Aug. 1, 1944.

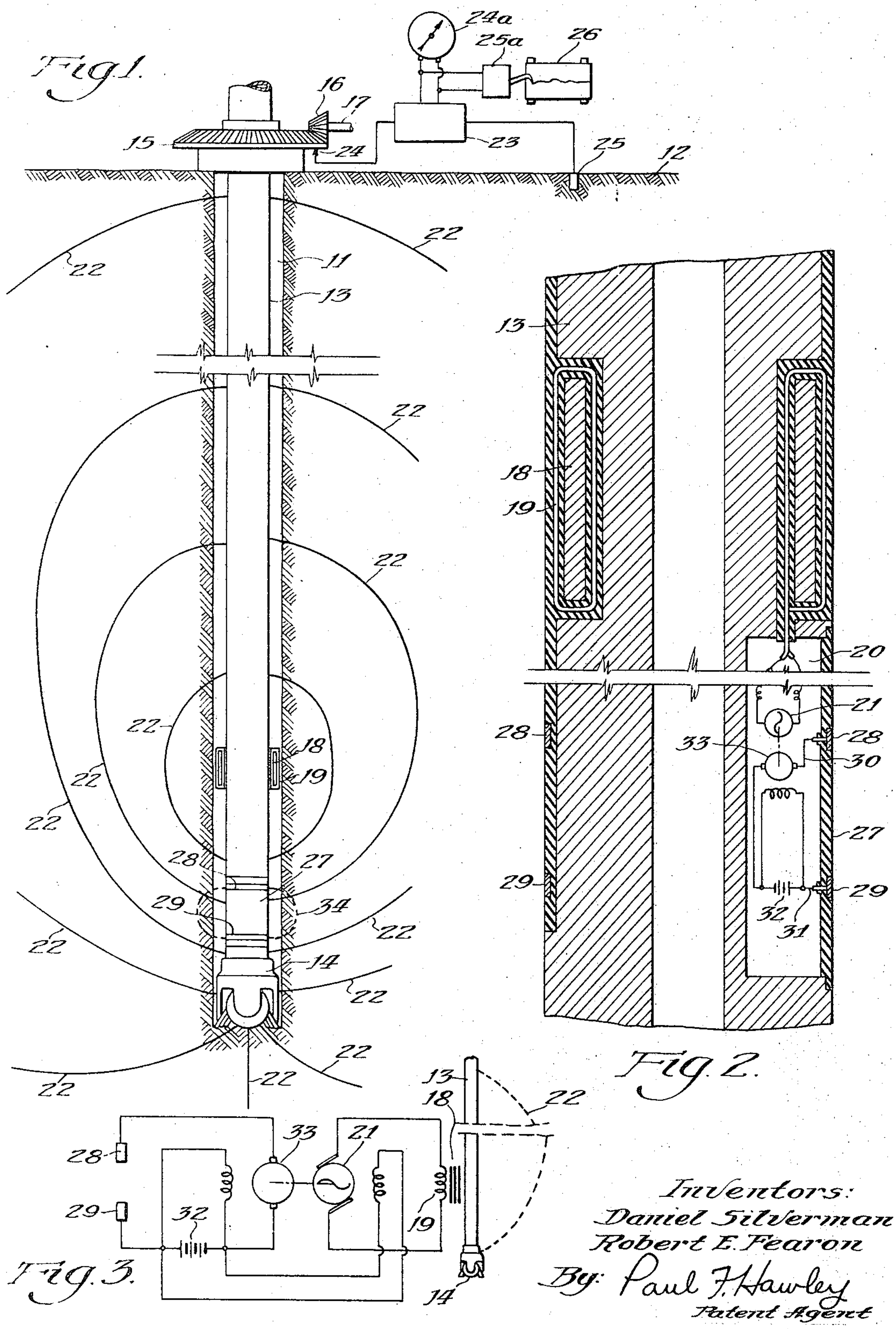
D. SILVERMAN ET AL

2,354,887

WELL SIGNALING SYSTEM

Filed Oct. 29, 1942

3 Sheets-Sheet 1



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WELL SIGNALING SYSTEM

Filed Oct. 29, 1942 3 Sheets-Sheet 2

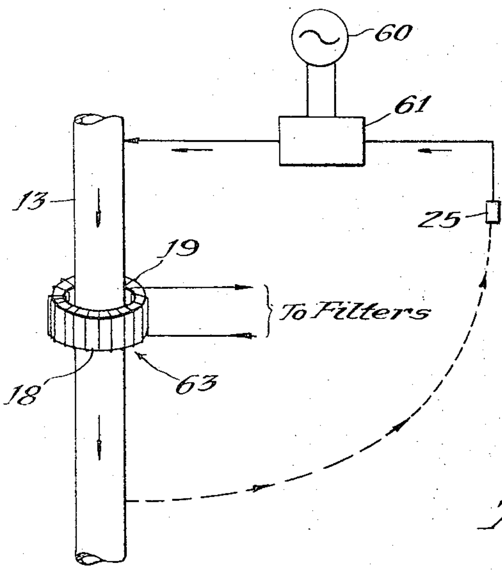


