



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

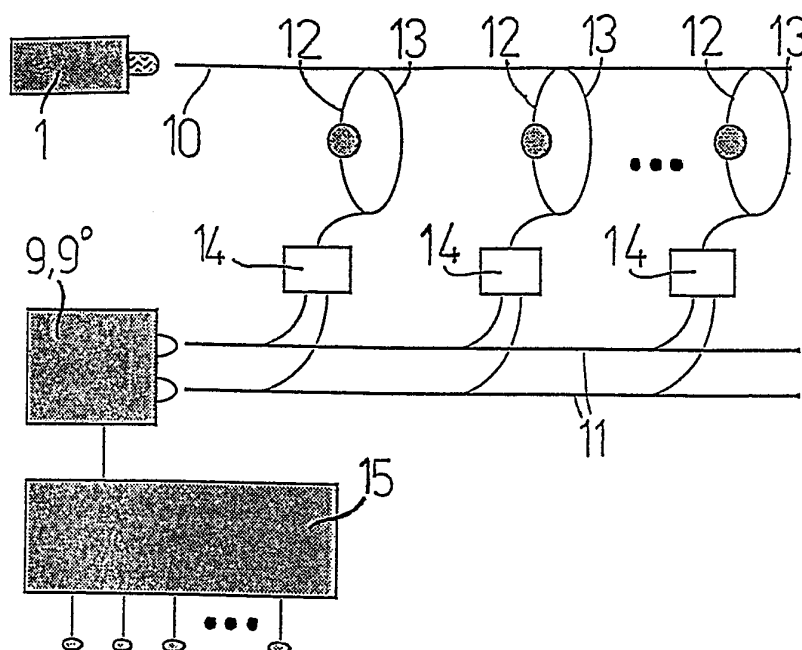
(51) International Patent Classification 5 : G02B 6/28	A1	(11) International Publication Number: WO 90/10883 (43) International Publication Date: 20 September 1990 (20.09.90)
--	-----------	--

(21) International Application Number: PCT/SE90/00094

(22) International Filing Date: 14 February 1990 (14.02.90)

(30) Priority data:
8900805-6 8 March 1989 (08.03.89) SE(71)(72) Applicant and Inventor: KARLSSON, Stefan [SE/SE];
Storhagsgatan 3, S-590 50 Vikingstad (SE).(74) Agent: FÖRSVARETS CIVILFÖRVALTNING; Paten-
tenheten, Box 80012, S-104 50 Stockholm (SE).(81) Designated States: AT (European patent), BE (European
patent), CH (European patent), DE (European patent),
DK (European patent), ES (European patent), FI, FR
(European patent), GB (European patent), IT (European
patent), JP, LU (European patent), NL (European pat-
ent), NO, SE (European patent), US.**Published***With international search report.
In English translation (filed in Swedish).*

(54) Title: A METHOD TO USE AN OPTICAL FIBRE AS A SENSOR



(57) Abstract

The present invention relates to a method to use an optical fibre as a sensor. The method involves designing an optical fibre to have a sensor area (12) where the external influence on the fibre that is to be measured, for example pressure or magnetic field, is freely able to influence the fibre. Coherent radiation is then transmitted through the sensor area in several modes. On the receiver side the radiation is split in a detector device (14) into two beams, each including the entire interference pattern created by the transmission in the fibre. After that the beams are plane-polarized in two different directions which are conducted to a signal processing device (9,9°) which detects the amplitude and/or frequency content of each beam and from this forms a signal which is a measure of their amplitude and/or frequency relation, which in its turn is a measure of the external influence in the sensor area (12).

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	ES	Spain	MG	Madagascar
AU	Australia	FI	Finland	ML	Mali
BB	Barbados	FR	France	MR	Mauritania
BE	Belgium	GA	Gabon	MW	Malawi
BF	Burkina Faso	GB	United Kingdom	NL	Netherlands
BG	Bulgaria	HU	Hungary	NO	Norway
BJ	Benin	IT	Italy	RO	Romania
BR	Brazil	JP	Japan	SD	Sudan
CA	Canada	KP	Democratic People's Republic of Korea	SE	Sweden
CF	Central African Republic	KR	Republic of Korea	SN	Senegal
CG	Congo	LI	Liechtenstein	SU	Soviet Union
CH	Switzerland	LK	Sri Lanka	TD	Chad
CM	Cameroon	LU	Luxembourg	TG	Togo
DE	Germany, Federal Republic of	MC	Monaco	US	United States of America
DK	Denmark				

