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[Continued on next page]

(54) Title: USING ELECTRO ACOUSTIC TECHNOLOGY TO DETERMINE ANNULUS PRESSURE

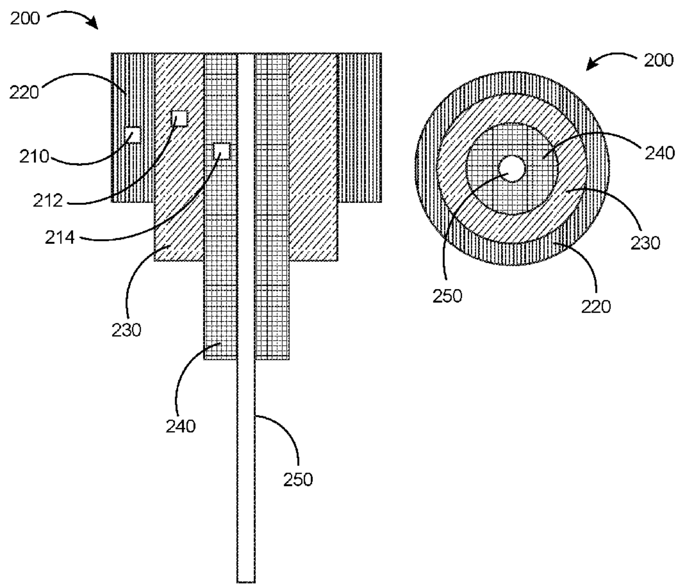

FIG. 3

(57) Abstract: A system for continuous determination of annulus pressure in subsurface wells comprises one or more electro acoustic technology sensor assemblies permanently installed in each annulus surrounding a subsurface well; and a fiber optic cable in close proximity to the electro acoustic technology sensor assemblies and in communication with a surface distributed acoustic fiber optic interrogator.

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Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *with international search report (Art. 21(3))*

Title

Using Electro Acoustic Technology to Determine Annulus Pressure

Background

This disclosure relates generally to systems and methods for monitoring the annular regions in downhole oil and gas systems.

Fiber optic distributed sensing systems were developed in the 1980s to replace older measurement systems composed of multiple individual sensors.

Fiber optic distributed sensing systems are commonly based on Optical Time-Domain Reflectometry (OTDR) and utilizes techniques originally derived from telecommunications cable testing. Today fiber optic distributed sensing systems provides a cost-effective way of obtaining hundreds, or even thousands, of highly accurate, high-resolution measurements and today find widespread acceptance in industries such as oil and gas, electrical power, and process control.

Oil and Gas wells require the use of several concentric casings to prevent contamination of fresh water, isolate different zones, and a myriad of other reasons. There is an unmet need to provide real time telemetry as to whether or not the annular regions have been compromised.

The systems and methods described herein address this need.

Brief Description of the Drawings

Figure 1 illustrates the electro acoustic technology concept for parameter monitoring.

Figure 2 illustrates a more complete system for utilizing electro acoustic technology in a subsurface well.

Figure 3 illustrates the placement of electro acoustic technology (EAT) devices into a well.

Detailed Description

In the following detailed description, reference is made to accompanying drawings that illustrate embodiments of the present disclosure. These embodiments are described in sufficient detail to enable a person of ordinary skill in the art to practice the disclosure without undue experimentation. It should be understood, however, that the embodiments and examples described herein are given by way of illustration only, and not by way of limitation. Various substitutions, modifications, additions, and rearrangements may be made without departing from the spirit of the present disclosure. Therefore, the description that follows is not to be taken in a limited sense, and the scope of the present disclosure will be defined only by the final claims.

As described in the background section, oil and gas wells require the use of several concentric casings to prevent contamination of fresh water, isolate different zones, and a myriad of other reasons. There is an unmet need in oil and gas wells that make use of such concentric casings to provide real time telemetry as to whether or not the annular regions have been compromised.

