

Description

This invention relates to the transmission of data within a well bore, and is especially useful in obtaining downhole data or measurements while drilling.

In rotary drilling, the rock bit is threaded onto the lower end of a drill string or pipe. The pipe is lowered and rotated, causing the bit to disintegrate geological formations. The bit cuts a bore hole that is larger than the drill pipe, so an annulus is created. Section after section of drill pipe is added to the drill string as new depths are reached.

During drilling, a fluid, often called "mud", is pumped downward through the drill pipe, through the drill bit, and up to the surface through the annulus carrying cuttings from the borehole bottom to the surface.

It is advantageous to detect borehole conditions while drilling. However, much of the desired data must be detected near the bottom of the borehole and is not easily retrieved. An ideal method of data retrieval would not slow down or otherwise hinder ordinary drilling operations, or require excessive personnel or the special involvement of the drilling crew. In addition, data retrieved instantaneously, in "real time", is of greater utility than data retrieved after time delay.

A system for taking measurements while drilling is useful in directional drilling. Directional drilling is the process of using the drill bit to drill a bore hole in a specific direction to achieve some drilling objective. Measurements concerning the drift angle, the azimuth, and tool face orientation all aid in directional drilling. A measurement while drilling system would replace single shot surveys and wireline steering tools, saving time and cutting drilling costs.

Measurement while drilling systems also yield valuable information about the condition of the drill bit, helping determine when to replace a worn bit, thus avoiding the pulling of "green" bits. Torque on bit measurements are useful in this regard. See T. Bates and C. Martin: "Mud-Sensor Measurements-While-Drilling Tool Improves Drilling Economics", Oil & Gas Journal, March 19, 1984, p. 119-37; and D. Grosso et al.: "Report on MWD Experimental Downhole Sensors", Journal of Petroleum Technology, May 1983, p. 899-907.

Formation evaluation is yet another object of a measurement while drilling system. Gamma ray logs, formation resistivity logs, and formation pressure measurements are helpful in determining the necessity of liners, reducing the risk of blowouts, allowing the safe use of lower mud weights for more rapid drilling, reducing the risks of lost circulation, and reducing the risks of differential sticking. See Bates and Martin article, supra.

Existing measurement while drilling systems are said to improve drilling efficiency, saving in excess of ten percent of the rig time; improve directional control, saving in excess of ten percent

of the rig time; allow logging while drilling, saving in excess of five percent of the rig time; and enhance safety, producing indirect benefits. See A. Kamp: "Downhole Telemetry From The User's Point of View", Journal of Petroleum Technology, October 1983, p. 1792-96.

The transmission of subsurface data from subsurface sensors to surface monitoring equipment, while drilling operations continue, has been the object of much inventive effort over the past forty years. One of the earliest descriptions of such a system is found in the July 15, 1935 issue of The Oil Weekly in an article entitled "Electric Logging Experiments Develop Attachments for Use on Rotary Rigs" by J. C. Karcher. In this article, Karcher described a system for transmitting geologic formation resistance data to the surface, while drilling.

A variety of data transmission systems have been proposed or attempted, but the industry leaders in oil and gas technology continue searching for new and improved systems for data transmission. Such attempts and proposals include the transmission of signals through cables in the drill string, or through cables suspended in the bore hole of the drill string; the transmission of signals by electromagnetic waves through the earth; the transmission of signals by acoustic or seismic waves through the drill pipe, the earth, or the mudstream; the transmission of signals by relay stations in the drill pipe, especially using transformer couplings at the pipe connections; the transmission of signals by way of releasing chemical or radioactive tracers in the mudstream; the storing of signals in a downhole recorder, with periodic or continuous retrieval; and the transmission of data signals over pressure pulses in the mudstream. See generally Arps, J. J. and Arps, J. L.: "The Subsurface Telemetry Problem — A Practical Solution", Journal of Petroleum Technology, May 1964, p. 487-93.

Many of these proposed approaches face a multitude of practical problems that foreclose any commercial development. In an article published in August of 1983, "Review of Downhole Measurement-While-Drilling Systems", Society of Petroleum Engineers Paper number 10036, Wilton Gravley reviewed the current state of measurement while drilling technology. In his view, only two approaches are presently commercially viable: telemetry through the drilling fluid by the generation of pressure-wave signals and telemetry through electrical conductors, or "hard-wires".

Pressure-wave data signals can be sent through the drilling fluid in two ways: a continuous wave method, or a pulse system.

In a continuous wave telemetry, a continuous pressure wave of fixed frequency is generated by rotating a valve in the mud stream. Data from downhole sensors is encoded on the pressure wave in digital form at the slow rate of 1.5 to 3 binary bits per second. The mud pulse signal loses half its amplitude for every 450 to 900 m

(1,500 to 3,000 feet) of depth, depending upon a variety of factors. At the surface, these pulses are detected and decoded. See generally the W. Gravley article, *supra*, p. 1440.

Data transmission using pulse telemetry operates several times slower than the continuous wave system. In this approach, pressure pulses are generated in the drilling fluid by either restricting the flow with a plunger or by passing small amounts of fluid from the inside of the drill string, through an orifice in the drill string, to the annulus. Pulse telemetry requires about a minute to transmit one information word. See generally the W. Gravley article, *supra*, p. 1440-41.

Despite the problems associated with drilling fluid telemetry, it has enjoyed some commercial success and promises to improve drilling economics. It has been used to transmit formation data, such as porosity, formation radioactivity, formation pressure, as well as drilling data such as weight on bit, mud temperature, and torque on bit.

Teleco Oilfield Services, Inc., developed the first commercially available mudpulse telemetry system, primarily to provide directional information, but now offers gamma logging as well. See Gravley article, *supra*; and "New MWD-Gamma System Finds Many Field Applications", by P. Seaton, A. Roberts, and L. Schoonover, *Oil & Gas Journal*, February 21, 1983, p. 80-84.

A mudpulse transmission system designed by Mobil R. & D. Corporation is described in "Development and Successful Testing of a Continuous-Wave, Logging-While-Drilling Telemetry System", *Journal of Petroleum Technology*, October 1977, by Patton, B. J. et al. This transmission system has been integrated into a complete measurement while drilling system by The Analyst/Schlumberger.

Exploration Logging, Inc., has a mudpulse measurement while drilling service that is in commercial use that aids in directional drilling, improves drilling efficiency, and enhances safety. Honeybourne, W.: "Future Measurement-While-Drilling Technology Will Focus On Two Levels", *Oil & Gas Journal*, March 4, 1985, p. 71-75. In addition, the Exlog system can be used to measure gamma ray emissions and formation resistivity while drilling occurs. Honeybourne, W.: "Formation MWD Benefits Evaluation and Efficiency", *Oil & Gas Journal*, February 25, 1985, p. 83-92.

