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Malpas et al.(10) **Pub. No.: US 2015/0297094 A1**(43) **Pub. Date: Oct. 22, 2015**(54) **METHODS, DEVICES AND SYSTEMS FOR SENSING FLOW, TEMPERATURE AND PRESSURE**(52) **U.S. CL.**CPC . *A61B 5/01* (2013.01); *A61B 5/031* (2013.01);
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(NZ); **Therese Clark**, Auckland (NZ)(21) Appl. No.: **14/602,105**(22) Filed: **Jan. 21, 2015****Related U.S. Application Data**(60) Provisional application No. 61/929,915, filed on Jan.
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(57)

ABSTRACT

A method for determining a flow rate of a substance in an environment includes positioning a device having a balanced circuit in or on an object or within a particular environment, wherein the balanced circuit comprises elements which are operationally sensitive to changes in a parameter of the object or the environment. The method further includes measuring a common mode signal of the balanced circuit and determining, from the common mode signal, a value of the flow rate. An exemplary implementation of the method includes determining temperature using a resistive sensor having a Wheatstone bridge circuit with two variable resistors and two fixed resistors. Embodiments of systems and devices configured to employ such methods are provided, particularly medical probes, electronic signal monitoring devices, and systems employing such devices.

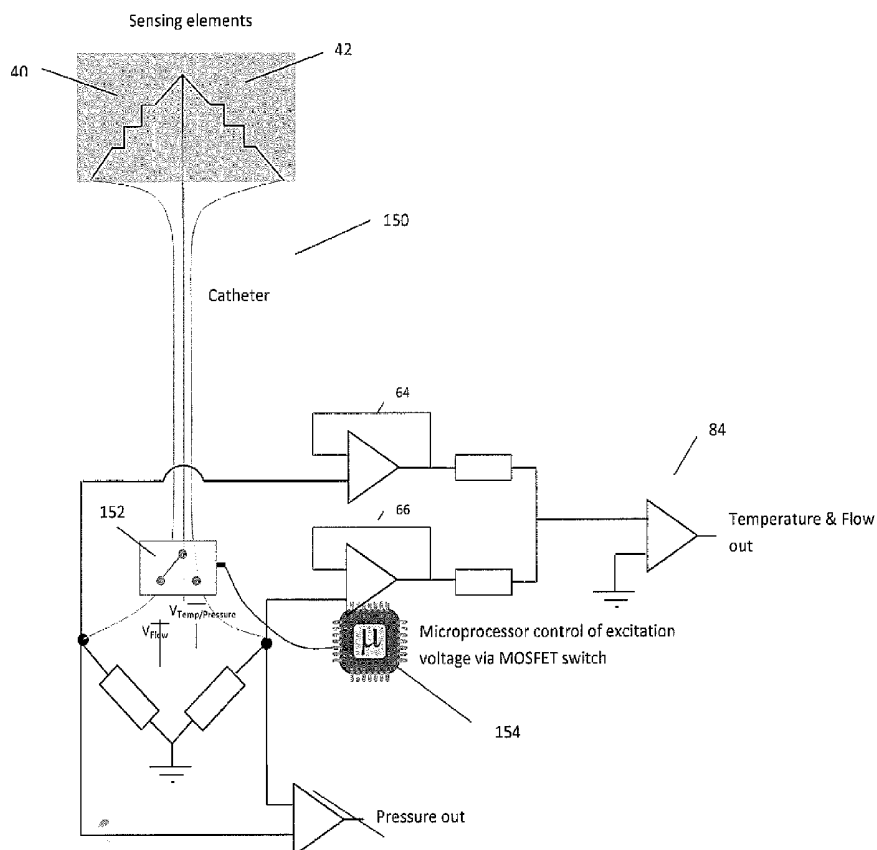
Schematic of Measurement Method

FIG 1

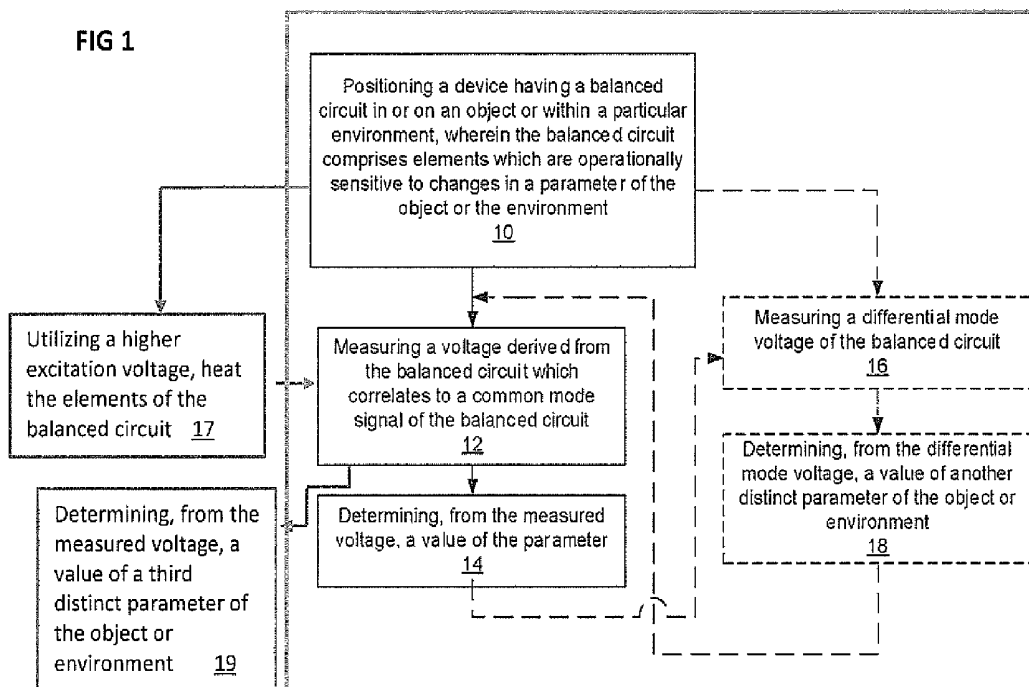
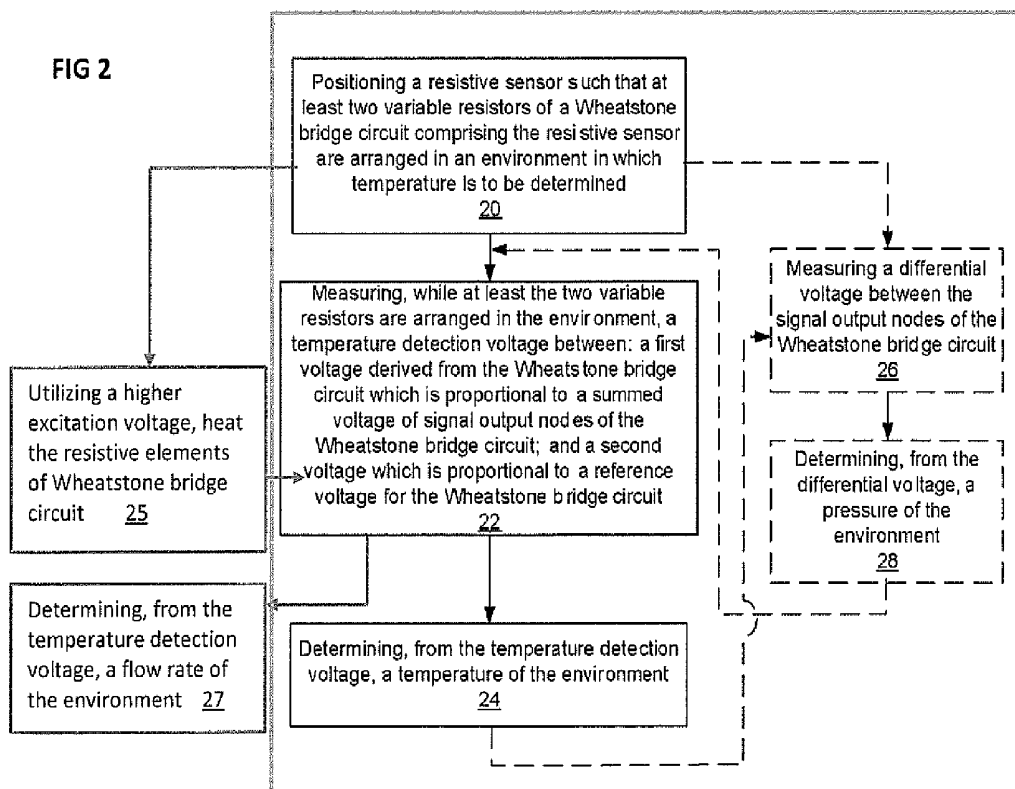


