Signal generating apparatus comprises a linear series of Hall-effect switches (44) arranged as a plurality of linear arrays in discrete probes (46a, 46b, 46n) which are butted end to end. Each switch is closed when in proximity of an actuating magnet (40) movable along the series of switches. In each array a resistance chain (66) is linked at intervals to the switches. Movement of the magnet along an array thereby gives a progressively changing voltage on an output line (50) from the resistance chain as a cumulative signal indicating the position of the magnet. When the magnet moves from one array to the succeeding array after generating a maximum cumulative signal from said one array, that signal is maintained by a latch connection (56) between the two arrays. A cumulative signal representing the magnet position relative to the complete series of switches can thus be generated. The arrays are powered in parallel so that it is possible to extend substantially the total number of switches or indicating points in the apparatus.
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Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.
This invention relates to signal generating apparatus, and in particular to position-responsive apparatus, for example for monitoring a liquid level, and to a method of deriving position-responsive signals, eg. in order to sense and display particular values and/or to control a variable determining those values.

There are many processes in which a directly contacting probe or the like cannot be employed to monitor changes of position, for example because of a hostile environment or the aggressive nature of the material being monitored. Non-contacting sensors must then be used, such as devices responsive to magnetic fields.

Non-contacting liquid level indicators have been described employing a vertical array of magnetic switches, as in the examples of GB 997861 and US 4627283 and 4589282, in which a magnet carried by a float operates the switches without contacting them. Such switches have an on-off operation so that they provide stepped measurements, but that is not necessarily a disadvantage if the steps are sufficiently small. In the last-mentioned US 4589282 in particular, there is proposed the use of Hall-effect switches, which provide relatively compact and convenient switching devices with a small power consumption.

These earlier proposals are limited in respect of
range and/or accuracy of measurement, however. It will be understood, that the incremented signal change between successive steps must be sufficient to be unaffected by circuit noise so that it soon becomes inconvenient to cope with the increasing signal voltage range if it is required to have an indicator with a very large number of steps, whether for increased accuracy or for greater range of measurement. In the apparatus of US 4589282 a vernier-like arrangement of switches and magnets is proposed to increase the accuracy of measurement but that requires complex circuitry which itself poses a practical limit to the maximum number of steps or graduations over the range of measurement.

According to one aspect of the present invention, there is provided position-responsive apparatus comprising a series of detecting elements disposed in succession alongside a path of relative movement with a non-contacting actuating means adapted to act on respective detecting elements by its proximity thereto along said path, and resistance means connected to the detecting elements to produce an output signal which is progressively changed with relative movement between the actuating means and the series of detecting elements over the length of said path of relative movement, the series of detecting elements being arranged in a plurality of arrays disposed in series to extend over different portions of said path of relative movement and means operable with the passage of the actuating means between successive arrays in a direction
away from one end of said path for transmitting a cumulative output signal which includes a component corresponding to the output signal from each preceding array from said one end of the path of relative movement.

Such apparatus provides for the possibility of connecting a supply voltage to each said array of detecting elements independently of the other arrays, conveniently by connecting them in parallel to a common supply, so that the range of measurement can be extended indefinitely and/or the accuracy of measurement is limited only by the nature of the detecting elements themselves. Nevertheless, because the signal state for each lower array can be made dependent to the action of the actuating means on a succeeding array, cumulative signals can be generated from the arrays jointly. Thus, if a liquid-level indicating means comprises a vertically arranged series of said detecting elements, when the actuating means rises above a first or lowest array of said detecting elements, the output signal indicating it had risen the height of that first array is maintained and is added to the height position signal that is generated from the succeeding array above the first array.

In a preferred arrangement, the actuating means has a switching influence over a path length greater than the pitch of succeeding detecting elements whereby each detecting element is switched by the actuating means element before the immediately preceding element is released from its switched state. In relative movement
from one array to the succeeding array away from said one end of the path, therefore, a momentary retention of the signal from said one array can be employed to establish a signal indicating the passage of the actuating means over the length of said one array. If that signal is held while the position of the actuating means remains above said one array, a cumulative signal can be built up although the signals from the respective arrays may be independent of each other.

