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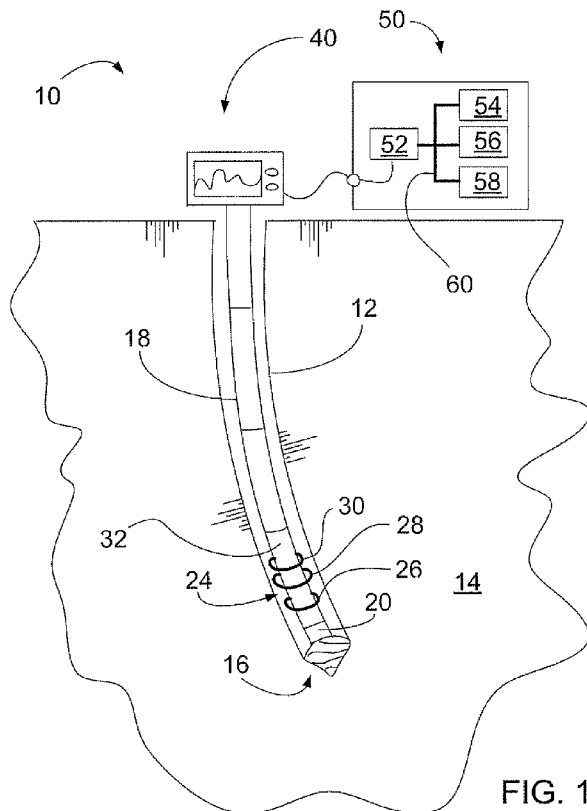


FIG. 1

(57) Abstract: A system and method for determining an electromagnetic response from a region in an earth formation. Receivers where raw response signals (V_{raw}) are measured are at different offset distances (L_1 , L_2) from a transmitter and are electromagnetically coupled to the transmitter by a support structure. The raw response signals (V_{raw}) are adjusted according to an exemplary method to provide an adjusted signal (V_{adj}). The effect of the support structure on the raw response signals (V_{raw}) is removed or reduced for the adjusted signal (V_{adj}) and the adjusted signal (V_{adj}) can be interpreted to determine information that is masked in each of the raw response signals (V_{raw}). The adjusted signal (V_{adj}) reflects the electromagnetic response from the region of the earth formation.



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METHOD OF DETERMINING A TRANSIENT ELECTROMAGNETIC RESPONSE OF A FORMATION

TECHNICAL FIELD

[0001] This invention relates generally to signal processing in the context of geological exploration and, more specifically, to determining the transient electromagnetic response of a region of an earth formation.

BACKGROUND

[0002] Electromagnetic investigation tools are often used to take measurements at points along the length of a borehole in an earth formation. In many instances, the tools are attached to or associated with a support structure such as a mandrel, bar, shaft, spindle, housing, cable or wire line. For example, in measuring while drilling (MWD) applications, also known as logging while drilling (LWD) applications, measurement tools may be attached to a high strength support structure that supports a drill bit as the drill bit forms a borehole. The high strength structure can cause the formation response measurements to be disrupted as the high strength structure is typically formed from an electrically conductive material, such as steel or another metal. Therefore, it is desirable to have a system and method that facilitate the removal or reduction of the contribution of the support structure to the measurement so as to reveal information that is provided by a formation response signal.

SUMMARY

[0003] The various embodiments of the present invention overcome the shortcomings of the prior art by providing a system and method for determining an electromagnetic response from a region in an earth formation. Raw response signals are measured with receivers at different offset distances from one or more transmitters. The receivers are electromagnetically coupled to the one or more transmitters by a support structure. The raw signals are adjusted according to an exemplary method to provide an adjusted signal where the effect of the support structure on the raw response

signals is removed or reduced. The adjusted signal can be interpreted to determine information that is masked in the raw response signals. In other words, the adjusted signal reflects the electromagnetic response from the region of the earth formation.

[0004] An exemplary method for determining an electromagnetic response from a region in an earth formation is now described. A measurement tool is conveyed into a borehole formed in the earth formation. The measurement tool can include multiple transmitters and multiple receivers. For example, the measurement tool can include a transmitter, a first receiver, and a second receiver, each positioned on or near an electrically conductive support structure. Here, the first receiver is positioned at a first distance from the transmitter and the second receiver is positioned at a second distance from the transmitter. One of the first receiver and the second receiver can be selected as a primary receiver and the other receiver can be selected as a secondary receiver, as described herein.

[0005] Once the measurement tool is positioned in the borehole, a source signal is transmitted from the transmitter. The source signal incites a first raw signal in the first receiver and a second raw signal in the second receiver. A data acquisition unit measures the first raw signal and the second raw signal and the raw signals are stored in a memory of a computing unit. The raw response signals exhibit an effect from the support structure coupling the transmitters to the receivers such that in a masked time interval the raw response signals do not reflect formation response signals.

[0006] The computing unit includes a processor unit that calculates an adjusted signal by determining a first function of the first raw signal, a second function of the second raw signal, a third function of the first distance, and a fourth function of the second distance. The third function and the fourth function relate the first function and the second function. The computing unit then modifies at least one of the first function and the second function according to the relationship between the third function and the fourth function and subtracts one of the resulting first and second functions from the other of the resulting first and second functions.

[0007] According to one aspect of the disclosure, the first function is the first raw signal, the second function is the second raw signal, the third function is the inverse of

the first distance cubed, and the fourth function is the inverse of the second distance cubed.

[0008] According to another aspect of the disclosure, the first function is the first raw signal, the second function is the second raw signal, the third function is the average of the first raw signal over the masked time interval, and the fourth function is the average of the second raw signal over the masked time interval.

[0009] In certain of the exemplary methods, a first reference signal and a second reference signal are respectively obtained at the first distance and the second distance in a reference medium having a resistivity that is higher than that of the region in the earth formation. For example, the reference medium can have a resistivity that is at least ten times that of the earth formation.

[0010] The computing unit can include memory that stores the first reference signal and the second reference signal.

[0011] According to an aspect of the disclosure, the first function is the first raw signal, the second function is the second raw signal, the third function is the first reference signal, and the fourth function is the second reference signal.

[0012] According to another aspect of the disclosure, the first function is a first calibrated signal that is determined by subtracting the first reference signal from the first raw signal, the second function is a second calibrated signal that is determined by subtracting the second reference signal from the second raw signal, the third function is the first distance, and the fourth function is the second distance.

[0013] According to another aspect of the disclosure, the first function is a first calibrated signal that is determined by subtracting the first reference signal from the first raw signal, the second function is a second calibrated signal that is determined by subtracting the second reference signal from the second raw signal, the third function is the average of the first calibrated signal over the masked time interval, and the fourth function is the average of the second calibrated signal over the masked time interval.

[0014] According to another aspect of the disclosure, the first function is a first calibrated signal that is determined by subtracting the first reference signal from the first

raw signal, the second function is a second calibrated signal that is determined by subtracting the second reference signal from the second raw signal, the third function is the cube root of the first reference signal, and the fourth function is the cube root of the second reference signal.

[0015] The adjusted signal can be interpreted to determine information about the formation that is masked by the raw response signals. For example, the number of layers present in the region in the formation may be determined by calculating the slope of the adjusted signal in the masked time interval.

[0016] It is envisaged that the method can be performed by the system where computer executable instructions are contained on a computer readable medium. For example, a processor unit of the computing unit can execute the instructions.