Fig. 7

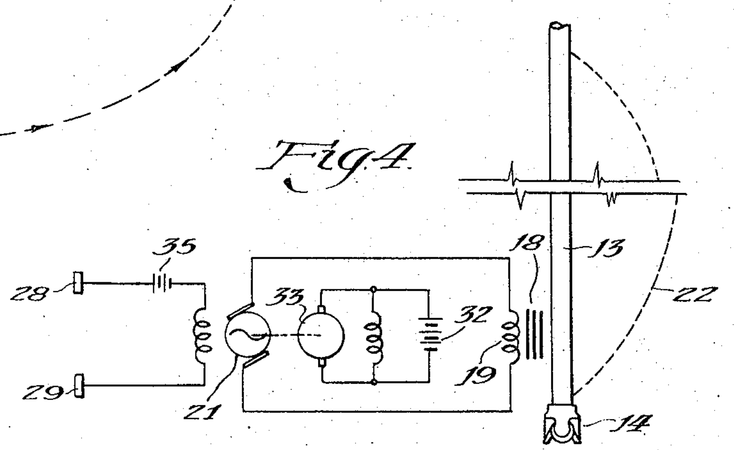
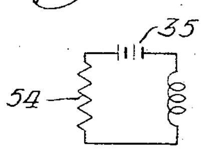


Fig. 4

Fig. 4A.



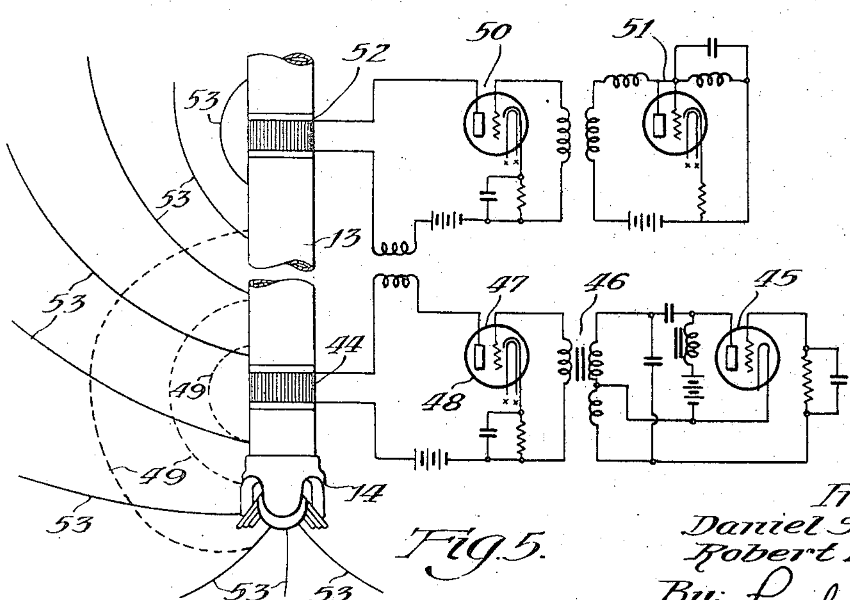


Fig. 5.

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Fig. 6.

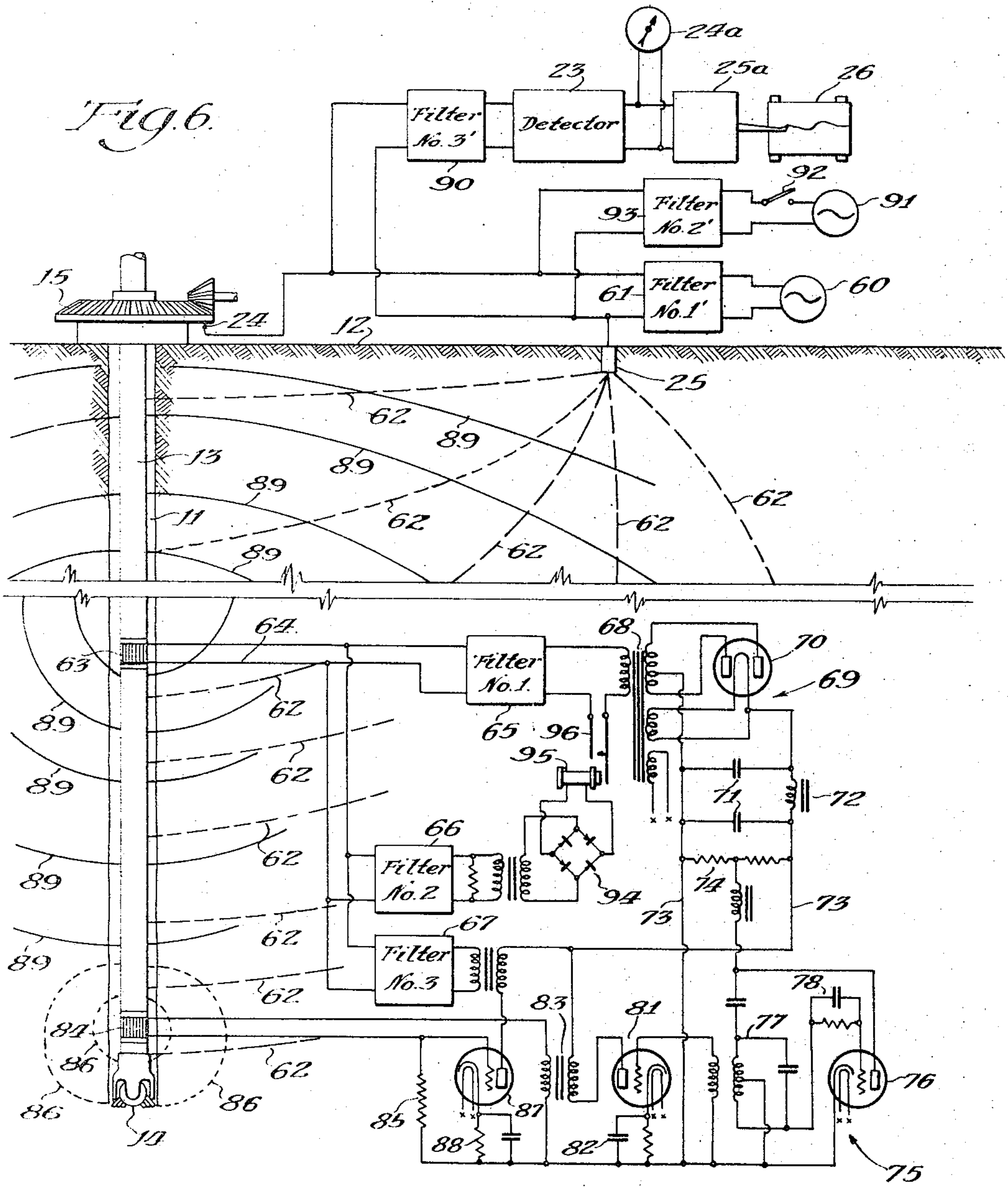
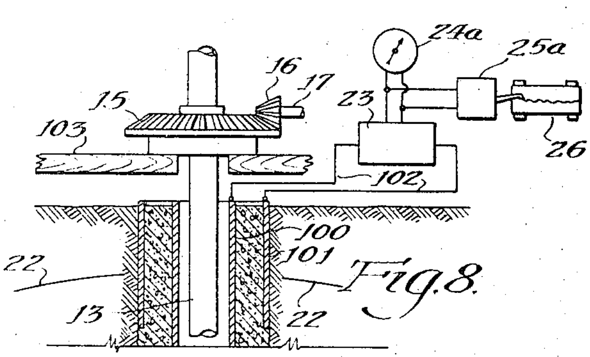