Preferably, for said holding of the signal each succeeding array is connected to latch means which are operative to latch on a 100% signal of a preceding array when the actuating means switches on the first or lowest element of the succeeding array.

It is also possible to associate each array of detecting elements with a respective cumulative indicating means and to provide means for the cumulative operation of the indicating means of all the arrays. Conveniently interconnecting means between the indicating means of successive arrays are arranged to hold said indicating means of a preceding array in a 100% cumulative state when there is relative movement of the actuating means in the direction away from said one end of the path to a following array, whereby the indicating means of the respective arrays are cumulatively operative with relative movement of the actuating means in said direction.

According to another aspect of the invention, there is provided a method of indicating the position of an
actuating member relatively movable to a succession of
detecting elements along the path of said relative
movement, said actuating member acting on respective
detecting elements by its proximity thereto, in which the
detecting elements are grouped in a plurality arrays in
series along said path, and an output signal is generated
from each said array by the proximity of the actuating
member thereto, independently of the other array or arrays,
and for the or each said array from one end of said path
preceding an array adjacent to which the actuating member
is located at any instant, a signal is generated

In a further aspect of the invention there is
provided a signal generating apparatus comprising means for
inputting a plurality of variable input signals to produce
a cumulative output signal and means for selectively
varying the number of said inputs, impedance-changing means
in the paths of the respective input signals for providing
a substantially constant impedance for the cumulative
output signal independent of the number of said inputs.
Although such means may also have other applications, they
can be employed advantageously for forming a cumulative
signal from the signals of the respective arrays, so that
the position indicating apparatus can be operated with a greater or lesser number of said arrays without modification of evaluation means for the cumulative signal.

By way of example, the invention will now be described with reference to the accompanying drawings, in which:

Fig. 1 is a block diagram of one form of apparatus according to the invention,

Fig. 2 is a circuit diagram of an array of position-detecting elements for the apparatus of Fig. 1,

Fig. 3 is a circuit diagram of a splitter circuit for powering the arrays of Fig. 1,

Fig. 4 is a circuit diagram of a signal processing circuit for the array of Fig. 2,

Figs. 5a and 5b are a circuit diagram of a control circuit in which the signal processing circuits of Fig. 4 are deployed, and

Fig. 6 illustrates the display panel of the apparatus of the preceding figures.

Referring to Fig. 1, the system shown is intended for sensing the liquid level L in a column or stand pipe C. A magnet 40 mounted on a float 42 in the column moves up and down with the change of the liquid level and can act on a vertical series of sensors 44 disposed at equal height intervals adjacent and parallel to the column C. The sensors are contained in a series of discrete elongate probes 46 identical to each other and arranged end to end to extend over the required height of the column. Each
probe contains a series array of individual sensors encapsulated in an outer casing 48 of non-magnetic material.

The respective probes are indicated in ascending order by the references 46a, 46b...46n. Output signal lines 50a, 50b...50n connect the probes to respective signal processing units 52a, 52b...52n in a corresponding series of signal processing units 52. Latching connections 56 are provided between successive pairs of signal processing units 52. Output lines 58a, 58b...58n from the signal processing units 52a, 52b...52n input to a control unit 60 for the generation of control signals and/or alarm signals as required. The control unit 60 also comprises power supply means, further described below, to which the individual probes 46 and signal processing units 52 are connected in respective parallel groups by conductors indicated generally in Fig. 1 by the reference 62. As will become clear later in this description, it is possible to operate the apparatus with less than the maximum number of probes if desired.

Fig. 2 illustrates the circuit of a probe 46 in more detail. Along its length are arranged a series of Hall-effect switches 64 (eg. UGS3140U switches supplied by Allegro Microsystems Inc of Worcester, Massachusetts) which are comprised in the sensors 44, and a series chain of resistors 66. The switches 64 are connected in parallel across -15V and 0V lines 68, 70 of the conductors 62. Each switch also has an output terminal connected to the chain
of resistors 66, the successive connections being made to successive stages in the chain. The output signal line 50 is connected to the end of the resistor chain at the top of the probe.