- 1 -

A method to use an optical fibre as a sensor

Fibre optical sensor technique is a field that during the last ten years has been predicted a very expanding market. The expansion has, however, not reached the pace that was predicted. The reason for this is principally the difficulty to separate the sensor information from the varying influence from the environment, both on the sensor and on the transmission to and from the sensors. Another reason is that the single-mode technique that has the highest degree of sensitivity is complex and demands that the components used are very accurate. The multimode technique, on the other hand, can allow a more simple design and moreover, it uses more robust components. Thereby it is possible to reach such a level for the costs for the fibre optical sensors that they become economically interesting. But the multimode technique has also not experienced a break-through, mostly due to the lower sensitivity that hitherto has been achieved with this technique. Conventional multimode technique is of course based on principles of intensity modulation of the light that is transmitted in the core of the multimode fibre. This technique is less sensitive than the phase-sensitive detection that the single-mode technique is based on.

The fibre optical sensors have potentially very great advantages, primarily due to their non-galvanic construction, that result in for instance insensibility for EMP, EMC etc. The sensitivity that can be achieved is also as good as or better than what can be achieved with other types of sensors. Another interesting characteristic of the fibre optical sensor technique is the possibility to multiplex several sensors along the same fibre optical cable and in that way implement sensor systems that is able to cover for instance large surveillance zones. The sensors of the system can be dimensioned to be sensitive to several physical quantities such as pressure and magnetism. Great tactical advantages can be achieved by this. In order to achieve this goal the sensors have to be based upon such a technique that a realization of the sensor technique is robust and functionally reliable and this at a reasonable cost in comparison with conventional technique.

The present invention relates to a method to use an optical fibre as a sensor. The detection is phase-sensitive and can be applied to both

single- and multimode fibres. The invention solves the present problem by the invention being designed as is evident from the following claim 1.

In the following the invention will be described in more detail with referens to the attached drawings where

fig 1 shows a laser, a fibre, in which the radiation propagates in several modes and the interference pattern after the fibre,

fig 2 shows an interference detector according to the invention,

fig 3 shows a first sensor system according to the invention,

fig 4 shows a second sensor system according to the invention,

fig 5 shows a third sensor system according to the invention,

fig 6 shows two variants of the sensor circuit in fig 5 and

fig 7 shows a fourth sensor system according to the invention.

The suggested sensor system is based on detection of variations in the phase condition of the light that is transmitted in an optical fibre. This is a more sensitive method of measuring mechanical influence on the optical fibre than measuring the variations in the effect or the intensity of the light. A mechanical influence on the optical fibre can be translated to serve as a measuring quantity of, for instance, acoustical waves or magnet fields. It is very important that the sensor system is not sensitive to external influence from the environmental parameters, that can give rise to an increased noise level for the measuring quantity of interest. For solutions that concerns multiplexing several fiber optical sensor, this is of particular relevance. The solution according to the invention is based on a principle which among other things means that the variations in the optical fibre due to the environment are filtered out and that only significant changes caused by the measuring quantity are presented by the sensor or sensor system. The principle is described below.

In a single-mode fibre there exists only one mode for light having a wavelength above the cut off wavelength of the fibre. Light of a shorter wavelength that is transmitted in the single-mode fibre will propagate in several modes. The single-mode fibre will then act as a multimode fibre.

In a multimode fibre there exists many directions of propagation due to the angle of incidence to the fibre that the incident "light rays" have. These directions of propagation are called modes. If coherent light, as in fig 1, from a laser 1 is transmitted in the fibre 2 and the emerging light illuminates for example a white paper, a pattern of interference 3 will appear on the paper. This pattern is usually called speckle pattern. The pattern is caused by the constructive or destructive combination of the different modes of the multimode fibre. This pattern of interference is extremely sensitive to external influence on the fibre as the relative phase relation is changed by the influence, which in its turn causes a movement of the pattern of interference. If this movement can be detected a very accurate method to detect influence on the fibre is achieved. The coherence length for the light must be longer than the difference in distance between the highest and the lowest modes.

One method to detect this pattern is to place a photodiode on a fixed spot for instance on an intensity maximum and watch the intensity variations. The disadvantage with this is that the pattern fades due to the random phase difference between emerging modes, which do not emerge uniformly during the time. Below a method to solve the problem is given.

