HARD-MOUNTED EM TELMETRY SYSTEM FOR MWD TOOL IN BOTTOM HOLE ASSEMBLY

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ABSTRACT

An MWD apparatus has a bottomhole assembly for supporting a tool string and an antenna. The tool string has a sensor and an electromagnetic telemetry device. The tool string affixes in a muleshoe and carrier sub of the assembly using a stinger and fastener. An antenna disposes in an emitter sub of the assembly. The antenna is attached to extend from the tool string so the antenna is in electrical communication with the telemetry device. Finally, the portions of the assembly are connected together, and the antenna is affixed in the uphole portion of the assembly using a conductive landing and one or more fasteners. In this way, the tool string and the antenna are held in tension inside the assembly. The MWD apparatus can be used with an air drilling assembly having an air hammer and a motor coupled downhole of the apparatus. Non-magnetic and regular drill collars can couple uphole of the apparatus, along with a jet sub.
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BACKGROUND OF THE DISCLOSURE

[0001] FIG. 1 illustrates an electromagnetic (EM) telemetry system 40 for a Measurement-While-Drilling (MWD) tool 50 used with a drilling system 20. The MWD tool 50 is deployed in a bottom hole assembly 30 on a drill string 24 from a rig 22 at the surface. The MWD tool 50 obtains various measurements as the bottom hole assembly 30 advances a borehole 12 in the subsurface formation 10. To communicate with the MWD tool 50 during drilling, the EM telemetry system 40 uses a surface antenna 42 and a transceiver 44 to detect current in bi-directional communications with an emitting antenna 60 of a downhole transceiver 45 of the MWD tool 50.

[0002] The EM telemetry system 40 can be similar to Weatherford’s EMpulse electromagnetic (EM) measurement-while-drilling (MWD) system. Overall, the EM telemetry system 40 allows operators to drill and survey the borehole 12 independent of the rig hydraulics. For example, by using EM telemetry rather than mud pulse telemetry, the pumps at the rig 22 do not need to be cycled to communicate with the MWD tool 50 in the borehole 12. This can make the drilling operation more efficient.

[0003] The downhole transceiver 45 of the EM telemetry system 40 is a sonde-based design configured for use in non-magnetic drillstring tubulars to provide two-way communication between the surface and the MWD tool 50 downhole. Operators can communicate instructions to the downhole instrumentation while drilling proceeds, and both uplink and downlink communications are completely independent of rig or drilling activity. Survey data can be obtained with the MWD tool 50 while the drillstring 22 is stationary for a short period of time to reduce the possibility of differential sticking or hole sloughing that can result from extended periods without circulation or pipe movement. Because the system 40 is independent of drilling hydraulics, there is no lag time or need to cycle the pumps for synchronization purposes when survey data is being transmitted.

[0004] In some implementations, the system’s antenna 60 along with the electronics of the MWD tool 50 can be retrieved from the bottom hole assembly 30 using fishing and other techniques. In other implementations, these components may not be retrievable via wireline or the like.

[0005] During use, the MWD tool 50 and the downhole transceiver 45 are typically powered by batteries. Up to 12 pump information, the downhole transceiver 45 uses the emitting antenna 60 to inject signals into the formation 10. The signals propagate to the surface, and the surface transceiver 44 receives the signal for decoding by data acquisition systems. As shown, the transceiver 44 can be coupled to the wellhead at the rig 22 and coupled to a ground antenna 42, creating two electrodes of a dipole antenna.

[0006] Various types of measurement equipment can be used on the MWD tool 50. For example, the tool 50 can include a gamma ray probe to measure gamma radiation in the borehole. The tool 50 can include an annular pressure sensor to measure downhole pressure conditions. The gamma ray probe and the pressure sensor can be mounted directly above the bit on the bottom hole assembly 30 to provide real-time inclination and gamma ray data near the bit. The oriented gamma ray sensor provides high-side and low-side gamma measurements while rotating. An inclination sonde can measure inclination close to the bit and can measure inclination-on-the-fly while sliding and rotating.

[0007] Given the various forms of measurements that can be obtained, various types of information can be transmitted from the MWD tool 50 to the surface in real-time, including: directional surveys, annulus pressure, total gamma ray, oriented gamma ray, inclination closer to the bit, inclination and gamma at bit, etc. For example, the EM telemetry system 40 can transmit the toolface, inclination, azimuth, gamma ray, and annulus-pressure data while drilling sections of the borehole 12. Because the rig’s mud system does not interfere with the functioning of the MWD tool 50, the MWD tool 50 can operate continuously during all drilling activities, even when the rig 22 makes drill pipe connections.

[0008] FIG. 2A illustrates an MWD tool 50 and elastic cable antenna 60 of an EM telemetry system according to the prior art disposed in portion of a bottom hole assembly 30. The MWD tool 50 is disposed in a tool carrier 34, which has one or more tubulars. The antenna 60 extends from the MWD tool 50 and positions in an emitter sub 32 of the assembly 30.