[0017] The foregoing has broadly outlined some of the aspects and features of the present invention, which should be construed to be merely illustrative of various potential applications of the invention. Other beneficial results can be obtained by applying the disclosed information in a different manner or by combining various aspects of the disclosed embodiments. Accordingly, other aspects and a more comprehensive understanding of the invention may be obtained by referring to the detailed description of the exemplary embodiments taken in conjunction with the accompanying drawings, in addition to the scope of the invention defined by the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] **FIG. 1** is an illustration of a system for determining an electromagnetic response from a region of an earth formation.

[0019] **FIG. 2** is an illustration of the system of **FIG. 1** in a homogenous region of the formation.

[0020] **FIGs. 3 and 4** are illustrations of the system of **FIG. 1** in two layer regions of the formation.

[0021] **FIG. 5** is a graph illustrating signals relating to the homogeneous region of **FIG. 2**.

[0022] FIGs. 6 and 7 are graphs illustrating signals relating to the two layer regions of FIGs. 3 and 4.

[0023] FIG. 8 is a graph illustrating calibrated signals relating to the regions of FIGs. 2-4.

[0024] FIG. 9 is a graph illustrating adjusted signals relating to the regions of FIGs. 2-4.

DETAILED DESCRIPTION OF THE INVENTION

[0025] As required, detailed embodiments of the present invention are disclosed herein. It must be understood that the disclosed embodiments are merely exemplary of the invention that may be embodied in various and alternative forms, and combinations thereof. As used herein, the word “exemplary” is used expansively to refer to embodiments that serve as illustrations, specimens, models, or patterns. The figures are not necessarily to scale and some features may be exaggerated or minimized to show details of particular components. In other instances, well-known components, systems, materials, or methods have not been described in detail in order to avoid obscuring the present invention. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention.

[0026] Systems and methods are described herein in the context of determining a transient electromagnetic response in a region of an earth formation. The electromagnetic formation response can be interpreted to determine characteristics of the formation, such as the resistivity or conductivity of regions of the formation and the locations of boundaries. However, it is envisaged that the systems and methods taught herein can be applied to other environments and other parameters.

Measurement System

[0027] Referring to FIG. 1, a system 10 is configured to drill a borehole 12 in a formation 14 and to take measurements while drilling (MWD). In alternative

embodiments, a borehole is drilled, the drill string is removed, and a measurement tool is then lowered into the borehole by a cable or other suitable suspension means.

[0028] To drill borehole **12**, a drill bit **16** is positioned at the end of a series of tubular elements, referred to as a drill string **18**. Drill bit **16** can be directed by a steering system **20**, such as a rotatable steering system or a sliding steering system. In certain applications, measurements facilitate directing drill bit **16**, for example, toward a hydrocarbon fluid reservoir.

[0029] System **10** includes a measurement tool **24** that is generally described as an array of transmitters and receivers and a corresponding support structure. In the illustrated embodiment, the support structure is a part of drill string **18**. The support structure provides a foundation to which the transmitters and receivers are attached or otherwise houses the array. Hereinafter, the support structure will be described as a mandrel **32**. However, the support structure could be any number of structures for supporting and positioning the array including a cable, housing, drill string element, combinations thereof, and the like.

[0030] Illustrated measurement tool **24** includes a transmitter **26**, a first receiver **28**, and a second receiver **30** that are each positioned along the length of mandrel **32**. As best shown in **FIGs. 2-4**, first receiver **28** is positioned at a first transmitter-receiver (TR) offset distance **L1** from transmitter **26** and second receiver **30** is positioned at a second transmitter-receiver offset distance **L2** from transmitter **26**. In the exemplary embodiment, each of transmitter **26** and receivers **28**, **30** includes a coil antenna that is wound around mandrel **32**. Transmitter **26** and receivers **28**, **30** are thereby arranged to be substantially coaxial. This arrangement is used for purposes of teaching. However, in alternative embodiments, transmitters and/or receivers can be multi-axial so as to send and receive signals along multiple axes. Further, in alternative embodiments, the measurement tool can include multiple transmitters and multiple receivers.

[0031] Generally described, a measurement tool includes a primary receiver and one or more secondary receivers. Various amounts of the responses from the secondary receivers are used to adjust the response of the primary receiver so as to minimize or reduce the mandrel effect, that is, the response due to electromagnetic

coupling of transmitters and receivers by a mandrel or support structure. In other words, an adjusted signal can be the sum of the response of a primary receiver and responses of the secondary receivers where the responses of the secondary receivers are scaled, altered, or modified according to certain relationships.

[0032] In an exemplary embodiment described herein, first receiver **28** is selected as the primary receiver and second receiver **30** is selected as the secondary receiver. The formulations of adjusted signals reflect this selection. However, in alternative embodiments, second receiver **30** may be selected as the primary receiver and first receiver **28** may be selected as the secondary receiver.

[0033] System **10** further includes a data acquisition unit **40** and a computing unit **50**. Data acquisition unit **40** controls output of transmitter **26** and collects the response at receivers **28**, **30**. The response and/or data representative thereof are provided to computing unit **50** to be processed according to the adjustment methods described herein. Computing unit **50** includes computer components including a data acquisition unit interface **52**, an operator interface **54**, a processor unit **56**, a memory **58** for storing information, and a bus **60** that couples various system components including memory **58** to processor unit **56**.

[0034] Computing unit **50** can be positioned at the surface or at a remote location such that information collected by measurement tool **24** while in borehole **12** is readily available. For example, a telemetry system can connect measurement tool **24**, data acquisition unit **40**, and computing unit **50**. In alternative embodiments, data acquisition unit **40** and/or computing unit **50** is combined with or integral to measurement tool **24** and processes signals while in borehole **12**.

Method of Measuring a Transient Electromagnetic Response

[0035] An exemplary method of measuring an electromagnetic response of a region of formation **14** is now described. The response is measured with measurement tool **24**. A transient electromagnetic (TEM) response is useful, for example, in deep reading electromagnetic (DEM) well logging applications to identify the boundaries and properties of layers of a region of a formation **14** at relatively large distances from borehole **12**.

[0036] To begin, data acquisition unit **40** causes a current to flow through transmitter **26** so as to generate a magnetic field. The source signal or input to transmitter **26** may vary. According to an exemplary method, current is passed through transmitter **26** for a time that is long enough to induce a substantially stable magnetic field. This magnetic field permeates both the region of formation **14** and mandrel **32**.

[0037] Then, the current is abruptly shut off and the changing magnetic fields of the region of formation **14** and mandrel **32** induce currents in receivers **28, 30**. Signals that are measured at receivers **28, 30** over time are termed raw response signals V_{raw} . Raw response signals V_{raw} include contributions from both the region of formation **14** and mandrel **32**. Raw response signals V_{raw} may be subjected to one or more operations such as noise suppression, pre-amplification, filtering, or transformation, prior to or as part of a method of adjusting the raw response signal.

[0038] In any event, mandrel **32** electromagnetically couples transmitter **26** to receivers **28, 30** so as to mask the electromagnetic response of the region of formation **14**.

Mandrel Effect Observed in Raw Signals

[0039] Referring to **FIGs. 2-7**, the effect of mandrel **32** is observed by comparing raw response signal V_{raw} to a formation response signal V_f , which represents the response of a region of formation **14** in the absence of mandrel **32**. Formation response signal V_f is substantially fully attributed to the region of formation **14**.

