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D E C I S I O N
of 19 July 2000

Case Number: T 0908/99 - 3.4.1

Application Number: 88402703.8

Publication Number: 0314573

IPC: G01V 3/30

Language of the proceedings: EN

Title of invention:

Well logging apparatus and method

Patentee:

SCHLUMBERGER LIMITED, et al

Opponent:

BAKER HUGHES INCORPORATED
Baroid Technology, Inc (a Delaware corporation)

Headword:

-

Relevant legal provisions:

EPC Art. 56

Keyword:

"Inventive step - (yes) after amendment"

Decisions cited:

-

Catchword:

-



Case Number: T 0908/99 - 3.4.1

D E C I S I O N
of the Technical Board of Appeal 3.4.1
of 19 July 2000

Appellant:
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Decision under appeal:

**Decision of the Opposition Division of the
European Patent Office posted 9 July 1999
revoking European patent No. 0 314 573 pursuant
to Article 102(1) EPC.**

Composition of the Board:

Chairman: G. Davies
Members: M. G. L. Rognoni
H. K. Wolfrum

Summary of Facts and Submissions

- I. The appellants (patentees) lodged an appeal, received on 9 September 1999, against the decision of the opposition division, dispatched on 9 July 1999, revoking the European Patent No. 0 314 573. The fee for the appeal was paid on 9 September 1999 and the statement setting out the grounds of appeal was received on 16 November 1999.
- II. Since the oppositions originally filed by Baker Hughes Incorporated (opponent 01) and Baroid Technology, Inc. (opponent 02) had been withdrawn in 1994 and 1998, respectively, the opponents took no part in the appeal.
- III. In the decision under appeal, the opposition division held that the subject-matter of claims 1 and 11 did not involve an inventive step within the meaning of Article 56 EPC, having regard to the following documents:
- D1: US-A-4 209 747
- D2: Rodney et al.: "The Electromagnetic Wave Resistivity MWD Tool", SPE 12167, 1983
- D6: GB-A-2 146 126
- IV. Oral proceedings were held on 19 July 2000.
- V. The appellants requested that the decision under appeal be set aside and a patent granted on the basis of the following documents:

Claims: 1 to 17 filed in the oral proceedings:

Description: pages 2, 3, 4 and 17 of the description filed in the oral proceedings; pages 5 to 16 of the description as granted;

Drawings: Figures 1 to 27 as granted.

VI. The wording of claim 1 now reads as follows:

"1. A logging apparatus (200) for determining the resistivity of earth formations surrounding a borehole while the borehole is being drilled with a drill bit (15) rotatable by means of a drill string (12), the apparatus coupleable in the drill string (12) and comprising:

- a transmitter (T1) for generating electromagnetic wave energy at a first location in the borehole; characterised by:
- a pair of receiver coils (R1, R2) for receiving electromagnetic wave energy, one at each of second and third locations in the borehole, said second and third locations being successively spaced longitudinally in the borehole from said first location;
- a circuit (261) for detecting the phase shift between electromagnetic wave energy received at said second and third locations in the borehole; and
- a circuit (262) for detecting the attenuation between electromagnetic wave energy received at said second and third locations in the borehole; wherein said apparatus includes
 - a system comprising means (270, 85) for determining, as a function of the detected phase shift, the resistivity of formations at a relatively shallow depth of investigation

around said second and third locations, and
- means (270, 85) for determining, as a function of the detected attenuation, the resistivity of formations at a relatively deep depth of investigation around said second and third locations,

wherein

- these resistivity determining means (270, 85) are arranged to determine said resistivities utilizing measurement information from only a single pair of receiver coils (R1, R2);

- these resistivity determining means (270, 85) are arranged for applying a transform, stored in such means, from phase shift to resistivity wherein said transform utilizes a predetermined functional relationship between the dielectric permittivity and conductivity of earth formations, and/or

- these resistivity determining means (270, 85) are arranged for applying a transform, stored in such means, from attenuation to resistivity wherein said transform utilizes a predetermined functional relationship between the dielectric permittivity and conductivity of earth formations."

The wording of claim 11 now reads as follows:

"11. A method for determining the resistivity of earth formations surrounding a borehole while the borehole is being drilled, the method comprising the steps of:

- providing a logging device which is coupleable in a drill string and movable through the borehole;
- generating electromagnetic wave energy at a first

location in the borehole;

- receiving electromagnetic wave energy at second and third locations in the borehole, said second and third locations being successively spaced longitudinally in the borehole from said first location;
- detecting the phase shift between electromagnetic wave energy received at said second and third locations in the borehole; and
- detecting the attenuation between electromagnetic wave energy received at said second and third locations in the borehole;

the method further comprising the steps of:

- determining, as a function of the detected phase shift, the resistivity of formations at a relatively shallow depth of investigation around said second and third locations;
- determining, as a function of the detected attenuation, the resistivity of formations at a relatively deep depth of investigation around said second and third locations;

wherein

- said resistivities are determined from electromagnetic wave energy received only at said second and third locations;
- a transform is applied from phase shift to resistivity wherein said transform utilizes a predetermined functional relationship between the dielectric permittivity and conductivity of earth formations;

and/or

- a transform is applied from attenuation to resistivity wherein said transform utilizes a predetermined functional relationship between the dielectric permittivity and conductivity

of earth formations."

