May 15, 1945. W. D. MOUNCE 2,376,168

WELL LOGGING

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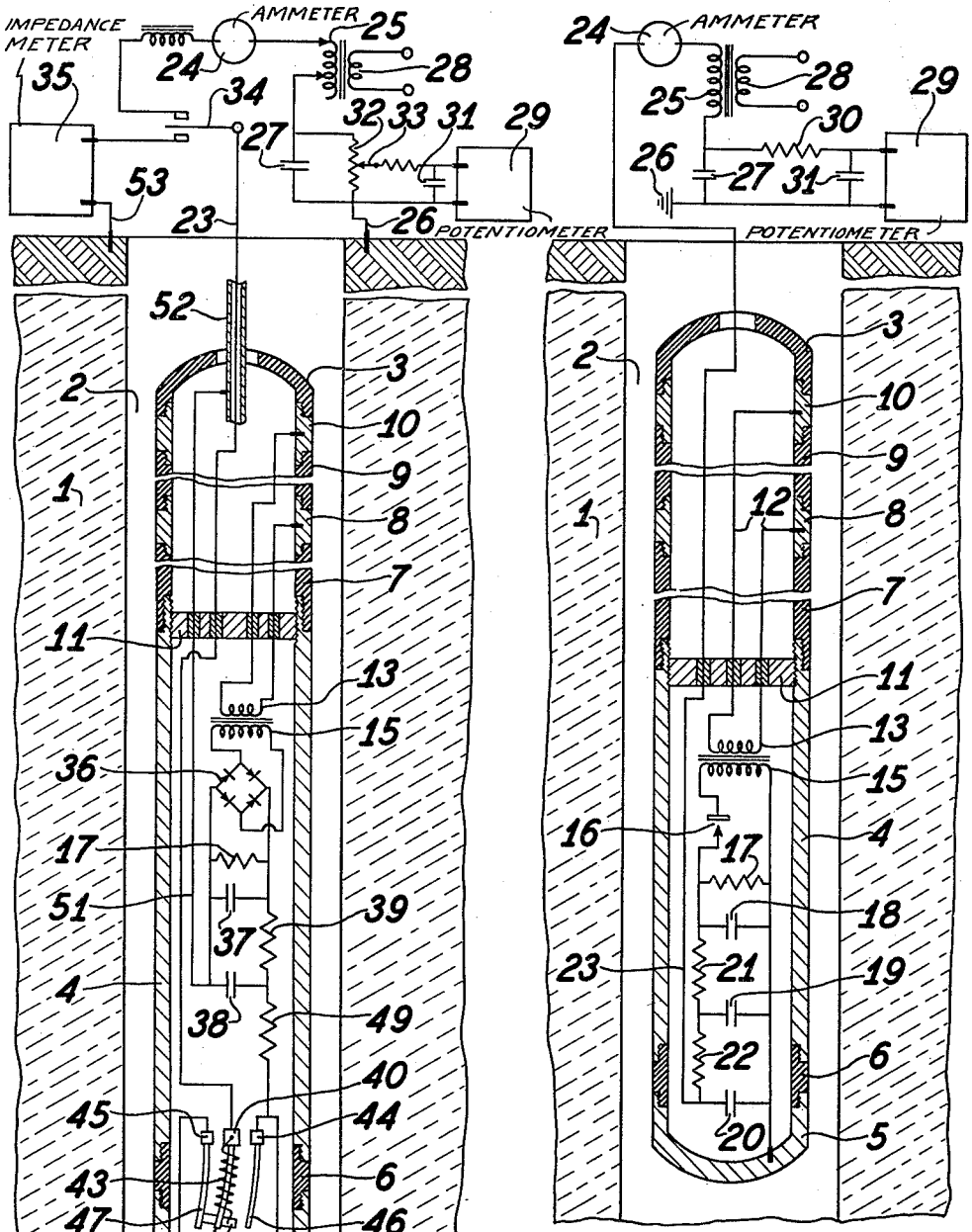

FIG_2_

FIG_1_

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WELL LOGGING

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25 Claims. (Cl. 175—182)

The present invention is directed to a method and apparatus for logging bore holes and particularly to a method and apparatus to be used in conjunction with the known impedance and potential method described and claimed in Patent No. 2,132,807, issued October 11, 1938, to Rust and Mounce.