To this end, we propose the use of electro acoustic technology (EAT) that can be deployed with a fiber optic Distributed Acoustic Sensor (DAS) or a Fiber Bragg Grating array interrogated via Time Domain Interferometry (TDI) or Continuous Wave (CW) Interferometry. Using these technologies, pressure in the different annuli can be determined without the need to compromise the integrity of the barriers separating the different annuli.

Electro acoustic technology (EAT) will be described below. The EAT's will be will be placed in each annulus permanently. Data can be encoded either with Amplitude Modulation at a set frequency, or via Frequency Modulation around a central frequency. In this manner each EAT can be on its own unique channel, and in theory it is possible to have 100's of EATs monitoring simultaneously. The EAT's can either continuously send data, or to save power be programmed to come online at a set interval and send their data. Since the receiver of the emitted signal is fiber optics installed in the well bore, an external probe such as one deployed on a remote operated vehicle (ROV) is not required.

Description of EAT (Electro Acoustic Technology) Sensors

The EAT sensors and EAT sensing technology described in this disclosure is a recently developed technology and has been described in a recently published PCT application: WO2015020642A1.

EAT Sensors represent a new approach to fiber optic sensing in which any number of downhole sensors, electronic or fiber optic based, can be utilized to make the basic parameter measurements, but all of the resulting information is converted at the measurement location into perturbations or a strain applied to an optical fiber that is connected to an interrogator that may be located at the surface of a downhole well. The interrogator may routinely fire optical signal pulses downhole into the optical fiber. As the pulses travel down the optical fiber back scattered light is generated and is received by the interrogator.

The perturbations or strains introduced to the optical fiber at the location of the various EAT sensors can alter the back propagation of light and those effected light propagations can then provide data with respect to the signal that generated the perturbations.

The EAT sensor system can be best understood by reference to Figure 1, which is an example embodiment of an EAT sensor system. System **100** can include a sensor **105**, a circuit **110** coupled to the sensor **105**, an actuator **115** coupled to the circuit **110**, and an interrogator **120**. The sensor **105** is operable to provide a measurement corresponding to a parameter at a location in a region **102**. The sensor **105** can be realized in a number of different ways depending on the parameter to be determined by the measurement using the sensor **105**. The parameter can include, but is not limited to, a chemical concentration, a pH, a temperature, a vibration, or a pressure. The sensor **105** has the capability of being disposed at a location in proximity of an optical fiber cable **125**. The sensor **105** can be located downhole at a drilling site with the interrogator **120** at the surface of the drilling site. The drilling site may be terrestrial or sea-based. Components of the system **100** may be disposed outside casing in cement or strapped to a production tube in a permanent installation. Components of the system **100** also may be disposed in a coiled tube that can be pushed through into a horizontal area of operation, or a wire line cable that can be tractored into a wellbore using an electrically driven tractor that pulls the wire line cable into the wellbore, or pumped into a wellbore with fluid that push/pulls a cable into the wellbore. The system **100** may be used with other drilling related arrangements. The circuit **110**, coupled to the sensor **105**, can be structured to be operable to generate a signal correlated to the parameter in response to the measurement by the sensor **105**. The circuit **110** may be integrated with the sensor **105**. For example, a sensing element **107** may be an integral part of the circuit **110** or directly coupled to a component of the circuit **110**. The sensing element **107** may be a diaphragm directly coupled to a component of the circuit **110**.

The actuator **115** can be coupled to the circuit **110** to receive the signal generated in response to the measurement by the sensor **105**. The signal can be a compensated signal, where a compensated signal is a signal having a characteristic that corresponds to the parameter of interest for which variations in one or more other parameters is substantially corrected or removed, or for which the characteristic is isolated to the parameter of interest. The actuator **115** can be integrated with the circuit **110**, integrated with the circuit **110** that is integrated with the sensor **105**, or a separate structure coupled to the circuit **110**.