FIG 2



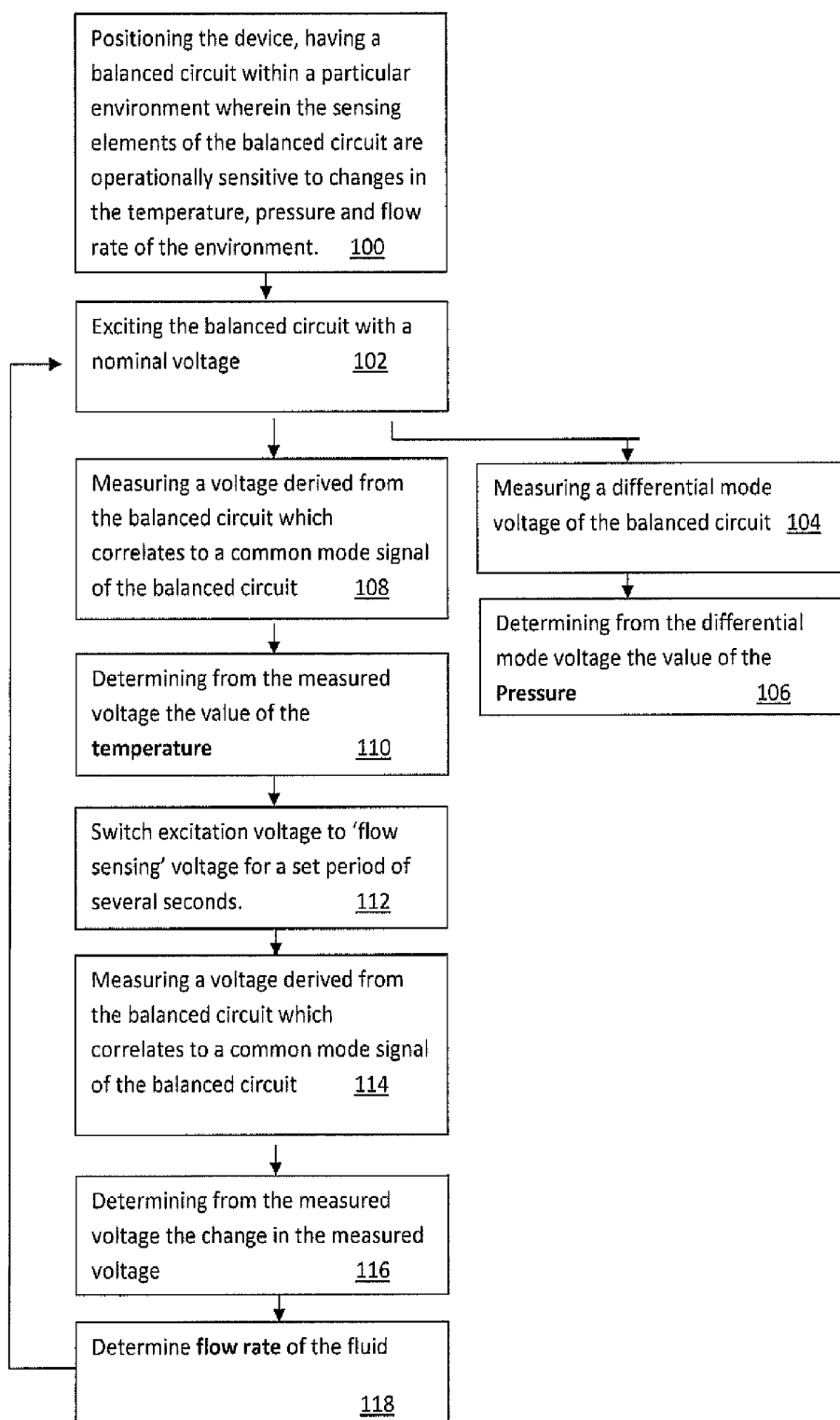


FIG 2A

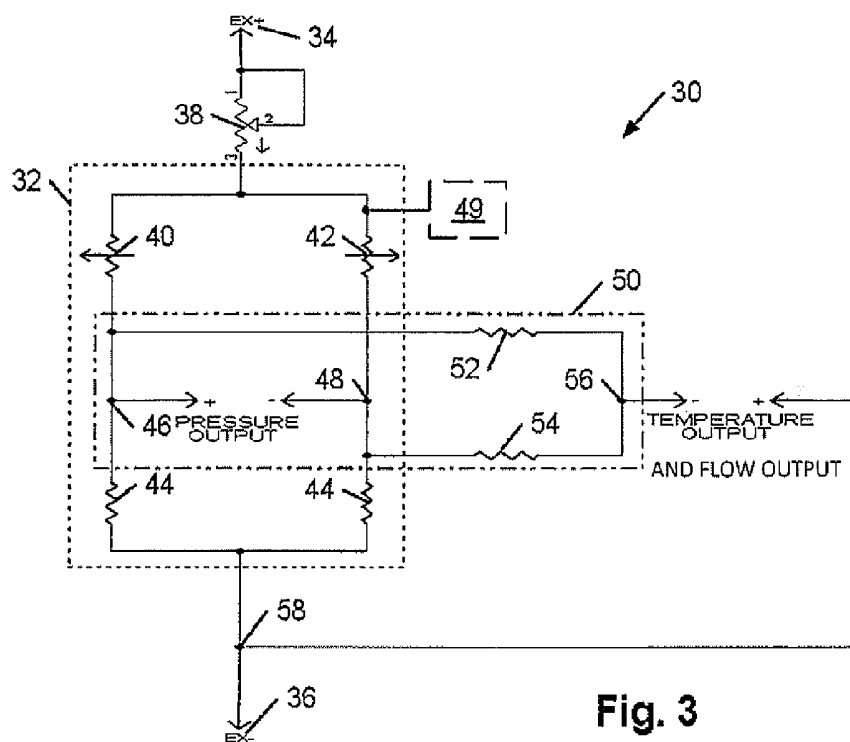


Fig. 3

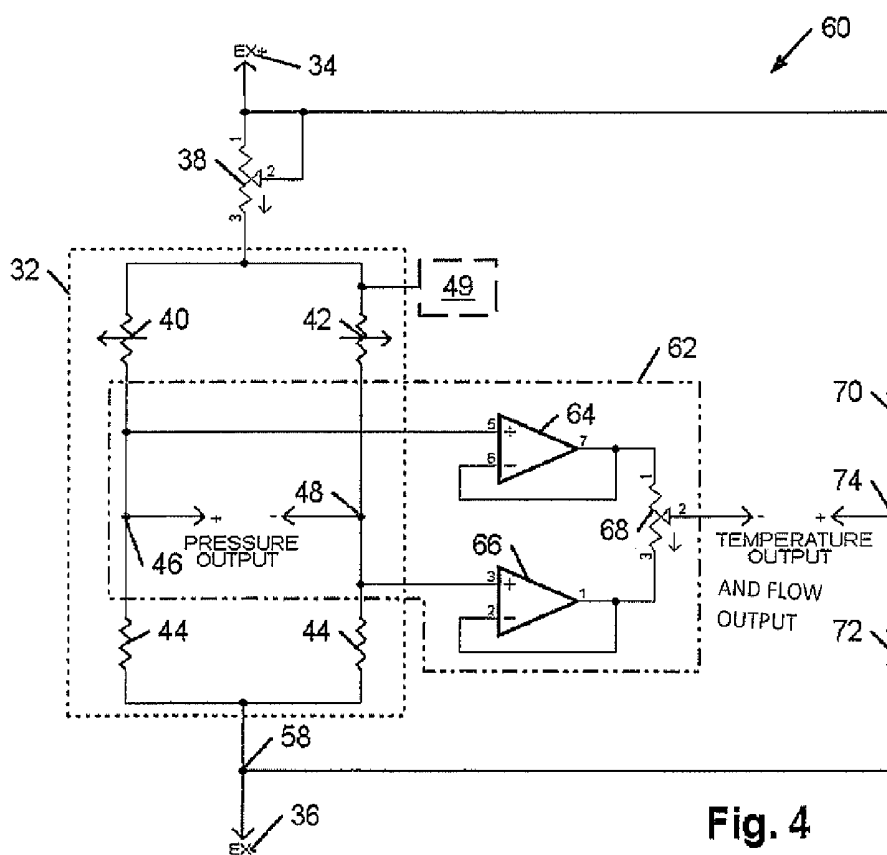
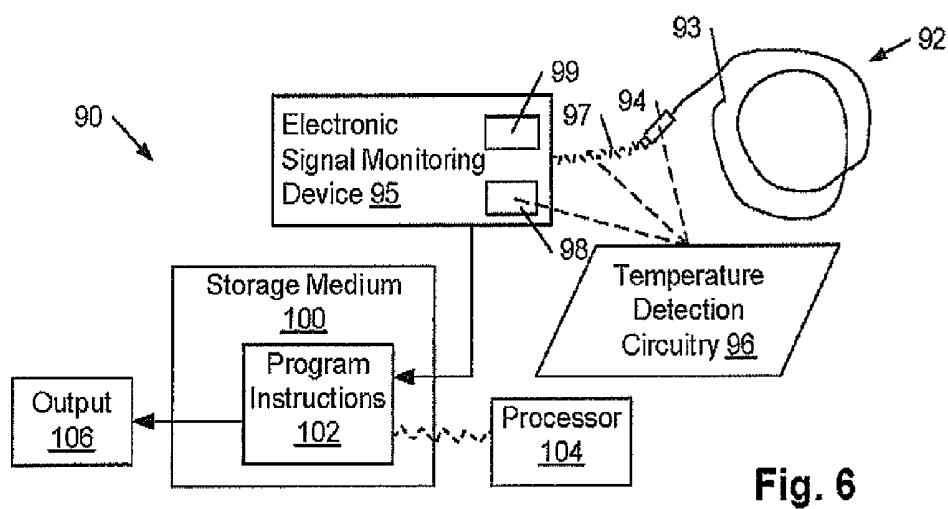
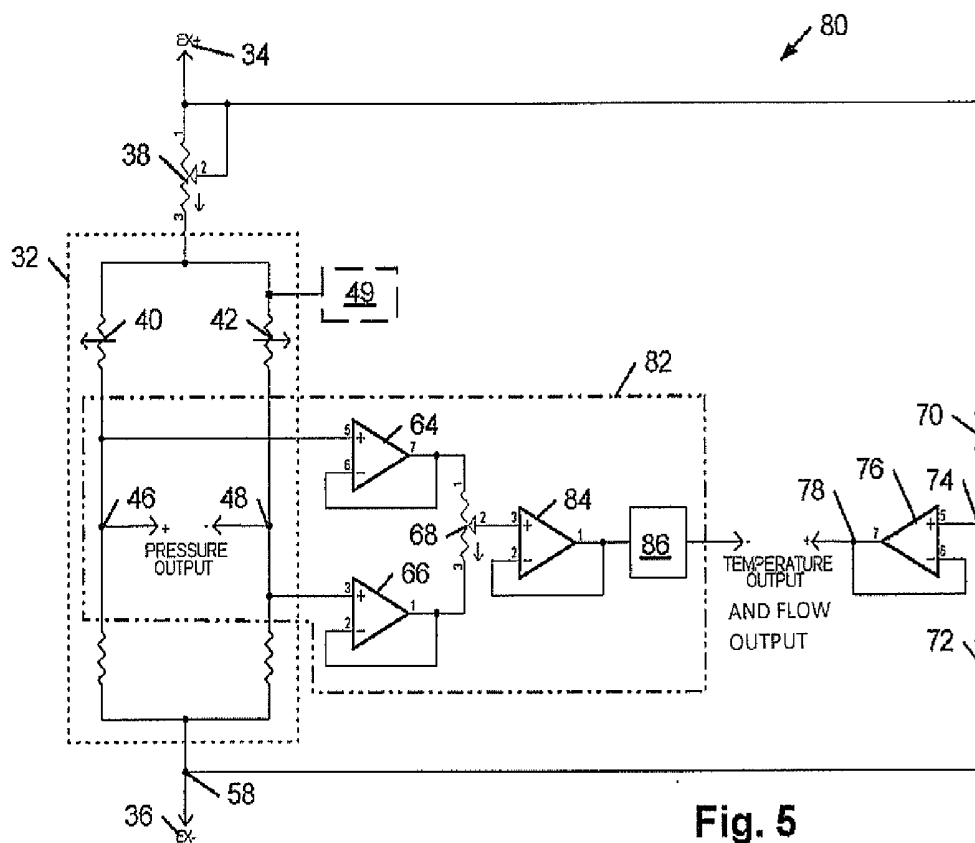