[0040] Referring to **FIGs. 2-4**, exemplary regions of the formation **14** are illustrated. **FIG. 2** illustrates measurement tool **24** positioned in a homogeneous region **N1** of formation **14** that has a resistivity **R1**. **FIGs. 3 and 4** illustrate measurement tool **24** in a heterogeneous region **N2** of formation **14** having two layers **100, 102**. In **FIG. 3**, layers **100, 102** have resistivities **R2, R3**, respectively, and in **FIG. 4**, layers **100, 102** have resistivities **R3, R2**, respectively. For purposes of teaching, resistivity **R3** is substantially greater than resistivity **R2**. A boundary **104** between layers **100, 102** is a distance **D** from measurement tool **24**.

[0041] Raw response signal V_{raw} and formation response signal V_f illustrated in **FIG. 5** relate to homogeneous region **N1** of **FIG. 2**. Raw response signal V_{raw} and formation response signal V_f of **FIG. 6** relate to heterogeneous region **N2** of **FIG. 3** where measurement tool **24** is positioned in first layer **100** having resistivity **R2**. Raw response signal V_{raw} and formation response signal V_f of **FIG. 7** relate to heterogeneous region **N2** of **FIG. 4** where measurement tool **24** is positioned in first layer **100** having resistivity **R3**.

[0042] In each case, the contribution of mandrel **32** to raw response signal V_{raw} causes raw response signal V_{raw} to deviate from formation response signal V_f . Mandrel **32** contributes to raw response signal V_{raw} during a time interval that is referred to as a masked time interval **M**. For example, masked time interval **M** may be approximately $10^{-5} \text{ s} < t < 10^{-2} \text{ s}$.

[0043] At sufficiently late time, formation response signal V_f decays essentially as $t^{-5/2}$ (when plotted on a double logarithmic graph). During masked time interval **M**, raw response signal V_{raw} decays substantially as $t^{-1/2}$. After the mandrel contribution dies out, raw response signal V_{raw} decays essentially as $t^{-5/2}$ and reflects formation response signal V_f . Raw response signal V_{raw} may also reflect formation response signal V_f at times before masked time interval **M** depending on the resistivity of the formation.

Adjustment Methods for Reducing the Mandrel Effect

[0044] During masked time interval **M**, it is difficult to interpret raw response signal V_{raw} , as raw response signal V_{raw} does not reflect formation response signal V_f . Adjustment methods can be applied to raw response signals V_{raw} to reduce the contribution of mandrel **32**. Resulting adjusted signals V_{adj} better reflect formation response signals V_f or provide information about formation **14** that is present in the masked time interval **M**. Adjusted signals V_{adj} can be analyzed to facilitate determining the parameters of a model of formation **14**, for example, the number of layers of formation **14**. Generally, adjusted signals V_{adj} can be determined based on a relationship between raw response signals V_{raw} or between raw response signals V_{raw} and reference signals V_{ref} .

[0045] Reference signals V_{ref} that are used in certain methods of adjusting are now described. Reference signals V_{ref} are measured by receivers **28**, **30** in a test environment. Typically, reference signals V_{ref} are collected to calibrate measurement tool **24** and are stored in memory **58**. One example of a test environment is a substantially homogeneous reference medium that has a resistivity that is high relative to the resistivity of a region of formation **14** from which an electromagnetic response is to be determined. For example, the resistivity of a suitable test environment can be at least ten times greater than the resistivity of the region of formation **14**. An example of a widely used test environment is air.

[0046] Reference signals V_{ref} are collected in the same manner as raw response signals V_{raw} with the difference being that reference signals V_{ref} are collected in a test environment and raw response signals V_{raw} are collected in a region of formation **14**. Where the resistivity of the test environment is relatively high, the contribution of mandrel **32** to reference signal V_{ref} is relatively high compared to the contribution of the test environment. Thus, reference signal V_{ref} approximates the mandrel contribution.

[0047] Generally, the measurement tool that is used to obtain reference signals V_{ref} is the same that is used to measure raw response signals V_{raw} . Here, TR offset distances **L1**, **L2** are the same in both the test environment and formation **14** to provide a relationship between reference signals V_{ref} and raw signals V_{raw} that have the same offset. In alternative embodiments, reference signals V_{ref} measured by one measurement tool can be used to adjust raw response signals V_{raw} measured by another measurement tool. For example, this may be acceptable where the different measurement tools have substantially equivalent conductive structures and arrays. In either case, reference signals V_{ref} and raw response signals V_{raw} that have the same offset can be related.

[0048] A calibrated signal V_{cal} that relates raw response signal V_{raw} and reference signal V_{ref} is now described. Calibrated signal V_{cal} is given by

$$V_{\text{cal}}(t) = V_{\text{raw}}(t) - V_{\text{ref}}(t).$$

Referring to **FIGs. 5-7**, calibrated signal $\mathbf{V}_{\text{cal}}$ reduces the dominant mandrel effect of raw response signal $\mathbf{V}_{\text{raw}}$ and decays essentially as $t^{-3/2}$ for the masked time interval **M**. This decay is slower than that of formation response signal $\mathbf{V}_{\text{f}}$ and is nearly proportional to the formation conductivity σ_f .

[0049] Certain of the methods of adjusting are based on a relationship between raw response signals at different offset distances along the length of mandrel **32**. These methods are termed “raw signal adjustment methods.” Other of the methods of adjusting are based on a relationship between calibrated signals at different offset distances along the length of mandrel **32**. These methods are termed “calibrated signal adjustment methods.”

Raw Signal Adjustment Methods

[0050] Relationships between raw response signals $\mathbf{V}_{\text{raw}}$ at different offset distances **L1**, **L2** and corresponding raw signal adjustment methods are now described. Raw response signal $\mathbf{V}_{\text{raw}}$ measured by one of receivers **28**, **30** depends not only on the resistivity of mandrel **32** and mandrel **32** geometry (e.g., diameter), but also strongly on TR offset distance **L1**, **L2**. Raw response signal $\mathbf{V}_{\text{raw}}$ is nearly independent of the TR offset distance **L1**, **L2** if there is no mandrel **32**. A combination of raw response signals $\mathbf{V}_{\text{raw}}$ measured at multiple TR offset distances **L1**, **L2** can be used to reduce the mandrel effect and better reflect formation response signal $\mathbf{V}_{\text{f}}$.