The actuator **115** can be structured to be operable to generate a perturbation, based on the signal, to an optical fiber cable **125,** that may include one or multiple optical fibers. The actuator **115** can be positioned in proximity to the optical fiber cable **125** at the effective location of the sensor **105**. The actuator **115** can be structured to be operable to generate the perturbation to the optical fiber cable **125** with the actuator **115** in contact with the optical fiber cable **125**. The actuator **115** can be structured to be operable to generate the perturbation to the optical fiber cable **125** with the actuator **115** a distance from the optical fiber cable **125**. The actuator **115** may be realized as a non-contact piezoelectric material, which can provide acoustic pressure to the optical fiber cable **125** rather than transferring vibrations by direct contact.

The optical fiber cable **125** can be perturbed with the optical fiber cable **125** in direct contact with the actuator **115** structured as a vibrator or with the actuator **115** structured having a form of voice coil at a distance away from the optical fiber cable **125**. The perturbation of the optical fiber can be provided as a vibration of the optical fiber cable 125 or a strain induced into the optical fiber cable **125**. Other perturbations may be applied such that the characteristics of the optical fiber are altered sufficiently to affect propagation of light in the optical fiber cable **125**. With the effects on the light propagation related to a signal that generates the perturbation, analysis of the effected light propagation can provide data with respect to the signal that generates the perturbation.

The interrogator **120** can be structured to interrogate the optical fiber cable **125** to analyze signals propagating in the optical fiber cable **125**. The interrogator **120** can have the capability to couple to the optical fiber cable **125** to receive an optical signal including the effects from the perturbation of the optical fiber cable **125** and to extract a value of the parameter of the measurement in response to receiving the optical signal from the perturbation. In an embodiment, the received signal may be a backscattered optical signal. The interrogator **120** may be structured, for example, to inject a short pulse into the optical fiber cable **125**. An example of a short pulse can include a pulse of 20 nanoseconds long. As the pulse travels down the optical fiber cable **125**, back-scattered light is generated. Interrogating a location that is one kilometer down the fiber, backscattered light is received after the amount of time it takes to travel one kilometer and then come back one kilometer, which is a round trip time of about ten nanoseconds per meter. The interrogator **120** can include an interferometric arrangement. The interrogator **120** can be structured to measure frequency based on coherent Rayleigh scattering using interferometry, to measure dynamic changes in attenuation, to measure a dynamic shift of Brillouin frequency, or combinations thereof.

The interrogator **120** can be arranged with the optical fiber cable **125** to use an optical signal provided to the interrogator **120** from perturbing the optical fiber cable **125** at a location along the optical fiber cable **125**. An arrangement different from using an optical signal backscattered from the perturbation can be utilized. For example, the optical fiber cable **125** can be structured having an arrangement selected from a fiber Bragg grating disposed in the optical fiber in vicinity of the actuator for direct wavelength detection based acoustic sensing, a non-wavelength selective in-line mirror disposed in the optical fiber in vicinity of the actuator, intrinsic Fabry-Perot interferometers as a mode of interrogation from fiber Bragg gratings placed apart in the optical fiber such that each fiber Bragg grating Fabry-Perot cavity is in vicinity of a respective actuator, Fizeau sensors in the optical fiber, a second optical fiber to transmit an optical signal from a perturbation of the optical fiber to a detection unit of the interrogator, or other arrangements to propagate a signal, representative of a measurement, in an optical fiber to an interrogation unit to analyze the signal to extract a value of a parameter that is the subject of the measurement.

The possible advantages from using the above described EAT systems in a variety of configurations may include using a variety of sensors, either electrical or fiber optic based, to measure for example a chemical concentration, a pH, a temperature, or a pressure and using a common optical fiber connected to a surface interrogator to measure perturbation signals from each EAT sensor location distributed along that common optical fiber and analyzing those signals to extract values of the parameters being measured. The approach can significantly reduce manufacturing complexity, reduce very expensive labor intensive production with expensive equipment like splicers and fiber winders, improve reliability, and widen industry acceptance by allowing the use of sensing technologies of choice.

