



(51) International Patent Classification:

E21B 7/06 (2006.01) *E21B 47/024* (2006.01)
E21B 23/12 (2006.01)

(21) International Application Number:

PCT/US2018/038427

(22) International Filing Date:

20 June 2018 (20.06.2018)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

15/656,256 21 July 2017 (21.07.2017) US

(71) Applicant: **BAKER HUGHES, A GE COMPANY, LLC**
[US/US]; 17021 Aldine Westfield, Houston, Texas 77073
(US).

(72) Inventors: **YANG, Lei**; 17021 Aldine Westfield, Houston, TX 77073 (US). **FANG, Lei**; 17021 Aldine Westfield, Houston, TX 77073 (US).

(74) Agent: **HENDRYX, Thomas et al.**; Baker Hughes, a GE company, LLC, 14990 Yorktown Plaza Drive, Houston, Texas 77040 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) Title: METHOD FOR ORIENTING WHIPSTOCK FOR CASING EXIT IN VERTICAL AND NEAR VERTICAL WELLS USING XY MAGNETOMETERS

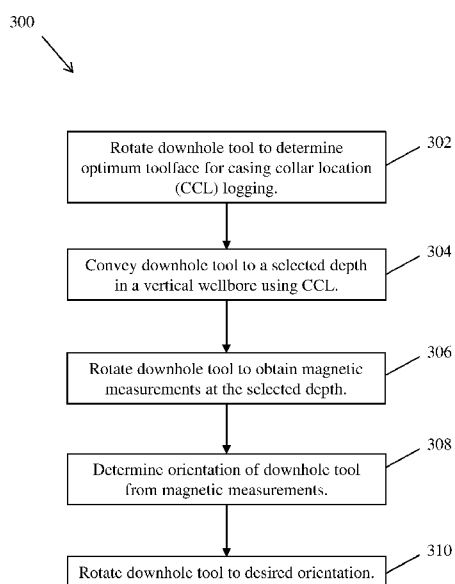


FIG. 3

(57) Abstract: A system and method for orienting a tool in a near vertical wellbore. The system includes a tool string having a whipstock at an end thereof, at least two magnetometers oriented transverse to a longitudinal axis of the tool string, and a processor. A first set of magnetic measurements of the earth's magnetic field is obtained during rotation of the tool using a first of the at least two magnetometers and a second set of magnetic measurements of the earth's magnetic field is obtained during rotation using a second of the at least two magnetometers. The processor fits a curve to the first and second sets of magnetic measurements to determine a peak value, determines magnetic north from the determined peak value, determines a toolface orientation of the drill string with respect to the determined magnetic north, and anchors the whipstock at the selected depth and toolface orientation.

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

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

METHOD FOR ORIENTING WHIPSTOCK FOR CASING EXIT IN VERTICAL AND NEAR VERTICAL WELLS USING XY MAGNETOMETERS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Application No. 15/656256, filed on July 21, 2017, which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] Whipstocks are used in wellbore drilling in order to divert a drill string from a pre-existing holes toward a new direction. Often whipstocks are employed in cased wellbores and the drill string is diverted for a casing exit. It is important to know the orientation of the whipstock so that the drill string is diverted along a desired direction. In a horizontal or deviated wellbore, accelerometers can be used to determine a whipstock orientation or an orientation of a string conveying the whipstock. However in vertical and near vertical wells, where well inclination is less than 5 degrees, accelerometer measurements are unable to determine toolface angle, as a result of which a gyroscope is usually used to determined true-north measurements.

BRIEF DESCRIPTION

[0003] In one aspect, the present disclosure provides a method of orienting a tool in a near vertical wellbore, including: rotating the tool at a selected depth of the vertical wellbore, the tool including at least two magnetometers oriented transverse to a longitudinal axis of the tool; obtaining, during rotation of the tool, a first set of magnetic measurements of the earth's magnetic field using a first of the at least two magnetometers and a second set of magnetic measurements using a second of the at least two magnetometers; fitting a curve to the first and second sets of magnetic measurements to determine a peak value; determining magnetic north from the determined peak value; and orienting the tool along a selected orientation based on the determined magnetic north.

[0004] In another aspect, the present disclosure provides a system for placing a whipstock in a near vertical wellbore, including: a tool string having the whipstock at an end thereof, the tool string including at least two magnetometers oriented transverse to a longitudinal axis of the tool string; a processor configured to: obtain, during rotation of the tool in the wellbore, a first set of magnetic measurements of the earth's magnetic field using a first of the at least two magnetometers and a second set of magnetic measurements using a

second of the at least two magnetometers, fit a curve to the first and second sets of magnetic measurements to determine a peak value, determine magnetic north from the determined peak value, determine a toolface orientation of the drill string with respect to the determined magnetic north, and anchor the whipstock at the selected depth and toolface orientation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

[0006] **FIG. 1** illustrates a drilling system that includes a milling tool string conveying a whipstock into a vertical wellbore for placement in the wellbore;

[0007] **FIG. 2** shows a detailed illustration of a section of drill string in an exemplary embodiment of the present disclosure;

[0008] **FIG. 2A** shows a view of the section of the milling tool string in another embodiment;

[0009] **FIG. 3** shows a flowchart illustrating a method for setting a whipstock in a vertical wellbore or a vertical section of a wellbore according to an embodiment of the present invention; and

[0010] **FIG. 4** illustrates magnetic field measurements that can be obtained using the at least two magnetometers of the downhole tool at the selected depth in the wellbore.

