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- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

[Continued on next page]

(54) Title: SYSTEM AND METHOD FOR ESTIMATING VELOCITY OF A DOWNHOLE COMPONENT

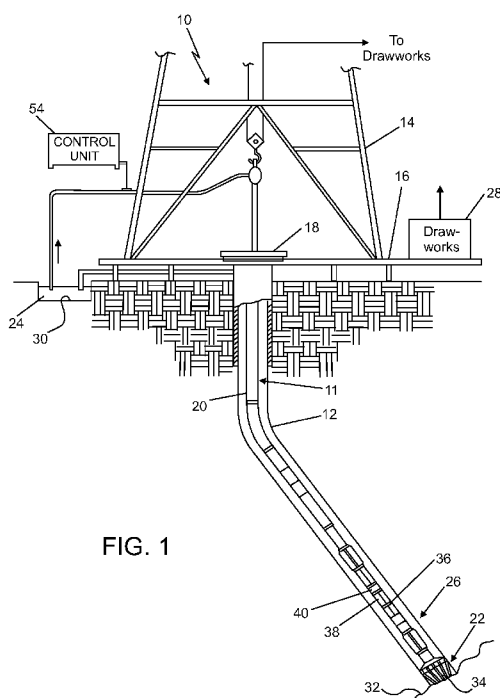


FIG. 1

(57) Abstract: A system for estimating a velocity of a downhole component is disclosed. The system includes: a sensor configured to produce a sensor signal that is proportional to at least one of a position and an acceleration of the downhole component; and a circuit in communication with the sensor and configured to receive the sensor signal and generate an output signal indicative of an instantaneous velocity of the downhole component. A method of estimating a velocity of a downhole component is also disclosed.



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SYSTEM AND METHOD FOR ESTIMATING VELOCITY OF A DOWNHOLE COMPONENT

BACKGROUND

[0001] In hydrocarbon exploration operations, well boreholes are drilled by rotating a drill bit attached to a drillstring, and may be bored vertically or bored in selected directions via geosteering operations. Various downhole devices located in a bottomhole assembly or other locations along the drillstring measure operating parameters and formation characteristics, and include sensors for determining the presence of hydrocarbons.

[0002] Various drilling parameters are monitored during drilling operations to assess the progress of a drilling operation and the performance of a drill bit. A drill bit's rate of penetration (ROP) is a significant parameter measured to monitor drilling progress as well as the presence of formation materials that affect the drilling performance and degradation of the drill bit. ROP is generally measured as an average over a selected period of time. Such average ROP measurements may compromise the ability to assess the actual ROP at any given moment and location during drilling.

BRIEF DESCRIPTION OF THE INVENTION

[0003] A system for estimating a velocity of a downhole component includes: a sensor configured to produce a sensor signal that is proportional to at least one of a position and an acceleration of the downhole component; and a circuit in communication with the sensor and configured to receive the sensor signal and generate an output signal indicative of an instantaneous velocity of the downhole component.

[0004] A method of estimating a velocity of a downhole component includes: lowering a sensor into a borehole in an earth formation, the sensor configured to produce a sensor signal that is proportional to at least one of a position and an acceleration of the downhole component; activating the sensor to generate the sensor signal; and transmitting the signal to a circuit and generating an output signal indicative of an instantaneous velocity of the downhole component via the circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The following description should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

[0006] FIG. 1 depicts an embodiment of a drilling and/or geosteering system;

[0007] FIG. 2 is a circuit diagram illustrating an embodiment of a circuit of the system of FIG. 1;

[0008] FIGS. 3A and 3B are circuit diagrams illustrating additional embodiments of a circuit of the system of FIG. 1;

[0009] FIG. 4 is a circuit diagram illustrating another embodiment of a circuit of the system of FIG. 1;

[0010] FIGS. 5A and 5B are circuit diagrams illustrating further embodiments of a circuit of the system of FIG. 1; and

[0011] FIG. 6 is a flow chart providing an exemplary method of estimating a velocity of a downhole component.

DETAILED DESCRIPTION OF THE INVENTION

[0012] Referring to FIG. 1, an exemplary embodiment of a well drilling and/or geosteering system 10 includes a drillstring 11 that is shown disposed in a borehole 12 that penetrates at least one earth formation during a drilling operation and makes measurements of properties of the formation and/or the borehole 12 downhole. In one embodiment, such measurements are of a movement of components within the borehole, such as the velocity of a drill bit. The velocity, in one embodiment, is related to the drill bit's rate of penetration (ROP), which can be measured by various sensors in the system 10. The system includes a sensor assembly having at least one sensor configured to measure position and/or acceleration of the drill bit or other component, and at least one circuit in communication with the at least one sensor. The at least one circuit is configured to receive a signal from the sensor and generate a signal representative of an instantaneous velocity of the component.