The chief problems with drilling fluid telemetry include: 1) a slow data transmission rate; 2) high signal attenuation; 3) difficulty in detecting signals over mud pump noise; 4) the inconvenience of interfacing and harmonizing the data telemetry system with the choice of mud pump, and drill bit; 5) telemetry system interference with rig hydraulics; and 6) maintenance requirements. See generally, Hearn, E.: "How Operators Can Improve Performance of Measurement-While-Drilling Systems", *Oil & Gas Journal*, October 29, 1984, p. 80-84.

The use of electrical conductors in the trans-

mission of subsurface data also presents an array of unique problems. Foremost, is the difficulty of making a reliable electrical connection at each pipe junction.

Exxon Production Research Company developed a hardwire system that avoids the problems associated with making physical electrical connections at threaded pipe junctions. The Exxon telemetry system employs a continuous electrical cable that is suspended in the pipe bore hole.

Such an approach presents still different problems. The chief difficulty with having a continuous conductor within a string of pipe is that the entire conductor must be raised as each new joint of pipe is either added or removed from the drill string, or the conductor itself must be segmented like the joints of pipe in the string.

The Exxon approach is to use a longer, less frequently segmented conductor that is stored down hole in a spool that will yield more cable, or take up more slack, as the situation requires.

However, the Exxon solution requires that the drilling crew perform several operations to ensure that this system functions properly, and it requires some additional time in making trips. This system is adequately described in L. H. Robinson et al.: "Exxon Completes Wireline Drilling Data Telemetry System", *Oil & Gas Journal*, April 14, 1980, p. 137-48.

Shell Development Company has pursued a telemetry system that employs modified drill pipe, having electrical contact rings in the mating faces of each tool joint. A wire runs through the pipe bore, electrically connecting both ends of each pipe. When the pipe string is "made up" of individual joints of pipe at the surface, the contact rings are automatically mated.

While this system will transmit data at rates three orders of magnitude greater than the mud pulse systems, it is not without its own peculiar problems. If standard metallic-based tool joint compound, or "pipe dope", is used, the circuit will be shorted to ground. A special electrically non-conductive tool joint compound is required to prevent this. Also, since the transmission of the signal across each pipe junction depends upon good physical contact between the contact rings, each mating surface must be cleaned with a high pressure water stream before the special "dope" is applied and the joint is made-up.

The Shell system is well described in Denison, E. B.: "Downhole Measurements Through Modified Drill Pipe", *Journal Of Pressure Vessel Technology*, May 1977, p. 374-79; Denison, E. B.: "Shell's High-Data-Rate Drilling Telemetry System Passes First Test", *The Oil & Gas Journal*, June 13, 1977, p. 63-66; and Denison, E. B.: "High Data Rate Drilling Telemetry System", *Journal of Petroleum Technology*, February 1979, p. 155-63.

A search of the prior patent art reveals a history of attempts at substituting a transformer or capacitor coupling in each pipe connection in lieu of the hardwire connection. U.S. patent number 2,379,800, Signal Transmission System, by D. G.

Here, discloses the use of a transformer coupling at each pipe junction, and was issued in 1945. The principal difficulty with the use of transformers is their high power requirement. U.S. patent number 3,090,031, Signal Transmission System, by A. H. Lord, is addressed to these high power losses, and teaches the placement of an amplifier and a battery in each joint of pipe. This prior art is described by the preambles of the independent claims.

The high power losses at the transformer junction remained a problem, as the life of the battery became a critical consideration. In U.S. patent number 4,215,426, Telemetry and Power Transmission For Enclosed Fluid Systems, by F. Klatt, an acoustic energy conversion unit is employed to convert acoustic energy into electrical power for powering the transformer junction. This approach, however, is not a direct solution to the high power losses at the pipe junction, but rather is an avoidance of the larger problem.

Transformers operate upon Faraday's law of induction. Briefly, Faraday's law states that a time varying magnetic field produces an electromotive force which may establish a current in a suitable closed circuit. Mathematically, Faraday's law is: $emf = d\Phi/dt$ Volts; where emf is the electromotive force in volts, and $d\Phi/dt$ is the time rate of change of the magnetic flux. The negative sign is an indication that the emf is in such a direction as to produce a current whose flux, if added to the original flux, would reduce the magnitude of the emf . This principal is known as Lenz's Law.

An iron core transformer has two sets of windings wrapped about an iron core. The windings are electrically isolated, but magnetically coupled. Current flowing through one set of windings produces a magnetic flux that flows through the iron core and induces an emf in the second windings resulting in the flow of current in the second windings.

The iron core itself can be analyzed as a magnetic circuit, in a manner similar to dc electrical circuit analysis. Some important differences exist however, including the often nonlinear nature of ferromagnetic materials.

Briefly, magnetic materials have a reluctance to the flow of magnetic flux which is analogous to the resistance materials have to the flow of electric currents. Reluctance is a function of the length of a material, L , its cross section, S , and its permeability U . Mathematically, Reluctance = $L/(U*S)$, ignoring the nonlinear nature of ferromagnetic materials.

Any air gaps that exist in the transformer's iron core present a great impediment to the flow of magnetic flux. This is so because iron has a permeability that exceeds that of air by a factor of roughly four thousand. Consequently, a great deal of energy is expended in relatively small air gaps in a transformer's iron core. See generally, HAYT: Engineering Electro-Magnetics, McGraw Hill, 1974 Third Edition, p. 305-312.

The transformer couplings revealed in the above-mentioned patents operate as iron core

transformers with two air gaps. The air gaps exist because the pipe sections must be severable.

Attempts continue to further refine the transformer coupling, so that it might become practical. In U.S. patent number 4, 605,268, Transformer Cable Connector, by R. Meador, the idea of using a transformer coupling is further refined. Here the inventor proposes the use of closely aligned small toroidal coils to transmit data across a pipe junction.

To date none of the past efforts have yet achieved a commercially successful hardwire data transmission system for use in a well bore.

The object of the invention is to overcome the foregoing disadvantages of the prior art.

According to the invention this object is achieved in the devices and methods of the preambles of the independent claims by the features of the characterizing parts thereof. Embodiments of the invention are claimed in the dependent claims.

In a preferred embodiment, an electromagnetic field generating means, such as a coil and ferrite core, is employed to transmit electrical data signals across a threaded junction utilizing a magnetic field. The magnetic field is sensed by the adjacent connected tubular member through a Hall Effect sensor. The Hall Effect sensor produces an electrical signal which corresponds to magnetic field strength. This electrical signal is transmitted via an electrical conductor that preferably runs along the inside of the tubular member to a signal conditioning circuit for producing a uniform pulse corresponding to the electrical signal. This uniform pulse is sent to an electromagnetic field generating means for transmission across the subsequent threaded junction. In this manner, all the tubular members cooperate to transmit the data signals in an efficient manner.