[0051] A first relationship between raw response signals $\mathbf{V}_{\text{raw}}$ measured at TR offset distances **L1**, **L2** is now described. For large offsets, by comparing raw response signals $\mathbf{V}_{\text{raw}}$ measured at different TR offset distances **L1**, **L2**, it is observed that raw response signal $\mathbf{V}_{\text{raw}}$ is approximately inversely proportional to the cube of TR offset distance **L1**, **L2**. Thus, a large offset approximation of the relationship between raw response signal $\mathbf{V}_{\text{raw}}$ at first offset distance **L1** and raw response signal $\mathbf{V}_{\text{raw}}$ at second offset distance **L2** is given by

$$\frac{V_{\text{raw}}(t, L_1)}{V_{\text{raw}}(t, L_2)} \approx \left(\frac{L_2}{L_1} \right)^3.$$

As this relationship relates the contributions of mandrel **32** at different offsets **L1**, **L2** but does not proportionally or directly relate the contributions of formation **14** at different offsets **L1**, **L2**, first adjusted signal $\mathbf{V}_{adj,1}$ can be determined whereby the first relationship is used to cancel out much of the mandrel contribution and better reflect formation response signal $\mathbf{V}_f$. First adjusted signal $\mathbf{V}_{adj,1}$ is given by

$$V_{adj,1}(t, L_1, L_2) = V_{raw}(t, L_1) - \left(\frac{L_2}{L_1} \right)^3 V_{raw}(t, L_2).$$

[0052] For smaller TR offset distances **L1**, **L2**, the first relationship described above is less applicable. A second adjusted signal $\mathbf{V}_{adj,2}$ can be given by

$$V_{adj,2}(t, L_1, L_2) = V_{raw}(t, L_1) - P_{adj,2}(L_1, L_2) V_{raw}(t, L_2)$$

where modifying function $P_{adj,2}(L_1, L_2)$ represents an observed or experimentally determined relationship found by analyzing the ratio of raw response signal $\mathbf{V}_{raw}$ at first offset distance **L1** to raw response signal $\mathbf{V}_{raw}$ at second offset distance **L2**. For example, modifying function $P_{adj,2}(L_1, L_2)$ can be determined by taking the average of the ratio over masked time interval **M**. In alternative embodiments, modifying function $P_{adj,2}(L_1, L_2)$ is also a function of time.

[0053] The first relationship described above is equally applicable to reference signals $\mathbf{V}_{ref}$ at different offset distances **L1**, **L2**. Accordingly, a third relationship between reference signals $\mathbf{V}_{ref}$ at offset distances **L1**, **L2** and raw response signals $\mathbf{V}_{raw}$ at the same offset distances **L1**, **L2** is given by

$$\frac{V_{raw}(t, L_1)}{V_{raw}(t, L_2)} \approx \frac{V_{ref}(t, L_1)}{V_{ref}(t, L_2)}.$$

This third relationship can similarly be used to provide a third adjusted signal $\mathbf{V}_{adj,3}$ that cancels out much of the mandrel contribution and reflects a formation signal. Third adjusted signal $\mathbf{V}_{adj,3}$ is given by

$$V_{adj,3}(t, L_1, L_2) = V_{raw}(t, L_1) - \frac{V_{ref}(t, L_1)}{V_{ref}(t, L_2)} V_{raw}(t, L_2).$$

Calibrated Signal Adjustment Methods

[0054] Relationships between calibrated signals $\mathbf{V}_{cal}$ at different offset distances **L1**, **L2** and corresponding calibrated signal adjustment methods are now described. For large offset distances, it is observed that calibrated signal $\mathbf{V}_{cal}$ is approximately inversely proportional to offset distance **L1**, **L2**. For large offset distance, a fourth relationship between calibrated signal $\mathbf{V}_{cal}$ at first offset distance **L1** and calibrated signal $\mathbf{V}_{cal}$ at second offset distance **L2** is given by

$$\frac{V_{raw}(t, L_1) - V_{ref}(t, L_1)}{V_{raw}(t, L_2) - V_{ref}(t, L_2)} = \frac{V_{cal}(t, L_1)}{V_{cal}(t, L_2)} \approx \frac{L_2}{L_1}.$$

A fourth adjusted signal $\mathbf{V}_{adj,4}$ that incorporates the fourth relationship is given by

$$V_{adj,4}(t, L_1, L_2) = V_{cal}(t, L_1) - \frac{L_2}{L_1} V_{cal}(t, L_2).$$

[0055] Similar to the second adjusted signal $\mathbf{V}_{adj,2}$ above, a fifth adjusted signal $\mathbf{V}_{adj,5}$ can accordingly be given by

$$V_{adj,5}(t, L_1, L_2) = V_{cal}(t, L_1) - P_{adj,5}(L_1, L_2) V_{cal}(t, L_2)$$

where modifying function $P_{adj,5}(L_1, L_2)$ represents an observed or experimentally determined relationship found by analyzing the ratio of calibrated signal $\mathbf{V}_{cal}$ at first offset distance **L1** to calibrated signal $\mathbf{V}_{cal}$ at second offset distance **L2**.

[0056] Based on a relationship between first adjusted signal $\mathbf{V}_{adj,1}$ and third adjusted signal $\mathbf{V}_{adj,3}$, a sixth adjusted signal $\mathbf{V}_{adj,6}$ can be similarly related to the fourth adjusted signal $\mathbf{V}_{adj,4}$. Sixth adjusted signal $\mathbf{V}_{adj,6}$ is given by

$$V_{adj,6}(t, L_1, L_2) = V_{cal}(t, L_1) - \left(\frac{V_{ref}(t, L_1)}{V_{ref}(t, L_2)} \right)^{1/3} V_{cal}(t, L_2).$$

[0057] A generalized adjustment signal $\mathbf{V}_{adj}$ that encompasses each adjustment signals $\mathbf{V}_{adj}$ is given by

$$V_{adj}(t, L_1, L_2) = f1(V_{raw}(t, L_1)) - \frac{f4(t, L_2)}{f3(t, L_1)} f2(V_{raw}(t, L_2))$$

where **f1** is a function of raw response signal **V_{raw}** at offset distance **L1**, **f2** is a function of raw response signal **V_{raw}** at offset distance **L2**, **f3** is a function of first distance **L1**, and **f4** is a function of second distance **L2**. With respect to the adjusted signals described above, functions **f1**, **f2** may be raw response signals **V_{raw}** or calibrated signals **V_{cal}** and functions **f3**, **f4** may be offset distances **L1**, **L2**, reference signals **V_{ref}**, raw response signals **V_{raw}**, and variations thereof raised to an exponent. In any event, functions **f3**, **f4** relate functions **f1**, **f2** to one another.

[0058] Functions **f3**, **f4** can be constant functions of offset distances **L1**, **L2**, respectively, or functions of both time and offset distances **L1**, **L2**, respectively.

[0059] Referring again to **FIGs. 5-7**, the graphs conceptually illustrate formation response signals **V_f**, raw response signals **V_{raw}**, calibrated signals **V_{cal}**, and adjusted response signals **V_{adj}** measured or calculated for each situation illustrated in **FIGs. 2-4**. For purposes of teaching, only one adjusted response signal **V_{adj}** is shown in each of **FIGs. 5-7**. Calibrated signal **V_{cal}** and adjusted response signal **V_{adj}** of each formation reduce the mandrel contribution of the raw response signal **V_{raw}** although neither fits formation response signal **V_f** during masked time interval **M**.

[0060] In general, during masked time interval **M**, raw response signals **V_{raw}** decay essentially as $t^{-1/2}$, calibrated signals **V_{raw}** decay essentially as $t^{-3/2}$, adjusted raw response signals **V_{raw}** decay essentially as $t^{-3/2}$, and adjusted calibrated response signals **V_{cal}** decay essentially as $t^{-5/2}$. For calibrated signals **V_{cal}** and adjusted signals **V_{adj}**, the mandrel contribution is particularly difficult to reduce toward the end of masked time interval **M** where deviations from a substantially constant decay are observed. The signals **V_{cal}**, **V_{adj}** may not provide useful information at this time although they can provide useful information at other times within and outside of masked time interval **M**.