[0013] In one embodiment, the system 10 includes a conventional derrick 14 mounted on a derrick floor 16 that supports a mud motor including a rotary table 18 that is rotated by a prime mover (not shown) at a desired rotational speed. The drillstring 11 includes one or more drill pipe sections 20 or coiled tubing that extend downward into the borehole 12 from the rotary table 18, and is connected to a drill bit assembly 22. Drilling fluid, or drilling mud 24 may be pumped through the drillstring 11 and/or the borehole 12. The well drilling system 10 also includes a bottomhole assembly (BHA) 26. The drill bit assembly 22 is powered by a surface rotary drive, a motor using pressurized fluid (e.g., the mud motor), an electrically driven motor and/or other suitable mechanism. In one embodiment, the drillstring 11 is coupled to a drawworks 28 that is operated to control

drilling parameters such as the weight on bit and the rate of penetration of the drillstring 11 (or components therein such as the drill bit assembly 22) into the borehole 12.

[0014] During drilling operations a suitable drilling fluid 24 from, for example, a mud pit 30 is circulated under pressure through the drillstring 11. The drilling fluid 24 passes into the drillstring 11, and the drilling fluid 24 is discharged at a borehole bottom 32 through an opening in a drill bit 34. The drilling fluid 24 circulates uphole between the drill string 11 and the borehole 12 and is discharged into the mud pit 30.

[0015] In one embodiment, the drilling assembly 22 is included in the bottomhole assembly (BHA) 26, which is disposable within the well logging system 10 at or near the downhole portion of the drillstring 11. The BHA 26 includes any number of downhole tools 36 for various processes including formation drilling, geosteering, and formation evaluation (FE) for measuring versus depth and/or time in order to characterize one or more physical quantities in or around a borehole.

[0016] The downhole tool 36, in one embodiment, includes at least one sensor or sensor assembly 38 to estimate or measure the velocity of one or more downhole components. The sensor assembly 38 or other components may also measure various mechanical, chemical and/or physicochemical properties of the formation, downhole components and/or the borehole 12. The data provided by the sensor assembly 38 may be utilized to control and adjust environmental and/or mechanical loads on the tool 36, the drill bit 34 and/or other components of the drillstring 11. Various sensor assemblies 38 may be located at various locations on the drill string 11, such as in the drill bit assembly 22, the downhole tool 36 or other various downhole subs or modules.

[0017] The sensor assembly 38 includes or is in operable communication with a circuit 40 that is configured to generate a signal that is indicative of the instantaneous velocity and/or ROP of a component. In one embodiment, the velocity is measured in one or more of various directions, including an axial direction (i.e., parallel to a direction of the borehole 12 and/or a direction of a gravitational field), a radial direction perpendicular to the axial direction, and a tangential direction perpendicular to the radial and axial directions. The sensor assembly 38 is thus capable of estimating an instantaneous velocity of the component at a selected time and/or the velocity of the component over a selected time period. The circuit 40 may be connected to the sensor assembly 38 in a single housing or assembly, or may be located at a remote location relative to the sensor assembly 38 such as a surface location.

[0018] In one embodiment, the sensor assembly 38 includes one or more sensors that are configured to generate a voltage signal that is proportional to a position and/or instantaneous velocity of the drill bit 34 or other component. In one embodiment, the one or more sensors include at least one of an accelerometer and a position sensor. The accelerometer includes components configured to generate a voltage signal that is proportional in magnitude to the change in instantaneous velocity of the moving component. The position sensor is a strain gauge or any sensor configured to generate a voltage signal that is proportional in magnitude to a position of the component. In one example, the strain gauge generates a voltage signal proportional to a strain on a component of the drill string 11, where the strain is an indication of the downhole position of the component.

[0019] The velocity/ROP signal may be obtained by integrating an accelerometer signal or by differentiating a strain gauge signal via the circuit 40, thus producing a resultant signal that is an indicator of instantaneous velocity and/or ROP rather than an indication of the change in bit ROP for a given period during a drilling mode. The configuration of the circuit 40 is merely exemplary, and may include additional elements as desired.

[0020] Referring to FIGS. 2 and 3A-B, in one embodiment, the circuit 40 includes an integrator circuit 40 in communication with an accelerometer that provides, in real time, an output signal that is the time integral of the input signal from the accelerometer. In one embodiment, as shown in FIG. 2, the circuit 40 is an active integrator circuit. The active integrator circuit includes, for example, an operational amplifier (op amp) 42. The active integrator circuit includes a negative feedback 44 to the inverting input 46 of the op amp 42, which ensures that the inverting input will be held at zero Volts (0 V), i.e., act as a virtual ground. The active integrator circuit also includes a resistor 48, and a capacitor 50 across the negative feedback 44.