Fig. 4



Schematic of Measurement Method

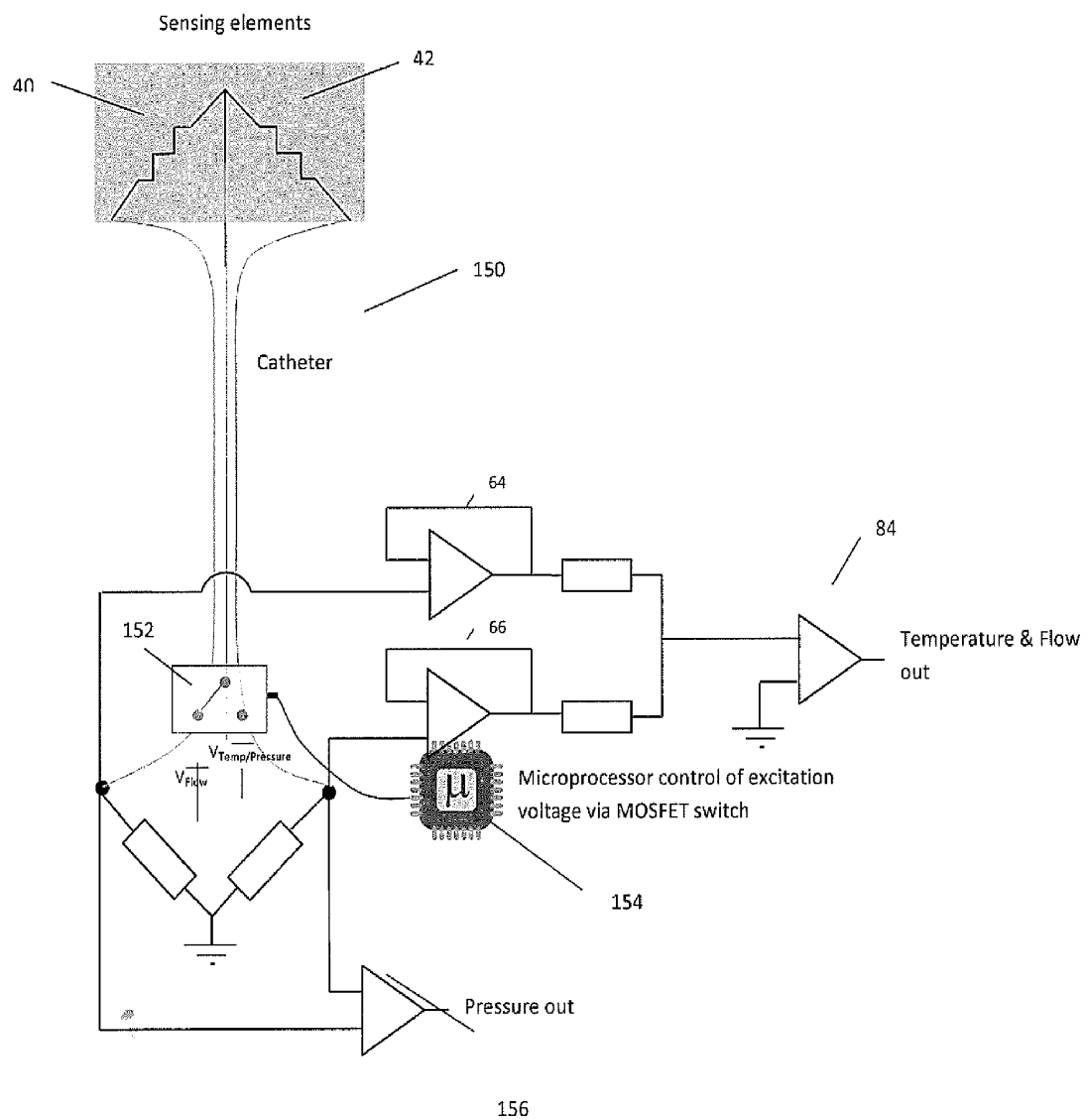


FIG 7

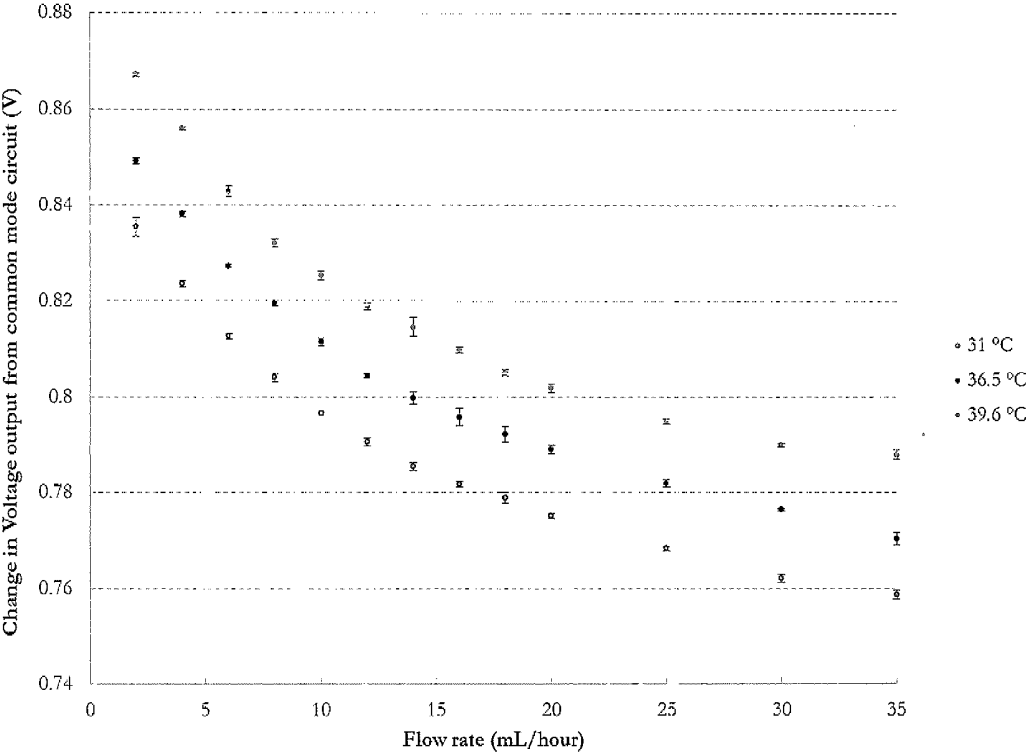


FIG 8

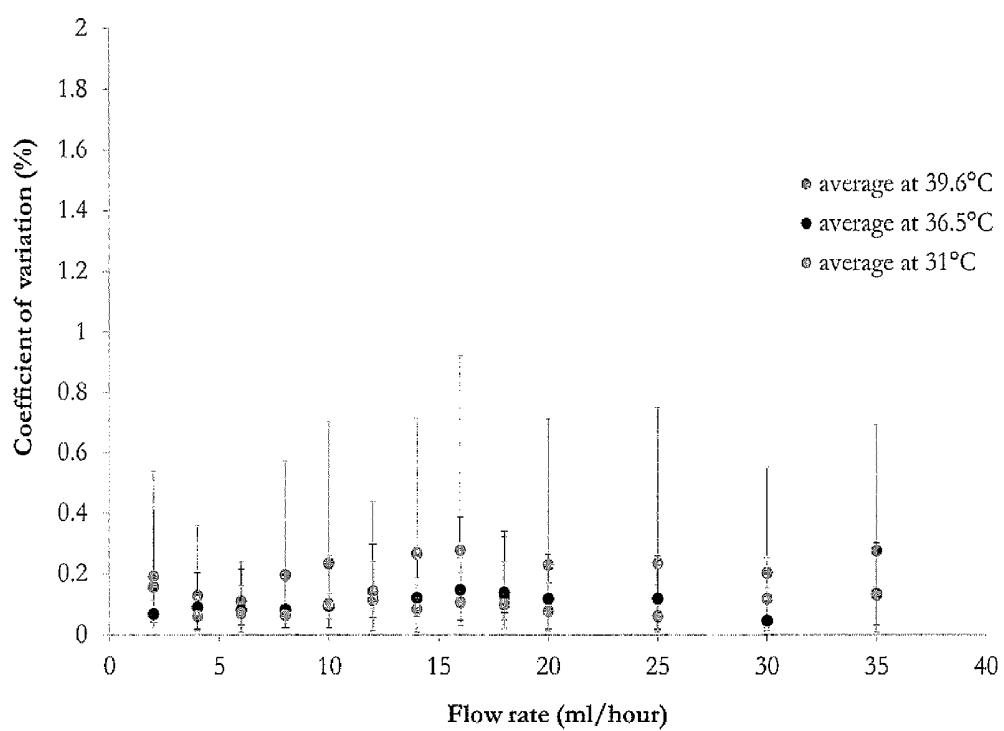


FIG 9

METHODS, DEVICES AND SYSTEMS FOR SENSING FLOW, TEMPERATURE AND PRESSURE

PRIORITY CLAIM

[0001] This application claims the benefit of prior U.S. Provisional Application Ser. No. 61/929,915 filed Jan. 21, 2014, the contents of which are hereby incorporated by reference.

FIELD OF THE INVENTION

[0002] This invention generally relates to methods, devices and systems for determining parameter values of substances, objects and environments and, more specifically, to methods, devices and systems which sense at least a flow rate, or a flow rate together with pressure and/or temperature.

BACKGROUND OF THE INVENTION

[0003] The following descriptions and examples are not admitted to be prior art by virtue of their inclusion within this section.

[0004] Many sensors employ balanced circuits for determining information. In particular, a balanced circuit may be configured such that information of interest for a sensor may be determined from a differential voltage between the output nodes of the balanced circuit. More specifically, each line of a balanced circuit may be configured with elements which are operationally sensitive to changes in a parameter of an object or an environment in which the balanced circuit is disposed and each of the elements may be configured to alter the voltage along its respective line in an opposing manner. In general, it is the objective of such balanced circuits to have signal lines of matched impedances such that noise and interference induced in each of the lines does not substantially affect the accuracy of the differential voltage measurement attributed to the information of interest. In particular, having matched impedances on each signal line allows noise and interference signals to be canceled for a differential voltage measurement. On the contrary, any inequality in the noise and/or interference induced in each line will result in such signals not being fully cancelled.

[0005] In order to ensure the accuracy of a differential voltage measurement, a common mode voltage between the signal output nodes of the balanced circuit is often monitored. In particular, a common mode voltage of a presumably balanced circuit is monitored relative to a target voltage or relative to the differential gain of the circuit, the latter scenario of which is referred to as a common-mode rejection ratio. The term "common mode voltage" refers to the voltage at a given location that appears equally and in phase from each signal conductor to a common reference. Alternatively stated, the term "common mode voltage" refers to the instantaneous algebraic average of two signals within a balanced circuit with both signals referenced to a common reference. Although both differential mode and common mode signals are analyzed when using a balanced circuit, they are generally referenced as "wanted signals" and "unwanted signals", respectively. In particular, differential mode signal measurements relate directly to determining the value of a parameter being measured by a sensor and, thus, are considered "wanted." In contrast, common mode signal measurements reflect the portions of the signals which do not contribute to determining the information of interest for a sensor and, thus,

are considered "unwanted." In other words, common mode signal measurements are only monitored in conventional practices for determining whether to accept or discard differential mode signal measurements relating to a variable parameter.