The invention may be summarized as a method which includes the steps of sensing a borehole condition, generating an initial signal corresponding to the borehole condition, providing this signal to a desired tubular member, generating at each subsequent threaded connection a magnetic field corresponding to the initial signal, sensing the magnetic field at each subsequent threaded connection with a sensor capable of detecting constant and time-varying magnetic fields, generating an electrical signal in each subsequent tubular member corresponding to the sensed magnetic field, conditioning the generated electrical signal in each subsequent tubular member to regenerate the initial signal, and monitoring the initial signal corresponding to the borehole condition where desired.

Fig. 1 is a fragmentary longitudinal section of two tubular members connected by a threaded pin and box, exposing the various components that cooperate within the tubular members to transmit data signals across the threaded junction.

Fig. 2 is a fragmentary longitudinal section of a portion of a tubular member, revealing conducting means within a protective conduit.

Fig. 3 is a fragmentary longitudinal section of a portion of the pin of a tubular member, demonstrating the preferred method used to place the Hall Effect sensor within the pin.

Fig 4 is a view of a drilling rig with a drill string composed of tubular members adapted for the transmission of data signals from downhole sensors to surface monitoring equipment.

Fig. 5 is a circuit diagram of the signal conditioning means, which is carried within each tubular member.

The preferred data transmission system uses drill pipe with tubular connectors or tool joints that enable the efficient transmission of data from the bottom of a well bore to the surface. The configuration of the connectors will be described initially, followed by a description of the overall system.

In Fig. 1, a longitudinal section of the threaded connection between two tubular members 11, 13 is shown. Pin 15 of tubular member 11 is connected to box 17 of tubular member 13 by threads 18 and is adapted for receiving data signals, while box 17 is adapted for transmitting data signals.

Hall Effect sensor 19 resides in the nose of pin 15, as is shown in Fig. 3. A cavity 20 is machined into the pin 15, and a threaded sensor holder 22 is screwed into the cavity 20. Thereafter, the protruding portion of the sensor holder 22 is removed by machining.

Returning now to Fig. 1, the box 17 of tubular member 13 is counter bored to receive an outer sleeve 21 into which an inner sleeve 23 is inserted. Inner sleeve 23 is constructed of a nonmagnetic, electrically resistive substance, such as "Monel". The outer sleeve 21 and the inner sleeve 23 are sealed at 27, 27' and secured in the box 17 by snap ring 29 and constitute a signal transmission assembly 25. Outer sleeve 21 and inner sleeve 23 are in a hollow cylindrical shape so that the flow of drilling fluids through the bore 31, 31' of tubular members 11, 13 is not impeded.

Protected within the inner sleeve 23, from the harsh drilling environment, is an electromagnet 32, in this instance, a coil 33 wrapped about a ferrite core 35 (obscured from view by coil 33), and signal conditioning circuit 39. The coil 33 and core 35 arrangement is held in place by retaining ring 36.

Power is provided to Hall Effect sensor 19, by a lithium battery 41, which resides in battery compartment 43, and is secured by cap 45 sealed at 46, and snap ring 47. Power flows to Hall Effect sensor 19 over conductors 49, 50 contained in a drilled hole 51. The signal conditioning circuit 39 within tubular member 13 is powered by a battery similar to 41 contained at the pin end (not depicted) of tubular member 13.

Two signal wires 53, 54 reside in cavity 51, and conduct signal from the Hall Effect sensor 19. Wires 53, 54 pass through the cavity 51, around the battery 41, and into a protective metal conduit 57 for transmission to a signal conditioning circuit and coil and core arrangement in the upper end

(not shown) of tubular member 11 identical to that found in the box of tubular member 13.

Two power conductors 55, 56 connect the battery 41 and the signal conditioning circuit at the opposite end (not shown) of tubular member 11. Battery 41 is grounded to tubular member 11, which becomes the return conductor for power conductors 55, 56. Thus, a total of four wires are contained in conduit 57.

Conduit 57 is silver brazed to tubular member 11 to protect the wiring from the hostile drilling environment. In addition, conduit 57 serves as an electrical shield for signal wires 53 and 54.

A similar conduit 57' in tubular member 13 contains signal wires 53', 54' and conductors 55', 56' that lead to the circuit board and signal conditioning circuit 39 from a battery (not shown) and Hall Effect sensor (not shown) in the opposite end of tubular member 13.

Turning now to Fig. 2, a mid-region of conduit 57 is shown to demonstrate that it adheres to the wall of the bore 31 through the tubular member 11, and will not interfere with the passage of drilling fluid or obstruct wireline tools. In addition, conduit 57 shields signal wires 53, 54 and conductors 55, 56 from the harsh drilling environment. The tubular member 11 consists generally of a tool joint 59 welded at 61 to one end of a drill pipe 63.

Fig. 5 is an electrical circuit drawing depicting the preferred signal processing means 111 between Hall Effect sensor 19 and electromagnetic field generating means 114, which in this case is coil 33 and core 35. The signal conditioning means 111 can be subdivided by function into two portions, a signal amplifying means 119 and a pulse generating means 121. Within the signal amplifying means 119, the major components are operational amplifiers 123, 125, and 127. Within the pulse generating means 121, the major components are comparator 129 and multivibrator 131. Various resistors and capacitors are selected to cooperate with these major components to achieve the desired conditioning at each stage.

As shown in Fig. 5, magnetic field 32 exerts a force on Hall Effect sensor 19, and creates a voltage pulse across terminals A and B of Hall Effect sensor 19. Hall Effect sensor 19 has the characteristics of a Hall Effect semiconductor element, which is capable of detecting constant and time-varying magnetic fields. It is distinguishable from sensors such as transformer coils that detect only changes in magnetic flux. Yet another difference is that a coil sensor requires no power to detect time varying fields, while a Hall Effect sensor has power requirements.

Hall Effect sensor 19 has a positive input connected to power conductor 49 and a negative input connected to power conductor 50. The power conductors 49, 50 lead to battery 41.

Operational amplifier 123 is connected to the output terminals A, B of Hall Effect sensor 19 through resistors 135, 137. Resistor 135 is connected between the inverting input of operational amplifier 123 and terminal A through signal con-

ductor 53. Resistor 137 is connected between the noninverting input of operational amplifier 123 and terminal B through signal conductor 54. A resistor 133 is connected between the inverting input and the output of operational amplifier 123. A resistor 139 is connected between the noninverting input of operational amplifier 123 and ground. Operational amplifier 123 is powered through a terminal L which is connected to power conductor 56. Power conductor 56 is connected to the positive terminal of battery 41.