[0021] In this configuration, if the input voltage (“ V_{in} ”) is exactly 0 V, there will be no current through the resistor 48, therefore no charging of the capacitor 50, and thus the output voltage (“ V_{out} ”) will not change. If the input voltage V_{in} from the accelerometer is a constant, positive voltage, the op amp 42 output V_{out} will fall negative at a linear rate, in an attempt to produce the changing voltage across the capacitor 50 necessary to maintain the current established by the voltage difference across the resistor 48. Conversely, if the input voltage V_{in} is a constant negative voltage, the resulting output voltage V_{out} is a linear, rising (positive) voltage. The output voltage rate-of-change is proportional to the value of the input voltage V_{in} . The output voltage V_{out} is related to the input voltage V_{in} based on the following equation:

$$\frac{dv_{out}}{dt} = - \frac{V_{in}}{RC}$$

or

$$V_{out} = \int_0^t - \frac{V_{in}}{RC} dt + c$$

where “R” is the resistance of the resistor 48, “C” is the capacitance of the capacitor 50, and “c” is the output voltage at a start time (t = 0).

[0022] Referring to FIGS. 3A and 3B, in one embodiment, the circuit 40 includes a passive integrator circuit that includes a four terminal circuit. As shown in FIG. 3A, the passive integrator circuit may be a capacitive integrator including the resistor 48 and the capacitor 50. The passive integrator circuit outputs a voltage signal proportional to the instantaneous velocity of the component based on the following equation:

$$Y = X [Z_C / (Z_C + Z_R)],$$

where “X” and “Y” are the input and output signals’ amplitudes respectively, and Z_R and Z_C are the impedances of the resistor 48 and the capacitor 50 respectively. In an alternative embodiment, shown in FIG. 3B, the passive integrator circuit is an inductive integrator including the resistor 48 and an inductor 52.

[0023] Referring to FIGS. 4 and 5A-B, the circuit 40 is a differentiator circuit in communication with a position sensor that provides, in real time, an output signal that is the time differential of the input signal from the position sensor. In one embodiment, as shown in FIG. 4, the circuit 40 is an active differentiator circuit including, for example, the op amp 42 and the negative feedback 44 to the inverting input 46 of the op amp 42. The op amp 42 measures a change in voltage V_{in} by measuring current through the capacitor 50 and outputs a voltage V_{out} proportional to that current, thereby providing a voltage signal indicative of the change in position (i.e., velocity) at a given time. The right-hand side of the capacitor C is held to a voltage of zero Volts (0V), due to the “virtual ground” effect. Thus, the current “through” the capacitor is solely due to the change in the input voltage V_{in} . A steady input voltage V_{in} does not result in an output voltage V_{out} , but a changing input voltage V_{in} will result in an output voltage V_{out} signal. The changing input voltage V_{in} induces a current drop across the feedback resistor 48 which is the same as the output voltage V_{out} . For example, a linear, positive rate of V_{in} change results in a steady (i.e., constant) negative V_{out} , and a linear negative rate of V_{in} change results in a steady positive V_{out} . The faster the rate of V_{in} change (and corresponding rate of position change or velocity), the greater the

V_{out} magnitude. The output voltage is related to the input voltage based on the following equation:

$$V_{out} = -RC \left. \frac{dv_{in}}{dt} \right|,$$

where “R” is the resistance of the resistor 48 and “C” is the capacitance of the capacitor 50.

[0024] Referring to FIGS. 5A and 5B, in one embodiment, the circuit 40 is a passive differentiator circuit that includes a four terminal circuit. The passive integrator circuit outputs a voltage signal proportional the instantaneous velocity of the component based on the following equation:

$$Y = X [Z_C / (Z_C + Z_R)],$$

where “X” and “Y” are the input and output signals’ amplitudes respectfully, and Z_R and Z_C are the impedances of the resistor 48 and the capacitor 50. In an alternative embodiment, shown in FIG. 5B, the passive integrator circuit is an inductive integrator including the resistor 48 and the inductor 52.

[0025] Each of the sensor assemblies 38 may include a single sensor or multiple sensors located at a single location. In one embodiment, the sensor assembly 38 includes one or more sensors configured to measure velocity along selected directions, such as the axial, radial and tangential directions. Furthermore, in other embodiments, each sensor assembly 38 includes additional components, such as clocks, memory processors, etc.