Interpretation of Adjusted Signal

[0061] Within masked time interval **M**, adjusted response signal **V_{adj}** reflects formation response signal **V_f** better than calibrated signal **V_{cal}**. To illustrate this,

referring first to **FIG. 8**, calibrated signals for V_{cal} comparing homogeneous and heterogeneous regions **N1**, **N2** are shown on the same graph. Here, for purposes of clarity, calibrated signals V_{cal} will be represented with unique element numbers. A first calibrated signal **C1** is determined from raw response signal V_{raw} measured in homogeneous region **N1** where resistivity **R1** is equal to resistivity **R2**. A second calibrated signal **C2** is determined from raw response signal V_{raw} measured in homogeneous region **N1** where resistivity **R1** is equal to resistivity **R3**. A third calibrated signal **C3** is determined from raw response signal V_{raw} measured in heterogeneous region **N2** where measurement tool **24** is positioned in first layer **100** having resistivity **R2**, as shown in **FIG. 3**. A fourth calibrated signal **C4** is determined from raw response signal V_{raw} measured in heterogeneous region **N2** where measurement tool **24** is positioned in first layer **100** having resistivity **R3**, as shown in **FIG. 4**.

[0062] The difference between calibrated signals **C2**, **C4** due to the different regions **N1**, **N2** is mainly observed in the form of a shift of the overall response. As this difference is similar to the difference that is observed between calibrated signals **C1**, **C2** due to the difference in resistivity **R2**, **R3** in the same region **N1**, it is difficult to determine whether calibrated signal **C4** represents heterogeneous region **N2** or homogeneous region **N1**. In other words, the calibrated signal **C3**, **C4** of heterogeneous region **N2** may be wrongly interpreted as that of homogeneous region **N1**.

[0063] In the case of **FIG. 4** where measurement tool **24** is located in the more conductive layer of heterogeneous region **N2**, a shift to less conductive layer is not readily observed. Accordingly, there is little difference between calibrated signals **C1**, **C3**. In either case, calibrated signal V_{cal} alone does not delineate the presence of a second layer.

[0064] Referring to **FIG. 9**, adjusted signals V_{adj} measured in different homogeneous and heterogeneous regions **N1**, **N2** are shown on the same graph. Here, for purposes of clarity, adjusted signals V_{adj} will be represented with unique element numbers. A first adjusted signal **A1** is determined from raw response signal V_{raw}

measured in homogeneous region **N1** where resistivity **R1** is equal to resistivity **R2**. A second adjusted signal **A2** is determined from raw response signal V_{raw} measured in homogeneous region **N1** where resistivity **R1** is equal to resistivity **R3**. A third adjusted signal **A3** is determined from raw response signal V_{raw} measured in heterogeneous region **N2** where measurement tool **24** is positioned in first layer **100** having a resistivity **R2**, as shown in **FIG. 3**. A fourth adjusted signal **A4** is determined from raw response signal V_{raw} measured in heterogeneous region **N2** where measurement tool **24** is positioned in first layer **100** having a resistivity **R3**, as shown in **FIG. 4**.

[0065] Here, the adjusted signals **A3**, **A4** measured in heterogeneous regions **N2** transition from the adjusted signals **A1**, **A2** measured in homogeneous region **N1** thereby clearly delineating the presence of a second layer. When measurement tool **24** is located in more a conductive layer, adjusted signal **A3** is more difficult to distinguish from adjusted signal **A1**.

[0066] Without prior knowledge of region **N1**, **N2** in which raw response signal V_{raw} is determined, raw response signal V_{raw} can be adjusted according to methods of adjusting described herein to provide adjusted response signal V_{adj} . Adjusted response signal V_{adj} at different points along the length of borehole **12** can be compared to one another to gain information about the formation **14** that is present in masked time interval **M** of each. For example, at one point along the length of the borehole, masked time interval **M** of adjusted response signal V_{adj} may have a certain slope in a substantially homogeneous region and, at another point along the length of borehole, masked time interval **M** of adjusted response signal V_{adj} may have a slope that transitions from that of the other adjusted response signal V_{adj} thereby indicating the presence of at least a second layer.

[0067] As the contribution of mandrel **32** has not been removed from adjusted signal V_{adj} toward the end of the masked time interval **M**, transitions from a constant slope line near this time may not delineate the presence of an additional layer.

[0068] The law does not require and it is economically prohibitive to illustrate and teach every possible embodiment of the present disclosure. Hence, the above-described embodiments are merely exemplary illustrations of implementations set forth

for a clear understanding of the principles of the invention. Variations, modifications, and combinations may be made to the above-described embodiments without departing from the scope of the claims. All such variations, modifications, and combinations are included herein by the scope of this disclosure and the following claims.

C L A I M S

1. A method for determining an electromagnetic response from a region in an earth formation, comprising:

conveying a measurement tool into a borehole formed in the earth formation, the measurement tool comprising a transmitter, a first receiver, and a second receiver, the first receiver and the second receiver being electromagnetically coupled to the transmitter by the support structure;

transmitting a source signal from the transmitter, thereby:

inciting a first raw signal (V_{raw}) in the first receiver, the first receiver being positioned at a first distance ($L1$) from the transmitter along the length of the electrically conductive support structure; and

inciting a second raw signal (V_{raw}) in the second receiver, the second receiver being positioned at a second distance ($L2$) from the transmitter along the length of the electrically conductive support structure;

measuring the first raw signal (V_{raw}) and the second raw signal (V_{raw}); and

calculating an adjusted signal (V_{adj}) that approximates the electromagnetic response from the region of the earth formation at least in part by:

determining a first function ($f1$) of the first raw signal (V_{raw}) and a second function ($f2$) of the second raw signal (V_{raw});

determining a third function ($f3$) of the first distance ($L1$) and a fourth function ($f4$) of the second distance ($L2$), wherein the third function ($f3$) and the fourth function ($f4$) relate the first function ($f1$) and the second function ($f2$);

modifying at least one of the first function ($f1$) and the second function ($f2$) to relate the first function ($f1$) and the second function ($f2$) using the third function ($f3$) and the fourth function ($f4$); and

subtracting one of the resulting first and second functions ($f1$, $f2$) from the other of the resulting first and second functions ($f1$, $f2$).

2. The method of claim 1, wherein the support structure contributes to the first raw signal (V_{raw}) and the second raw signal (V_{raw}) in a masked time interval (M).
3. The method of claim 2, wherein the first function (f1) is the first raw signal (V_{raw}), the second function (f2) is the second raw signal (V_{raw}), the third function (f3) is the average of the first raw signal (V_{raw}) over the masked time interval (M), and the fourth function (f4) is a the average of the second raw signal (V_{raw}) over the masked time interval (M).
4. The method of claim 1, wherein the first function (f1) is the first raw signal (V_{raw}), the second function (f2) is the second raw signal (V_{raw}), the third function (f3) is the inverse of the first distance (L1) cubed, and the fourth function (f4) is the inverse of the second distance (L2) cubed.
5. A computer readable medium comprising computer executable instructions adapted to perform the method of claim 1.
6. A system for determining an electromagnetic response from a region in an earth formation, comprising:
 - an electrically conductive support structure;
 - a measurement tool, comprising:
 - a transmitter for transmitting a source signal to incite an electromagnetic field in the region in the earth formation;
 - a first receiver for receiving a first raw signal (V_{raw}), the first receiver being positioned at a first distance (L1) from the transmitter;
 - a second receiver for receiving a second raw signal (V_{raw}), the second receiver being positioned at a second distance (L2) from the transmitter, the first

