US010385683B1

(12) **United States Patent**
Kaur

(10) **Patent No.: US 10,385,683 B1**
(45) **Date of Patent: Aug. 20, 2019**

(54) **DEEPSET RECEIVER FOR DRILLING APPLICATION**

(71) Applicant: **Nabors Drilling Technologies USA, Inc.**, Houston, TX (US)

(72) Inventor: **Harmeet Kaur**, Houston, TX (US)

(73) Assignee: **Nabors Drilling Technologies USA, Inc.**, Houston, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/887,607**

(22) Filed: **Feb. 2, 2018**

(51) **Int. Cl.**
E21B 47/12 (2012.01)
E21B 17/02 (2006.01)

(52) **U.S. Cl.**
CPC ***E21B 47/122*** (2013.01); ***E21B 17/023*** (2013.01)

(58) **Field of Classification Search**
CPC E21B 47/122
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,225,668	A	12/1940	Subkow et al.	
2,653,220	A	9/1953	Bays	
3,333,239	A	7/1967	Silverman	
3,495,209	A	2/1970	Engle	
3,590,141	A	6/1971	Mildner	
3,967,201	A	6/1976	Rorden	
5,160,925	A	11/1992	Dailey et al.	
5,642,051	A	6/1997	Babour et al.	
5,820,416	A	10/1998	Carmichael	
6,160,492	A	12/2000	Herman	
6,163,155	A	12/2000	Bittar	
6,626,253	B2	9/2003	Hahn et al.	
6,899,178	B2	5/2005	Tubel	
7,064,676	B2	6/2006	Hall et al.	
7,080,699	B2	7/2006	Lovell et al.	
7,098,858	B2	8/2006	Bittar et al.	
7,249,636	B2	7/2007	Ohmer	
7,477,161	B2	1/2009	Macpherson et al.	
7,565,936	B2	7/2009	Zhang et al.	
7,573,397	B2	8/2009	Petrovic et al.	
8,120,509	B2	2/2012	Young	
8,164,476	B2	4/2012	Hache et al.	
8,400,326	B2	3/2013	Codazzi	
9,052,043	B2	6/2015	Mueller et al.	
9,110,099	B2	8/2015	Homan et al.	
9,347,277	B2	5/2016	Taherian et al.	
9,459,371	B1 *	10/2016	Holmen	E21B 47/122
9,647,381	B2	5/2017	Head	
9,719,345	B2	8/2017	Switzer et al.	
9,761,962	B2	9/2017	Nicholson	
2005/0126777	A1	6/2005	Rolovic et al.	

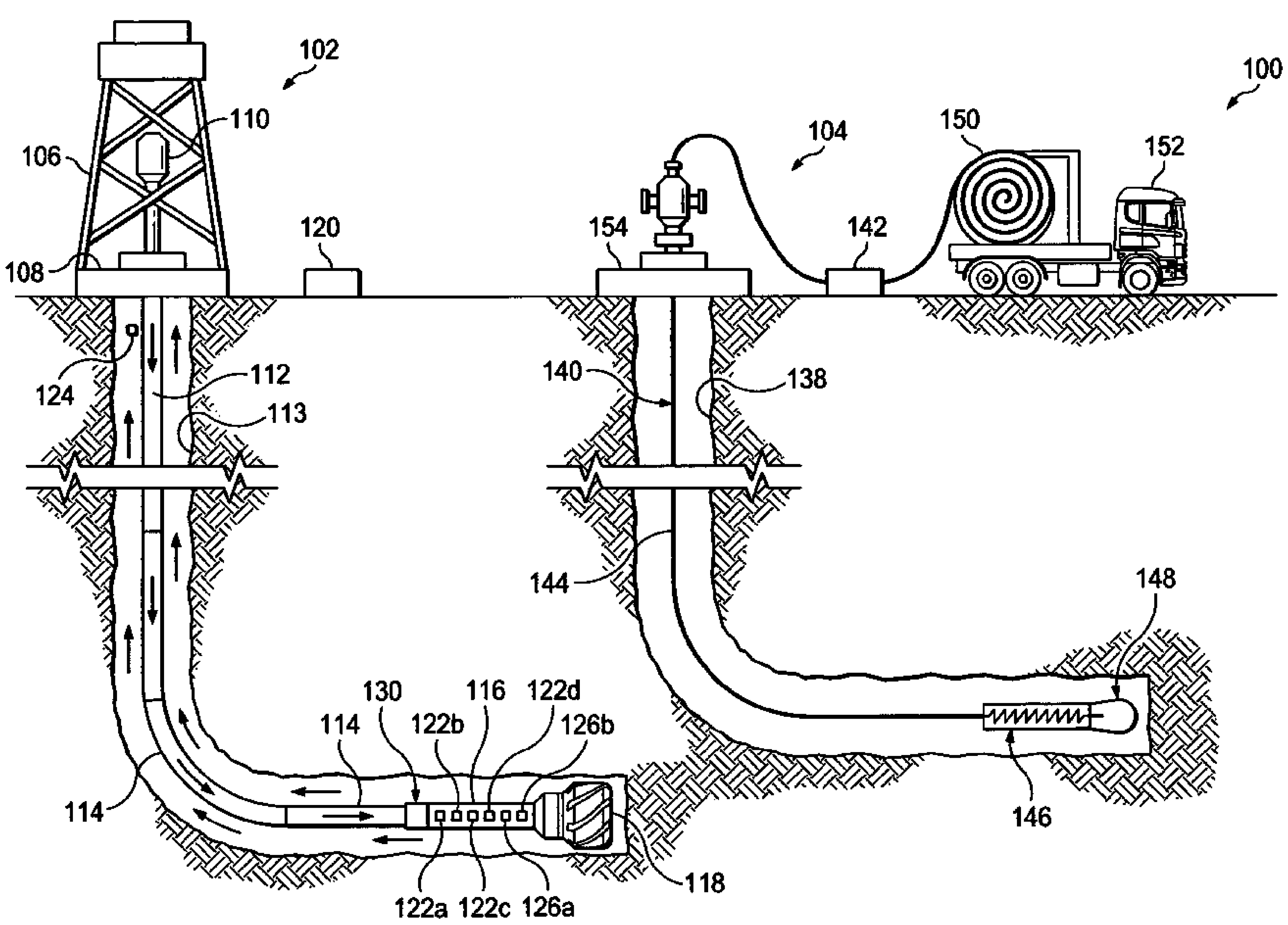
(Continued)

Primary Examiner — Amine Benlagsir
(74) *Attorney, Agent, or Firm* — Haynes and Boone, LLP

(57) **ABSTRACT**

Drilling telemetry systems and methods include a cable antenna a cable antenna in an auxiliary borehole in a subterranean formation arranged to receive electromagnetic signal transmitted from an EM tool in an adjacent wellbore in the subterranean formation. The cable antenna may include a wireline cable having a center core, an insulated electrical cable head in direct electrical communication with the center core, and an uninsulated signal receiver in direct electrical communication with electrical cable head. The uninsulated signal receiver may have an outer surface formed of a conductive material and configured to contact a natural subterranean formation.

