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(72) Inventor(s):
Steven Hough
Edward Richards

(73) Proprietor(s):
Schlumberger Technology B.V.
(Incorporated in the Netherlands)
IP Department, Parkstraat 83, 2514 JG Den Haag,
Netherlands

(74) Agent and/or Address for Service:
Schlumberger Technology B.V.
IP Department, Parkstraat 83, 2514 JG Den Haag,
Netherlands

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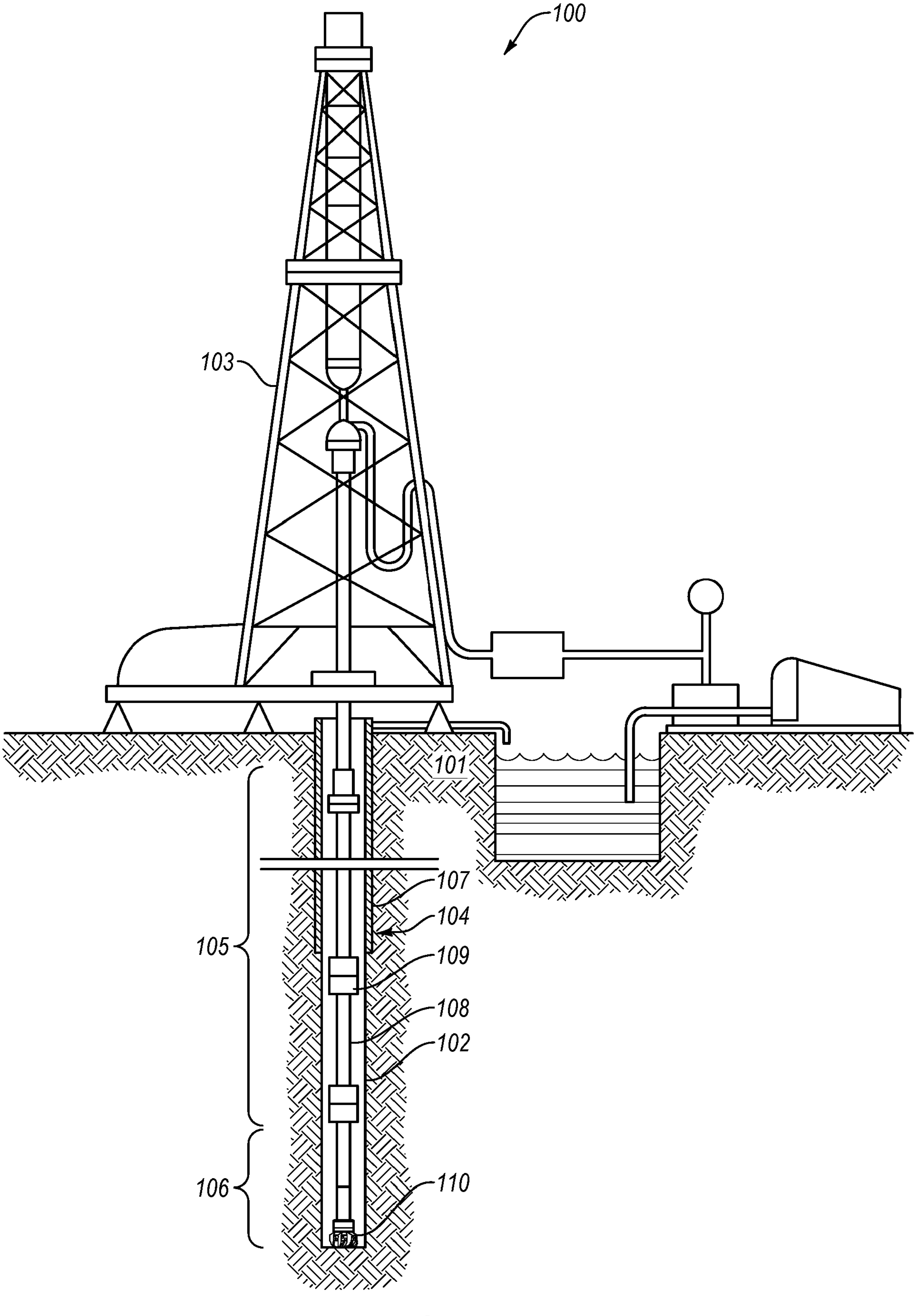