Claims 2 to 10 and 12 to 17 are dependent on claims 1 and 11, respectively.

VII. The appellants' arguments may be summarised as follows:

The present invention related to a logging apparatus for determining the resistivity of earth formations surrounding a borehole while the borehole was being drilled with a drill bit rotatable by means of a drill string. This apparatus, which comprised two receiver coils and a transmitter coil, was designed to allow the determination of resistivity at two different depths of investigation from measurements of phase shift and attenuation performed at the same receiver coils. The gist of the invention consisted essentially in applying a transform from phase shift and/or attenuation to resistivity which utilised a predetermined functional relationship between dielectric permittivity and conductivity of the earth formations in order to minimise errors in the resistivity measurements due to the effect of dielectric permittivity. Since the available prior art failed to teach or even suggest that a suitable correlation between dielectric permittivity and conductivity could be utilised in the transformation from phase shift and/or attenuation to resistivity, the subject-matters of claims 1 and 11 involved an inventive step within the meaning of Article 56 EPC.

Reasons for the Decision

1. The appeal is admissible.

2.1 Claim 1 differs from the apparatus claim as original filed and as granted essentially in that it comprises features relating to the application of a transform from phase shift and/or attenuation to resistivity which is stored in "resistivity determining means" and "utilizes a predetermined functional relationship between permittivity and conductivity of earth formations". Such features find support in the application as originally filed (page 12, line 21 to page 13, line 1; Figures 6, 7 and 8) and constitute a further limitation of the scope of the apparatus claim as granted.

The method claim 11 is based essentially on the same features of claim 1 expressed in terms of method steps.

2.2 Hence, the Board finds that all the amendments made to the description and the claims are admissible under Articles 123(2)(3) EPC.

3.1 The present invention relates to a logging apparatus and a method for investigating earth formations by determining their resistivity at two different radial depths of investigation while using signals received at a single pair of receiver coils operating in differential arrangement. As pointed out in the description (cf. application as originally filed, page 1, lines 10 to 14), resistivity logging is a particularly important well logging technique, because porous earth formations having high resistivity generally indicate the presence of hydrocarbons, while porous earth formations with low resistivity are generally water saturated.

3.2 Document D2, which is considered to represent the closest prior art, provides an overview of the development of a 2 MHz MWD (Measurement-While-Drilling) resistivity logging tool.

The logging tool shown in D2 comprises a single transmitter and two receivers having receiver coils spaced longitudinally from the transmitter coil. Since the effects of the dielectric constant of the medium on the propagation of an electromagnetic wave are negligible at the chosen operating frequency (2 MHz), the phase shift and the attenuation experienced by a wave travelling through the medium are primarily a function of the medium's resistivity. Thus, as pointed out in D2 (page 2: "BASIC APPROACHES"), the resistivity of earth formations can be inferred from:

- the difference in phase between the two signals at the receiving coils;
- the ratio of amplitude of the signals (attenuation) at the receiving coils;
- a combination of phase and amplitude ratio (attenuation) measurements.

3.3 Furthermore, it is known in the art of well logging (D1, column 4, lines 3 to 17) that, when electromagnetic wave energy is emitted from a first location in a borehole into the surrounding earth formations and then received at a second location in the borehole, measurements of wave energy **attenuation** and of **relative phase** taken at the **second location** are affected by different volumes and shapes of the formations. In particular, the attenuation measurement

is more affected by portions of the formations further from the borehole than are measurements of phase; i.e. the **attenuation** measurement looks **deeper** into the formations than does the **phase** measurement.

Hence, the resistivity values obtained with the logging tool suggested in D2 relate necessarily to different regions of the rock formations, depending on whether they are derived from phase shift or attenuation measurements.

3.4 In the opinion of the Board, the teaching of document D2 implies for the person skilled in the art of well logging the disclosure of a logging apparatus for determining the resistivity of earth formations surrounding a borehole which comprises the following features recited in claim 1:

- a transmitter for generating electromagnetic wave energy at a first location in the borehole;
- a pair of receiver coils (Figure 2: "far receiver", "near receiver") for receiving electromagnetic wave energy, one at each of second and third locations in the borehole, said second and third locations being successively spaced longitudinally in the borehole from said first location;
- a circuit for detecting the phase shift between electromagnetic wave energy received at said second and third locations in the borehole;
- a circuit for detecting the attenuation between electromagnetic wave energy received at said second and third locations in the borehole;

- a system comprising means for determining, as a function of the detected phase shift, the resistivity of formations at a relatively shallow depth of investigation around said second and third locations;
- means for determining, as a function of the detected attenuation, the resistivity of formations at a relatively deep depth of investigation around said second and third locations;
- wherein, these resistivity determining means are arranged to determine said resistivities utilising measurement information from only a single pair of receiver coils .