DETAILED DESCRIPTION

[0011] A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

[0012] **FIG. 1** illustrates a drilling system **100** that includes a tool string **120** conveying a whipstock **110** into a vertical wellbore **104** for placement in the wellbore **104**. In various embodiments, the tool string **120** can be a milling tool string or a drill string for drilling the wellbore **104**. A milling tool string can include a mill **112** at a bottom end thereof, and a drill string can include a drill bit at a bottom end thereof. The wellbore **104** can be a vertical wellbore or a near vertical wellbore, whereas a near vertical wellbore deviates from vertical by less than about 5 degrees. Wellbore **104** is formed in formation **102** and includes a casing **106** therein. The tool string **120** is conveyed from drilling rig **105** for a casing exit operation. In the casing exit operation, the whipstock **110** is conveyed to a selected depth of the wellbore **104** and rotated until its toolface angle is at a selected

orientation. The whipstock **110** is then anchored in the casing **106** at the selected depth and orientation and detached from the tool string **120**. The tool string **120** is then lowered with the mill **112** rotating. As the tool string **120** is lowered, the whipstock **110** diverts the mill **112** into the casing **106**, thereby causing the mill **112** to drill an exit from the wellbore **104** through the casing **106**. In the illustrative example, the whipstock **110** is anchored within the casing **106**. However, the whipstock **110** can also be anchored in an uncased region of the wellbore **104** in other embodiments.

[0013] The tool string **120** includes a bottomhole assembly (BHA) **114** that includes sensors for taking various survey measurements of the wellbore **104**. The BHA **114** can include accelerometers for measuring movement of the tool string **120** as well as for providing toolface orientation in horizontal or deviated wellbores. The BHA **114** may also include magnetometers for measuring a magnetic field within the casing **106**. The magnetic field measurements can be used to determine a depth of the tool string **120** in the wellbore by measuring the disturbance of the magnetic field of the earth due to the presence of the casings and, in particular, the presence of the casing collars. Additionally, the magnetic field measurements can be used to measure the Earth's magnetic field to thereby determine magnetic North. The magnetic measurements can also be used to determine the spinning speed of the BHA **114** during the milling process. The determined magnetic North can be used to orient the tool string **120** and hence the whipstock **110** within the vertical wellbore **104**. A detailed description of the BHA **114** is provided below with respect to **FIGS. 2** and **2A**.

[0014] **FIG. 2** shows a detailed illustration of a section **210** of tool string **120** in an exemplary embodiment of the present disclosure. The section **210** includes a BHA **114** that includes various sensors suitable for determining orientation and placement of a whipstock **110** in a wellbore **104**. In one embodiment, the sensors include at least two magnetometers, with each magnetometer having a measurement axis oriented in a selected direction. A tool-based coordinate system describes orthogonal x-, y- and z-axes, with the z-axis directed along a longitudinal axis **222** of the tool string **120** and the x-axis and y-axis lying within a plane transverse to the longitudinal axis **222**. An x-directed magnetometer **212** is oriented so as to measure magnetic components (M_x) that are along the x-axis of the tool-based coordinate system. A y-directed magnetometer **214** is oriented so as to measure magnetic components (M_y) that are along the y-axis of the tool-based coordinate system. A z-directed magnetometer **216** is oriented so as to measure magnetic components (M_z) along the z-axis of the tool-based coordinate system. In various embodiments of the present invention, the z-

directed magnetometer **216** is not necessary to perform the methods of orienting the tool string **120** and can thus be left off of the tool string **120**.

[0015] The transverse magnetometers (**212**, **214**) of the tool string **120** obtain magnetic measurements of the casing **106** as the tool string **120** is conveyed through the wellbore **104**. The measurements may be individual measurements or in the form of a magnetic log. Measurements made by the x-directed magnetometer **212** and the y-directed magnetometer **114** may be sent to a processing unit **224** of the BHA **114** that may include a processor **226**, various programs **228** for implementing methods for determining an orientation of the tool string **120**, and a memory **230** for storing data. In addition, the tool string **120** may include a telemetry unit **232** that may be used to transmit data to a surface location and to receive data from a surface location. One or more of the magnetic measurements may be sent via the telemetry unit **232** to a processing unit **240** at the surface location that includes processor **242**, programs **244** and memory **246** for determining the orientation of the tool string **120** using the methods disclosed herein. The processing units **224** and **240** may also include programs for determining depth of the tool string **120** and or orienting the toolface of the tool string **120** to a selected orientation. The results of the processing may be sent to a display **250** for viewing by an operator or user.

[0016] **FIG. 2A** shows a view of section **210** of the tool string **120** in another embodiment. The magnetometers **212**, **214** and/or **216** may be disposed on a member **238** that is extendable radially by arm **239** so that the magnetometers **212**, **214** and/or **216** can either be disposed along the longitudinal axis **222** or extended from the longitudinal axis **222** by a selected offset R_{offset} . When articulated from the longitudinal axis, one of the x-directed magnetometer **212** and the y-directed magnetometer **214** may be oriented with its measurement axis directed along a radial line of the casing **100** while the other of the x-directed magnetometer **212** and y-directed magnetometer **214** may be oriented with its measurement axis directed in a circumferential direction.

[0017] The section **210** may include one or more stabilizers **236** that hold the section **210** in place within the casing **106** while magnetic measurements are being obtained. The azimuth or toolface angle can also be changed, generally by rotation of the section **210** via a motor (not shown) at either a surface location or a downhole location.

[0018] Referring to either **FIG. 2** or **FIG. 2A**, the casing **106** may be an assembly of multiple casing tubulars. In one embodiment, casing **106**, including the first casing tubular **106a** and the second casing tubular **106b**, is made of a non-magnetized material or a soft magnetic material that does not carry a residual magnetic field. However, an applied

magnetic field proximate the casing induces a magnetic field in the casing **106**. Thus, in the downhole environment the magnetic field of the Earth induces a magnetic field in casing **106**.

[0019] In one embodiment, the first casing tubular **106a** is fastened to the second casing tubular **106b** via a threaded surface on an exterior surface of the first casing tubular **106a** and a threaded surface on an interior surface of the second casing tubular **106b**. In general, the casing tubulars **106a**, **106b** carry substantially homogenous induced magnetic fields along their length. The casing joint or collar **108** however introduces a perturbation into the induced magnetic field that can be detected to determine depth of the downhole tool in the wellbore.