[0026] In one embodiment, the sensor assembly 38, downhole tool 36 and/or BHA 26 is equipped with transmission equipment to communicate ultimately to a remote location such as a surface processing unit 54. In one embodiment, the surface processing unit 54 is configured as a surface drilling control unit which controls various drilling parameters such as rotary speed, weight-on-bit, drilling fluid flow parameters and others. Such transmission equipment may take any desired form, and different transmission media and connections may be used. Examples of connections include wired, fiber optic, wireless connections or mud pulse telemetry.

[0027] In one embodiment, the surface processing unit 54, the sensor assembly 38, downhole tool 36 and/or BHA 26 include components as necessary to provide for storing and/or processing data collected from the sensor assembly 38. Exemplary components include, without limitation, at least one processor, storage, memory, input devices, output devices and the like.

[0028] FIG. 3 illustrates a method 60 of estimating a velocity of a downhole component. The method 60 includes one or more of stages 61-64 described herein. The

method may be performed continuously or intermittently as desired. The method is described herein in conjunction with the sensor assemblies 38 and circuits 40, although the method may be performed in conjunction with any number and configuration of circuits, sensors and tools. The method may be performed by one or more processors or other devices capable of receiving and processing measurement data. In one embodiment, the method includes the execution of all of stages 61-64 in the order described. However, certain stages 61-64 may be omitted, stages may be added, or the order of the stages changed.

[0029] In the first stage 61, the sensor assembly 38 is lowered into a borehole, along with other components such as the drill bit assembly 22 during, for example, a drilling and/or geosteering operation.

[0030] In the second stage 62, the sensor assembly 38 generates a voltage signal that is proportional in magnitude to an acceleration or position of the sensor assembly 38. The sensor assembly 38 includes at least one of an accelerometer and a position sensor such as a strain gauge.

[0031] In the third stage 63, the voltage signal is input into the circuit 40, which generates an output voltage that is proportional to an instantaneous velocity of the sensor assembly 38 at a selected time and/or over a selected time period.

[0032] In the fourth stage 64, the output voltage signal is transmitted to a user or processor to indicate the instantaneous velocity of the sensor assembly 38 and the associated downhole component. In one embodiment, data relating to the output voltage signal and velocity measurement is stored in the sensor assembly 38 or another downhole component, and/or is transmitted to a processor such as the surface processing unit 54, and can be retrieved therefrom and/or displayed for analysis. As used herein, a "user" may include a drillstring operator, a processing unit and/or any other entity selected to retrieve the data and/or control the drillstring 11.

[0033] Although the methods and systems described herein are utilized to determine rotational velocity and/or ROP in a downhole system, the methods and systems are not so limited and may be utilized with any type of downhole or above-ground system that would benefit from measurements of instantaneous velocity of a component.

[0034] "Drillstring" or "string" as used herein, refers to any structure or carrier suitable for lowering a tool through a borehole or connecting a drill bit to the surface, and is not limited to the structure and configuration described herein. For example, the borehole string 11 is configured as a hydrocarbon production string or formation evaluation string. The term "carrier" as used herein means any device, device component, combination of

devices, media and/or member that may be used to convey, house, support or otherwise facilitate the use of another device, device component, combination of devices, media and/or member. Exemplary non-limiting carriers include drill strings of the coiled tube type, of the jointed pipe type and any combination or portion thereof. Other carrier examples include casing pipes, wirelines, wireline sondes, slickline sondes, drop shots, downhole subs, BHA's, drill string.

[0035] The systems and methods described herein provide various advantages over prior art techniques. The systems and methods herein reduce or minimize conversion errors, as compared with conventional methods that require post processing of acceleration and/or strain data, by including the integrator circuits with accelerometers and/or differentiator circuits with position sensors such as strain gauges. In addition, the systems and methods described herein allow for ease of use, as velocity measurements can be achieved through the inclusion of acceleration/position sensors in existing modules, and also can be more simply produced as contact with the actual borehole and/or drilling environment is unnecessary.

[0036] In support of the teachings herein, various analyses and/or analytical components may be used, including digital and/or analog systems. The system may have components such as a processor, storage media, memory, input, output, communications link (wired, wireless, pulsed mud, optical or other), user interfaces, software programs, signal processors (digital or analog) and other such components (such as resistors, capacitors, inductors and others) to provide for operation and analyses of the apparatus and methods disclosed herein in any of several manners well-appreciated in the art. It is considered that these teachings may be, but need not be, implemented in conjunction with a set of computer executable instructions stored on a computer readable medium, including memory (ROMs, RAMs), optical (CD-ROMs), or magnetic (disks, hard drives), or any other type that when executed causes a computer to implement the method of the present invention. These instructions may provide for equipment operation, control, data collection and analysis and other functions deemed relevant by a system designer, owner, user or other such personnel, in addition to the functions described in this disclosure.

