



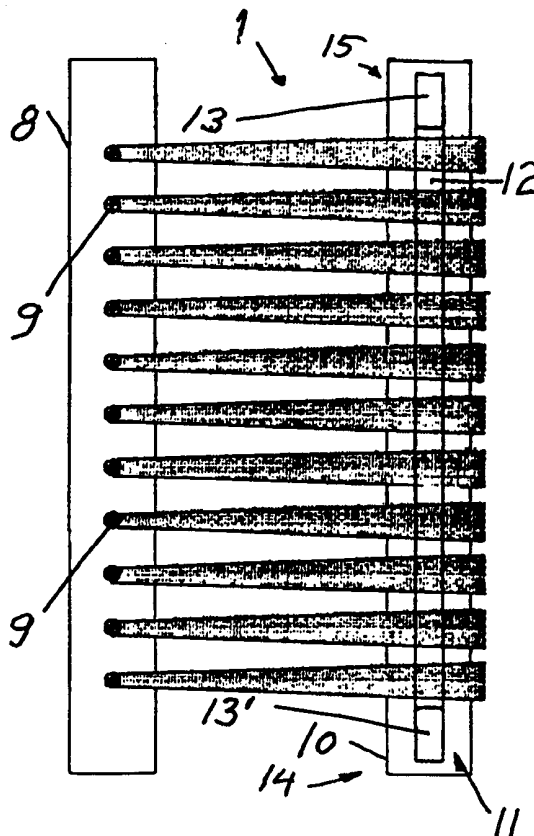
## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
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| <b>(51) International Patent Classification <sup>6</sup> :</b><br><b>G01F 23/288, G01N 23/10</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | <b>A1</b> | <b>(11) International Publication Number:</b> <b>WO 99/17085</b><br><b>(43) International Publication Date:</b> 8 April 1999 (08.04.99)                                                                                                                                                                                                                                                                                                              |
| <b>(21) International Application Number:</b> PCT/SE98/01666<br><b>(22) International Filing Date:</b> 16 September 1998 (16.09.98)<br><br><b>(30) Priority Data:</b><br>9703360-9                      17 September 1997 (17.09.97)      SE<br><br><b>(71) Applicant (for all designated States except US):</b> BTG KÄLLE<br>INVENTING AB [SE/SE]; P.O. Box 602, S-661 29 Säffle<br>(SE).<br><br><b>(72) Inventor; and</b><br><b>(75) Inventor/Applicant (for US only):</b> GRØNLI, Bjørn [NO/NO];<br>Skogerveien 58, N-3034 Drammen (NO).<br><br><b>(74) Agents:</b> BJELKSTAM, Peter et al.; Kransell & Wennborg AB,<br>P.O. Box 27834, S-115 93 Stockholm (SE). |           | <b>(81) Designated States:</b> BR, GB, MX, NO, SE, US, European<br>patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR,<br>IE, IT, LU, MC, NL, PT, SE).<br><br><b>Published</b><br><i>With international search report.</i><br><i>Before the expiration of the time limit for amending the<br/>         claims and to be republished in the event of the receipt of<br/>         amendments.</i><br><i>In English translation (filed in Swedish).</i> |

**(54) Title:** AN ARRANGEMENT AND A METHOD FOR MEASURING LEVEL, INTERFACE LEVEL AND DENSITY PROFILE OF A FLUID IN TANKS OR CONTAINERS

**(57) Abstract**

The invention relates to an arrangement and a method for measuring level, interface level and/or density profile of at least one fluid located in a tank or container (2, 3) by the aid of at least two nuclear radiation sources (9) vertically arranged at a predetermined distance from each other inside or both inside and outside the tank and a detector unit (11), which are located at a suitable distance from each other and inserted into separate protection pipes (8, 10). The detector unit (11) comprises a long vertical detector in the form of a scintillator rod (12) covering the total height in the tank or the container (2, 3) having a photo multiplier tube (13) at each end and associated electronics that provides both information on position as well as radiation level at different positions along the scintillator rod (12) by measuring pulse amplitudes measured from the photo multiplier tube. According to the method the radiation absorbed from the radiation sources (9) takes place in the scintillator rod (12) forming the detector unit (11) by the aid of the photo multiplier tubes (13) at each of its ends, which transform the radiation to electric pulses having an amplitude proportion to the light intensity of the radiation at the actual position along the rod (12), whereby the amplitude is measured electronically on the two simultaneous pulses and a ratiometric calculation is then used to determine the position of the corresponding radiation quant.