20 Claims, 3 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2006/0290528	A1	12/2006	MacPherson et al.	
2009/0120689	A1	5/2009	Zaeper et al.	
2011/0017512	A1	1/2011	Codazzi	
2011/0176387	A1	7/2011	Froelich	
2012/0112753	A1 *	5/2012	Wittle	E21B 43/16 324/347
2014/0041391	A1 *	2/2014	DiCintio	F01D 9/023 60/752
2015/0145687	A1 *	5/2015	Roberts	E21B 47/122 340/853.2
2015/0155073	A1 *	6/2015	Varkey	H01B 7/046 174/105 R
2015/0247401	A1 *	9/2015	Cramer	E21B 47/122 324/338
2016/0003029	A1 *	1/2016	Hay	E21B 47/022 702/7
2016/0273902	A1 *	9/2016	Eitschberger	F42D 1/05
2017/0241259	A1 *	8/2017	White	E21B 47/04

* cited by examiner

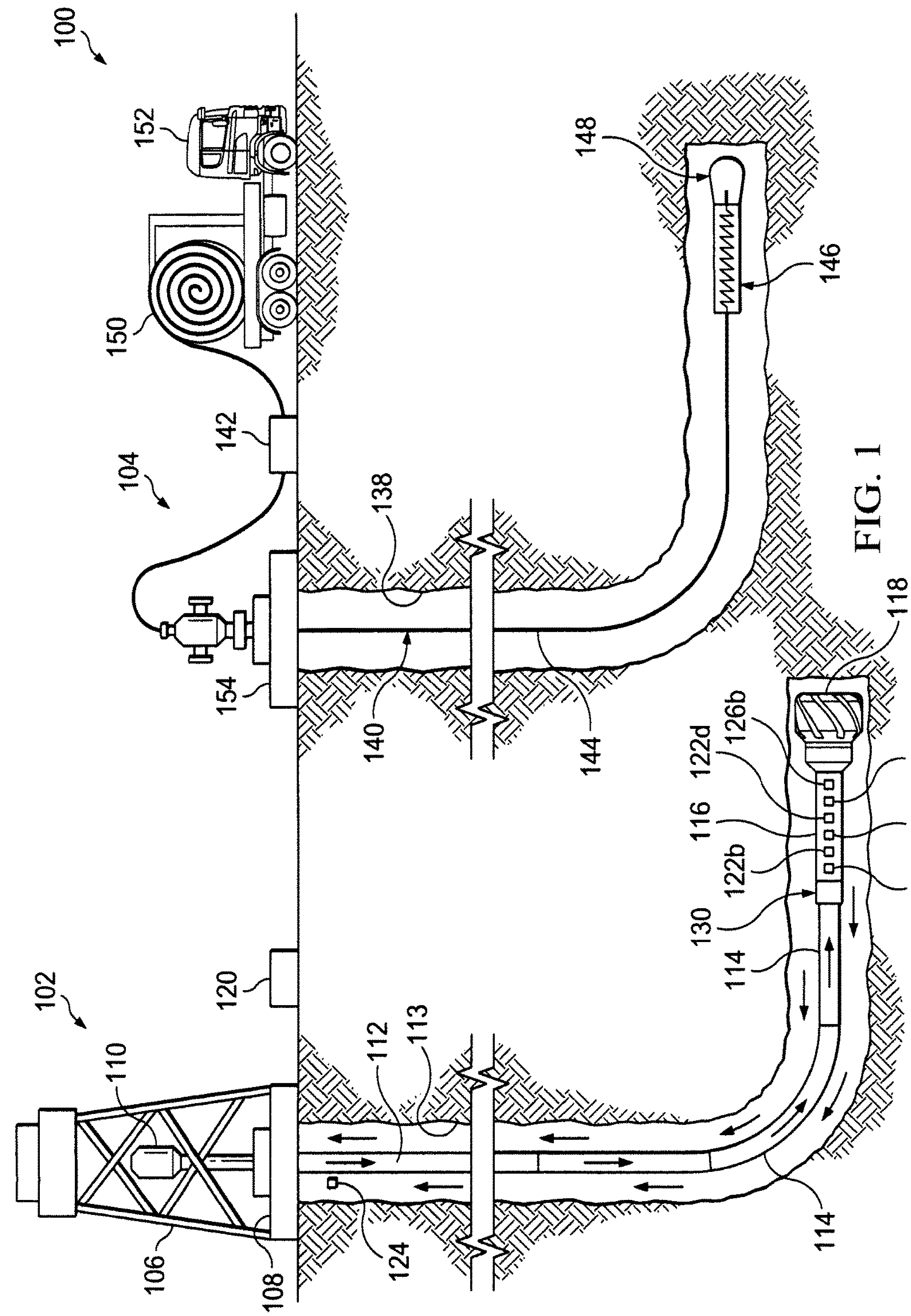

100
102
104
106
108
110
112
113
114
114
116
118
120
122a
122b
122c
122d
124
126a
126b
130
138
140
142
144
146
148
150
152
154

