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(54) Title: LIQUID LEVEL SENSOR HAVING A REFERENCE CAPACITANCE

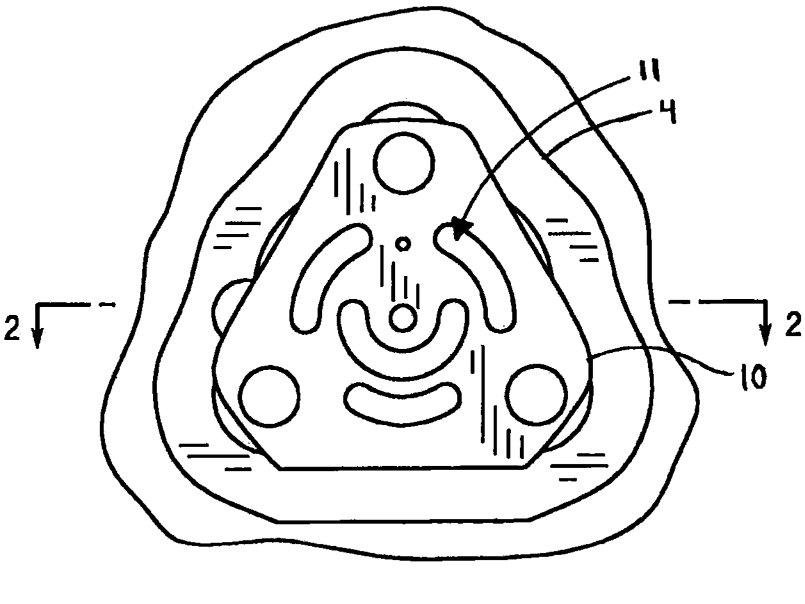

FIG. 1

(57) Abstract: A liquid level sensor employs a coaxial conductor for measuring a level of a liquid within a reservoir is disclosed. The liquid level sensor comprises a reference capacitor formed in part by the coaxial conductor configured to sense the liquid such that the liquid level sensor can determine a dielectric constant of the liquid. The liquid level sensor further comprises a level capacitor also formed in part by the coaxial conductor configured to sense the liquid such that the liquid level sensor can determine the level of the liquid using the dielectric constant of the liquid.

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LIQUID LEVEL SENSOR HAVING A REFERENCE CAPACITANCE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 61/138,008 filed December 16, 2008, the disclosure of which is hereby incorporated by reference in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

FIELD OF THE INVENTION

[0003] The invention is related generally to liquid level sensors and more particularly to a capacitance-based liquid level sensor.

BACKGROUND OF THE INVENTION

[0004] Liquid level sensors are used in a variety of applications to sense liquid levels in reservoirs where it is important or desirable to periodically or continuously measure the level of liquid within the reservoir.

[0005] Prior art sensors include conventional fuel sensors which comprise a float carried on the end of a long pivoting arm suspended within the interior of the fuel supply tank. As the arm pivots, a short wiper blade having a ball contact slideably engages wires on a wound wire rheostat that varies in resistance in accordance with the position of the float and hence liquid level. The angular position of the pivoting float arm, or more particularly the incremental angle of the arm, is not directly proportional to the vertical incremental change in float position and hence not directly proportional to liquid levels. An improvement in this type of mechanism is disclosed in U.S. Pat. No. 4,920,798 issued to Weaver. This reference teaches a fuel level sensor which has a vertically reciprocal foam float that carries a slideable dual dwell contact member biased by springs in the float toward a fixed film resistor plate.

[0006] Another form of liquid level sensor employs a capacitive probe having a pair of continuous elongated elements positioned on a substrate of the probe. This form of sensing system makes use of the difference in the dielectric constant of air from various liquids. In such systems, some means is provided for generating a signal that is applied to one plate of the probe. The overall capacitance of the capacitor formed by the two plates, and thus the magnitude of the signal coupled onto the other one of the plates on the probe, will change as the percentage of the probe submerged in a liquid changes. Thus, the magnitude of the signal coupled onto the output plate of the probe can provide a relative indication of the area of the probe that is submerged in liquid.

[0007] While the prior art devices have proven effective in certain applications, various problems exist with each style of sensor. Mechanical-type sensors have proven less reliable and difficult to use when the space required for the sensor must be minimized. Therefore, in many applications, the use of the mechanical device is not an option. In contrast, the capacitive sensors require less space. Capacitive-type sensors rely on the difference of the dielectric constant of the liquid and air. However, the dielectric constant of different types of liquids, such as different grades of fuel, also differs. As a result, capacitive sensors require calibration to provide accurate liquid level measurements for liquids with different dielectric constants.

[0008] Considering the limitations of prior art liquid level sensors, it would be desirable to have a liquid level sensor that does not need calibration for use with liquids having different dielectric constants.