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**An arrangement and a method for measuring  
level, interface level and density profile  
of a fluid in tanks or containers**

5     In many industrial processes there is a need of one or  
more measurements of level, i.e. the vertical position  
of the surface of a fluid; interface level, i.e. the  
vertical position of the layer between two fluids; and  
density profile, i.e. the density of fluids as a func-  
10    tion of the height measured at discrete points or  
continuously along a vertical axis; in tanks to enable  
automatic control of the related operation. For certain  
processes the measurement may be very hard or impos-  
sible to carry out. Some factors that make this measure-  
15    ment difficult can be harsh or inaccessible environ-  
ments, aggressive or dangerous fluids and/or liquids,  
high pressure or temperatures, fluids causing deposits  
inside the tank/container, and so on. One example of a  
process that involves several of these problems is in  
20    sub-sea oil separator tanks. A nucleonic system is one  
method of measurement in this type of separator tanks.

In the technique previously known one usually uses a  
vertical array of several gamma radiation sources and a  
25    vertical array of several radiation detectors posi-  
tioned at a suitable distance from each other. The  
sources and the detectors are normally inserted in two  
separate protection pipes. The two pipes are mounted  
either both inside the tank or one inside and the other  
30    outside it. The gamma radiation sources are also  
shielded by lead with openings towards the detectors.  
Horizontal radiation beams from the gamma sources are  
pointed at each of the detectors. The attenuation of  
the radiation beam passing through the actual fluids,  
35    i.e. the gas and/or liquids, will vary depending on the  
amount of gas and the density of the liquid. A higher  
density will cause more attenuation and lower signals

from the detector. In this way the detector signals along the vertical axis represent a function of the density profile. Differences in adjacent detector signals indicate a fluid surface or interface level at that position. Instead of an array of radiation detectors, it is possible to use one long vertical detector according to the present invention having associated electronics that can separate the radiation from the different beams. In both cases scintillation detectors could be used. The array of separate gamma radiation sources could be replaced by one vertical wire source.

The problems when using an array of PTM detectors, i.e. a scintillator with an attached photo multiplier tube, are that the reliability of the system will be reduced and the costs will increase for large tanks or containers because of the fact that a large number of parts will be needed. This also limits the height resolution because of the size of the detectors and the maximum number that is practical. By the expression "scintillator" is meant a material that emits light flashes when exposed to nuclear radiation, preferably gamma radiation. It typically consists of plastic or crystal for industrial applications.

The object of the present invention is to provide an arrangement of the type mentioned in the introduction, whereby the drawbacks existing in previously known technique are eliminated. The characterizing features are set forth in the accompanying claims.

According to the invention there is proposed a solution with a long detector unit comprising a long scintillator rod with associated photo multiplier tubes covering the total height used instead of the array of PMT detectors. The long detector unit has a PMT, i.e. a photo multiplier tube, constituted by a photo detector,

which is very sensitive to light, at each end and associated electronics that provides both information on position as well as radiation level at the different positions along the detector unit.

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The invention will be described more in detail below by the aid of preferred embodiments, reference being made to the accompanying drawings, in which

10 Fig. 1 schematically shows a cross-section through a tank intended to be placed as a sub-sea separator and which contains water, oil and gas and is provided with a measurement arrangement according to the invention,

15

Fig. 2 schematically shows a cross-section through a sludge tank containing sludge, water and air, in which a measurement arrangement according to the invention is used for determining level and density profile of the different media,

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Fig. 3 schematically shows a known measurement arrangement, where an array of radiation detectors is used in the detector unit,

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Fig. 4 schematically shows the measurement arrangement according to the present invention, where the detector unit consists of a long detector rod having a photo multiplier tube at each end, and

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Fig. 5 shows a block diagram for a detector rod system according to the invention.