receiver and the second receiver being electromagnetically coupled to the transmitter by the support structure;

a data acquisition unit for measuring the first raw signal (V_{raw}) and the second raw signal (V_{raw});

a memory for storing the first raw signal (V_{raw}) and the second raw signal (V_{raw});

a processor unit for executing instructions stored in the memory, the instructions comprising:

calculating an adjusted signal (V_{adj}) that approximates the electromagnetic response from the region of the earth formation at least in part by:

determining a first function (f_1) of the first raw signal (V_{raw}) and a second function (f_2) of the second raw signal (V_{raw});

determining a third function (f_3) of the first distance (L_1) and a fourth function (f_4) of the second distance (L_2), wherein the third function (f_3) and the fourth function (f_4) relate the first function (f_1) and the second function (f_2);

modifying at least one of the first function (f_1) and the second function (f_2) to relate the first function (f_1) and the second function (f_2) using the third function (f_3) and the fourth function (f_4); and

subtracting one of the resulting first and second functions (f_1 , f_2) from the other of the resulting first and second functions (f_1 , f_2).

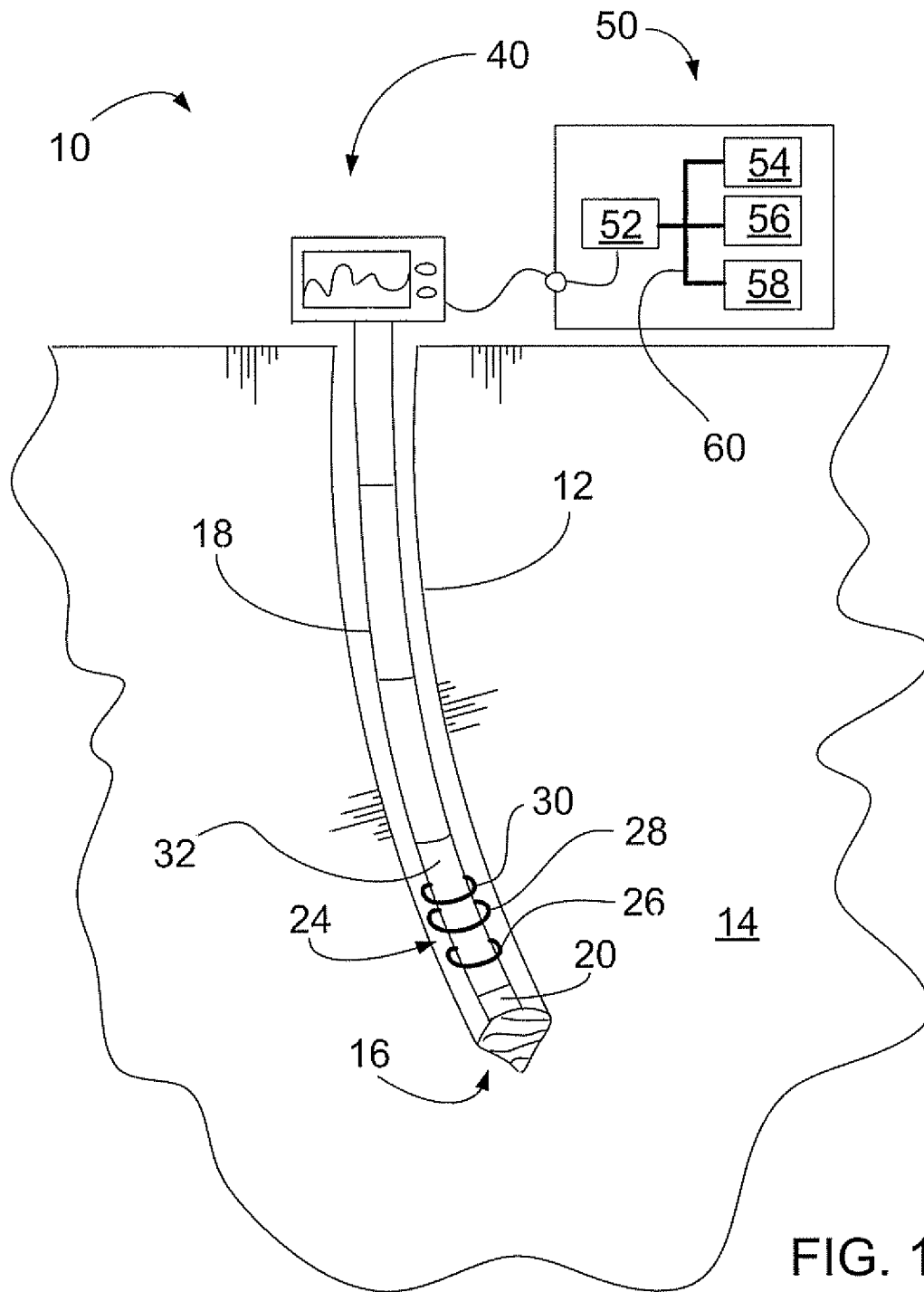
7. The system of claim 6, wherein the memory stores a first reference signal (V_{ref}) and a second reference signal (V_{ref}) that are respectively obtained by the first receiver and the second receiver in a reference medium having a resistivity that is higher than that of the region in the earth formation.

8. The system of claim 7, wherein the first function ($f1$) is a first calibrated signal (V_{cal}) that is determined by subtracting the first reference signal (V_{ref}) from the first raw signal (V_{raw}), the second function ($f2$) is a second calibrated signal (V_{cal}) that is determined by subtracting the second reference signal (V_{ref}) from the second raw signal (V_{raw}), the third function ($f3$) is the first distance ($L1$), and the fourth function ($f4$) is the second distance ($L2$).

9. The system of claim 7, wherein the support structure contributes to the first raw signal (V_{raw}) and the second raw signal (V_{raw}) in a masked time interval (M);

wherein the first function ($f1$) is a first calibrated signal (V_{cal}) that is determined by subtracting the first reference signal (V_{ref}) from the first raw signal (V_{raw}), the second function ($f2$) is a second calibrated signal (V_{cal}) that is determined by subtracting the second reference signal (V_{ref}) from the second raw signal (V_{raw}), the third function ($f3$) is the average of the first calibrated signal (V_{cal}) over the masked time interval (M), and the fourth function ($f4$) is the average of the second calibrated signal (V_{cal}) over the masked time interval (M).

10. The system of claim 14, wherein the first function ($f1$) is the first raw signal (V_{raw}), the second function ($f2$) is the second raw signal (V_{raw}), the third function ($f3$) is the inverse of the first distance ($L1$) cubed, and the fourth function ($f4$) is the inverse of the second distance ($L2$) cubed.