FIG. 1

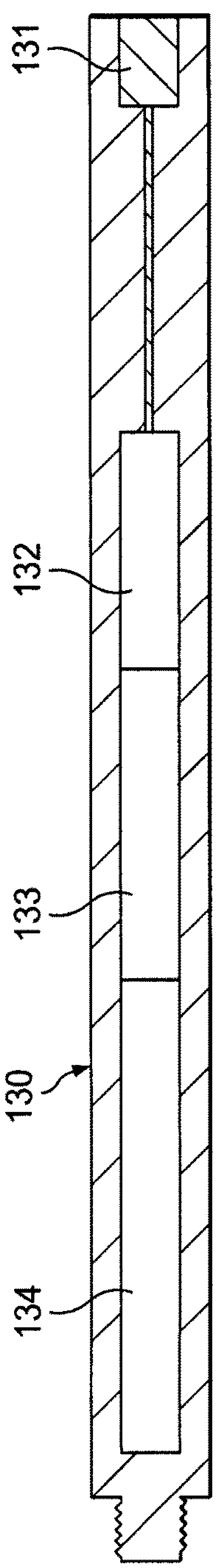

131
132
133
130
134

FIG. 2

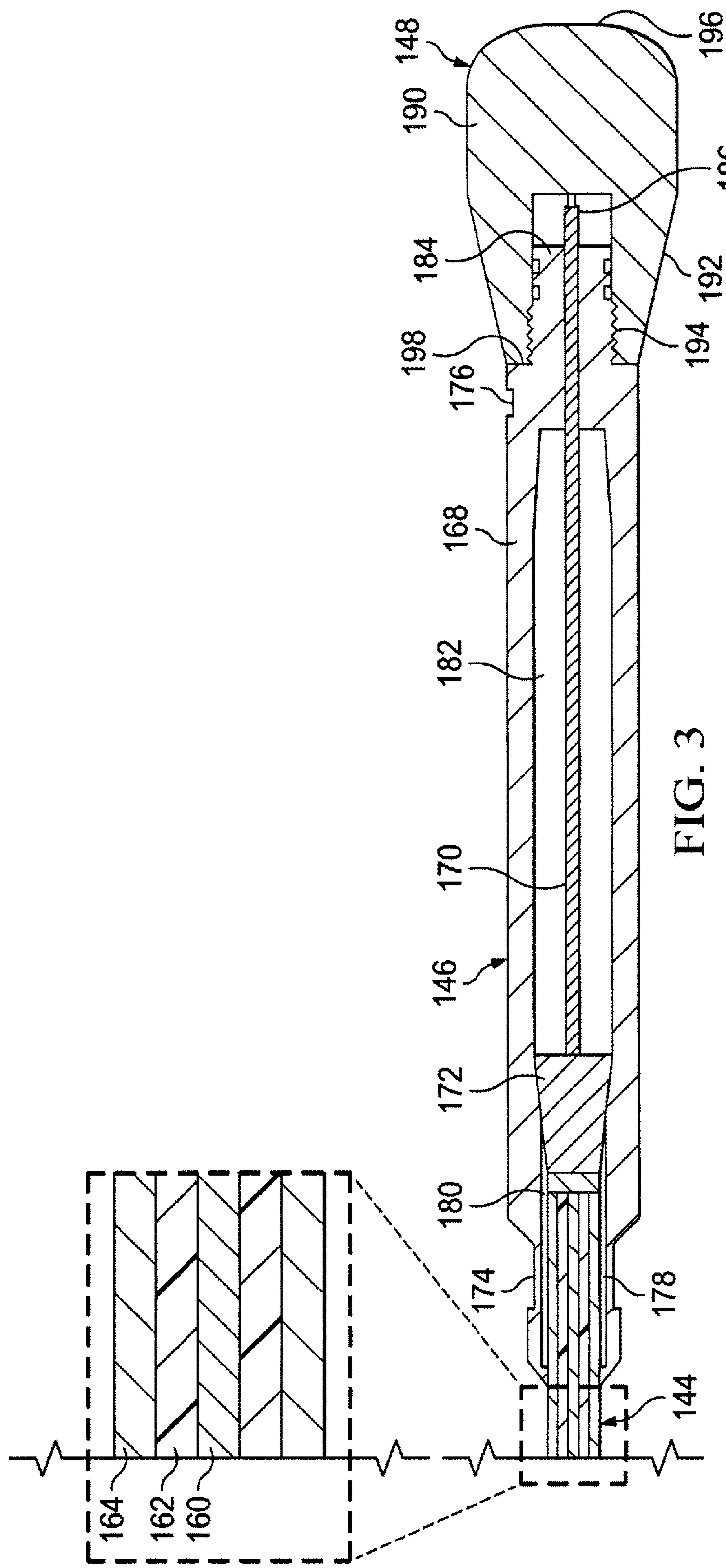

148
196
190
186
184
192
198
194
176
168
182
170
146
172
180
174
178
144
164
162
160

