWD module may include one or more of the following types of measuring devices: a weight-on-bit measuring device, a torque measuring device, a vibration measuring device, a shock measuring device, a stick slip measuring device, a direction measuring device, and an inclination measuring device. The MWD tool can further include an apparatus (not shown) for generating electrical power to the downhole system. This may include a mud turbine generator powered by the flow of the drilling fluid, it being understood that other power and/or battery systems may be employed.

Borehole seismic surveys are versatile downhole measurement techniques used in the oil field. The various types of waves generated and survey geometries achieved combine to deliver information relating to subsurface structural features such as for example reservoir depth, extent, heterogeneity as well as about hydrocarbon content, rock mechanical properties, pore pressure, enhanced-oil-recovery progress, elastic anisotropy, natural-fracture orientation and density, and induced-fracture geometry. Borehole seismic surveys, or VSPs, reduce the uncertainty of reservoir properties near the borehole. With their measurement scale between those of well logs and surface seismic surveys, VSPs extend near-wellbore observations, explore interwell volumes, and link time-based surface seismic images with depth-based logs.

Figure 3 illustrates several VSP survey configurations. The VSP surveys enable interrogation of the earth to obtain among other things: (i) a detailed velocity profile at the seismic scale which can be correlated to depth (log) and time (seismic) as well as (ii) some type of fracture image (e.g. walkaway, etc.).

Figure 3 also illustrates a seismic-while-drilling tool which can be the LWD tool 120, or can be part of an LWD tool suite 120A of the type disclosed in P. Breton et al., "Well Positioned Seismic Measurements," Oilfield Review, pp. 32-45, Spring, 2002. The downhole LWD tool can have a single receiver (as depicted in Figures 3A and 3B), or plural receivers (as depicted in Figures 3C and 3D), and can be employed in conjunction with a single seismic source at the surface (as depicted in Figures 3A and 3C) or plural seismic sources at the surface (as depicted in Figures 3B and 3D). Accordingly, Figure 3A, which includes reflection off a bed boundary, and is called a "zero-offset" vertical seismic profile arrangement, uses a single source and a single receiver, Figure 3B, which includes reflections off a bed boundary, and is called a "walkaway" vertical seismic profile arrangement, uses plural sources and a single receiver, Figure 3C, which includes refraction through salt dome boundaries, and is called a "salt proximity" vertical seismic profile, uses a single source and plural receivers, and Figure 3D, which includes some reflections off a bed boundary, and is called a "walk above" vertical seismic profile, uses plural sources and plural receivers.

As mentioned, a significant decrease in signal-to-noise ratio can be observed when the geophone loses contact with the wall of the borehole. Referring now to Figure 4, the downhole tool 300, according to the present disclosure, which may be a bare sensor, a shuttle having one or more sensors, or a MWD (or LWD) tool having one or more sensors, can cooperate with suitable means for maintaining contact between the sensor and borehole to reduce or eliminate loss of contact. More specifically, the downhole tool 300 includes gripping devices 310 capable of puncturing, or creating an indentation in, the borehole wall 315 (or the casing of a borehole wall, if the borehole wall is cased) when appropriate force is applied to the downhole tool 300. The sensors may be any downhole sensor for which contact between the sensor and borehole wall is desirable, for example geophones or accelerometers.

As shown, the downhole tool 300 is a shuttle having a housing 305 to which three gripping devices 310 are mounted. Also as shown, the gripping devices 310 are spikes configured in a triangular geometry relative to one another. Embodiments within scope of the present disclosure are not limited to this specific embodiment (i.e. three spikes in a triangular configuration about the downhole tool housing), however, such a configuration may provide additional stabilization as compared to, as examples, a single spike (or single protrusion or gripping device) or as compared to a linear arrangement. As a person of skill can understand from reading the present disclosure any gripping device and any configuration of gripping

device which reduces the chance of slippage as compared to conventional devices which rely merely on friction between the surface of the downhole tool and borehole wall (or casing) are within scope of the present disclosure.

The shuttle housing 305 and gripping devices 310 can be a unitary device, or the gripping devices 310 can be mounted onto the housing 305, as shown in Figure 4. As a person of skill would understand from reading the present disclosure, the gripping devices 310 can be made of any material that is able to withstand the force applied to the housing 305, for causing and/or maintaining contact between the sensor module (or downhole tool) and the borehole wall, and the material should be desirably harder than the borehole wall (or casing of the borehole wall). One example of a suitable material is tungsten carbide. However a person of skill with an understanding from the present disclosure can select suitable alternative materials such as high speed steel and ceramics.