In the electrical logging of wells, it frequently happens that a similar electric response is obtained from both oil sands and water sands, thereby rendering a differentiation of the two difficult. It has been postulated that this difficulty can be attributed to infiltration of drilling mud into the porous formations which carry water, gas and oil, whereby for some distance into the formations substantially the same resistance is offered to the flow of current, regardless of the fluid contained in the formation.

The type of well-logging to which the present invention is directed is the single conductor single cable type in which alternating current is employed. In this type of logging, it may often be desirable to vary the effective penetration of the values measured into the formations traversed. Means are provided, according to the present invention, for achieving this result without increasing the number of conductors in the cable.

Briefly, according to the present invention, the customary single electrode single conductor cable is provided with an additional pair of spaced electrodes which are employed to pick up the A. C. potential resulting from an alternating current of constant value introduced by the current electrode. This procedure may be practiced in a separate run from the customary run in which impedance and natural earth potential are measured or the latter values may be measured on the down-trip and the former value measured on the up-trip. The latter procedure is preferred.

The present invention will be better understood from the following detailed description of the accompanying drawing in which Fig. 1 is a diagrammatic view of one form of apparatus suitable for the practice of the present invention, and Fig. 2 is a similar view of an alternative embodiment of the present invention.

Referring specifically to Fig. 1, numeral 1 designates the earth in which is a bore hole 2 which is customarily filled with drilling fluid. An electrode carrier 3 is suspended in the bore hole by a cable not shown, this cable being trained over a sheave at the surface in the customary manner. The electrode carrier comprises a metal cylinder 4 having a lower metal tip 5 separated from the cylinder by a ring of insulating material 6. A collar 7 of insulating material is secured to the upper end of cylinder 4. Threaded to the collar is a metal ring 8 to which, in turn, is threaded a second insulating collar 9, the other end of which is connected to a second metal ring 10. The inside of the upper end of cylinder 4 is provided with an insulating plate 11 which is perforated for the passage of wires therethrough. The electrodes are tip 5 and metal rings 8 and 10.

A conductor 12 is connected to rings 8 and 10 which may be spaced any desired distance apart by varying the length of collar 9. Similarly the distance between electrodes 5 and 8 may be varied by varying the length of collar 7. A continuation of conductor 12 comprises a coil 13 which constitutes one winding of a step-up transformer, the other winding 15 of which has one of its ends connected to the earth through electrode 5 and the other of its ends connected to a rectifier 16. Arranged across the output of the rectifier and winding 15 is a resistance 17. Arranged in parallel with resistance 17 are condensers 18, 19, and 20. Resistances 21 and 22 are arranged in series with the output of rectifier 16 in a conductor connecting said output to one side of condensers 18, 19, and 20, the other side of these condensers being connected to the conductor connecting winding 15 with the earth. The rectifier side of condenser 20 is connected through a conductor 23 to an ammeter 24 at the surface. The other side of the ammeter is connected in series with one end of a winding 25 of a transformer the other end of which is connected to the ground 26 through a condenser 27. The other winding 28 of the transformer is connected to a source of alternating current which is preferably the usual city power line supply, but may be an alternator of suitable power. Connected across condenser 27 is a D. C. potentiometer 29. Arranged between the condenser and the meter is a low pass filter comprising a resistance 30 and a condenser 31.

In the practice of the present method, the electrode carrier is moved along the bore hole at the end of a cable carrying conductor 23. It is preferable to supply an A. C. current of a fairly high frequency and of a large amplitude for reasons hereinafter stated. The A. C. current will pass through condenser 20 to the metal tip 5. Condenser 19 and resistance 22 and condenser 18 and resistance 21 comprise a low pass filter which is provided to prevent the supplied A. C. current from affecting the D. C. current output of the rectifier 16, and in some cases may be omitted.