FIG. 3

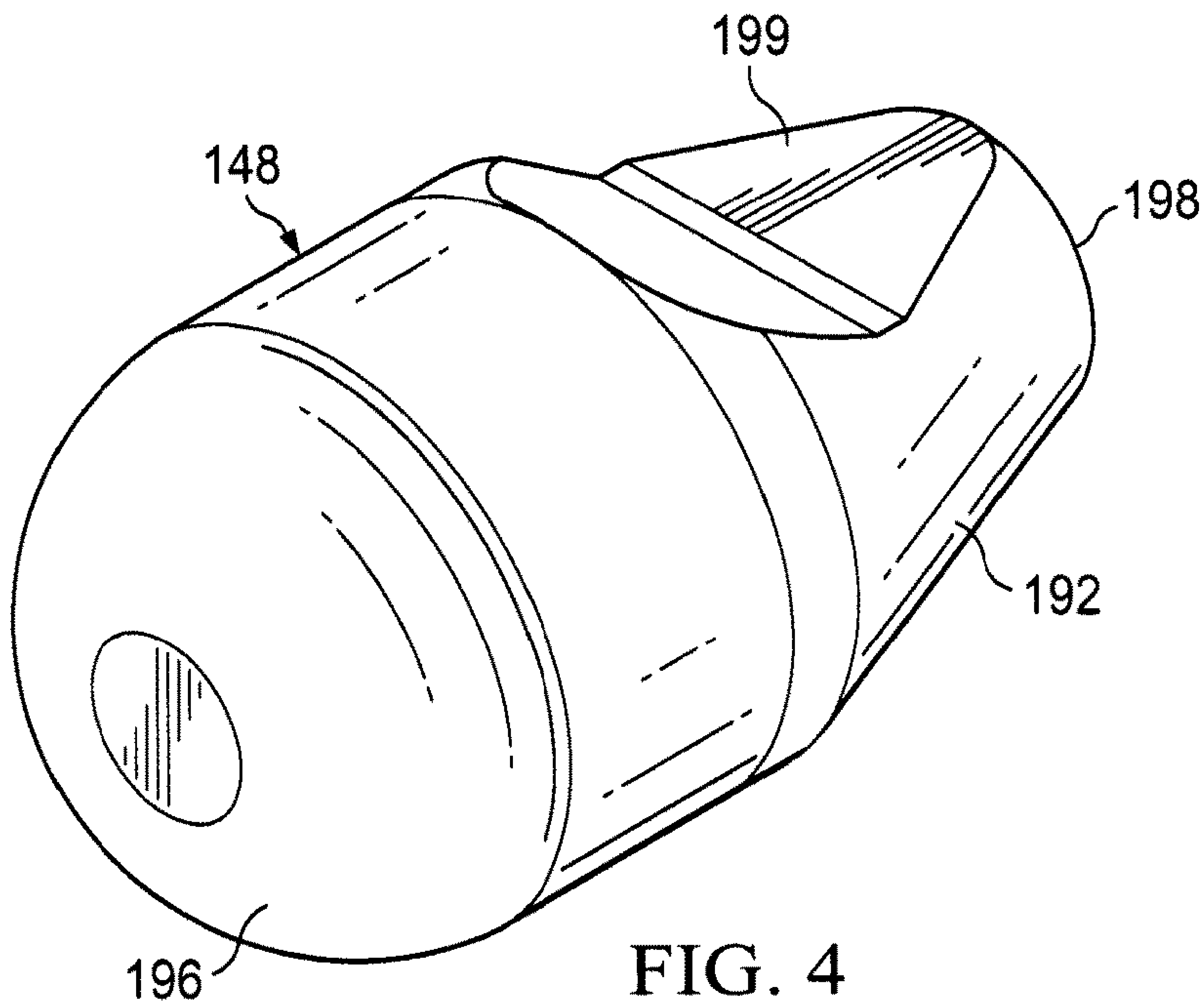

199
148
198
192
196

FIG. 4

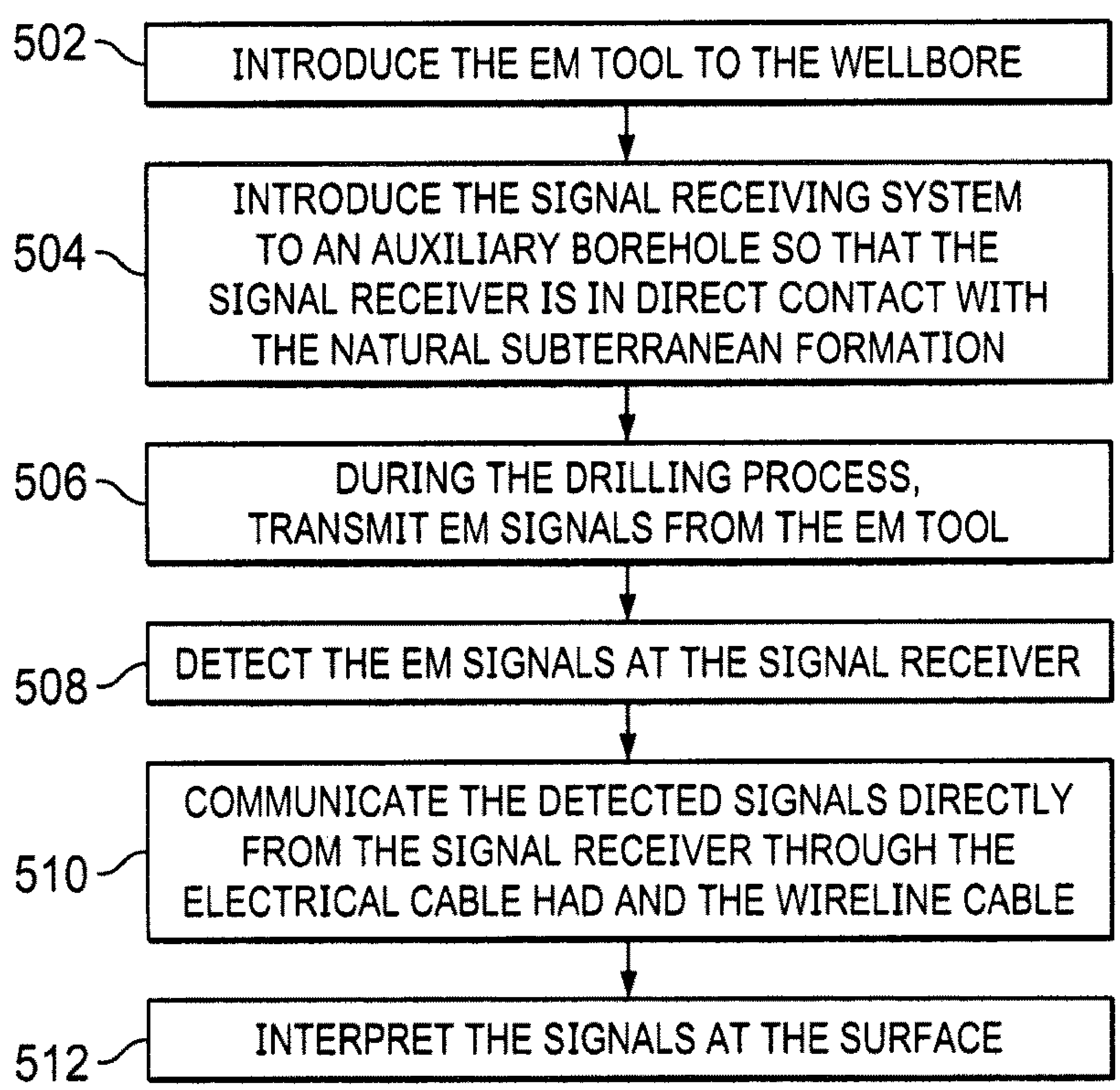

502
INTRODUCE THE EM TOOL TO THE WELLBORE
504
INTRODUCE THE SIGNAL RECEIVING SYSTEM TO AN AUXILIARY BOREHOLE SO THAT THE SIGNAL RECEIVER IS IN DIRECT CONTACT WITH THE NATURAL SUBTERRANEAN FORMATION
506
DURING THE DRILLING PROCESS, TRANSMIT EM SIGNALS FROM THE EM TOOL
508
DETECT THE EM SIGNALS AT THE SIGNAL RECEIVER
510
COMMUNICATE THE DETECTED SIGNALS DIRECTLY FROM THE SIGNAL RECEIVER THROUGH THE ELECTRICAL CABLE HAD AND THE WIRELINE CABLE
512
INTERPRET THE SIGNALS AT THE SURFACE

FIG. 5

DEEPSET RECEIVER FOR DRILLING APPLICATION

BACKGROUND OF THE DISCLOSURE

The present disclosure relates in general to logging tools and particularly to receivers used in electromagnetic logging tools.

Measurement-while-drilling (MWD) tools and logging-while-drilling (LWD) tools capture information during the process of drilling a wellbore. However, the ability of current receivers to receive signals using MWD tools typically provide drilling parameter information such as weight on the bit, torque, temperature, pressure, direction, and inclination. LWD tools typically provide formation evaluation measurements such as resistivity, porosity, and NMR distributions (e.g., T**1** and T**2**). MWD and LWD tools often have characteristics common to wireline tools (e.g., transmitting and receiving antennas), but MWD and LWD tools must be constructed to not only endure but to operate in the harsh environment of drilling.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

FIG. **1** is an illustration of an exemplary drilling telemetry system in a subterranean formation according to one or more aspects of the present disclosure.

FIG. **2** is an illustration of a cross-sectional view of an exemplary electromagnetic tool of the telemetry system of FIG. **1** according to one or more aspects of the present disclosure.

FIG. **3** is an illustration of a cross-sectional view exemplary signal receiving system of the telemetry system of FIG. **1** according to one or more aspects of the present disclosure.

FIG. **4** is an illustration of a perspective view of the exemplary signal receiver according to one or more aspects of the present disclosure.

FIG. **5** is a flow chart diagram of at least a portion of a method according to one or more aspects of the present disclosure.

DETAILED DESCRIPTION

It is to be understood that the following disclosure provides many different embodiments, or examples, for implementing different features of various embodiments. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed. Moreover, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed interposing the first and second features, such that the first and second features may not be in direct contact.

This disclosure is directed to an improved system and method for obtaining downhole information during a well drilling process. In some implementations, the system and method employ a transmitting element on a drill string that communicates electromagnetic signals through subterranean formations to a receiver disposed in a separate auxiliary borehole. The receiver may be particularly arranged to detect and receive signals, even weak signals, passed through the subterranean formation. In this implementation, the receiver is particularly designed without exterior material that may insulate or dampen signals that may be received through the subterranean formation. That is, in some exemplary implementations, the receiver comprises a conductive material forming an external surface of the receiver and disposed in direct contact with the subterranean formation. In addition, the conductive material may be in direct communication with a center core or wire forming a portion of the wireline cable. Signal processing may occur at the surface.

FIG. **1** shows an example of a drilling telemetry system **100** for signaling in a subterranean formation. In this implementation, the drilling telemetry system **100** is formed of a drilling rig system **102** and a signal receiving system **104**. The drilling rig system **102** includes, among other components, a transmitter, and the signal receiving system **104** includes, among other components, a receiver. The drilling rig system **102** may electromagnetically communicate information to the receiving system **104**. For example, the drilling rig system **102** may transmit information, such as information relating to the status of the drilling rig system **102**, the wellbore, or other information to the receiving system **104**. In other examples, the drilling rig system **102** may emit electromagnetic signals that may be captured by the receiving system **104** that may allow the receiving system **104** to detect geological formation characteristics or other information relating to the geographic material through which the signals are transmitted.

The drilling rig system **102** may be, for example, a land-based drilling rig system—however, one or more aspects of the present disclosure are applicable or readily adaptable to any type of drilling rig system (e.g., a jack-up rig, a semisubmersible, a drill ship, a coiled tubing rig, a well service rig adapted for drilling and/or re-entry operations, and a casing drilling rig, among others). The drilling rig system **102** includes a mast **106** that supports lifting gear above a rig floor **108**, which lifting gear may include a crown block and a traveling block. The crown block may be disposed at or near the top of the mast **106**. The traveling block may hang from the crown block by a drilling line. The drilling line may extend at one end from the lifting gear to drawworks, which drawworks are configured to reel out and reel in the drilling line to cause the traveling block to be lowered and raised relative to the rig floor **108**.