FIG. 1

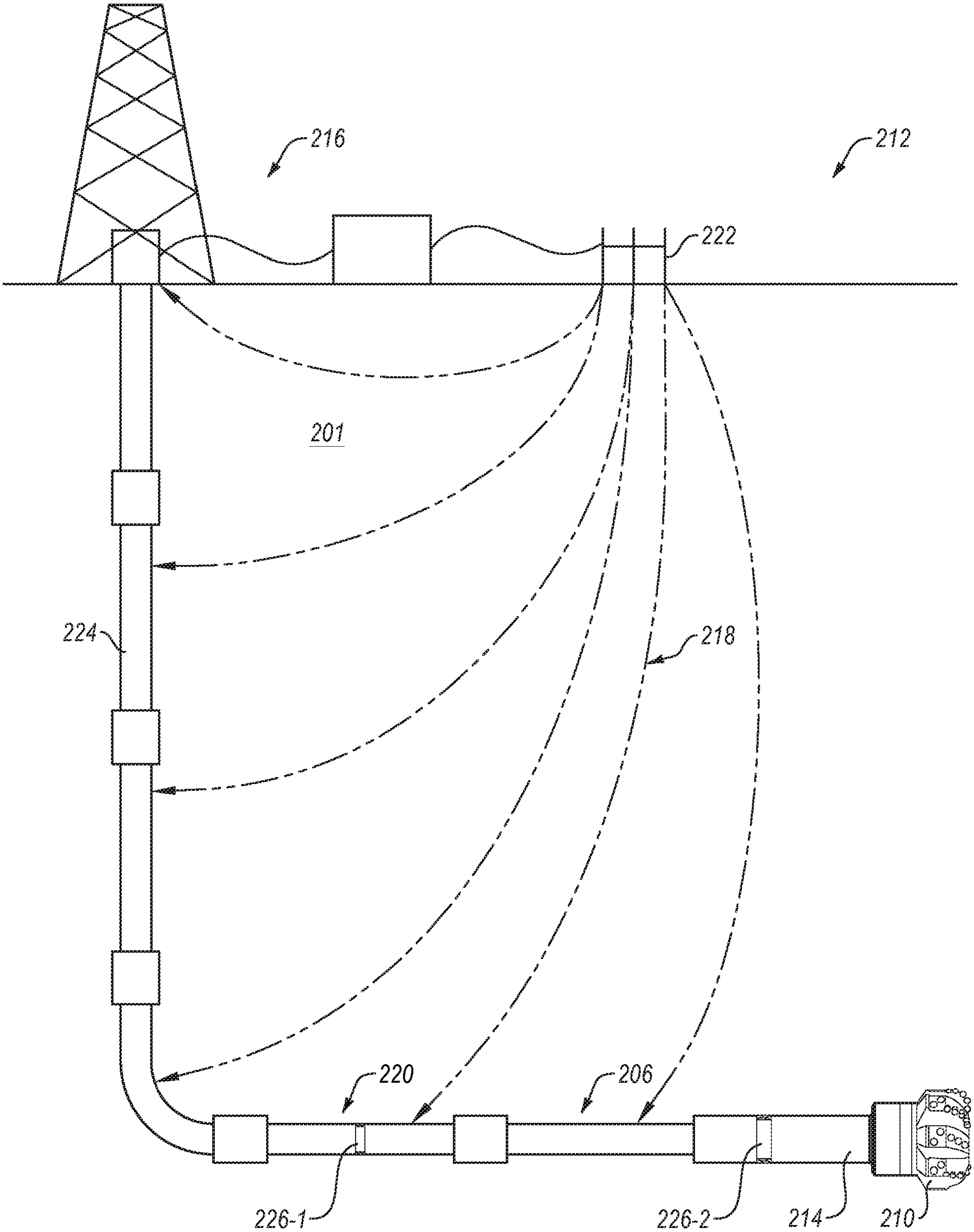

FIG. 2

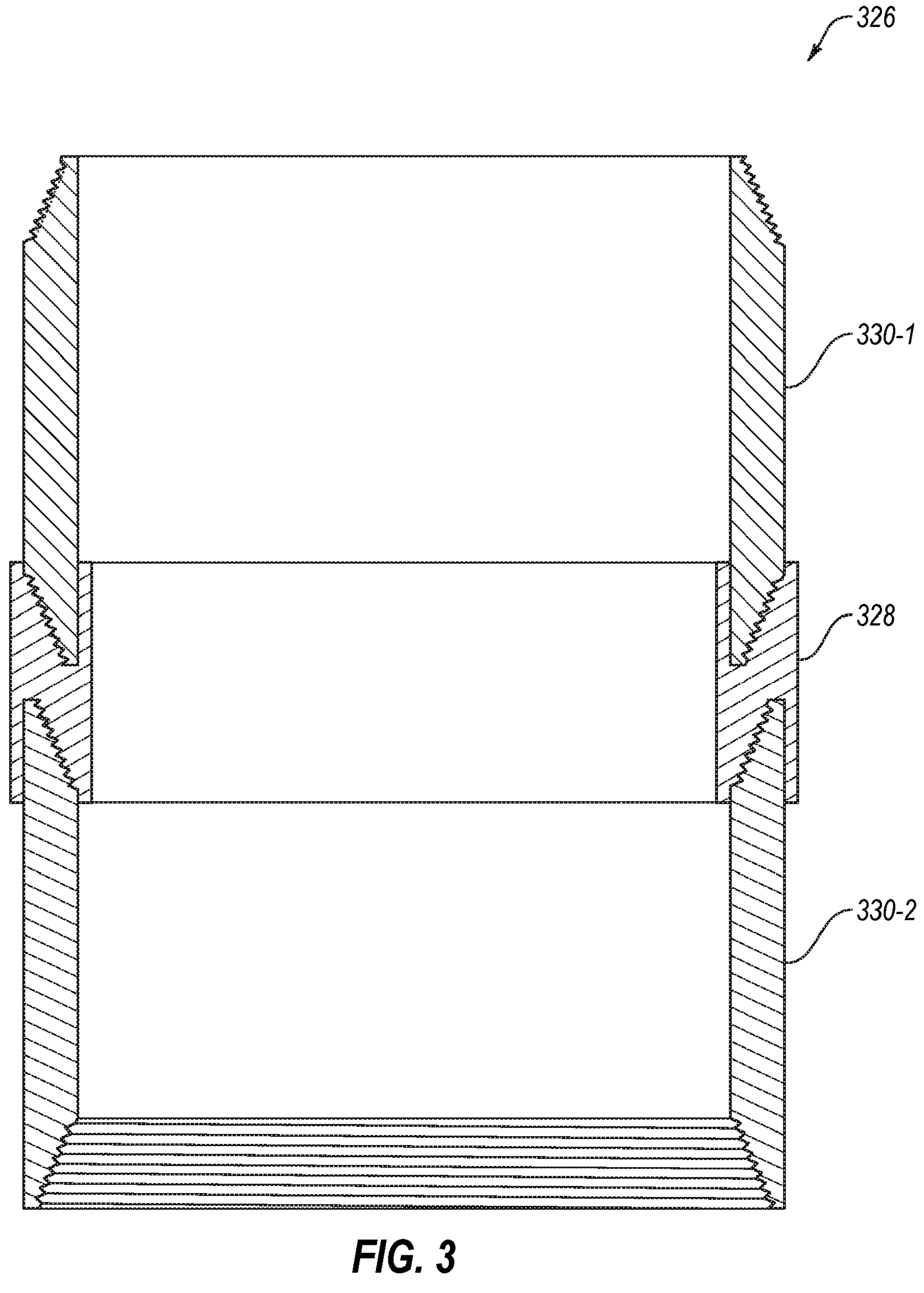

FIG. 3

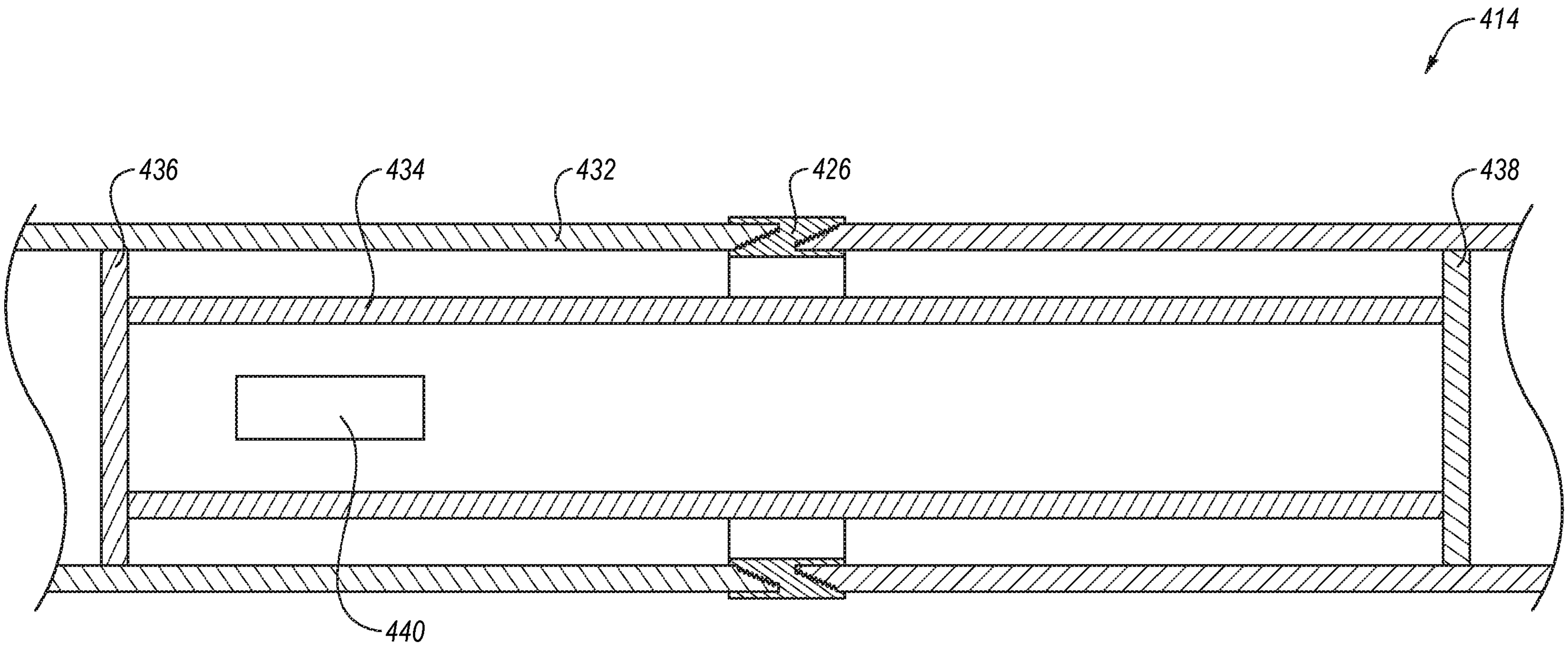