SUMMARY OF THE INVENTION

[0009] In one aspect, the present invention provides a liquid level sensor for measuring a level of a liquid within a reservoir. The liquid level sensor comprises a reference capacitor configured to sense the liquid such that the liquid level sensor can determine a dielectric constant of the liquid. The liquid level sensor further comprises a level capacitor configured to sense the liquid such that the liquid level sensor can determine the level of the liquid using the dielectric constant of the liquid. The liquid level sensor further comprises a coaxial cable having at least two conductors partially defining both the reference capacitor and the level capacitor.

[0010] In another aspect, the liquid level sensor comprises a housing, an outer capacitor tube supported by the housing; and a coaxial capacitor disposed within the outer capacitor tube. The coaxial capacitor includes an inner coaxial element formed of a conductor, a dielectric insulator disposed radially about the inner coaxial element, and an outer coaxial element formed of a conductor. The outer coaxial element is disposed radially about the dielectric insulator. The liquid level sensor further comprises a reference capacitor tube disposed radially about the coaxial capacitor and disposed within the outer capacitor tube proximate an end of the outer capacitor tube opposite the housing. The liquid level sensor is configured to determine a dielectric constant of the liquid using the reference capacitor tube.

[0011] These aspects and advantages of the invention will be apparent from the detailed description and drawings. What follows is merely a description of some preferred embodiments of the present invention. To assess the full scope of the invention the claims should be looked to as these preferred embodiments are not intended to be the only embodiments within the scope of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The invention will now be described by way of example with reference to the accompanying figures of which:

[0013] FIG. 1 is a partial bottom view of an exemplary liquid level sensor according to the invention;

[0014] FIG. 2 is a cross-sectional view of the liquid level sensor along line 2-2 of FIG. 1;

[0015] FIG. 3 is a partial bottom view of an alternate embodiment of the liquid level sensor; and

[0016] FIG. 4 is a cross-sectional view of the liquid level sensor along line 4-4 of FIG. 3.

DETAILED DESCRIPTION OF THE INVENTION

[0017] The present invention provides a liquid level sensor that includes two capacitors for accurate measurement of a liquid level within a reservoir. One of the capacitors is configured to determine the dielectric constant of the fluid being measured. The other of the capacitors is configured to accurately measure the fluid level using the dielectric constant and other information. Advantageously, the liquid level sensor does not need calibration for use with liquids having different dielectric constants.

[0018] A first exemplary embodiment of the liquid level sensor according to the present invention will first be described generally with reference to FIGS. 1 and 2. The liquid level sensor includes a housing 2, 3, 4 for receiving a circuit board 1 therein, a cover (not shown) located over the housing, an outer capacitor tube 5, a reference capacitor tube 9, a coaxial capacitor 6, 7, 8 with a solid dielectric insulator 7 separating the inner coaxial element 6 and the outer coaxial element 8, and a second circuit board 10 on which the reference capacitor tube 9 is mounted. Beginning with the housing 2, 3, 4, each of these components will be described in greater detail.

[0019] The housing 2, 3, 4 is formed of an insulating material and has a bottom wall 3, an upper side wall 2, and a lower side wall 4. The bottom wall 3, upper side wall 2, and a cover (not shown) over the top of the housing define a cavity into which the circuit board 1 is placed. Various circuit board locating features and circuit board support features may be provided on the bottom wall 3, upper side wall 2, cover, or anywhere within the cavity in order to position the circuit board.

[0020] The cover would have a top wall, a side wall, and an electrical connector housing formed in the top wall. A plurality of resilient contacts could be located within the connector housing and extend from a mating connector-receiving opening through the top wall and into the cavity to mate with the circuit board 1. The contacts of the electrical connector are electrically connected to the circuit board 1 by resilient engagement upon application of the cover to the housing as will be more fully described below.

[0021] The circuit board 1 is mounted within the cavity parallel to the bottom wall 3 and the top wall of the cover. It should be noted that positioning features are provided within the cavity and they may extend either from the cover or from any portion of the housing 2, 3, 4 such as the upper side wall 2 or bottom wall 3. The parallel orientation of the circuit board 1 facilitates electrical connection to the resilient contacts as the cover is lowered into the housing 2, 3, 4. Contact pads are located on the circuit board 1 for receiving the resilient contacts.

[0022] The circuit board 1 includes an RC (resistor and capacitor) oscillator circuit for determining the capacitances of the two capacitors as described below. In addition, the circuit board 1 includes two electronic switches to permit the RC oscillator circuit to measure one sensing element, connect the other sensing element to ground, and to switch between which sensing element is measured and grounded. This aspect of the liquid level sensor is described in further detail below.