The phase relations can change due to changes in the spectral characteristics of the source of light caused by for instance modulation of the laser diode, by temperature variations of the source of light, by temperature variations along the optical fibre and by random distribution of the modes in the optical fibre, for instance caused by the concatenation points. Such unwanted phase variations have an uniform effect on the radiation in all directions of polarisation, which is not the case for the phase variations that are caused by the external influence in the sensor areas.

The light emerging from the end of the fibre is therefore split by a beam splitter 4 into two beams, see figure 2. Each beam includes the entire interference pattern created by the transmission in the fibre. It is suitable to choose to split the beam into two beams that are on the whole equally strong, even though this is not necessary. The two beams are then plane-polarized in different directions by two polarizers 5 and 6. It is suitable to choose two directions that are essentially perpendicular to each other, even though this is not necessary. In a suitable embodiment of the invention the two emerging beams are then detected by detectors 7 and 8 independently from each other and the difference in amplitude is compared in a differential amplifier 9. The signal coming from the differential amplifier 9 is a measure of the external influence.

In stead of forming a difference signal, it is possible to form, in another type of signal processing device 9⁰, other types of signals that are a measure of the quantity one wishes to measure. Thus it is possible to detect the difference in the quotient between the two signals or the variations in the frequency distribution between them.

It is possible to use several sensors, 12 or 12 and 13, according to the invention in a sensor system. Then the radiation is transmitted in short pulses through a distribution cable 10 in the form of an optical fibre. Along the distribution cable the sensors are distributed. The radiation pulses are coupled from the distribution cable to the sensors by means of first optical couplers, that couple a certain amount of the effect of the laser pulses to the sensor and let the rest pass on to other sensors. By means of other optical couplers the radiation pulses are coupled from the sensors to one or more return cables 11 in the form of optical fibres, in which the radiation pulses from different sensors are time-multiplexed. From the return cable or cables the radiation is conducted to a signal processing device 9,9⁰ that detects the amplitude and/or frequency content of each radiation beam, and from this forms a signal that is a measure of their amplitude relation or frequency relation, which in its turn is a measure of the external influence in the sensor area. The result is presented in a presentation device.

If it is possible to make sure that all influence on the cable takes place in special sensor areas and the rest of the optical fibre, in both the distribution cable and return cable, is completely undisturbed, which is very difficult considering the tremendous sensitivity of the phase sensitive detection, then one sensor area 12 would be enough in the sensors. In practice this is not easy and above all, one does not wish to be forced to protect the distribution cables and return cables from external influence to the extent necessary in order to reach successful results. Therefore one often designs each sensor with one sensor area 12, in the form of a sensor fibre, as well as one well protected reference fibre 13. By designing the sensor in this way, it is possible to take out a reference signal at the time and place of the signal from the sensor area and by comparison with it, filter out changes just in the sensor fibre.

In a first variant of the invention, the sensor with a sensor fibre 12 and a reference fibre 13 could be made as a fibre optical ring, in which pulses of radiation is conducted. The radiation is first conducted through the reference half 13, after which a part of the radiation is conducted to the detector device. The rest will travel around in the ring and passes the sensor fibre 12 and thereafter the reference fibre 13, after which a part of the radiation is again conducted to the detector device etc. with lower and lower signal amplitude. The first signal will then be a pure reference signal.

At least two ways to implement the system is conceivable. In the first system, according to figure 3, an interference detector 14 is placed after each sensor. The radiation from the detector device 14 in the two different polarisation directions are connected to a common signal processing device 9,9⁰ via separate optical fibres 11. Finally a demultiplexing takes place in a demultiplexor 15 in order to separate the radiation from the different sensors.

The second system according to figure 4 is on the whole similar to the first, but on the receiver side there is some difference. Thus the radiation from each sensor 12, 13 is conducted, time-multiplexed when there is several sensors, by one and the same optical fibre 11 to a

common interference detector 14, that is followed by a signal processing device 9,9⁰ and a demultiplexor 15 in the same way as in the first system.

In stead of using a sensor ring as above, in other variants of the invention one could be using two seperate adjacent optical fibres connected in parallel, where one is a reference fibre 13 and the other a sensor fibre 12. This is shown in figure 5. As the signal is not running around in the sensor, in this case one only gets one reference signal and one sensor signal. In other respects the system can be designed exactly as in the two earlier mentioned cases. Besides, in practice one only considers one reference signal and one sensor signal also in the case with the sensor ring.

Figure 6 shows variants of the sensor coupling in fig 5, which in principle gives the same situation as in this figure. Certain system related advantages can, however, occur with this method.

