



- (51) **International Patent Classification:**
G01F 1/66 (2006.01) *G01N 22/04* (2006.01)
G01F 1/74 (2006.01) *G01N 33/28* (2006.01)
- (21) **International Application Number:** PCT/GB2012/051339
- (22) **International Filing Date:** 13 June 2012 (13.06.2012)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:** 1109878.7 13 June 2011 (13.06.2011) GB
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- (81) **Designated States (unless otherwise indicated, for every kind of national protection available):** AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States (unless otherwise indicated, for every kind of regional protection available):** ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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(54) **Title:** APPARATUS AND METHOD FOR FLUID MEASUREMENT

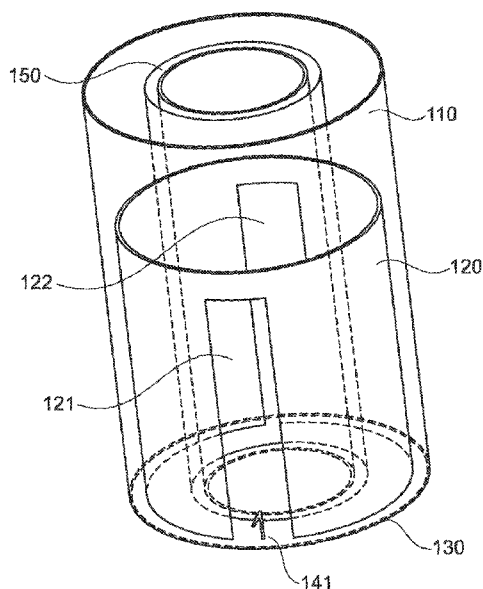


Fig. 1

(57) **Abstract:** Embodiments of the present invention provide a sensor for measuring water content in a pipeline, comprising a resonator (120) for surrounding a pipeline carrying a fluid, wherein the resonator (120) is generally cylindrically shaped for forming a wall around the pipeline, a shield (110) arranged to surround the resonator (120) and a ground plane (130) connecting the resonator (120) and the shield (110).



Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

Apparatus and Method for Fluid Measurement

Embodiments of the invention relate to apparatus and methods for fluid measurement within a pipeline. In particular, although not exclusively, embodiments of the present invention relate to apparatus and methods for multiphase fluid measurement.

Background

Microwave fluid sensors are known which may be used to measure the properties of fluids. In particular, microwave sensors have been used to measure the properties of multiphase fluid flows, such as measurement of the quantities of the respective phases of the fluid flow, for example the water content of oil or the properties of fluids having a higher gas content known as wet gas flows. It is often particularly desired to determine the water volume fraction (WVF) in a fluid flow, such as a wet gas flow.

It is an object of embodiments of the invention to at least mitigate one or more of the problems of the prior art.

Brief Description of the Drawings

Embodiments of the invention will now be described by way of example only, with reference to the accompanying figures, in which:

Figure 1 shows a perspective view of a sensor according to an embodiment of the invention;

Figure 2 shows a side view of the sensor according to an embodiment of the invention;

Figure 3 shows a horizontal cross section through the sensor;

Figure 4 shows electric fields in the operative sensor according to an embodiment of the invention;

Figure 5 shows a measurement circuit according to an embodiment of the invention;

Figure 6 shows plots of resonant frequency of an embodiment of the invention; and

- 5 Figure 7 is a plot of water volume fraction against frequency for an embodiment of the invention

Detailed Description of Embodiments of the Invention

- 10 Embodiments of the present invention provide a sensor suitable for measuring a water volume fraction (WVF) of a fluid in a pipe. In particular, embodiments of the invention provide a sensor suitable for measuring a water volume fraction of a wet gas within the pipe. The sensor utilises microwave frequency resonance to determine the WVF within the pipe, as will be explained.

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A sensor 100 according to an embodiment of the invention comprises a shield 110, a resonator 120 and a ground plane 130, as shown particularly in Figures 1 to 3. The sensor 100 is arranged to surround a portion of a pipe 150 within which a fluid flows of which it is desired to measure fluid properties, such as WVF.

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The shield 110 is a generally cylindrical shaped conductive member which extends in a length-wise direction from the ground plane 130 with which it is electrically connected. The upper end of the shield distal from the ground plane is open, although other embodiments may be envisaged in which the shield comprises a closed end,
25 which may be advantageous in reducing field leakage.

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- The ground plane 130 is generally circularly shaped and forms an end of the shield 110. As shown in Figure 1 particularly, the ground plane 130 is shaped to correspond to the cross-sectional shape of the shield 110, although it will be realised that the ground plane 130 may adopt other shapes and thereby extend beyond the periphery of
30 the shield 110 in some embodiments. The shield 110 has a diameter approximately equal to the length of the resonator 120. The shield 110 is formed from a planar sheet material, such as a suitable sheet metal or a suitable metallic coated conducting film or other substrate.