[0020] In one aspect, a configuration of the magnetometers **212**, **214** is selected that provides suitable magnetic measurements for determining the toolface angle using the methods disclosed herein. For example, an optimal or suitable offset for the magnetometers **212**, **214** can be determined. In various embodiments, the configuration of the magnetometers **212**, **214** can be determined using a computer simulation or by testing the configuration at the surface location or within the first casing of the wellbore.

[0021] **FIG. 3** shows a flowchart **300** illustrating a method for setting a whipstock in a vertical wellbore or a vertical section of a wellbore according to an embodiment of the present invention. In Box **302**, the downhole tool (e.g., tool string **120**) conveying the whipstock is rotated to determine an optimal configuration of the tool string **120** for obtaining casing collar location logging. In various embodiments, the tool string **120** includes at least two magnetometers, such as magnetometers **212** and **214** that lie in a plane transverse to the longitudinal axis of the tool string **120**. The configuration may include a selected offset of the magnetometers from the longitudinal axis of the tool string **120**, for example. In box **304**, the downhole tool is conveyed downhole to a selected depth within the wellbore using, for example, casing collar locating (CCL) logging from magnetic measurements obtained by the at least two magnetometers in the configuration determined in box **302**. The CCL log can be used to position the magnetometers **212** and **214** at a location away from the casing collars **108**, where magnetic measurements obtained for determining orientation are unaffected by any magnetic disturbances due to casing collars **108**. In box **306**, once the selected depth of the downhole tool has been reached, the downhole tool is rotated so that magnetic measurements can be obtained at a plurality of azimuthal angles (i.e., over at least a 360-degree range). The magnetic measurements include measurements of a magnetic field induced in the casing by the Earth's magnetic field. In box **308**, the orientation of the downhole tool is determined from the magnetic measurements obtained at the plurality of

azimuthal angles. In box **310**, the downhole tool is rotated from its determined orientation to a desired or selected toolface orientation. The rotation is made by determining an angular difference between the determined toolface orientation of the tool and the desired toolface orientation of the tool and measuring a rotation of the downhole tool as the downhole tool is rotated through the angular difference to achieve desired toolface orientation.

[0022] The magnetometer measurements are often weak and/or noisy due to such effects as the damping effect of the casing on the strength of the Earth's magnetic field in the wellbore, residual magnetic fields of casing, a transverse offset of the tool string from the casing axis, the tool string not being parallel with casing axis, etc. The processing method discussed below can be used to determine the direction of magnetic north.

[0023] **FIG. 4** illustrates magnetic field measurements that can be obtained using the at least two magnetometers of the downhole tool at the selected depth in the wellbore. Graph **400** shows magnetic measurements M_x **402** obtained using the x-directed magnetometer **212** as the downhole tool is rotated through a plurality of azimuthal angles, such as through a 360-degree rotation of the downhole tool. Although magnetic measurements obtained through a rotation of 360-degree would appear to be sinusoidal, the magnetic measurements M_x **402** are generally not perfect sinusoids due to distortion by the casing **106**. In order to smooth the measurements M_x **402**, sinusoidal curve **404** is fit to magnetic measurements M_x **402** using a suitable fitting program. Once the curve **404** has been fit, a peak value of the curve **404** can be selected as representative of magnetic north.

[0024] Graph **410** shows magnetic measurements M_y **412** obtained using the y-directed magnetometer **214** as the downhole tool is rotated through a plurality of azimuthal angles, specifically through a 360-degree rotation of the downhole tool. Magnetic measurements M_y **412** similarly diverge from a sinusoidal curve for the same reasons presented above with respect to measurements M_x **402**. Sinusoidal curve **414** can therefore be fit to magnetic measurements M_y **412** using a suitable fitting program. Once the curve **414** has been fit, a peak value of the curve **414** can be selected as representative of magnetic north.

[0025] In one embodiment, sinusoidal curves **404** and **414** are fit to their respective magnetic measurements M_x **402** and M_y **412** with the constraint that a 90-degree phase difference is maintained between them. The peak values from curves **404** and **414** can be used to determine an orientation of the downhole tool with respect to magnetic north. Once the orientation of the downhole tool has been determined, the downhole tool can be rotated into a desired orientation. In one embodiment, the downhole tool can be rotated from its

determined current orientation to the desired orientation by determining an angular difference between determined orientation and desired orientation and tracking angular rotation of the downhole tool with a suitable rotation sensor through the angular difference until the desired orientation has been reached. Once the desired toolface orientation is achieved, the whipstock can be anchored into the casing and released from the downhole tool in preparation for a next stage of a casing exit operation. Additional operation that required a selected orientation in a vertical wellbore can also be performed by determining the orientation using the methods disclosed herein.

[0026] The method of the present invention enables conducting a single trip casing exit operation in a vertical wellbore. The at least two magnetometers orthogonal to the longitudinal axis of the downhole tool can be used for both CCL logging to determine tool (e.g., whipstock) depth and for orienting the tool. When drilling with a drill string, once the drill string has exited the vertical wellbore, the drill string can continue to drill to obtain a deviated well using the magnetometers as well as any accelerometers that may be provided with the drill string.

[0027] Set forth below are some embodiments of the foregoing disclosure:

[0028] Embodiment 1: A method of orienting a tool in a near vertical wellbore, including: rotating the tool at a selected depth of the near vertical wellbore, the tool including at least two magnetometers oriented transverse to a longitudinal axis of the tool; obtaining, during rotation of the tool, a first set of magnetic measurements of the earth's magnetic field using a first of the at least two magnetometers and a second set of magnetic measurements using a second of the at least two magnetometers; fitting a curve to the first and second sets of magnetic measurements to determine a peak value; determining magnetic north from the determined peak value; and orienting the tool along a selected orientation based on the determined magnetic north.

[0029] Embodiment 2: The method of embodiment 1 further comprising conveying the tool to the selected depth using magnetic measurements of a casing in the wellbore obtained by the at least two magnetometers.

[0030] Embodiment 3: The method of embodiment 1, wherein orienting the tool further comprises determining a first orientation of the tool with respect to magnetic north, determining an angular difference between the selected orientation and the first orientation and measuring a rotation of the tool through the angular difference.