[0006] Sensing parameters such flow, pressure and temperature is important in connection with hydrocephalus shunts. A hydrocephalus shunt typically diverts fluid from the ventricles to the peritoneal (abdominal) cavity. Shunts are prone to complications. Common modes of failure are by obstruction (72%) of the catheter followed by infection (19%). The detection of shunt malfunction is problematic. Invasive methods carry obvious risks to the patient as well as being time consuming and expensive. Imaging methods can also have inherent dangers and can also be expensive. Intracranial pressure (ICP) monitoring is another method of assessing shunt function, but has the disadvantage of requiring a patient to be held in hospital for the duration of the monitoring process. Contemporary solutions generally utilise an implantable flow sensor. Such a flow sensor usually uses a thermal flow sensing method which requires a separate dedicated sensor having a separate heating element.

SUMMARY OF THE INVENTION

[0007] It is an object of some versions of the present invention to provide an apparatus, method or system which at least ameliorates one or more of the disadvantages of known apparatus, methods or systems.

[0008] It is another object of some versions of the present invention to provide a means for measuring flow rate from a common mode signal of a balanced circuit.

[0009] It is another object of some versions of the present invention to provide a means for measuring flow rate, pressure, temperature and of an environment using a single sensing element (pair) in order to sequentially or simultaneously measure all three physical characteristics of an environment.

[0010] It is another object of some versions of the present invention to provide a means for measuring pressure, temperature and flow rate of an environment using a single sensing element (pair) such that the device is minimal in size.

[0011] It is another object of some versions of the present invention to provide a means for measuring pressure, temperature and flow rate of an environment using a single sensing element (pair) in order to compensate for cross-sensitivity to environmental factors in each measurement; enhancing the precision of each measurement.

[0012] It is another object of some versions of the present invention to provide a means for measuring pressure, temperature and flow rate of an environment using a single sensing element (pair) in order to monitor physiological parameters which are vital for health.

[0013] It is another object of some versions of the present invention to provide a means for measuring pressure, temperature and flow rate of an environment using a single sensing element (pair) in order to diagnose situations of increased risk- for example over-or-under-drainage through a hydrocephalus shunt or infection in a hydrocephalus shunt.

[0014] The following description of various embodiments of methods, devices and systems is not to be construed in any way as limiting the subject matter or scope of the invention.

[0015] Embodiments of a method for determining a value of a parameter of an object and/or substance in an environment using a balanced circuit provided within the environment, the balanced circuit comprising elements which are

operationally sensitive to changes in a parameter of the object or the environment. In addition, the method includes measuring a voltage derived from the balanced circuit which correlates to a common mode signal of the balanced circuit and determining, from the measured voltage, a value of the parameter.

[0016] In one aspect the parameter is flow of a substance in the environment.

[0017] In another aspect a plurality of parameters, including flow, are determined.

[0018] In one embodiment a method for determining a flow rate of a substance in an environment uses a balanced circuit provided within the environment, the balanced circuit comprising circuit elements which are sensitive to changes in temperature of the substance or the environment, the method comprising: supplying energy to the circuit elements; measuring a voltage derived from the balanced circuit which correlates to a common mode signal of the balanced circuit; and determining, from the measured voltage, the flow rate.

[0019] The method may include supplying energy to the circuit elements for a predetermined time period, or supplying energy until a predetermined temperature is reached, or until a steady state temperature is reached.

[0020] The method may further comprise measuring a differential mode voltage of the balanced circuit to determine a measurement of the pressure of the environment or the substance.

[0021] In another embodiment apparatus is provided for determining a flow rate of a substance in an environment, the apparatus comprising: a balanced circuit comprising circuit elements which are sensitive to changes in temperature of the substance or the environment, and; a controller operable to: supply energy to the circuit elements; measure a voltage derived from the balanced circuit which correlates to a common mode signal of the balanced circuit; and determining, from the measured voltage, the flow rate.

[0022] In another embodiment apparatus is provided for determining a flow rate of a substance in an environment, the apparatus being electrically connectable to a balanced circuit comprising circuit elements which are sensitive to changes in temperature of the substance or the environment, the apparatus comprising means operable to: connect the circuit elements to a supply of electrical energy; measure a voltage derived from the balanced circuit which correlates to a common mode signal of the balanced circuit; and determining, from the measured voltage, the flow rate.

[0023] Embodiments of a method for determining temperature using a resistive sensor having a Wheatstone bridge circuit with at least two variable resistors includes positioning the resistive sensor such that the at least two variable resistors of the Wheatstone bridge circuit are arranged in an environment in which temperature and/or flow is to be determined. The method further includes measuring, while the two variable resistors are arranged in the environment, a temperature detection voltage between a first voltage derived from the Wheatstone bridge circuit which is proportional to a summed voltage of signal output nodes of the Wheatstone bridge circuit and a second voltage which is proportional to a reference voltage for the Wheatstone bridge circuit. Moreover, the method includes determining, from the temperature detection voltage, a temperature of the environment and/or in a flow rate in the environment.

[0024] Embodiments of medical probes include a Wheatstone bridge circuit with at least two variable resistors and

temperature detection circuitry coupled to the Wheatstone bridge circuit which generates a voltage which is proportional to a summed voltage of signal output nodes of the Wheatstone bridge circuit. The medical probes further include compensation circuitry coupled to the Wheatstone bridge circuit which is configured to compensate for variations of a resistive coefficient of a conductive material comprising the Wheatstone bridge circuit due to ambient temperature changes of the conductive material.

[0025] Embodiments of electronic signal monitoring devices for monitoring and processing signals received from a balanced circuit of a medical probe include a first means for receiving output signals from the balanced circuit. In addition, the electronic signal monitoring devices include a second means for determining from one or more of the received output signals a voltage which correlates to a common mode signal of the balanced circuit. Moreover, the electronic signal monitoring device includes program instructions which are executable by a processor for determining, from the voltage, a temperature and/or flow in or of an environment in which a tip of the medical probe is arranged or in which apparatus is otherwise provided.

[0026] Embodiments of systems include a catheter or shunt having a resistive sensor with a Wheatstone bridge circuit having at least two variable resistors. The systems further include an electronic signal monitoring device configured for electrical communication with the medical probe to measure electrical parameters of the resistive sensor. Moreover, the systems include flow detection circuitry coupled to the Wheatstone bridge circuit that is configured to generate a first voltage which is proportional to a summed voltage of signal output nodes of the Wheatstone bridge circuit. The electronic signal monitoring device includes a means for measuring a temperature detection voltage between the first voltage and a second voltage which is proportional to a reference voltage for the Wheatstone bridge circuit. The systems further include a storage medium with program instructions which are executable by a processor for determining, from the temperature detection voltage, a temperature and/or flow of or in an environment in which a medical device is arranged.

[0027] In one aspect the invention provides a method and/or apparatus by which a single sensor such as a balanced circuit can sense flow, temperature and pressure in an environment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] Preferred and alternative examples of the present invention are described in detail below with reference to the following drawings:

[0029] Other objects and advantages of the invention will become apparent upon reading the following detailed description and upon reference to the accompanying drawings in which:

[0030] FIG. 1 is a flowchart of a method for determining a value of a number of parameters of an object or substance in an environment;

[0031] FIG. 2 is a flowchart of a method for determining temperature of an environment using a resistive sensor, and for determining a flow rate in the environment;

[0032] FIG. 2A, flow chart is shown for an embodiment which allows a balanced circuit (i.e. essentially one sensor) to measure at least three parameters of the environment.

[0033] FIG. 3 is a schematic diagram of an exemplary circuit which may be utilized in the method outlined in the preceding figures;

[0034] FIG. 4 is a schematic diagram of another exemplary circuit which may be utilized in the method outlined in the preceding figures;

[0035] FIG. 5 is a schematic diagram of yet another exemplary circuit which may be utilized in the method outlined in FIGS. 1-2A; and

[0036] FIG. 6 is a schematic diagram of a medical probe system for determining temperature of an environment in which a medical probe is arranged.

[0037] FIG. 7 is a schematic diagram of a system for determining flow, pressure and temperature in a catheter.

[0038] FIG. 8 is a graphical representation of calibration data set of one sensor at three ambient temperatures in the physiological (subcutaneous) range for flow sensing in accordance with the invention.

[0039] FIG. 9 is a graphical representation of the repeatability of the flow measurement described herein.

[0040] While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that the drawings and detailed description thereto are not intended to limit the invention to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the present invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0041] Turning to the drawings, a flowchart of a method for determining or sensing a value of a parameter of an object or an environment is shown in FIG. 1. A specific application of such a method utilizing a resistive sensor for determining temperature of an environment is outlined in a flowchart depicted in FIGS. 2 and 2A. FIGS. 3-5 depict schematic diagrams of exemplary circuits which may be utilized in the method outlined in FIGS. 1-2A. These include a balanced circuit in the form of a Wheatstone bridge and associated control circuitry and/or processing devices which provide the means for implementing the methods to obtain the required measurements from the balanced circuit. FIG. 6 illustrates an exemplary system configured to perform the method outlined in FIG. 2 or 2A. In particular, FIG. 6 illustrates a schematic diagram of a medical probe system for determining temperature of an environment in which a medical probe is arranged. FIG. 7 illustrated schematically an exemplary configuration of a catheter having sensing elements as described herein, which may be used in a hydrocephalus shunt (as an example of one possible application). Although FIGS. 3-5 are specifically directed to methods and circuits involving a resistive sensor with a Wheatstone bridge circuit having two variable resistors and two fixed resistors, FIG. 6 is specific to systems and devices involving medical probes and FIG. 7 to a catheter, the methods, systems and devices encompassed by the disclosure provided herein are not so restricted. Furthermore, although FIGS. 2-7 are described for determining temperature and pressure of an object or environment, and/or flow of a substance, the methods, systems and devices provided herein are not so limited.

[0042] Rather, as encompassed by the flowchart of FIG. 1, the methods, systems and devices considered herein may

involve any device having a balanced circuit which includes elements which are operationally sensitive to changes in a parameter of a substance, object or an environment. The device may be any tool, mechanism or physical means which can accommodate the balanced circuit and which can be placed in proximity to, on, or within an object or environment of interest. The balanced circuit may be of any configuration having any type of operationally sensitive elements known in the art. Thus, the methods, systems and devices described herein are not limited to use of resistive sensors. Furthermore, the methods, systems and devices considered herein may be used to determine any measurable parameter of interest which relates to operationally sensitive elements of a balanced circuit and, moreover, may be used on or within any object or environment in which a device having the balanced circuit can access. As such, the methods, systems and devices considered herein are not restricted to determining flow, or temperature or pressure of an object or an environment, much less an environment in which a medical probe is arranged. It is noted that applications and devices alternative to those disclosed in reference to FIGS. 2-7 are provided throughout this disclosure, but the citation of such should not be construed to limit the scope of the methods, systems and devices which may encompass the method outlined in FIG. 1.