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As appears from Figs. 1 and 2 there are here illustrated two fields of application for the measurement arrangement 1 according to the invention, namely e.g.

in a sub-sea separator tank or container 2 and in a sludge tank 3.

5 In Fig. 3 there is illustrated a previously known measurement arrangement 4 comprising a radiation source 5 and a radiation detector unit 6, the latter of which comprises an array of radiation detectors 7.

10 Fig. 4 illustrates the measurement arrangement 1 according to the invention comprising radiation sources 9, e.g. gamma radiation sources, inserted in a protection pipe 8 and a detector unit 11 inserted in another separate protection pipe 10, the detector unit 11 covering the total height used. The detector unit 11  
15 comprises a long scintillator rod 12 with a PMT or photo multiplier tube 13, 13' fixed at each end 14 and 15. The scintillator rod 12 consists, as mentioned above, of a photo detector, which is very sensitive to light, with a structure and associated electronics,  
20 which provide information both on position as well as radiation level at different positions along the scintillator rod 12.

25 A special signal processing is, however, needed to obtain information on both position as well as radiation level at the different positions along the long detector unit 11. This is achieved by attaching a PMT, e.g. a photo multiplier tube 13, 13', to each end of the long scintillator rod 12. The scintillator material  
30 consists of special plastic and the material as well as the surface treatment are made to provide a suitable light attenuation along the length of the scintillator rod 12. The interaction between the radiation and the scintillator rod 12 is caused by single radiation  
35 quants being absorbed in the plastic and producing a light flash. Depending on the position in the scintillator rod 12, where the radiation quant is absorbed,

the light has a certain distance to travel before it reaches each of the photo multiplier tubes 13, 13'. During this travel the light is attenuated. Each photo multiplier tube 13, 13' emits an electric pulse of amplitude proportional to the intensity of the light at that end. The pulses from each of the photo multiplier tubes will occur simultaneously. The more the light is attenuated during the travel in the scintillator rod 12, the lower is the pulse amplitude of the photo multiplier tube. If the detection is in the middle of the length of the scintillator rod 12, the pulse amplitude of the two simultaneous pulses will be equal. If the detection is at the end of the length of the scintillator rod 12, the pulse amplitude will be high at the near end and low at the far end. An electronics measures the amplitude of the two simultaneous pulses and makes a ratiometric calculation to determine the position of the corresponding radiation quant. The rate of quants being absorbed by the scintillator rod 12 is proportional to the radiation intensity. Consequently, the pulse rate from the photo multiplier tubes represents the radiation intensity. By incrementing a position buffer in the memory of the electronics corresponding to the position of each quant being absorbed in the scintillator rod 12, the intensity and the radiation are measured at small discrete steps along the detector unit 11.

Since the photo multiplier tubes 13, 13' are inherently unstable devices, they need to be controlled by feedback to produce a sufficiently accurate signal in industrial applications. The normal way of control for smaller detectors is to do some type of analysis by comparing the pulse heights. In a long detector unit, where the pulse heights change when the level of the fluid or liquid in the process changes, this method of stabilization will not work well. Three ways will be

mentioned below, by means of which this problem is solved in accordance with the invention, namely:

1. A small reference radiation source (isotope) is attached directly to the scintillator rod 12. The pulse height from various isotopes depends on the type of radiation. The type of reference source and the mounting on the scintillator rod 12 are chosen to get higher pulses than that from the radiation passing through the fluid. The electronics extracts the higher pulses by pulse height discriminators and uses that in a feedback to control the photo multiplier tubes 13, 13'.
2. A light-emitting diode (LED) is attached directly to the scintillator rod 12. The light-emitting diode is pulsed and the pulses are extracted by the electronics by pulse height discriminators and used as feedback to control the photo multiplier tubes 13, 13'.
3. Two pipes are mounted horizontally between the radiation sources and the long photo multiplier tube detector unit each near the top and the bottom. This prevents the fluid from attenuating the radiation and, therefore, the intensity of the radiation will be constant near the ends of the detector unit. The radiation near the end will produce the highest pulses at that end. The electronics extracts the higher pulses by pulse height discriminators and uses that in a feedback to control the photo multiplier tubes.