Fig. 8.



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UNITED STATES PATENT OFFICE

2,354,887

WELL SIGNALING SYSTEM

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Application October 29, 1942, Serial No. 463,774

14 Claims. (Cl. 177—352)

This application relates to signaling systems for use in wells or the like, and has particular application to systems for determining properties or characteristics of earth formations in a well while such well is being drilled. It is not, however, limited to such applications.

Various type of systems have been employed in the past for logging a well, that is, determining one or more characteristics of the formations penetrated by the bit while the well was being drilled. In general these methods of logging utilize a system of spaced electrodes placed near the lower end but insulated from the string of drill pipe. Thus, for example, the bit in some systems has been electrically insulated from the balance of the drill pipe so that current could be passed between these two elements, this current being modified by the electrical characteristics of the earth so penetrated. Such systems share certain common disadvantages; for example, the necessity for insulating electrically a section of the drill string from the rest of the drill string, whereas the whole string is constantly being subjected to violent shocks in tension, compression, and shear which must be transmitted mechanically through the insulation. It is well known that insulators are a great deal less strong and far more subject to fracture and fatigue than the steel conductor itself, consequently all of such systems are mechanically weak. Likewise, the systems share the disadvantage that the insulation which is on the inside of the pipe is subject to rapid erosion due to the stream of drilling fluid which is constantly passing over it. It is nearly impossible to replace this inside insulation without completely rebuilding the special pipe section.

The majority of such logging-while-drilling systems also have the great disadvantage that a conductor insulated from the drill string must be run from top to bottom of the well. The practical difficulties in constructing such an arrangement which is mechanically strong, electrically insulated, and capable of articulation are enormous.

We have found a system particularly applicable to systems of logging while drilling in which the drill bit or portions of the drill pipe can be used for an electrode, either for measuring an electrical characterist'c of the formation or for other purposes, in which the portion utilized is in electrical contact with the balance of the drill pipe. This system can also be used for impressing a signal current between two portions of the drill string or a similar conductor, which act thereby as virtual electrodes for setting up electric currents through the earth. These currents can be detected at the surface of the ground without the need of an electrically insulated section between such electrodes. Furthermore, this same system is applicable to the inverse operation of picking up, near the drill bit, electric signals which are transmitted from the surface of the earth, whereupon various control apparatus located in the drill string near the drill bit can be actuated, or power for carrying on certain operations can be provided, without the necessity of using an insulated conductor from such control means to the surface of the ground.

It is accordingly an object of this invention to provide a well signaling or logging system by means of which a part of a conductor extending into a well from the surface thereof can be used as an electrode whereby a difference of potential can be developed between adjacent sections of such conductor, and electric currents can be made to flow through the adjoining section of the well formations even though such adjacent sections are in electrical contact. A further object of this invention is to provide an improved system for determining at least one characteristic of the formations adjacent a well during the process of drilling it, in which electric signals are generated between adjacent portions of the lower part of the drill string, flow through the earth and portions thereof are detected at the surface, without the use of insulated conductors between the lower end of the drill pipe where the signals are generated and the surface of the earth. It is a further object of this invention to provide such a system in which the drill pipe may be rotated at will during the logging operations. It is also an object of this invention to provide means whereby power generated at the surface can be transmitted to and used in electrical equipment at or near the lower end of a drill string. Further objects and advantages of this system will be apparent from a perusal of this specification.

Certain embodiments of the invention are illustrated in the attached figures which form a part of this specification and are to be read in conjunction therewith. In these figures, which are merely for the purpose of illustrating the principles involved, the same reference numeral refers to the same or a corresponding part.

Figure 1 represents in diagrammatic form a cross section of the earth penetrated by a well, illustrating one embodiment of this invention.