The current supplied to metal tip 5 is grounded to the bore hole fluid and passes upwardly

through the ground to metal rings 8 and 10 and also to ground 26. At the surface the band pass filter 30 and 31 prevents the supplied A. C. current from influencing the values recorded by the potentiometer 29. The greater the space between tip 5 and rings 8, and 10, the greater will be the penetration of the currents which impress A. C. voltages upon these rings. The difference in A. C. voltage between rings 8 and 10 is impressed across coil 13, the primary of the step-up transformer, and this voltage sets up a corresponding alternating voltage of greater amplitude in coil 15. The value of this voltage is determined by the A. C. conductivity of the earth material surrounding the electrode system and hence by the stratification of the subsurface.

This alternating voltage passes an A. C. to the rectifier 16 the output of which is a series of D. C. pulses. These D. C. pulses set up a potential drop across resistance 17 which may be made large so as to make the potential drop easily measurable. This potential drop is impressed across the plates of condensers 18, 19, and 20. Since for direct currents, condenser 31 will be eventually charged to the same potential as condenser 18, the time required being determined by the values of the capacity and resistance elements, this D. C. potential drop will be impressed across the plates of condenser 31 and can be measured there by the potentiometer 29. The A. C. current supplied is made large and the resistance 17 is made large so that the natural earth potential will be negligible compared to the direct potential difference set up across resistance 17, and will not effect the measurement of the latter.

Thus, during the movement of the electrode carrier, there is a continuous measurement of the difference in A. C. potential between rings 8 and 10. Thus, there is a continuous measurement of the A. C. conductivity of the earth material around the electrodes. It will be understood that meter 29 will in practice be of the recording type and will be preferably so arranged as to record on a strip of paper which, in accordance with usual practice, will be moved at such a rate as to indicate the depth of the electrode in the ground at any given time.

The embodiment shown in Fig. 2 is the one employed in following the procedure of making a log of earth impedance and natural earth potential, in the manner shown in U. S. Patent 2,132,807, issued October 11, 1938, to Mounce and Rust, while the electrode carrier is moving in one direction and a log of the difference in potential between the spaced rings while the electrode carrier is moving in the opposite direction. Parts corresponding to those shown in Fig. 1 bear the same numeral. In this embodiment, the surface circuit is different from that shown in Fig. 1 in that a resistance 32 is connected across the condenser 27, said resistance being connected to the potentiometer 29 by a pointer 33 by the manipulation of which any desired portion of the drop across resistance 17 may be measured. In addition, the conductor 23 is provided with a switch 34 by means of which either the potentiometer and its accompanying circuit can be connected to the electrode or the known impedance meter 35 can be connected. As is known, the latter includes a source of A. C. power and is also provided with a current galvanometer and an A. C. ammeter. A typical impedance meter is shown in co-pending application Ser. No. 160,213, filed August 21, 1937, now Patent No. 2,222,182, issued November 19, 1940. This impedance meter is employed when a log showing the natural earth potential and the earth impedance is produced.

In the electrode carrier, the winding 15 is connected to opposite poles of a full wave rectifier 36. The other opposite poles of this rectifier are connected across resistance 17. Connected in parallel with resistance 17 are condensers 37 and 38, there being a resistance 39 in series with these condensers.

In this embodiment, the conductor 23 is connected to a post 40 fixed in the electrode carrier. Pivoted on this post is a bi-metallic strip 41 which normally has the shape shown and which carries at its free end a block 42 to which is connected a coil 43 which is wrapped around the strip 41 and has its other end connected to conductor 23. Mounted on either side of the post 40 are posts 44 and 45. Fixed to post 44 is a depending strip 46 of spring material, and a similar strip 47 is fixed to post 45. These strips are normally curved inwardly toward their free ends and are so spaced that in normal position they are a distance apart equal to the width of block 42 and that when said block is in its center position, it contacts both of the strips. Post 45 is connected to tip 5 by a conductor 48. Post 44 is connected to resistance 39 through a resistance 49 and is also connected to tip 5 through a condenser 50.