[0043] Turning to FIG. 1, the flowchart includes block 10 for positioning a device having a balanced circuit in or on an object or within a particular environment, wherein the balanced circuit comprises elements which are operationally sensitive to changes in a parameter of the object or the environment. As set forth in detail below in reference to FIGS. 2-7, an example of an applicable balanced circuit for the device is a silicon strain gauge, such as a Wheatstone bridge circuit, having at least one gauge configured to increase in resistance with a change in pressure and at least one other gauge configured to decrease in resistance with the change in pressure. The balanced circuits encompassed by the methods, systems and devices disclosed herein, however, are not restricted to being operationally sensitive to pressure nor are they restricted to being silicon strain gauges. In particular, other types of parameter sensitive elements and/or balanced circuits may be used, including but not limited to those which may be sensitive to changes in acceleration, tension, force, temperature, volume, velocity, pH, oxygen concentration or humidity.

[0044] Similar to the balanced circuit, the device employing the balanced circuit and the object and/or environment in which the device is placed may vary. As noted above, the device may be any tool, mechanism or physical means which can accommodate the balanced circuit and which can be placed in proximity, on, or within an object or environment of interest. Furthermore, the object or environment of interest may be any object or environment having a variable parameter that is desired to be measured. As an example, FIGS. 2-7 describe methods, device and systems in which temperature pressure and flow are the variable parameters desired for measurement and FIGS. 6 and 7 discuss exemplary implementations. As noted above, however, the methods, devices and systems encompassed by the disclosure herein are not limited to the description of FIGS. 2-7. As such, the methods, devices and systems described herein may be configured to measure variable parameters other than temperature pressure and flow, such as but not limited to acceleration, tension, force, volume, velocity, pH, oxygen concentration or humidity. Further, the methods described herein may be imple-

mented in devices and systems other than for use with medical probes or catheters. For example, an electrocardiogram system could be configured to implement the methods described herein.

[0045] Turning back to FIG. 1, the method outlined therein includes, as denoted in blocks 12 and 14, measuring a voltage derived from the balanced circuit which correlates to a common mode signal of the balanced circuit and further determining, from the measured voltage, a value of the parameter. Applications of such steps in the method outlined in FIG. 2 are respectively denoted in blocks 22 and 24. In particular, the method outlined in FIG. 2 includes block 20 for positioning a resistive sensor (e.g., a piezoresistive sensor) such that at least two variable resistors of a Wheatstone bridge circuit of the sensor are arranged in an environment in which temperature is to be measured. Thereafter, block 22 includes measuring a temperature detection voltage while the two variable resistors are arranged in the environment and, then at block 24, a temperature of the environment is determined from the measured temperature detection voltage.

[0046] It is noted that when a Wheatstone bridge circuit includes more than two variable resistors, two or more (and possibly all) of the variable resistors may be arranged in the environment in which temperature is to be measured and, thus, the process of measuring the temperature detection voltage may be when two or more (and possibly all) of the variable resistors are arranged in the environment.

[0047] As denoted in block 22, the temperature detection voltage is measured between a first voltage derived from the Wheatstone bridge circuit which is proportional to a summed voltage of signal output nodes of the Wheatstone bridge circuit and a second voltage which is proportional to a reference voltage for the Wheatstone bridge circuit. The operation of such steps may be better understood when described in relation to the exemplary circuits depicted in FIGS. 3-5 as set forth below. In general, however, the processes outlined in blocks 12, 14, 22 and 24 of FIGS. 1 and 2 are directed to measuring a common mode signal of a balanced circuit and using the common mode signal to determine a value of a parameter of an object or an environment. This is contrast to conventional techniques of monitoring common mode signals against predetermined thresholds to simply accept or reject a differential mode signal measurement.

[0048] In addition to steps 12 and 14, the method of FIG. 1 may, in some embodiments, include measuring a differential mode voltage of the balanced circuit as denoted in block 16 and further determining from the differential mode voltage a value of another distinct parameter of the object or environment in which at least part of the balanced circuit is arranged as denoted in block 18.

[0049] Applications of such steps in the embodiment of FIG. 2 are outlined in blocks 26 and 28, specifically measuring a differential voltage between signal output nodes of the Wheatstone bridge circuit and determining from the differential voltage measurement a pressure of the environment. As with the description of the processes outlined in blocks 12, 14, 22 and 24, the operation of the processes outlined in blocks 16, 18, 26 and 28 may be better understood when described in relation to the exemplary circuits depicted in FIGS. 3-5 as set forth below. As noted above, the processes outlined in blocks 12, 14, 22 and 24 of FIGS. 1 and 2 are directed to using a common mode signal to determine a value of a parameter of an object or an environment.

[0050] Combining such a technique with measuring a differential mode signal to determine a value of another parameter of an object or environment as outlined in blocks 16, 18, 26 and 28 advantageously increases the functionality of balanced circuit sensors for determining more information of interest. In some cases, combining the techniques may allow fewer sensors to be used for an evaluation of an object or an environment. For example, the method discussed in reference to FIG. 2 may obviate a need for a temperature sensor distinct from the resistive sensor in a system.

[0051] The dotted lines between some of the blocks in FIG. 1 denote that the operations outlined in blocks 16 and 18 may be conducted prior to, subsequent to, or at substantially the same time as the operations outlined in blocks 12 and 14. Likewise, the dotted lines between the some of the blocks in FIG. 2 denote that the operations outlined in blocks 26 and 28 may be conducted prior to, subsequent to, or at substantially the same time as the operations outlined in blocks 22 and 24. In some cases, it may be advantageous (i.e., time effective) for the processes outlined in blocks 14 and 18 to be performed simultaneously. Likewise, it may be desirable (i.e., time effective) for the processes outlined in blocks 24 and 28 to be performed simultaneously in some embodiments. In any case, the dotted lines around blocks 16, 18, 26 and 28 in FIGS. 1 and 2 denote the processes outlined therein are optional. In particular, it is noted that the methods, devices and systems described herein may be performed to determine a value of a single parameter of an object or environment and do not need to include measuring a differential mode voltage of the balanced circuit or determining a parameter value therefrom. To this end, it is noted that although a resistive sensor (e.g., a piezoresistive sensor) may include elements which are operationally sensitive to changes in environmental pressure as described above, the sensor need not be used to measure pressure in an environment. The resistive sensor could be simply used to measure temperature of that environment. Alternatively, the resistive sensor could be used to measure both pressure and temperature of the environment as described above.

[0052] As noted above, the circuits depicted in FIGS. 3-5 are examples of which may be employed for the method outlined in FIG. 2. Other circuits employing additional, fewer and/or different elements, however, may be employed to effect the operations outlined in FIG. 2. For example, although a Wheatstone bridge having two variable resistors and two fixed resistors (commonly referred to as a half-bridge circuit) is specifically described in reference to FIGS. 3-5, silicon strain gauges having four variable resistors (commonly referred to as full-bridge circuits) may be alternatively used. Furthermore, different summation circuitry may be employed for the temperature detection circuitry described in reference to FIGS. 3-5. Moreover, different reference voltage circuitry other than what is disclosed in reference to FIGS. 4-5 may be used. In some cases, the summation operations described in reference to FIGS. 3-5 may be partially or wholly done via software (i.e., via processor-executable program instructions) instead of partially or wholly via circuitry. In other words, the temperature detection circuitry described in reference to FIGS. 3-5 may, in some cases, be partially or wholly substituted by software having program instructions for performing such computational operations. A particularly suitable application of such is to have computational program instructions disposed on or accessible by an electronic monitoring system which is in electrical communication with the

device comprising the balanced circuit as described in more detail below in reference to FIGS. 6 and 7.

[0053] The methods referred to in FIGS. 1-2A may also be used to sense flow of a substance in an environment. As shown in step 17 in FIG. 1, this process may be implemented by heating selected elements of the balanced circuit. Then, after a selected time period, performing step 12. Then, in step 19, this information can be used to determine a third parameter of the object or environment. Before discussing this process more specifically with reference to FIG. 2, those skilled in the art should be aware that step 17 could be performed after step 12 and the information from those two steps may then be used to determine the third parameter in step 19. In step 17, energy is supplied to a selected element, or elements, of the relevant circuit. As set forth in step 25 of the flow chart of FIG. 2, this may involve using a higher excitation voltage to heat resistive sensing elements of a Wheatstone bridge circuit. However, those skilled in the art will appreciate that other balanced circuits may be used. Furthermore, as shown in FIG. 2, the change in temperature of the elements and/or the environment, or an adjacent object in the environment, can be determined using the measuring process described above with reference to steps 12 and 22. Information relating to the temperature detection voltage before energy was supplied to the system (i.e. heating the elements of the balanced circuit), and the temperature prior to the energy being supplied, allows a flow rate of a substance in the environment to be determined as shown in step 27.

[0054] There are a number of different ways in which the flow rate parameter can be sensed using the general method outlined above with reference to FIGS. 1 and 2. For example, a voltage which corresponds to an initial temperature of the environment (prior to any energy being supplied to the circuit elements) can be determined, then energy can be supplied to the circuit elements for a selected period of time, and subsequently the temperature can be measured by looking at the voltage of the common mode signal of the balanced circuit for example. From the temperature change over the known time period a flow rate for the substance can be determined. Another approach is to supply energy to the circuit elements while monitoring a parameter of the circuit which represents an electrical property which is dependent upon temperature (such as resistance) to see how the property changes over a time period in response to the energy supplied. In one example, if a constant or increasing voltage is applied to the circuit elements so as to increase their temperature, then the current may be monitored to detect the change in resistance over a time period. In this way, the amount of energy required over a time period to maintain the elements at a particular temperature or reach a steady state temperature (i.e. a temperature above the nominal temperature of the substance or environment) can be used as an indication of flow rate. In yet another approach, the sensor can be brought up to a known temperature based on a known resistance from the voltage and current being supplied to the elements, then the temperature once energy is no longer being supplied to the elements can be measured at a known time thereafter. From the change in temperature an indication of flow rate can be determined.

[0055] Some approaches may thus be summarised as follows: (1) One method of flow detection is to start injecting energy and measure the increase in temperature after a pre-determined interval. The rise in temperature is then processed to determine flow. (2) Another method of flow detection is to start injecting energy at a fixed rate and measure the time to

achieve a specific rise in temperature. The time to achieve the temperature increase is then processed to determine flow. (3) Another method is to inject energy at an increasing rate until a steady state temperature is obtained at a pre-determined (higher) temperature level than normal operation. The amount of power delivered to sustain the elevated temperature is then processed to determine flow.