In some implementations, the drilling rig system **102** may include a top drive **110** suspended from the bottom of the traveling block. A drill string **112** may be suspended from the top drive **110** and suspended within a wellbore **113**.

The drill string **112** may include interconnected sections of drill pipe **114**, a bottom-hole assembly ("BHA") **116**, and a drill bit **118**. The BHA **116** may include stabilizers, drill collars, and/or measurement-while-drilling ("MWD") or wireline conveyed instruments, among other components. The drill bit **118** (also be referred to herein as a tool) is connected to the bottom of the BHA **116** or is otherwise attached to the drill string **112**.

The downhole MWD or wireline conveyed instruments may be configured for the evaluation of physical properties such as pressure, temperature, torque, weight-on-bit ("WOB"), vibration, inclination, azimuth, toolface orientation in three-dimensional space, and/or other downhole parameters. These measurements may be made downhole, stored in solid-state memory for some time, and downloaded from the instrument(s) at the surface and/or transmitted real-time to the surface. In the implementations described herein, data may be transmitted electromagnetic pulses. In some implementations, in addition to transmission capability, the MWD tools and/or other portions of the BHA **116** may have the ability to store measurements for later retrieval via wireline and/or when the BHA **116** is tripped out of the wellbore **113**.

In the embodiment of FIG. **1**, the top drive **110** is utilized to impart rotary motion to the drill string **112**. However, aspects of the present disclosure are also applicable or readily adaptable to implementations utilizing other drive systems, such as a power swivel, a rotary table, a coiled tubing unit, a downhole motor, and/or a conventional rotary rig, among others.

The drilling rig system **102** also includes a control system **120** configured to control or assist in the control of one or more components of the drilling rig system **102**—for example, the control system **120** may be configured to transmit operational control signals to a drawworks, the top drive **110**, the BHA **116** and/or additional equipment. In some embodiments, the control system **120** includes one or more systems located in a control room proximate the drilling rig system **102**, such as the general purpose shelter often referred to as the "doghouse" serving as a combination tool shed, office, communications center, and general meeting place. The control system **120** may be configured to transmit the operational control signals to the drawworks, the top drive **110**, the BHA **116**, and/or other equipment via wired or wireless transmission (not shown). The control system **120** may also be configured to receive electronic signals via wired or wireless transmission (also not shown) from a variety of sensors included in the drilling rig system **102**, where each sensor is configured to detect an operational characteristic or parameter. Some example sensors from which the control system **120** is configured to receive electronic signals via wired or wireless transmission (not shown) may include one or more of the following: a torque sensor, a speed sensor, and a WOB sensor. In some implementations, the BHA **116** may also include sensors disposed thereon. Some exemplary sensors include for example, a downhole annular pressure sensor **122***a*, a shock/vibration sensor **122***b*, a toolface sensor **122***c*, a WOB sensor **122***d*, a surface casing annular pressure sensor **124**, a mud motor delta pressure ("ΔP") sensor **126***a*, and one or more torque sensors **126***b*. The sensors are merely examples of any of a variety of sensors that may be included on the BHA **116**, the drill bit **118**, and/or otherwise disposed about the drilling rig system **102**.

In this exemplary embodiment, the BHA **116** also includes an EM tool **130**. The EM tool **130** may be configured to propagate an electromagnetic signal to convey information from the BHA for receipt and analysis by drilling rig personnel. Although identified as a part of the BHA **116**, in some implementations, the EM tool **130** is disposed elsewhere along the drill string **112** and down in the wellbore **113**. Some implementations include multiple EM tools **130** arranged to propagate a signal through the subterranean formations. The EM tool **130** may form a part of the measurement while drilling MWD tool. In some implementations, the EM tool **130** may form a part of a collar or stabilizer of the drill string. Some implementations of the EM tool **130** feature 2-way EM communication, while other implementations include only transmission capability. In some implementations, the power, the data rate, and the carrier wave may be adjustable while drilling to help transmit through changing formations. In some implementations, the EM tool may operate using batteries or a turbine alternator. The turbine alternator may enable longer downhole times, and higher transmitting power for longer periods. Some implementations may include backup batteries for operation during periods of no flow.

FIG. **2** shows an example of an EM tool **130** that may form a part of the BHA **116**. The EM tool **130** may include an electrode **131**, a downlink receiver **132**, a transmitter **133**, and the power source **134**, such as batteries. The electrode **131** may enable the EM tool **130** to communicate with other downhole systems such as, for example, sensing systems that may be carried on the BHA. The downlink receiver **132** may be configured to receive signals and information from the surface, from other EM tools, or other equipment that may be in communication with the EM tool **130**. The transmitter **133** transmits EM signals through geological formations. In some implementations, the transmitter **133** is a high-voltage transmitter configured to automatically select the necessary power usage for the formation resistance. This may help extend the life of the power source **134** by reducing the need to transmit at full power in certain situations.

Returning to FIG. **1**, the signal receiving system **104** may be disposed in an auxiliary borehole **138**. The signal receiving system **104** may include a cable antenna **140** and a signal processing system **142**. In the implementation shown, the cable antenna **140** includes a wireline cable **144**, an electrical cable head **146**, and a signal receiver **148**. In this example, the wireline cable **144** may extend or be wound around a cable coil or reel **150** disposed on steerable equipment, such as a working vehicle **152**, such as a truck. In the deployed configuration shown, the wireline cable **144** may extend from the cable coil **150** through a bore head **154**, and into the auxiliary borehole **138**.

FIG. **3** shows a cross-section of a portion of the signal receiving system **104**, including a portion of the wireline cable **144**, the electrical cable head **146**, and the signal receiver **148**. The wireline cable **144** may include a center core **160**, a polymer jacket **162** surrounding the center core **160**, and a protective or armor layer **164** disposed about the polymer jacket **162**. The center core **160** may be formed of a conductive material and may extend the length of the wireline cable **144**. The center core **160** may be configured to communicate signals from the electrical cable head **146** and the signal receiver **148** to the processing system **142**. In some examples, the polymer jacket is a polytetrafluoroethylene (PTFE) material, and in some implementations, the polymer jacket is or includes TEFLON® material. The polymer jacket **162** may insulate or isolate the center core **160** from the armor layer **164**. The protective or armor layer **164** may be formed of any material that provides protection and strength to the wireline cable **144**. For example, it may comprise a metal or metal-clad, hollow cable that provides sufficient tensile strength to the wireline cable **144**. It may be formed of a plurality of braided wires or otherwise formed. It may be metal or some other material, including non-conductive materials. It may be designed to carry the weight of electrical cable head **146** and the signal receiver **148**. The armor layer **164** may form the outer surface of the wireline cable **144**. In some implementations, the armor layer is a steel armor layer.