Figure 2 expands on the use of electro acoustic technology (EAT) sensing systems by illustrating a more complete system. A subsurface well **130** is illustrated, in which a production casing **135** is shown extending through the well. In some applications the production casing may be non-metallic. At the far downhole end of the well an electro acoustic technology sensor assembly **140** is shown. In this example it is shown on the outside of the casing. In some applications the EAT sensor assembly could be within the casing. In many applications there could be multiple EAT sensor assemblies and the technology can easily accommodate that. In close proximity to the EAT sensor assembly shown is a fiber optic cable **145** that is deployed all through the well and back to the surface, then through a wellhead **155**. The fiber optic cable **145** may be clamped to the EAT sensor assembly **140** to ensure good transmission of signals. The fiber optic cable **145** exits through a wellhead exit **165** and is connected using a surface fiber cable **175** within an outdoor cabin or enclosure to a Distributed Acoustic System (DAS) interrogator **185**. The interrogator may then have a laser source **190** that fires interrogation pulses down through the fiber optic cable and receives backscattered light back from the fiber optic cable.

The fiber optic cable **145** may be permanently installed, or in some applications could be attached to some type of movable logging cable such as wireline or slickline cables. It could also be clamped on tubing inside the casing **135** in some applications.

Using EAT to Monitor Annulus Pressures

Figure 3, represented by the numeral **200**, is an illustration of the placement of multiple EAT's in a well. The casing structure is represented on the left hand side by a side cross section of the casings and on the right hand side by a top view of the same casings. An outside annulus **220**, inner annulus **240** and middle annulus **230** is shown surrounding a central casing **250** with EAT sensors **210, 212, and 214** placed in all of them. The fiber optic cable **145** of Figure 2 (not shown in Figure 3) may be a single fiber optic cable attached immediately outside the casing or in some cases inside the casing, clamped on tubing inside the casing. It is also feasible in the case that the signal levels are too low to use the interior electro acoustic technology sensor assemblies such as **212** and **214** as signal repeaters to transfer signals from a more distant electro acoustic sensor assembly such as **210** to the fiber optic cable.

As described earlier, the EAT's will be placed in each annulus permanently. Data can be encoded either with Amplitude Modulation at a set frequency, or via Frequency Modulation around a central frequency. In this manner each EAT can be on its own unique channel, and in theory you could have 100's of EATs monitoring simultaneously. The EAT's can either continuously send data, or to save power be programmed to come online at a set interval and send their data. Since the receiver of the emitted signal is fiber optics installed in the well bore, an external probe such as one deployed on an ROV is not required.

The data from the EAT's is transmitted to the surface through a distributed acoustic system through a fiber optic cable as described in the electro acoustic technology discussion.

The use of EAT sensors provides the ability to monitor casing integrity continuously and remotely. And all of the sensors can be read continuously and simultaneously. This can be done without compromising the casing.

Although certain embodiments and their advantages have been described herein in detail, it should be understood that various changes, substitutions and alterations could be made without departing from the coverage as defined by the appended claims. Moreover, the potential applications of the disclosed techniques is not intended to be limited to the particular embodiments of the processes, machines, manufactures, means, methods and steps described herein. As a person of ordinary skill in the art will readily appreciate from this disclosure, other processes, machines, manufactures, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufactures, means, methods or steps.