The ground plane 130 includes a central cut-out portion which allows the pipe 150 to pass there-through. The cut-out portion has, in the shown embodiment, a size and shape corresponding to the pipe 150 such that the ground plane closely fits around the pipe 150 which advantageously concentrates the electro-magnetic field within the sensor 100 by preventing leakage and improves a Q factor of the sensor's resonant response. The cut-out portion or hole through the ground plane is of a smaller diameter than the resonator 120. The pipe 150 is formed of a non-conductive material.

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The resonator 120 is generally cylindrically shaped and is configured around the pipe 150 within the shield 110. The resonator is electrically connected to and extends upward from the ground plane 130 generally coaxial with the shield 110 and the pipe 150. The upper end of the resonator 120 is not closed i.e. the resonator comprises an open upper end. The resonator 120 is formed from a planar sheet material.

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The resonator 120 is arranged around a periphery of an inner volume of the shield 110 diametrically spaced apart from the pipe 150. In the shown embodiment, the resonator 120 is configured to be spaced closer to the interior of the shield 110 than to the pipe 150. The spacing of the resonator 120 apart from the pipe 150 causes electric field lines generated by the resonator 120 to have an improved distribution within an interior of the pipe 150 i.e. for the electric field to be more uniform within the pipe 150. The uniformity of the electric field within the pipe 150 allows more accurate WVF measurement within the pipe 150 with reduced dependence on the location of the liquid within the pipe 150 volume. Often in a wet gas the liquid present adheres to the interior wall of a pipe through which the wet gas is transported. Thus it is important that the sensor is sensitive to the presence of the liquid present on the interior wall of the pipe 150. The resonator 120 is shorter, i.e. in length extending from the ground plane 130, than the shield 110.

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A pair of microwave feed points 141, 142 are provided which extend outward from the shield in a base region of the sensor generally proximal to the ground plane 130. The feed points 141, 142 are L-shaped, although other shaped feed points may be envisaged. A portion of each of the feed points 141, 142 intersecting the shield extend

horizontally through and outward from the shield 110 facilitating electrical connection. The feed points 141, 142 are insulated from the shield 110. A portion of the feed points 141, 142 interior to the shield 110 extend downward to electrically contact the ground plane 130 diametrically outward of the resonator 120. The feed
5 points are arranged at opposing sides of the sensor 110.

The resonator 120 comprises a pair of openings 121, 122 each associated with one of the feed points 141, 142. The openings 121, 122 allow the electric and magnetic field lines generated by the resonator 120 to more easily penetrate into the pipe 150
10 for detecting the WVF of the fluid within the pipe 150. In the embodiment of the invention shown in the Figures, the openings 121, 122 are generally rectangular shaped and extend upward from the ground plane 130 toward an upper region of the resonator 120. In this sense, each opening 121, 122 represents a rectangular shaped cut-out of the resonator from the base of the resonator 120 contacting the ground
15 plane 130. Whilst the sensor 100 is described as comprising two openings 121, 122 each associated with a respective feed point 141, 142, embodiments of the invention are envisaged comprising other numbers and shapes of openings 121, 122. As shown in Figures 1 and 2, the each of the openings 121, 122 is aligned with a respective one of the feed points 141, 142. Thus the openings 121, 122 are also arranged at opposed
20 sides of the sensor 100. The alignment of the openings 121, 122 and feed points 141, 142 improves a purity of a resonant mode of the sensor 100.

An interior of the sensors 100 may be empty (filled with air) as shown in the Figures, or may be filled, either completely or in a region of the sensor 100 between the
25 resonator 120 and the pipe 150, with a dielectric material. The dielectric material may be the same material as the pipe 150. However, the use of other materials is envisaged.

The height of the resonator is chosen to be an integer division of an expected resonant
30 frequency wavelength of the pipe 150 and fluid travelling there-through. In the embodiment shown in the Figures, the resonator has a height of $\lambda/4$ wherein λ is the expected resonant wavelength. As an example, an expected resonant frequency of 688.8 MHz, as in the table below, has a wavelength of 0.435 meters and a one quarter wavelength of approximately 100 mm, as discussed below.

In a particular embodiment of the invention, the shield 110 has a height of 150mm and an outer diameter of 120mm. The shield has a wall thickness of 20mm, providing an inner diameter of 100mm. The resonator has a height of 100mm, an outer diameter of 90mm and a wall thickness of 4mm. The openings 121, 122 in the resonator are 90mm in height, providing a 10mm strip of the resonator material above each opening 121, 122, and 20mm in width, wherein the feed points 141, 142 are centrally aligned with each opening 121, 122. The feed points 141, 142 are arranged 15mm above the ground plane 130. The pipe 150 around which the shown embodiment of sensor 100 is shown arranged has an outer diameter of 60mm and a wall thickness of 10mm. It will be realised that these dimensions are merely exemplary and that other dimensions may be used.