The electrical cable head **146** may be disposed between the wireline cable **144** and the signal receiver **148**. It may electrically connect the center core **160** to the conductive material of the signal receiver **148**. In some implementations, electrical cable head **146** may include a housing **168**, an electrical conductor **170**, and a cable anchor **172**. The housing **168** extends from a proximal end **174** to a distal end **176**. The proximal end **174** may include an opening **178** through which the wireline cable **144** may extend. The opening **178** may lead to an anchor cavity **180** in communication with a passage **182**. The distal end **176** of the housing **168** may include a threaded tip **184**.

The electrical conductor **170** may be in electrical communication with the center core **160** of the wireline cable **144**. In some implementations, the electrical conductor **170** may extend in the passage **182** from the proximal end **174** to the distal end **176** and may terminate at the threaded tip **184**. In some implementations, the electrical conductor **170** comprises a spring-loaded contact **186** projecting from the distal end **176** that contacts the signal receiver **148**.

The cable anchor **172** may be disposed within the anchor cavity **180** and may be connected to the wireline cable **144**. In some implementations, the cable anchor **172** is attached to the armor layer **164** of the wireline cable **144**. In some implementations, the center core **160** is electrically connected with the electrical conductor **170** through the cable anchor **172**. Some implementations include an insulative cover about the electrical conductor **170**. The insulative cover may be for example a ceramic or polymeric material that prevents electrical communication between the electrical conductor **170** and the housing **168**.

The signal receiver **148** is connected to the distal end **176** of the housing **168**. The signal receiver **148** may be formed of a heavy, conductive material. In some implementations, the signal receiver **148** is formed of a solid stainless steel material. In other implementations, the signal receiver **148** is formed of copper, silver, or other highly conductive material and with features aiding deployment and contact with formation or casing it is deployed in. In the implementation shown, the signal receiver **148** is formed of a solid bulbous head **190** with sides **192** that taper toward the housing **168**, forming a frustum. A threaded bore or threaded cavity **194** is disposed in the end of the frustum and receives the threaded tip **184** of the housing **168**. The signal receiver **148** is formed to abut in direct contact with the walls or sides of the auxiliary borehole **138** (FIG. **1**) through which it is introduced. Accordingly, the signal receiver **148** is in contact with the natural geological formation of the auxiliary borehole **138**. In some embodiments, signal receiver **148** may contact the hole casing in case of cased holes. As such, the signal receiver **148** also acts as the signal receiver from the EM tool **130**. Because the signal receiver **148** is in direct contact with the subterranean formation, the signal receiver **148** is configured and arranged to receive EM signals from the EM tool **130** without interference or dampening from unnatural components about the signal receiver **148**. For example, the signal receiver **148** is free of insulative or protective materials that may interfere or dampen reception of signals. Also, it is deployed deeper relative to a conventional EM antenna at the surface which is prone to signal attenuation for long reach wells and signal loss in case of salt domes in certain basins. Because of this, the signal receiver **148** may be particularly sensitive to even weak signals emitted from the EM tool **130** and propagated through the subterranean formation. Furthermore, the electrically conductive outer surface (the exterior surface) of the signal receiver **148** is in direct electrical communication with the electrical conductor **170** of the cable anchor **172**, and with the center core **160** of the wireline cable **144**. This electrical connection may be free of filtering or other signal distorting components so that the signal communicated to the ground surface is the complete and natural signal received at the signal receiver **148**.

In this implementation, the shape of the signal receiver **148** may contribute to the receptivity of the EM signals. For example, the bulbous head, having a diameter greater than the diameter of the electrical cable head **146** insures that a significant portion of the signal receiver **148** is in contact with the natural subterranean formation. In the implementation shown, the signal receiver **148** has the largest cross-sectional diameter of any of the wireline cable **144** or the electrical cable head **146**. This may help increase the likelihood that the signal receiver **148** will be in contact with the subterranean formation whether disposed in a vertical auxiliary borehole or in a curved or a horizontal auxiliary borehole.

FIG. **4** shows a perspective view of an example of a signal receiver **148**. The signal receiver **148** in this implementation includes a rounded leading end **196** and a trailing end **198**. The tapering sides **192** taper toward the trailing end **198**. In this implementation, the signal receiver **148** has a substantially teardrop-shape, with the rounded leading end **196** forming the large diameter bulbous head. A notch **199** may be formed in a side to enable the signal receiver **148** to be grasped by a tool for threading onto the electrical cable head **146**. In some implementations, the signal receiver **148** has a diameter in the range of about 2 to 12 inches, and has a length in a range of about 3 to 18 inches, although larger and smaller diameters and lengths are contemplated. In some implementations, the signal receiver **148** has a diameter in the range of about 2 to 4 inches and has a length in the range of about 4 to 8 inches. Furthermore, the rigidity of the bulbous signal receiver reduces the likelihood of hang-up when the signal receiver **148** is introduced and fed through the auxiliary borehole **138**. For example, a loose cable or other flexible component at the distal end may interfere with advancement of the signal receiving system **104**.

In some implementations, an insulative covering may isolate the signal receiver **148** from the housing **168** of the electrical cable head **146**. In such implementations, the signal receiver **148** is still in electrical communication with the electrical conductor **170** projecting from the threaded tip **184** of the housing **168**. In some implementations, the electrical conductor **170** is the only component in electrical communication with the signal receiver **148**.

The signal processing system **142** may be disposed at the surface adjacent the bore hole and may be configured to receive and process signals detected or received at the signal receiver **148**. In some implementations, the processing system **142** is in direct communication with the center core **160** of the wireline cable **144**. Accordingly, signals detected at the signal receiver **148** may be communicated through the electrical cable head **146** and the wireline cable **144** to the processing system **142**. In some implementations, the processing system **142** is a computer having software configured to interpret EM signals received from the EM tool **130**.

Because the signal receiver **148** is able to directly contact the subterranean formations, and there is no isolation or insulative elements between the signal receiver **148** and the center core **160**, EM signals may be more easily received and captured for processing. The cable antenna **140** implementation shown in FIG. **3** may be a retrievable type and may be easily deployable by means of coil tubing or wireline or the center conductor can be isolated or connected to the polymeric material. In some implementations, this receiver may be used for a multitude of wells being drilled across the pad as well as nearby pads. In some implementations, the wireline cable **144**, the electrical cable head **146**, and the signal receiver **148** form a simple conductive connection having no control feedback or logic system. It may receive and relay the signal to the surface. In some implementations, the system does not require electric/magnetic isolation between the center core and the polymeric jacket. Furthermore, in some implementations, the system does not require insulation between the signal receiver **148**, the electrical conductor **170**, and the center core **160**.

FIG. **5** is a flow diagram showing a process of using the drilling telemetry system **100** according to an exemplary implementation. At **502**, a user may introduce the EM tool **130** to the wellbore. The EM tool **130** may form a part of or be disposed adjacent to a BHA during a drilling operation carried out by the drilling rig system **102**. In some implementations, the EM tool **130** may be spaced apart from the BHA, but may be downhole in the subterranean formation.

At **504**, a user may introduce the signal receiving system to an auxiliary borehole. Because of the size and shape of the signal receiver **148**, the signal receiver may be in direct contact with the natural subterranean formation. That is, because the signal receiver **148** forms the distal most tip of the signal receiving system, and because the signal receiver **148** may, in some implementations, have a diameter larger than other components around the signal receiver **148**, the signal receiver **148** may be in direct contact with the natural subterranean formation. Since the signal receiver **148** is also un-insulated, EM signals propagated through the subterranean formation may be detected or picked up directly from the subterranean formation without interference or dampening from insulative or isolating materials other than the natural subterranean formation. The signal receiving system **104** may be introduced to the auxiliary borehole with the electrical cable head **146** and the signal receiver **148** suspended from the wireline cable **144**. The signal receiver and the electrical cable head **146** each include direct electrical contact with each other.