Claims

1. A system for continuous determination of annulus pressure in subsurface wells comprising:
    a. one or more electro acoustic technology sensor assemblies permanently installed in each annulus surrounding a subsurface well; and
    b. a fiber optic cable in close proximity to the electro acoustic technology sensor assemblies and in communication with a surface distributed acoustic fiber optic interrogator.
2. The system for continuous determination of annulus pressure in subsurface wells of claim 1 wherein the fiber optic cable in close proximity to the electro acoustic technology sensor assemblies is attached to the outside of the casing.
3. The system for continuous determination of annulus pressure in subsurface wells of claim 1 wherein the fiber optic cable in close proximity to the electro acoustic technology sensor assemblies is attached to tubing inside of the casing.
4. The system for continuous determination of annulus pressure in subsurface wells of claim 1 wherein the fiber optic cable in close proximity to the electro acoustic technology sensor assemblies is attached to a movable wireline cable inside the casing.
5. The system for continuous determination of annulus pressure in subsurface wells of claim 1 wherein the fiber optic cable in close proximity to the electro acoustic technology sensor assemblies is attached to a movable slickline cable inside the casing.
6. The system for continuous determination of annulus pressure in subsurface wells of claim 1 wherein the electro acoustic technology sensor assemblies utilize pressure sensing elements.

7. A method for continuous determination of annulus pressure in subsurface wells comprising:
    a. providing one or more electro acoustic technology sensor assemblies permanently installed in each annulus surrounding a subsurface well;
    b. providing a fiber optic cable in close proximity to the electro acoustic technology sensor assemblies and in communication with a surface distributed acoustic fiber optic interrogator; and
    c. continuously interrogating the one or more electro acoustic technology sensor assemblies permanently installed in each annulus surrounding a subsurface well to determine the annulus pressures.
8. The method for continuous determination of annulus pressure in subsurface wells of claim 7 wherein the fiber optic cable in close proximity to the electro acoustic technology sensor assemblies is provided on the outside of the casing.
9. The method for continuous determination of annulus pressure in subsurface wells of claim 7 wherein the fiber optic cable in close proximity to the electro acoustic technology sensor assemblies is provided attached to tubing inside of the casing.
10. The method for continuous determination of annulus pressure in subsurface wells of claim 7 wherein the fiber optic cable in close proximity to the electro acoustic technology sensor assemblies is provided attached to a movable wireline cable inside the casing.
11. The method for continuous determination of annulus pressure in subsurface wells of claim 7 wherein the fiber optic cable in close proximity to the electro acoustic technology sensor assemblies is provided attached to a movable slickline cable inside the casing.

12. The method for continuous determination of annulus pressure in subsurface wells of claim 7 wherein pressure sensing elements are provided in the electro acoustic technology sensor assemblies.