In some applications, especially with the sensor fibre 12 and the reference fibre 13 connected in parallel as above, it could be necessary to introduce a well defined delay in the form of a transmission line of a determined length in order to adjust the time relation between the reference signal and the sensor signal from one sensor.

It is possible to design a system, in which interference between different modes is only localized to the sensors. If one uses as distribution and return fibres 10, 11 single-mode fibres having a cut off wavelength below the wavelenght of the present radiation in the system, so that the radiation is only transmitted in one mode in the fibre, no interference between different modes occur here. Then one uses for the sensor part together with the connections belonging to it either a multimode fibre or a single-mode fibre having such a high cut off wavelenght that the radiation in the system have a wavelength below this cut off wavelenght, so that the radiation is transmitted in several modes. This solution is perhaps most advantageous in the system according to figure 3.

Figure 7 shows what such a system could look like, with single-mode fibres operated in single-mode in the distribution and return fibres 10, 11 and a fibre operated in multimode as sensor fibre 12.

Claims:

1. A method to use an optical fibre as a sensor, characterized in that an optical fibre is designed to have a sensor area (12) where the external influence on the fibre that is to be measured, for example pressure or magnetic field, is freely able to influence the fibre, that coherent radiation is transmitted through the sensor area in several modes, that on the receiver side the radiation is split in a detector device (14) into two beams, each including the entire interference pattern created by the transmission in the fibre, that the beams are plane-polarized in two different directions which are conducted to a signal processing device (9,9⁰) which detects the amplitude and/or frequency content of each beam and from this forms a signal which is a measure of their amplitude and/or frequency relation, which in its turn is a measure of the external influence in the sensor area (12).
2. A method according to claim 1, characterized in that the radiation is split into two beams of on the whole the same intensity.
3. A method according to claim 1 or 2, characterized in that the beams are plane-polarized in two on the whole perpendicular directions.
4. A method according to one of the claims 1 - 3, characterized in that the radiation is transmitted in short pulses along a distribution cable (10) in the form of an optical fibre and coupled by means of first optical couplers along the distribution cable to a number of sensors (12,13), each comprising a sensor area (12), that the radiation from the sensors is coupled by means of second optical couplers to one or more return cables (11) in the form of optical fibres, in which the pulses of radiation is wavelength multiplexed.
5. A method according to one of the previous claims, characterized

t e r i z e d i n that each sensor is designed as two adjacent parts of optical fibres, one of which is a reference fibre (13) and the other a sensor fibre (12).

6. A method according to claim 5, c h a r a c t e r i z e d i n that each sensor is designed as a fibre optical ring, in which the radiation is conducted, said ring having a reference half (13), to which the radiation is first conducted, and a sensor half (12), that the radiation is conducted to the detector device (14) from the reference half (13), which result in the first signal to the detector device being a pure reference signal, after which follows signals that have passed the sensor fibre (12) and the reference fibre (13) a successively increasing number of times.

7. A method according to claim 5, c h a r a c t e r i z e d i n that each sensor (12,13) is designed as two separate optical fibres connected in parallel.

8. A method according to one of the claims 4 - 7, c h a r a c - t e r i z e d i n that a detector device (14) is placed after each sensor (12,13), from which devices the radiation in the two directions of polarisation is conducted in an optical fibre (11) each to a common signal processing device (9,9⁰) and then, in a system with several sensors, to a demultiplexor (15).

9. A method according to one of the claims 4 - 7, c h a r a c - t e r i z e d i n that the radiation from the sensors (12,13) is conducted in one optical fibre (11) to a common detector device (14) and a signal processing device (9,9⁰) and then, in a system with several sensors, to a demultiplexor (15).

10. A method according to one of the previous claims, c h a r a c - t e r i z e d i n that only those parts of a fibre that is part of a sensor (12,13) is chosen such that the radiation is transmitted in several modes, while the other parts of fibre (10,11) is chosen such that the radiation is transmitted in only one mode.