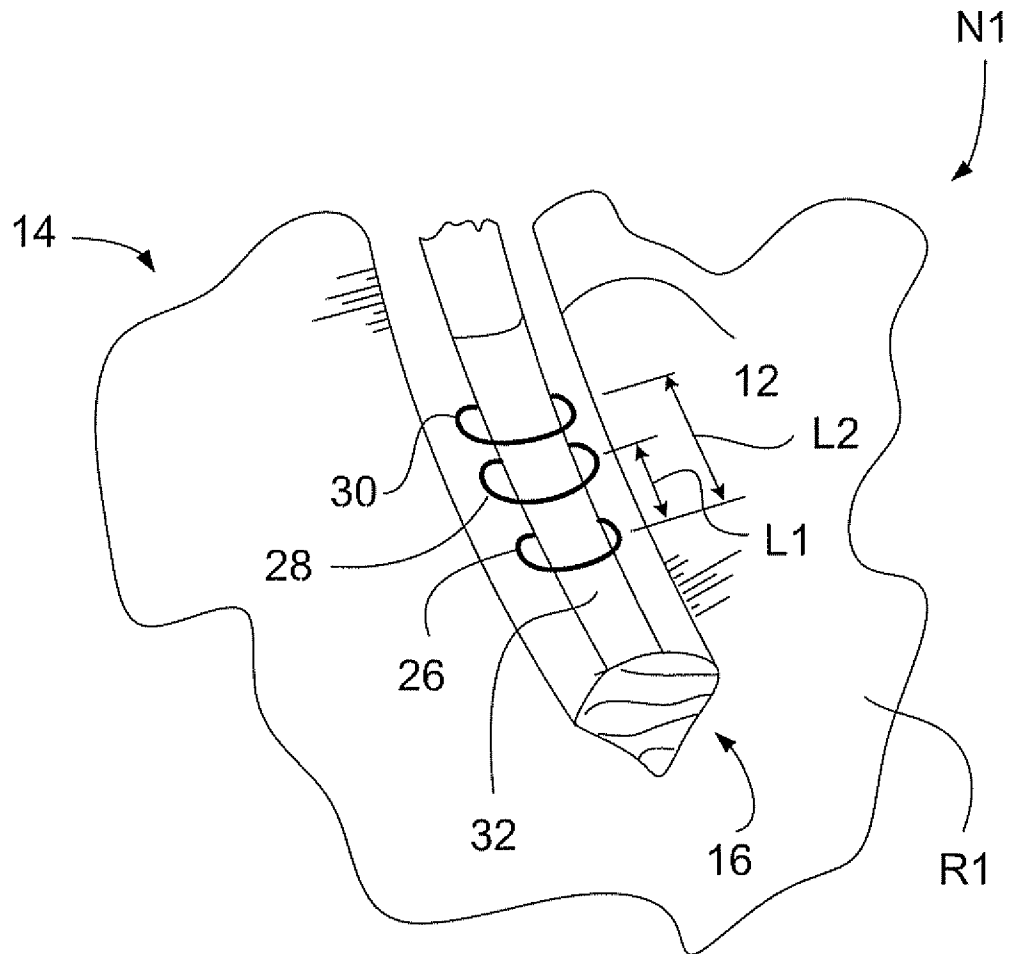


FIG. 2

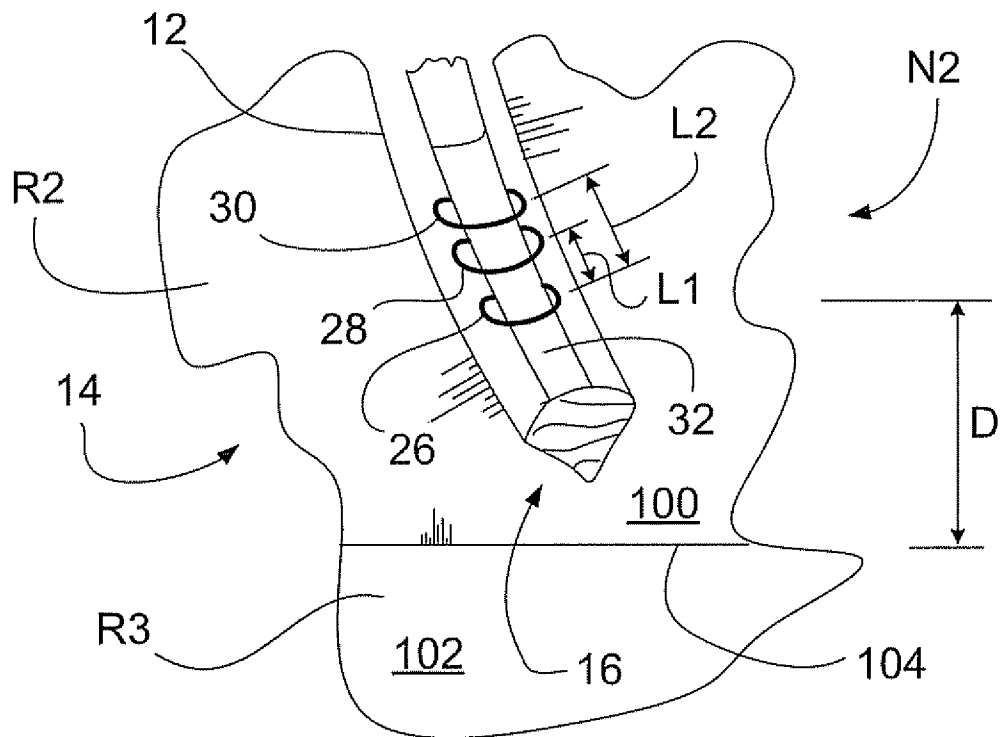


FIG. 3

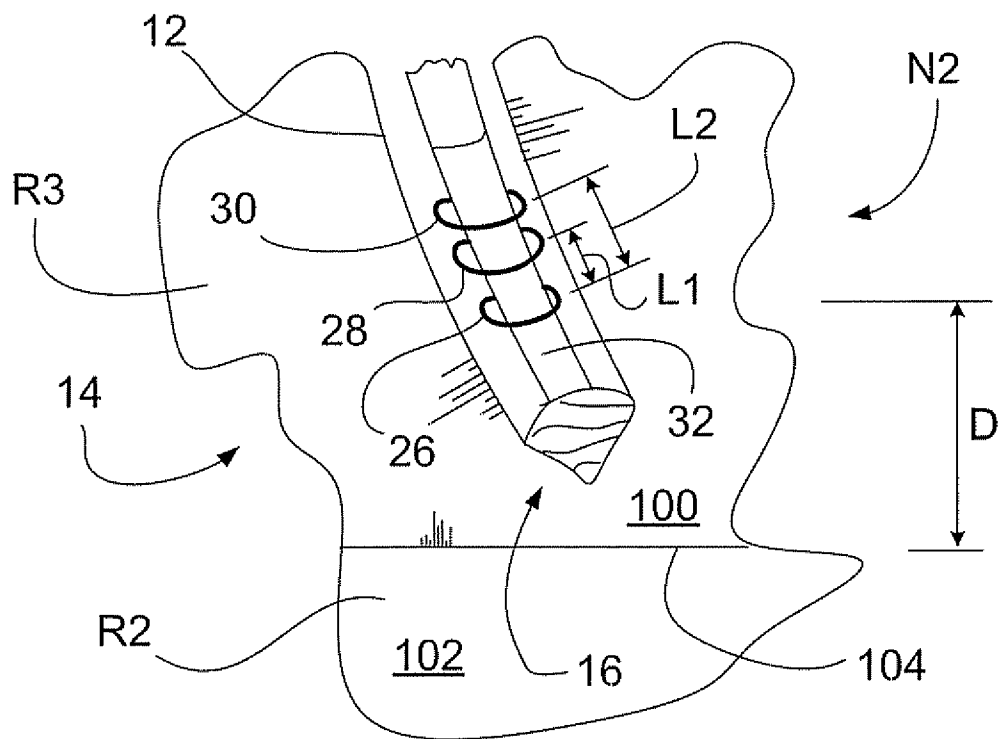


FIG. 4