[0009] The MWD tool 50 can mount in the bottom hole assembly 30 in a number of ways. For example, FIGS. 2A and 2B illustrate a stinger-mounted configuration of the MWD tool 50 according to the prior art. As shown, the MWD tool 50 includes a communication section 52 (e.g., EM transceiver), a battery section 54, and various other detection sections 56 (e.g., vibration sensors, gamma ray sensors, bore/annular pressure sensors, directional sensors, etc.). A stinger 58 at the downhole end of the tool 50 is used for stinging into a muleshoe sub 38 of the bottom hole assembly 30. The antenna 60 installs at the uphole end of the MWD tool 50 for positioning in the emitter sub 32, as noted above.

[0010] In FIG. 2C, the MWD tool 50 uses a top-hanger configuration to install in the bottom hole assembly (30). Here, the MWD tool 50 includes a landing collar 59 for supporting the tool 50 in the bottom hole assembly (30). Therefore, the downhole end of the MWD tool 50 lacks a stinger (58) and does not position in a muleshoe sub (32).

[0011] FIGS. 3A-3B illustrates the elastic cable antenna 60 according to the prior art in assembled and disassembled states. The elastic antenna 60 includes a rod 62 having a protective sleeve thereabout. A coupling 64 and centralizer 55 are installed on the downhole end of the rod 62 and connect the antenna 60 to an uphole end of the MWD tool 50. A coupling 66 on the uphole end of the rod 62 has a cable head 65 and a fishing head 68a installed thereon. The cable head 65 is used to make electromagnetic contact of the rod 62 with the tubular wall of the emitter sub (32: FIG. 2A), and the fishing head 68a is used for deploying and/or retrieving the MWD tool 50 and antenna 60 with wireline or the like.

[0012] Although existing configurations of MWD tools and antennas for EM telemetry system are effective, operators seek to use EM telemetry in harsher drilling conditions and in more diverse drilling operations. The subject matter of the present disclosure is directed to overcoming, or at least reducing the effects of, one or more of the problems set forth above.

SUMMARY OF THE DISCLOSURE

[0013] A measurement-while-drilling apparatus has a bottom hole assembly, a tool string, and an antenna. The tool string is engaged in a first end or downhole portion of the bottomhole assembly. The tool string has at least one sensor
and has an electromagnetic telemetry device in electrical communication with the at least one sensor.

[0014] The at least one sensor of the tool string can be a vibration sensor, a gamma ray sensor, a bore/annular pressure sensor, a directional sensor, etc. The electromagnetic telemetry device is preferably an electromagnetic telemetry transceiver configured to send and receive electromagnetic telemetry signals. The first end or downhole portion of the bottomhole assembly can include a tool carrier having a muleshoe sub disposed thereon. A downhole component, such as a stinger on the tool string, can engage in the muleshoe sub and can be held therein using a fastener, a pin, a key, a lock, or the like.

[0015] The antenna extends in the bottom hole assembly from the tool string and is in electrical communication with the electromagnetic telemetry device. A conductive landing affixed to the antenna is engaged in a second end or uphole portion of the bottomhole assembly. The landing in conjunction with the downhole component holds the tool string and the antenna in tension inside the bottomhole assembly.

[0016] In one implementation, the antenna includes a conductive rod in electrical communication with the electromagnetic telemetry device. The conductive landing is disposed on an uphole threaded end of the antenna and is held in place against the second end with one or more threaded fasteners.

[0017] The bottomhole assembly can include an emitter sub at least partially holding the antenna therein. The conductive landing can engage against a shoulder in the emitter sub. The conductive rod can have non-conductive centralizers disposed thereon and centralizing the conductive rod inside the bottomhole assembly. The conductive rod can also have a plurality of non-conductive sleeves disposed thereon.

[0018] The foregoing summary is not intended to summarize each potential embodiment or every aspect of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. 1 illustrates an electromagnetic (EM) telemetry system for a Measurement-While-Drilling (MWD) tool used in a drilling assembly.

[0020] FIG. 2A illustrates an MWD tool with an EM antenna according to the prior art disposed in tubulars of a drilling assembly.

[0021] FIG. 2B illustrates a stinger-mounted configuration of an MWD tool with an EM antenna according to the prior art.

[0022] FIG. 2C illustrates a top-hanger configuration of an MWD tool with an EM antenna according to the prior art.

[0023] FIGS. 3A-3B illustrates an EM antenna according to the prior art in assembled and disassembled states.

[0024] FIG. 4A illustrates a drilling assembly according to the present disclosure having an air hammer bit, a drilling motor, an MWD assembly, and a jet sub.

[0025] FIG. 4B schematically illustrates an MWD tool and a hard-mounted EM antenna incorporated into the drilling assembly of FIG. 4A.

[0026] FIGS. 4C-1 and 4C-2 illustrate an embodiment of an MWD tool and a hard-mounted EM antenna according to the present disclosure for positioning in tubular members of the disclosed drilling assembly.

[0027] FIG. 4D illustrates a cross-sectional view of a stinger with a muleshoe disposed in a UBHO sub of the disclosed drilling assembly.

[0028] FIG. 4E illustrates a perspective view of a stinger bolt insert for the disclosed drilling assembly.