Operational amplifier 123 operates as a differential amplifier. At this stage, the voltage pulse is amplified about threefold. Resistance values for gain resistors 133 and 135 are chosen to set this gain. The resistance values for resistors 137 and 139 are selected to complement the gain resistors 137 and 139.

Operational amplifier 123 is connected to operational amplifier 125 through a capacitor 141 and resistor 143. The amplified voltage is passed through capacitor 141, which blocks any dc component, and obstructs the passage of low frequency components of the signal. Resistor 143 is connected to the inverting input of operational amplifier 125.

A capacitor 145 is connected between the inverting input and the output of operational amplifier 125. The noninverting input or node C of operational amplifier 125 is connected to a resistor 147. Resistor 147 is connected to the terminal L, which leads through conductor 56 to battery 41. A resistor 149 is connected to the noninverting input of operational amplifier 125 and to ground. A resistor 151 is connected in parallel with capacitor 145.

At operational amplifier 125, the signal is further amplified by about twenty fold. Resistor values for resistors 143, 151 are selected to set this gain. Capacitor 145 is provided to reduce the gain of high frequency components of the signal that are above the desired operating frequencies. Resistors 147 and 149 are selected to bias node C at about one-half the battery 41 voltage.

Operational amplifier 125 is connected to operational amplifier 127 through a capacitor 153 and a resistor 155. Resistor 155 leads to the inverting input of operational amplifier 127. A resistor 157 is connected between the inverting input and the output of operational amplifier 127. The noninverting input or node D of operational amplifier 127 is connected through a resistor 159 to the terminal L. Terminal L leads to battery 41 through conductor 56. A resistor 161 is connected between the noninverting input of operational amplifier 127 and ground.

The signal from operational amplifier 125 passes through capacitor 153 which eliminates the dc component and further inhibits the passage of the lower frequency components of the signal. Operational amplifier 127 inverts the signal and provides an amplification of approximately thirty fold, which is set by the selection of resistors 155 and 157. The resistors 159 and 161 are selected to provide a dc level at node D.

Operational amplifier 127 is connected to comparator 129 through a capacitor 163 to eliminate the dc component. The capacitor 163 is connected to the inverting input of comparator 129. Comparator 129 is part of the pulse generating means 121 and is an operational amplifier operated as a comparator. A resistor 165 is connected to the inverting input of comparator 129 and to terminal L. Terminal L leads through conductor 56 to battery 41. A resistor 167 is connected between the inverting input of comparator 129 and ground. The noninverting input of comparator 129 is connected to terminal L through resistor 169. The noninverting input is also connected to ground through series resistors 171, 173.

Comparator 129 compares the voltage at the inverting input node E to the voltage at the noninverting input node F. Resistors 165 and 167 bias node E of comparator 129 to one-half of the battery 41 voltage. Resistors 169, 171, and 173 cooperate together to hold node F at a voltage value above one-half the battery 41 voltage.

When no signal is provided from the output of operational amplifier 127, the voltage at node E is less than the voltage at node F, and the output of comparator 129 is in its ordinary high state (i.e., at supply voltage). The difference in voltage between nodes E and nodes F should be sufficient to prevent noise voltage levels from activating the comparator 129. However, when a signal arrives at node E, the total voltage at node E will exceed the voltage at node F. When this happens, the output of comparator 129 goes low and remains low for as long as a signal is present at node E.

Comparator 129 is connected to multivibrator 131 through capacitor 175. Capacitor 175 is connected to pin 2 of multivibrator 131. Multivibrator 131 is preferably an L555 monostable multivibrator.

A resistor 177 is connected between pin 2 of multivibrator 131 and ground. A resistor 179 is connected between pin 4 and pin 2. A capacitor 181 is connected between ground and pins 6, 7. Capacitor 181 is also connected through a resistor 183 to pin 8. Power is supplied through power conductor 55 to pins 4, 8. Conductor 55 leads to the battery 41 as does conductor 56, but is a separate wire from conductor 56. The choice of resistors 177 and 179 serves to bias input pin 2 or node G at a voltage value above one-third of the battery 41.

A capacitor 185 is connected to ground and to conductor 55. Capacitor 185 is an energy storage capacitor and helps to provide power to multivibrator 131 when an output pulse is generated. A capacitor 187 is connected between pin 5 and ground. Pin 1 is grounded. Pins 6, 7 are connected to each other. Pins 4, 8 are also connected to each other. The output pin 3 is connected to a diode 189 and to coil 33 through a conductor 193. A diode 191 is connected between ground and the cathode of diode 189.

The capacitor 175 and resistors 177, 179 provide an RC time constant so that the square pulses at the output of comparator 129 are trans-

formed into spiked trigger pulses. The trigger pulses from comparator 129 are fed into the input pin 2 of multivibrator 131. Thus, multivibrator 131 is sensitive to the "low" outputs of comparator 129. Capacitor 181 and resistor 183 are selected to set the pulse width of the output pulse at output pin 3 or node H. In this embodiment, a pulse width of 100 microseconds is provided.

The multivibrator 131 is sensitive to "low" pulses from the output of comparator 129, but provides a high pulse, close to the value of the battery 41 voltage, as an output. Diodes 189 and 191 are provided to inhibit any ringing, or oscillation encountered when the pulses are sent through conductor 193 to the coil 33. More specifically, diode 191 absorbs the energy generated by the collapse of the magnetic field. At coil 33, a magnetic field 32' is generated for transmission of the data signal across the subsequent junction between tubular members.

As illustrated in Fig. 4, the previously described apparatus is adapted for data transmission in a well bore.

A drill string 211 supports a drill bit 213 within a well bore 215 and includes a tubular member 217 having a sensor package (not shown) to detect downhole conditions. The tubular members 11, 13 shown in Fig. 1 just below the surface 218 are typical for each set of connectors, containing the mechanical and electronic apparatus of Figs. 1 and 5.

The upper end of tubular member and sensor package 217 is preferably adapted with the same components as tubular member 13, including a coil 33 to generate a magnetic field. The lower end of connector 227 has a Hall Effect sensor, like sensor 19 in the lower end of tubular member 11 in Fig. 1.

Each tubular member 219 in the drill string 211 has one end adapted for receiving data signals and the other end adapted for transmitting data signals.

The tubular members cooperate to transmit data signals up the borehole 215. In this illustration, data is being sensed from the drill bit 213, and from the formation 221, and is being transmitted up the drill string 211 to the drilling rig 229, where it is transmitted by suitable means such as radio waves 231 to surface monitoring and recording equipment 233. Any suitable commercially available radio transmission system may be employed. One type of system that may be used is a PMD "Wireless Link", receiver model R102 and transmitter model T201A.

In operation of the electrical circuitry shown in Fig. 5, dc power from battery 41 is supplied to the Hall Effect sensor 19, operational amplifiers 123, 125, 127, comparator 129, and multivibrator 131. Referring also to Fig. 4, data signals from sensor package 217 cause an electromagnetic field 32 to be generated at each threaded connection of the drill string 211.

