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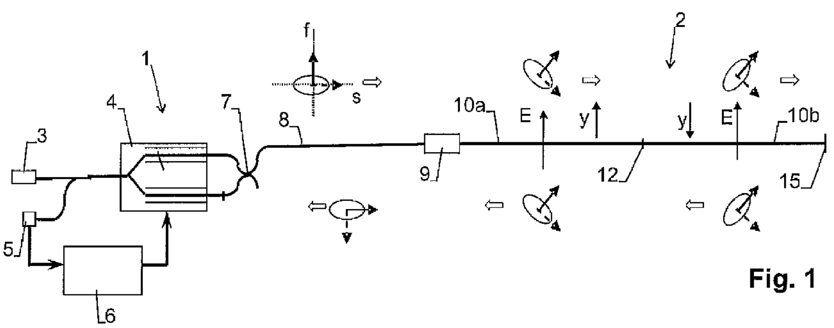

Fig. 1

(57) Abstract: Two transversely poled fibers (10a, 10b) are wound around a holder (30) with their poling directions being anti-parallel. A coupling (12) exchanges the polarization directions of the modes of the fibers. This design has the advantage that thermally and mechanically caused birefringence changes are substantially cancelled, while electrical field induced birefringence changes are added, which allows to provide a more robust high voltage measuring device.

WO 2009/138120 A1

High voltage measurement device using poled fibers

DESCRIPTION

Technical field

The invention relates to a high voltage measurement device based on poled waveguides.

Background

WO90/08970 describes a procedure for poling an optical glass fiber by applying a transverse, high electric field at elevated temperatures. The poling imparts permanent second order nonlinearity to the fiber. A transverse electric field applied to the poled fiber induces refractive index changes proportional to the field strength (Pockels effect). In contrast, unpoled fibers (having macroscopic inversion symmetry) exhibit only the Kerr effect, i.e. the index change is very small and varies in proportion to the square of the field strength. WO90/08970 and WO 97/01100 describe voltage sensors using a poled fiber. The fiber describes helical or spiral-like paths running from ground to high voltage potential. The light waves in the fiber experience an optical phase shift which is a measure for the voltage. The phase shift is measured in a Mach-Zehnder interferometer or by polarimetric means.

However, this type of sensor is sensitive to various external parameters, such as temperature, mechanical shock and vibration, which can lead to an optical phase change and can therefore seriously deteriorate the voltage measurement.

Summary of the invention

The problem to be solved by the present invention is to reduce the influence of such external parameters on the measured signal. This problem is solved by the device of claim 1.

Accordingly, a first waveguide poled in a first poling direction and a second waveguide poled in a second poling direction are provided. Both waveguides are of essentially identical type (i.e. they are of the same materials and have the same waveguiding properties) and are arranged parallel to each other. Each waveguide is dimensioned to carry at least one spatial mode having two orthogonal light polarizations. In the following the orthogonally polarized waves are referred to as orthogonal (polarization) modes. Both waveguides are commonly supported on a holder with the first and second poling directions being anti-parallel to each other. The two waveguides are optically coupled to each other, e.g. directly or through an intermediary fiber, in such a manner that the coupling exchanges the light polarization directions of the orthogonal modes in the first and in the second fiber.

This design has the advantage that electro-optically induced phase delays between the two polarization directions in the first and second waveguides are added, while strain- or temperature induced phase delays compensate each other, which allows to make a more accurate voltage measurement that is less dependent on the types of external parameters or perturbations mentioned above.

A coupling between the waveguides that "exchanges the polarization direction of the modes" of the waveguides is to be understood as a coupling that converts a photon running along one waveguide and being polarized along the "slow axis" of the waveguide to a photon being polarized along the "fast axis" of the other waveguide, and vice versa. In a most simple embodiment, such a coupling can e.g. be achieved by direct orthogonal splicing of the two waveguides. Alternatively, a coupling fiber may be provided between the two waveguides; the coupling fiber is formed by a polarization maintaining fiber that is spliced to the first waveguide in a first orientation and to the second waveguide in a second orientation, with the first and second orientations being rotated by 90°.