[0031] Embodiment 4: The method of embodiment 1, wherein the at least two magnetometers includes a first magnetometer oriented along a first radial direction

orthogonal to a longitudinal axis of the tool and a second magnetometer oriented along a second radial direction orthogonal to both the first radial direction and the longitudinal axis of the tool.

[0032] Embodiment 5: The method of embodiment 1, further comprising fitting a first sinusoidal curve to the first set of magnetic measurements and fitting a second sinusoidal curve to the second set of magnetic measurements, wherein the first sinusoidal curve and the second sinusoidal curve are 90 degrees out of phase.

[0033] Embodiment 6: The method of embodiment 5, further comprising determining magnetic north from a peak of the first sinusoidal curve and a peak of the second sinusoidal curve.

[0034] Embodiment 7: The method of embodiment 1, wherein the tool includes a whipstock and setting the tool further comprises anchoring the whipstock at the selected orientation.

[0035] Embodiment 8: The method of embodiment 1, further comprising obtaining the magnetic measurements with the at least two magnetometers offset from the longitudinal axis of the tool.

[0036] Embodiment 9: A system for placing a whipstock in a near vertical wellbore, including: a tool string having the whipstock at an end thereof, the tool string including at least two magnetometers oriented transverse to a longitudinal axis of the tool string; a processor configured to: obtain, during rotation of the tool in the wellbore, a first set of magnetic measurements of the earth's magnetic field using a first of the at least two magnetometers and a second set of magnetic measurements using a second of the at least two magnetometers, fit a curve to the first and second sets of magnetic measurements to determine a peak value, determine magnetic north from the determined peak value, determine a toolface orientation of the drill string with respect to the determined magnetic north, and anchor the whipstock at the selected depth and toolface orientation.

[0037] Embodiment 10: The system of embodiment 9, wherein the processor is further configured to determine a selected depth of the drill string using casing collar location measurements obtained by the at least two magnetometers.

[0038] Embodiment 11: The system of embodiment 9, wherein the processor is further configured to obtain a selected toolface orientation by determining the toolface orientation of the drill string with respect to magnetic north, determining an angular difference between the selected toolface orientation and the determined toolface orientation and measuring a rotation of the tool through the angular difference.

[0039] Embodiment 12: The system of embodiment 9, wherein the at least two magnetometers includes a first magnetometer oriented along a first radial direction orthogonal to the longitudinal axis of the drill string and a second magnetometer oriented along a second radial direction orthogonal to both the first radial direction and the longitudinal axis of the drill string.

[0040] Embodiment 13: The system of embodiment 9, wherein the processor is further configured to fit a first sinusoidal curve to the first set of magnetic measurements and fit a second sinusoidal curve to the second set of magnetic measurements, wherein the first sinusoidal curve and the second sinusoidal curve are 90 degrees out of phase.

[0041] Embodiment 14: The system of embodiment 13, wherein the processor is further configured to determine magnetic north from a peak of the first sinusoidal curve and a peak of the second sinusoidal curve.

[0042] Embodiment 15: The system of embodiment 9, wherein the at least two magnetometers offset from the longitudinal axis of the tool.

[0043] The use of the terms “a” and “an” and “the” and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. Further, it should further be noted that the terms “first,” “second,” and the like herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another. The modifier “about” used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context (e.g., it includes the degree of error associated with measurement of the particular quantity).

[0044] The teachings of the present disclosure may be used in a variety of well operations. These operations may involve using one or more treatment agents to treat a formation, the fluids resident in a formation, a wellbore, and / or equipment in the wellbore, such as production tubing. The treatment agents may be in the form of liquids, gases, solids, semi-solids, and mixtures thereof. Illustrative treatment agents include, but are not limited to, fracturing fluids, acids, steam, water, brine, anti-corrosion agents, cement, permeability modifiers, drilling muds, emulsifiers, demulsifiers, tracers, flow improvers etc. Illustrative well operations include, but are not limited to, hydraulic fracturing, stimulation, tracer injection, cleaning, acidizing, steam injection, water flooding, cementing, etc.

[0045] While the invention has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without

departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the claims. Also, in the drawings and the description, there have been disclosed exemplary embodiments of the invention and, although specific terms may have been employed, they are unless otherwise stated used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention therefore not being so limited.

CLAIMS

What is claimed is:

1. A method of orienting a tool in a near vertical wellbore, comprising:
rotating the tool at a selected depth of the near vertical wellbore, the tool including at least two magnetometers oriented transverse to a longitudinal axis of the tool;
obtaining, during rotation of the tool, a first set of magnetic measurements of the earth's magnetic field using a first of the at least two magnetometers and a second set of magnetic measurements using a second of the at least two magnetometers;
fitting a curve to the first and second sets of magnetic measurements to determine a peak value;
determining magnetic north from the determined peak value; and
orienting the tool along a selected orientation based on the determined magnetic north.
2. The method of claim 1, further comprising conveying the tool to the selected depth using magnetic measurements of a casing in the wellbore obtained by the at least two magnetometers.
3. The method of claim 1, wherein orienting the tool further comprises determining a first orientation of the tool with respect to magnetic north, determining an angular difference between the selected orientation and the first orientation and measuring a rotation of the tool through the angular difference.
4. The method of claim 1, wherein the at least two magnetometers includes a first magnetometer oriented along a first radial direction orthogonal to a longitudinal axis of the tool and a second magnetometer oriented along a second radial direction orthogonal to both the first radial direction and the longitudinal axis of the tool.
5. The method of claim 1, further comprising fitting a first sinusoidal curve to the first set of magnetic measurements and fitting a second sinusoidal curve to the second set of magnetic measurements, wherein the first sinusoidal curve and the second sinusoidal curve are 90 degrees out of phase.
6. The method of claim 5, further comprising determining magnetic north from a peak of the first sinusoidal curve and a peak of the second sinusoidal curve.
7. The method of claim 1, wherein the tool includes a whipstock and setting the tool further comprises anchoring the whipstock at the selected orientation.