Figure 4 illustrates a simulated electric field present within the sensor shown in Figures 1-3. As can be appreciated, the sensor 100 is most sensitive to an area of the pipe 150 proximal to an upper region of the resonator. However, the region within the interior volume of the pipe 150 within the sensor has a particularly flat or linear response such that sensor does not over respond to any particular area within the pipe 150 surrounded by the sensor.

Figure 5 illustrates a sensor 100 and resonant frequency measurement circuit according to an embodiment of the invention. The circuit comprises a MOSFET 510, a mixer 520, a reference oscillator 530, an amplifier 540, a filter 550, a frequency counter 560 and an output unit 570.

The MOSFET 510 forms an oscillator with the sensor 100. The MOSFET 510 acts as an amplification device and it will be appreciated that other types of active device may be used, such as a transistor(s).

A first input 511 to the mixer is provided from the sensor 100 which oscillates at a resonant frequency f_s determined, in part, by the WVF of fluid in the pipe 150. A second input 512 to the mixer 520 is provided from the reference oscillator 530 which has a predetermined frequency f_r . An output of the mixer is an intermediate frequency f_i given by the following equation:

$$f_i = f_s - f_r$$

The output of the mixer is provided to the amplifier 540 and filter 550 before being received by the frequency counter 560. The frequency counter 560 determines the intermediate frequency f_i which is provided to the output unit 570. The output unit 570 is, for example, a display device for outputting frequency information to the user to determine the WVF of the fluid in the pipe. It will be noted that other measurement circuits may be used with the sensor 100.

Embodiments of the invention are particularly useful for measuring a WVF of a fluid, such as a wet gas within the pipe 150, of up to 20%.

Figure 6 illustrates a resonant frequency response of the embodiment of the present invention shown in Figures 1-4 for different water volume fractions within the pipe 150. As can be appreciated, the resonant frequency response varies responsive to the WVF within the pipe. Details of the WVF thickness, percentage WVF and resonant frequency of the sensor depicted in Figure 7 are provided in Table 1 below. WVF thickness is a thickness, or depth, of water adhered to an interior wall of the pipe 150, as discussed above.

Thickness (mm)	Percentage	Frequency (MHz)
0	0.000%	688.8
0.1	0.798%	683.4
0.2	1.594%	681.1
0.3	2.386%	680.2
0.4	3.174%	678.8
0.5	3.960%	676
0.6	4.742%	675
0.7	5.522%	673.7
0.8	6.298%	671.8
0.9	7.070%	670.6
1	7.840%	669.4

1.1	8.606%	667.3
1.2	9.370%	665.2
1.3	10.130%	663.1
1.4	10.886%	660.8
1.5	11.640%	658.7
1.6	12.390%	656.5
1.7	13.138%	654.2
1.8	13.882%	652.4
1.9	14.622%	649.6
2	15.360%	645.2
2.1	16.094%	642.2
2.2	16.826%	639.4
2.3	17.554%	635.5
2.4	18.278%	631.3
2.5	19.000%	627.5
2.6	19.718%	624.4
2.7	20.434%	621
2.8	21.146%	617.1
2.9	21.854%	613

Table 1

Figure 7 shows a plot of resonant frequency against WVF fraction and demonstrates a linearity of resonant frequency response of embodiments of the present invention.

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It will be appreciated that embodiments of the present invention provide a microwave resonant sensor suitable for determining a water volume fraction of a fluid flowing through a pipeline, such as a wet gas. The design of embodiments of the present invention provides a sensor which is sensitive to water adhered to an interior wall of the pipeline, as expected with a wet gas being transported through the pipeline. Furthermore, the design provides an improved purity and Q factor of a resonant response of the sensor such that the resonant frequency is easier to measure and consequently the WVF is more easily and accurately determined.

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15 All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed,

may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

5 Each feature disclosed in this specification (including any accompanying claims, abstract and drawings), may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

10 The invention is not restricted to the details of any foregoing embodiments. The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed. The claims should not be construed to cover merely the
15 foregoing embodiments, but also any embodiments which fall within the scope of the claims.

CLAIMS

1. A sensor for measuring water content in a pipeline, comprising:

5 a resonator (120) for surrounding a pipeline carrying a fluid, wherein the resonator (120) is generally cylindrically shaped for forming a wall around the pipeline;

 a shield (110) arranged to surround the resonator (120); and

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 a ground plane (130) connecting the resonator (120) and the shield (110).