[0037] Further, various other components may be included and called upon for providing aspects of the teachings herein. For example, a sample line, sample storage, sample chamber, sample exhaust, pump, piston, power supply (e.g., at least one of a generator, a remote supply and a battery), vacuum supply, pressure supply, refrigeration (i.e., cooling) unit or supply, heating component, motive force (such as a translational force, propulsive force or a rotational force), magnet, electromagnet, sensor, electrode,

transmitter, receiver, transceiver, controller, optical unit, electrical unit or electromechanical unit may be included in support of the various aspects discussed herein or in support of other functions beyond this disclosure.

[0038] One skilled in the art will recognize that the various components or technologies may provide certain necessary or beneficial functionality or features. Accordingly, these functions and features as may be needed in support of the appended claims and variations thereof, are recognized as being inherently included as a part of the teachings herein and a part of the invention disclosed.

[0039] While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications will be appreciated by those skilled in the art to adapt a particular instrument, situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

CLAIMS

1. A system for estimating a velocity of a downhole component, the system comprising:

a sensor configured to produce a sensor signal that is proportional to at least one of a position and an acceleration of the downhole component; and

a circuit in communication with the sensor and configured to receive the sensor signal and generate an output signal indicative of an instantaneous velocity of the downhole component.

2. The system of claim 1, wherein the sensor signal is a voltage signal.

3. The system of claim 1, wherein the sensor is selected from at least one of an accelerometer and a strain gauge.

4. The system of claim 1, wherein the sensor is an accelerometer configured to generate an input voltage proportional to an acceleration of the downhole component, and the circuit is an integrator circuit.

5. The system of claim 4, wherein the integrator circuit is an active integrator circuit having an operational amplifier.

6. The system of claim 1, wherein the sensor is a position sensor configured to generate an input voltage proportional to a position of the downhole component, and the circuit is a differentiator circuit.

7. The system of claim 6, wherein the integrator circuit is an active differentiator circuit having an operational amplifier.

8. The system of claim 1, wherein the component is a drill bit.

9. The system of claim 1, wherein the instantaneous velocity is related to a rate of penetration (ROP) of the component.

10. The system of claim 1, wherein the sensor includes one or more sensors positioned to measure at least one of the acceleration and a change of the position of the downhole component along at least one axis.

11. The system of claim 10, wherein the at least one axis extends along a direction selected from at least one of an axial direction parallel to a borehole, a radial direction perpendicular to the axial direction, and a tangential direction perpendicular to the radial and axial directions.

12. A method of estimating a velocity of a downhole component, the method comprising:

lowering a sensor into a borehole in an earth formation, the sensor configured to produce a sensor signal that is proportional to at least one of a position and an acceleration of the downhole component;

activating the sensor to generate the sensor signal; and

transmitting the signal to a circuit and generating an output signal indicative of an instantaneous velocity of the downhole component via the circuit.

13. The method of claim 12, wherein the sensor signal is a voltage signal.

14. The method of claim 12, wherein the sensor is selected from at least one of an accelerometer and a strain gauge.

15. The method of claim 12, wherein the sensor is an accelerometer configured to generate an input voltage proportional to an acceleration of the downhole component, and generating the output signal includes integrating the input voltage over a selected period of time via the circuit.

16. The method of claim 15, wherein integrating includes integrating the input voltage with an active integrator circuit having an operational amplifier.

17. The method of claim 12, wherein the sensor is a position sensor configured to generate an input voltage proportional to a position of the downhole component, and generating the output signal includes differentiating the input voltage over a selected period of time via the circuit.

18. The method of claim 17, wherein differentiating includes differentiating the input voltage with an active differentiation circuit having an operational amplifier.

19. The method of claim 12, wherein the instantaneous velocity is related to a rate of penetration (ROP) of the component.