8. The method of claim 1, further comprising obtaining the magnetic measurements with the at least two magnetometers offset from the longitudinal axis of the tool.

9. A system for placing a whipstock in a near vertical wellbore, comprising:
a tool string having the whipstock at an end thereof, the tool string including at least two magnetometers oriented transverse to a longitudinal axis of the tool string;
a processor configured to:
obtain, during rotation of the tool in the wellbore, a first set of magnetic measurements of the earth's magnetic field using a first of the at least two magnetometers and a second set of magnetic measurements using a second of the at least two magnetometers,
fit a curve to the first and second sets of magnetic measurements to determine a peak value,
determine magnetic north from the determined peak value,
determine a toolface orientation of the drill string with respect to the determined magnetic north, and
anchor the whipstock at the selected depth and toolface orientation.

10. The system of claim 9, wherein the processor is further configured to determine a selected depth of the drill string using casing collar location measurements obtained by the at least two magnetometers.

11. The system of claim 9, wherein the processor is further configured to obtain a selected toolface orientation by determining the toolface orientation of the drill string with respect to magnetic north, determining an angular difference between the selected toolface orientation and the determined toolface orientation and measuring a rotation of the tool through the angular difference.

12. The system of claim 9, wherein the at least two magnetometers includes a first magnetometer oriented along a first radial direction orthogonal to the longitudinal axis of the drill string and a second magnetometer oriented along a second radial direction orthogonal to both the first radial direction and the longitudinal axis of the drill string.

13. The system of claim 9, wherein the processor is further configured to fit a first sinusoidal curve to the first set of magnetic measurements and fit a second sinusoidal curve to the second set of magnetic measurements, wherein the first sinusoidal curve and the second sinusoidal curve are 90 degrees out of phase.

14. The system of claim 13, wherein the processor is further configured to determine magnetic north from a peak of the first sinusoidal curve and a peak of the second sinusoidal curve.