In operation, the downhole tool 300 is lowered into a borehole, and force is applied to the downhole tool 300 to cause it to contact and/or maintain contact with the borehole wall in order to couple the sensor to the formation. The force can be applied by any suitable means, such as the clamping or locking mechanism 212 shown in Figure 1. Alternatively, or in addition, the force may be applied, for example, by inflatable bellows, extendible mechanical arms, or bow springs. The force should be sufficient to also cause the gripping devices 310 to puncture, or create an indentation in, the borehole wall (or the casing of a borehole wall, if the borehole wall is cased). As a result, because at least a portion of the gripping devices 310 reside below the original surface of the borehole wall 320, the downhole tool 300 resists slipping and loss of contact with the borehole wall to a greater degree than a downhole tool without the gripping devices 310.

In some embodiments, the disclosed contact arrangement between downhole tool and borehole wall and method of maintaining contact between the downhole tool and borehole wall may enhance coupling between the sensor and formation, which is now not limited to frictional contact for reducing slippage between the sensor and the formation surface. Further, in some embodiments, the resultant coupling frequency is generally higher than similar non-penetrative systems. For example, in some embodiments, a downhole tool with gripping devices according to the present disclosure (such as the exemplified spikes arranged in a triangular geometry) has a coupling frequency of at least 1000 Hz as compared to the few hundred Hz of conventional systems without the gripping devices. Consequently, in some embodiments, downhole tools

equipped with gripping devices should result in improved data collection as compared to downhole tools without gripping devices in view of the fact that microseismic events can contain high frequency components, for example at least up to 2000 Hz. Accordingly, some embodiments according to the present disclosure may improve coupling between the sensor package and the formation surface to be monitored. And some and/or further embodiments according to the present disclosure may enhance the frequency range due to higher coupling frequency as compared to downhole tools without the gripping devices.

While the detailed description has been made with respect to a limited number of embodiments, those skilled in the art, having the benefit of the present disclosure, will appreciate numerous modifications and variations therefrom. For example, while the specification refers mainly to seismic monitoring, the devices and methods are also applicable to any sensor system which could benefit from contact between the sensor and borehole wall or surface to be monitored. It is intended that the appended claims cover such modifications and variations as fall within the true spirit and scope of the present disclosure.

WHAT IS CLAIMED IS:

1. A downhole tool for monitoring seismic waves, comprising:
 - a. a housing comprising at least one gripping device adapted to puncture or create an indentation in a borehole wall or casing of a borehole wall, if the borehole wall is cased, when the at least one gripping device contacts the borehole wall and sufficient force is applied to the housing; and
 - b. at least one sensor integral with the housing.
2. A downhole tool according to claim 1, wherein the at least one gripping device includes at least one protruding spike.
3. A downhole tool according to claim 1, wherein the at least one gripping device is mounted to the housing.
4. A downhole tool according to claim 1, wherein the at least one gripping device includes at least three gripping devices and the at least three gripping devices are arranged in a non-linear pattern on the housing.
5. A downhole tool according to claim 1, wherein the at least one gripping device is three gripping devices which are arranged in a triangular geometry about the housing.
6. A downhole tool according to claim 1, wherein the at least one gripping device is made of a material that is harder than the borehole wall or the casing of the borehole wall, if the borehole wall is cased.
7. A downhole tool according to claim 6, wherein the material comprises tungsten carbide.
A downhole tool according to claim 1, wherein the downhole tool has a coupling frequency of at least 1000 Hz.
8. A downhole tool according to claim 1, wherein the at least one sensor is mounted on or within the housing.
9. A method for coupling a sensor to a borehole wall, comprising:
 - a. lowering a downhole tool into a borehole, wherein the downhole tool comprises a housing having at least one gripping device and at least one sensor;
 - b. contacting the at least one gripping device with a borehole wall; and
 - c. applying a sufficient force to the downhole tool to cause the at least one gripping device to penetrate or create an indentation in the borehole wall.
10. A method according to claim 10, wherein the borehole wall is cased, and the penetration or indentation is in the casing of the borehole wall.