20. The method of claim 12, wherein lowering the sensor includes drilling at least a portion of the borehole.

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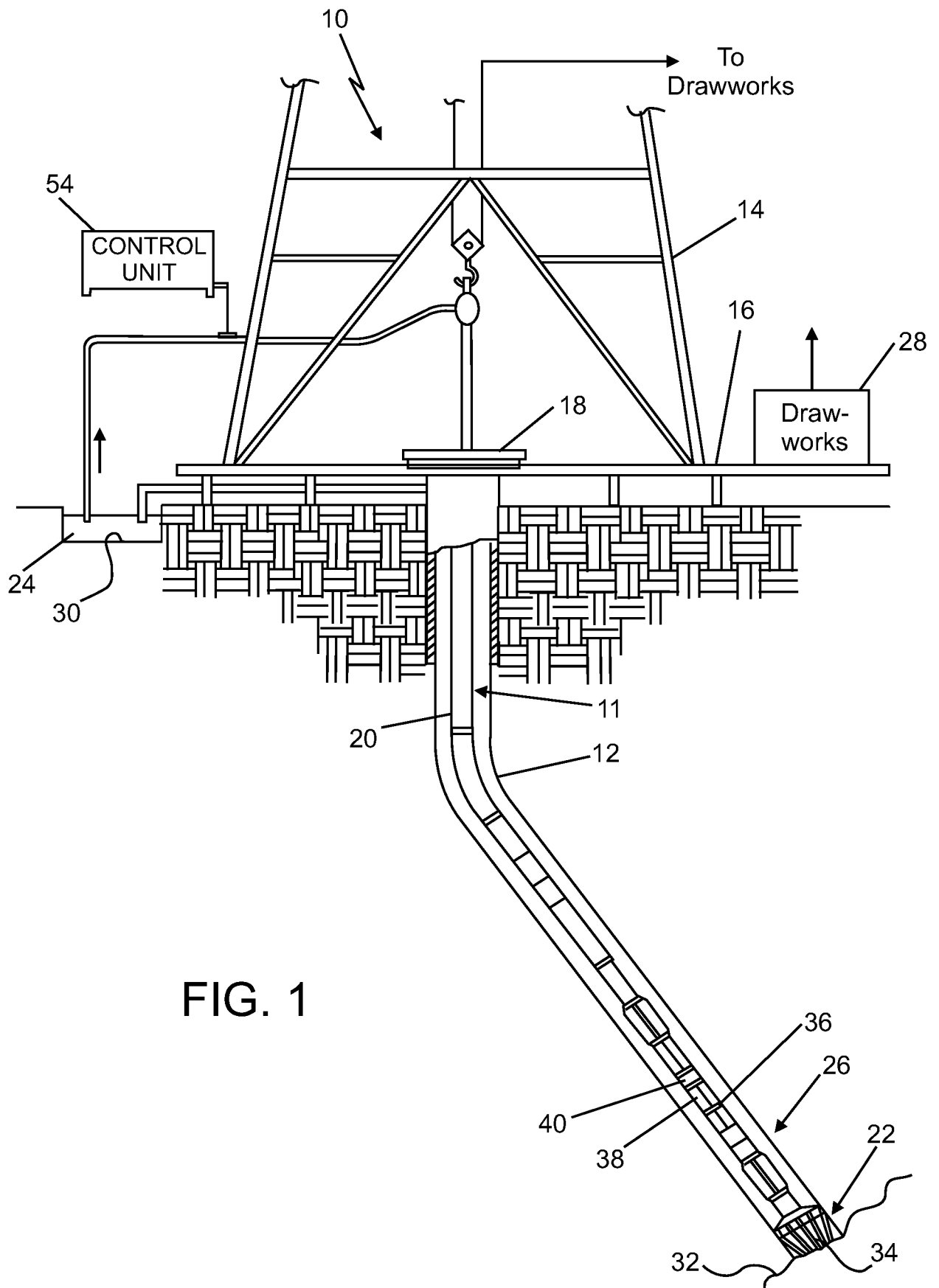
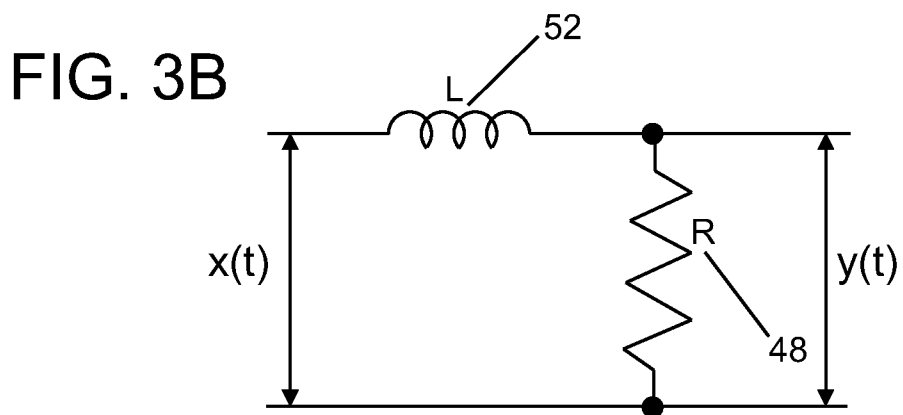
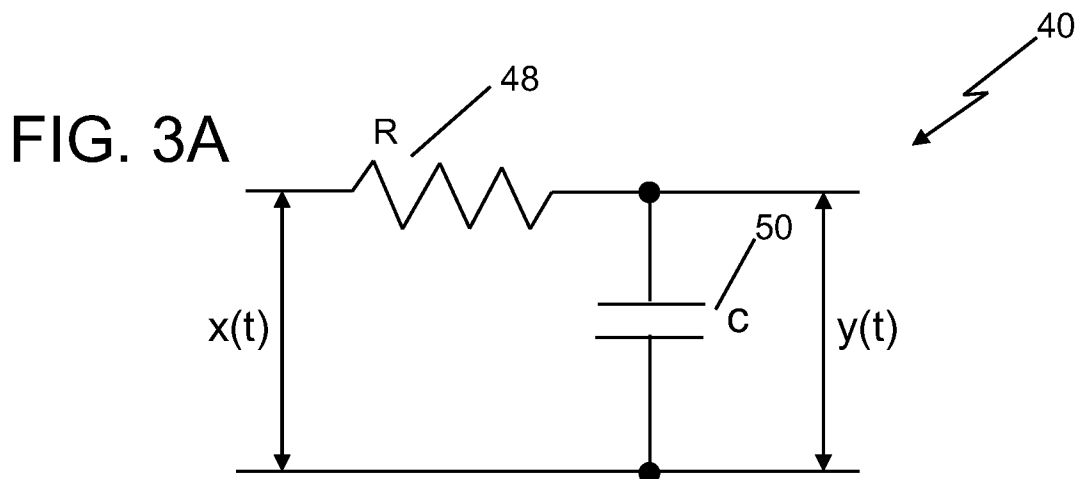
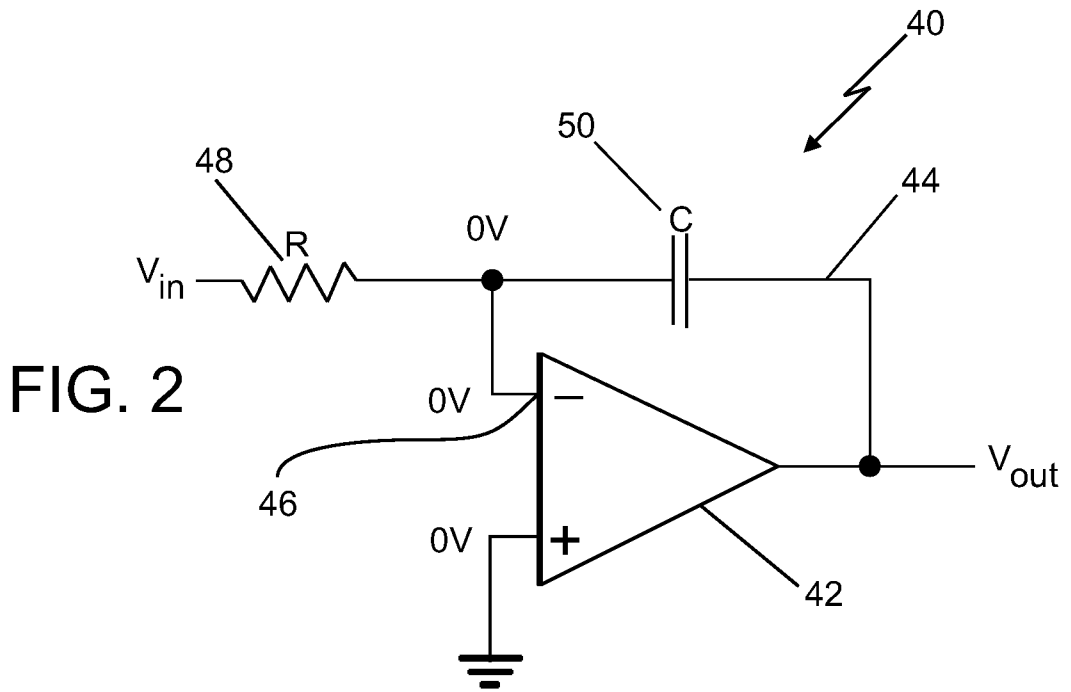