[0029] FIGS. 4F-4G illustrate an embodiment of a jet sub for the disclosed drilling assembly in side and end views, respectively.

[0030] FIGS. 5A-5B illustrate a perspective view and an elevational view of the hard-mounted EM antenna according to the present disclosure.

[0031] FIGS. 6A-6B illustrate an extension for the hard-mounted EM antenna according to the present disclosure in assembled and disassembled states.

[0032] FIG. 7 illustrates the hard-mounted EM antenna according to the present disclosure in a disassembled state.

[0033] FIG. 8A illustrates a conductive landing of the EM antenna.

[0034] FIG. 8B illustrates a cross-sectional view of the conductive landing disposed against a landing shoulder in the emitter sub.

[0035] FIG. 8C illustrates a side view of a buffer element for use with the conductive landing.

[0036] FIGS. 9A-9C illustrate a bottom centralizer for the EM antenna in assembled, disassembled, and cross-sectional views.

[0037] FIGS. 10A-100 illustrate a top centralizer for the EM antenna in assembled, disassembled, and cross-sectional views.

[0038] FIGS. 11A-11C illustrate perspective, side, and end views of a centralizer for use with the MWD tool.

[0039] FIG. 12A illustrates an end-section of a rotor and a stator for the mud motor of the drilling system.

[0040] FIG. 12B illustrates portion of the mud motor adapted for air drilling according to the present disclosure.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0041] FIG. 4A illustrates a drilling assembly 100 according to the present disclosure having an air hammer bit 101, a drilling motor 102, an electromagnetic (EM) MWD assembly 104, and a jet sub 108. FIG. 4B schematically illustrates the drilling assembly 100 of FIG. 4A showing an MWD tool 150 and a hard-mounted antenna 170 incorporated into the EM MWD assembly 104.

[0042] The air hammer 101 couples to the drilling motor 102 that is adapted for air drilling, and the drilling motor 102 couples with a shock sub 103 to the MWD assembly 104. A non-magnetic pony collar (not shown) may be used to connect the MWD assembly 104 to the shock sub 103. The MWD assembly 104 includes a mule shoe sub 110, such as a universal bottom hole orientation (UBHO) sub for supporting the MWD tool 150. A double pin connector 105 connects a tool carrier 120 to the UBHO sub 110, and an emitter sub 130 is coupled to the tool carrier 120. As best shown in FIG. 4B, the MWD tool 150 is supported in the tool carrier 120 and the EM antenna 170 extends into the emitter sub 130.

[0043] Disposed above the emitter sub 130, the drilling assembly 100 includes a non-magnetic drill collar 106 followed by conventional drill collars 107A and cross-over subs 107B. Finally, the assembly 100 includes the jet sub 108 coupled above the drilling collars 107A, and a heavy weight drillpipe (HWPD) section 109 connects the jet sub 108 to a length of drillpipe 22. In general, the jet sub 108 can be positioned practically any distance from the other downhole components and still achieve its purposes.
0044) The drilling assembly 100 can be used in directional drilling. To do this, directional measurements and other information obtained with the MWD tool 150 can be used to direct the drilling. The mud motor 102 can impart rotation to the air hammer 101 and can include a bent sub or housing with a preconfiguring bend. In this way, a combination of rotation and sliding of the drilling assembly 100 can be used in conjunction with the bent sub of the mud motor 102 to achieve directional drilling.

0045) Drilling with air requires a number of considerations because vibration and air surging issues can cause damage and may cause the MWD tool 105, the antenna 170, or other components to fail. Therefore, the drilling assembly 100 and the process employed during drilling attempt to reduce vibration and prevent over-spinning of the motor 102. During the drilling operations, for example, staging the drilling air “on” and “off” for the string is necessary, and all air must be turned off if the drilling assembly 100 is “off bottom” for extended amounts of time. The motor 102 is kept “on bottom” as much as possible to reduce vibration and to reduce over-spinning of the hammer 101. String floats can be used to keep pressure trapped within drillstring 22 to reduce surge effects against the MWD tool 150 and the motor 102. String floats can also reduce blow down time while bleeding air off when making connections between sections of the drillstring.

0046) To reduce the motor speed, the jet sub 108 disposed above the motor 102 diverts drilling air to the borehole. Not only does this aid in moving material in the annulus away from the drilling assembly 100, but the jet sub 108 is configured to limit the air delivered to the drilling motor 102. In general, the drilling motor 102 preferably rotates at less than 120 RPM. These considerations help reduce excessive vibration and over spinning of the motor 102.

0047) As shown in FIG. 4B, the MWD tool 150 is supported inside the tool carrier 120, and the EM antenna 170 coupled to the MWD tool 150 extends into the emitter sub 130. A distal end of the MWD tool 150 has a stinger 158 supported in the UBHO sub 110, and a proximal end of the antenna 170 having a conductive landing 180 is supported in the emitter sub 130. The end-to-end support of the MWD tool 150 and the antenna 170 is used to hold the MWD tool 150 and the antenna 170 in tension so they can withstand the detrimental conditions, vibrations, and the like associated with air drilling.