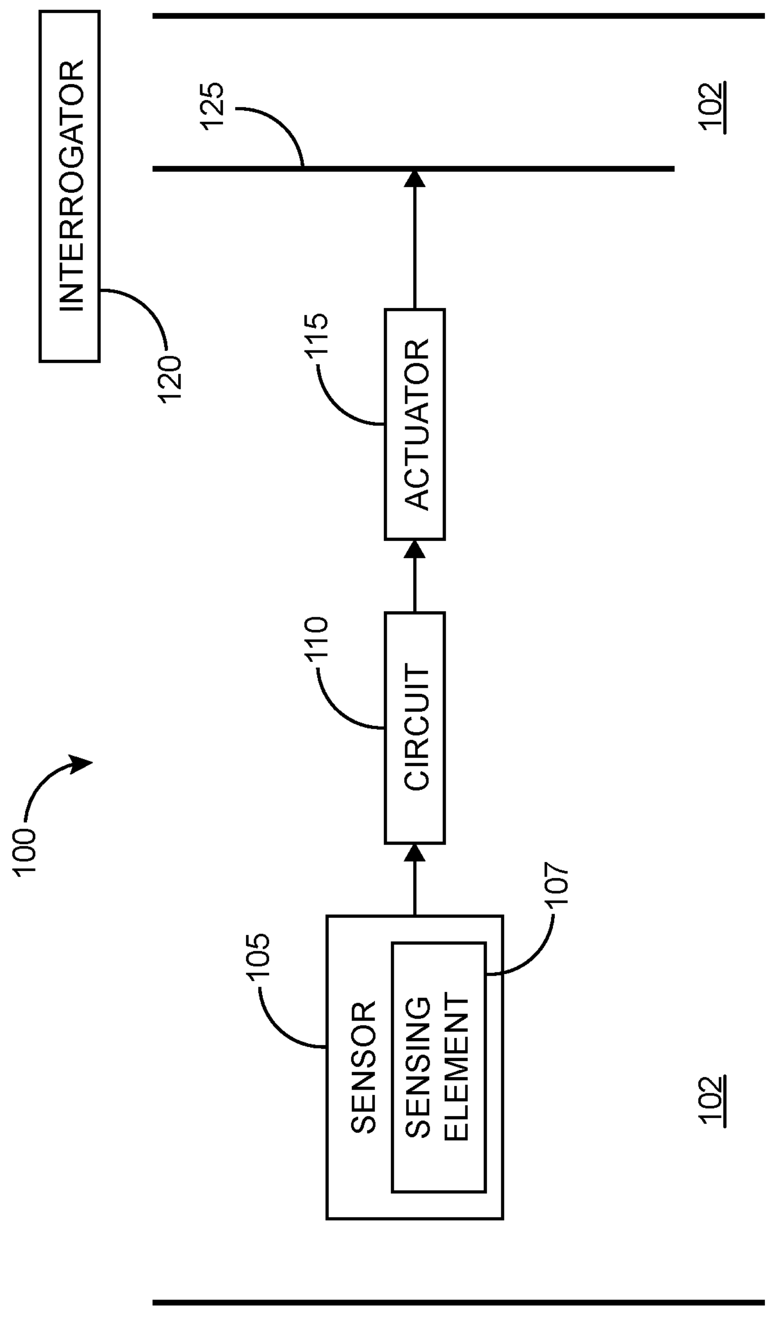
INTERROGATOR
120
125
102
ACTUATOR
115
CIRCUIT
110
100
SENSOR
105
SENSING ELEMENT
107
102