A "transversally poled" optical waveguide is a waveguide that has been poled and therefore has a non-centric structure in a poling direction transversally, in particular perpendicularly, to its longitudinal axis.

The current invention is especially suited for measuring high voltages above 10 kV.

Brief description of the drawings

Further embodiments, advantages and applications of the invention are disclosed in the dependent claims as well as in the following description, which makes reference to the figures:

Fig. 1 shows a first embodiment of an electro-optic voltage sensor,

Fig. 2 shows a second embodiment of an electro-optic voltage sensor,

Fig. 3 shows a third embodiment of an electro-optic voltage sensor,

Fig. 4 shows part of a fourth embodiment of an electro-optic voltage sensor,

Fig. 5 shows part of a fifth embodiment of an electro-optic voltage sensor,

Fig. 6 shows a cross section of a fiber with circular cladding,

Fig. 7 shows a cross section of a fiber with a D-shaped cladding,

Fig. 8 shows a cross section of a fiber with an elliptical cladding,

Fig. 9 shows a cross section of a fiber with rectangular cladding,

Fig. 10 shows a first embodiment of a sensor device,

Fig. 11 shows a sectional view of a detail of Fig. 10,

Fig. 12 shows a second embodiment of a sensor device,

Fig. 13 shows a third embodiment of a sensor device,

Fig. 14 shows a partial sectional view of a device in its insulation housing,

Fig. 15 shows a second embodiment of a device in its insulation housing,

Fig. 16 shows a device with corona rings, and

Fig. 17 shows a cross section of a fiber with two cores.

Embodiments of the invention

Measurement principle:

Fig. 1 shows a fiber-optic voltage sensor having a control unit 1 and two fibers 10a, 10b. Fibers 10a, 10b form polarization maintaining waveguides. They are transversally poled fibers that exhibit, under the application of a transversal electrical field, a linear field-induced birefringence change.

Control unit 1 comprises a light source 3, a phase modulator 4 for a non-reciprocal phase modulation, a light detector 5, a signal processor 6, and a polarization maintaining fiber coupler 7. Control unit 1 and the fibers 10a, 10b form a polarization-rotated reflection interferometer and use an interrogation technique as known from fiber gyroscopes, for details see Ref. [1, 2].

Two orthogonal linearly polarized light waves (indicated by solid and dashed arrows) exit from control unit 1 and travel through a polarization maintaining (pm) feed fiber 8 (e.g. an elliptical-core fiber) to a Faraday rotator 9 with a rotation angle of 45° per pass (or, equivalently, a rotation angle of 45° + k·90° with k being any integer number). In other words, each light wave is rotated by 45° each time it passes through Faraday rotator 9. The rotation is non-reciprocal, i.e. the rotation as seen from an observer looking towards the light beam is, for example, clockwise if the beam propagates from left to right, but counter-clockwise if the beam propagates from right to left. The total rotation is thus 90° (or 90° + k·180° with k being an integer number). The light waves exiting from Faraday rotator 9 are coupled into a first transversally poled pm sensing fiber 10a. The fast and slow axes of this sensing fiber are oriented at 45° with regard to the axes of the pm feed fiber 8 left of the rotator 9. As a result the polarization directions after the rotation again coincide with the birefringent fiber axes. A second identical transversally poled pm sensing fiber 10b is spliced at a splice 12 with its axes rotated by 90° with respect to first sensing fiber 10a. The waves polarized parallel to the slow axis in first fiber 10a are then polarized along the fast axis in second fiber 10b and vice versa. The waves are reflected at the end of second fiber 10b by a mirror 15 and then retrace their paths. Non-reciprocal Faraday rotator 9 introduces another 45° rotation that adds to the first rotation. The total rotation on the way forward and backward is thus 90°, i.e. the light waves again return with swapped polarizations to control unit 1, as in the current sensor of EP 1 154 278 (to be included herewith). This is advantageous because it keeps the total roundtrip path imbalance of the waves at or near zero and thus within the coherence length of the low coherent light source 3. Furthermore temperature and vibration induced optical phase changes in the fiber between modulator 4 and Faraday rotator 9 largely cancel each other.