Resistances 39 and 49 and post 44 are connected to one plate of condenser 38, the other plate of which is connected by a conductor 51 to sheath 52 of the cable by which it is grounded.

As previously stated, block 42 is normally in contact with strip 47. With the parts in this position, the switch 34 is connected to impedance meter 35 and the electrode carrier is lowered through the well. In this case the current flows through conductor 23, coil 43, block 42, strip 47, and conductor 48 to tip 5 and thence through the ground to ground wire 53. The current supplied by the impedance meter is not of sufficient strength to heat up coil 43. These connections are maintained while the electrode carrier is making the trip through the bore hole in one direction.

When this trip is completed, switch 34 is thrown into the circuit of potentiometer 29 and thereby connects the electrode circuit with the greater source of power introduced through transformer primary 28. As stated with reference to Fig. 1, this source of power is usually the city power lines and supplies a sufficient current to heat up coil 43, causing the bi-metallic strip 41 to bend toward strip 46. Since strips 46 and 47 in their normal position are so spaced as to contact block 42 simultaneously, there will be no break of the current through coil 43 and, consequently, no cooling down which might prevent the completion of the circuit through strip 46. The bi-metallic strip exerts sufficient force to bend strips 46 and 47 out of their natural shape, so that positive separation of the two circuits is insured.

When block 42 is in contact only with strip 46, the alternating current flows through coil 43, block 42, strip 46, and condenser 50 to tip 5 and thence through the ground to ground wire 26 and to metal rings 8 and 10. Here as before, the difference in A. C. potential between rings 8 and 10 supplies alternating voltage to rectifier 36. Since this is a full wave rectifier, a substantially continuous D. C. voltage of varying value is set up across resistance 17 and condenser 37 and

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across the plates of condenser **38** through resistance **39**. One plate of this condenser is connected to one plate of condenser **27** through resistance **49**, strip **46**, coil **43**, conductor **23**, switch **34**, and winding **25**. The other plate of condenser **38** is connected to the other plate of condenser **27** through conductor **51**, sheath **52**, and the ground. Thus, the D. C. potential across condenser **38** is impressed across condenser **27** and across resistance **32** and may be measured by potentiometer **29**.

It will be understood that the procedure and apparatus described above is susceptible to considerable variation without departure from the underlying principles of the present invention. Such variations are contemplated within the scope of the present invention which is defined in the appended claims in which it is intended to claim the invention as broadly as the prior art permits.

I claim:

1. A method for logging a well which comprises moving spaced electrodes along said well at the end of a cable carrying a single conductor, supplying alternating current of constant value to one of said electrodes by means of said conductor, and measuring the alternating current potential difference between other of said electrodes at points along said well spaced from each other and from the electrode to which the current is supplied.

2. A method for logging a well which comprises moving spaced electrodes along a well at the end of a cable carrying a single conductor, supplying alternating current of constant value to one of said electrodes through said conductor whereby an alternating current potential difference is set up between two other electrodes spaced from each other and from the electrode to which the current is supplied, translating said alternating current potential differences into direct current impulses, transmitting said impulses to the surface through said conductor and measuring said impulses.

3. A method for logging a well which comprises arranging an electrode at the surface and at least three electrodes in a borehole with said surface electrode being connected to one of said borehole electrodes, moving said borehole electrodes in a given direction along said borehole, supplying alternating current of constant value to the electrode connected to the surface electrode, measuring the impedance and the natural earth potential between said surface electrode and the borehole electrode connected thereto, reversing the direction of movement of said borehole electrodes, and measuring the A. C. potential difference between two of said borehole electrodes spaced from each other and from the electrode to which the current is supplied.

4. An apparatus for logging a well comprising a single conductor cable carrying at least three spaced electrodes, a source of alternating current connected to one of said electrodes through said conductor, a second conductor connecting two other electrodes whereby an alternating current is set up in said second conductor due to A. C. potential differences between said connected electrodes, means for converting said alternating current to a D. C. potential and means for measuring said D. C. potential.