15. The system of claim 9, wherein the at least two magnetometers offset from the longitudinal axis of the tool.

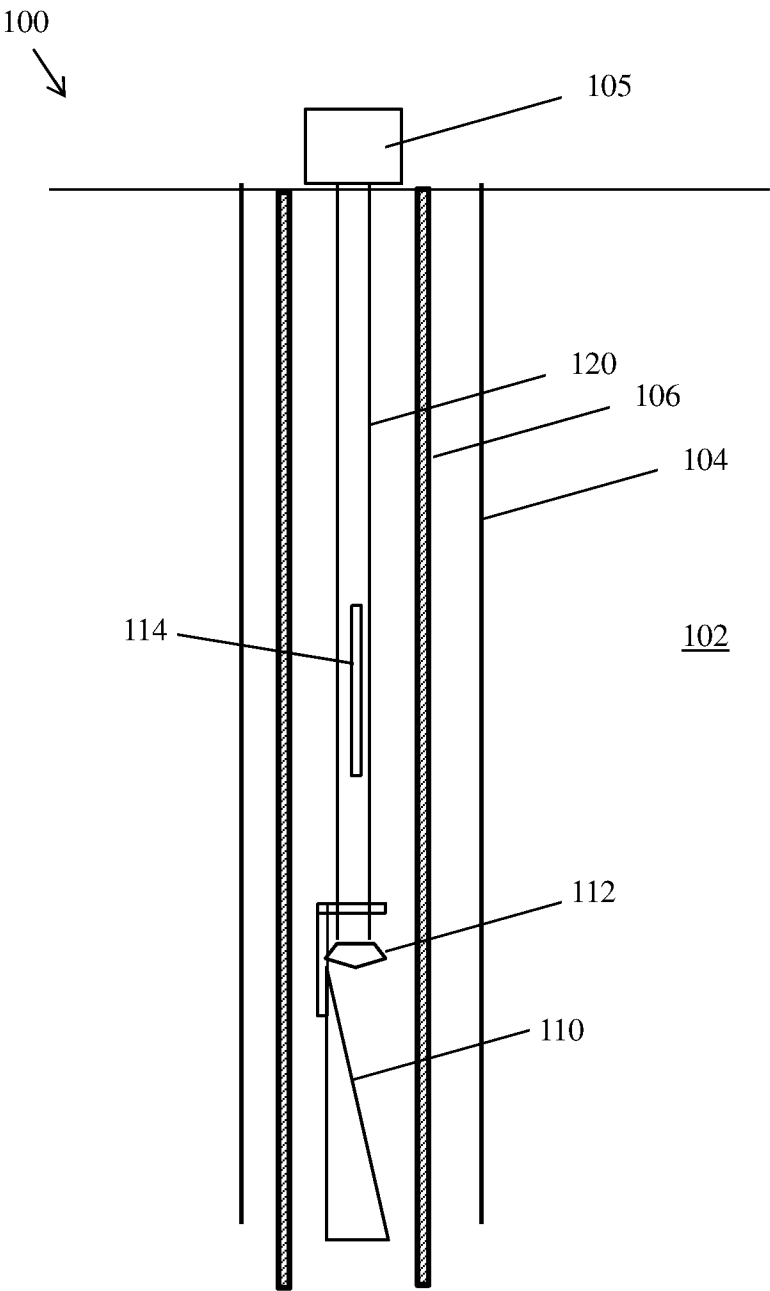


FIG. 1

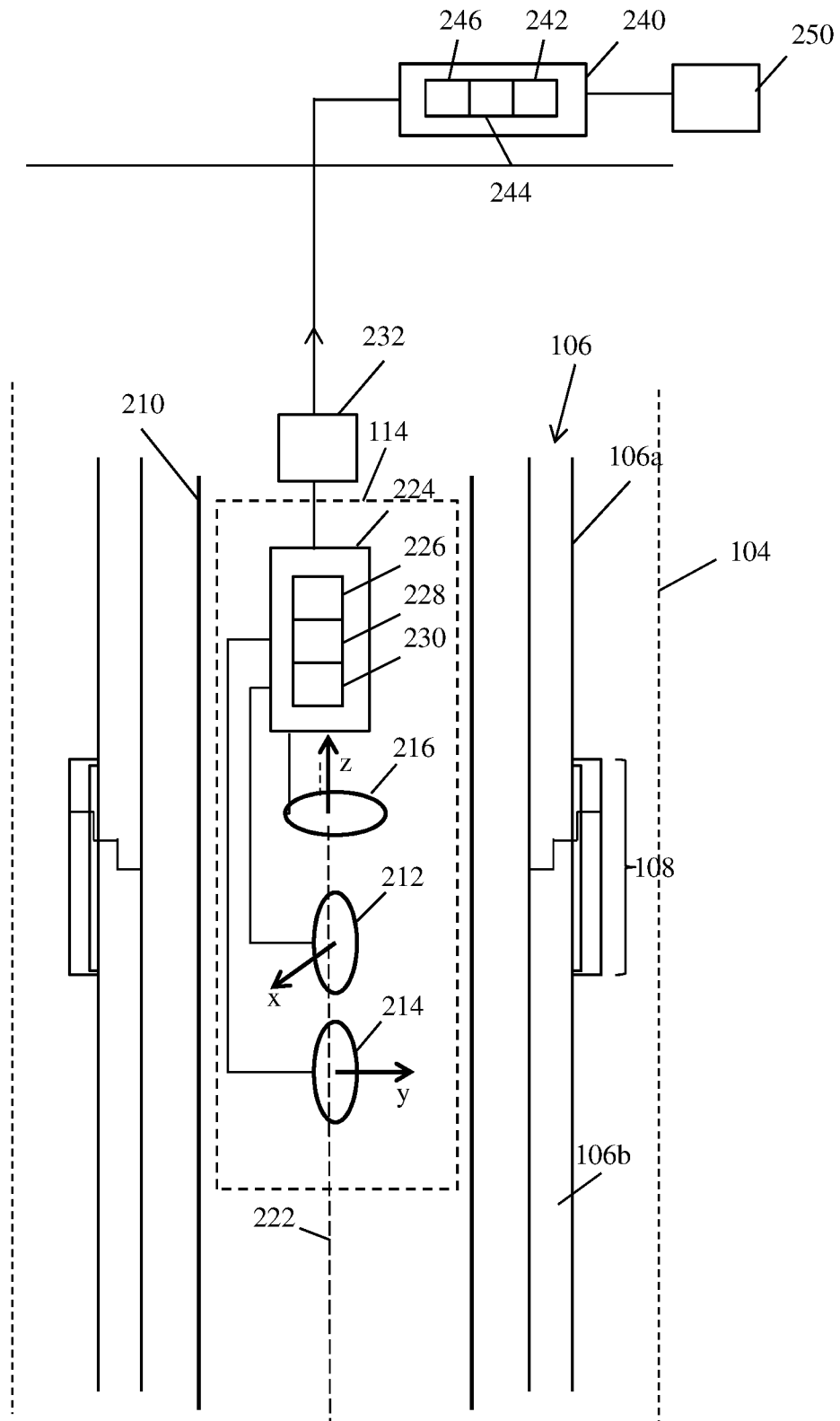


FIG. 2

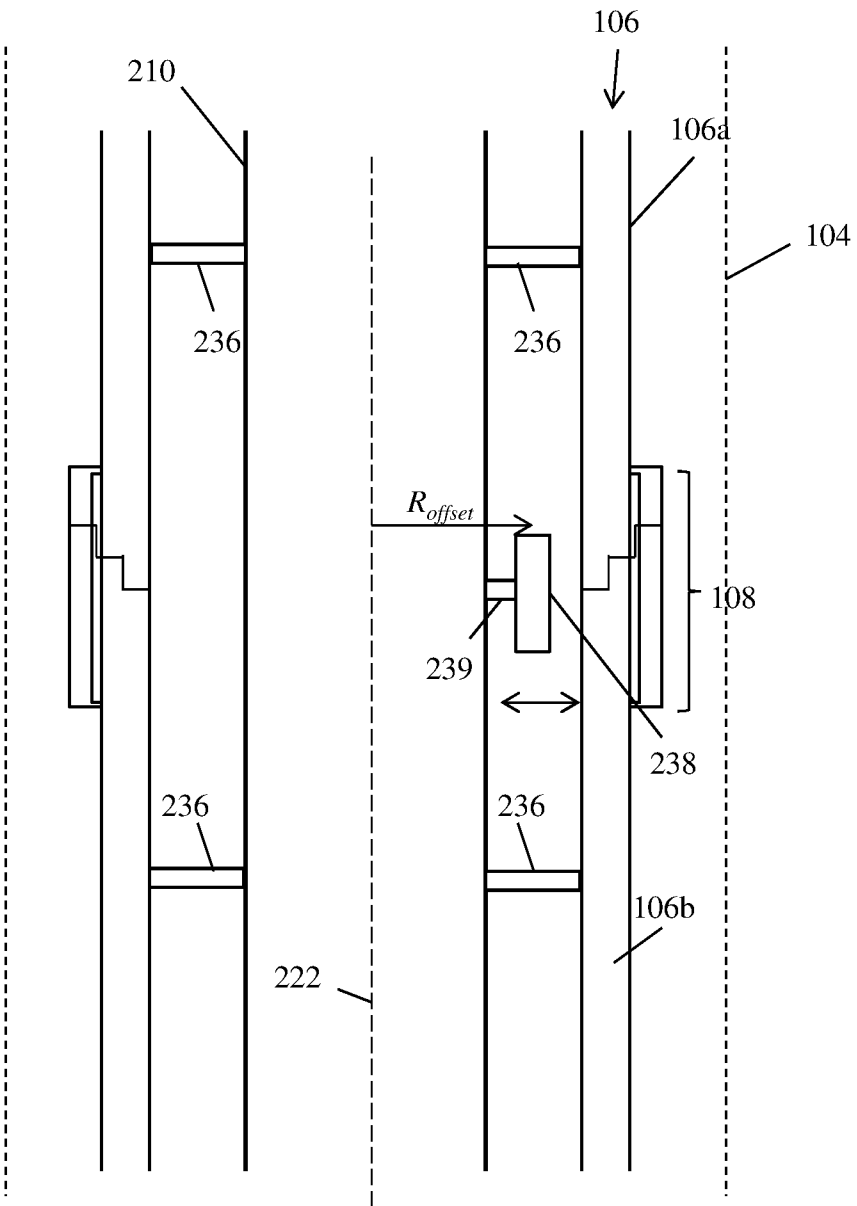


FIG. 2A

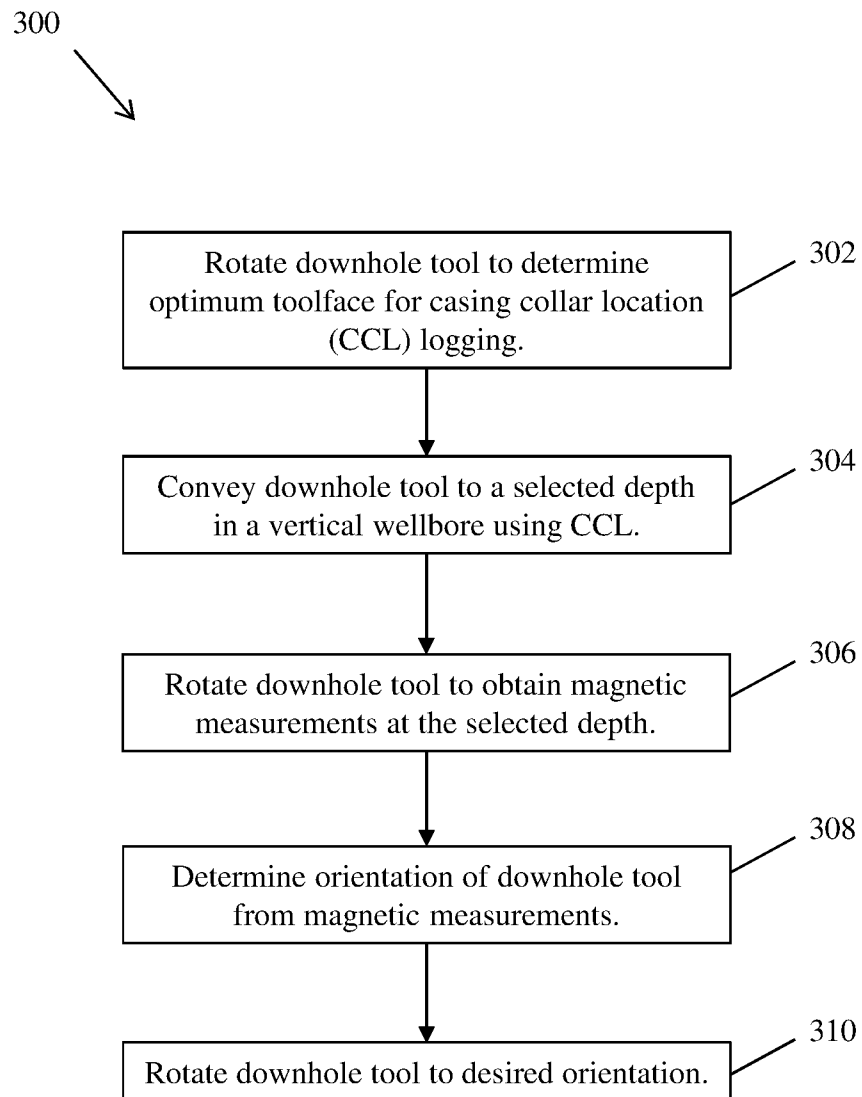


FIG. 3

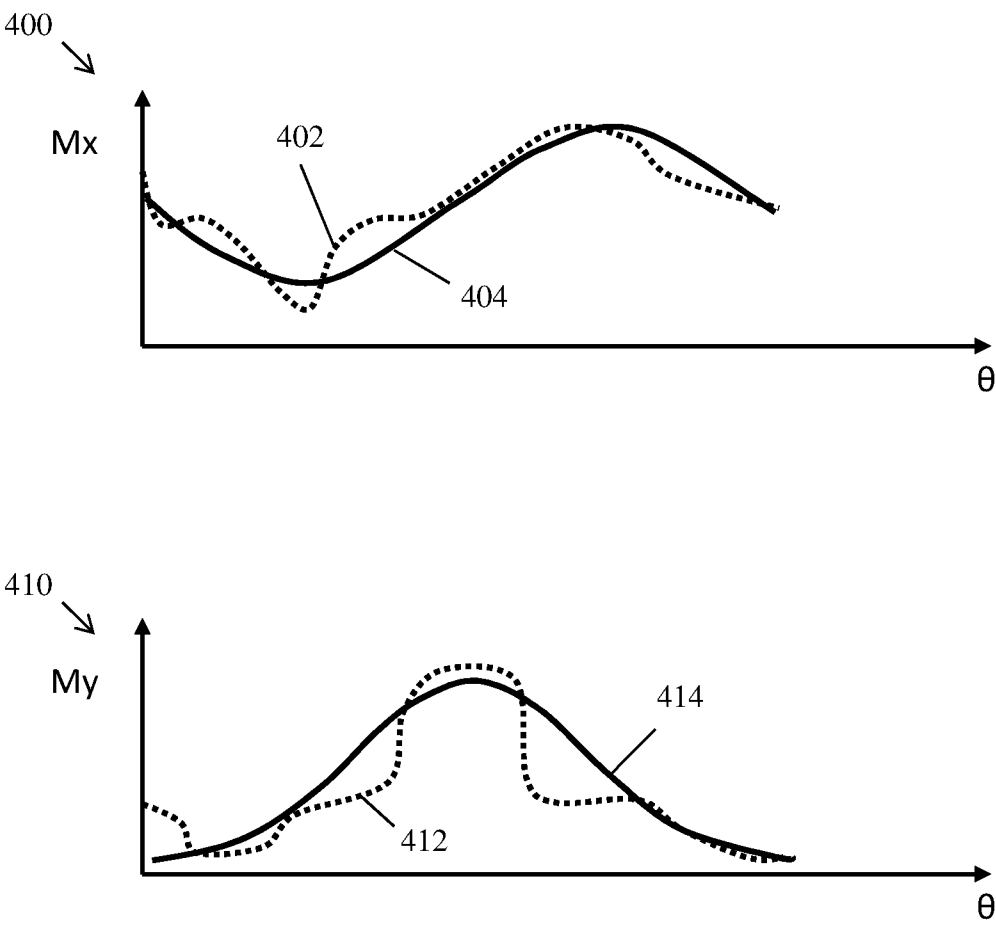


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/038427**A. CLASSIFICATION OF SUBJECT MATTER****E21B 7/06(2006.01)i, E21B 23/12(2006.01)i, E21B 47/024(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 7/06; E21B 29/06; E21B 43/119; E21B 47/024; E21B 47/09; G01V 3/08; G01V 3/18; G01V 3/38; E21B 23/12

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: vertical wellbore, tool, magnetometer, magnetic north, fitting

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003-0236627 A1 (ESTES, ROBERT A.) 25 December 2003 See paragraphs [0004], [0014]-[0021], [0042]-[0099]; claims 1-13; and figures 1, 4.	1-6,8
Y		7,9-15
Y	WO 2007-015087 A1 (MAXWELL DOWNHOLE TECHNOLOGY LIMITED et al.) 08 February 2007 See page 1, line 12 - page 7, line 6.	7,9-15
A	US 2014-0131036 A1 (HUVAL et al.) 15 May 2014 See paragraphs [0012]-[0017]; and figures 1-2.	1-15
A	US 2015-0025805 A1 (HANAK et al.) 22 January 2015 See paragraphs [0024]-[0027], [0033]-[0036]; and figures 1, 6.	1-15
A	WO 2009-085615 A2 (SCHLUMBERGER CANADA LIMITED et al.) 09 July 2009 See paragraphs [0049], [0069]-[0088]; and figures 6, 8, 10.	1-15