FIG. 1

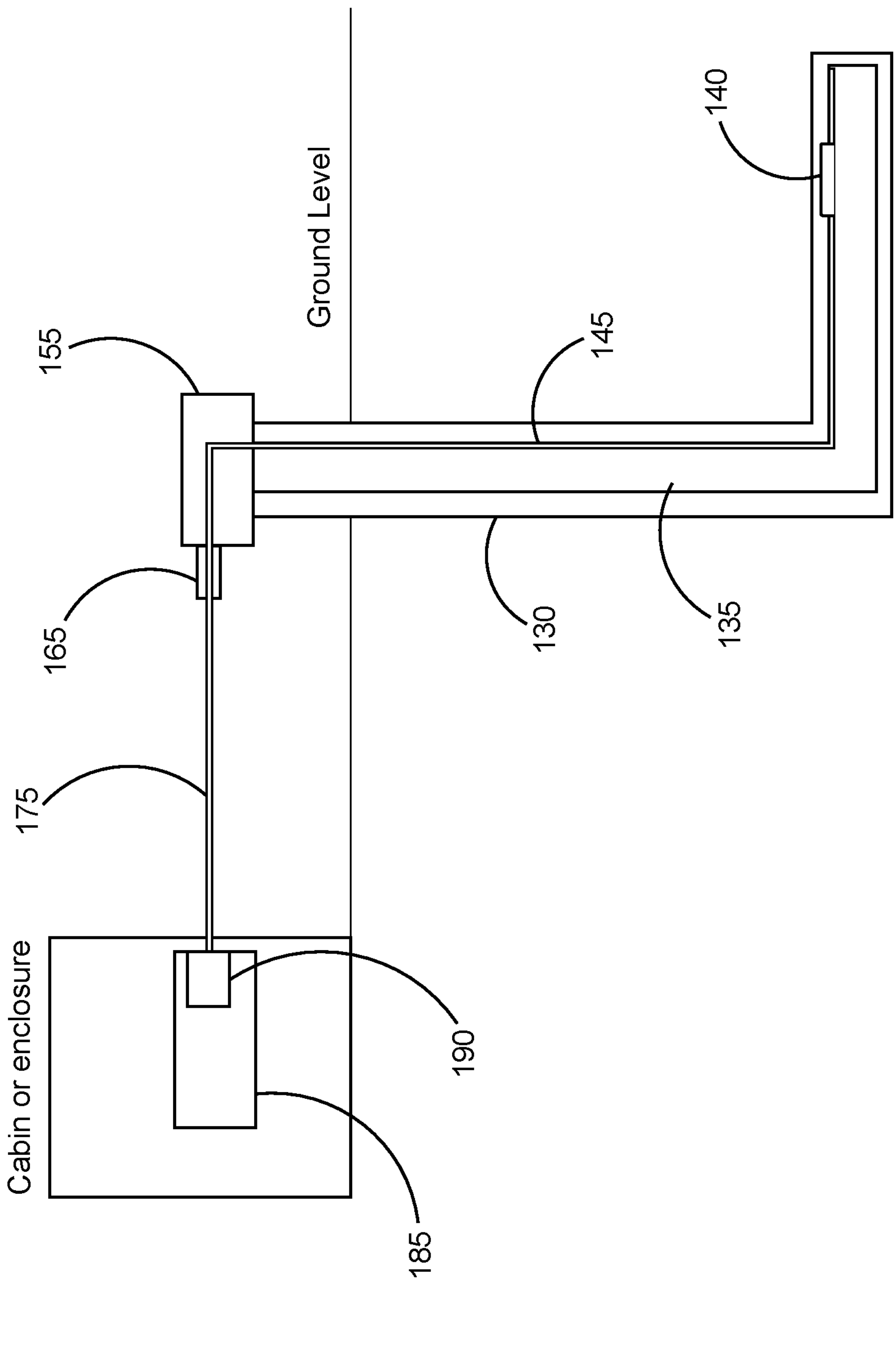
Ground Level
155
145
140
165
130
135
175
Cabin or enclosure
190
185