[0023] The outer capacitor tube 5 is an electrically conductive metallic component (*e.g.*, aluminum) that includes axial channels along the length of the tube. These channels are used to secure the outer capacitor tube 5 to the housing 2, 3, 4 as follows. The outer capacitor tube 5 is inserted into the cavity formed by the bottom wall 3 and lower side wall 4 of the housing 2, 3, 4 such that it sits flush against the bottom wall 3. With the circuit board 1 positioned in the housing 2, 3, 4 and the outer capacitor tube 5 flush against the bottom wall 3, self-threading screws 12 are inserted through holes in the circuit board 1 and into holes in the bottom wall 3. The self-threading screws 12 thread through both the bottom wall 3 and into the channels of the outer capacitor tube 5 such that the circuit board 1 and outer capacitor tube 5 are mechanically secured to the housing 2, 3, 4. In addition, the self-threading screws 12 are preferably metallic to electrically connect the outer capacitor tube 5 to contact pads around the screw holes on the circuit board 1.

[0024] The reference capacitor tube 9 is metallic (*e.g.*, copper) and has a smaller diameter and a shorter length than the outer capacitor tube 5. The length of the reference capacitor tube 9 is such that it forms a capacitor of appropriate capacitance and is only a small fraction of the length of the outer capacitor tube 5. The length of the reference capacitor tube 9 is preferably small so that the entire length of the reference capacitor tube 9 is normally immersed in the liquid to be measured during operation for reasons described below. As such, the length of the reference capacitor tube 9 is preferably less than half of the length of the outer capacitor tube 5, and more preferably less than one-quarter of the length of the outer capacitor tube 5. Stated another way, the outer capacitor tube 5 defines a sensor length, and the reference capacitor tube 9 preferably terminates in the bottom half of the sensor length, and more preferably terminates in the bottom quarter of the sensor length. In some exemplary embodiments, the reference capacitor tube 9 may have a length of 1" and the outer capacitor tube 5 may have a length of 24". The diameter of the reference capacitor tube 9 is such that the reference capacitor tube 9 is evenly spaced between the inside diameter of the outer capacitor tube 5 and the outer diameter of the coaxial capacitor 6, 7, 8. For example, the reference capacitor tube 9 may have a diameter of 1" in some embodiments.

[0025] The second circuit board 10 includes contact pads to accept the reference capacitor tube 9, and the reference capacitor tube 9 is soldered to the second circuit board 10 to provide both a mechanical and electrical connection. The contact pads are electrically connected to a contact pad in the center of the second circuit board 10 to accept the inner element 6 of the coaxial capacitor 6, 7, 8. The second circuit board 10 also includes a plurality of liquid openings 11 which allow the liquid being measured to pass between the capacitor tubes 5 and 9 and the coaxial capacitor 6, 7, 8, and a plurality of mounting holes that line up with the channels on the outer capacitor tube 5. The second circuit board 10 is secured to the outer capacitor tube 5 with self-threading screws 12.

[0026] The coaxial capacitor 6, 7, 8 is comprised of three elements: an outer cylindrical tube or outer coaxial element 8, a solid dielectric insulator 7, and a solid inner cylindrical wire or inner coaxial element 6. In a preferred embodiment, the coaxial capacitor 6, 7, 8 is a coaxial cable typically used for high-power radio frequency broadcasts. Such a coaxial cable is semi-rigid and includes an inner solid copper conductor element 6 and an outer tubular copper conductor element 8, and a Teflon® dielectric insulator 7 between them. The end of the coaxial capacitor 6, 7, 8 that connects to the second circuit board 10 has a small portion of the outer element 8 and solid dielectric insulator 7 stripped away leaving a small length of the inner element 6 exposed. The small length of the inner element 6 extends through the center hole in the second circuit board 10 and is soldered to the contact pad in the center of the second circuit board 10, thereby providing both a mechanical and electrical connection to the second circuit board 10 and the reference capacitor tube 9.

[0027] The other end of the coaxial capacitor 6, 7, 8 extends up through a hole in the bottom wall 3 of the housing 2, 3, 4 and a hole in the circuit board 1. This end of the coaxial capacitor 6, 7, 8 has a length of the outer coaxial element 8 stripped away as well as a shorter length of the solid dielectric insulator 7 stripped away, leaving a small length of the solid dielectric insulator 7 and a longer length of the inner element 6 exposed. The outer element 8 is soldered to contact pads around the hole in the circuit board 1 providing both a mechanical and electrical connection to a trace on the circuit board 1. The inner element 6 is bent down and soldered to a different contact pad trace on the circuit board 1 providing an electrical connection to the circuit board 1.