2. The sensor of claim 1, wherein the resonator (120) comprises one or more openings.

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3. The sensor of claim 2, wherein the one or more openings are provided through the wall of the resonator (120).

4. The sensor of claim 2 or 3, comprising a pair of openings arranged at opposing
20 sides of the resonator (120).

5. The sensor of any preceding claim, comprising a pair of microwave feed points arranged at opposing sides of the sensor and electrically connected to the ground plane (130).

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6. The sensor of claim 5 when dependent on claim 4, wherein each feed point is generally aligned with a respective opening.

7. The sensor of claim 4 or 5, wherein each feed point is arranged through the
30 shield (110).

8. The sensor of claim 7, wherein each feed point is electrically insulated from the shield (110).

9. The sensor of claim 7 or 8, wherein each feed point is connected to the ground plane (130) via an L-shaped connection.
10. The sensor of any preceding claim, wherein the resonator (120) and the shield (110) are substantially coaxial.
11. The sensor of any preceding claim, wherein the ground plane (130) comprises a cut-out for allowing the pipe to pass there-through, wherein the cut-out has a size and shape generally corresponding to a cross-section of the pipe.
12. The sensor of claim 11, wherein the resonator (120) is arranged generally closer to the shield (110) than a periphery of the cut-out.
13. The sensor of any preceding claim, wherein the shield (110) has a length greater than a length of the resonator (120).
14. The sensor of any of claim 2, 3 or 4 or any claim dependent thereon, wherein each opening is a slot extending from the ground plane (130).
15. The sensor of claim 14 wherein each slot is a rectangular shaped cut-out of the resonator (120) extending from the base of the resonator (120) contacting the ground plane (130).
16. The sensor of any preceding claim, wherein the resonator (120) has a length of approximately one quarter of a resonant wavelength of the sensor.

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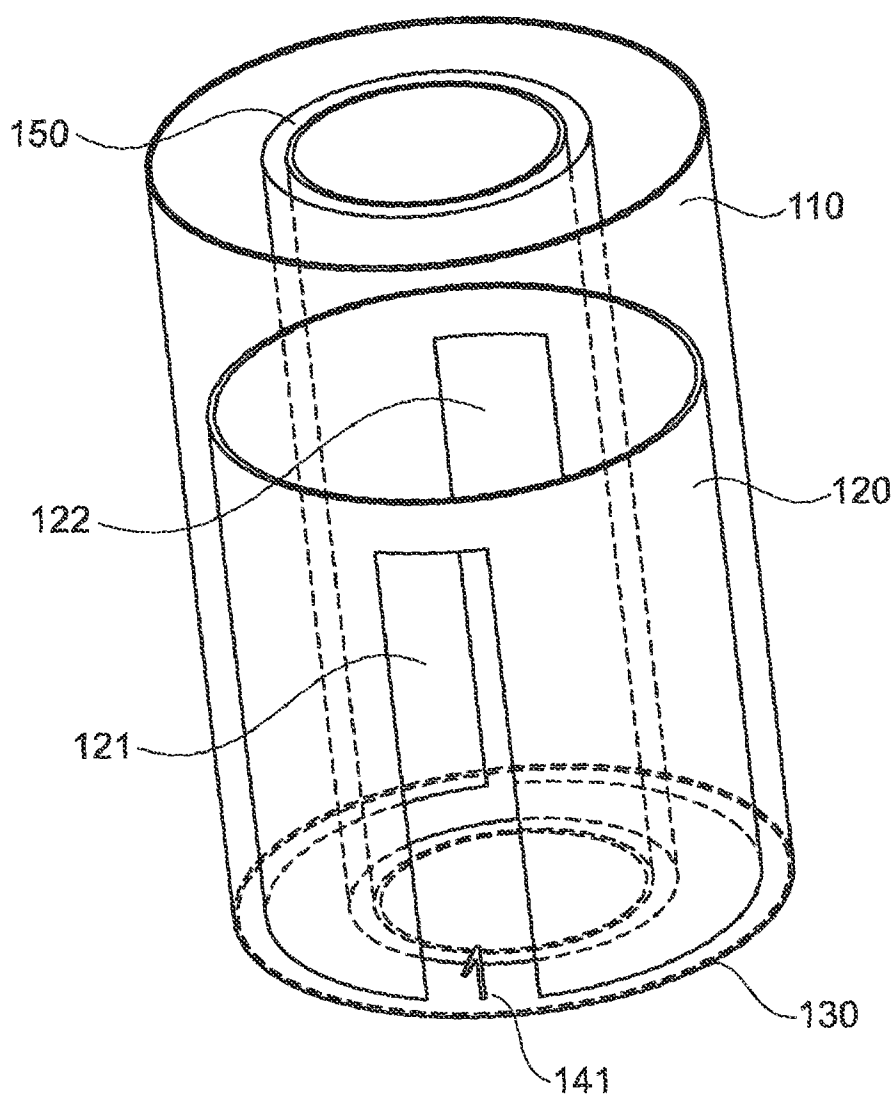