FIG. 2

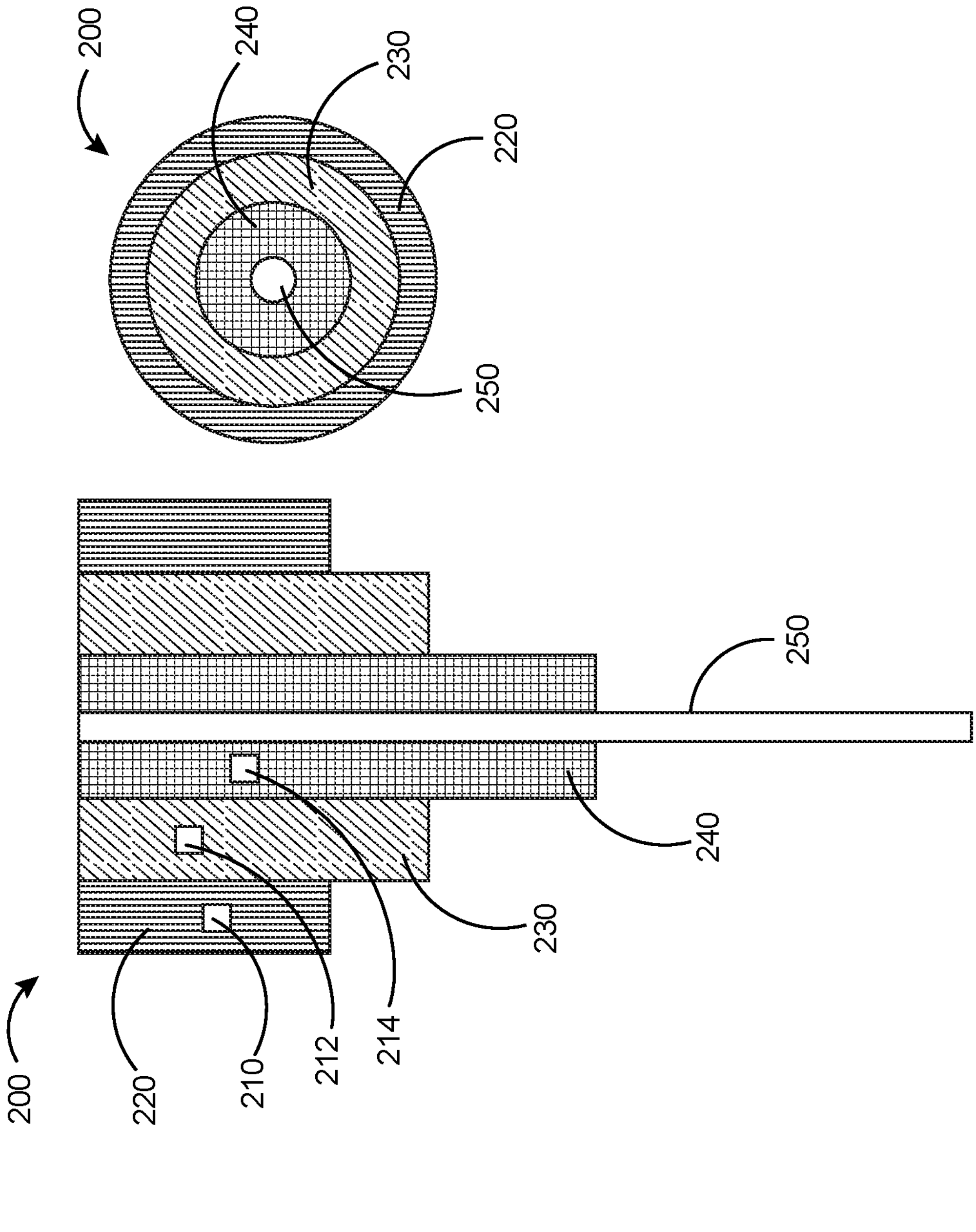

FIG. 3

INTERNATIONAL SEARCH REPORT	International application No. **PCT/US2015/065956**

A. CLASSIFICATION OF SUBJECT MATTER

E21B 47/06(2006.01)i, G01V 1/40(2006.01)i, G01V 1/46(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)
E21B 47/06; E21B 7/00; G01V 1/42; E21B 47/00; G01V 1/06; G01V 8/20; E21B 47/16; E21B 47/12; G01V 1/40; G01V 1/46

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: wellbore, subterranean, drilling, annulus pressure, electro acoustic technology sensor, interrogator, casing, tubing, wireline, slickline and fiber optic cable

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2014-0191120 A1 (HALLIBURTON ENERGY SERVICES, INC.) 10 July 2014 See paragraphs [0015]-[0021] and figures 1-3E.	1-12
Y	US 5022485 A (MITCHELL, DONALD K.) 11 June 1991 See column 1, lines 32-39, column 5, lines 9-19 and figure 1.	1-12
A	US 2015-0198031 A1 (DUNCAN, ROGER G.) 16 July 2015 See paragraphs [0013]-[0030] and figures 1-4.	1-12
A	US 2015-0285065 A1 (HOWELL et al.) 08 October 2015 See paragraphs [0018]-[0039] and figures 1-6.	1-12
A	US 2014-0036628 A1 (HILL et al.) 06 February 2014 See paragraphs [0042]-[0050] and figures 1-2.	1-12

☐ 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
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 September 2016 (12.09.2016)	**12 September 2016 (12.09.2016)**

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/065956

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