Cross-coupling from adjacent radiation beams causes an error in the measured density due to scattering of the

gamma radiation. Some of the scattered radiation will hit the adjacent detectors. The most significant error occurs when the beam above is penetrating lighter liquid or gas than the measured beam.

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To overcome this problem a more accurate density is determined at each discrete position with the following algorithm:

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In e.g. position 4:  $ro = k_0 + k_1 \cdot x_3 + k_2 \cdot x_3^2 + k_3 \cdot x_4 + k_4 \cdot x_4^2$ ,

15

where  $ro$  is the density,  $x_3$  is the signal in position 3,  $x_4$  is the signal in position 4 and the indexes are numbered from the top and down,  $x_1$  being the signal at the top and  $x_n$  at the lowest point of the detector and  $k_0$ ,  $k_1$ ,  $k_2$ ,  $k_4$  are calibration constants and are determined by multiple regression after measuring all the signals  $x_1$ ,  $x_2$ , ... with a number of different densities. The other positions are made in the same way.

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An array of PMT or PIN detectors has a limited height resolution due to the discrete measurement positions of the detectors and a long PMT detector has a limited height resolution due to the discrete positions of the radio sources. This has been solved in the following manner. An improved height resolution is obtained according to the invention by a special radiation beam geometry and corresponding signal processing. Each radiation beam is made wide enough to partially overlap the beam on each side. In the case of an array of photo multiplier tube detectors the signal from each detector represents discrete positions along the vertical axis. In the case of a long photo multiplier tube detector the detector signal is divided into discrete intervals along the vertical axis. A more accurate level is determined at each discrete position with the following algorithm:

In e.g. position 3:  $y=k_0+k_1*x_3+k_2*x_3^2+k_3*x_4+k_4*x_4^2$ ,

where  $y$  is the more accurate height,  $x_3$  is the signal  
in position 3,  $x_4$  is the signal in position 4 and the  
5 indexes are numbered from the top and down,  $x_1$  being  
the signal at the top and  $x_n$  at the lowest point of the  
detector unit and  $k_0, k_1, k_2, k_3, k_4$  are calibration  
constants and are determined by multiple regression  
after measuring all the signals  $x_1, x_2, \dots$  with a  
10 number of different fluid levels. The other positions  
are made in the same way.

### Claims

1. An arrangement for measuring level, interface level and/or density profile of at least one fluid located in a tank or container (2, 3) by the aid of at least two nuclear radiation sources (9) vertically arranged at a predetermined distance from each other inside or both inside and outside the tank and a detector unit (11), which are located at a suitable distance from each other and inserted into separate protection pipes (8, 10), **characterized** in that the detector unit (11) comprises a long vertical detector in the form of a scintillator rod (12) covering the total height in the tank or container (2, 3) having a photo multiplier tube (13) at each end and associated electronics that provides both information on position as well as radiation level at different positions along the scintillator rod (12) by measuring pulse amplitudes measured from the photo multiplier tube.

2. An arrangement according to claim 1, **characterized** in that the scintillator rod (12) consists of plastic or crystal, which have been surface-treated to provide a suitable light attenuation along the length of the scintillator rod (12).