Figure 2 is a cross section of a part of the drill pipe shown in Figure 1, illustrating diagrammatically certain apparatus useful in this invention.

Figures 3 and 4 are circuit diagrams of electrical apparatus which can be used in connection with the transmitting system shown in Figure 1.

Figure 4A shows a portion of the circuit shown in Figure 4 modified to measure temperature instead of resistance.

Figure 5 is a diagrammatic cross section of the earth penetrated by a well showing a second embodiment of the invention.

Figure 6 is a schematic diagram illustrating the principles of operation of the apparatus as shown in Figure 5.

Figure 7 is a wiring diagram of still another embodiment of the invention applied to a system used in logging while drilling.

Figure 8 represents in diagrammatic form a cross section of a portion of the earth near a well head, illustrating a particularly advantageous arrangement of electrodes for use in accordance with our invention.

In Figure 1 a well 11 is shown penetrating various formations beneath the surface of the earth, indicated by numeral 12. A drill string 13 carrying at the lower end thereof a drill bit 14 is lowered into this well. The entire drill string from the surface to the drill bit is in electrical contact at all times during the logging operation. At the surface the drill string is supported by standard apparatus (not shown) and is rotated by a rotary table 15 driven by a bevel gear 16 through a shaft 17 attached to the drilling engine (not shown). All of this equipment is standard equipment used in rotary drilling.

A core 18 of ferromagnetic material, for example silicon steel, Mu metal, Permalloy, etc., encloses the drill pipe or drill collar preferably near the lower end. This core may be, as shown in Figure 2, cylindrical in form, and of relatively uniform cross section, although this is not requisite for the successful operation of the system. A coil of insulated wire 19 is wound around the core, passing from inside to outside of the core on each turn. When the wire is wound in this fashion it is said to be coupling the core, since electrical current flowing through the coil 19 causes magnetic flux to flow through the core. The two ends of the coil 19 are connected to leads which are brought into a chamber 20 in the drill string or drill collar itself, where these leads are connected to either electrical generating apparatus or control apparatus, depending upon the particular application of this system.

In Figure 2 electrical generating apparatus is shown connected to the coil 19. This includes means for producing a pulsating electro-motive force 21, which can suitably be a small alternator or a vacuum-tube oscillator. Whenever this generator is in operation the coil 19 will be energized with pulsating electric current which causes a varying magnetic field in the core 18. This varying magnetic field surrounds the drill pipe or conductor 13 as it varies, induces currents into this pipe in such a direction as to oppose the variation in the magnetic field in accordance with Lenz's law. These currents are caused to flow because a difference of potential has been produced in the region in which the magnetic flux varies. Thus, although the regions above and below the core 18 are in electrical contact, they are maintained at a pulsating difference of potential. The return circuits for the currents which flow through the drill pipe as the result of this action are through the earth itself. Various paths of such currents are shown in Figure 1 as paths 22. It is to be noted that certain of these currents flow through the ground immediately below the surface 12. This flow causes a difference of potential between the region immediately around the drill pipe or conductor 13 and the ground at a point a substantial distance from the top of the well, or well head. There is likewise a difference in potential between any two points at different radial distances from the well. At the surface of the ground a detector 23 which may suitably be an amplifier of pulsating currents is connected between a point adjacent the upper portion of the conductor (for example by means of the brush 24) and a grounded electrode 25 which is at a greater distance from the top of the well than the first contact. Using the embodiment shown in Figure 1, it is particularly advantageous to connect one input terminal of the detector 23 to the conductor itself, as shown, although in a number of cases quite satisfactory results can be obtained by connecting the conductor, shown in Figure 1 to be attached to brush 24, to a grounded electrode near the upper portion of the conductor. The amplified output of this detector 23 is connected to either or both an electric meter 24*a* and a recording electric meter 25*a*, which records on the chart 26. In either case the visual indication from the output of the detector 23 is directly related to the signal transmitted to the surface of the ground as described above.

Referring back to Figure 2, in this particular embodiment the resistivity of the earth formations is being logged. In order to accomplish this result a section of the outside of the drill pipe 13 has been covered with a layer of insulation 27 which may suitably be Bakelite or any other insulating material with reasonable abrasion resistance. In the surface of this insulation two metal electrodes, approximately cylindrical in shape, and substantially flush with the surface of the drill pipe are fixed. These electrodes 28 and 29 are connected through insulated leads 30 and 31 to a battery 32 or other source of electric potential and the armature of an electric motor 33. The field of electric motor 33 is supplied from the battery 32. In order for the armature of the motor to revolve, current must flow between electrodes 28 and 29. Such currents will flow when the drill in the well is immersed in the mud stream, through paths such as those shown by dotted lines 34. The speed of the motor is therefore related directly to the conductivity of the paths 34, which in turn is governed by the conductivity of the formations adjacent the electrodes 28 and 29. The electric generator 21 therefore produces pulsating current at a frequency which varies directly with the conductivity of the formation. The signal, at varying frequency, induces by means of the coil 19 and the core 18, currents in the paths 22 also of varying frequency which currents are detected by detector 23 at the surface. In this case obviously the detector 23 incorporates a frequency-sensitive circuit, the output of which varies with the frequency of the incoming signals, so that the meter 24*a* or the recording meter 25*a* produces a visual indication directly related to the conductivity of the formation. Such frequency meters are already well known in the art and therefore no detailed description of such a device is deemed necessary at this point.