At **506**, the EM tool **130** may transmit EM signals through the subterranean formation. The signals may relate to detected parameters of the wellbore and its surrounding environment, of the drilling equipment, or of the subterranean formation. Accordingly, the transmitted EM signals may include MWD or LWD information. The EM signals may be transmitted while actual drilling is occurring, or may be transmitted during down times of the drilling process, such as when stands are being introduced to the drill string or during other stoppages in actual drilling.

At **508**, the signal receiver **148** may detect the EM signals directly from the subterranean formation. Since the signal receiver **148** is particularly shaped to provide a large amount of surface contact area, as well as have a wider diameter than other components of the downhole signal receiving system, the signal receiver **148** may receive signals left otherwise undetected by conventional telemetry systems. In some implementations, the EM signals are received only at the signal receiver. In such implementations, the electrical cable head **146** and the wireline cable **144** may include insulative or protective materials disposed about their respective conductive portions that may inhibit reception of EM signals transmitted or propagated through the subterranean formation.

At **510**, the detected signals may be communicated directly from the signal receiver through the electrical cable head **146** and the wireline cable **144** to the processing system **142**. Since the signal receiver is in direct electrical communication with the electrical conductor of the electrical cable head **146**, and since the electrical conductor **170** is in direct electrical communication with the center core **160** of the wireline cable **144**, signals may be communicated directly to the processing system **142**, even when the processing system **142** is disposed above ground. At **512**, the processing system **142** may interpret the signals at the surface.

In an exemplary aspect, the present disclosure is directed to a drilling telemetry system that may include an EM tool sized and configured to be disposed on a drill string and introduced into a wellbore in a subterranean formation. The EM tool may comprise a transmitter configured to transmit an electromagnetic signal through the subterranean formation. The drilling telemetry system may also include a cable antenna sized and configured to be introduced into an adjacent auxiliary borehole in the subterranean formation and arranged to receive the electromagnetic signal transmitted from the EM tool. The cable antenna may comprise a wireline cable having a center core, an insulated electrical cable head in direct electrical communication with the center core, and an uninsulated signal receiver in direct electrical communication with electrical cable head. The uninsulated signal receiver may have an outer surface formed of a conductive material and configured to engage against a natural subterranean formation.

In some aspects, the uninsulated signal receiver has a teardrop shape forming a bulbous head. In some aspects, the uninsulated signal receiver comprises a threaded cavity formed therein for receiving a portion of the electrical cable head. In some aspects, the cable antenna comprises a polymeric jacket around the center core, and a protective layer disposed around the polymeric jacket. In some aspects, the armor layer is embedded within and fixedly attaches the insulated electrical cable head to the cable. In some aspects, the conductive material of the uninsulated signal receiver comprises stainless steel. In some aspects, the EM tool comprises a transmitter and a power source. In some aspects, the uninsulated signal receiver has a diameter of about 2 to about 12 inches, and a length of about 3 to about 18 inches.

In an exemplary implementation, a method of using a drilling telemetry system may include introducing an EM tool to a wellbore; introducing a signal receiving system to an adjacent auxiliary borehole; transmitting an EM signal from the EM tool in the wellbore; detecting the transmitted EM signal with the signal receiver having a conductive exterior surface in direct contact with walls of the auxiliary borehole, the conductive exterior surface being in direct electrical communication with an electrical cable head and a wireline cable; and communicating the detected EM signal to a signal processing system in communication with the wireline cable.

In some aspects, detecting the transmitted EM signal with the signal receiver comprises detecting the transmitted EM signal only at the signal receiver. In some aspects, the method may include performing a drilling operation, and wherein transmitting the EM signal from the EM tool occurs during the drilling operation. In some aspects, the method may include insulating or isolating a conductive center core in the wireline cable and a conductor in the electrical cable head from contact with the walls of the auxiliary borehole. In some aspects, communicating the detected EM signal comprises communicating the detected EM signal through a conductor in the electrical cable head and through a conductive center core of the wireline cable. In some aspects, the exterior surface of the signal receiver is in direct conductive electrical communication with the conductor in the electrical cable head. In some aspects, the method may include threading the signal receiver on to a distal end of the electrical cable head to place a spring-loaded contact in electrical communication with the signal receiver. In some aspects, the uninsulated signal receiver has a teardrop shape forming a bulbous head. In some aspects, transmitting an EM signal comprises transmitting an EM signal representative of one or more detected parameters of the wellbore, an environment surrounding the wellbore, of the drilling equipment, of the subterranean formation, or a combination thereof.

In an exemplary aspect, the present disclosure is directed to a drilling telemetry system that includes an EM tool sized and configured to be disposed on a drill string and introduced into a wellbore in a subterranean formation. The EM tool may include a transmitter configured to transmit an electromagnetic signal through the subterranean formation. The drilling telemetry system may also include a cable antenna sized and configured to be introduced into an adjacent auxiliary borehole in the subterranean formation and to receive the electromagnetic signal transmitted from the EM tool. The cable antenna may include a wireline cable having a center core, a polymeric insulative layer disposed about the center core, and an outer protective layer disposed about the polymeric insulative layer. The cable antenna also may include an electrical cable head having a housing, an electrical conductor in electrical communication with the center core of the wireline and extending through the housing, and a cable anchor attached to the outer protective layer and configured to secure the electrical cable head to the wireline cable. The housing may have a distal end having a spring-loaded contact. The cable antenna also may include an uninsulated signal receiver disposed at a distal-most end of the cable antenna and formed of a rigid, conductive material having a diameter of about 2 to about 12 inches. The uninsulated signal receiver may have a conductive outer surface exposed to engage against a natural subterranean formation when the cable antenna is disposed in borehole. The uninsulated signal receiver may be in direct electrical communication with the spring-loaded contact to provide uninterrupted electrical communication between the conductive outer surface and the electrical conductor of the electrical cable head.

In some aspects, the uninsulated signal receiver has a teardrop shape forming a bulbous head. In some aspects, the uninsulated signal receiver comprises a threaded cavity formed therein for receiving a portion of the electrical cable head.

In several exemplary embodiments, the elements and teachings of the various illustrative exemplary embodiments may be combined in whole or in part in some or all of the illustrative exemplary embodiments. In addition, one or more of the elements and teachings of the various illustrative exemplary embodiments may be omitted, at least in part, and/or combined, at least in part, with one or more of the other elements and teachings of the various illustrative embodiments.

Any spatial references such as, for example, "upper," "lower," "above," "below," "between," "bottom," "vertical," "horizontal," "angular," "upwards," "downwards," "side-to-side," "left-to-right," "right-to-left," "top-to-bottom," "bottom-to-top," "top," "bottom," "bottom-up," "top-down," etc., are for the purpose of illustration only and do not limit the specific orientation or location of the structure described above.

In several exemplary embodiments, while different steps, processes, and procedures are described as appearing as distinct acts, one or more of the steps, one or more of the processes, and/or one or more of the procedures may also be performed in different orders, simultaneously and/or sequentially. In several exemplary embodiments, the steps, processes and/or procedures may be merged into one or more steps, processes and/or procedures.