The two sensing fibers 10a, 10b to the right of Faraday rotator 9 act as field sensors and are used to measure the periodic field induced extra birefringence caused by an alternating electric field E having a transversal component to the longitudinal axis of the fibers. The induced birefringence causes a corresponding differential phase shift between the two orthogonal waves.

The poling directions y of the two fibers, i. e. their polar axes, are anti-parallel as shown in Fig.1.

The combination of the anti-parallel poling directions and the swapping of the polarization directions due to the 90°-splice between the fibers results in field-induced phase shifts in the sensing fibers of the same magnitude and sign, if the electric field distributions E(z) along the two fibers are the same. In a voltage sensor, equal field distributions are achieved by aligning the two fibers as illustrated in Fig. 10-13 shown below.

The advantages of using a first and a second sensing fiber 10a, 10b joint by a 90°-splice and with an alignment as in Fig. 10-13 are the following:

- The second pm sensing fiber 10b balances the optical path imbalance between the two orthogonal waves introduced in first sensing fiber 10a. As mentioned, this is necessary as it keeps the total path imbalance within the coherence length of a low coherent light source.
- As both fibers experience the same temperature and mechanically induced phase shifts (e. g. due to shock and vibration) the corresponding optical phase shifts in the two fibers cancel each other. Thus, the sensor becomes significantly more robust with regard to external perturbations than sensors according to the state of the art. Furthermore, the signal processing becomes simpler, if large quasi-

static phase excursions (e. g. due to temperature changes) are avoided. Ideally the total phase changes should remain within an interval of ±π.

- Second fiber 10b doubles the sensitivity of the voltage sensor.

It should be noted that with an interrogation technique based on nonreciprocal phase modulation the apparent sensitivity of the two poled fibers 10a, 10b to an applied alternating voltage varies as a function of the time delay between the forward and backward propagating waves and thus as a function of the length of the fibers and the location along the fiber. The voltage-induced roundtrip optical phase shift is at its maximum, if the time delay is negligible compared to the period of the alternating voltage and becomes zero, if the delay corresponds to half a period. Furthermore, the effective sensitivities of two sections will differ, if the delay is not negligible. However, for a voltage of a frequency of 50 or 60 Hz and fiber lengths of some meters the time delay is negligible and the delay effects can be disregarded.

Fig. 2 shows a modification of the set-up in Fig. 1. A pm fiber coupler 13 and the two transversally poled pm sensing fibers 10a, 10b form a loop mirror. The coupler end at Faraday rotator 9 is oriented like first sensing fiber 10a section in Fig. 1. The loop contains two 90°-splices 12, 14. The splices divide the loop in two halves with identical lengths. An extra reflector is not needed. Two pairs of orthogonal polarizations with orientations as indicated counter-propagate in the loop. The functions of the two loop halves are the same as the ones of the two sensing fibers 10a, 10b in Fig. 1. The phase shifts in the fibers 10a, 10b add, if the poling directions y and the field directions E are as indicated in Fig. 2. A potential advantage of this configuration is that the effective sensitivities of fibers 10a, 10b are always the same independent of the time delay.

The phase modulator 4 in Figs. 1 and 2 is e.g. an integrated-optics lithium modulator, see e.g. Ref. [1]. The modulator also acts as a polarizer. Another alternative is a piezoelectric modulator as illustrated in Ref. [2].