A schematic view of the equipment involved in setting up current paths 22 in the earth is shown in Figure 3. Here the motor 33, which is preferably a shunt motor, is arranged with the field connected directly across a battery 32. The armature of this motor 33 is connected in series with the battery and with the two electrodes 28 and 29. The speed of the motor, therefore, varies inversely with the resistance of the path through the earth between these two electrodes. The pulsating current generator 21 which preferably is a small alternator in this embodiment of the invention has a field which is excited from the battery 32 and an armature which is driven by the motor 33. The output frequency of this generator is therefore directly related to the speed of motor 33, hence is related to the resistivity of the formations. The output of the generator 21 is applied across the terminals of the coil 19 which in turn is coupled by transformer action through the core 18 surrounding the drill pipe 13, the circuit including pipe 13 and return current paths 21, which forms in effect a one-turn secondary of a transformer in which coil 19 is the primary.

In Figure 8 one particularly advantageous arrangement of surface electrodes is shown. In this figure pipe 100 is the usual surface pipe employed to prevent dirt from falling into the well. In most cases this pipe extends down for only a few feet from the surface. It is surrounded by a somewhat larger pipe 101 and separated from pipe 100 by a layer of resistant or imperfectly conducting material, such as rubble, Portland cement, slightly damp earth or the like, in such a fashion that there is an electric resistance between pipes 100 and 101. The leads 102 from the detector 23 are connected to the pipes 100 and 101. The currents flowing to the drill pipe cross the region between pipes 100 and 101 as shown by the current paths 22 in Figure 8. In so doing they produce a difference of potential in the filling between these two pipes. This difference of potential is led by conductors 102 to the detector 23 where it is handled as discussed above. In a system arranged in this fashion it is impossible for external disturbances. i. e. current flowing through the earth other than those flowing to the drill pipe 13, to cause the innermost pipe 100 to have a different potential from the outer pipe 101, since pipe 100 is in the space which is electrically shielded by the grounded pipe 101. The system therefore detects only currents which are conducted into the shielded space along the pipe. It is understood in this figure that the drilling apparatus is supported by a platform 103 so that there is access to the top parts of the electrodes 100 and 101. This system is particularly well adapted to produce a very good signal-to-noise ratio in the recording steps of this invention. The pipe 101 need not be cylindrical in shape nor need it be entirely continuous. Any system of electric conductors driven into the ground like pipe 101 around the inner electrode 100 and connected together will form an electrode having the same functions as that of pipe 101. The important thing in this arrangement is to connect the detecting means between a grounded electrode adjacent the top of the pipe and a second grounded electrode spaced from the pipe and surrounding the first grounded electrode.

Normally it is desirable to utilize the variation in frequency to indicate the formation characteristics being logged rather than the variation in amplitude of the detected signals at the surface of the earth. This results from the usual consideration of improved ratio of characteristic signal-to-background noise. However, in some cases we prefer to measure the amplitude of the signals reaching the surface of the earth. The equipment shown in Figure 3 can be used to accomplish this result since the voltage output of the generator 21 is proportional to the speed. On the other hand, it may be desirable to utilize a system in which the frequency of the signals impressed on the coil 19 is constant and only the amplitude varies. In Figure 4 we have shown schematically one such system. In this case the battery 32 is connected across both the field and the armature of motor 33, thereby driving this machine at a substantially constant speed. The frequency of the alternations of alternator 21 are likewise substantially constant. However, the field of the alternator 21 is connected in series with a battery 35 across the electrodes 28 and 29 so that the field current of this alternator varies in inverse relationship to the resistivity of the formations. The average output of the alternator 21 varies therefore in direct relationship to the conductivity of the formations adjacent these electrodes. This output is coupled through the coil 19 and core 18 to the one-turn secondary circuit comprising the drill pipe 13 and the return current paths 22, and is detected at the surface as shown in Figure 1. In this case, however, the detector 23 merely amplifies and preferably rectifies the detected signal, and the amplitude of the output of the detector is shown by meter *24a* or recorded by meter *25a*.

It is to be understood that the system already described can be utilized equally well to generate signals in the well which are detected at the surface or, on the other hand, can be utilized to generate signals on the surface of the ground which are picked up by the apparatus in the well through the coil-and-core arrangement and utilized to effect some control operation in the well. In other words, the device which is essentially a transformer, with an actuating system and a control or detecting system can be utilized either to transmit signals into the well or out of the well, dependnig upon the particular system to which the apparatus is adapted. It is also apparent that either frequency or amplitude modulation of the signals can be easily effected.

It is possible to use a plurality of core-and-coil combinations in order to make more than one virtual electrode along the conductor extending into a well. One example of this is shown in Figure 5. In this case the lower core-and-coil combination 44 is mounted adjacent the drill bit 14, whereas the upper core-and-coil is mounted at a substantial distance above the bit 14, for example of the order of 50 to 500 feet. A simple oscillating circuit 45 is coupled by a transformer 46 to a power amplifier circuit 47 including a vacuum tube 48. The plate current of this vacuum tube flows through the coil of the core-and-coil combination 44 thereby producing a virtual electrode, including the bit 14, and causing currents to flow through the earth over paths such as that indicated by dotted lines 49. The current flowing through these paths reacts upon the plate current of the vacuum tube 48, thus substantially modifying the amplitude of this current in accordance with the resistivity of the formations. The plate current of this tube is used to modulate the current from another vacuum tube 50 which is driven by a second oscillating circuit 51, preferably at a much higher frequency than that of the oscillating circuit 45. Thus, for example, the frequency of the oscillating circuit 45 may be in the range from 10 to 200 cycles, whereas the frequency of the second oscillating circuit 51 may be of the order of 500 to 5000 cycles or more and in every case will be considerably greater than that of circuit 45. The output of the vacuum tube 50 modulated by the plate current of the tube 48 is impressed on the coil of the upper coil-and-core combination 52, by means of which currents of the order of thousands of cycles per second modulated by a relatively low frequency, the amplitude of which varies with the resistivity of the earth formations, flow through the earth from a virtual electrode composed of the drill pipe 13 below the coil 52 to the drill pipe above this section. Some of these current paths are shown labeled 53. The entire electrical apparatus is, of course, mounted within the drill pipe in suitable chambers in the drill collar or drill pipe proper. By apparatus of this type it is possible to have several virtual electrodes, i. e., several different current paths utilizing varying sections of the conductor or drill pipe. Each of such circuits can be independent of every other such circuit.