[0028] The capacitor elements, that is, the outer capacitor tube 5, the reference capacitor tube 9, and the coaxial capacitor 6, 7, 8, are arranged such that two distinct capacitors are formed and may be electrically connected to the RC oscillator circuit at different instants. Those skilled in the art will recognize that stray capacitance exists due to the non-ideal construction of the sensor, but it shall be neglected for the sake of simplicity. A first capacitor, or reference capacitor as it will be referred to from here on, is formed by the parallel combination of three capacitors: the capacitor formed between the inner coaxial element 6 and the outer coaxial element 8, the capacitor formed between the outer coaxial element 8 and the reference capacitor tube 9, and the capacitor formed between the reference capacitor tube 9 and the outer capacitor tube 5. A second capacitor, or level capacitor as it will be referred to from here on, is also formed by the parallel combination of three capacitors: the capacitor formed between the inner coaxial element 6 and the outer coaxial element 8, the capacitor formed between the outer coaxial element 8 and the reference capacitor tube 9, and the capacitor formed between the outer coaxial element 8 and the outer capacitor tube 5.

[0029] In operation, the reference and level capacitances are measured separately using the RC oscillator circuit and the electronic switches. In the RC oscillator circuit, the oscillation frequency depends on the values of resistance and capacitance in the circuit. The resistance is a known and fixed value, and as a result, the capacitance in the circuit may be determined by observing the oscillation frequency. The capacitance of the reference capacitor is measured by connecting the inner coaxial element 6, and therefore the reference capacitor tube 9, to the RC oscillator circuit and grounding the outer coaxial element 8 through the electronic switches. In contrast, the capacitance of the level capacitor is measured by grounding the inner coaxial element 6, and therefore the reference capacitor tube 9, and connecting the outer coaxial element 8 to the RC oscillator circuit through the electronic switches. In both cases, the outer capacitor tube 5 is electrically connected to ground.

[0030] The liquid level sensor determines the liquid level by first determining the capacitance of the reference capacitor using the RC oscillator circuit as described above. Next, the dielectric constant of the liquid is determined by the liquid level sensor using the capacitance of the reference capacitor and the following formula:

(1) $E_L = (C_1 - K_1)K_2$

where:

E_L = dielectric constant of liquid
C_1 = capacitance of reference capacitor (Farads)
K_1 = constant (Farad)
K_2 = constant (Farad^{-1})

Constants K_1 and K_2 are derived from the equation for a cylindrical capacitor and the dimensions of the capacitor elements. Specifically, the constants K_1 and K_2 are determined from the following formulas:

(2) $K_1 = K_E E_P (L_{OUTER} + L_{TOP}) / \ln(B/A)$
(3) $K_2 = 1/(K_E L_{INNER}(1/\ln(D/C) + 1/\ln(F/E)))$

where:

$K_E = 2\pi E_o$
E_o = permittivity of free space
E_P = dielectric constant of solid dielectric insulator 7
A = outer diameter of inner coaxial element 6
B = inner diameter of outer coaxial element 8
C = outer diameter of outer coaxial element 8
D = inner diameter of reference capacitor tube 9
E = outer diameter of reference capacitor tube 9
F = inner diameter of outer capacitor tube 5

L_{OUTER} = length of outer capacitor tube 5
L_{INNER} = length of reference capacitor tube 9
L_{TOP} = length of coaxial capacitor 6, 7, 8 extending above outer capacitor tube 5

Next, the capacitance of the level capacitor is determined by the liquid level sensor using the RC oscillator circuit as described above. The capacitance of the level capacitor and the dielectric constant of the liquid are then used by the liquid level sensor to determine the liquid level using the following formula:

(4) $D = (K_3C_2 - K_4 - K_5E_L)(K_6/(E_L - E_A))$

where:

E_A = dielectric constant of air; approximated as 1
D = depth of liquid (meters)
C_2 = capacitance of level capacitor (Farads)
K_3 = constant (meter/Farad)
K_4 = constant (meter)
K_5 = constant (meter)
K_6 = constant (unitless)

Constants K_3 through K_6 are derived from the following formulas:

(5) $K_3 = 1/K_E$
(6) $K_4 = E_PL_{TOP}/\ln(B/A) + (E_P/\ln(B/A) + E_A/\ln(F/C))L_{OUTER}$
(7) $K_5 = (1/\ln(D/C) - 1/\ln(F/C))L_{INNER}$
(8) $K_6 = \ln(F/C)$

where each parameter is as described above.

[0031] It should be understood that the above equations are not accurate if the reference capacitor tube 9 is not completely immersed in the liquid. In some embodiments, the device only determines the dielectric constant when the reference capacitor tube 9 is completely immersed in the liquid. Furthermore, when the capacitor tube 9 is not completely immersed in the liquid, the device may use a dielectric constant value of the liquid measured while the reference capacitor tube 9 was completely immersed in the liquid (*i.e.*, a stored dielectric constant value) to accurately determine the liquid level.