The switches 64 are normally in an off state but each is closed when the magnet 40 is in proximity to it. If the magnet is below the height of the probe, therefore, all the switches will be off and no signal appears on the output line 50. When the magnet closes the lowermost switch, the -15V supply line 68 is connected to the output line 50 through the chain of resistors 66. As the magnet moves upwards successive ones of the switches 64 are closed. A decreasing portion of the resistance chain remains in circuit with the supply voltage and an increasing voltage signal is thus obtained on the line 50. Each output line 50 connects to ground through a respective shunt resistance 72a, 72b...72n (Fig. 5) in the control unit. The value of the shunt resistances can be varied over a limited range to compensate for variations in conductor resistance between the probe and the control unit. The value of the shunt resistance is set to give a maximum probe signal output of -5.5 volts and the resistance steps between each switch of a probe are selected to give an equal change in the shunt resistor current for each step. It is therefore convenient to form some of the steps from parallel resistors, as shown. The arrangement is such that as the magnet rises and falls, it will switch on a succeeding switch before it allows the
preceding switch to open.

The switches 64 are grouped closely in the probe, for example at 20mm intervals so that a fifty-switch probe monitors a height of one metre. The overall length of the probes is controlled to allow them to be butted together with their adjacent end switches positioned at the same 20mm interval.

The connections between the probes 46 and the processing and control units 52, 60 are conveniently made through a splitter unit 76 (Fig. 3) disposed adjacent the probes 46. The splitter unit 76 has a plug connector 70 for a connection from the control unit 60 comprising heavy cable conductors for main power -15V and 0V lines. These conductors are coupled in the unit 76 to each of four sockets 82 for respective plug and socket connections to the individual probes. Each of the sockets 82 also provides a connection for the output signal line 50 of its probe to further conductors in the connector 80 to input the probe signals to respective terminals 84a, 84b... 84n (Fig. 5a) of the socket connection on the control unit for the connector 80. The use of the splitter unit is able to avoid any excessive voltage drop in the power supply to the probes while allowing a relatively compact form of plug and socket connection at the probes themselves.

The signal processing units 52a, 52b... 52n are a series of identical printed circuit cards, illustrated in more detail in Fig. 4, which are simply plugged into the control unit which takes the form of a motherboard. Each
plug has main power connections from +15V, -15V and 0V lines and also a nominal 3.0V supply connection for driving an LED display 90 (Fig. 6). The probe output signal on line 50 is fed through a further input terminal 92 of the signal processing unit to a DC inverter 94 which transforms the probe signal to a positive voltage for operating a series of five display driver units in the form of integrated circuits 96a...96e associated with the LED decade displays 90 shown in Fig. 6.

Each display driver circuit 96 has reference connection pins 9 and 11. Pin 11 of the first circuit 96a of the series (i.e. that for the first or lowermost decade of the display) is connected to the 0V line and its pin 9 is connected to pin 11 of the next higher circuit. This pattern of connection is continued through the circuits until, in the uppermost circuit, the connection pin 9 is connected to an accurate reference voltage provided by a voltage reference IC 98. With a reference voltage of 5V set by the diode 98, each driver circuit 96 therefore has a reference range of substantially 1V.

The output signal from the inverter 94 reaches the display driver circuits through respective potentiometers 100a...100e. As already mentioned, the maximum probe voltage is 5.5V whereas the maximum signal required for the five driver units is 5V and the potentiometers are trimmed to give a 1V signal range for each driver circuit. In this way it is possible to compensate for variations in the resistance values in the
LED driver units and ensure that an inverter output signal of 1.1V actuates the ten readout digits of the first decade, a 2.2V output also actuates the further ten readout digits of the second decade, and so on.