3. A method for measuring level, interface level and/or density profile of at least one fluid located in a tank or container (2, 3) by the aid of at least two nuclear radiation sources (9) vertically arranged at a predetermined distance from each other inside or both inside and outside the tank and a detector unit (11), which are located at a suitable distance from each other and inserted into separate protection pipes (8, 10), **characterized** in that the radiation absorbed from the radiation sources (9) takes place in the scintillator rod (12) forming the detector unit (11) by the aid

of the photo multiplier tubes (13) at each of its ends, which transform the radiation to electric pulses having an amplitude proportional to the light intensity of the radiation at the actual position along the rod (12),  
5 whereby the amplitude is measured electronically on the two simultaneous pulses and a ratiometric calculation is then used to determine the position of the corresponding radiation quant.

10 4. A method according to claim 3, **characterized** in that the photo multiplier tubes (13, 13') are controlled by feedback to produce a sufficiently accurate signal by attaching a small reference radiation source in the form of an isotope directly to the scintillator  
15 rod (12), which results in higher pulses than that from the radiation normally passing through the actual fluids.

20 5. A method according to claim 4, **characterized** in that the isotope is exchanged to a light-emitting diode (LED), which is directly attached to the scintillator rod (12) and the pulses of which are extracted electronically by pulse height discriminators and used as feedback to control the photo multiplier tubes (13,  
25 13').

30 6. A method according to claim 3, **characterized** in that two pipes are mounted horizontally between the radiation sources (9) and the long detector unit (11), each near the top and the bottom of the unit (11), which prevents the fluid from attenuating the radiation, the intensity of which will therefore be constant near the ends of the detector unit, whereby the radiation near the end will produce the highest pulses at  
35 that end at the same time as the electronics extracts the higher pulses by the pulse height discriminators

and uses them in a feedback to control the photo multiplier tubes (13, 13').

7. A method according to claim 3, **characterized** in that, to achieve a more accurate density when the radiation from the radiation sources in the scintillator rod overlaps the beams on each side, said density is determined at each discrete position along the scintillator rod with the following algorithm:

in e.g. position 4:  $ro = k_0 + k_1 \cdot x_3 + k_2 \cdot x_3^2 + k_3 \cdot x_4 + k_4 \cdot x_4^2$ ,

where  $ro$  is the density,  $x_3$  is the signal in position 3,  $x_4$  is the signal in position 4 and the indexes are numbered from the top and down,  $x_1$  being the signal at the top and  $x_n$  at the lowest point of the detector and  $k_0$ ,  $k_1$ ,  $k_2$ ,  $k_4$  are calibration constants and are determined by multiple regression after measuring all the signals  $x_1$ ,  $x_2$ , ... with a number of different densities.

8. A method according to claim 3, **characterized** in that an improved high resolution of the radiation from the radiation sources (9) is obtained by a special radiation beam geometry and corresponding signal processing, where each radiation beam is made wide enough to partially overlap the beams on each side, whereby the detector signal obtained along discrete positions on the vertical axis of the scintillator rod is divided into discrete intervals along said vertical axis at the same time as a more accurate level is determined at each discrete position with the following algorithm:

in e.g. position 3:  $y = k_0 + k_1 \cdot x_3 + k_2 \cdot x_3^2 + k_3 \cdot x_4 + k_4 \cdot x_4^2$ ,

where  $y$  is the more accurate height,  $x_3$  is the signal in position 3,  $x_4$  is the signal in position 4 and the

indexes are numbered from the top and down,  $x_1$  being the signal at the top and  $x_n$  at the lowest point of the detector unit and  $k_0, k_1, k_2, k_3, k_4$  are calibration constants and are determined by multiple regression

5 after measuring all the signals  $x_1, x_2, \dots$  with a number of different fluid levels.