[0032] In a preferred embodiment, the dielectric constant of the liquid is measured as often as the liquid level to ensure the sensor continuously adjusts to the liquid being measured. Both the dielectric constant and the liquid level may be measured, for example, several times per second. As an alternative, the dielectric constant may be measured only when the liquid level is at or near the maximum level or another level when it is assured that the reference capacitor tube 9 is completely immersed in the liquid.

[0033] The liquid level sensor may provide an output to a controller or a fluid level gauge in various forms. For example, the output may be provided as a pulse-width modulation signal or a range of DC voltages (for example, 1 to 4V). As another example, the output may be provided as a data bus signal that includes both the liquid level and the fuel type. The liquid level sensor may also provide an indication if the reference capacitor tube 9 is not completely immersed in the liquid; that is, if the measured dielectric constant begins to change significantly. In this situation, the liquid level sensor may provide a signal such that the fluid level gauge indicates the reservoir is empty.

[0034] The device of the present invention advantageously does not need calibration for use with a specific liquid. That is, the liquid level can be determined based on measured capacitances and component geometry and does not depend on the properties of the liquid being measured. As a result, the sensor is readily usable and adaptable for use with various liquids having different dielectric constants.

[0035] An alternate embodiment of the liquid level sensor is shown in FIGS. 3 and 4. The alternate embodiment of the liquid level sensor measures liquid levels in the same manner as the first embodiment of the liquid level sensor. However, the alternate embodiment differs from the first embodiment of the liquid level sensor in that the housing 2, 3, 4 is cast from metal and the outer capacitor tube 5 does not have any channels along the length of the tube. The cover, electrical connector, circuit board 1, reference capacitor tube 9, small circuit board 10, and coaxial capacitor 6, 7, 8 are similar to those of the first embodiment of the liquid level sensor; therefore, these components will not be described here in detail. Instead, the description of the alternate embodiment liquid level sensor will be limited to those components that are significantly different from those of the first embodiment of the liquid level sensor.

[0036] In the alternate embodiment of the liquid level sensor the outer capacitor tube 5 is both mechanically and electrically connected to the housing. This can be accomplished using one of two methods. The first method requires that the upper end of the outer capacitor tube 5 be slightly tapered, the lower side wall 4 be slightly tapered, or both. The slight taper allows the outer capacitor tube 5 to be press fit into the cavity formed by the bottom wall 3 and lower side wall 4 of the housing 2, 3, 4 such that the end of the outer capacitor tube 5 sits flush against the bottom wall 3. The second method requires that the outside surface of the upper end of the outer capacitor tube 5 be threaded and that the inside surface of the lower side wall 4 of the housing be tapped. The outer capacitor tube 5 is screwed into the threaded lower side wall 4 such that the end of the outer capacitor tube 5 sits flush against the bottom wall 3 forming a secure mechanical and electrical connection between the housing 2, 3, 4 and the outer capacitor tube 5.

[0037] With the circuit board 1 positioned in the housing 2, 3, 4, self-threading screws 12 are inserted through holes in the circuit board 1 and into blind holes in the bottom wall 3. The self-threading screws 12 thread into the holes in the bottom wall 3 such that the circuit board 1 is mechanically secured to the housing 2, 3, 4. In addition, contact pads around the screw holes on the bottom side of the circuit board 1 electrically connect the metal housing to the circuit board 1.

[0038] A preferred embodiment of the invention has been described in considerable detail. Many modifications and variations to the preferred embodiment described will be apparent to a person of ordinary skill in the art. Therefore, the invention should not be limited to the embodiment described.

CLAIMS

1. A liquid level sensor for measuring a level of a liquid within a reservoir, comprising:

a reference capacitor configured to sense the liquid such that the liquid level sensor can determine a dielectric constant of the liquid;

a level capacitor configured to sense the liquid such that the liquid level sensor can determine the level of the liquid using the dielectric constant of the liquid;

a coaxial cable having at least two conductors partially defining both the reference capacitor and the level capacitor.

2. The liquid level sensor of claim 1, wherein the liquid level sensor is configured to determine the dielectric constant of the liquid based on the capacitance of the reference capacitor.

3. The liquid level sensor of claim 2, further comprising an RC oscillator circuit configured to determine the capacitance of the reference capacitor.

4. The liquid level sensor of claim 1, wherein the liquid level sensor is configured to determine the level of the liquid based on the capacitance of the level sensor.

5. The liquid level sensor of claim 4, further comprising an RC oscillator circuit configured to determine the capacitance of the level capacitor.

6. The liquid level sensor of claim 1, further comprising an RC oscillator circuit and at least one switch electrically connected to the RC oscillator circuit, the RC oscillator circuit being configured to determine the capacitances of the reference capacitor and the level capacitor, respectively, separately through the switch.