The signal processing unit also includes a latch 102 comprising a comparator having first input at a constant voltage determined by divider resistors 104, 106 connected between the +15V and -15V supply terminals. A second input comes from pin 2 on the first driver circuit 96a. The first 0.1V increment to the driver circuits, i.e. the actuation of the lowermost switch of the probe array by the magnet 40 switches the pin 2 of the first driver circuit 96a low to below the nominal 3V voltage applied to pin 3 of that circuit as a reference voltage. Base of transistor 108 of the latch is thereby switched low and the -15V line is connected through output terminal 110 to the latching connection 56 indicated in Fig. 1. More specifically, the output from the terminal 110 goes through a respective voltage limiting circuit 112 in the control unit (see Fig. 5a), each said circuit comprising a voltage reference IC 114 and trimmable resistance 116 to set a maximum -5.5V voltage (100% probe reading) for the signal through the latch connection 56 to the probe input terminal of the preceding signal processing unit. Fig. 5a only shows three resistor-potentiometer pairs, of course, because there is no latching input connection to the signal processing unit for the uppermost probe.

By linking the operation of the respective signal
processing units by the latches 102, as the float rises from the region of one probe to a succeeding higher probe the latch of the signal processing unit of the latter inputs a voltage signal corresponding to the 100% output reading from the lower probe after the magnet has moved above it. A cumulative output signal is thereby generated despite the fact that the independently operating lower probe is no longer actuated by the magnet.

As already mentioned, the switches 64 of the probes operate in an overlapping manner with each succeeding switch closing before the preceding switch breaks. This means that as the magnet rises past the junction between two probes, while the uppermost switch of the lower probe is still closed, the lowermost switch of the upper probe is made. The display of the lower circuit is therefore kept fully activated at least as long as is needed to close the lowermost switch of the upper probe and so close the latch. Conversely, when the magnet falls, the latch is opened only after the uppermost switch of the lower probe has been actuated. Drop out is thus avoided in either direction of movement.

It will be apparent that as the float rises past the junction between two probes and the latch is made, that new source is a second current input because the uppermost switch of the lower probe has not yet opened. The voltage limiting circuit 112 avoids disturbances from this source by limiting the voltage to the 100% probe reading of -5.5V.
On the motherboard forming the control unit 60, in addition to those components already identified are a power supply circuit 122, a signal division matrix 124, a current generating circuit 126 for an external circuit (not shown), and an alarm generating circuit 128.

The power supply circuit 122 comprises transformer and rectifying units 132, 134 producing DC ±15V outputs controlled by voltage regulators 136, 138 for the main operating functions, and a further rectifying unit 140 tapping the transformer unit 132 for an unregulated 3V DC supply for the LED displays.

The signal division matrix 124 is provided to ensure that the signal to the current generating and alarm circuits 126, 128 is independent of the number of probes employed, within the capacity of the apparatus. It comprises a series of parallel gangs of corresponding resistances, in this instance four gangs each of four resistances because there are four signal processing units 52. The resistance value chosen for each resistance in this example is 4.7k ohms. Switches SW1/1 to SW4/4, which may take the form of 4-pole DIL switches, in the matrix allow the resistances of each gang to be brought into circuit between the respective signal output lines 134a...134d of the associated signal processing units, and a common output line 136. The cumulative output signals from the matrix therefore give a rising positive voltage on line 136 as the probe signals increase.

It has already been mentioned that the apparatus
will function if fewer than the full number of probes are used. If in a particular installation one probe and its signal processing unit is fitted, for example the first probe 46a and unit 52a giving a signal output on line 134a, only the switch SW1/4 is closed. Because the other signal output lines are open-circuited there is therefore an impedance of 4.7k ohm placed on the common line 136 by the single resistance SW1/4. If there are two probes 46a,46b in use and the lines 134a and 134b are both connected to their respective signal processing units 52a,52b switches SW1/3 and SW2/3 are closed, giving 2 x 4.7k ohms resistances in circuit in each of two parallel lines, ie. a resultant impedance again of 4.7k ohms. In a similar manner, the impedance is to be kept the same if a greater number of probes are employed.

The signal division matrix 124 also allows the range of operation to be compressed to a part of the maximum range. If, for example, switch SW3/4 only is closed, it provides the only current path through the matrix, ie. the matrix only passes signals processed from the associated third probe. The current output range for the signal and alarm circuits 126,128 otherwise available for the signals from all four probes is now restricted to the travel length of the one probe.