1 / 4

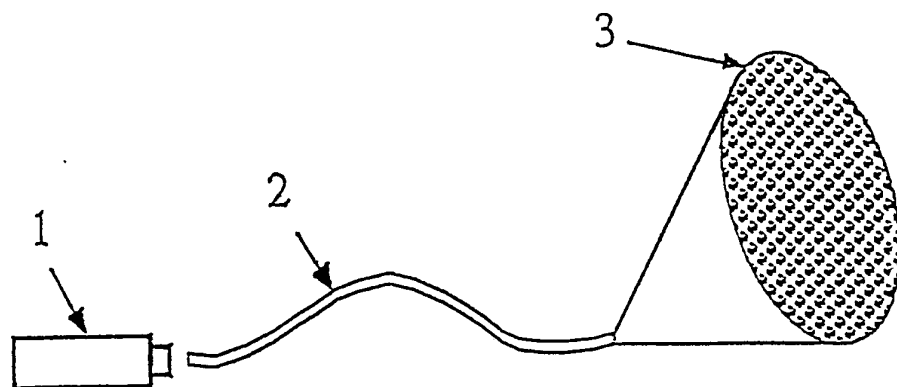


FIG 1

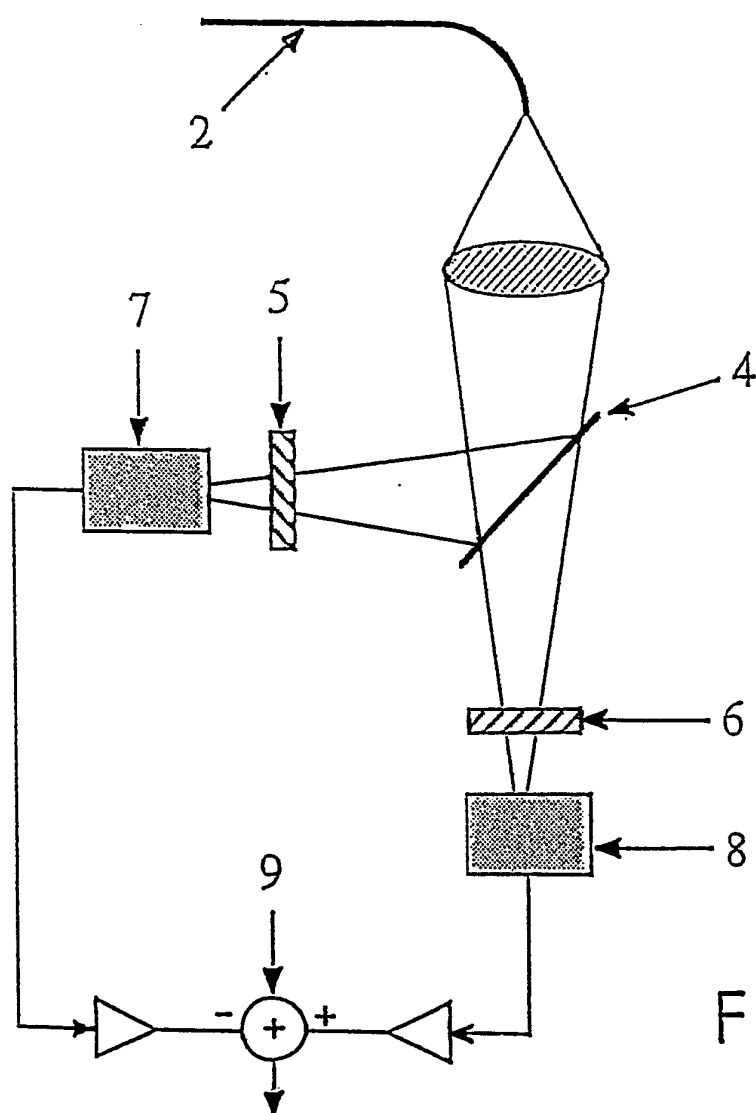