5. An apparatus for logging a well comprising an electrode carrier having at least three spaced electrodes, a cable adapted to suspend said electrode carrier in a borehole, a condenser in said electrode carrier having one of its plates connected to one of said electrodes, a single conductor carried by said cable connected to the other plate of said condenser and to a source of alternating current, a second conductor connecting two other electrodes of said electrode carrier whereby an alternating current is set up in said second conductor due to A. C. potential differences between said connected electrodes, a transformer carried by said electrode carrier having one of its windings arranged in series with said second conductor, a rectifier connected to the other winding of said transformer, a resistance arranged across said rectifier, means for electrically connecting said resistance across said condenser, a second condenser at the surface, means, including the ground, for connecting one plate of the electrode carrier condenser to one plate of the surface condenser, means, including the cable conductor, for connecting the other plate of the electrode carrier condenser to the other plate of the surface condenser, and means at the surface for measuring the D. C. potential across said surface condenser.

6. An apparatus for logging a well comprising an electrode carrier having at least three spaced electrodes, two sources of alternating current of different power, a cable adapted to suspend said electrode carrier in a borehole, a single conductor in said cable, switch means for connecting said conductor to either source of power, means in said electrode carrier for connecting said conductor to one of said electrodes, a circuit connecting two other of said electrodes including means for converting A. C. potential differences between said connected electrodes into D. C. potentials, and means carried by said electrode carrier for closing said circuit when said conductor cable is connected to the A. C. source of greater power.

7. An apparatus for logging a well comprising an electrode carrier having at least three spaced electrodes, a source of alternating current, a conductor for connecting said source to only one of said electrodes, a second conductor connecting two other electrodes, whereby an alternating current is set up in said second conductor due to A. C. potential differences between said connected electrodes, means carried by said electrode carrier and electrically connected to said first conductor for converting said alternating current to a D. C. potential, and means electrically connected to said first conductor at the surface for measuring said D. C. potential.

8. A method for logging a well which comprises arranging an electrode at the surface, and at least three electrodes in a bore hole with said surface electrode being connected to one of said bore hole electrodes, moving said bore hole electrodes in a given direction along said bore hole, supplying alternating current of constant value to the electrode connected to the surface electrode, measuring the impedance between said surface electrode and the bore hole electrode connected thereto, reversing the direction of movement of said bore hole electrode, and measuring the A. C. potential differential between two of said bore hole electrodes spaced from each other and from the electrodes to which the current is supplied.

9. A method for logging a well which comprises arranging an electrode at the surface and at least three electrodes in a bore hole with said surface electrode being connected to one of said

bore hole electrodes, moving said bore hole electrodes in a given direction along said bore hole, supplying alternating current of constant value to the electrode connected to the surface electrode, measuring the natural earth potential between said surface electrode and the bore hole electrode connected thereto, reversing the direction of movment of said bore hole electrode and measuring the A. C. potential difference between two of said bore hole electrodes spaced from each other and from the electrode to which current is supplied.

10. In a system for investigating the electrical properties of formation wherein an input circuit establishes an electrical field through formation between a pair of electrodes and a probe circuit is established through a probe electrode located in said electrical field, the combination of: a transmission line common to said circuits; means interposed between said probe electrode and transmission line for converting the current picked up by said probe electrode to current distinguishable from that of said input circuit and delivering such converted current to said transmission line; and means for isolating the remaining portions of each circuit from the effects of the current flowing in the other.