0048) To properly support the assembly 104, the MWD tool 150 and the antenna 170 are seated within tight tolerances and configured with suitable tension. To configure the tension, consideration is given to any axial changes, such as the compression, experienced by the drilling assembly 100 during drilling operations. In general, the axial distance between the support of the stinger 158 in the UBHO sub 110 and the support of the landing 180 in the emitter sub 110 may change during operation so that the static length of the MWD tool 150 and the antenna 170 and the fixation of the stinger 158 and the landing 180 are configured to accommodate or account for expected changes in the axial distance during operations.

0049) Turning to FIGS. 4C-1 and 4C-2, an embodiment of the MWD tool 150, an extension 160, and the hard-mounted antenna 170 according to the present disclosure is illustrated. In FIG. 4C-1, the MWD tool 150, the extension 160, and the hard-mounted antenna 170 are shown next to the UBHO sub 110, the tool carrier 120, and the emitter sub 130 for the disclosed MWD assembly 104. In FIG. 4C-2, the MWD tool 150, the extension 160, and the hard-mounted antenna 170 are shown with their separate components, connectors, couplings, etc.

0050) As already indicated, the MWD tool 150 positions in the tool carrier 120. As shown in FIG. 4C-1, for example, the MWD tool 150 includes an electromagnetic telemetry device 152, which can be a transceiver for sending and receiving data. The EM telemetry device 152 is in electrical communication with one or more MWD sensors 156 of the MWD tool 150. In general, the MWD tool 150 can include a battery section 154, gamma section, annular pressure sensor, centralizers 155, and other sensor sections commonly used. Typically, several centralizers 155 are used on the MWD tool 150 to support it in the tool carrier 120. As shown in FIG. 4C-2, some elongated centralizers 200, described in more detail below, can be used on the MWD tool 150.

0051) As already indicated, the antenna 170 positions in the emitter sub 130 of the MWD assembly 104 and is supported by several centralizers 178, e.g. The antenna 170 extends from the MWD tool 150 inside the assembly 104 and is in electrical communication with the EM telemetry device 152. As shown in FIG. 4C-2 of the MWD tool 150, and can extend beyond the tool carrier 120 for connection to the antenna 170. Use of the extension 160 may facilitate assembly, but may not be necessary in every implementation.

0052) The tool’s stinger 158 affixes in the UBHO sub 110 with one or more fasteners, such as stinger bolts, to hold the MWD tool 150 at the downhole end. On the opposite end of the assembly 104, the conductive landing 180 on the uphole end of the antenna 170 secures firmly in the emitter sub 130. Securing the MWD tool 150 and the EM antenna 170 with the stinger 158 at one end and with the landing 180 at the opposite end allows the entire configuration to be held in tension inside the MWD assembly 104. Being held secure in tension inside the MWD assembly 104 allows the MWD tool 150 and the antenna 170 to be used in harsher environments than conventionally permitted.

0053) For example, the MWD assembly 104 can be used with the percussion air hammer (101: FIG. 4A-4B) on the end of the drilling assembly 100 to drill an advancing borehole. In general, the percussion air hammer (101) requires a low weight-on-bit to ensure that the hammer (101) is in contact with the face of the formation, and the string rotation in hammer drilling is slower than conventionally practiced and can be between 20 to 45 rpm. However, the communicated air required for drilling with the hammer (101) creates a high vibration environment that can be harmful to the MWD tool 150 and the EM antenna 170. The stabilized nature of the disclosed MWD assembly 104 can thereby allow the MWD tool 150 and the EM antenna 170 to withstand harsher conditions.

0054) In addition to being held in tension, the MWD tool 150 and the antenna 170 can be centralized in the MWD assembly 104 to protect the MWD tool 150 and the antenna 170 from damage. For example, the sections (e.g., battery, gamma, and CDS/HTC) of the MWD tool 150 can be supported with centralizers 155, which are preferably composed of rubber or the like for electrical isolation. Similarly, sections of the antenna 170 can be supported with centralizers, as discussed below.

0055) As noted above, the stinger 158 of the MWD tool 150 stings into the UBHO sub 110 and affixes in the UBHO sub 110 with one or more fasteners (e.g., stinger bolts), locks,
keys, or the like. For example, FIG. 4D illustrates a portion of such a stinger 158 with a muleshoe 157 disposed in a UHB100 sub 110, which is shown in cross-section. As is typical, the UHB100 sub 110 has a sleeve 114 affixed in the sub’s bore 112 with pins 116 and has an alignment key 117 for engaging in a slot of the muleshoe 157 on the stinger 158. The muleshoe 157 and key 117 help keep the MWD tool 150 in a predetermined orientation relative to the other components of the assembly.

One or more stinger bolts 118 affix the stinger 158 in the UHB100 sub 110. The bolts 118 can be positioned just about anywhere on the stinger 158. Preferably, a stinger bolt insert 159 is used with the stinger bolt 118. FIG. 4E shows a perspective view of such a stinger bolt insert 159. The insert 159 is a grommet composed of a suitable elastomer to help dampen vibration experienced by the MWD tool 150.