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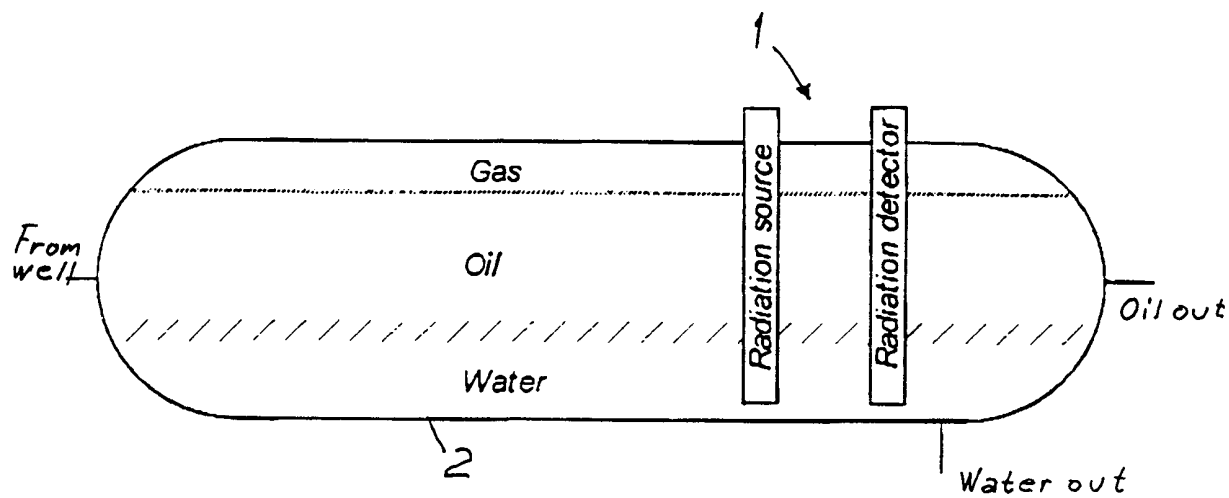