FIG. 4

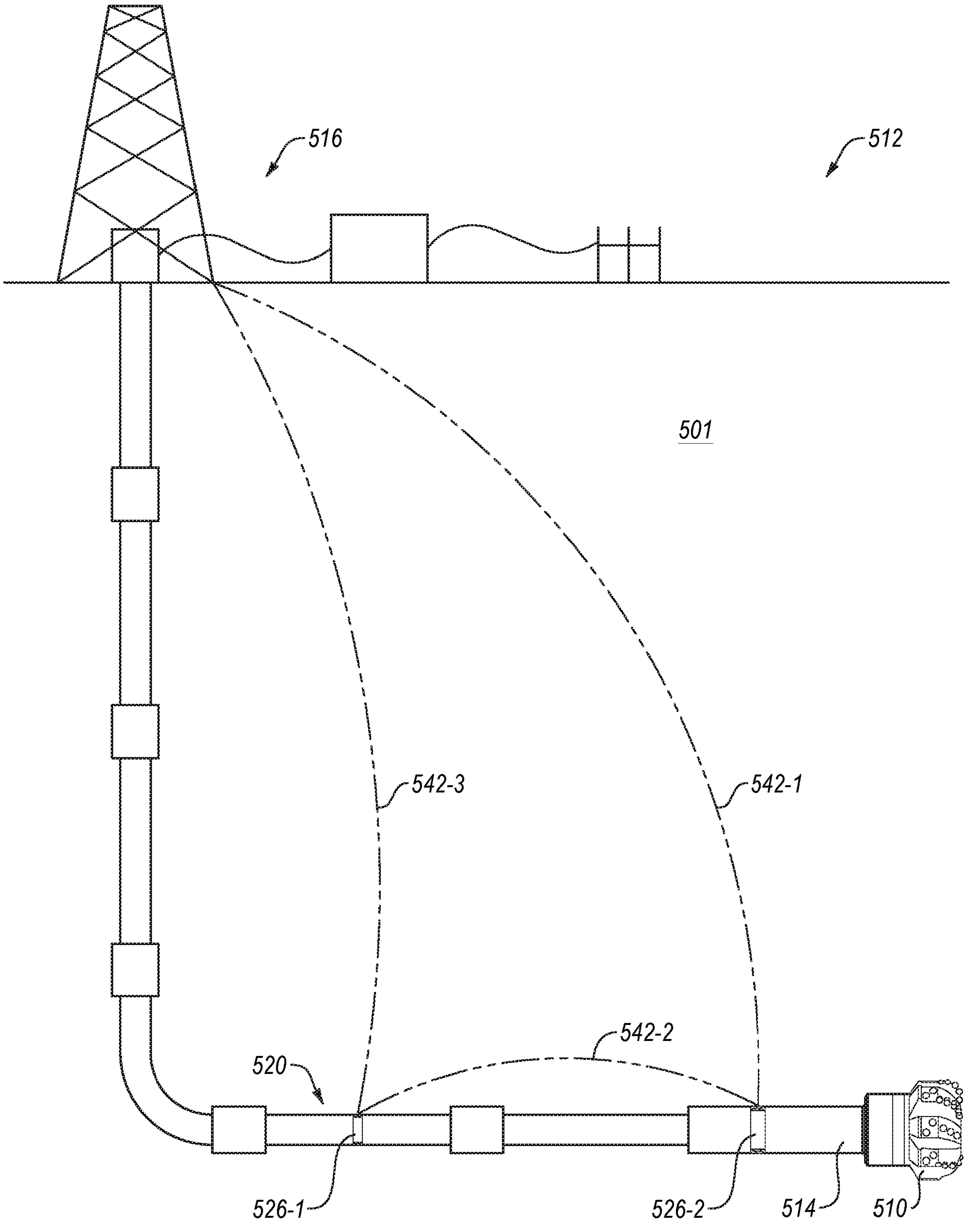

FIG. 5

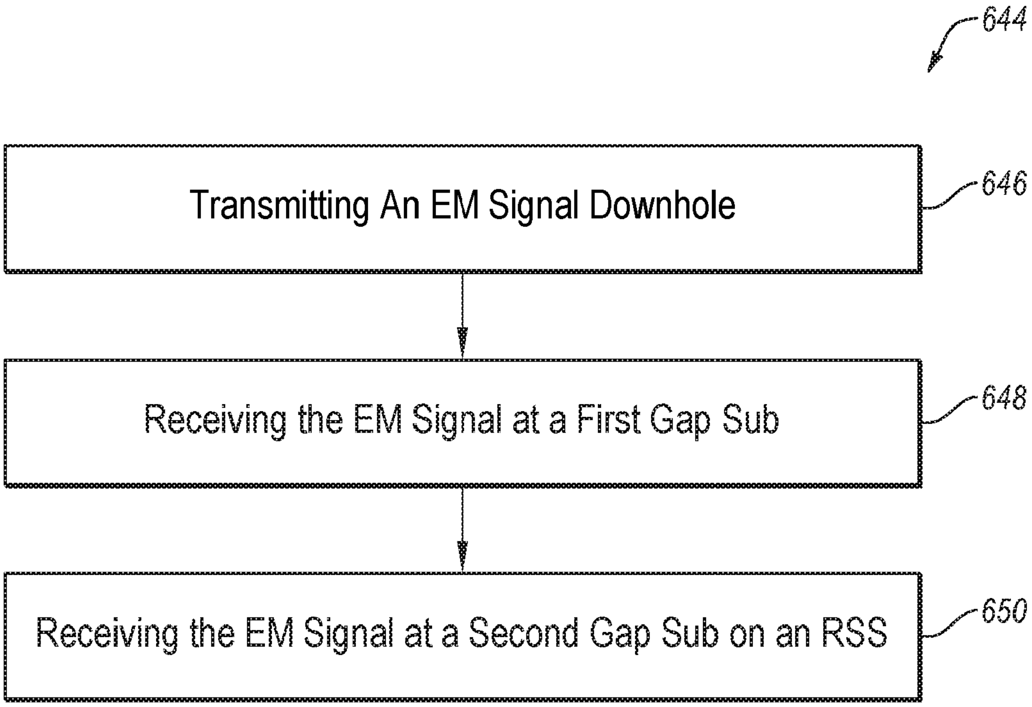
644
Transmitting An EM Signal Downhole
646
Receiving the EM Signal at a First Gap Sub
648
Receiving the EM Signal at a Second Gap Sub on an RSS
650