FIGS. 4F-4G illustrate a portion of a jet sub 230 for the disclosed drilling assembly 100 in side and end views, respectively. The jet sub 230 is a drill collar of an acceptable length (e.g., about 30-ft). An arrangement of upwardly angled ports 234 communicates the sub’s bore 232 outside the jet sub 230. These ports 234 can be arranged around the circumference of the sub 230 at certain angular displacements (e.g., every 90-degrees), and the ports 234 may be staggered axially along the length of the sub 230. The ports 234 have threads 236 formed therein to receive nozzles, valves, or other components (not shown) to control the flow of air from the ports 234 into the surrounding annulus. The ports 234 may be clustered together anywhere along the length of the sub 230, such as toward the upstream end, the middle, or the downstream end (as shown).

Discussion now turns to more details of the hard-mounted antenna 170 and related components. In particular, FIGS. 5A-5B illustrate the hard-mounted antenna 170 and the extension 160 of the present disclosure in isolated detail. FIGS. 6A-6B illustrate the extension 160 in assembled and disassembled states, and FIG. 7 illustrates the hard-mounted antenna 170 in an exploded view.

As best shown in FIGS. 6A-6B, the extension 160 includes a conductive rod 162, a rod protector 165, a tandem connector 166, and a centralizer 168. To assemble the extension 160, the tandem connector 166 threads to a first end 164a of the rod 162 and is torqued tight. The rod protector 165, which can be a fiberglass sleeve, installs over the conductive rod 162 and engages O-rings 167 installed on the connector 166. The centralizer 168 is then installed on the other end 164b of the rod 162 and is secured with a distance 169 threaded to the rod 162.

In general, the extension 160 can be about 36-in. long. As will be discussed below, the extension 160 allows operators to perform pre-job testing, and other configurations may not require the use of such an extension 160. Either way, the extension 160 in its assembled state can be transported to a field location in one piece.

As best shown in FIG. 7, the antenna 170 includes a conductive rod 172, rod protectors 175a-b, centralizer support 176a-c, centralizers 178a-c, and a conductive landing 180. In general, the antenna 170 can be about 116-in. long. Moreover, more or less centralizers 178a-c can be used depending on the implementation.

To assemble the antenna 170, the bottom centralizer 178a attaches to the downhole end 174a of the rod 172. Support components 176a-b are joined together and are threaded on the inside to connect to the threaded end 174a of the rod 172. The bottom centralizer 178a is slipped over the support components 176a-b and is retained by an insulating nut 179a. FIGS. 9A-9C illustrate various views of the bottom centralizer 178a for the antenna 170.

After installing the bottom centralizer 178a, the lower protector 175a (e.g., fiberglass sleeve) is positioned on the rod 172, and the mid-span centralizer 178b is installed. In particular, the mid-span support components 176a-b are assembled in a similar fashion to the bottom support components, but they are not threaded to the rod 172. Instead, the support components 176a-b slide on the rod 172, and the mid-span centralizer 178b is positioned on the support components 176a-b and is held by a nut 179a.

The second protector 175b is installed on the rod 172 and can be secured with an epoxy. Finally, the top centralizer 178c is then installed on the rod 172. (FIGS. 10A-100 illustrate various views of the top centralizer 178c for the antenna 170.) The top centralizer 178c fits on the smooth surface of a top support 176c and is secured with locking nuts 179b. The support 176c has threads inside that thread onto the upstream end 174b of the rod 172. The antenna 170 in this assembled state can be transported to a field location in one piece.

In the field, the drilling assembly 100 is assembled for use. Initially, the MWD tool 150 has the extension 160 installed thereon, and operators test and program the MWD tool 150 for use. Once the downhole components (air hammer 101, motor 102, UHB100 sub 110, and tool carrier 120) of the drilling assembly 100 are installed at the rig, the MWD tool 150, the extension 160, and the antenna 170 can be installed. Then, the remainder of the drilling assembly 100 can be assembled.

With the UHB100 sub 110 and the tool carrier 120 held at the rig, the MWD tool 150 is picked up and stabbed into the tool carrier 120 by positioning the tool’s stinger 158 in the UHB100 sub 110 and securing it with a stinger bolt 118. At this point, the extension 160 extends beyond the tool carrier 120 and allows operators to continue testing and programming as needed.

Once these steps are completed, the threaded end 174a of the antenna 170 inserts into the emitter sub 130, and the emitter sub 130 is lifted and positioned over the tool carrier 120. The connection between the antenna 170 and the extension 160 is then made.

The top centralizer 178c is installed on the antenna’s rod 172 and tightened down with a retaining nut. All the other centralizers 178a-b have been previously installed. The emitter sub 130 is then made up to the tool carrier 120. Once the emitter sub 130 is screwed to the tool carrier 120, the assembly is lowered, and slips are set on the emitter sub 130 to hold it at the rig.

At the upstream end of the emitter sub 130, operators slip the conductive landing 180 over the threaded end 174b of the rod 172 and seat the landing 180 flush within the emitter sub’s bore back. A first nut 189a threads onto the threaded end 174b of the rod 172 and tightens against the landing 180. Then, a second nut 189b threads on the rod 172 and is tightened against the first nut 189a. A buffer 190 then installs above the landing 180 and will abut against the pin end of the non-magnetic collar 106 when made up to the end of the emitter sub 106.