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

"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

"&" document member of the same patent family

Date of the actual completion of the international search

17 October 2018 (17.10.2018)

Date of mailing of the international search report

17 October 2018 (17.10.2018)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

Facsimile No. +82-42-481-8578

Authorized officer

LEE, Jong Kyung

Telephone No. +82-42-481-3360



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/038427

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2003-0236627 A1	25/12/2003	AU 1628399 A	16/06/1999
		AU 1866502 A	09/05/2002
		AU 749937 B2	04/07/2002
		AU 767165 B2	06/11/2003
		CA 2312742 A1	10/06/1999
		CA 2312742 C	24/04/2007
		CA 2356025 A1	28/02/2002
		CA 2356025 C	20/11/2007
		DE 60117110 T2	14/09/2006
		DE 60117877 T2	16/11/2006
		DE 60118803 T2	23/11/2006
		EP 1184539 A2	06/03/2002
		EP 1184539 A3	03/03/2004
		EP 1184539 B1	08/02/2006
		EP 1426552 A2	09/06/2004
		EP 1426552 A3	15/09/2004
		EP 1426552 B1	08/03/2006
		EP 1431510 A2	23/06/2004
		EP 1431510 A3	15/09/2004
		EP 1431510 B1	12/04/2006
		GB 2347224 A	30/08/2000
		GB 2347224 B	22/05/2002
		GB 2369188 A	22/05/2002
		GB 2369188 B	17/07/2002
		GB 2370645 A	03/07/2002
		GB 2370645 B	21/05/2003
		GB 2385078 A	13/08/2003