Fig. 3 shows the same configuration as Fig. 1 but with a different type of integrated-optics phase modulator 4. The modulator is a birefringence modulator which directly modulates the phase of orthogonal light waves. The pm coupler 7 of Fig. 1 and 2 is then no longer needed. The depolarized light from light source 3 (depolarizer not shown) is polarized in a fiber polarizer 21 and subsequently coupled into an entrance pm fiber lead 22 of the modulator at splice 23. The polarization direction is at 45° to the axes of the pm fiber lead (45° splice). As a result two orthogonal waves of equal amplitude are excited. The fast and slow axes of both pm fiber leads 22, 8 of modulator 4 are parallel to the electro-optic axes of the modulator.

Fig. 4 shows a modification of the sensor. (The sensor parts left of the rotator 9 are the same as in any of the previous Figures and for simplicity are not shown in Fig. 4 and 5). Here, there are two unpoled pm fiber sections 2a, 2b put between the sensing fiber 10a, 10b, with the splice 12a to first sensing fiber 10a being a 0°splice, the splice 12b between the unpoled pm fiber sections 2a, 2b being a 90° splice and the splice 12c to second sensing fiber 10b being a 0°splice. Alternatively, the splices between 10a/12a and 12b/10b may both be 90°-splices. The unpoled sections 2a, 2b are preferably of circular cross-section and facilitate the connection of e.g. two poled fibers with D-shape. Direct splicing of two D-shaped fibers (as described above) with a 90°-offset in the core orientation is more difficult. The two unpoled sections 2a, 2b are preferably identical in type and length and joined with a 90°-splice in order to keep the total path imbalance of the orthogonal modes at zero.

Alternatively, and as shown in Fig. 5, one of the unpoled fiber sections 2a, 2b may be between Faraday rotator 9 and first poled sensing fiber 10a, connected to first sensing fiber 10a by means of splice 12d. The splices are again oriented in such a way that the path imbalances in 12a/12b cancel each other. Alternatively one of the unpoled fiber sections 2a, 2b can be arranged between second poled sensing fiber 10b and reflector 15 (not shown).

In the embodiments shown so far, we have:

a control unit 1 for sending light at least once through the first fiber 10a, a coupling (either formed by splice 12 or by unpoled fibers 2a, 2b and their splices) and through the second fiber 10b;

- a control unit 1 adapted to measure a phase delay suffered between
  - light waves that travel through first fiber 10a with a polarization along the poling direction y of the first fiber and through the second fiber 10b with a polarization perpendicular to the poling direction of the second fiber and
  - light waves that travel through the first fiber 10a with a polarization perpendicular to the poling direction y of the first fiber and through the second fiber 10b with a polarization along the poling direction 10b of the second fiber.

The above described scheme of reciprocal phase modulation using a Faraday rotator is particularly advantageous, but the measurement can also be carried out by means of a more conventional polarimetric set-up. Preferably, the two orthogonal light waves, after having passed fibers 10a, 10b, are sent through another pair of identical polarization maintaining fibers that are part of the detection system and are again joined with a 90° splice. Subsequently, the waves are brought to interference at two polarizers oriented at +/-45° with respect to the fiber axes. The resulting interference signals are of opposite phase. The difference of the two signals is fed to a phase controller which maintains the differential phase of the interfering waves at quadrature. Quadrature may be adjusted by means of a piezoelectric modulator which controls the length of one of the pm fibers, see Ref [5]. Fibers 10a, 10b may be operated in transmission or in reflection in this context.

Poled fibers:

The sensing fibers 10a, 10b of the above devices need to be transversally poled (or need to have at least a transverse poling direction component) in order to exhibit a linear electro-optic effect.

The thermal poling of glass fibers has been described e.g. in WO90/08970 as well as in Ref [3] and [4]. Fiber poling is achieved by applying to the fiber core region a high transverse electric field at elevated temperatures, e.g. at 300°C. The field causes a rearrangement of electric charges. As a result, a permanent electric field 28 (see Fig. 6) remains frozen within the fiber after the fiber has been cooled down to room temperature under the applied poling field. The poling-induced anisotropy leads to an electro-optic effect which varies linearly with an applied electric field.