FIG. 1



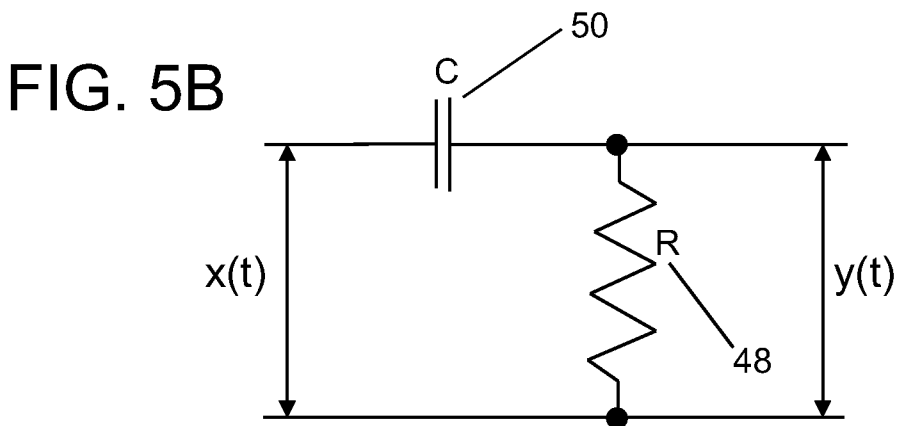
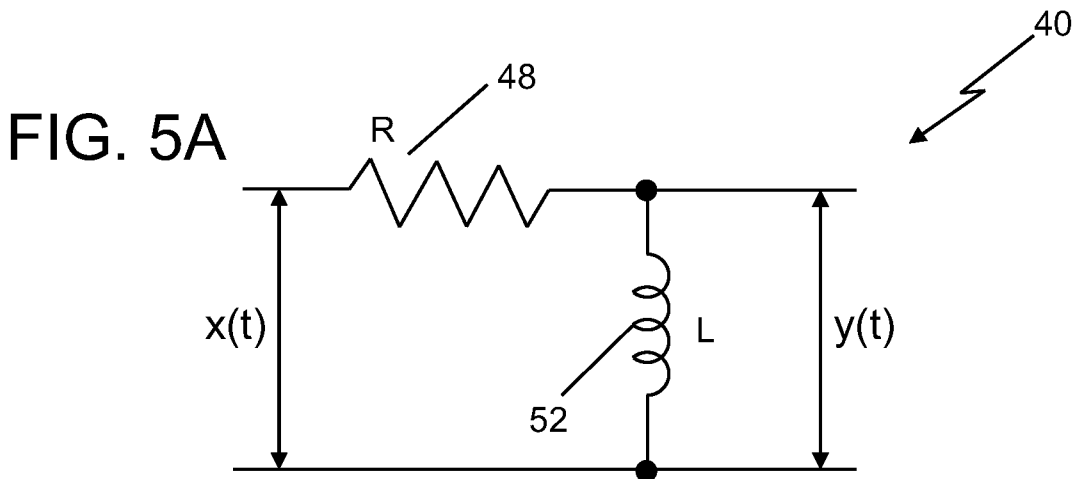
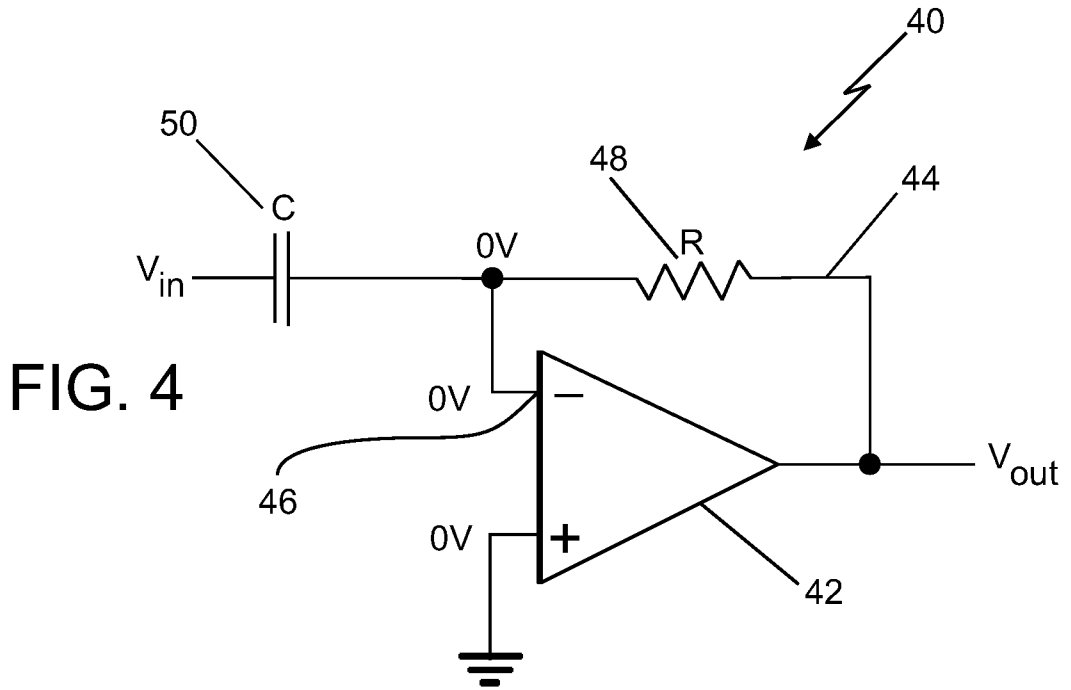


FIG. 6