FIG. 6

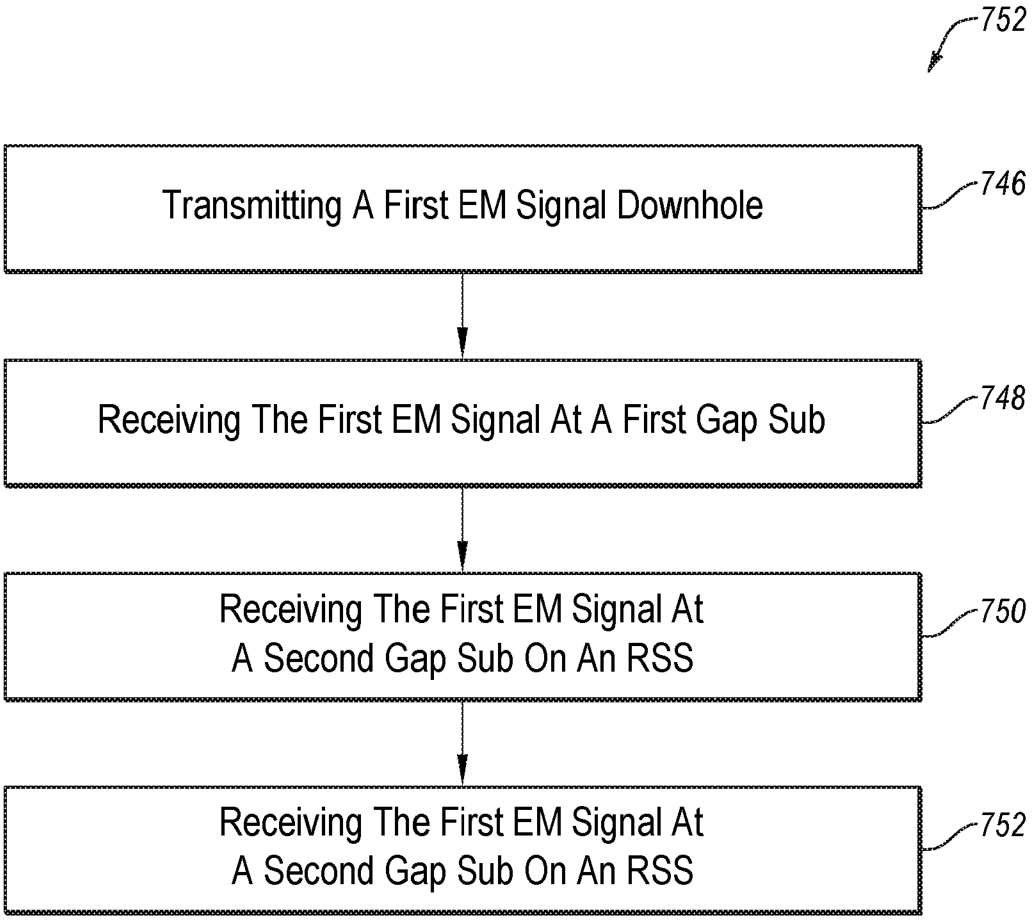
752
Transmitting A First EM Signal Downhole
746
Receiving The First EM Signal At A First Gap Sub
748
Receiving The First EM Signal At A Second Gap Sub On An RSS
750
Receiving The First EM Signal At A Second Gap Sub On An RSS
752

FIG. 7

SYSTEMS AND METHODS FOR DOWNHOLE COMMUNICATION

BACKGROUND OF THE DISCLOSURE

[0001] Downhole drilling systems may include many sensors and/or tools. An operator at the surface may communicate with the tools using a variety of communication methods, including pressure pulses, wired drill pipe, wired communication, wireless communication, electromagnetic downlink, and combinations thereof. Electromagnetic uplink and downlink communication systems transmit an electromagnetic signal through a formation to be received at a downhole location.

SUMMARY

[0002] In one aspect of this invention, a downhole communication system includes a rotary steerable system (RSS). The RSS includes an outer member, an independently rotating inner member, and an electrically insulating gap sub located on the outer member for enabling electromagnetic signals to be received as electric potential across the gap sub.. In some embodiments, the downhole communication system includes two gap subs. The first gap sub is located on the drill string above the RSS, and the second gap sub is located on the RSS.

[0003] In another aspect of this invention, a method for downhole communication includes transmitting an electromagnetic signal downhole from a surface location. An electromagnetic signal is received at a first electrically insulating gap sub, and the electromagnetic signal is received at a second electrically insulating gap sub located at an outer member of an RSS. Each electrically insulating gap sub enables electromagnetic signals to be received as electric potential across the gap sub.

[0004] This summary is not intended to be used as an aid in limiting the scope of the claimed subject matter. Additional features and embodiments of the disclosure will be set forth herein, and in part will be obvious from the description, or may be learned by the practice of such embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] In order to describe the manner in which the above-recited and other features of the disclosure can be obtained, a more particular description will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. For better understanding, the like elements have been designated by like reference numbers throughout the various accompanying figures. While some of the drawings may be schematic or exaggerated representations of concepts, at least some of the drawings may be drawn to scale. Understanding that the drawings depict some example embodiments, the embodiments will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

[0006] FIG. 1 is a schematic representation of a downhole drilling system, according to at least one embodiment of the present disclosure;

[0007] FIG. 2 is a schematic representation of an electromagnetic downlink communication system, according to at least one embodiment of the present disclosure;

[0008] FIG. 3 is a representation of a gap sub, according to at least one embodiment of the present disclosure;

[0009] FIG. 4 is a representation of an RSS, according to at least one embodiment of the present disclosure;

[0010] FIG. 5 is schematic representation of another downhole communication system, according to at least one embodiment of the present disclosure;

[0011] FIG. 6 is a representation of a method for downhole communication, according to at least one embodiment of the present disclosure; and

[0012] FIG. 7 is a representation of another method for downhole communication, according to at least one embodiment of the present disclosure.

DETAILED DESCRIPTION

[0013] This disclosure generally relates to devices, systems, and methods for electromagnetic uplink and/or downlink communication. A downhole communication system includes an electrically insulating gap sub and may include two gap subs. A first gap sub may be located at a communication tool, such as an MWD. A second gap sub may be located at an RSS. An electromagnetic (EM) downlink signal transmitted from the surface may be received at one or both gap subs. For example, the EM signal may be received directly at the RSS. In some examples, the EM signal may be received by the gap sub at the MWD, which may relay the EM signal wirelessly to be received at the gap sub at the RSS. In this manner, the EM signal may be received at the RSS, thereby enabling the surface to communicate with the RSS. Communication with the RSS may allow the RSS to receive direction and/or information from the surface, which may help improve directional drilling of the RSS.