Fig. 1

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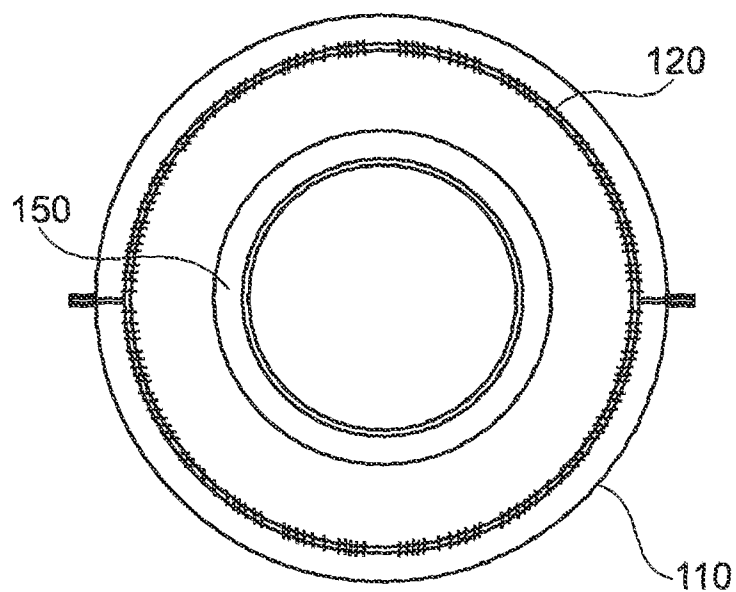
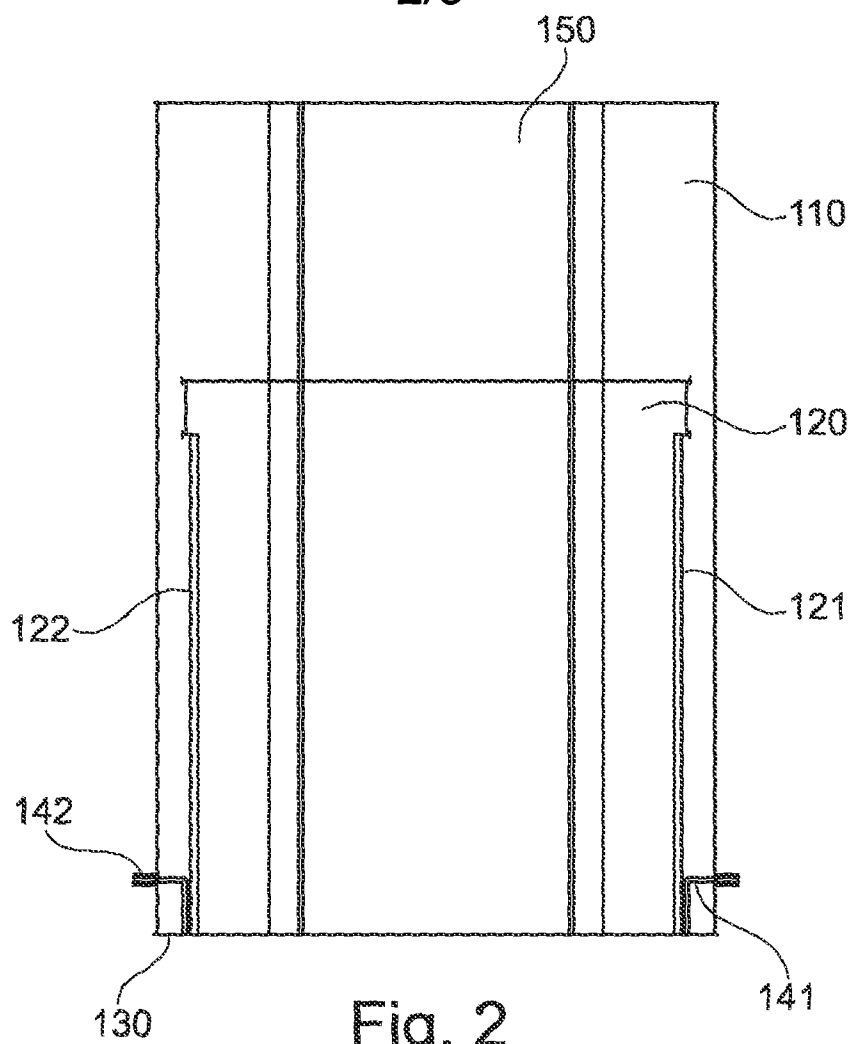