		GB 2385078 B	05/11/2003
		GB 2385079 A	13/08/2003
		GB 2385079 B	11/02/2004
		NO 20002859 A	03/08/2000
		NO 20014170 A	01/03/2002
		NO 20035134 A	03/08/2000
		NO 20035135 A	03/08/2000
		NO 320927 B1	13/02/2006
		NO 321998 B1	31/07/2006
		NO 326611 B1	19/01/2009
		NO 327372 B1	15/06/2009
		US 2001-0041963 A1	15/11/2001
		US 2002-0116130 A1	22/08/2002
		US 6151553 A	21/11/2000
		US 6347282 B2	12/02/2002
		US 6529834 B1	04/03/2003
		US 6712159 B2	30/03/2004
		US 6842699 B2	11/01/2005
		WO 99-28594 A1	10/06/1999
WO 2007-015087 A1	08/02/2007	None	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/038427

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014-0131036 A1	15/05/2014	AU 2013-345289 A1 AU 2013-345289 B2 CA 2890694 A1 CA 2890694 C GB 2523048 A NO 20150555 A1 US 9062508 B2 WO 2014-078028 A1	30/04/2015 17/11/2016 22/05/2014 16/05/2017 12/08/2015 06/05/2015 23/06/2015 22/05/2014
US 2015-0025805 A1	22/01/2015	AU 2014-290733 A1 AU 2014-290733 B2 CA 2915363 A1 GB 2534701 A GB 2534701 B NO 20151681 A1 US 9863236 B2 WO 2015-009373 A1	24/12/2015 14/12/2017 22/01/2015 03/08/2016 18/10/2017 09/12/2015 09/01/2018 22/01/2015
WO 2009-085615 A2	09/07/2009	AU 2008-343464 A1 AU 2008-343464 B2 CA 2710621 A1 EP 2250343 A2 US 2009-0166035 A1 US 2012-0230151 A1 US 8201625 B2 WO 2009-085615 A3 WO 2009-085615 A9	09/07/2009 15/05/2014 09/07/2009 17/11/2010 02/07/2009 13/09/2012 19/06/2012 17/09/2009 05/11/2009