In several exemplary embodiments, one or more of the operational steps in each embodiment may be omitted. Moreover, in some instances, some features of the present disclosure may be employed without a corresponding use of the other features. Moreover, one or more of the above-described embodiments and/or variations may be combined in whole or in part with any one or more of the other above-described embodiments and/or variations.

Although several exemplary embodiments have been described in detail above, the embodiments described are exemplary only and are not limiting, and those skilled in the art will readily appreciate that many other modifications, changes and/or substitutions are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of the present disclosure. Accordingly, all such modifications, changes and/or substitutions are intended to be included within the scope of this disclosure as defined in the following claims. In the claims, any means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures.

The foregoing outlines features of several embodiments so that a person of ordinary skill in the art may better understand the aspects of the present disclosure. Such features may be replaced by any one of numerous equivalent alternatives, only some of which are disclosed herein. One of ordinary skill in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. One of ordinary skill in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the present disclosure.

The Abstract at the end of this disclosure is provided to comply with 37 C.F.R. § 1.72(b) to allow the reader to quickly ascertain the nature of the technical disclosure. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims.

Moreover, it is the express intention of the applicant not to invoke 35 U.S.C. § 112, paragraph 6 for any limitations of any of the claims herein, except for those in which the claim expressly uses the word "means" together with an associated function.

What is claimed is:

1. A drilling telemetry system comprising:

an electromagnetic (EM) tool sized and configured to be disposed on a drill string and introduced into a wellbore in a subterranean formation, the EM tool comprising a transmitter configured to transmit an electromagnetic signal through the subterranean formation; and

a cable antenna sized and configured to be introduced into an adjacent auxiliary borehole in the subterranean formation and arranged to receive the electromagnetic signal transmitted from the EM tool, the cable antenna comprising:

a wireline cable having a center core;

an electrical cable head having a housing, an electrical conductor in direct electrical communication with the center core of the wireline cable and extending around a distal-most portion of the center core; and

an uninsulated signal receiver comprising an outer surface formed from a rigid, conductive material, the uninsulated signal receiver disposed at a distal-most end of the electrical cable head, the uninsulated signal receiver in direct electrical communication with the electrical cable head to provide uninterrupted electrical communication between the conductive outer surface and the electrical conductor of the electrical cable head, the uninsulated signal receiver being exposed to engage against the subterranean formation when the cable antenna is disposed in the adjacent auxiliary borehole.

2. The drilling telemetry system of claim **1**, wherein the uninsulated signal receiver has a teardrop shape forming a bulbous head.

3. The drilling telemetry system of claim **1**, wherein the uninsulated signal receiver further comprises a threaded cavity formed therein for receiving a portion of the electrical cable head.

4. The drilling telemetry system of claim **1**, wherein the cable antenna further comprises a polymeric jacket around the center core, and a protective layer disposed around the polymeric jacket.

5. The drilling telemetry system of claim **4**, wherein the protective layer is embedded within and fixedly attaches the electrical cable head to the wireline cable.

6. The drilling telemetry system of claim **1**, wherein the conductive material of the uninsulated signal receiver comprises stainless steel.

7. The drilling telemetry system of claim **1**, wherein the EM tool further comprises a power source.

8. The drilling telemetry system of claim **1**, wherein the uninsulated signal receiver has a diameter of 2 to 12 inches, and a length of 3 to 18 inches.

9. A method of using a drilling telemetry system comprising:

introducing an electromagnetic (EM) tool to a wellbore, the EM tool sized and configured to be disposed on a drill string, the EM tool comprising a transmitter configured to transmit an electromagnetic signal through a subterranean formation;

introducing a signal receiving system comprising an uninsulated signal receiver, an electrical cable head, and a wireline cable to an adjacent auxiliary borehole;

transmitting the EM signal from the EM tool in the wellbore;

detecting the transmitted EM signal with the uninsulated signal receiver disposed at a distal-most end of the signal receiving system, the uninsulated signal receiver having a conductive exterior surface in direct contact with walls of the auxiliary borehole, the conductive exterior surface being in direct electrical communication with a distal-most end of the electrical cable head to provide uninterrupted electrical communication between the conductive exterior surface and an electrical conductor of the electrical cable head, the electrical cable head being in direct electrical communication with a distal-most end of the wireline cable; and

communicating the detected EM signal to a signal processing system in communication with the wireline cable.

10. The method of claim **9**, wherein said detecting the transmitted EM signal with the signal receiver comprises said detecting the transmitted EM signal only at the signal receiver.

11. The method of claim **9**, further comprising performing a drilling operation, and wherein said transmitting the EM signal from the EM tool occurs during the drilling operation.

12. The method of claim **9**, further comprising insulating or isolating a conductive center core in the wireline cable and the electrical conductor in the electrical cable head from contact with the walls of the auxiliary borehole.

13. The method of claim **9**, wherein said communicating the detected EM signal comprises said communicating the detected EM signal through the electrical conductor in the electrical cable head and through a conductive center core of the wireline cable.

14. The method of claim **9**, wherein the exterior surface of the signal receiver is in direct conductive electrical communication with the electrical conductor in the electrical cable head.

15. The method of claim **9**, further comprising threading the signal receiver on to the distal-most end of the electrical cable head to place a spring-loaded contact in electrical communication with the signal receiver.

16. The method of claim **9**, wherein the signal receiver has a teardrop shape forming a bulbous head.

17. The method of claim **9**, wherein said transmitting the EM signal comprises said transmitting the EM signal representative of one or more detected parameters of the wellbore, an environment surrounding the wellbore, of drilling equipment, of the subterranean formation, or a combination thereof.

18. A drilling telemetry system comprising:

an electromagnetic (EM) tool sized and configured to be disposed on a drill string and introduced into a wellbore in a subterranean formation, the EM tool comprising a transmitter configured to transmit an electromagnetic signal through the subterranean formation; and

a cable antenna sized and configured to be introduced into an adjacent auxiliary borehole in the subterranean formation and to receive the electromagnetic signal transmitted from the EM tool, the cable antenna comprising:

a wireline cable having a center core, a polymeric insulative layer disposed in the center core, and an outer protective layer disposed in the polymeric insulative layer;

an electrical cable head having a housing, an electrical conductor in electrical communication with the center core of the wireline cable and extending through the housing, and a cable anchor attached to the outer protective layer and configured to secure the electrical cable head to a distal-most end of the wireline cable, the housing having a distal end having a spring-loaded contact; and

an uninsulated signal receiver disposed at a distal-most end of the cable antenna and formed of a rigid, conductive material having a diameter of 2 to 12 inches, the uninsulated signal receiver having a conductive outer surface exposed to engage against the subterranean formation when the cable antenna is disposed in the adjacent auxiliary borehole, the uninsulated signal receiver being in direct electrical communication with the spring-loaded contact to provide uninterrupted electrical communication between the conductive outer surface and the electrical conductor of the electrical cable head.

19. The drilling telemetry system of claim **18**, wherein the uninsulated signal receiver has a teardrop shape forming a bulbous head.

20. The drilling telemetry system of claim **18**, wherein the uninsulated signal receiver further comprises a threaded cavity formed therein for receiving a portion of the electrical cable head.

* * * * *