[0014] FIG. 1 shows one example of a drilling system 100 for drilling an earth formation 101 to form a wellbore 102. The drilling system 100 includes a drill rig 103 used to turn a drilling tool assembly 104 which extends downward into the wellbore 102. The drilling tool assembly 104 includes a drill string 105, a bottomhole assembly (BHA) 106, and a bit 110, with the bit 110 attached to the downhole end of drill string 105.

[0015] The drill string 105 includes several joints of drill pipe 108 connected end-to-end through tool joints 109. The drill string 105 transmits drilling fluid through a central bore and transmits rotational power from the drill rig 103 to the BHA 106. In some embodiments, the drill string 105 may further include additional components such as subs, pup joints, etc. The drill pipe 108 provides a hydraulic passage through which drilling fluid is pumped from the surface. The drilling fluid discharges through selected-size nozzles, jets, or other orifices in the bit 110 for the purposes of cooling the bit 110 and cutting structures thereon, and for lifting cuttings out of the wellbore 102 as it is being drilled.

[0016] The BHA 106 may include other components as well as the bit 110. An example BHA 106 may include additional or other components (e.g., coupled between to the drill string 105 and the bit 110). Examples of additional BHA components include drill collars, stabilizers, measurement- while-drilling (MWD) tools, logging-while-drilling (LWD) tools, downhole motors, underreamers, section mills, hydraulic disconnects, jars, vibration or dampening tools, other components, or combinations of the foregoing. The BHA 106 includes an RSS. The RSS includes directional drilling tools that change a direction of the bit 110, and thereby the trajectory of the wellbore. At least a portion of the RSS may maintain a geostationary position relative to an absolute reference frame, such as gravity, magnetic north, and/or true north. Using measurements obtained with the geostationary position, the RSS may locate the bit 110, change the course of the bit 110, and direct the directional drilling tools on a projected trajectory.

[0017] In general, the drilling system 100 may include other drilling components and accessories, such as special valves (e.g., kelly cocks, blowout preventers, and safety valves). Additional components included in the drilling system 100 may be considered a part of the drilling tool assembly 104, the drill string 105, or a part of the BHA 106 depending on their locations in the drilling system 100.

[0018] The bit 110 in the BHA 106 may be any type of bit suitable for degrading downhole materials. For instance, the bit 110 may be a drill bit suitable for drilling the earth formation 101. Example types of drill bits used for drilling earth formations are fixed-cutter or drag bits. In other embodiments, the bit 110 may be a mill used for removing metal, composite, elastomer, other materials downhole, or combinations thereof. For instance, the bit 110 may be used with a whipstock to mill into casing 107 lining the wellbore 102. The bit 110 may also be a junk mill used to mill away tools, plugs, cement, other materials within the wellbore 102, or combinations thereof. Swarf or other cuttings formed by use of a mill may be lifted to surface, or may be allowed to fall downhole.

[0019] FIG. 2 is a schematic representation of a downhole drilling system 212, an embodiment of the present disclosure. The downhole drilling system 212 includes a BHA 206. As well as a drill bit, the BHA 206 may include other downhole tools, such as reamers, mills, casing cutters, other downhole tools, and combinations thereof. In some embodiments, the BHA 206 includes one or more MWD and/or LWD tools. The MWD and/or the LWD may include one or more sensors used to measure borehole and/or BHA properties.

[0020] An operator at a surface location 216 may desire to communicate with the BHA 206. For example, the operator may desire to send instructions to one or more downhole tools of the BHA 206. These instructions may include directions for directional drilling, instructions for a sensor to perform a measurement, instructions to actuate an expandable tool, other downhole instructions, and combinations thereof.

[0021] To communicate with the BHA 206 from the surface, a signal 218 may be sent from the surface location 216 to the BHA 206. Communication methods may include one or more of mud pulse generation, wired electromagnetic communication, wireless electromagnetic communication (e.g., electromagnetic downlink), RFID tags sent through the drilling fluid, drop balls, other communication methods, and combinations thereof. In some embodiments, communication method may communicate at a high bit rate (e.g., greater than 1 bits per section, greater than 3 bits per section, greater than 5 bits per section, greater than 10 bits per section) without wired communication and/or a wired drill pipe. In other words, wireless downhole communication, including non-wired downhole communication, may communicate at a high bit rate.

[0022] In some embodiments, electromagnetic downlink to the BHA 206 may include one or more transmitters 222 on the surface (such as metal stakes driven into the ground). An EM signal 218 may be transmitted into the formation 201 through the transmitters 222and travel through the formation 201. At least a portion of the EM signal 218 may be collected by a length of drill pipe 224 in a wellbore. The EM signal 218 may travel through the length of drill pipe 224 to a gap sub (collectively 226) in the length of drill pipe 224. The gap sub 226 may be located anywhere along the length of drill pipe 224. For example, the gap sub 226 may be located at or near the BHA 206.

[0023] The gap sub 226 includes a section of insulating material (e.g., a material having a high impedance) separating two sections of drill pipe 224. The electric potential across the gap sub 226 may be measured. Because the EM signal 218 travels along the length of the drill pipe 224, the EM signal 218 may be received at the gap sub 226 by recording the electric potential across the gap sub 226. The EM signal 218 may then be demodulated at the BHA 206 and the information encoded in the EM signal 218 retrieved.