Fig. 1

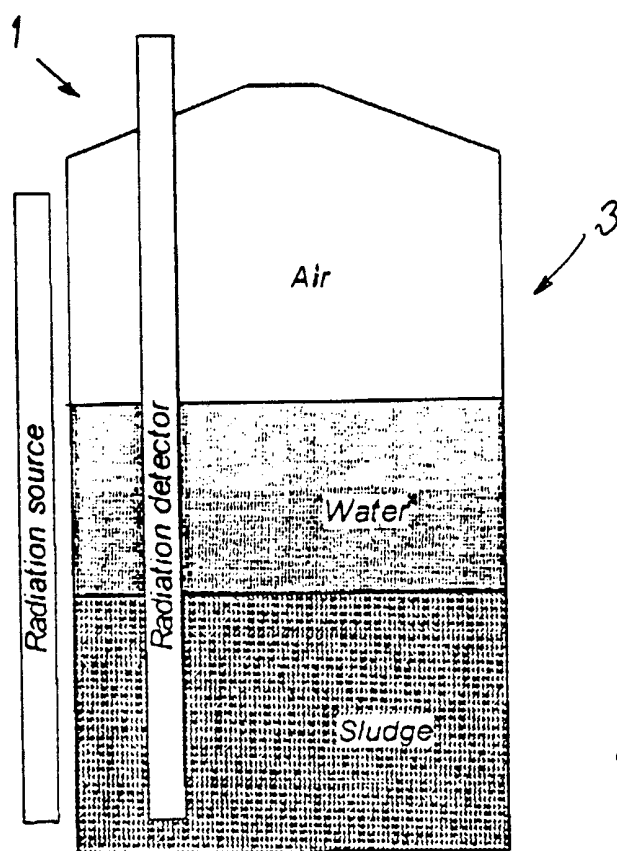


Fig. 2

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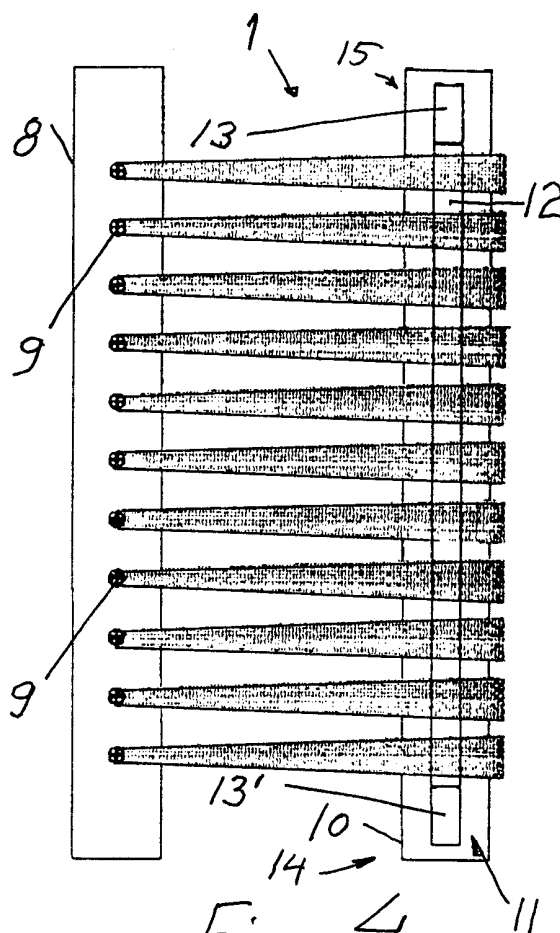
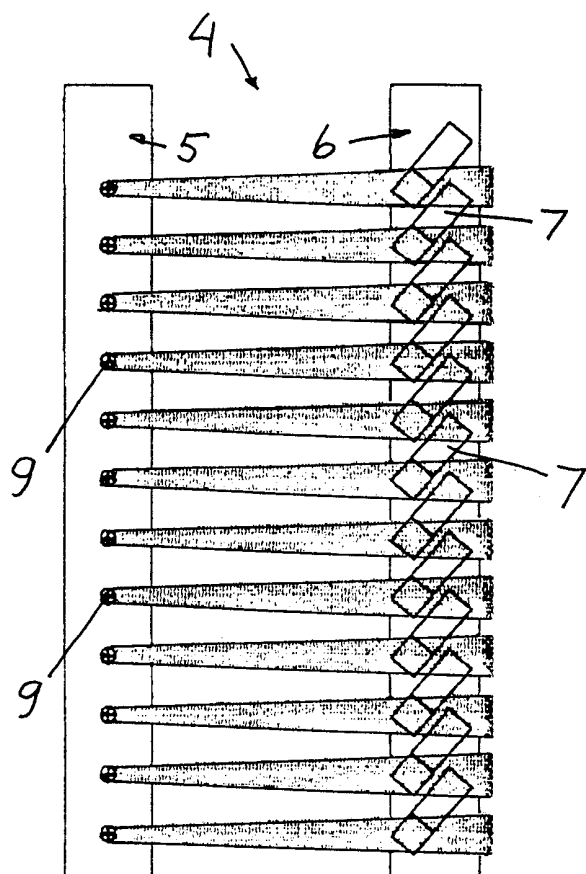