11. In a system for electrologging wells wherein a plurality of electrodes are suspended in a well-bore from a pair of conductors and are in electrical association with formation confronting or in proximity to the well-bore, wherein an alternating current input circuit is associated through said conductors with certain of said electrodes and a direct current probe circuit is also associated through said conductors with others of said electrodes, wherein means are provided to rectify alternating current picked up by the electrodes associated with said probe circuit, and wherein conductors are normally isolated from the effect of direct current originating in the formation, the combination of: a third circuit including a meter for measuring the effects of direct current originating in the formation; means for connecting said third circuit to said conductors in alternation with said other circuits; and means incorporated in said input circuit, operable when said circuit is closed, to maintain the isolation of said conductors from the effect of direct current originating in the formation, and operable when said input circuit is open to associate electrically said third circuit with said direct current originating in the formation.

12. In a system for investigating the electrical properties of formation wherein an input circuit establishes an electrical field through formation between a pair of electrodes and a probe circuit is established through a probe electrode located in said electrical field, the combination of: a transmission line common to said circuits; means interposed between said probe electrode and transmission line for converting the current picked up by said probe electrode to current distinguishable from that of said input circuit and delivering such converted current to said transmission line and means for isolating the remaining portions of each circuit from the effects of the current flowing in the other.

13. A system as specified in claim 12 wherein meters are provided in the respective circuits to measure the electrical field as sampled by said electrodes.

14. A method of electrically investigating formation traversed by a well-bore, characterized by establishing an input circuit producing an electrical field in the formation between a pair of input electrodes suspended in a well-bore, measuring in said circuit the electrical properties of said field in proximity to one of said electrodes; establishing a probe circuit including a probe electrode in said field, converting in proximity to said probe electrode the current picked up by said electrode to a current distinguishable from that flowing in said input circuit, introducing said converted current into said input circuit between said input electrodes and the source of input current; isolating such converted current from the measurements made in said input circuit and measuring such isolated converted current to determine the electrical properties of said field as picked up by said probe electrode.

15. An apparatus for investigating the electrical properties of formation, comprising: an input circuit including a transmission line, a pair of electrodes, one of materially greater area than the other, both contacting the formation to be investigated and adapted to establish an electrical field therein, measuring means in said input circuit for determining the electrical properties of said field in proximity to the smaller electrode; a probe circuit utilizing said transmission line and including a probe electrode adapted to pick up current flowing in said field at a point spaced from said input electrodes, means interposed between said transmission line and said probe electrode for rendering the current picked up thereby distinguishable from the current of said probe circuit, and measuring means for determining the electrical properties of the formation as picked up by said probe electrode; and instrumentalities in said circuits for isolating each measuring means from the current intended for the other measuring means.

16. In an apparatus for investigating the electrical properties of formation: means for establishing an electrical field in formation to be investigated, said means including a source of energy and input electrodes; means for probing said electrical field, said latter means including probe electrodes; a transmission line common to said means; and a device in immediate association with one of said means and interposed between its electrodes and said transmission line, to render distinguishable the currents of the two means flowing in said transmission line.

17. In an apparatus for investigating the electrical properties of formation: means for establishing an electrical field in formation to be investigated, said means including a source of energy and input electrodes; means for probing said electrical field, said latter means including probe electrodes; a transmission line common to said means; a device in immediate association with one of said means and interposed between its electrodes and said transmission line, to render distinguishable the currents of the two means flowing in said transmission line; meters associated with each of said means; and instrumentalities for segregating the current intended for one meter from that intended for the other.

18. In an apparatus for electrologging formation traversed by a well-bore wherein a plurality of electrodes are suspended in a well-bore and an input circuit is connected with a source of electrical energy and associated with one set of said electrodes to establish an electrical field in the bore-hole and surrounding formation, and wherein a probe circuit is associated with another

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set of said electrodes to sample said field, the combination of: a transmission line common to said circuits and incorporating said electrodes; means interposed between one set of said electrodes and said transmission line to render the current flowing in the corresponding circuit distinguishable from that flowing in the other; meters in each of said circuits; and means for segregating the currents intended for said meters.