Often, the poling electric field is generated by applying a voltage of a few kilovolt to electrode wires in two holes 25 in the fiber cladding 26, see Fig. 6. The holes 25 run on opposite sides along the fiber core 27, which forms the fiber's waveguide. For voltage sensing it is advantageous to use a birefringent fiber (i.e. a polarization-maintaining fiber, pm fiber), such as an elliptical core fiber, which supports two modes with orthogonal polarization directions (parallel to the slow and fast birefringent fiber axes x and y). In an elliptical-core fiber these are the major and minor core axes. The poling direction is chosen parallel to a birefringent axis (y-direction in Fig. 6).

Once the fiber is poled, an electric field of strength E along y induces an electro-optic index difference for the two orthogonally polarized light waves

$$\Delta n_{eo} = r\ E \qquad (1),$$

where r is an effective electro-optic coefficient, typically on the order of 1 pm/V. The resulting differential electro-optic phase shift of the two waves of wavelength λ in a fiber of length l is then

$$\Delta\varphi_{eo} = (2\pi/\lambda)\cdot\Delta n_{eo}\cdot l \qquad (2).$$

Fields along x or z (z = fiber direction) do not produce any differential phase shift. The field strength E is the effective field strength at the fiber core, which at a given external field strength E′ depends on the dielectric constant and the shape of cross-section of the fiber.

For voltage measurement the fiber (with the wires for poling removed) is e.g. placed on a helical path of constant pitch angle between the two electric potentials, for example ground and high-voltage. The fiber axes are aligned such that at any point along the fiber the poling direction is approximately parallel to the longitudinal axis of the helix, see WO90/08970 and WO 97/01100. It can be shown that the total induced phase shift $\Delta\varphi_{eo}$ then corresponds in good approximation to the path integral $\int E\cdot ds$ along the longitudinal axis of the helix and thus to the voltage to be measured.

In order to facilitate the fiber alignment (alignment of the poling direction) it is of advantage to employ fibers with non-circular fiber cross-section. Examples are shown in Figs. 7, 8 and 9. Fig. 7 shows a fiber with a cladding having D-shape, Fig. 8 a fiber with a cladding having elliptical shape, and Fig. 9 a fiber with a cladding having rectangular or square shape.

Voltage sensor set-up and packaging:

Figs. 10 and 11 show an embodiment of the high voltage measurement device. It comprises a holder 30, which is advantageously a rod with a longitudinal axis 31. Holder 30 is arranged between ground and the high voltage to be measured, with longitudinal axis 31 extending substantially along the electrical field.

Holder 30 has an outer cylindrical surface 32. First fiber 10a and second fiber 10b are helically wound around surface 32, i.e. they run in a bifilar manner along a helical path whose center is at the location of longitudinal axis 31. The helical path has constant pitch angle. The poling directions y of the two fibers are not orthogonal (but essentially constant) with respect to the longitudinal axis 31 such that an electric field along said axis generates a linear electro-optic effect in the fiber's waveguide. Preferably the poling directions are essentially parallel to axis 31.

First fiber 10a and second fiber 10b extend parallel to each other, preferably at a mutual distance smaller than the pitch of their helical paths. Each fiber 10a, 10b extends over the whole length of holder 30 between high voltage and ground.

Fig. 11 shows an exemplary embodiment in which orientations of fiber axes and the poling directions y are shown which are needed to achieve the objectives of cancelling thermal and mechanical phase shifts and doubling the electro-optic phase shifts. The directions of the two polarization modes with respect to the core axes are swapped in the two fiber sections as a result of the intermediate 90°-splice 12.