[0056] The method of injecting energy is based on the heating of resistive elements in a bridge configuration. The same energy injection process can be achieved independent from the direction of the current running through the resistive elements. The direction of current may be alternated to maintain a mean voltage differential across each element of zero volts. This is true when injecting energy for flow measurements and when not injecting energy and just obtaining pressure data.

[0057] Referring to FIG. 2A, a flow chart is shown for an embodiment which allows a balanced circuit (i.e. essentially one sensor) to measure at least three parameters of an environment. As shown in step 100, initially the device is positioned in the environment so that sensing elements of the balanced circuit are operationally sensitive to changes in the environment. Those skilled in the art will be aware that this step may be performed as part of a surgical procedure in which a hydrocephalus shunt for example which includes the sensor is implanted in the patient. At step 102 the balanced circuit is excited with a nominal voltage, so that as described above, measuring a differential mode voltage of the balanced circuit may be performed in step 104 and from that a value of the pressure in the environment may be determined at step 106. In step 108 the voltage correlating to a common mode signal of the balance circuit is measured in step 108 and this, as described above, allows a temperature in the environment to be derived as shown in step 110. Furthermore, the excitation voltage applied to the circuit may be increased for a set period of time, for example several seconds in this embodiment. This occurs in step 112 and effectively supplies energy to the sensing elements which are resistive will heat up. In step 114 the voltage derived from the balanced circuit at a selected time after energy has been supplied to the circuit from step 112 is then measured in step 114. Then, in step 116, the change in measured voltage is determined, and that is used in step 118 to determine a flow rate of the substance such as fluid, in the environment, as discussed above.

[0058] Turning to FIG. 3, circuit 30 is shown having Wheatstone bridge 32 coupled between power supply 34 and reference 36. Reference 36 may be ground or any node of circuit 30 common to Wheatstone bridge 32. The specifications of power supply 34 may generally depend on the application in which the circuit is employed and, thus, may vary widely among systems.

[0059] An exemplary specification for power supply 34 when circuit 30 is applied within a medical probe system, for example, may be a maximum of 5 volts, but specifications of larger and smaller voltages may be employed. In some cases, circuit 30 may include potentiometer 38 for adjusting the level of the power transmitted to Wheatstone bridge 32 as shown in FIG. 3, but such an element is optional. It is noted that the dotted line to which numeral 32 refers to in FIG. 3 is used to schematically indicate which elements of circuit 30 make up Wheatstone bridge 32. The dotted line to which numeral 32 refers is not part of the circuit nor does it indicate that Wheatstone bridge 32 is an optional element in circuit 30.

[0060] As shown in FIG. 3, Wheatstone bridge 32 may include two variable resistors 40 and 42 and two fixed resistors 44. In some embodiments, variable resistors 40 and 42 may be configured to be operationally sensitive to changes in pressure in an environment in which they are arranged. In particular, one of variable resistors 40 and 42 may be configured to increase in resistance with a change in environmental pressure and the other variable resistor may be configured to decrease in resistance with the change in environmental pressure. An example of a Wheatstone bridge having such characteristics is one which has variable resistors 40 and 42 made of a semiconductive material and, thus, the Wheatstone bridge serves as a piezoresistive sensor. In any case, ensuing to a design of varying resistance with changes in environmental pressure, a differential mode voltage of Wheatstone bridge 32 (i.e., a differential voltage between signal output nodes 46 and 48) may be measured and then used to determine (i.e., quantitate) the pressure of the environment in which the variable resistors are arranged as noted in FIG. 3. Such process steps are denoted in blocks 26 and 28 of FIG. 2. In alternative embodiments, variable resistors 40 and 42 may be configured to be operationally sensitive to changes in a parameter other than pressure, such as but not limited to temperature, humidity, force, tension, volume, velocity, pH, oxygen concentration and acceleration. In such cases, the differential mode measurement will accordingly be used to quantitate the noted parameter.

[0061] As further shown in FIG. 3, circuit 30 may optionally include compensation circuitry 49 coupled to Wheatstone bridge 32. In general, compensation circuitry 49 is configured to compensate for variations of a resistive coefficient of a conductive material comprising the Wheatstone bridge circuit, specifically variable resistors 40 and 42, due to ambient temperature changes of the conductive material. For example, in embodiments in which variable resistors 40 and 42 are made of a semiconductive material, compensation circuitry 49 may be configured to compensate for variations of a piezoresistive coefficient of the semiconductive material due to ambient temperature changes of the semiconductive material. There are a wide variety of manners known in the art in which to compensate for temperature changes and, thus, compensation circuitry 49 is depicted very generally in FIG. 3 so as to not limit the scope to which it may be. An example of compensation circuitry which may be used is one or more fixed resistors in parallel with at least one of variable resistors 40 and 42 of Wheatstone bridge 32. It is noted that the compensation circuitry is not limited to when Wheatstone bridge 32 includes two variable resistors and, more specifically, may be employed when Wheatstone bridge 32 includes any plurality of variable resistors.

[0062] In any case, with the inclusion compensation circuitry 49 in circuit 30, the accuracy of the differential mode measurement of Wheatstone bridge 32 in relation to a parameter of interest may be improved. In particular, compensation circuitry 49 may aid in counteracting changes in pressure sensitivity of a conductive material comprising Wheatstone bridge 32 due to temperature changes such that resistance changes of variable resistors 40 and 42 are maintained substantially uniform with pressure changes regardless of the ambient temperature. Although compensation circuitry may be beneficial in some cases, it is not required for the methods, devices and systems described herein. In particular, a balanced circuit may be void of such compensation circuitry if

the effects on pressure sensitivity are not large enough to warrant significant inaccuracy of a differential mode measurement from the circuit.

[0063] In any case, circuit 30 may include temperature detection circuitry 50 coupled to Wheatstone bridge 32 as shown in FIG. 3. Similar to the dotted line encompassing the elements of Wheatstone bridge 32, the dotted line to which numeral 50 refers to in FIG. 3 is used to schematically indicate which elements of circuit 30 make up temperature detection circuitry 50.

[0064] The dotted line to which numeral 50 refers is not part of the circuit nor does it indicate that temperature detection circuitry 50 is an optional element in circuit 30. FIG. 3 depicts temperature detection circuitry 50 including two signal lines coupled to Wheatstone bridge 32. As one skilled in the art would be aware, the signal lines are effectively coupled to signal output nodes 46 and 48 of Wheatstone bridge 32. Direct coupling to the signal output nodes is not shown in FIG. 3 to simplify the depiction of temperature detection circuitry 50.

[0065] As shown in FIG. 3, the signal lines of temperature detection circuitry 50 include fixed resistors 52 and 54, respectively, and are joined to form a closed loop. Such a design, in effect, produces a measurable voltage at node 56 which is proportional to a summed voltage of signal output nodes 46 and 48 of Wheatstone bridge 32. Alternatively stated, a measurable voltage is generated at node 56 which is proportional to a summation of the voltages at the output nodes of Wheatstone bridge 32. In yet other words, the design produces a measurable voltage at node 56 which correlates to a common mode signal of Wheatstone bridge 32. As used herein, the term "common mode signal" refers to the average value of signals at the positive and negative output nodes of a differential circuit. A quantitative measure of a common mode signal is referred to as common mode voltage, which as noted above refers to the voltage at a given location that appears equally and in phase from each signal conductor to a common reference. Alternatively stated, the term "common mode voltage" refers to the instantaneous algebraic average of two signals within a balanced circuit with both signals referenced to a common reference.

[0066] Depending on the resistances of resistors 52 and 54, the voltage measured between nodes 56 and 58 may be the common mode voltage of Wheatstone bridge 32 or may be of greater or lesser proportion thereto. In particular, when the resistances of resistors 52 and 54 are substantially equal, the voltage measured between nodes 56 and 58 is the common mode voltage of Wheatstone bridge 32. In some cases, however, it may be advantageous to produce a voltage which is larger or smaller than the common mode voltage of Wheatstone bridge 32 and, thus, in some cases, resistors 52 and 54 may have different resistances. For example, it may be desirable to produce a voltage which is larger than the common mode voltage of Wheatstone bridge 32 such that a voltage reading between nodes 56 and 58 may be amplified. In particular, an amplified voltage measurement between nodes 56 and 58 may aid in ascertaining a temperature of the object or environment in which at least variable resistors 40 and 42 of Wheatstone bridge 32 are disposed. Regardless of whether the voltage measured between nodes 56 and 58 is the common mode voltage of Wheatstone bridge 32 or is of greater or lesser proportion thereto, the measured voltage may be referenced as correlating to a common mode signal of Wheatstone bridge 32 since the measured voltage is in relationship with

the average value of signals at the signal output nodes of Wheatstone bridge. As used herein, the term “proportional” means corresponding in value by a set ratio, wherein the ratio is a non-negative number (whole or fractional) that is less than, equal, or greater than 1. As such, the term “proportional” is inclusive to values which are the same as well as those which are non-negative multiples of each other.

[0067] As shown in FIG. 3, a voltage reading between nodes 56 and 58 may relate to temperature, particularly when Wheatstone bridge 32 includes resistive elements as described above. In view thereof, the voltage reading between nodes 56 and 58 is sometimes referred to herein as “a temperature detection voltage.” In other embodiments, the voltage reading between nodes 56 and 58 may relate to a different variable parameter of an object or environment, depending on the sensitivity of resistors 40 and 42 to different parameters. As discussed above, flow rate can be detected using this circuit and those of FIGS. 1, 4 and 5. In any case, the voltage reading between nodes 56 and 58 is used to determine a value of a parameter of interest for an object or environment. More specifically, a computational correlation between a parameter and voltage readings between nodes 56 and 58 of circuit 30 may be predetermined and the correlation may be used to determine the value of the parameter from a given voltage reading. In some cases, the computational correlation may be a polynomial equation having a voltage reading between nodes 56 and 58 of circuit 30 as a variable. Accordingly, the process outlined in block 24 of FIG. 2 may include computing temperature of the environment from a polynomial equation having the temperature detection voltage as a variable. In some cases, the polynomial equation may be a first degree polynomial equation (i.e., a linear equation), but polynomial equations of larger degrees are possible.