Once assembly is complete, the MWD tool 150 is held firmly at its downhole end at the UHB100 sub 110 (e.g., by means of the locking pin 118 attached to the stinger 158).
the uphole end, the antenna 170 affixed to the MWD tool 150 by the extension 160 is held by the conductive landing 180 firmly screwed to the contact rod 172 connected to the MWD tool 150. The landing 180 contacts a shoulder in the emitter sub 130. This setup allows for EM telemetry to be conducted under the most adverse drilling conditions, including air/mist operations when the air hammer (101) and the motor (102) are used on the end of the drilling assembly 100 for drilling.

[0071] FIG. 8A illustrates the conductive landing 180 of the antenna (170). FIG. 83 illustrates a cross-sectional view of the landing 180 disposed against a mounting shoulder 138 in the emitter sub 130. The landing 180 includes an outer ring 186 disposed about an inner tubular body 182 that fits onto the conductive rod (172). The inside passage 183 of the inner tubular body 182 is preferably not threaded, although it could be.

[0072] One or more cross members 184 connect the tubular body 182 to the surrounding outer ring 186 and form gaps or passages for the flow of fluid (e.g., air) through the landing 180 to other parts of the drilling assembly. The end 188 of the outer ring 186 is preferably beveled or contoured so that the landing 180 centers against the emitter sub’s landing shoulder 138, which is also preferably beveled or contoured in a complementary manner.

[0073] FIG. 8C illustrates an example of the buffer 190 for positioning against the top of the landing 180. The buffer 190 includes alternating layers of metal (e.g., copper) 196 and elastomer 198. The lower end 192 rests against the top of the landing 180, and the upper end 194 is engaged by and abuts against the pin end (not shown) of the non-magnetic drill collar (106) that threads to the box end of the emitter sub 130 so that the buffer 190 sits sandwiched therebetween.

[0074] The MWD tool 150 can be stabilized in the tool carrier 120 using conventional types of centralizers. Alternatively, the MWD tool 150 can be stabilized using another form of centralizer. Turning to FIGS. 11A-11C, an alternative centralizer 200 for use with the MWD tool (150) is shown in perspective, side, and end views. The centralizer 200 has collet ends 210 and a centralizer body 220. The collet ends 210 include bottom collets 212 that connect to the centralizer body 220 and the housing (not shown) on which the centralizer 200 positions. The collet ends 210 also include top collets 214 that thread onto the bottom collets 212 to grip the centrally-positioned housing (not shown). Holes for fasteners are provided on the collet ends 210 to affix in place.

[0075] As best shown in FIG. 11C, the centralizer 200 defines a central opening through which the housing (not shown) positions. Fins 224 of the centralizer 220 do not extend perpendicular to the axis of the centralizer 200. Instead, the fins 224 tend to orient tangential to the central portion of the centralizer 200. In this way, the fins 224 do not tend to directly transmit force to the central portion of the centralizer 200 and any housing, tool, or other component centrally supported by the centralizer 200.

[0076] Features of the centralizer 200 of FIGS. 11A-11C can also be used for the centralizers of the antenna (178) and extension (160). The centralizer body 220 of the centralizer 200 as well as the other centralizers (168, 178-re) are preferably composed of an elastomer suitable for use with air, gas, or the like. The elastomer preferably avoids explosive decompression due to entrained air. In one embodiment, the elastomer can be an Extended Carboxylated Nitrile (XNBR). This nitrile rubber is resistant to oil and solvent and has poor electrical properties similar to conventional nitrile rubber; however, the preferred nitrile rubber includes an additive that aids in “off gassing” during decompression in high pressure applications.

[0077] The mud motor 102 has a number of modifications adapting it for use with air. As shown in FIG. 12A, the stator 302 of the motor 102 preferably uses an elastomer, such as an NBR 250 elastomer, to prevent explosive decompression. The motor 102 also may have a looser fit between the rotor 300 and the stator 302 to accommodate air flow. In general, the fit between rotor and stator for a drilling motor when using the fluid to be drilled is expected to be ±0.015 to ±0.020-in. According to the modifications disclosed herein, the fit between the rotor 300 and the stator 302 are configured to have a clearance of ±0.010 to ±0.025-in.

[0078] Additionally, the disclosed motor 102 is configured with a number of multiple lobes that would make the motor 102 more suited for high speed and low torque applications. However, other controls are used to achieve the motor speeds desired during drilling operations. In general, the ratio of lobes for rotor and stator of a drilling motor that uses drilling fluid is expected to be 7:8. According to the modifications disclosed herein, the ratio of lobes for the rotor 300 and the stator 302 are configured to also be 7:8, but the stages of the power section determine use for air. For instance, a 7:8 lobed, 3 stage motor can be used for 64-in motor operations using air. Alternatively, a 7:8 lobed, 2.5 stage motor can be used for 8" motor operations using air. A stage is defined as a 360-degree wrap of the lobes along the rotor 300. A smaller number of stages on the rotor 300 means the rotor 300 has low pitched lobes for the air to push against. This gives a slower revolutions per min at a given flow rate compared to a rotor with a higher number of stages above 3.