7. The liquid level sensor of claim 1, further comprising a reference capacitor tube partially defining both the reference capacitor and the level capacitor, and wherein the liquid level sensor only determines the dielectric constant if the reference capacitor tube is completely submerged in the liquid in the reservoir.

8. The liquid level sensor of claim 1, further comprising a reference capacitor tube partially defining both the reference capacitor and the level capacitor, and wherein the liquid level sensor uses a stored value of the dielectric constant to determine the level of the liquid if the reference capacitor tube is not completely submerged in the liquid in the reservoir.

9. The liquid level sensor of claim 1, further comprising a reference capacitor tube partially defining both the reference capacitor and the level capacitor, and wherein the liquid level sensor provides an indication if the reference capacitor tube is not completely submerged in the liquid in the reservoir.

10. The liquid level sensor of claim 1, further comprising:

a housing;

an outer capacitor tube partially defining both the reference capacitor and the level capacitor, the outer capacitor tube having a first length and having a first end connected to the housing; and

a reference capacitor tube partially defining both the reference capacitor and the level capacitor, the reference capacitor tube having a second length and being disposed at a second end of the outer capacitor tube, and the second length being less than half of the first length.

11. The liquid level sensor of claim 10, wherein the second length is less than one quarter of the first length.

12. A liquid level sensor for measuring a level of a liquid within a reservoir, comprising:

a housing;

an outer capacitor tube supported by the housing;

a coaxial capacitor disposed within the outer capacitor tube, the coaxial capacitor comprising:

an inner coaxial element formed of a conductor;

a dielectric insulator disposed radially about the inner coaxial element;

an outer coaxial element formed of a conductor, the outer coaxial element being disposed radially about the dielectric insulator;

a reference capacitor tube disposed radially about the coaxial capacitor and disposed within the outer capacitor tube proximate an end of the outer capacitor tube opposite the housing; and

wherein the liquid level sensor is configured to determine a dielectric constant of the liquid using the reference capacitor tube.

13. The liquid level sensor of claim 12, wherein the inner coaxial element is electrically connected to the reference capacitor tube.

14. The liquid level sensor of claim 13, wherein the outer capacitor tube, the coaxial capacitor, and the reference capacitor tube form a reference capacitor and a level capacitor, the reference capacitor being configured to sense the liquid such that the liquid level sensor can determine a dielectric constant of the liquid, and the level capacitor being configured to sense the liquid such that the liquid level sensor can determine the level of the liquid using the dielectric constant of the liquid.

15. The liquid level sensor of claim 13, further comprising an RC oscillator circuit and at least one switch electrically connected to the RC oscillator circuit, the RC oscillator circuit being configured to determine the capacitances of the reference capacitor and the level capacitor, respectively, separately through the switch.

16. The liquid level sensor of claim 12, wherein the liquid level sensor only determines the dielectric constant if the reference capacitor tube is completely submerged in the liquid in the reservoir.

17. The liquid level sensor of claim 12, wherein the liquid level sensor uses a stored value of the dielectric constant to determine the level of the liquid if the reference capacitor tube is not completely submerged in the liquid in the reservoir.

18. The liquid level sensor of claim 12, wherein the liquid level sensor provides an indication if the reference capacitor tube is not completely submerged in the liquid in the reservoir.

19. The liquid level sensor of claim 12, wherein the outer capacitor tube defines a sensor length, and the reference capacitor tube terminates in a bottom half of the sensor length.

20. The liquid level sensor of claim 19, wherein the reference capacitor tube terminates in a bottom quarter of the sensor length.