It should be emphasized that the possibility of spacing the core-and-coil combination at a distance of 50 to 500 feet from the end of the conductor is exceedingly important. Such a distance is, of course, small with respect to the total length of the drill pipe so that the core can be said to be adjacent the drill pipe, but it is sufficiently removed from the end of this pipe so that the surface area of the drill pipe below this coil which is exposed and in electric contact with the formations is great. Accordingly, the contact resistance between the part of the drill pipe 13 lying below this coil to the formations is extremely low. The potential available for circulating current through the paths 22 is usually small, so that the success of this signaling system at great depths is enhanced by lowering this contact resistance. We have found by actual test that it is possible to circulate currents through paths 22 of the order of one-half ampere when using not more than a few millivolts difference of potential between the upper and lower portions of the drill pipe.

If an insulated joint were used in the drill string so that a difference of potential could be applied between the upper and lower parts of the drill pipe separated by this insulated section, it would be necessary to provide an auxiliary conductor from the drill collar containing the electrical apparatus including the generator of the signals, to the portion of the drill pipe above the insulated joint. It would be impossible to provide such a conductor which would have so low resistance that its presence would not greatly limit the signaling current. This is particularly true in view of the above facts showing that the resistance of the whole circuit is of the order of a few thousandths of an ohm. In our invention the transformer not only eliminates the need of an insulated joint but it also provides the possibility of transmitting the signaling power to the signaling coil at high impedance and transforming it by the coil to match the low impedance between the upper and lower parts of the drill stem so that maximum power transfer may be approached.

It is understood that other characteristics of the formations than the resistivity or impedance of these formations can be measured. Thus, for example, the circuit shown in Figure 4 can be modified as shown in Figure 4A by disconnecting the electrodes 28 and 29 and connecting instead a simple resistance thermometer 54, the resistance of which varies with the temperature of the drill pipe as effected by the temperature of the formations. Since this resistance will vary with the temperature of the formations, the field current of the generator 21 will likewise vary with the temperature, thus sending a suitable signal through coil 19, which in turn transmits it to the surface of the ground.

In Figure 6 we have shown a preferred form of apparatus in accordance with our invention by means of which two-way transmission is effected from the surface of the ground to the region near the bottom of the well. By this means power to operate the equipment located in chambers in the drill string is obtained from the surface of the ground without cables to the surface and without interfering with transmission of the logging signals back to the surface. An alternating current generator 60 is connected through a filter 61 (marked Filter No. 1') between a grounded electrode 25 located some distance from the well and a brush 24, which makes contact with the rotary table 15 and hence with the drill string 13. The filter 61 is used to remove any harmonics from the output of the alternator 60. Any desired frequency may be used for this alternator such as, for example, 60 cycles or 500 cycles. The filter 61 is tuned to the fundamental frequency of the alternator 60. The current flowing through the earth due to the E. M. F. of alternator 60 flows through paths such as paths 62 shown in dashed lines in Figure 6, since the drill string is in electric contact with the ground from the bottom of the string to the top, the drilling fluid forming the contacting medium. A core and coil combination 63 (which for convenience is hereinafter called a toroidal transformer and is similar to that described in connection with Figure 2) is located some distance above the drill bit itself, for example 30 to 90 feet above the bit. It is apparent that considerable current from the generator 60 will flow into the drill pipe 13 below the location of the toroidal transformer 63. The current which flows through the drill pipe 13 inside of the toroidal transformer causes a difference of potential to be generated across the ends of the coil 19, which is apparent from inspection of Figure 7. This difference of potential is utilized to supply the energy necessary for the equipment located in the bottom of the well.

In this connection it is apparent that the current flowing through path 62 to the drill pipe 13 the point above the location of toroidal transformer 63 does not aid in the energization of the apparatus in the well. Accordingly, it is desirable to decrease such current without decreasing that flowing through paths 62 to drill pipe 13 below this transformer 63. The current can be reduced by the provision of insulation about the drill pipe extending from a point above the transformer to the surface of the earth. Solid mechanical insulation is expensive and difficult to provide but electrolytic insulation can be utilized. This can be accomplished by providing an electrolyte adjacent the drill pipe in the upper sections thereof which will polarize as current flows through it, to produce a film of hydrogen gas as the surface of the drill pipe 13 in the region above the toroidal transformer 63 in which it is desired to eliminate or reduce the flow of current through the paths 62. The pipe can, for example, be coated with chemical agents, salts, etc., that react with the drill fluid to produce electrolytes which polarize as current passes thereinto. Other methods can, of course, be used, if desired.