- 3.5 Since the error introduced by disregarding the permittivity of the earth formations increases with the medium's resistivity (cf. D2, Figure 5), it is further suggested in D2 to improve the accuracy of the logging tool in highly resistive formations with well known lithologies by inferring the dielectric constant from the lithology and by applying a linear correction to the resistivity readings (page 4, left-hand column, first paragraph).
- 3.6 Starting from the teaching of D2, the problem addressed by the present patent could be defined as improving the accuracy of the resistivity measurements derivable from a phase shift measurement and/or an attenuation measurement.
- 3.7 The gist of the invention as specified in claim 1 consists essentially in applying a transform from phase shift to resistivity and/or from attenuation to resistivity which utilises a predetermined functional

relationship between the permittivity and the conductivity of earth formations.

As pointed out in the description, the conversion from phase shift and/or attenuation to resistivity is based on a mathematical model of the propagation of an electromagnetic wave which considers the medium's resistivity as the unknown to be determined and assumes that permittivity and conductivity are mutually linked by a predetermined functional relationship not directly dependent on a particular lithology. According to an embodiment of the invention shown in the description, a functional relationship between permittivity and conductivity may be obtained from statistical data taken from different rock formations.

- 3.8 As submitted by the appellants, an essential difference between the correction suggested in D2 and the subject-matter of claim 1 is that the latter does not presuppose any knowledge of the characteristics of the particular rock formations surrounding the borehole, because the dielectric permittivity is assumed to be a predetermined function of conductivity (i.e. of the resistivity which the logging apparatus is expected to determine). Furthermore, the error correction shown in D2 would not compensate for the substantial deviations between the inferred and the actual permittivities which may be encountered while drilling a borehole through different rock formations. The correction according to the present invention, however, would allow for different lithologies surrounding the same borehole by **continuously** varying the assumed value of permittivity as a function of the medium's conductivity, thereby reducing the maximum error which can be expected in the determination of the resistivity

of unspecified rock formations.

- 4.1 The apparatus and method for determining permittivity and conductivity of rock formations according to document D1 operate in a frequency domain (10 to 100 MHz) in which both dielectric permittivity and conductivity have a substantial effect upon the propagation of an electromagnetic wave, so that measurements of attenuation and phase shift can be used to solve two simultaneous equations with respect to the dielectric constant and the conductivity of the rock formations through which the wave travels (column 2, lines 56 to 64).
- 4.2 The logging apparatus shown in document D1 comprises a transmitter coil and two coil pairs spaced from the transmitter coil, whereby the first coil pair is spaced further from the transmitter coil than the second coil pair. The phase shift at the first coil pair and the attenuation at the second coil pair are used to determine both the resistivity and the permittivity of a certain region of a rock formation. By taking the phase shift measurement at the first coil pair (far coil pair) and the attenuation measurement at the second coil pair (near coil pair), it is ensured that both the phase shift and the attenuation measurements are related to the same region of the rock formation, since, for a given spacing between transmitter coil and receiver coils, the attenuation measurement looks deeper into the formations (cf. point 3.3, above).

A further assessment of the resistivity at a greater "depth" of investigation is made by utilising attenuation measurements taken at the far receiver pair and the value of permittivity derived from the

attenuation measured at the near receiver pair and the phase shift at the far receiver pair. Although the permittivity employed in determining the resistivity from the attenuation measurement taken at the far receiver coils represents the dielectric constant of somewhat "shallower" formations, in most cases this would not give rise to a substantial percentage error in the determination of the resistivity of the "deeper" formations (cf.: D1, column 16, lines 28 to 50).

5. Document D6 relates to a logging apparatus coupleable in the drill string having a transmitter and a single pair of receiver coils. The operating frequency is chosen so that the signal is predominantly influenced by the conductivity of the formations and not very strongly affected by dielectric constant variations (page 4, lines 57 to 67). This document does not suggest applying any corrections to the measured resistivity on the basis of assumptions concerning the value of the permittivity.
- 6.1 In summary, the Board finds that none of the available prior art documents suggests that resistivity measurements obtained from phase shift or attenuation measurements taken at a single pair of receiver coils of a logging apparatus could be improved by assuming that the dielectric constant is a function of the conductivity and by introducing a functional relationship between permittivity and conductivity into the calculations which are carried out to convert phase shift or attenuation measurements into the medium's resistivity.
- 6.2 Hence, the subject matter of claim 1 involves an inventive step within the meaning of Article 56 EPC.

6.3 Independent claim 11 is based essentially on the features of claim 1 expressed in terms of method steps. Hence, the subject-matter of the method claim also complies with the requirements of Article 56 EPC.

Claims 2 to 10 and 12 to 17 are dependent, and, therefore, their subject-matters also involve an inventive step.

7. For the above reasons, the Board finds that the appellants' request meets the requirements of the EPC and that a patent can be granted on the basis thereof.

Order

For these reasons it is decided that:

1. The decision under appeal is set aside.
2. The case is remitted to the department of the first instance with the order to grant a patent on the basis of the appellants' request (cf. V, above).

The Registrar:

The Chairman:

R. Schumacher

G. Davies