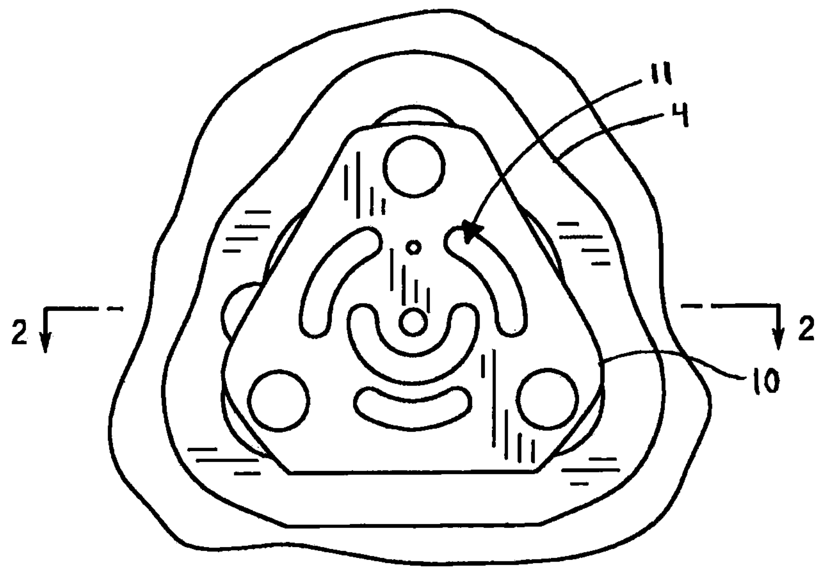

FIG. 1

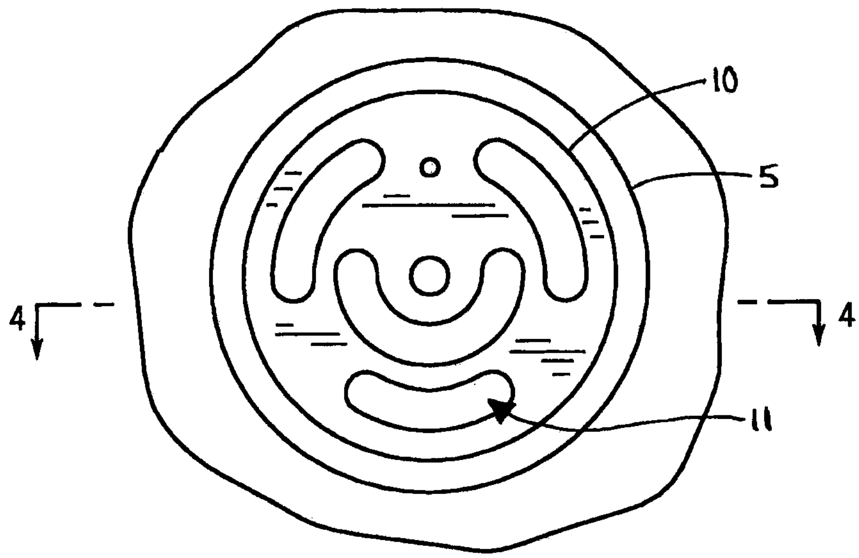

FIG. 3

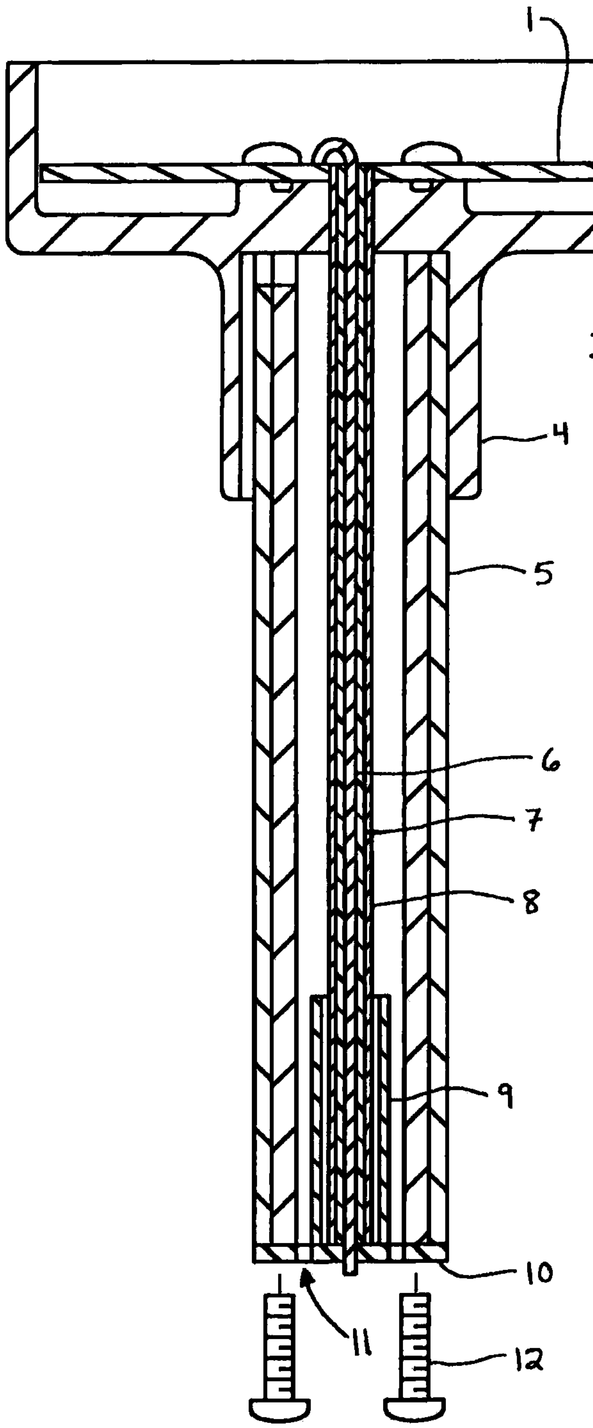

FIG. 2

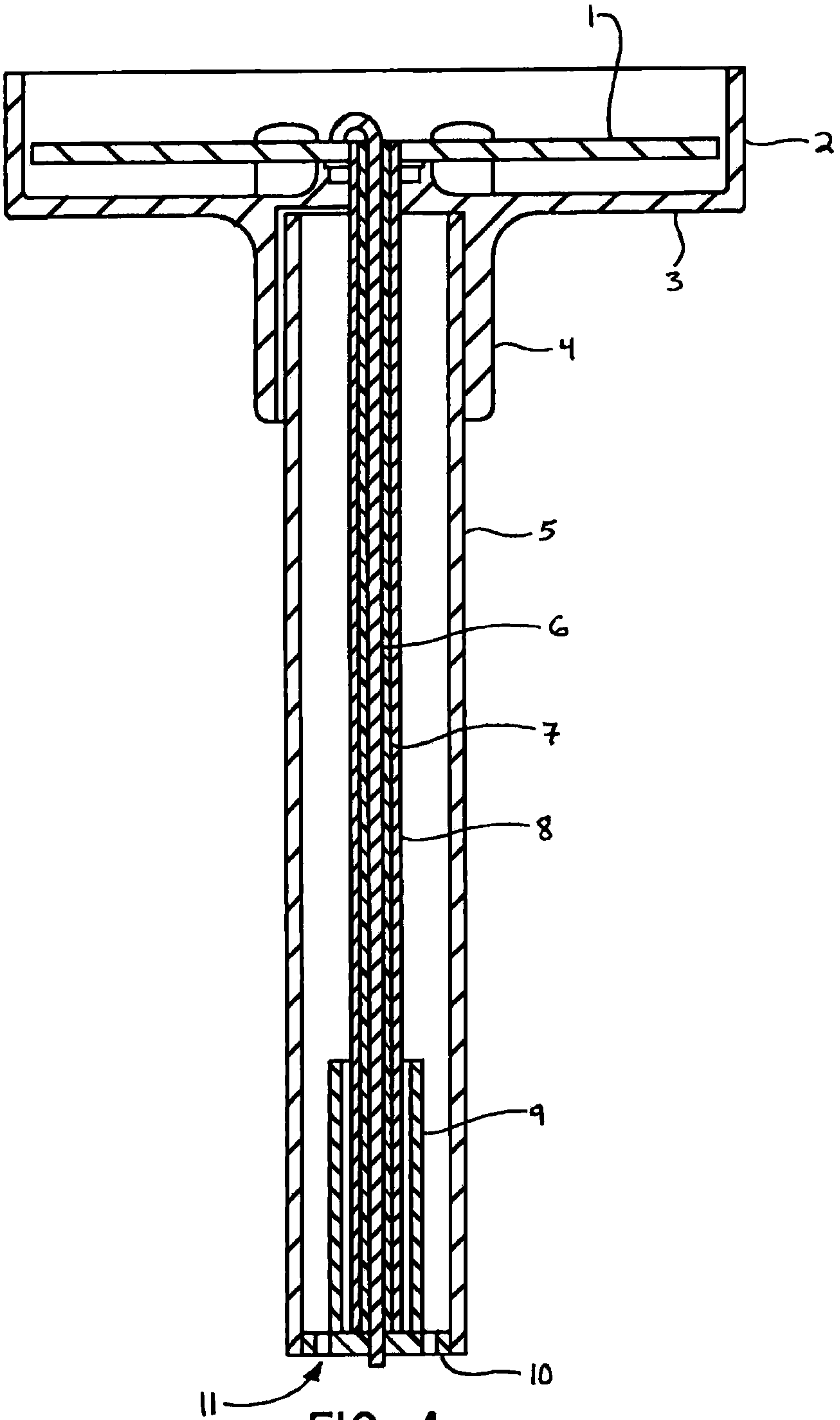

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2009/068149

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G01F 23/26 (2010.01)
USPC - 73/304C
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - G01F 23/26 (2010.01)
USPC - 73/290R, 304C, 307, 308, 313, 314

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
MicroPatent, Google Patents

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 4,434,657 A (MATSUMURA et al) 06 March 1984 (06.03.1984) see document	1-2, 4, 12-14 and 16-20 -------- 3, 5-6 and 15
Y	US 4,383,444 A (BEAMAN et al) 17 May 1983 (17.05.1983) see document	3, 5-6 and 15
Y	US 2008/0092647 A1 (KUMAZAWA et al) 24 April 2008 (24.04.2008) see document	1 and 7-11
Y	US 6,237,412 B1 (MORIMOTO) 29 May 2001 (29.05.2001) see document	1 and 7-11
A	US 6,935,173 B2 (STEHMAN et al) 30 August 2005 (30.08.2005) see document	1-20
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☐ Further documents are listed in the continuation of Box C. ☐

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22 January 2010

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