Fig. 3

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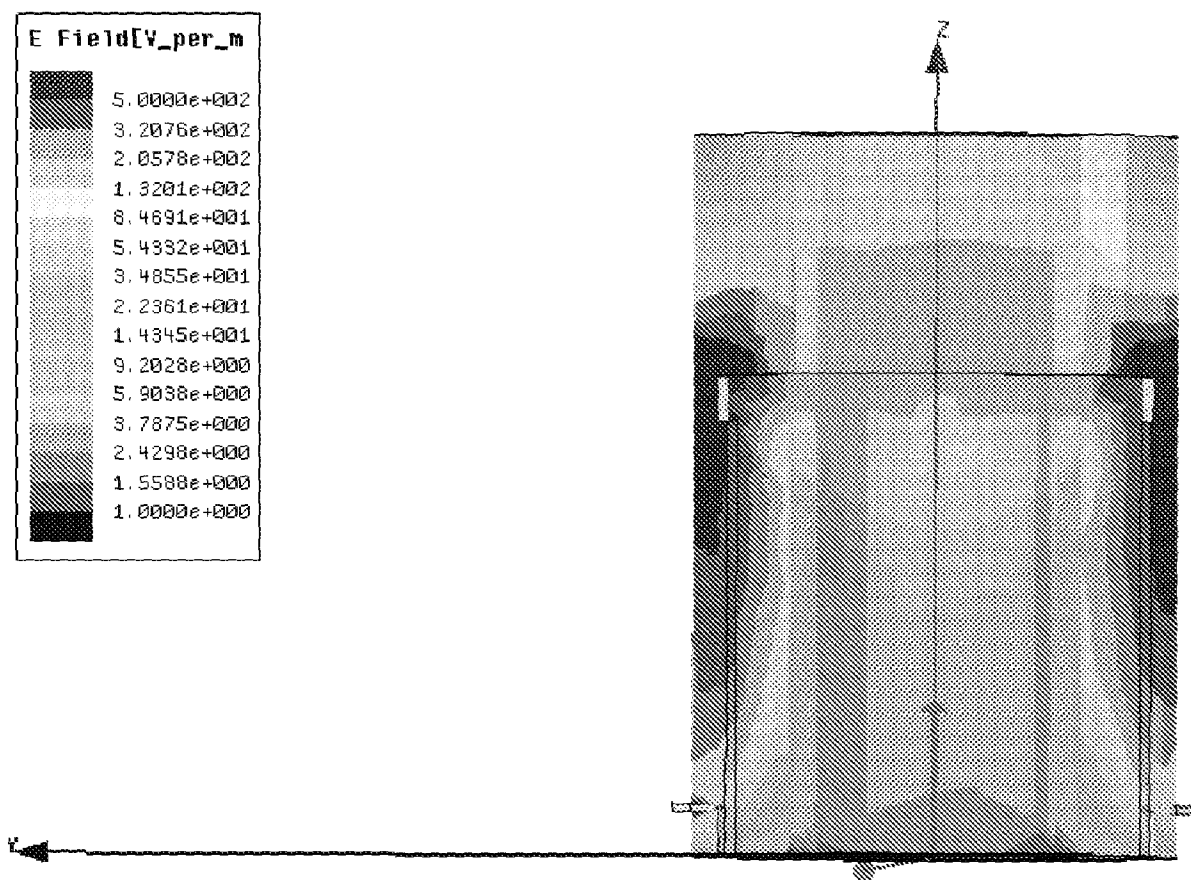