Fig. 3

Fig. 4

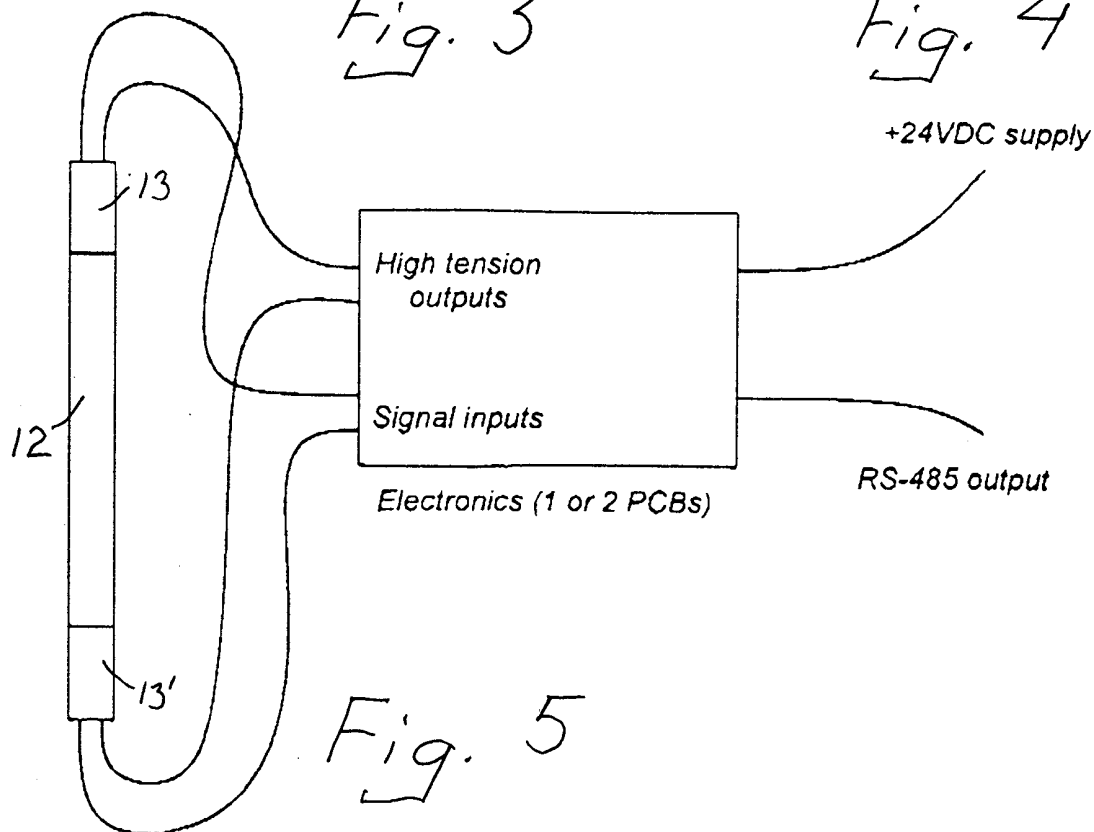


Fig. 5

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 98/01666

| <b>A. CLASSIFICATION OF SUBJECT MATTER</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                        |                                                                        |
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| <b>IPC6: G01F 23/288, G01N 23/10</b><br>According to International Patent Classification (IPC) or to both national classification and IPC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                        |                                                                        |
| <b>B. FIELDS SEARCHED</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                        |                                                                        |
| Minimum documentation searched (classification system followed by classification symbols)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                        |                                                                        |
| <b>IPC6: G01F, G01N</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                        |                                                                        |
| Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                        |                                                                        |
| <b>SE,DK,FI,NO classes as above</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                        |                                                                        |
| Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                        |                                                                        |
| <b>WPI</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                        |                                                                        |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                        |                                                                        |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Citation of document, with indication, where appropriate, of the relevant passages                                                     | Relevant to claim No.                                                  |
| E,X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | DE 19722837 A1 (ABB RESEARCH LTD.),<br>3 December 1998 (03.12.98), figures 2,3,<br>abstract<br><br>--                                  | 1-8                                                                    |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | US 4611117 A (FRANK SEIBERT ET AL), 9 Sept 1986<br>(09.09.86), column 9, line 56 - column 10, line 45,<br>figure 6, abstract<br><br>-- | 1-8                                                                    |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | US 4520266 A (EDWIN FLETCHER ET AL), 28 May 1985<br>(28.05.85), figures 1,2, abstract<br><br>--                                        | 1-8                                                                    |
| A                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | US 5218202 A (DIETER EVERS), 8 June 1993<br>(08.06.93), figure 1, abstract<br><br>--                                                   | 1-8                                                                    |
| <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                        |                                                                        |
| * Special categories of cited documents:<br>"A" document defining the general state of the art which is not considered to be of particular relevance<br>"E" earlier document but published on or after the international filing date<br>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)<br>"O" document referring to an oral disclosure, use, exhibition or other means<br>"P" document published prior to the international filing date but later than the priority date claimed<br>"I" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention<br>"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone<br>"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art<br>"&" document member of the same patent family |                                                                                                                                        |                                                                        |
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International application No.

PCT/SE 98/01666

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