The common output line 136 for the signal division matrix contains a series potentiometer 140 and fixed resistance 142 which form a dropper chain with the selected matrix resistances between the +15V and 0V lines.
Taps from the dropper chain between the matrix resistances and the pair 140, 142 provide an input voltage to pin 2 of comparator 146 of the current generator circuit 126 and to the alarm circuit 128.

The positive voltage on line 136 is applied to pin 2 of the comparator and causes the comparator output to attempt to rise. If instrumentation or another external current loop (not shown) is connected to the terminals 148 of the output circuit, that rising effect will try to balance the input on pin 1 of the comparator with that on pin 2. Current will then flow through the line containing the resistance 150 and potentiometer 152 until the voltages at the pins 1 and 2 are balanced. The current flow in the external loop is thus dependent upon the signal output voltage applied to pin 2. The current range can be chosen by adjustments of the potentiometers 140 and 152. In this example, over the matrix output range of 0V to +5.5V the current range may be set at 4mA to 20mA.

The connection from the line 136 to the alarm circuit 128 carries the same signal output voltage as that applied to the comparator 146. The alarm circuit comprises two comparators 154 and 156 which are fed with the signal voltage in inverse sense to each other to provide rising and falling alarm indications respectively. The other input to each comparator is a reference voltage set by respective 10-turn potentiometers 158, 160 on the display panel 162 (Fig. 6) of the apparatus. The potentiometers can be manually adjusted between 0 and 100% levels for
independent adjustment of either alarm level.

Each comparator 154,156 is connected to an output transistor 164,166 respectively which switches low when the selected reference voltage of its comparator is passed, in one case on a rising signal and in the other on a falling signal. This brings into operation a respective high or low alarm LED 168,170 on the display panel, and also an associated opto-coupler 172 in series therewith. The opto-couplers output through external plug connectors 174 for remote alarm indication.

Although the invention has been illustrated by its application to a liquid level indicator it will be understood that it is capable of being employed for other kinds of position indication, including rotary position.

It will also be understood that the signal matrix circuit is applicable more widely than in the illustrated example, to assist the coupling of a plurality of input signals of any parameter to a common output line giving a cumulative signal value for operational purposes.
CLAIMS

1. Position-responsive apparatus comprising a series of detecting elements disposed in succession alongside a path of relative movement with a non-contacting actuating means adapted to act on respective detecting elements by its proximity thereto along said path, and resistance means connected to the detecting elements to produce an output signal which is progressively changed with relative movement between the actuating means and the series of detecting elements over the length of said path of relative movement, said series of detecting elements being arranged in a plurality of arrays of elements disposed in series to extend said path of relative movement, and means operable in the passage of the actuating means between successive arrays for transmitting a cumulative output signal which includes a component corresponding to the output signal from each preceding array from one end of said path of relative movement.

2. Apparatus according to claim 1 wherein the actuating means has a switching influence over a path length greater than the pitch of succeeding detecting elements whereby each detecting element is switched by the actuating means element before the immediately preceding element is released from its switched state.

3. Apparatus according to claim 2 wherein latch means are provided for operation in the direction of said
relative movement away from said one end of the path to
latch on a 100% signal of a preceding array when the
actuating means switches on the first element of the
succeeding array.

4. Apparatus according to claim 2 or claim 3 wherein
each array of detecting elements is associated with a
respective cumulative indicating means and interconnecting
means are provided between the indicating means of
successive arrays for holding said indicating means in a
100% cumulative state on passage of the actuating means in
the direction away from said one end of the path to a
following array, whereby the indicating means of the
respective arrays are cumulatively operative with relative
movement of the actuating means in said direction.

5. Apparatus according to any one of the preceding
claims wherein a plurality of parallel electrical paths are
provided for inputting the output signals of the respective
arrays to a common output line to produce a cumulative
signal therefrom, and impedance-changing means are provided
in said parallel paths for providing a substantially
constant impedance for the output line independent of the
number of input signals.

6. Apparatus according to claim 5 wherein said
impedance changing means comprises a plurality of
resistances in parallel, each resistance being in series
with a respective input signal and all the resistances being connected to a common output for the cumulative signal, means for open circuiting the resistances to which no inputs are to be applied, and means varying the resistances in those lines to which the inputs are to be applied in dependence upon the number of said inputs.