19. In an apparatus for electrologging formation traversed by a well-bore wherein a plurality of electrodes are suspended in a well-bore and an input circuit is connected with a source of electrical energy and associated with one set of said electrodes to establish an electrical field in the bore-hole and surrounding formation, and wherein a probe circuit is associated with another set of said electrodes to sample said field, the combination of: a transmission line common to said circuits and incorporating said electrodes; means interposed between one set of said electrodes and said transmission line to render the current flowing in the corresponding circuit distinguishable from that flowing in the other; meters in each of said circuits; and means comprising condensers and filters interposed between said transmission line and said meters, and between said transmission line and electrodes for segregating said currents.

20. In an apparatus for electrologging formation traversed by a well-bore wherein a plurality of electrodes are suspended in a well-bore and an input circuit is connected with a source of electrical energy and associated with one set of said electrodes to establish an electrical field in the bore-hole and surrounding formation, and wherein a probe circuit is associated with another set of said electrodes to sample said field, the combination of: a transmission line including a conductor and a grounded metallic sheath, which sheath may be incorporated in said sets of electrodes; means interposed between certain of said electrodes and said transmission line for rendering the current flowing in the associated circuit distinguishable from that flowing in the other circuit; meters in each of said circuits; and means for segregating the currents intended for said meters.

21. In an apparatus for electrologging formation traversed by a well-bore wherein a plurality of electrodes are suspended in a well-bore and an input circuit is connected with a source of electrical energy and associated with one set of said electrodes to establish an electrical field in the bore-hole and surrounding formation, and wherein a probe circuit is associated with another set of said electrodes to sample said field, the combination of: a transmission line including a conductor and a grounded metallic sheath, which sheath may be incorporated in said sets of electrodes; means interposed between certain of said electrodes and said transmission line for rendering the current flowing in the associated circuit distinguishable from that flowing in the other circuit; meters in each of said circuits; and means comprising condensers and filters interposed between said transmission line and said meters, and between said transmission line and electrodes, for segregating said currents.

22. An apparatus for electrologging formation traversed by a well-bore, comprising: an input circuit including one set of electrodes adapted to establish an electrical field in the formation to be investigated; a probe circuit including a set of probe electrodes for sampling said field; a transmission line common to said circuits; means including condensers and filters for causing the independent portion of one of said circuits to pass direct current and the independent portion of the other circuit to pass alternating current; and means interposed between one set of electrodes and said transmission for altering the current passing said electrodes so as to pass through the corresponding circuit.

23. An apparatus for electrologging formation traversed by a well-bore, comprising: a transmission line including an insulated conductor and grounded sheath; an input circuit including a source of alternating current and a pair of input electrodes incorporated in said transmission line and supplied with alternating current from said source to establish, when said electrodes are suspended in a well-bore, an alternating current field through the formation therebetween; probe electrodes carried by said transmission line for picking up alternating current flowing in said field; means for rectifying the alternating current picked up by said probe electrodes and feeding the rectified current to said transmission line; means for isolating said conductor from direct current picked up by said electrodes, whereby the direct current passed thereby aggregates at said rectifier; means for confining the alternating current received by said probe electrodes to that passing in said alternating current field; a meter in said input circuit for measuring said alternating field; another meter connected to the isolated portion of said conductor to measure the rectified current from said probe electrodes; and means for blocking transfer of alternating current from said conductor to said sheath, except through the formation between said input electrodes.

24. In a system for electrologging wells which employs current input electrodes and proble electrodes, which utilizes a single conductor for both an input circuit and a probe circuit associated with said electrodes, and which includes means for distinguishing the input and probe currents flowing in said conductor, the combination of: a third circuit adapted to be connected with one of said electrodes through said conductor; means for connecting said first and second, and said third circuits, in alternation with said conductor.

25. In a system for electrologging wells wherein input electrodes and probe electrodes are connected through a common conductor to an alternating current input circuit and a direct current probe circuit, respectively, and condensers are interposed between at least some of said electrodes and said conductor to isolate the same from any effect of direct current passing said electrodes, the combination of: a third circuit also utilizing said conductor; means for connecting said third circuit to said conductor in alternation with the other circuits; and means operable when said input circuit is open to by-pass certain of said condensers whereby direct current may pass from the corresponding electrode through said conductor.

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