[0068] As noted above, the circuits depicted in FIGS. 4 and 5 offer additional examples which may be employed for the method outlined in FIG. 2. The circuits of FIGS. 4 and 5 are similar to circuit 30 depicted in FIG. 3 in that they include Wheatstone bridge 32 and optional potentiometer 38 coupled between power supply 34 and reference 36 and further include optional compensation circuitry 49. The specifics of such elements discussed above with respect to FIG. 3 may be applied to the circuits depicted in FIGS. 4 and 5 and are not reiterated for the sake of brevity. As set forth in more detail below, the circuits of FIGS. 4 and 5 differ from circuit 30 depicted in FIG. 3 by the inclusion of different temperature detection circuitry as well as reference voltage circuitry configured to generate a biased reference voltage relative to an excitation voltage applied to Wheatstone bridge 32. The disclosure of the different temperature detection circuitry in FIGS. 4 and 5 emphasizes that the voltage derived from Wheatstone bridge 32 may be of any proportion to a summed voltage of signal output nodes of the Wheatstone bridge. Furthermore, as set forth in more detail below, the inclusion of reference voltage circuitry in the circuits of FIGS. 4 and 5 discloses that the “second voltage” specified in block 22 of FIG. 2 may, in some embodiments, be in reference to power supply 34 rather than just in reference to reference 36 as depicted in FIG. 3. As such, it is noted that the phrase “reference voltage for the Wheatstone bridge” denoted in block 22 of FIG. 2 can refer to either the excitation source or a common reference of a Wheatstone bridge.

[0069] As shown in FIG. 4, circuit 60 includes temperature detection circuitry 62 as well as resistors 70 and 72 between power supply 34 and reference 36. In general, resistors 70 and

72 makeup exemplary reference voltage circuitry which is configured to generate a biased reference voltage at node 74 relative to an excitation voltage applied to Wheatstone bridge 32. In other words, resistors 70 and 72 bias reference 36 to power supply 34 such that the voltage to which the output voltage from temperature detection circuitry 62 is referenced may be set to a predetermined value relative to power supply 34. An example of a bias is half of power supply 34, but resistors 70 and 72 may be configured to generate other proportions of power supply 34.

[0070] It is noted that resistors 70 and 72 are merely an example of reference voltage circuitry which may be used to bias reference 36 to power supply 34. Any biasing techniques known to those skilled in art may be used in circuit 60 and, thus, the methods, devices and system described herein are not necessarily limited to the embodiment depicted in FIG. 4.

[0071] Temperature detection circuitry 62 of FIG. 4 differs from temperature detection circuitry 50 of FIG. 3 by the inclusion of buffers 64 and 66 as well as potentiometer 68 instead of resistors 52 and 54. Buffers 64 and 66 may be generally configured to ensure that the voltage reading between potentiometer 68 and node 74 does not have a loading effect on the differential mode measurement between signal output nodes 46 and 48 of Wheatstone bridge 32. Potentiometer 68 may be configured to match an incoming signal at a particular reference temperature to that of the biased signal at node 74 such that voltage output for that temperature would be zero volts. Such a design may aid in simplifying the determination of temperature from a given temperature detection voltage. As with the reference voltage circuitry of resistors 70 and 72, the use of buffers 64 and 66 is merely an example of circuitry which may be used to ensure that a loading effect is not imposed on Wheatstone bridge 32. Likewise, the use of potentiometer 68 with biasing circuitry is merely an example in which to null out a voltage reading for a particular temperature. Other techniques known to those skilled in art may be used in circuit 60 and, thus, the methods, devices and system described herein are not necessarily limited to the embodiment depicted in FIG. 4.

[0072] As shown in FIG. 5, circuit 80 differs from circuit 60 depicted in FIG. 4 by inclusion of temperature detection circuitry 82 as well as buffer 76 from node 74. Circuit 80 includes resistors 70 and 72 as is included in circuit 60 of FIG. 4. In addition, temperature detection circuitry 82 includes buffers 64 and 66 as well as potentiometer 68 as is included in temperature detection circuitry 62 of FIG. 4. The specifics of such elements discussed above with respect to FIG. 4 may be applied to circuit 80 depicted in FIG. 5 and are not reiterated for the sake of brevity. As shown in FIG. 5, temperature detection circuitry 82 includes amplifier 84 and amplifier calibrator controls 86. In general, amplifier 84 adjusts voltage output from potentiometer 68 based on the presets in amplifier calibrator controls 86. Such circuitry allows for bi-directional voltage output depending on the null output voltage adjustment of potentiometer 68. Buffer 76 offers impedance isolation from power supply 34 and reference 36 to improve the temperature detection voltage reading from circuit 80 relative to circuits 30 and 60 of FIGS. 3 and 4. It is noted that use of buffer 76, amplifier 84, and amplifier calibrator controls 86 are merely examples of circuitry which may be used to offer impedance isolation and amplify signals. Other techniques known to those skilled in art may be used in circuit 80

and, thus, the methods, devices and system described herein are not necessarily limited to the embodiment depicted in FIG. 5.

[0073] As set forth above, the methods, systems and devices considered herein may be used to determine any measurable parameter of interest which relates to the operationally sensitive elements of a balanced circuit and, moreover, may be used on or within any object or environment in which a device having the balanced circuit can access. As merely an example of a system which may be configured to perform the methods described herein, FIG. 6 depicts a schematic diagram of medical probe system 90 having a device which includes circuitry by which to measure a voltage derived from a balanced circuit arranged within medical probe 92 which correlates to a common mode signal of the balanced circuit. In addition, medical probe system 90 includes processor executable program instructions 102 for determining from the measured voltage a temperature of an environment in which a tip of medical probe 92 is arranged. As described in more detail below, an alternative configuration to medical probe system 90 is to incorporate the computational operations of temperature detection circuitry 96 and/or the reference voltage circuitry described below into program instructions 102, thus negating the inclusion of either or both of such circuitry within the system.

[0074] In any case, the medical probe systems described in reference to FIG. 6 (including variations to the depiction in FIG. 6) may be used for any application using a medical probe in which temperature of bodily fluids, cavities or tissue may be of interest and/or temperature of fluids administered into a body via a catheter may be of interest. Examples of applications include but are not limited to the drainage or administration of fluids into a body, measuring/monitoring arterial or vein blood pressure, measuring/monitoring pressure of body cavities, and their modulation techniques. It is noted that medical probe system 90 is merely an example of a system which may be configured to perform the methods described herein. Other medical probe systems including devices and features additional or alternative to those described in reference to FIG. 6 may be suitable as well. In addition, a variety of other types of systems in any field may be configured to perform the methods described herein, particularly any of which involve differential signal processing.

[0075] In general, medical probe 92 of medical probe system 90 may include any type of medical probe, i.e., medical probe 92 may be a medical probe of any size, material, type, purpose, etc. and may be a single or multiple tipped medical probe. The term "medical probe," as used herein, refers to a long, slender instrument for exploring wounds, body cavities, or body passages. Thus, the term "medical probe" encompasses catheters as well as devices including no lumen. In general, the term "catheter" as used herein is inclusive to catheters having an open lumen (i.e., having an unblocked lumen) as well as catheters having a closed lumen (i.e., a lumen having an obstruction such that the catheter cannot be used for the passage of fluid). As common to all medical probes, medical probe 92 includes at least one tip 93 which is used to access a particular bodily fluid, body part or body region. Specific to the medical probes considered herein, tip 93 includes at least a portion of a balanced circuit, particularly elements of a balanced circuit which are operationally sensitive to a parameter of a bodily fluid, a body part or a body region. The balanced circuit may be of any type or configuration.

[0076] An example of a balanced circuit which may be suitable for a medical probe is a Wheatstone bridge with two variable resistors and two fixed resistors. Alternatively, a Wheatstone bridge having four variable resistors may be used. In yet other embodiments, another type of balanced circuit may be employed. In any case, the entire balanced circuit may be disposed within tip 93 in some embodiments. In other cases, however, less than the entire balanced circuit may be disposed within tip 93 and, in some embodiments, only the operationally sensitive elements of the balanced circuit may be disposed within tip 93. In particular, in some case, it may be desirable to minimize the size of tip 93 as well as the areal space of the medical probe tubing and, thus, it may be beneficial to include only a portion of a balanced circuit therein. In any of such cases, the remaining portion of the balanced circuit may be disposed in electrical connector 94 of medical probe 92 and/or within the tubing of the medical probe.

[0077] As shown by operational connection 97 in FIG. 6, electrical connector 94 and electronic signal monitoring device 95 may be jointly configured for electrical communication with each other. In particular, electronic signal monitoring device 95 is configured to measure electrical parameters of the balanced circuit disposed within medical probe 92 and, thus, electrical connector 94 includes a means for sending output signals of the balanced circuit therein and electronic signal monitoring device 95 includes a means for receiving such output signals. In some embodiments, each of electrical connector 94 and electronic signal monitoring device 95 may include an electrical port configured for securely and operatively coupling with an electrical connector of the other (i.e., hard-wired input/output terminals). In such cases, the coupling may be direct or may be through intermediary means. In yet other embodiments, electrical connector 94 and electronic signal monitoring device 95 may additionally or alternatively include transmitters to transmit signals wirelessly. In any case, electronic signal monitoring device 95 may be configured to process data received from the balanced circuit disposed within medical probe 92, as described in more detail below with respect to means 98 and 99. In some embodiments, electronic signal monitoring device 95 may be configured to supply power and ground to the balanced circuit within medical probe 92 as well as any other circuitry disposed therein. As such, electronic signal monitoring device 95 may, in some cases, include an excitation voltage terminal for supplying an excitation voltage to the balanced circuit disposed within medical probe 92 and also a reference common voltage terminal for supplying a reference common voltage for the balanced circuit.

[0078] As described above in reference to FIGS. 2-5, the methods, devices and systems described herein may utilize a resistive sensor (i.e., a balanced circuit having resistive elements) and, thus, in some embodiments, medical probe 92 may include a resistive sensor. In such cases, medical probe 92 may optionally include compensation circuitry coupled to the balanced circuit disposed therein. In general, as described above in reference to FIG. 3, the compensation circuitry is configured to compensate for variations of a resistive coefficient of a conductive material comprising the balanced circuit due to ambient temperature changes of the conductive material. As further described above, although compensation circuitry may be beneficial in some cases, it is not required for the methods, devices and systems described herein and, thus, medical probe 92 may be void of compensation circuitry in

some embodiments. In any case, medical probe **92** may, in some cases, include reference voltage circuitry for generating a biased reference voltage relative to an excitation voltage applied to the balanced circuit disposed therein. In addition or alternatively, electronic signal monitoring device **95** and/or a device between medical probe **92** and electronic signal monitoring device **95** may include such circuitry.

[0079] Examples of such circuitry are described in reference to FIGS. **4** and **5**, but the scope of such is not so limited. In yet other embodiments, the computational operations of such reference voltage circuitry may be incorporated into program instructions **102**, thus negating the inclusion of such circuitry within medical probe **92** and/or electronic signal monitoring device **95**. In yet other embodiments, medical probe system **90** may be void of means to change values of a reference voltage.