[0079] Finally, the motor 102 has bearing clearances that help cool the bearings and flush the bearings of debris using the air. For instance, FIG. 12B illustrates portion of the mud motor 102 for the disclosed assembly 100. During drilling operations, the motor 102 needs to be cooled properly to avoid premature lock up of radial sleeves. Unfortunately, lubrication injection rates in air drilling may be insufficient to cool the radial bearings in the motor 102 because the injection rates in dry air/mist applications are considerably lower. As a consequence, tight radial clearances and low injection rates can create a buildup of heat that can eventually “fuse” the bearings.

[0080] As shown in FIG. 12B, the motor 102 includes upper and lower radial bearings 310 and 312 on either side of a thrust bearing assembly 314. The radial bearings 310 and 312 facilitate rotation of the motor’s drive shaft 316, while the thrust bearing assembly 314 takes up thrust transmitted to the motor’s drive shaft 316.

[0081] Conventionally, the radial bearings on a mud motor operated with drilling mud have a clearance of about 0.005 to 0.015-in. To allow the upper and lower radial bearings 310 and 312 to be cooled with lower injection rates on the disclosed motor 102, the radial clearances between the static and dynamic bearings are “opened” up as specified in the Table below. This additional radial clearance can be achieved by grinding bearings to desired sizes.
TABLE

<table>
<thead>
<tr>
<th>Motor size</th>
<th>Upper Radial Bearing Sleeve Clearance</th>
<th>Lower Radial Bearing Sleeve Clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;4(\frac{1}{4})&quot;&quot;</td>
<td>0.020/0.030</td>
<td>0.020/0.030</td>
</tr>
<tr>
<td>&quot;6(\frac{1}{4})&quot;&quot;</td>
<td>0.020/0.030</td>
<td>0.020/0.030</td>
</tr>
<tr>
<td>&quot;8&quot;</td>
<td>0.020/0.030</td>
<td>0.020/0.030</td>
</tr>
<tr>
<td>&quot;9(\frac{1}{4})&quot;&quot;</td>
<td>0.020/0.030</td>
<td>0.020/0.030</td>
</tr>
</tbody>
</table>

[0082] The MWD tool 150, extension 160, the antenna, and other disclosed components can be used with any suitable downhole assembly, including the air drilling assembly disclosed herein. Moreover, although the disclosure has referenced the use of “air” for drilling, other fluids can be used, including conventional drilling fluids provided a suitable drill bit and motor are coupled to the MWD assembly. Moreover, reference herein to use of “air” is meant to apply to the use of any suitable gas, foam, mist, aerated mud, and the like.

[0083] The foregoing description of preferred and other embodiments is not intended to limit or restrict the scope or applicability of the inventive concepts conceived of by the Applicants. It will be appreciated with the benefit of the present disclosure that features described above in accordance with any embodiment or aspect of the disclosed subject matter can be utilized, either alone or in combination, with any other described feature, in any other embodiment or aspect of the disclosed subject matter.

[0084] In exchange for disclosing the inventive concepts contained herein, the Applicants desire all patent rights afforded by the appended claims. Therefore, it is intended that the appended claims include all modifications and alterations to the full extent that they come within the scope of the following claims or the equivalents thereof.

What is claimed is:

1. A measurement-while-drilling apparatus, comprising:
   a bottom hole assembly having downhole and uphole portions;
   a tool string disposed in the bottom hole assembly and having a first end, the first end engaged at the downhole portion of the bottom hole assembly, the tool string having at least one sensor and having an electromagnetic telemetry device in electrical communication with the at least one sensor;
   an antenna extending in the bottom hole assembly from the tool string and in electrical communication with the electromagnetic telemetry device, the antenna having a second end engaged at the uphole portion of the bottom hole assembly, wherein the first and second ends affix to the uphole and downhole portions respectively and hold the tool string and the antenna in tension inside the bottom hole assembly.

2. The apparatus of claim 1, wherein the bottom hole assembly comprises a muleshoe sub at the downhole portion, a tool carrier sub coupled to the muleshoe sub, and an emitter sub at the uphole portion coupled to the tool carrier sub.

3. The apparatus of claim 2, wherein the bottom hole assembly comprises a non-magnetic drill collar coupled uphole of the emitter sub.

4. The apparatus of claim 1, wherein the tool string comprises a stinger disposed on the tool string and secured in a muleshoe sub at the downhole portion of the bottom hole assembly.

5. The apparatus of claim 4, wherein a fastener secures the stinger to the muleshoe sub, and wherein the bottom hole assembly comprises a grommet composed of elastomer and engaged between the fastener and the stinger.

6. The apparatus of claim 1, wherein the antenna comprises a conductive rod in electrical communication with the electromagnetic telemetry device.

7. The apparatus of claim 6, wherein the antenna comprises a conductive landing disposed on the conductive rod at the second end of the antenna.

8. The apparatus of claim 7, wherein the conductive rod comprises an uphole threaded end, the conductive landing disposed on the uphole threaded end and held in place against the second end with at least one lock-down fastener threaded on the uphole threaded end.