11. A method according to claim 10, wherein the at least one gripping device includes at least three protruding spikes mounted to the downhole tool and arranged in a non-linear pattern, and contacting comprises contacting each of the three protruding spikes with the borehole wall, and applying comprises applying a sufficient force to cause each of the three protruding spikes to penetrate or create an indentation in the borehole wall.
12. A method according to claim 10, wherein the force is applied by a clamping or locking mechanism.
13. A method according to claim 13, wherein the clamping or locking mechanism is chosen from extendable mechanical arms, an inflatable bladder, bow springs and combinations thereof.
14. A method according to claim 10, wherein the downhole tool is a bare sensor, a shuttle or a drill string tubular.
15. A method according to claim 10, wherein the downhole tool is a shuttle or a drill string tubular and the at least one sensor is mounted on or within the shuttle or drill string tubular.

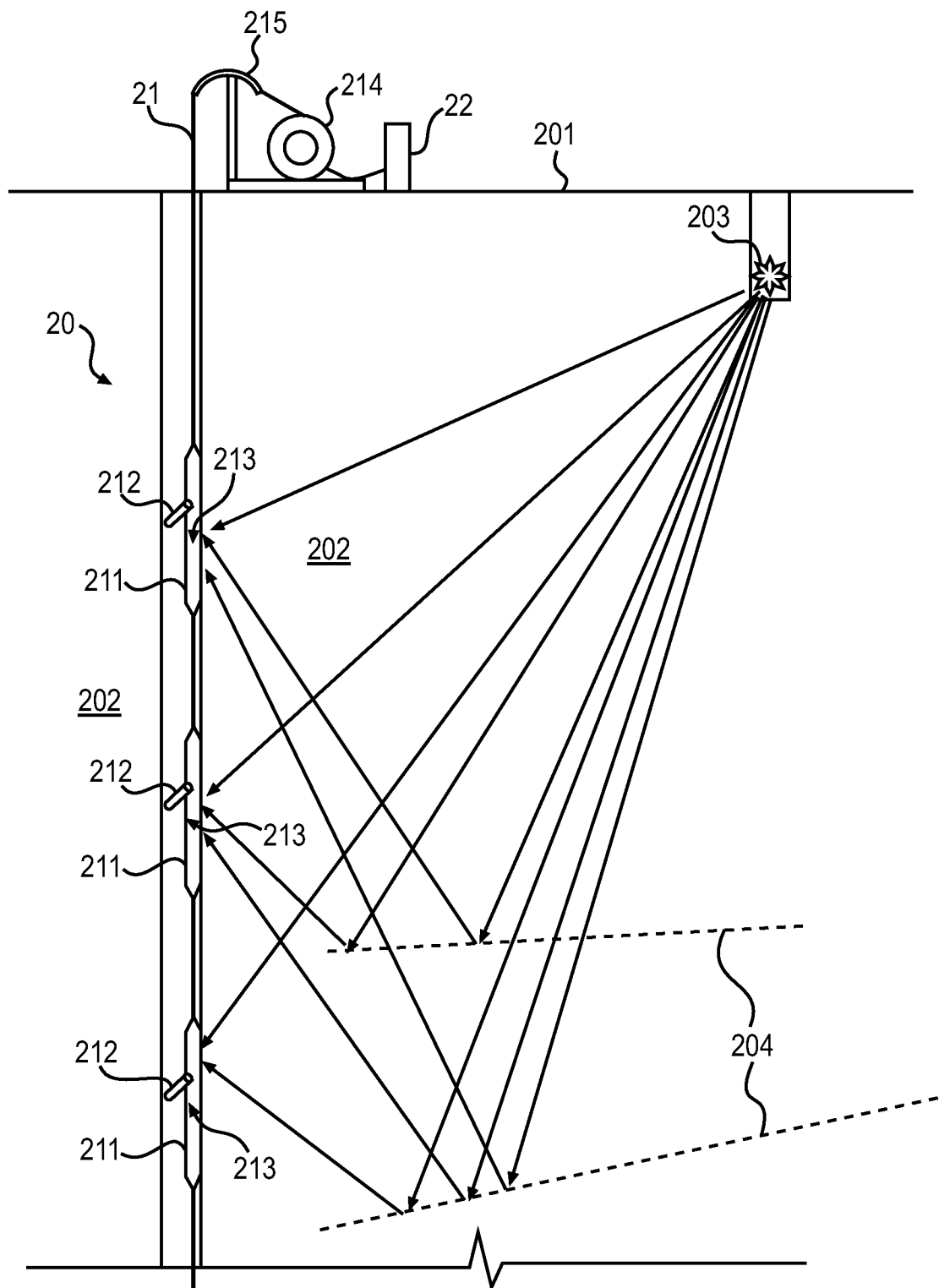


FIG. 1

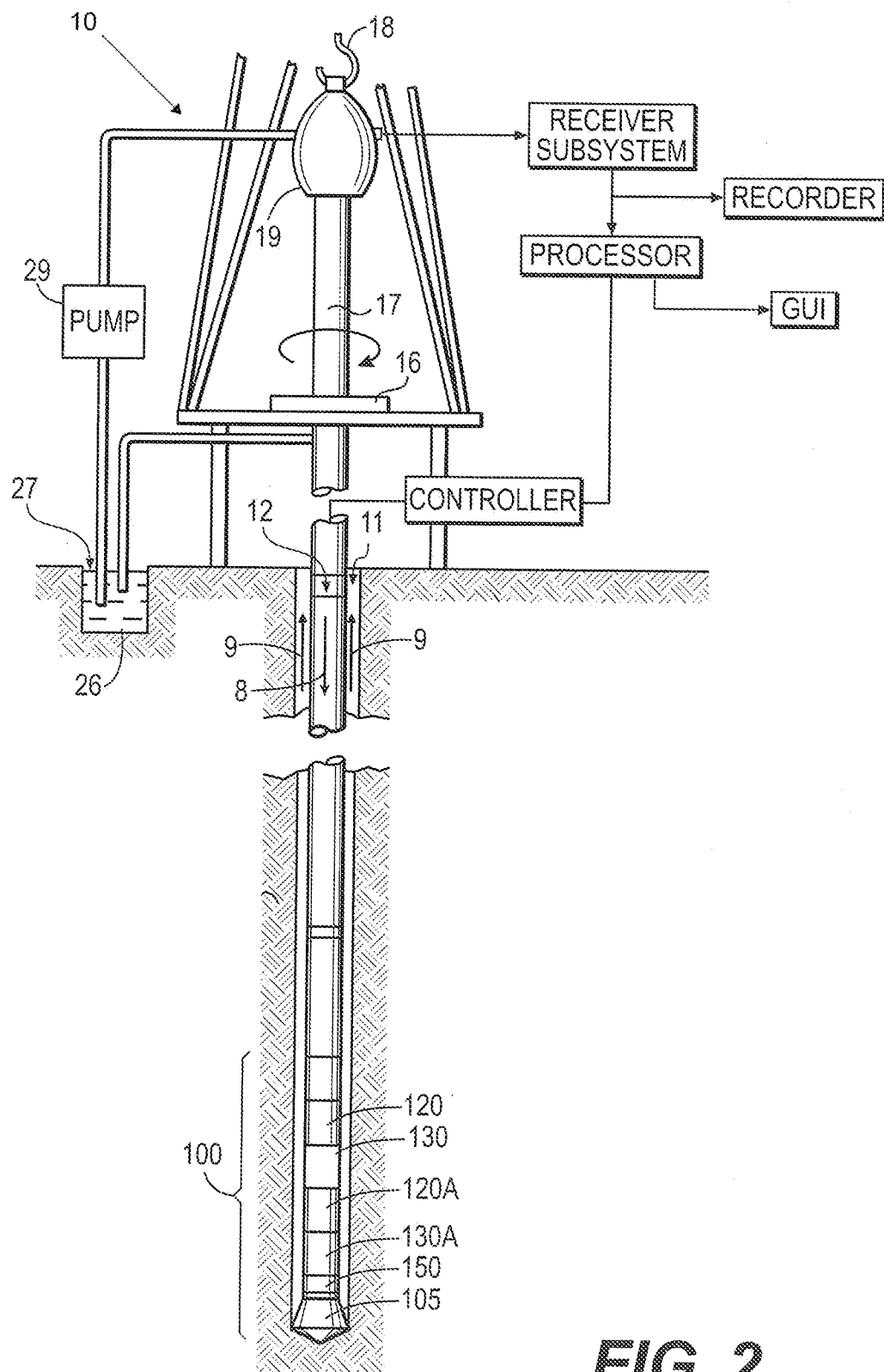


FIG. 2

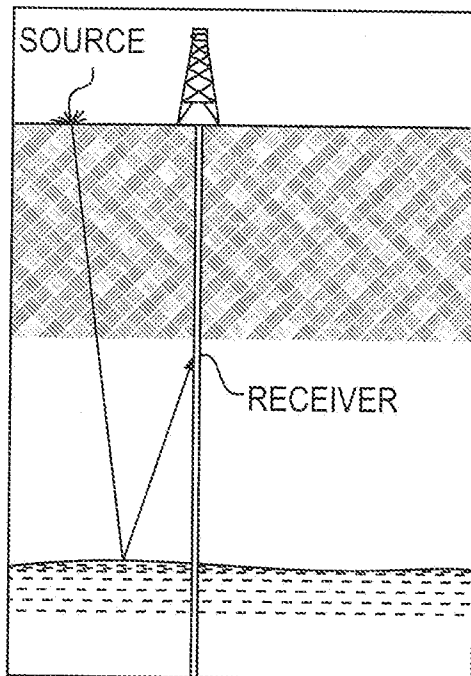


FIG. 3A

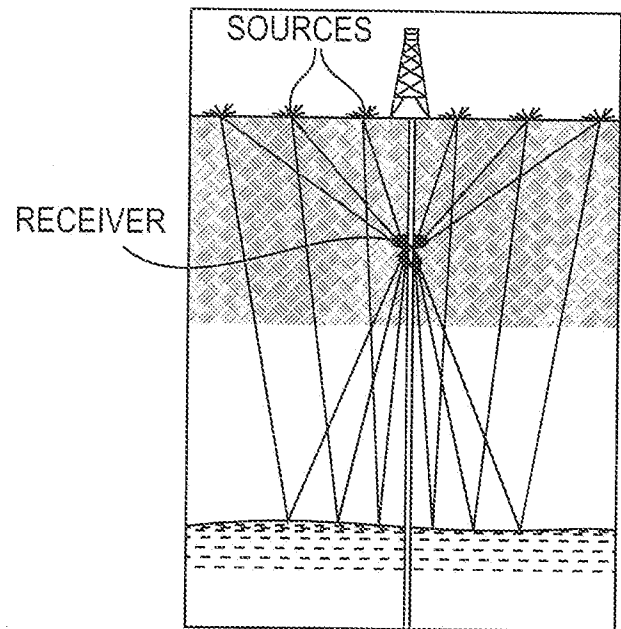


FIG. 3B

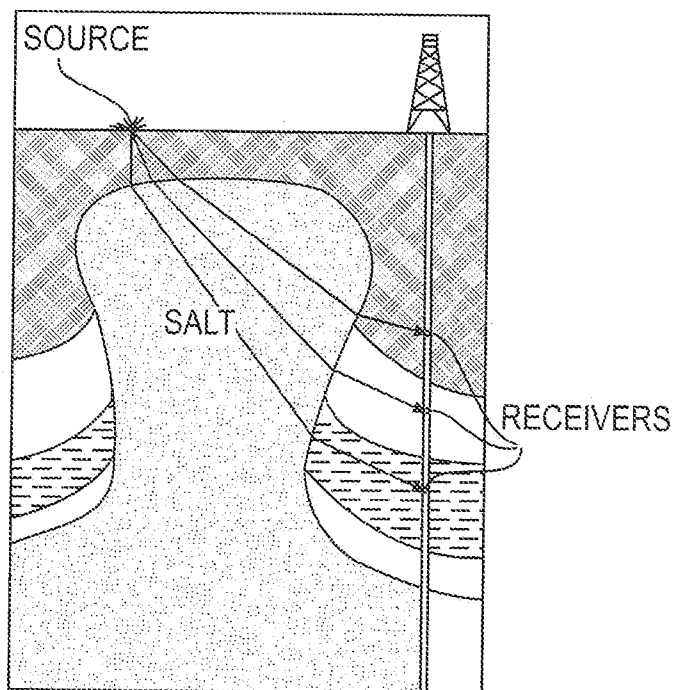


FIG. 3C

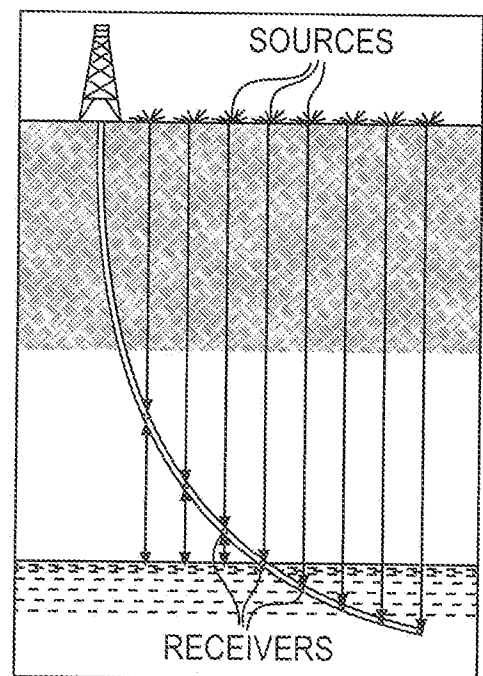