7. Apparatus according to claim 6 wherein each parallel resistance line comprises a series of similar value resistors the total number of which in each line corresponds to a maximum number of said input signals.

8. Apparatus according to any one of the preceding claims wherein each array of detecting elements is connected in series to a common line and to an array of resistance elements at positions in said resistance array dependent upon the positions of the detecting elements in their array, whereby the resistance between said array of resistance elements and the common line is dependent upon the detecting element or elements acted upon by the actuating means for producing an output voltage signal dependent upon the position of the actuating means along said path of relative movement.

9. Apparatus according to claim 8 wherein the resistance elements are arranged to provide substantially equal voltage signal steps from the actuation of successive detecting elements.
10. Apparatus according to any one of the preceding claims wherein the detecting elements are Hall-effect switches.

11. A method of indicating the position of an actuating member relatively movable to a succession of detecting elements along the path of said relative movement, said actuating member acting on respective detecting elements by its proximity thereto, in which the detecting elements are grouped in a plurality of arrays in series along said path, and an output signal is generated from each said array by the proximity of the actuating member thereto, independently of the other array or arrays, and for the or each said array from one end of said path preceding an array adjacent to which the actuating member is located at any instant, a signal is generated corresponding to the signal obtained when the actuating member is at the end of the respective array remote from said one end of the path, and the or each said signal is evaluated cumulatively with the signal from said array adjacent the actuating member for said indication of the actuating member position along said path.

12. A signal generating apparatus comprising means for inputting a plurality of variable input signals to produce a cumulative output signal and means for selectively varying the number of said inputs, impedance-
changing means in the paths of the respective input signals for providing a substantially constant impedance for the cumulative output signal independent of the number of said inputs.

13. Apparatus according to claim 12 wherein said impedance changing means comprises a plurality of resistances in parallel, each resistance being in series with a respective input signal and all the resistances being connected to a common output for the cumulative signal, means for open circuiting the resistances to which no inputs are to be applied, and means varying the resistances in those lines to which the inputs are to be applied in dependence upon the number of said inputs.

14. Apparatus according to claim 13 wherein each parallel resistance line comprises a series of similar value resistors the total number of which in each line corresponds to a maximum number of said input signals.

15. Position responsive apparatus constructed and arranged for use and operation substantially as described herein with reference to the accompanying drawings.

16. A method of indicating the position of an actuating member substantially as described herein.
Fig. 4.

SKT1
27 +15V
32 3.0V NOM.

C2
C3

R2

LATCH
110

R1

IC1

102

104

108

COMPARATOR

O/P TO 4-20mA CCT
31

AND ALARM
29

COMPARATORS

6

SIGNAL I/P FROM
21 PROBE
92

R3

IC2

R5

OP AMP

94

R4

0V
23

-15V
C1
INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION OF SUBJECT MATTER
   (If several classification symbols apply, indicate all) 6

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 G01D5/252; G01F23/72; G01F23/70

II. FIELDS SEARCHED

Classification System

Classification Symbols

Int.Cl. 5 G01F; G01B; G01D

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched 8

III. DOCUMENTS CONSIDERED TO BE RELEVANT 9

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<td>DE,A,2 314 363 (REAKTIVA SZÖVETKEZET) 3 October 1974 see the whole document</td>
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Special categories of cited documents: 10

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IV. CERTIFICATION

Date of the Actual Completion of the International Search

18 DECEMBER 1992

Date of Mailing of this International Search Report

15, 01, 93

International Searching Authority

EUROPEAN PATENT OFFICE

Signature of Authorized Officer

BROCK T.J.
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<td>US A 4 466 284 (SPRAGUE ELECTRIC COMPANY) 21 August 1984 cited in the application</td>
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<td>A</td>
<td>FR A 2 212 532 (WESTINGHOUSE ELECTRIC CORP) 26 July 1974 see page 4, line 8 - page 5, line 31 see page 7, line 18 - page 19, line 29; figures 1-6</td>
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ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO. GB 9201601
SA 63950

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information. 18/12/92

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