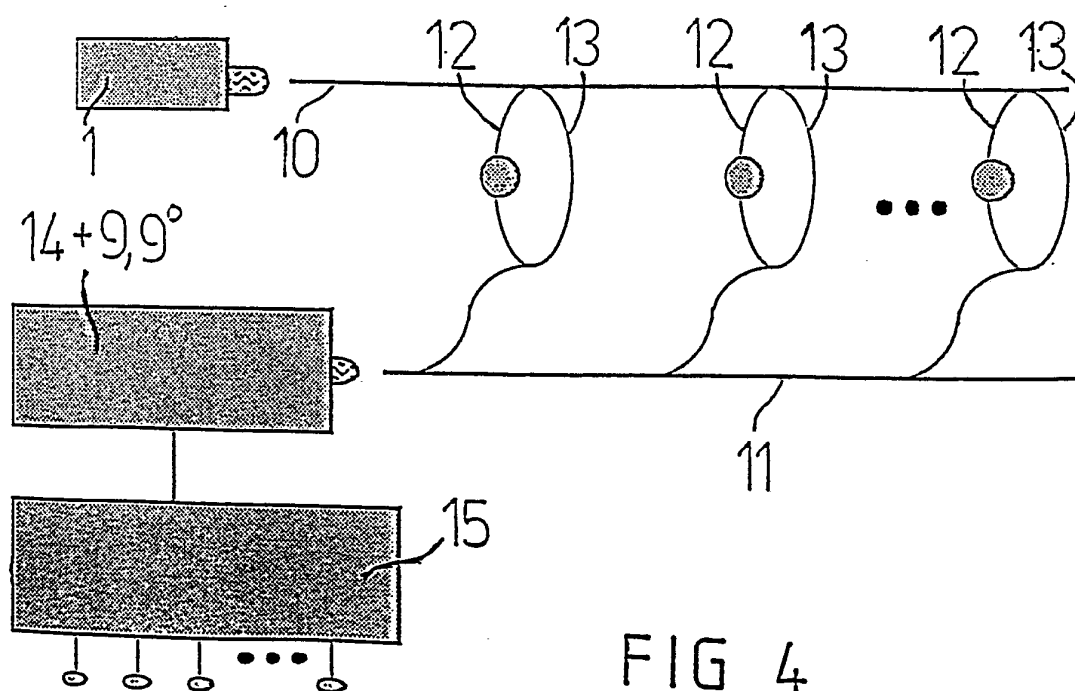
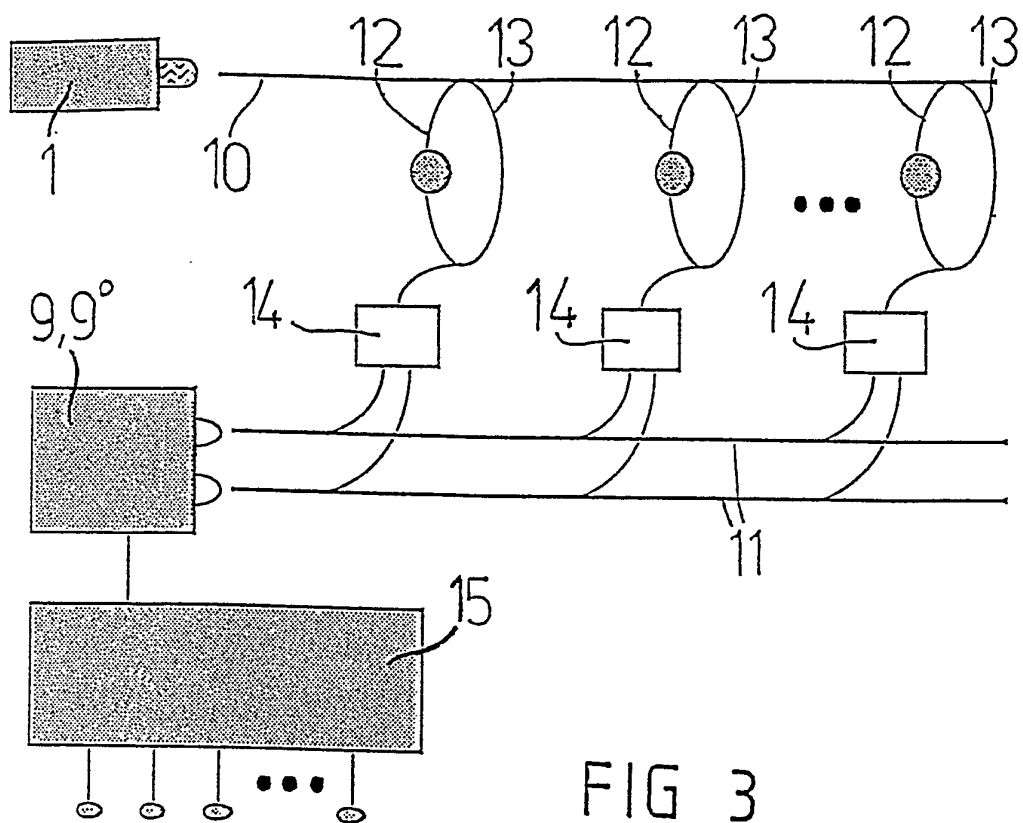