FIG. 3D

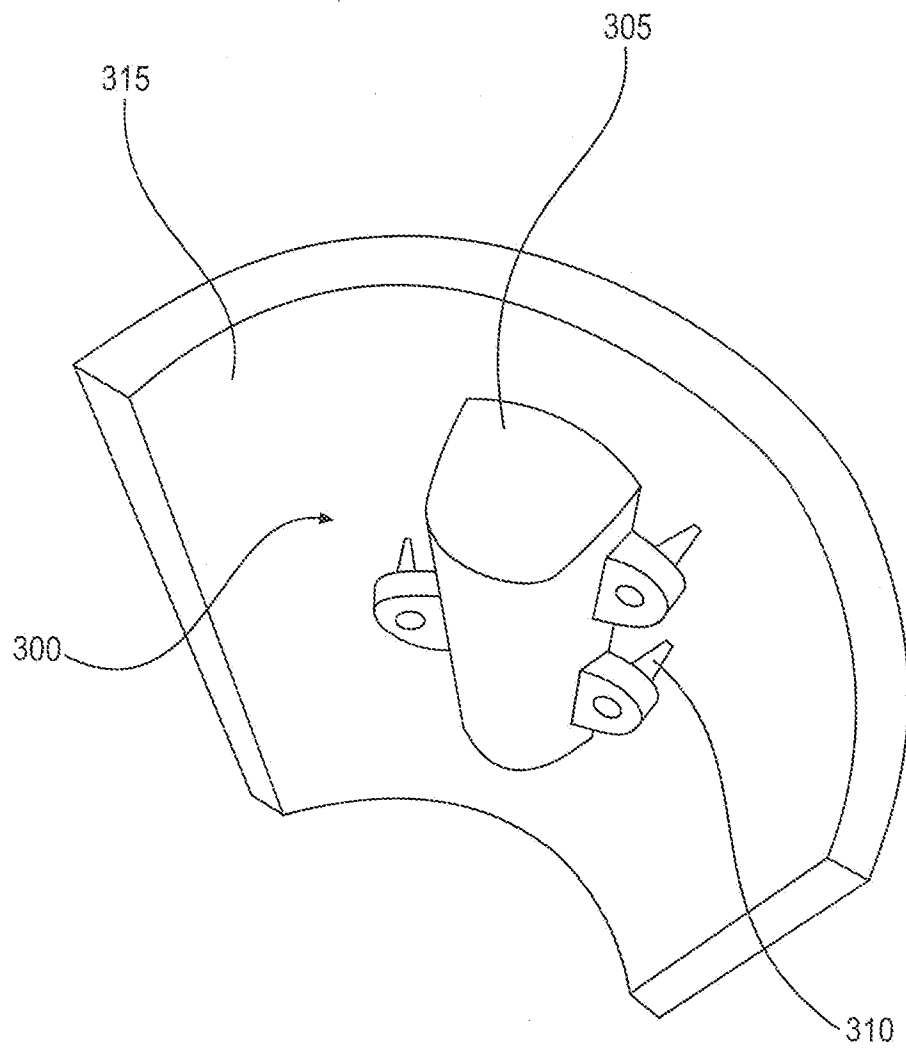


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2013/059568**A. CLASSIFICATION OF SUBJECT MATTER****G01V 1/40(2006.01)i, G01V 1/52(2006.01)i**

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 1/40; G01V 1/48; E21B 47/14; G01V 1/00; G01V 1/52

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: downhole tool, seismic, sensor, housing, wall, penetrate, clamp

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4670862 A (STARON et al.) 02 June 1987 See abstract, column 6 lines 5-61, column 7 lines 8-10, column 8 lines 11-17, and figures 1,3.	1-7,7(1),8-15
A	EP 0224285 B1 (SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.) 08 May 1991 See column 2 line 35-column 3 line 3, claim 1, and figure 1.	1-7,7(1),8-15
A	US 4783771 A (PAULSSON, BJORN N. P.) 08 November 1988 See abstract, column 4 line 10-column 5 line 11, and figure 2.	1-7,7(1),8-15
A	US 2010-0265794 A1 (JOHNSON et al.) 21 October 2010 See abstract, paragraphs [0020]-[0022], [0025], and figure 1.	1-7,7(1),8-15
A	US 2008-0149330 A1 (HAHEIM et al.) 26 June 2008 See abstract, paragraphs [0019]-[0022], [0027], and figure 1.	1-7,7(1),8-15



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

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