[0024] In some embodiments, the downhole drilling system 212 may include a first gap sub 226-1 located at a first location in the BHA 206. For example, the first gap sub 226-1 may be located at an MWD 220. In some examples, the first gap sub 226-1 may be located uphole of the MWD 220 (e.g., further up the length of drill pipe 224 toward the surface location 216). In some embodiments, the MWD 220 may be a communication relay station, that only includes the first gap sub 226-1, a way to measure electric potential across the gap sub, and a communication module, such as an EM generator, a pressure/flow rate pulse generator, or other communication module.

[0025] In some embodiments, the BHA may include an RSS 214. The RSS 214 may be located adjacent to the bit 210. In some embodiments, the RSS 214 may include a second gap sub 226-2. At least a portion of the EM signal 218 may be collected along a second length of drill pipe 225 between the first gap sub 226-1 and the second gap sub 226-2. The second length of drill pipe 225 may include one or more downhole tools of the BHA 206, including the MWD 220, or the casing or collar of the MWD 220. The second length of drill pipe 225 may pick up the EM signal 218. The EM signal 218 may travel through the second length of drill pipe 225 to the second gap sub 226-2. The electrical potential across the second gap sub 226-2 may be measured, and the EM signal 218 may be received and decoded. In this manner, an operator at the surface location 216 may communicate directly with the RSS 214. In this manner, the operator may provide the RSS 214 with directional drilling instructions, survey information, instructions to perform measurements using sensors on the RSS, and other information. As will be discussed herein, in some embodiments, both the first gap sub 226-1 and the second gap sub 226-2 may receive the EM signal 218. In some embodiments, the EM signal 218 may be received at the first gap sub 226-2 and relayed to the RSS 214 using any communication mechanism, including EM downlink, pressure/flow rate pulses, wired communication, and other communication mechanisms.

[0026] FIG. 3 is a representation of a gap sub 326, according to at least one embodiment of the present disclosure. The gap sub 326 includes a resistive layer 328 located between a first drill pipe 330-1 and a second drill pipe 330-2. The first drill pipe 330-1 and the second drill pipe 330-2 are conductive. The EM signal (e.g., EM signal 218 of FIG. 2) may be received as an electric current in one or both of the first drill pipe 330-1 and the second drill pipe 330-2. The electric potential across the resistive layer 328 may be measured, and the information encoded in the EM signal can then be decoded from the electric potential.

[0027] In some embodiments, the resistive layer 328 may be threaded into the one or both of the first drill pipe 330-1 and the second drill pipe 330-2. In some embodiments, the resistive layer 328 may be bonded to one or both of the first drill pipe 330-1 and the second drill pipe 330-2, such as with an adhesive, epoxy, polymer, weld, braze, other bonding mechanism, and combinations thereof. In some embodiments, the resistive layer 328 may be connected to one or both of the first drill pipe 330-1 and the second drill pipe 330-2 with a mechanical fastener, such as a bolt, a screw, or other mechanical fastener. In some embodiments, the resistive layer 328 may be connected to one or both of the first drill pipe 330-1 and the second drill pipe 330-2 with any combination of threads, bonding material, or mechanical fastener.

[0028] FIG. 4 is a representation of an RSS 414, according to at least one embodiment of the present disclosure. The RSS 414 includes an outer member 432 (e.g., a collar, housing) and an inner member 434 (e.g., a control unit). The inner member 434 is rotatable relative to the outer member 432 and may rotate to maintain a geostationary position. For example, the inner member 434 may maintain a rotationally stable position with respect to an external reference, such as the force of gravity, magnetic north, true north, or other external reference.

[0029] The outer member 432 includes a lower gap sub 426. The lower gap sub 426 is made from an insulating material (e.g., a material having a high impedance) such that an electric current may not pass across the lower gap sub 426. By measuring the electric potential across the lower gap sub 426, an EM signal that is picked up by the drill pipe may be received. In this manner, the RSS may receive an EM downlink signal from the surface or other location. This may allow direct and high-speed communication with the RSS (e.g., direct from the surface, direct from an MWD). Direct communication with the RSS may allow an operator at the surface to send instructions to the RSS, such as directional drilling instructions, survey information, instructions to perform a measurement with a sensor, or other instructions. Sending instructions to the RSS may help the RSS to drill on a target trajectory, which may improve the drilling efficiency, thereby lowering drilling costs.

[0030] In the embodiment shown, the lower gap sub 426 is located between the upper connection 436 and the lower connection 438. In this manner, a circuit may be broken from the lower connection 438, across the inner member 434 to the upper connection 436, and across the outer member 432 back to the lower connection 438. Breaking the circuit between the upper connection 436 and the lower connection 438 may allow the outer member 432 to function as an antenna to transmit an electromagnetic signal generated at the inner member. In some embodiments, the lower gap sub 426 may be located halfway between the upper connection 436 and the lower connection 438. In some embodiments, the lower gap sub 426 may be closer to the upper connection 436 or closer to the lower connection 438.

[0031] The inner member 434 may be connected to the outer member 432 with an upper connection 436 and a lower connection 438. It should be understood that references to “upper” and “lower” are not limited to up and down with respect to the gravitational force. Rather, upper and lower may refer to uphole and downhole, respectively. In this manner, the lower connection 438 is further from a surface location than the upper connection 436.

[0032] The upper connection 436 and/or the lower connection 438 may be any type of rotating connection. For clarity, the following discussion will describe the upper connection 436. However, it should be understood that the structures and connections described herein may be similarly applied to the lower connection 438, either in combination with or independently of the upper connection 438. In some embodiments, the upper connection 436 may include a bearing, such as a thrust bearing, a hanger bearing, a radial bearing, any other type of bearing, and combinations thereof.