In each tubular member, the electromagnetic field 32 causes an output voltage pulse on terminals A, B of Hall Effect sensor 19. The voltage

pulse is amplified by the operational amplifiers 123, 125 and 127. The output of comparator 129 will go low on receipt of the pulse, providing a sharp negative trigger pulse. The multivibrator 131 will provide a 100 millisecond pulse on receipt of the trigger pulse from comparator 129. The output of multivibrator 131 passes through coil 33 to generate an electromagnetic field 32' for transmission to the next tubular member.

This invention has many advantages over existing hardwire telemetry systems. A continuous stream of data signals pulses, containing information from a large array of downhole sensors can be transmitted to the surface in real time. Such transmission does not require physical contact at the pipe joints, nor does it involve the suspension of any cable downhole. Ordinary drilling operations are not impeded significantly; no special pipe dope is required, and special involvement of the drilling crew is minimized.

Moreover, the high power losses associated with a transformer coupling at each threaded junction are avoided. Each tubular member has a battery for powering the Hall Effect sensor, and the signal conditioning means; but such battery can operate in excess of a thousand hours due to the overall low power requirements of this invention.

The present invention employs efficient electromagnetic phenomena to transmit data signals across the junction of threaded tubular members. The preferred embodiment employs the Hall Effect, which was discovered in 1879 by Dr. Edwin Hall. Briefly, the Hall Effect is observed when a current carrying conductor is placed in a magnetic field. The component of the magnetic field that is perpendicular to the current exerts a Lorentz force on the current. This force disturbs the current distribution, resulting in a potential difference across the current path. This potential difference is referred to as the Hall voltage.

The basic equation describing the interaction of the magnetic field and the current, resulting in the Hall voltage is:

$$V_H = (R_H/t) * I_c * B * \sin X, \text{ where:}$$

I_c is the current flowing through the Hall sensor;
 $B \sin X$ is the component of the magnetic field that is perpendicular to the current path;

R_H is the Hall coefficient; and
 t is the thickness of the conductor sheet.

If the current is held constant, and the other constants are disregarded, the Hall voltage will be directly proportional to the magnetic field strength.

The foremost advantages of using the Hall Effect to transmit data across a pipe junction are the ability to transmit data signals across a threaded junction without making a physical contact, the low power requirements for such transmission, and the resulting increase in battery life.

This invention has several distinct advantages over the mudpulse transmission systems that are commercially available, and which represent the

state of the art. Foremost is the fact that this invention can transmit data at two to three orders of magnitude faster than the mudpulse systems. This speed is accomplished without any interference with ordinary drilling operations. Moreover, the signal suffers no overall attenuation since it is regenerated in each tubular member.

Claims

1. An improved data transmission system for use in a well bore, comprising:

a tubular member (11, 13) with threaded ends (15, 17) adapted for connection in a drill string having one end adapted for transmitting data signals and the other end adapted for receiving data signals;

a power supply means (41), located in the tubular member, and an electromagnetic field generating means (33) carried by the transmitting end of the tubular member; characterized

a Hall Effect sensor means (19) carried by the receiving end of the tubular member for receiving data signals; and

a signal conditioning means (39) located in the tubular member and electrically connected to the Hall Effect sensor means (19) and to the electromagnetic field generating means (33) for shaping the data signals received by the Hall Effect sensor means (19), prior to transmission by the electromagnetic field generating means (33);

said power supply means (41) providing electrical power to the Hall Effect sensor (19) means and the signal conditioning means (39).

2. A drill string having a plurality of sections (11, 13) connected together, having one end adapted for receiving data signals and the other end adapted for transmitting data signals, and an improved means for transmitting electrical signals through the string which comprises:

an electromagnetic field generating means (33) mounted in the transmitting end of each section; and a power supply means (41) located in each section;

characterized in that said electrical signal transmitting means further comprises:

a Hall Effect sensor (19) mounted in the receiving end of each section for sensing an electromagnetic field and for producing electrical signals corresponding thereto;

a signal conditioning means (39) located in each section for shaping the electrical signals produced by the Hall Effect sensor;

said electromagnetic field generating means (33) mounted in the transmitting end of each section generating an electromagnetic field corresponding to the processed electrical signals produced by the signal conditioning means (39);

said power supply means (41) providing electrical power to the Hall Effect sensor and the signal conditioning means; and

an electrical conduction means (49, 50, 53-56)

communicating between the Hall Effect sensor (19), the signal conditioning means (39), the electromagnetic field producing means (33), and the power supply means (41).

3. The improved data transmission system of claim 1, wherein

said tubular member has a pin end (15) adapted for receiving data signals and a box end (17) adapted for transmitting data signals;

said Hall Effect sensor (19) is mounted in the pin end (15) of the tubular member;

said electromagnetic field generating means (33) includes an electromagnet (32) mounted in the box end (17) of the tubular member for generating a magnetic field in response to the output of the signal conditioning means (39); and wherein

an electrical conducting means (53-56) is provided for communicating between the Hall Effect sensor (19), the signal conditioning means (39), and the electromagnet.

4. The drill string of claim 2, wherein each section has a box (17) on the upper end of each section and a pin (15) on the lower end of each section;

the Hall Effect sensor (19) is mounted in the pin (15) of each section; and wherein

the electromagnetic field generating means (33) comprises an electromagnet (32) mounted in the box (17) of each section.

5. The drill string of claim 4, wherein the Hall Effect sensor (19) is responsive to the magnetic flux density of a magnetic field for generating a Hall voltage corresponding thereto;

the signal conditioning means (39) comprises a signal amplifying means (119) for amplifying and filtering the Hall voltage generated by the Hall Effect sensor (19), electrically connected to the Hall Effect sensor and located in each tubular member; and wherein

a pulse generating means (121) is provided for producing a pulse of uniform amplitude and duration in response to the amplified and filtered Hall voltage, electrically connected to the signal amplifying means (119) and located in each tubular member; and wherein

the electromagnetic field generating means (33) comprises a coil wrapped about a ferromagnetic HF core (35) located in the box (17) of each tubular member and electrically connected to the pulse generating means (121) for producing an electromagnetic field in response to the pulse.

6. The improved data transmission system of claim 3, wherein:

the Hall Effect sensor (19) is responsive to the magnetic flux density of a magnetic field, for generating a Hall voltage corresponding thereto;

the signal conditioning means (39) comprises a signal amplifying means (119) and a pulse generating means (121), electrically connected to the Hall Effect sensor (19) and located in each tubular member;

said signal amplifying means (119) amplifies the Hall voltage generated by the Hall Effect

state of the art. Foremost is the fact that this invention can transmit data at two to three orders of magnitude faster than the mudpulse systems. This speed is accomplished without any interference with ordinary drilling operations. Moreover, the signal suffers no overall attenuation since it is regenerated in each tubular member.