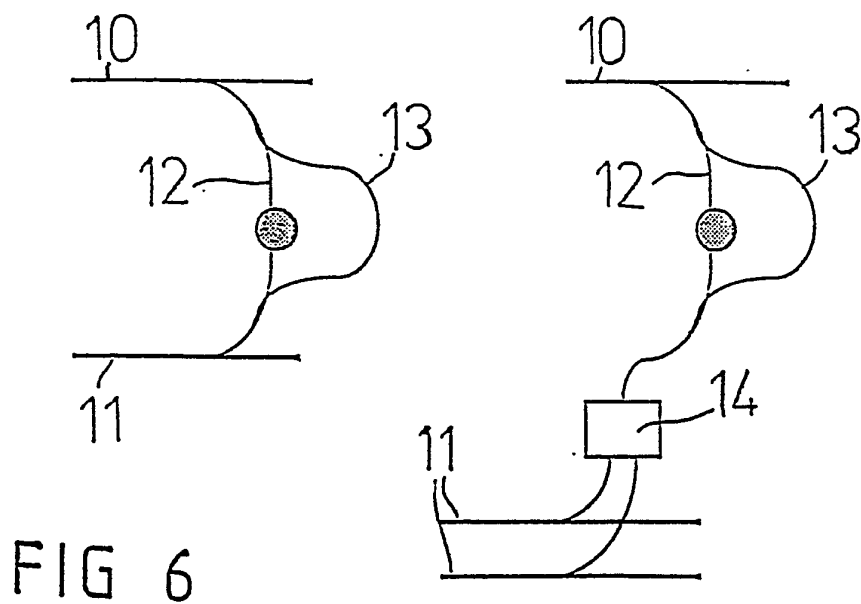
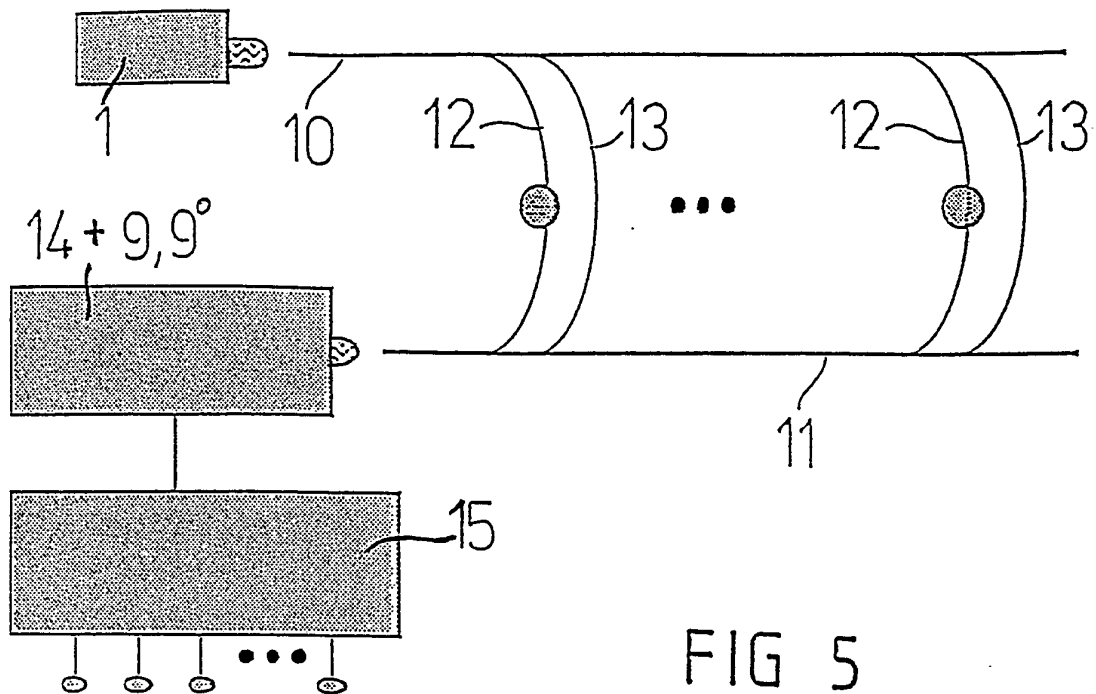
FIG 2