9. The apparatus of claim 6, wherein the conductive rod comprises a plurality of non-conductive centralizers disposed thereon and centralizing the conductive rod inside the bottom hole assembly.

10. The apparatus of claim 6, wherein the conductive rod comprises a plurality of non-conductive sleeves disposed thereon.

11. The apparatus of claim 7, wherein the bottom hole assembly comprises a beveled shoulder at the second end; and wherein the conductive landing comprises a beveled end engaging the beveled shoulder and centrally holding the second end of the antenna therein.

12. The apparatus of claim 11, wherein one or more lock-down nuts threaded on the second end of the antenna hold the conductive landing engaged with the beveled shoulder.

13. The apparatus of claim 1, wherein at least one sensor is selected from the group consisting of a gamma ray sensor, a pressure sensor, an inclinometer, and a directional sensor.

14. The apparatus of claim 1, wherein the electromagnetic telemetry device comprises an electromagnetic telemetry transceiver configured to send and receive electromagnetic telemetry signals.

15. The apparatus of claim 1, further comprising a drilling assembly disposed downhole of the bottom hole assembly and drilling an advancing borehole using flow delivered thereto through the bottom hole assembly.

16. The apparatus of claim 15, wherein the drilling assembly comprises:
   an impact hammer operable with the flow delivered thereto; and
   a motor coupled uphole of the impact hammer, the motor operable with the delivered flow and imparting rotation to the hammer.

17. The apparatus of claim 16, wherein the motor comprises one or more of: radial bearings with increased clearances of 0.025 to 0.030-in., a ratio of ¼ lobes for a stator and a rotor of the motor with a number of stages on the rotor being less than or equal to 3, a fit separation of -0.010 to -0.025-in. between the stator and the rotor of the motor, and a stator composed of a nitride rubber resistant to explosive decompression.

18. The apparatus of claim 16, further comprising a jet sub coupled uphole of the motor, the jet sub diverting at least a
portion of the delivered flow to an annulus of the advancing borehole and limiting the rotation imparted by the motor to the hammer.

19. The apparatus of claim 18, wherein the jet sub is coupled upright of the bottom hole assembly.

20. A measurement-while-drilling apparatus, comprising:
   a bottom hole assembly having downhole and upright portions;
   a tool string disposed in the bottom hole assembly and
   having at least one sensor, the tool string having an
   electromagnetic telemetry device in electrical communica-
   tion with the at least one sensor;
   first means disposed on the tool string for affixing the tool
   string to the downhole portion of the bottom hole assembly;
   an antenna extending in the bottom hole assembly from the
   tool string and in electrical communication with the
   electromagnetic telemetry device; and
   second means disposed on the antenna for affixing the
   antenna to the upright portion of the bottom hole assembly;
   the first and second means holding the tool string and
   the antenna in tension inside the bottom hole assembly.

21. A measurement-while-drilling method, comprising:
   assembling a tool string having at least one sensor and
   having an electromagnetic telemetry device in electrical
   communication with the at least one sensor;
   affixing the assembled tool string in a first portion of the
   bottom hole assembly;
   affixing an antenna to extend from the tool string;
   disposing the antenna in a second portion of the bottom
   hole assembly;
   connecting the first portion to the second portion; and
   holding the tool string and the antenna in tension inside the
   bottom hole assembly by affixing the antenna in the second
   portion.

22. The method of claim 21, wherein affixing the assembled tool string in the first portion of the bottom hole assembly comprises securing a stinger disposed on the tool string in the first portion.

23. The method of claim 21, wherein attaching the antenna to extend from the tool string comprises attaching a conductive rod in electrical communication with the electromagnetic telemetry system.

24. The method of claim 23, wherein affixing the antenna in the second portion comprises disposing a conductive landing on a threaded end of the antenna and holding the conductive landing against a shoulder in the bottom hole assembly with
   at least one fastener threaded on the threaded end.

25. The method of claim 23, wherein affixing the antenna in the second portion comprises centralizing the conductive rod in the second portion with a plurality of non-conductive centralizers disposed on the conductive rod.

26. The method of claim 23, wherein affixing the antenna in the second portion comprises isolating portion of the conductive rod inside the second portion with a plurality of non-conductive sleeves disposed on the conductive rod.

27. The method of claim 23, wherein attaching the antenna to extend from the tool string comprises threading a downhole end of the conductive rod to the tool string.

28. The method of claim 21, wherein connecting the first portion to the second portion comprises:
   connecting an emitter sub of the second portion to a carrier
   sub of the first portion, the emitter sub at least partially
   holding the antenna therein, the carrier sub at least par-
   tially holding the tool string therein.

29. The method of claim 28, wherein carrier sub comprises a muleshoes housing at the first end.

30. The method of claim 21, wherein the at least one sensor is selected from the group consisting of a gamma ray sensor, a pressure sensor, an inclinometer, and a directional sensor.

31. The method of claim 21, wherein the electromagnetic telemetry device comprises an electromagnetic telemetry transceiver configured to send and receive electromagnetic telemetry signals.

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