Claims

1. An improved data transmission system for use in a well bore, comprising:

a tubular member (11, 13) with threaded ends (15, 17) adapted for connection in a drill string having one end adapted for transmitting data signals and the other end adapted for receiving data signals;

a power supply means (41), located in the tubular member, and an electromagnetic field generating means (33) carried by the transmitting end of the tubular member; characterized

by a Hall Effect sensor means (19) carried by the receiving end of the tubular member for receiving data signals; and

a signal conditioning means (39) located in the tubular member and electrically connected to the Hall Effect sensor means (19) and to the electromagnetic field generating means (33) for shaping the data signals received by the Hall Effect sensor means (19), prior to transmission by the electromagnetic field generating means (33);

said power supply means (41) providing electrical power to the Hall Effect sensor (19) means and the signal conditioning means (39).

2. A drill string having a plurality of sections (11, 13) connected together, having one end adapted for receiving data signals and the other end adapted for transmitting data signals; and an improved means for transmitting electrical signals through the string which comprises:

an electromagnetic field generating means (33) mounted in the transmitting end of each section; and a power supply means (41) located in each section;

characterized in that said electrical signal transmitting means further comprises:

a Hall Effect sensor (19) mounted in the receiving end of each section for sensing an electromagnetic field and for producing electrical signals corresponding thereto;

a signal conditioning means (39) located in each section for shaping the electrical signals produced by the Hall Effect sensor;

said electromagnetic field generating means (33) mounted in the transmitting end of each section generating an electromagnetic field corresponding to the processed electrical signals produced by the signal conditioning means (39);

said power supply means (41) providing electrical power to the Hall Effect sensor and the signal conditioning means; and

an electrical conduction means (49, 50, 53-56)

communicating between the Hall Effect sensor (19), the signal conditioning means (39), the electromagnetic field producing means (33), and the power supply means (41).

3. The improved data transmission system of claim 1, wherein

said tubular member has a pin end (15) adapted for receiving data signals and a box end (17) adapted for transmitting data signals;

said Hall Effect sensor (19) is mounted in the pin end (15) of the tubular member;

said electromagnetic field generating means (33) includes an electromagnet (32) mounted in the box end (17) of the tubular member for generating a magnetic field in response to the output of the signal conditioning means (39); and wherein

an electrical conducting means (53-56) is provided for communicating between the Hall Effect sensor (19), the signal conditioning means (39), and the electromagnet.

4. The drill string of claim 2, wherein each section has a box (17) on the upper end of each section and a pin (15) on the lower end of each section;

the Hall Effect sensor (19) is mounted in the pin (15) of each section; and wherein

the electromagnetic field generating means (33) comprises an electromagnet (32) mounted in the box (17) of each section.

5. The drill string of claim 4, wherein the Hall Effect sensor (19) is responsive to the magnetic flux density of a magnetic field for generating a Hall voltage corresponding thereto;

the signal conditioning means (39) comprises a signal amplifying means (119) for amplifying and filtering the Hall voltage generated by the Hall Effect sensor (19), electrically connected to the Hall Effect sensor and located in each tubular member; and wherein

a pulse generating means (121) is provided for producing a pulse of uniform amplitude and duration in response to the amplified and filtered Hall voltage, electrically connected to the signal amplifying means (119) and located in each tubular member; and wherein

the electromagnetic field generating means (33) comprises a coil wrapped about a ferromagnetic HF core (35) located in the box (17) of each tubular member and electrically connected to the pulse generating means (121) for producing an electromagnetic field in response to the pulse.

6. The improved data transmission system of claim 3, wherein:

the Hall Effect sensor (19) is responsive to the magnetic flux density of a magnetic field, for generating a Hall voltage corresponding thereto;

the signal conditioning means (39) comprises a signal amplifying means (119) and a pulse generating means (121), electrically connected to the Hall Effect sensor (19) and located in each tubular member;

said signal amplifying means (119) amplifies the Hall voltage generated by the Hall Effect



sensor (19);

said pulse generating means (121) produces a pulse of uniform amplitude and duration in response to the amplified Hall voltage; and wherein

said electromagnetic field generating means (33) comprises a ferrite core (35) located in the box (17) of each tubular member, and

a coil (33) wrapped about the ferrite core (35) and electrically connected to the signal conditioning means (121), for producing an electromagnetic field in response to the pulse produced by the pulse generating means.

7. A method of data transmission a well bore (215) having a string of tubular members (219) with threaded connectors (227) suspended within it, the method comprising the steps of:

sensing a borehole condition;

generating an initial signal corresponding to the sensed borehole condition;

providing the initial signal to a desired tubular member;

generating at each subsequent threaded connection a magnetic field corresponding to the initial signal;

sensing the magnetic field at each subsequent threaded connection;

generating an electrical signal in each subsequent tubular member that corresponds to the sensed magnetic field; and monitoring the borehole condition; characterized in that:

the magnetic field is sensed with a sensor (19) capable of detecting constant and time-varying magnetic fields and the generated electrical signal is conditioned in each subsequent tubular member to regenerate the initial signal.

8. The method of transmitting a data signal of claim 7 for transmitting the data to a desired location comprising:

repeating the steps thereof at each threaded connection until the data signal arrives at the desired location; and

monitoring the data signal at the desired location.

9. The method of data transmission of claim 8, wherein

the borehole condition is monitored at the earth's surface.

10. A method of logging while drilling utilizing a plurality of connected threaded tubular members (219) suspended in a well bore (215), the method comprising the steps of:

sensing a formation condition;

generating an initial signal corresponding to the sensed formation condition;

providing the initial signal to a desired tubular member;

generating at each subsequent threaded connection a magnetic field corresponding to the initial signal;

sensing the magnetic field at each subsequent threaded connection;

generating an electrical signal in each subsequent tubular member that corresponds to the sensed magnetic field; and

monitoring the formation condition; characterized in that:

the magnetic field is sensed with a sensor (19) capable of detecting constant and time-varying magnetic fields;

the generated electrical signal is conditioned in each subsequent tubular member to regenerate the initial signal; and

the formation condition is recorded.