2 / 4



SUBSTITUTE SHEET

3 / 4



SUBSTITUTE SHEET

4 / 4

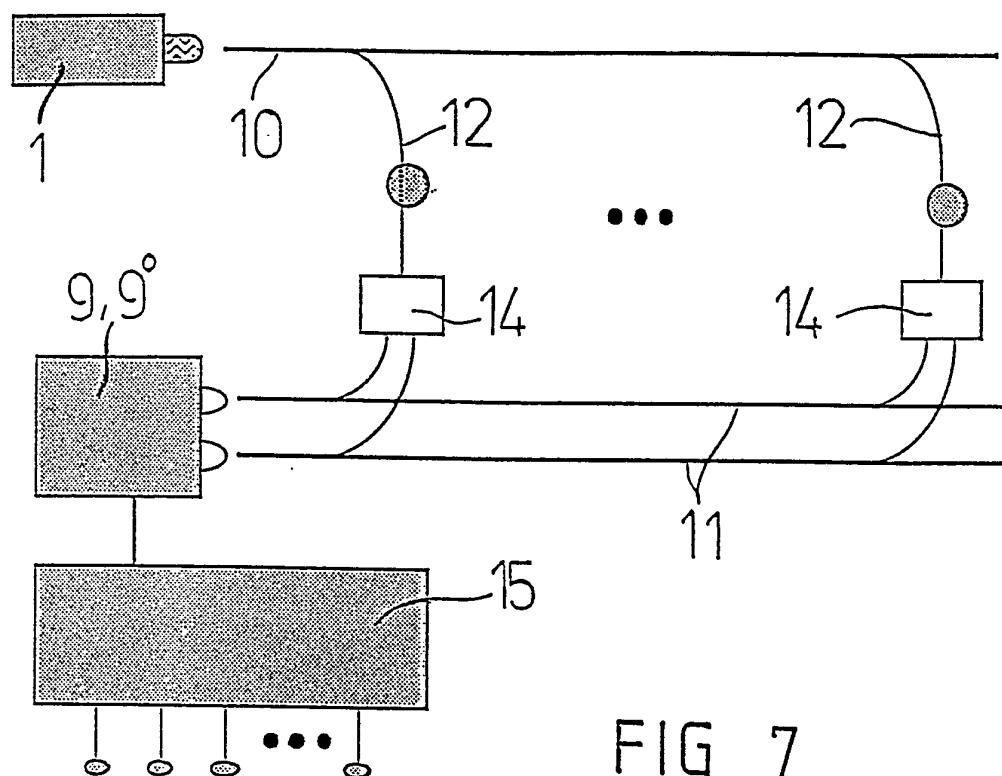


FIG 7

INTERNATIONAL SEARCH REPORT

International Application No PCT/SE 90/00094

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 IPC5: G 02 B 6/28		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
IPC5	G 02 B; H 04 B	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched ⁸		
SE,DK,FI,NO classes as above		
III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹		
Category *	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
A	US, A, 4784453 (SHAW ET AL) 15 November 1988, see the whole document --	1-10
A	US, A, 4636029 (JOHANSSON ET AL) 13 January 1987, see the whole document --	1-10
A	US, A, 3854792 (KOELLE) 17 December 1974, see the whole document --	1-10
A	US, A, 4297684 (BUTTER) 27 October 1981, see the whole document --	1-10
A	US, A, 4697926 (YOUNGQUIST ET AL) 6 October 1987, see the whole document --	1-10
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>* Special categories of cited documents: ¹⁰</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"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)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" 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</p> <p>"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"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.</p> <p>"&" document member of the same patent family</p> </div> </div>		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
23rd May 1990	1990 -06- 08	
International Searching Authority	Signature of Authorized Officer	
SWEDISH PATENT OFFICE	Karin Säfsten	

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	US, A, 4070091 (TAYLOR ET AL) 24 January 1978, see the whole document --	1-10
A	US, A, 4770535 (KIM ET AL) 13 September 1988, see the whole document -- -----	1-10

**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.PCT/SE 90/00094**

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 Swedish Patent Office EDP file on 90-05-07
The Swedish Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4784453	88-11-15	EP-A- 0277746	88-08-10
US-A- 4636029	87-01-13	CA-A- 1226038	87-08-25
		EP-A-B- 0136271	85-04-03
		SE-B-C- 438396	85-04-15
		SE-A- 8304733	85-03-02
US-A- 3854792	74-12-17	NONE	
US-A- 4297684	81-10-27	DE-A- 3011052	80-10-09
		FR-A- 2452749	80-10-24
		GB-A- 2046437	80-11-12
US-A- 4697926	87-10-06	AU-D- 5270986	86-08-14
		EP-A- 0191589	86-08-20
		JP-A- 61204520	86-09-10
		US-A- 4770535	88-09-13
US-A- 4070091	78-01-24	NONE	
US-A- 4770535	88-09-13	AU-D- 5270986	86-08-14
		EP-A- 0191589	86-08-20
		JP-A- 61204520	86-09-10
		US-A- 4697926	87-10-06
		EP-A- 0251632	88-01-07
		JP-A- 1105122	89-04-21