One suitable type logging apparatus used at the bottom of the well is shown in Figure 6. The apparatus shown in the wiring diagram of this figure is suitably located in one or more chambers within the drill collar adjacent the toroidal transformer 63. Two wires 64 lead from the ends of the coil 19 of the transformer to three filters 65, 66 and 67, respectively. Filter 65 (labeled Filter No. 1) is tuned to the same frequency as filter 61; namely, the frequency of the power currents travelling paths 62. The output of this filter is applied across transformer 68 which forms part of a power pack designated generally by numeral 69. In this power pack is included a high voltage rectifier 70 which with the condensers 71 and choke 72 produces across lines 73 a D. C. difference of potential. Another winding on the transformer 68 produces filament voltage across the terminals marked x/x, which terminals are suitably connected to the filaments of the various vacuum tubes discussed below in a manner well known to those skilled in the electronic art. A tapped resistor 74 is connected across the output of the power pack 69.

A second A. C. generator, in this case an oscillator designated generally by the numeral 75 is used to generate A. C. current signals at a frequency differing widely from that passed by filter 65. As shown in Figure 6, this comprises a normal Hartley oscillator with a triode 76, a tank circuit 77 and a grid biasing circuit 78. The plate is energized preferably through a choke coil 79 from the tap on resistor 74. An output coil 80 is loosely coupled to the inductance of tank circuit 77 and drives the grid of an amplifying triode 81 which is supplied with a suitable cathode biasing circuit 82. The amplified signals from the output of the triode 81 are applied through transformer 83 to a second toroidal transformer 84 (which is located close to the drill bit 14) in series with a resistor 85. The current flowing in the coil of the toroidal transformer 84 produces a difference of potential in the one turn secondary made up of the drill pipe 13 and the return paths through the earth, thus causing currents to flow in these return paths 86. The amount of current flow in these paths will be largely determined by the resistance of the formations adjacent the drill bit. Accordingly, the current flowing through the coil of the toroidal transformer 84 and through resistor 85 will be affected chiefly by the resistivity of these formations, increasing as the resistivity decreases. Since the currents flowing through paths 84 are at an entirely different frequency from that of the currents flowing through paths 62, there will be no mutual reaction between these currents.

The voltage drop across resistor 85 is amplified by a triode 86 suitably supplied with a cathode biasing circuit 88. The amplified output from this tube is impressed on the input of a filter 67 (Filter No. 3), the output of which is connected across wires 64 leading to the coil of toroidal transformer 63. By this means a fairly pure sine wave, the amplitude of which characteristic of the resistivity of the formations adjacent the drill bit is applied to the primary of the toroidal transformer, which, as has already been described, will cause currents to flow through the formations above and below the coil. Such currents flow through paths such as paths 89 shown in solid lines in Figure 6. This current produces a difference of potential between the top of the well and points radially distant from that point such as electrode 25. A filter 90 (Filter No. 3′) at the surface of the ground is connected between brush 24 and electrode 25 and is tuned to the frequency of filter 67 (Filter No. 3), so that filter 90 is responsive solely to the returning signals characterizing the resistivity of the formations adjacent the drill bit and is unaffected by the drop of potential produced by alternator 60. The output from Filter No. 3 is amplified and preferably rectified by detector 23 and appears either across the indicating meter 24a or on the chart 26 as discussed in connection with Figure 1.

Sometimes it is desirable to be able to operate control means in the well either in connection with the logging operations or otherwise. Of course, the power pack 69 is one form of control device since its deenergization stops the logging operation. Another simple control means is also shown in Figure 6. A small alternator 91 in series with a switch 92 is connected to a filter 93 which is connected between brush 24 and electrode 25. The filter 93 is, of course, tuned to the frequency of the alternator 91, which frequency is chosen to be decidedly different from that of alternator 60 or that of oscillator 75, for ease in filtering. Whenever switch 92 is closed the output of alternator 91 is superimposed on that of alternator 60, passing through the same paths 62 and independently producing voltage in the coil of toroidal transformer 63. Filter 66 (Filter No. 2) is tuned to the same frequency as filter 93 so that it accepts signals only due to alternator 91. The output of this filter is impressed on a rectifier 94, the output of which is applied to a coil 95 of a relay 96. The contacts of relay 96 are in series with the primary of transformer 68. The operation of this circuit is apparent from this description. Only at such times as switch 92 is closed is the output of alternator 91 applied to the ground producing a signal in the coil of the toroidal transformer 63. This signal is filtered out by filter 66, rectified, and applied across the coil 95 of relay 96, thus closing the contacts of this relay and permitting power pack 69 to be energized. Other control circuits can easily be worked out using the principles outlined above.

It can be seen from this description that by the use of apparatus such as that shown in Figure 6, it is possible to construct a unit which can easily be mounted in the drill collar and which can be made entirely separately energized from the surface without employing any conductor other than the drill string itself between the surface of the ground 12 and the bottom of the well. This circuit can be controlled at will and produce output signals which can be picked up at the surface of the earth substantially unaffected by the operation of the power circuits.

Other measures can be utilized at the will of the operator. Numerous measurements already well known in the prior art in the logging of wells can be adapted to this well signaling system. The novelty does not lie in the particular type of characteristic being measured or controlled but is best defined by the scope of the appended claims.

We claim:

1. A well signaling system including an uninsulated conductor extending into said well, a core of ferromagnetic material enclosing said conductor within said well, a coil of insulated wire coupling said core, means for producing a pulsating electromotive force, and means for detecting pulsating

electric signals, one of said means being connected between two spaced points, one of which is adjacent the upper portion of said conductor and the other of which is grounded and located at a greater distance from the axis of said conductor than said first-named point, and the other of said means being located within said well and connected across the ends of said coil of wire.