[0080] In any case, medical probe system **90** may, in some embodiments, include temperature detection circuitry **96** as illustrated in FIG. **6**. In general, temperature detection circuitry **96** is configured to generate a voltage which is proportional to a summed voltage of signal output nodes of the balanced circuit disposed within medical probe **92** (i.e., a voltage which is proportional to a summation of the voltages at the signal output nodes of the balanced circuit).

[0081] Examples of circuitry are described in reference to FIGS. **3-5**, but temperature detection circuitry **96** is not necessarily so limited. As denoted by the dotted lines extending from temperature detection circuitry **96** in FIG. **6**, temperature detection circuitry **96** may be disposed within medical probe **92**, electronic signal monitoring device **95**, and/or between medical probe **92** and electronic signal monitoring device **95** (i.e., within an intermediary means between the devices).

[0082] In cases in which temperature detection circuitry **96** is disposed within medical probe **92**, temperature detection circuitry **96** may be disposed within tip **93** and/or electrical connector **94**.

[0083] As described above, an alternative configuration to medical probe system **90** is to incorporate the computational operations of temperature detection circuitry **96** into program instructions **102**, thus negating the inclusion of such circuitry within the system.

[0084] As shown in FIG. **6**, electronic signal monitoring device **95** may, in some cases, include means **98** for determining a voltage between the voltage generated by temperature detection circuitry **96** (or comparable program instructions) and another voltage which is proportional to the common reference voltage or the excitation voltage supplied to the medical probe. The voltage determined by means **98** is referred to herein as a temperature detection voltage since it is used to determine the temperature of the environment in which tip **93** is arranged, particularly by program instructions **102** in medical probe system **90**. In particular, FIG. **6** shows medical probe system **90** with storage medium **100** including program instructions **102** coupled to electronic signal monitoring device **95** via input therefrom. In general, program instructions **102** are executable by processor **104** for generating output **106** and, more specifically, for determining, from the temperature detection voltage measured by means **98**, a temperature of an environment in which tip **93** of medical probe **92** is arranged. Such a process may include any of the particularities described in reference to block **24** of FIG. **2** and are not reiterated for the sake of brevity. In some embodiments, electronic signal monitoring device **95** and storage

medium **100** may be one of the same and, thus, in some cases, electronic signal monitoring device **95** may include program instructions **102**. In other cases, storage medium **100** may be a device distinct from electronic signal monitoring device **95**.

[0085] In general, the term “storage medium,” as used herein, may refer to any electronic medium configured to hold one or more set of program instructions, such as but not limited to a read-only memory, a random access memory, a magnetic or optical disk, or magnetic tape. The term “program instructions” may generally refer to commands within a program which are configured to perform a particular function, such as receiving input, recording receipts of signals, and processing signals. Program instructions may be implemented in any of various ways, including procedure-based techniques, component-based techniques, and/or object-oriented techniques, among others. For example, the program instructions may be implemented using ActiveX controls, C++ objects, JavaBeans, Microsoft Foundation Classes (“MFC”), or other technologies or methodologies, as desired. Program instructions implementing the processes described herein may be transmitted over on a carrier medium such as a wire, cable, or wireless transmission link.

[0086] As shown in FIG. **6**, electronic signal monitoring device **95** may, in some embodiments, include means **99** for measuring a differential mode voltage of the balanced circuit disposed within medical probe **92**, particularly via signals transmitted from electrical connector **94** of medical probe **92**. In such cases, program instructions **102** may be further executable by processor **104** for determining, from the differential voltage, a pressure of the environment in which tip **93** is arranged. As such, medical probe system **90** may be used in such embodiments to determine temperature and/or pressure of the environment in which tip **93** is arranged. As described in detail above, a benefit of the methods, devices and systems described herein is that a balanced circuit may be used to monitor two variable parameters of an object or an environment.

[0087] Hence, fewer sensors may be used for an evaluation of an object or an environment. As such, medical probe **92** may, in some embodiments, be absent a temperature sensor distinct from the temperature detection means dually provided by the balanced circuit disposed therein and temperature detection circuitry **96**. Alternatively stated for cases in which medical probe **92** includes a resistive Wheatstone bridge and compensation circuitry, medical probe **92** may be absent a temperature sensor distinct from the resistive sensor made up by the Wheatstone bridge, the compensation circuitry and temperature detection circuitry **96**. Such scenarios may be particularly advantageous when available space at tip **93** is limited. In any case, electronic signal monitoring device **95** may be configured to utilize means **98** and **99** at the same time or in succession.

[0088] Referring to FIG. **7** is a schematic representation of a system which uses a sensor to sense at least three parameters of an environment shown. Features that have already been described with reference to FIG. **5** use like reference numerals. As can be seen, the variable resistive sensing elements **40** and **42** are disposed in catheter **150** so that they are present in use in an environment such as a catheter of a hydrocephalus shunt, and the sensing elements are exposed to the fluid in the catheter in use. Switch means **152** (which may comprise a mosfet for example) are operated by a control apparatus such as microprocessor **154** to switch between providing a temperature/pressure detection voltage to the balanced circuit

and between presenting a flow measurement voltage to the circuit in accordance with the methods described above. This allows temperature and flow of the substance in the catheter to be determined and pressure within the environment in the catheter to be determined from the differential measurement using amplifier 156.

[0089] Turning now to FIGS. 8 and 9, FIG. 8 is a graphical representation of calibration data set of one sensor at three ambient temperatures in the physiological (subcutaneous) range for flow sensing in accordance with the invention. FIG. 9 is a graphical representation of the repeatability of the flow measurement described herein. Four senses are represented, each with five measurements made at each flow rate over a short period of time. Data were collected at three ambient temperatures. Repeatability is expressed as coefficient of variation.

[0090] It will be appreciated to those skilled in the art having the benefit of this disclosure that this invention is believed to provide methods, devices and systems which utilize a voltage reading associated with a common mode signal of a balanced circuit to determine a value of a parameter of an object or an environment. Further modifications and alternative embodiments of various aspects of the invention will be apparent to those skilled in the art in view of this description. For example, although the description of methods, devices and systems provided herein are specific to Wheatstone bridge circuits including resistive elements for determining temperature of an environment, the methods, devices and systems provided herein may be constructed with a variety of balanced circuits having any type of operationally sensitive elements for determining any type of variable parameter of an object or environment. In particular telemetry systems can be used to provide information relating to measured parameters to remote equipment (e.g. equipment outside a body in which the sensor apparatus may be implanted). Telemetry systems may also be used to control the sensor, and wireless power systems may be used to charge or power the sensor.

[0091] Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the general manner of carrying out the invention. It is to be understood that the forms of the invention shown and described herein are to be taken as the presently preferred embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed, and certain features of the invention may be utilized independently, all as would be apparent to one skilled in the art after having the benefit of this description of the invention. Changes may be made in the elements described herein without departing from the spirit and scope of the invention as described in the following claims.

We claim:

1. A method for determining a flow rate of a substance in an environment using a balanced circuit provided within the environment, the balanced circuit comprising circuit elements which are sensitive to changes in temperature of the substance or the environment, the method comprising:

supplying energy to the circuit elements;
measuring a voltage derived from the balanced circuit which correlates to a common mode signal of the balanced circuit, and;
determining, from the measured voltage, the flow rate.

2. The method of claim 1 wherein energy is supplied to the circuit elements for a predetermined time period.

3. The method of claim 1 wherein the measured voltage provides a temperature measurement of the circuit elements or the substance.

4. The method of claim 1 wherein supplying energy to the circuit elements changes the temperature of the circuit elements.

5. The method of claim 3 wherein energy is supplied to the circuit elements until a predetermined temperature is reached.

6. The method of claim 3 wherein energy is supplied to the circuit elements until a steady state temperature is reached.

7. The method of claim 3 comprising measuring the temperature of the circuit elements or the substance prior to supplying energy to the circuit elements.

8. The method of claim 1 further comprising measuring a differential mode voltage of the balanced circuit.

9. The method of claim 8 further comprising using the differential mode voltage to determine a measurement of the pressure of the environment or the substance.

10. An apparatus for determining a flow rate of a substance in an environment, the apparatus comprising:

a balanced circuit comprising circuit elements which are sensitive to changes in temperature of the substance or the environment, and;

a controller operable to:

supply energy to the circuit elements;

measure a voltage derived from the balanced circuit which correlates to a common mode signal of the balanced circuit, and;

determining, from the measured voltage, the flow rate.

11. The apparatus of claim 10, wherein the controller uses the measured voltage to obtain a temperature measurement of the circuit elements or the substance.

12. The apparatus of claim 10, wherein the controller also measures a differential mode voltage of the balanced circuit.

13. The apparatus of claim 12 wherein the controller uses the differential mode voltage to determine a measurement of the pressure of the environment or the substance.

14. The apparatus of claim 10 wherein the circuit elements are resistive or piezoresistive.

15. The apparatus of claim 10 wherein at least two of the circuit elements have a variable resistance dependent on pressure.

16. The apparatus of claim 10 wherein the apparatus comprises a medical device.

17. The apparatus of claim 16 wherein the device comprises an implantable device.

18. The apparatus of claim 13 wherein the apparatus comprises a catheter.

19. The apparatus of claim 13 wherein the device comprises a hydrocephalus shunt.

20. An apparatus for determining a flow rate of a substance in an environment, the apparatus being electrically connectable to a balanced circuit comprising circuit elements which are sensitive to changes in temperature of the substance or the environment, the apparatus comprising means operable to:

connect the circuit elements to a supply of electrical energy;

measure a voltage derived from the balanced circuit which correlates to a common mode signal of the balanced circuit, and;

determining, from the measured voltage, the flow rate.

* * * * *

专利名称(译)	用于感测流量，温度和压力的方法，装置和系统		
公开(公告)号	US20150297094A1	公开(公告)日	2015-10-22
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[标]申请(专利权)人(译)	米勒INSTR		
申请(专利权)人(译)	米勒仪器有限公司		
当前申请(专利权)人(译)	米勒仪器有限公司		
[标]发明人	MALPAS SIMON CHARLES BUDGETT DAVID MORTIMER CLARK THERESE		
发明人	MALPAS, SIMON CHARLES BUDGETT, DAVID MORTIMER CLARK, THERESE		
IPC分类号	A61B5/01 A61B5/00 A61B5/03		
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摘要(译)

一种用于确定环境中物质的流速的方法，包括将具有平衡电路的装置定位在物体中或物体上或特定环境内，其中平衡电路包括对物体参数的变化在操作上敏感的元件。或环境。该方法还包括测量平衡电路的共模信号并从共模信号确定流速的值。该方法的示例性实施方式包括使用具有惠斯通电桥电路的电阻传感器确定温度，该电路具有两个可变电阻器和两个固定电阻器。提供了配置成采用这种方法的系统和设备的实施例，特别是医疗探针，电子信号监测设备和采用这种设备的系统。