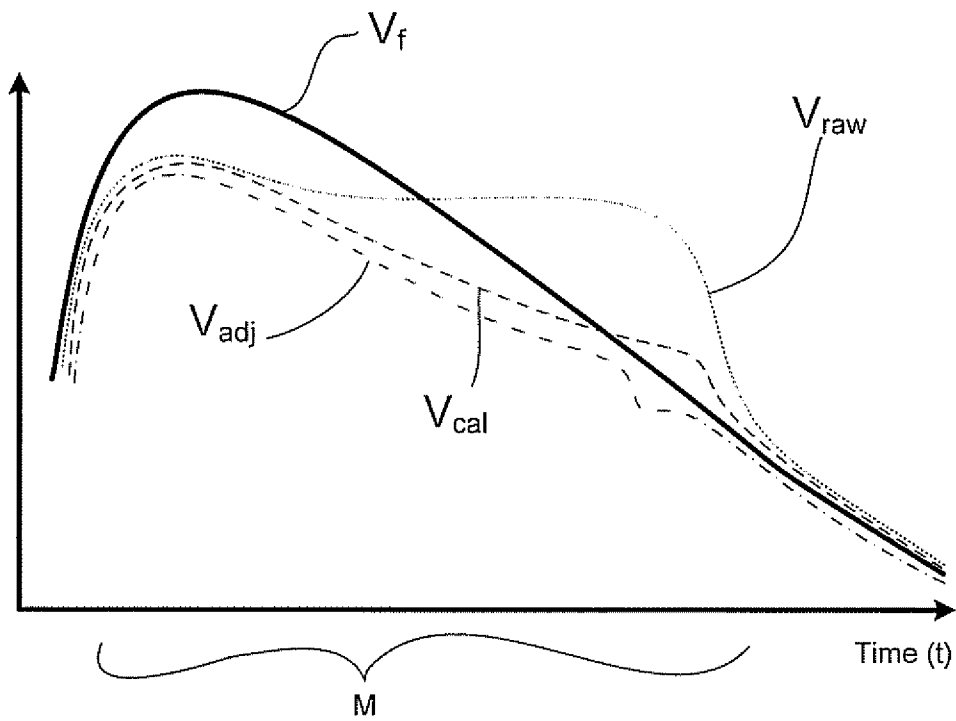


FIG. 5

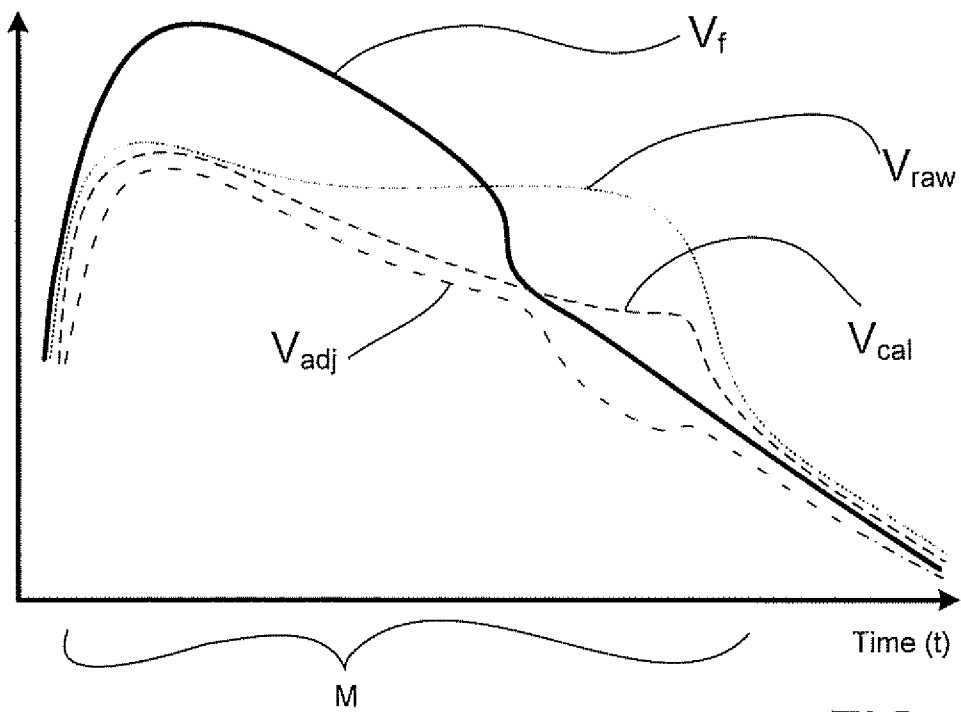


FIG. 6

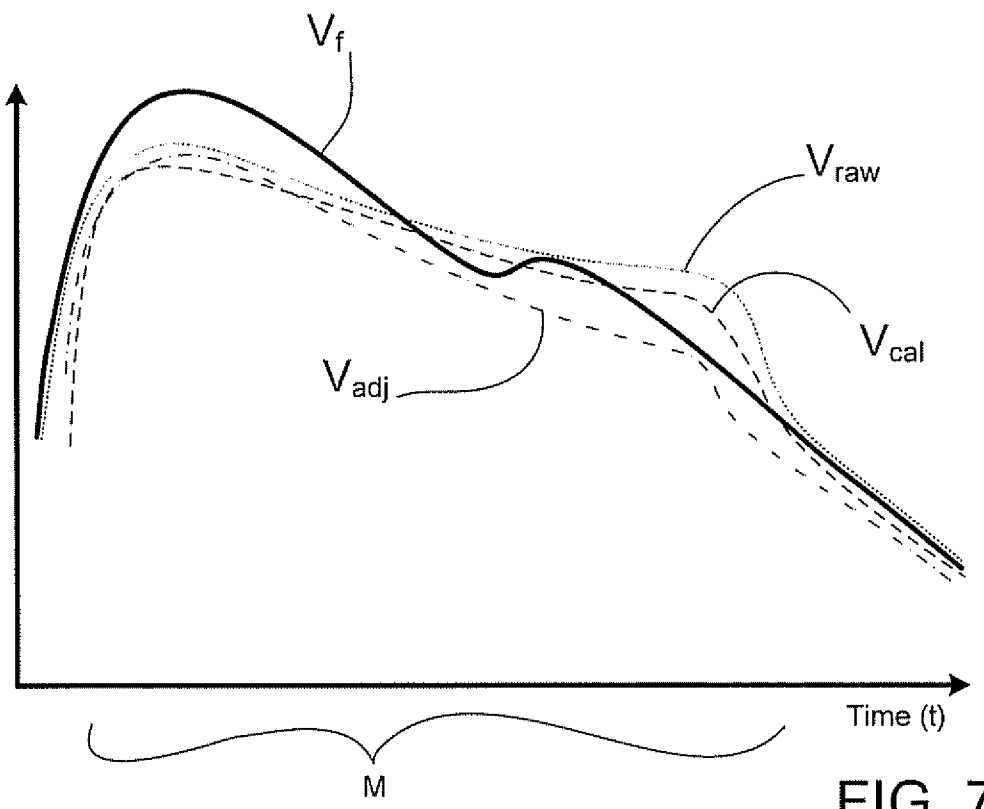


FIG. 7