2. A well signaling system including an uninsulated conductor extending into said well, a core of ferromagnetic material enclosing said conductor within said well, a coil of insulated wire coupling said core, means for producing a pulsating electromotive force, and means for detecting pulsating electric signals, one of said means being connected between said conductor and ground at a distance from said conductor, and the other of said means being located within said well and connected across the ends of said coil of wire.

3. A well signaling system including an uninsulated conductor extending into said well, a core of ferromagnetic material enclosing said conductor within said well, a coil of insulated wire coupling said core, means for producing alternating potential connected between a point adjacent the upper portion of said conductor and the ground distant from said conductor, and control means mounted within said well adjacent the lower portion of said conductor and connected to the terminals of said coil, whereby said control means is actuated by part of the alterating current flowing between said conductor and the ground.

4. A well signaling system including an uninsulated conductor extending into said well, a circuit including means for producing alternating potential in said well and means for varying a characteristic of said potential as a function of a characteristic of the formations in said well adjacent said circuit, a core of ferromagnetic material enclosing said conductor, a coil of insulated wire coupling said core, the terminals of said coil being connected to said potential producing means, and means at the surface of the earth connected between a point adjacent said conductor and a point on said surface a greater distance from said conductor than said first-named point, said last-mentioned means being adapted to produce an indication of alternating currents flowing through the earth as a result of operation of said potential producing means.

5. A well signaling system according to claim 4 in which the spacing of said coil from the lower end of said conductor lies between about 50 feet and about 500 feet.

6. Apparatus for logging a well including a string of pipe extending into said well from the top thereof, a core of ferromagnetic material enclosing said pipe adjacent the lower end thereof, a coil of wire coupling said core, means within said drill pipe and adjacent said core for generating alternating current signals, said means being connected to the ends of said coil, means for modifying the output of said generating means in relation to changes in at least one characteristic of said well, and detecting means at the top of said well connected between a point adjacent the top of said pipe and a point distant from said well, said detecting means being adapted to produce an indication varying with said modified output of said generating means.

7. Apparatus according to claim 4 in which said modifying means operate to change the frequency of said alternating current signals directly in relation to changes in said at least one characteristic of said well, and said detecting means is adapted to produce an indication varying with the frequency of the signals flowing between said adjacent point and said distant point.

8. Apparatus for logging a well while drilling including a string of drill pipe extending into said well from the top thereof, a core of ferromagnetic material enclosing said pipe and spaced from the lower end thereof, a coil of wire coupling said core, an alternating current generator positioned within said drill pipe and insulated therefrom, the output of said generator being coupled to the ends of said coil, means distinct from said core and said coil for passing an electric current between two points separated by a vertical distance and positioned near the lower end of said drill pipe, means for modifying the output of said generator in accordance with the variations in said electric current, and detecting means at the top of said well connected between a point adjacent the top of said pipe and a grounded electrode spaced from said pipe, said detecting means being adapted to produce an indication varying with said modified output of said generator.

9. Apparatus according to claim 8 in which said grounded electrode surrounds said pipe.

10. Apparatus according to claim 8 in which said spacing from said core to the lower end of said pipe lies between about 50 feet and about 500 feet.

11. Apparatus according to claim 8 in which said means for passing said electric current include a second core of ferromagnetic material enclosing said drill pipe, and a second coil of wire coupling said second core, said second coil being coupled to said generator in such fashion that the change in current in said coil due to variation in said characteristic of said well causes said modification in the output of said generator.

12. Apparatus for logging a well while drilling including a string of drill pipe extending into said well from the top thereof, a core of ferromagnetic material enclosing said pipe adjacent the lower end thereof, a coil of wire coupling said core, an alternating current generator positioned within said drill pipe and insulated therefrom, the output of said generator being coupled to the ends of said coil, a second core of ferromagnetic material enclosing said drill pipe, and a second coil of wire coupling said second core, a second alternating current generator the frequency of which is widely different from that of said first-named generator, said second generator and said second coil being electrically connected to said first-named generator whereby the current through said second coil modulates the output of said generator, and detecting means at the top of said well connected between a point adjacent said drill pipe and ground at a point removed from the top of said well for producing an indication of said modulation of said first-named generator.

13. Apparatus for logging a well while drilling including a string of drill pipe extending into said well from the top thereof, an alternating current generator connected between a point adjacent the upper portion of said pipe and the ground at a distance from said pipe, a core of ferromagnetic material enclosing said pipe adjacent the lower end thereof, a coil of wire coupling said core, a plurality of electric filters connected to the ends of said coil, a second alternating current generator positioned within said drill pipe and insulated therefrom, the frequencies of said first-named generator and said

second generator being widely different, a circuit for energizing said second generator actuated from said first-named generator, the input to said circuit being connected to the ends of said coil through one of said filters, means for modifying the output of said second generator in accordance with a characteristic of the formations forming the walls of said well at a zone of investigation adjacent the lower end of said drill pipe, the input to said modifying means being connected to the output of said second generator and the output from said modifying means being connected through another of said filters to the ends of said coil, and detecting means at the surface of the earth connected through a filter tuned to the frequency of said second generator across the output of said first-named generator for producing a visual indication proportional to the strength of said modified output of said second generator.

14. Apparatus according to claim 13 in which said modifying means includes a second ferromagnetic core enclosing said drill pipe, a second coil of insulated wire coupling said second core, means for applying an alternating current signal proportional to the output of said second generator to said coil and means for applying a signal proportional to the current in said second coil to said another of said filters.

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