Patentansprüche

1. Verbessertes Datenübertragungssystem zur Verwendung in einem Bohrloch, mit:

einem rohrförmigen Teil (11, 13) mit Gewindeenden (15, 17) zur Verbindung in einem Bohrgestänge, wobei ein Ende zum Senden von Datensignalen und das andere Ende zum Empfangen von Datensignalen ausgebildet ist;

einer Stromversorgungseinrichtung (41), die in dem rohrförmigen Teil angeordnet ist, und einer elektromagnetischen Felderzeugungseinrichtung (33), die durch das Sendeende des rohrförmigen Teils gehalten ist; gekennzeichnet durch:

eine Hall-Sensoreinrichtung (19) die durch das Empfangsende des rohrförmigen Teils zum Empfangen von Datensignalen gehalten ist; und

eine Signalformeinrichtung (39), die in dem rohrförmigen Teil angeordnet und mit der Hall-Sensoreinrichtung (19) und mit der elektromagnetischen Felderzeugungseinrichtung (33) elektrisch verbunden ist, um die durch die Hall-Sensoreinrichtung (19) empfangenen Datensignale zu formen, bevor sie durch die elektromagnetische Felderzeugungseinrichtung (33) gesendet werden;

wobei die Stromversorgungseinrichtung (41) die Hall-Sensoreinrichtung (19) und die Signalformeinrichtung (39) mit elektrischem Strom versorgt.

2. Bohrgestänge mit mehreren Abschnitten (11, 13), die miteinander verbunden sind, wobei ein Ende zum Empfangen von Datensignalen und das andere Ende zum Senden von Datensignalen ausgebildet ist, und mit einer verbesserten Einrichtung zum Übertragen von elektrischen Signalen über das Gestänge, welche beinhaltet:

eine elektromagnetische Felderzeugungseinrichtung (33), die in dem Sendeende jedes Abschnitts befestigt ist; und eine Stromversorgungseinrichtung (41), die in jedem Abschnitt vorgesehen ist;

dadurch gekennzeichnet, daß die Einrichtung zum Übertragen von elektrischen Signalen weiter umfaßt:

einen Hall-Sensor (19), der in dem Empfangsende jedes Abschnitts befestigt ist, zum Erfassen eines elektromagnetischen Feldes und zum Erzeugen von diesem entsprechenden elektrischen Signalen;

eine Signalformeinrichtung (39), die in jedem Abschnitt vorgesehen ist, zum Formen der durch den Hall-Sensor erzeugten elektrischen Signale;

wobei die elektromagnetische Felderzeugungs-



einrichtung (33), die in dem Sendeende jedes Abschnitts befestigt ist, ein elektromagnetisches Feld erzeugt, das den verarbeiteten elektrischen Signalen entspricht, die durch die Signalformeinrichtung (39) erzeugt werden;

wobei die Stromversorgungseinrichtung (41) den Hall-Sensor und die Signalformeinrichtung mit elektrischem Strom versorgt; und

eine elektrische Leitungseinrichtung (49, 50, 53-56) die eine Verbindung zwischen dem Hall-Sensor (19), der Signalformeinrichtung (39), der elektromagnetischen Felderzeugungseinrichtung (33) und der Stromversorgungseinrichtung (41) bildet.

3. Verbessertes Datenübertragungssystem nach Anspruch 1, wobei das rohrförmige Teil ein Zapfenende (15) hat, das zum Empfangen von Datensignalen vorgesehen ist, und ein Muffenende (17), das zum Senden von Datensignalen vorgesehen ist;

wobei der Hall-Sensor (19) in dem Zapfenende (15) des rohrförmigen Teils befestigt ist;

wobei die elektromagnetische Felderzeugungseinrichtung (33) einen Elektromagnet (32) aufweist, der in dem Muffenende (17) des rohrförmigen Teils befestigt ist, zum Erzeugen eines Magnetfeldes, aufgrund des Ausgangssignals der Signalformeinrichtung (39); und

wobei eine elektrische Leitungseinrichtung (53-56) vorgesehen ist, die eine Verbindung zwischen dem Hall-Sensor (19), der Signalformeinrichtung (39) und dem Elektromagnet bildet.

4. Bohrgestänge nach Anspruch 2, wobei jeder Abschnitt eine Muffe (17) an dem oberen Ende jedes Abschnitts und einen Zapfen (15) an dem unteren Ende jedes Abschnitts hat;

wobei der Hall-Sensor (19) in dem Zapfen (15) jedes Abschnitts befestigt ist; und

wobei die elektromagnetische Felderzeugungseinrichtung (33) einen Elektromagnet (32) aufweist, der in der Muffe (17) jedes Abschnitts befestigt ist.

5. Bohrgestänge nach Anspruch 4, wobei der Hall-Sensor (19) auf die Magnetflußdichte eines Magnetfeldes hin eine Hall-Spannung erzeugt, die dieser entspricht;

wobei die Signalformeinrichtung (39) eine Signalverstärkungseinrichtung (119) zum Verstärken und Filtern der durch den Hall-Sensor (19) erzeugten Hall-Spannung enthält, die mit dem Hall-Sensor elektrisch verbunden ist und in jedem rohrförmigen Teil vorgesehen ist; und

wobei eine Impulserzeugungseinrichtung (121) vorgesehen ist zum Erzeugen eines Impulses mit gleichmäßiger Amplitude und Dauer aufgrund der verstärkten und gefilterten Hall-Spannung, die mit der Signalverstärkungseinrichtung (119) verbunden und in jedem rohrförmigen Teil angeordnet ist; und

wobei die elektromagnetische Felderzeugungseinrichtung (33) eine Spule aufweist, die um einen ferromagnetischen HF-Kern (35), der in der Muffe (17) jedes rohrförmigen Teils vorgesehen ist, gewickelt und mit der Impulserzeu-

gungseinrichtung (121) elektrisch verbunden ist, um aufgrund des Impulses ein elektromagnetisches Feld zu erzeugen.

6. Verbessertes Datenübertragungssystem nach Anspruch 3, wobei:

der Hall-Sensor (19) auf die magnetische Flußdichte eines Magnetfeldes anspricht, um eine dieser entsprechende Hall-Spannung zu erzeugen;

wobei die Signalformeinrichtung (39) eine Signalverstärkungseinrichtung (119) und eine Impulserzeugungseinrichtung (121) enthält, die mit dem Hall-Sensor (19) verbunden und in jedem rohrförmigen Teil vorgesehen sind;

wobei die Signalverstärkungseinrichtung (119) die durch den Hall-Sensor (19) erzeugte Hall-Spannung verstärkt;

wobei die Impulserzeugungseinrichtung (121) einen Impuls mit gleichmäßiger Amplitude und Dauer aufgrund der verstärkten Hall-Spannung erzeugt;

wobei die elektromagnetische Felderzeugungseinrichtung (33) einen Ferritkern (35) enthält, der in der Muffe (17) jedes rohrförmigen Teils vorgesehen ist, und

eine Spule (33), die um den Ferritkern (35) gewickelt und mit der Signalformeinrichtung (121) elektrisch verbunden ist, zum Erzeugen eines elektromagnetischen Feldes aufgrund des Impulses, der durch die Impulserzeugungseinrichtung erzeugt wird.