Fig. 4

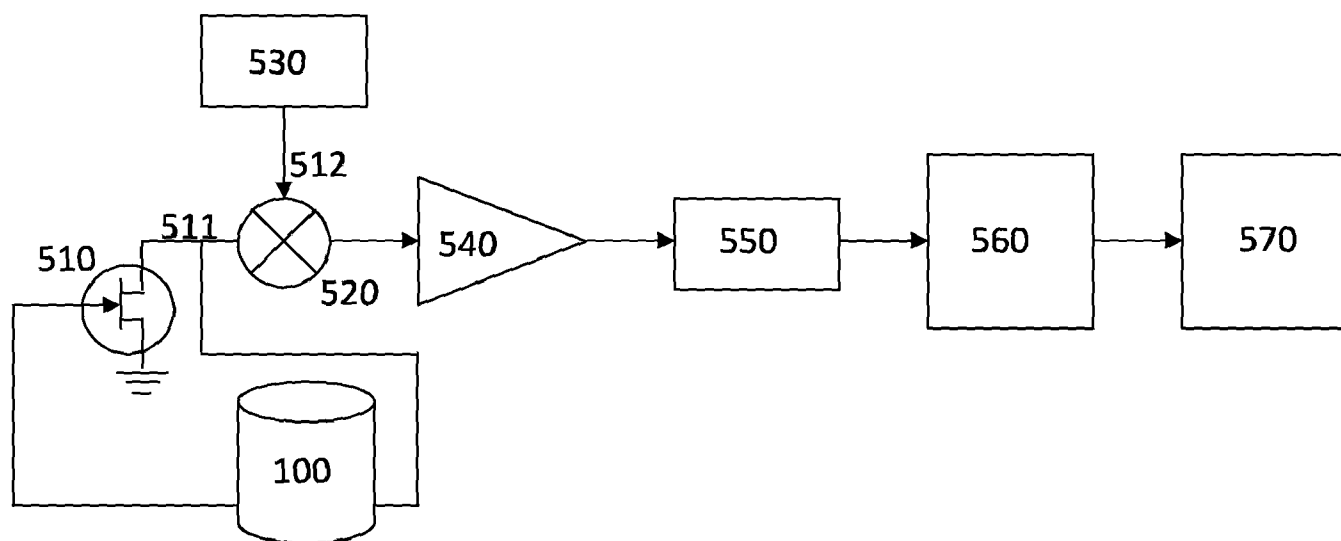


Fig. 5

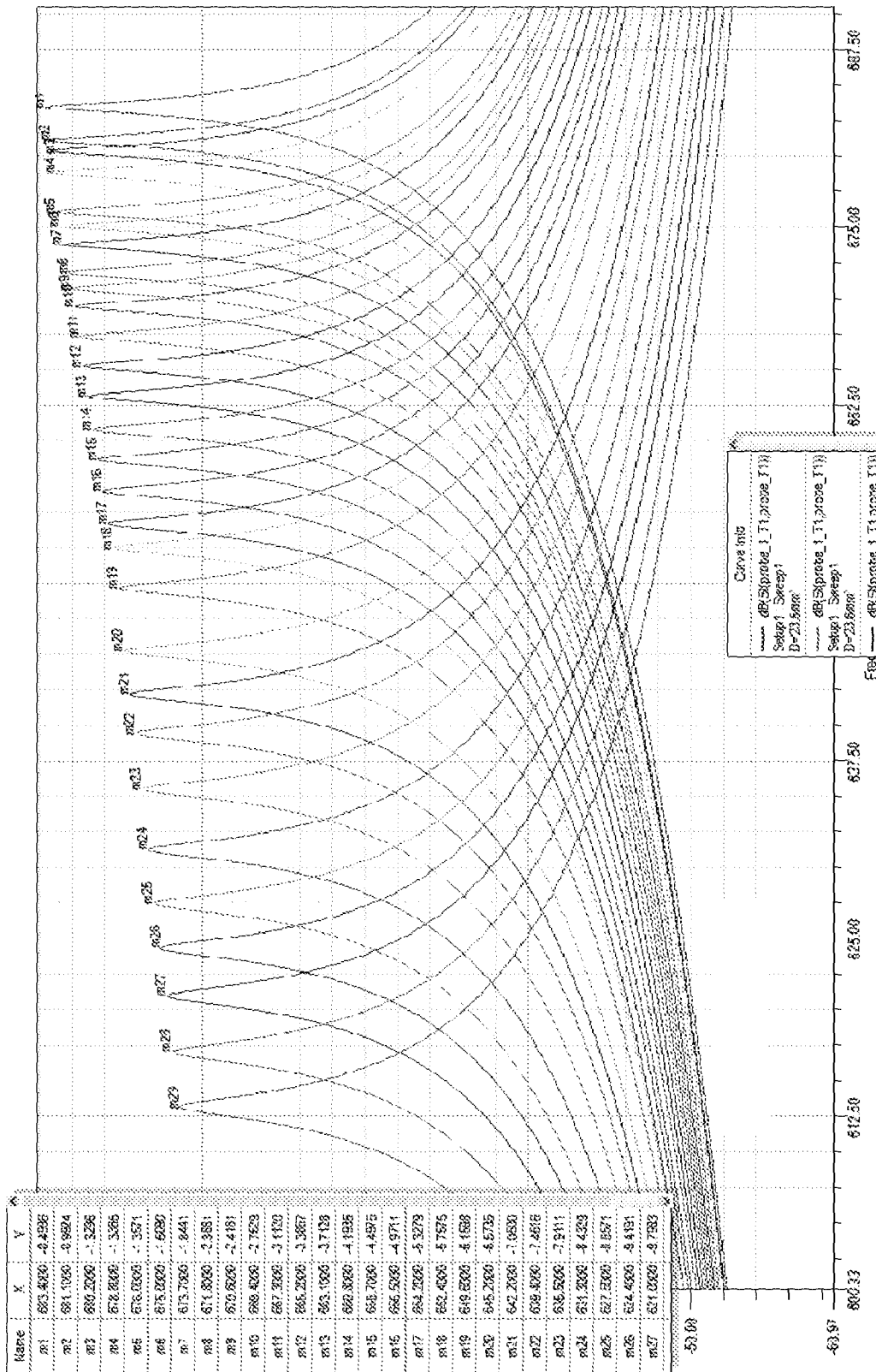


Fig. 6

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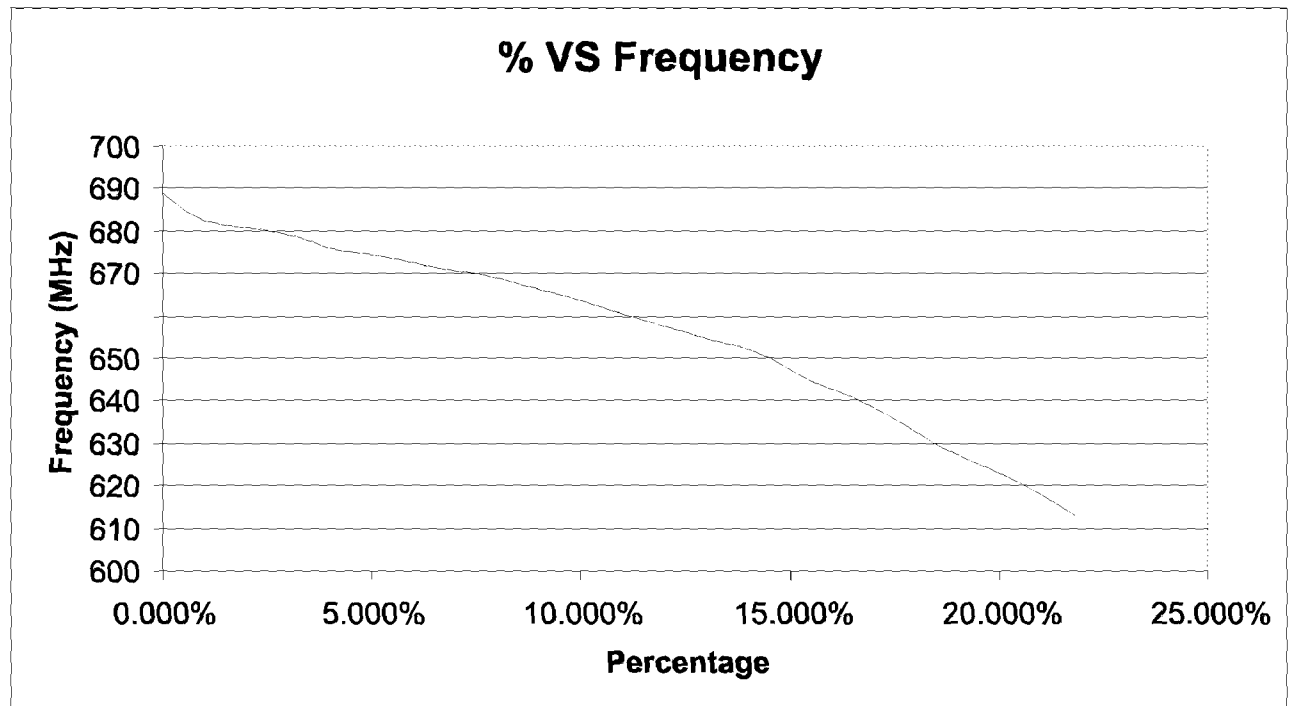


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2012/051339

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01F1/66 G01F1/74 G01N22/04 G01N33/28
ADD.

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)

G01F G01N

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)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 61 078458 A (SHIMADZU CORP) 22 April 1986 (1986-04-22) the whole document	1-8,10, 11
Y	----- DATABASE WPI Week 200864 Thomson Scientific, London, GB; AN 2008-K89042 XP002684980, -& RU 2 334 217 C1 (TAMBOV MILITARY AVIAT ENG COLLEGE) 20 September 2008 (2008-09-20) the whole document ----- -/-	1-11,13



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

10 October 2012

Date of mailing of the international search report

25/10/2012

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2012/051339

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DATABASE INSPEC [Online] THE INSTITUTION OF ELECTRICAL ENGINEERS, STEVENAGE, GB; May 1972 (1972-05), WENGER N C ET AL: "Hydrogen density measurements using an open-ended microwave cavity", XP002684981, Database accession no. 382724 the whole document -& IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT USA, vol. IM-21, no. 2, 2 May 1972 (1972-05-02) , pages 105-114, XP002684989, ISSN: 0018-9456 -----	1-11,13
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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