[0033] In some embodiments, the upper connection 436 includes an electrical connection. For example, the upper connection 436 may include a rotary electrical connection, such as a slip ring or other rotary electrical connection. In this manner, an electrical circuit may be closed between the outer member 432 and the inner member 434. This may allow for communication between the outer member 432 and the inner member 434, or to utilize the outer member 432 as an antenna to transmit signals through a formation.

[0034] In the embodiment shown, the inner member 434 includes an electromagnetic signal generator 440. The electromagnetic signal generator 440 may be configured to conduct current along the inner member 434 that is transferred to the outer member 432 across the upper connection 436 and/or the lower connection 438. The current may be interrupted at the lower gap sub 426, thereby causing the outer member 432 to act as an antenna. In this manner, an EM signal may be generated at the RSS 414 and may transmit information originating at the RSS 414. For example, the EM signal may transmit into the formation, through the wellbore, or otherwise transmit to a surface location or to another gap sub in a downhole drilling assembly.

[0035] In some embodiments, the electromagnetic signal generator 440 may include an antenna. In some embodiments, the electromagnetic signal generator 440 includes an insulated gap along the inner member 434, with a switch that may selectively bridge the gap, thereby closing the circuit. The switch may be located between the upper connection 436 and the lower connection 438. In some embodiments, the switch may be located at the upper connection 436 or the lower connection 438. By opening and closing the switch in a pattern, the pattern including encoded data, a signal may be generated and transmitted from the RSS 414.

[0036] FIG. 5 is a schematic representation of a downhole drilling system 512, according to at least one embodiment of the present disclosure. The downhole drilling system includes a first gap sub 526-1 (e.g., an upper gap sub) located at an MWD 520. A second gap sub 526-2 (e.g., a lower gap sub) is located at an RSS 514. In the embodiment shown, an operator at a surface location 516 may communicate with the RSS 514 and the RSS 514 may communicate to the surface location 516 along a communication path (collectively 542).

[0037] A first communication path 542-1 may be from the surface location 516 to the second gap sub 526-2 at the RSS 514. For example, an EM signal may be generated at the surface location 516 and pass through the formation 501 to be received at the second gap sub 526-2 through EM downlink. In this manner, the operator at the surface location 516 may communicate directly with the RSS 514 via EM downlink, without any intervening communication relays, to provide steering information, instructions, and other information to the RSS 514.

[0038] In some embodiments, the RSS 514 may communicate along the first communication path 542 to the surface location 516. For example, the RSS 514 may include an EM signal generator generating EM signals emitted at the second gap sub 526-2. The EM signals may travel through the formation 501 to the surface location 516 through EM uplink. In this manner, the RSS 514 may communicate directly

CLAIMS

1. A downhole communication system comprising: a rotary steerable system (RSS), the RSS including:

    an outer member;
    an independently rotating inner member;
    an electrically insulating gap sub located on the outer member, for enabling electromagnetic signals to be received as electric potential across the gap sub.

2. The downhole communication system of claim 1, wherein the RSS further includes a circuit between the outer member and the independently rotating inner member.

3. The downhole communication system of claim 2, wherein the RSS further includes an upper connection and a lower connection, the gap sub being located between the upper connection and the lower connection.

4. The downhole communication system of claim 3, wherein at least one of the upper connection or the lower connection is electrically conductive.

5. The downhole communication system of claim 3, wherein the gap sub is located halfway between the upper connection and the lower connection.

6. The downhole communication system of claim 2, wherein the circuit includes a switch.

7. The downhole communication system of claims, wherein the switch is located across at least one of an upper connection or a lower connection of the RSS.

8. A downhole communication system comprising:

a drill string;

a first electrically insulating gap sub located on the drill string for enabling electromagnetic signals to be received as electric potential across the first gap sub; and

a rotary steerable system below the first gap sub on the drill string, wherein the rotary steerable system includes:

an outer member;

an independently rotating inner member and

a second electrically insulating gap sub located on the outer member of the rotary steerable system (RSS) for enabling electromagnetic signals to be received as electric potential across the second gap sub.

9. The downhole communication system of claim 8, wherein the RSS includes an electromagnetic signal generator.

10. The downhole communication system of claim 8, wherein the first gap sub is located on an MWD tool.

11. A method for downhole communication, comprising:

transmitting an electromagnetic signal downhole from a surface location; receiving the electromagnetic signal as electric potential across a first electrically insulating gap sub; and

receiving the electromagnetic signal as electric potential across a second gap sub located at a rotary steerable system (RSS)which includes

an outer member; and

an independently rotating inner member;

with the second gap sub located on the outer member of the rotary steerable system (RSS).

12. The method of claim 11, wherein the electromagnetic signal is a first electromagnetic signal, and further comprising transmitting a second electromagnetic signal from the RSS.

13. The method of claim 12, further comprising receiving the second electromagnetic signal at a surface location.

14. The method of claim 12, further comprising receiving the second electromagnetic signal at the first gap sub.

15. The method of claim 12, further comprising: relaying the second electromagnetic signal; and receiving the relayed second electromagnetic signal at a surface location.

16. The method of claim 12, wherein transmitting the second electromagnetic signal includes applying an electric current to the R SS.

17. The method of claim 12, wherein transmitting the first electromagnetic signal includes transmitting the first electromagnetic signal with a first frequency, and wherein transmitting the second electromagnetic signal includes transmitting the second electromagnetic signal at a second frequency, the second frequency being different from the first frequency.

18. The method of claim 12, wherein transmitting the first electromagnetic signal and transmitting the second electromagnetic signal occur at the same time.

19. The method of claim 12, wherein transmitting the first electromagnetic signal and transmitting the second electromagnetic signal occur at different times.