7. Verfahren zur Datenübertragung in einem Bohrloch (215), in welchem ein Strang von rohrförmigen Teilen (21a) mit Gewindeverbindern (227) aufgehängt ist, wobei das Verfahren die Schritte beinhaltet:

Erfassen eines Bohrlochzustands;

Erzeugen eines Anfangssignals, das dem erfaßten Bohrlochzustand entspricht;

Abgeben des Anfangssignals an ein gewünschtes rohrförmiges Teil;

Erzeugen eines Magnetfeldes in jeder folgenden Gewindeverbindung, das dem Anfangssignal entspricht;

Erfassen des Magnetfeldes an jeder folgenden Gewindeverbindung;

Erzeugen eines elektrischen Signals in jedem folgenden rohrförmigen Teil, welches dem erfaßten Magnetfeld entspricht; und Überwachen des Bohrlochzustands;

dadurch gekennzeichnet, daß:

das Magnetfeld mit einem Sensor (1a) erfaßt wird, der in der Lage ist, konstante und zeitlich veränderliche Magnetfelder zu erfassen, und daß das erzeugte elektrische Signal in jedem folgenden rohrförmigen Teil geformt wird, um das Anfangssignal zu regenerieren.

8. Verfahren zum Übertragen eines Datensignals nach Anspruch 7, zum Übertragen der Daten zu einer gewünschten Stelle, beinhaltend:

Wiederholen der Schritte desselben an jeder Gewindeverbindung bis das Datensignal an der gewünschten Stelle ankommt; und Überwachen des Datensignals an der gewünschten Stelle.

9. Verfahren zur Datenübertragung nach



Anspruch 8, wobei der Bohrlochzustand an der Erdoberfläche überwacht wird.

10. Verfahren zum Messen während des Bohrens unter Verwendung von mehreren miteinander verbundenen, mit Gewinde versehenen rohrförmigen Teilen (21a), die in einem Bohrloch (215) aufgehängt sind, wobei das Verfahren die Schritte beinhaltet:

Erfassen eines Formationszustands;

Erzeugen eines Anfangssignals, das dem erfaßten Formationszustand entspricht;

Abgeben des Anfangssignals an ein gewünschtes rohrförmiges Teil;

Erzeugen eines Magnetfeldes, das dem Anfangssignal entspricht, an jeder folgenden Gewindeverbindung;

Erfassen des Magnetfeldes an jeder folgenden Gewindeverbindung;

Erzeugen eines elektrischen Signals in jedem folgenden rohrförmigen Teil, das dem erfaßten Magnetfeld entspricht; und Überwachen des Formationszustands: dadurch gekennzeichnet, daß:

das Magnetfeld mit einem Sensor (1a) erfaßt wird, der in der Lage ist, konstante und zeitlich veränderliche Magnetfelder zu erfassen;

das erzeugte elektrische Signal in jedem folgenden rohrförmigen Teil geformt wird, um das Anfangssignal zu regenerieren; und

der Formationszustand aufgezeichnet wird.

Revendications

1. Perfectionnements aux systèmes de transmission de données utilisés dans les puits de forage comprenant:

un élément tubulaire (11, 13) possédant des extrémités filetées (15, 17) conçues pour être connectées à une extrémité d'une tige de forage conçue pour la transmission de signaux de données, l'autre extrémité étant conçue pour recevoir les signaux de données;

des moyens d'alimentation de puissance (41) disposés dans un élément tubulaire, et

des moyens (33) de production d'un champ magnétique supportés par l'extrémité de transmission de l'élément tubulaire;

caractérisé en ce qu'il comporte des moyens capteurs (19) à effet Hall supportés par l'extrémité de réception de l'élément tubulaire pour recevoir les signaux de données; et

des moyens de traitement du signal (39) disposés dans l'élément tubulaire et reliés électriquement aux moyens capteurs à effet Hall (19) et aux moyens de production de champ magnétique (33) pour mettre en forme les signaux de données reçus par les moyens capteurs à effet Hall (19) avant la transmission par les moyens de production de champ magnétique (33),

des moyens d'alimentation de puissance (41) fournissant la puissance électrique aux moyens capteurs à effet Hall (19) et aux moyens de traitement des signaux (39).

2. Tige de forage comportant une pluralité de sections (11, 13) reliées ensemble, possédant une extrémité conçue pour recevoir les signaux de

données et l'autre extrémité conçue pour transmettre les signaux de données et des moyens pour transmettre les signaux électriques au travers de la tige de forage qui comprennent:

des moyens de production de champ magnétique (33) monté à l'extrémité de transmission de chaque section, et des moyens d'alimentation en puissance (41) disposés dans chaque section;

caractérisée en ce que les moyens de transmission des signaux électriques comprennent de plus:

un capteur à effet Hall (19) monté dans l'extrémité de réception de chaque section pour mesurer un champ électromagnétique et pour produire des signaux électriques correspondants à celui-ci; des moyens de traitement du signal (39) disposés dans chaque section pour mettre en forme les signaux électriques produits par le capteur à effet Hall;

des moyens de production de champ électromagnétique (33) disposés à l'extrémité de transmission de chaque section produisant un champ électromagnétique correspondant aux signaux électriques traités produits par les moyens du traitement de signal (39);

des moyens d'alimentation de puissance (41) fournissant la puissance électrique au capteur à effet Hall et aux moyens de traitement du signal; et

des moyens de conduction électrique (49, 50, 53-56) communiquant entre le capteur à effet Hall (19) et les moyens (39) de traitement du signal, les moyens de production de champ électromagnétique (33) et les moyens d'alimentation de puissance (41).

3. Système de transmission de données perfectionné suivant la revendication 1 caractérisé en ce que l'élément tubulaire comporte une extrémité en forme de broche (15) conçue pour recevoir les signaux de donnée et une extrémité en forme de boîte (17) conçue pour la transmission des signaux de donnée;

le capteur à effet Hall (19) est monté sur l'extrémité en forme de broche (15) de l'élément tubulaire;

les moyens de production du champ électromagnétique (33) comprennent un électroaimant (32) disposé sur l'extrémité en forme de boîte (17) de l'élément tubulaire pour produire un champ magnétique en réponse à la sortie des moyens de traitement de signal (39), et dans lequel:

des moyens de conduction électrique (53, 56) sont prévus pour réaliser la communication entre le capteur à effet Hall (19), les moyens de traitement de signal (39), et l'électroaimant.

4. Tige de forage suivant la revendication 2 caractérisée en ce que chaque section comporte une boîte (17) à son extrémité supérieure et une broche (15) à son extrémité inférieure;

le capteur à effet Hall (19) est monté sur la broche (15) de chaque section, et

les moyens de production de champ électromagnétique (33) comprennent un électroaimant (32) monté dans la boîte (17) de chaque section.

5. Tige de forage suivant la revendication 4