The two sensing fibers 10a, 10b with waveguides or cores 27 are commonly supported on holder 30. In the embodiment of Fig. 10 and 11, the two sensing fibers 10a, 10b are preferably mounted on opposite sides of a common carrier 33 such that they experience the same temperature changes and mechanical perturbations. Due to the mode swapping between the fibers 10a, 10b the resulting differential optical phase shifts are equal in magnitude, but opposite in sign and therefore cancel each other. Furthermore, the sensing fibers 10a, 10b are mounted with opposite directions of the frozen-in electric field. This measure, in combination with the polarization swapping, doubles the electro-optic phase shift.

Carrier 33 has, in the embodiment of Fig. 11, the form or a ledge protruding from surface 32 and extending helically around holder 30.

In Fig. 11 two sensing fibers 10a, 10b of D-shape are mounted on the top and bottom surfaces of carrier 33 in order to achieve the proper fiber alignment. Alternatively, fibers with elliptical, square or rectangular cross-sections may be used, such as shown in Figs. 6 - 8, which may be wrapped directly to the surface 32 of holder 30, as shown in Fig. 12.

A further alternative is shown in Fig. 13. Here, the two fibers are pre-mounted in grooves 34 of a flexible support strip 33′ acting as a carrier. Subsequently, the strip 33′ is wrapped on the holder 30. This procedure may facilitate the sensor preparation. Furthermore, the fibers are mechanically protected within the grooves 34 during the further packaging of the device (see below). If needed, the grooves 34 may be covered by appropriate lids (not shown).

Fig. 14 and 15 show two options for high-voltage proof packaging of the sensor for outdoor applications. In Fig. 14, holder 30 according to Fig. 10 - 13 is arranged in an insulation housing 35 of silicon that carries a plurality of circumferential sheds 35a. The sheds 35a provide a sufficiently large electric creep distance. The silicone is applied to holder 30 in a mould process, with the fibers 10a, 10b being arranged between holder 30 and insulation housing 35.

Both ends of the device are equipped with metal flanges 36. A similar packaging technique is used for example in the manufacturing of surge arresters. A number of composite rods may be included in the structure to increase its mechanical strength.

In Fig. 15, holder 30 is mounted in a composite insulator tube 37 of fibre-reinforced resin. For electric insulation, the gap between insulator tube 37 and holder 30 is advantageously filled with a solid insulation material 38. An example is polyurethane foam with sufficient compressibility to avoid excessive stresses due to thermal expansion. Other options are dielectric liquids (e.g. transformer oil, silicone oil) or insulating gases (e.g. SF_6, nitrogen, air).

Advantageously, the sensor is equipped with one or several corona rings 39, as shown in Fig. 16, which provide a more homogeneous distribution of the electric field. Fig. 16 also shows two suspension cables 40 for mounting the device.

Further sensor modifications:

Fig. 17 shows the cross section of a poled fiber with two cores 27a, 27b. In this geometry two frozen-in electric fields 28 with opposite directions as indicated are created in the core regions during poling. In this way the two-fiber arrangement depicted in Fig. 11 can be replaced by a single fiber body allowing for even better temperature and vibration compensation. Furthermore, sensor manufacturing becomes simpler.

In general, the present invention is applicable to a device having a first and a second elongate waveguide, which can be formed by a single fiber having two cores or by two fibers having single cores. Advantageously, the waveguides are single-mode waveguides.

When using single-core fibers as shown in Figs. 6 - 9 and 11, the waveguides correspond to the cores 27 of two fibers. The fibers can be mounted to a common holder 30, and in particular to opposite sides of a common carrier 33, 33′, such as shown in Figs. 11 and 13. The two fibers can, however, also be arranged adjacent to each other, and, in particular, they can e.g. be directly welded or glued to each other. In any case, the two fibers should advantageously be of identical design, such that all effects except for electrical-field induced refractive index changes cancel each other.

Alternatively, the two waveguides can be formed by two cores 28a, 28b of a single fiber, such as shown in Fig. 17.

Instead of using a series two pairs of poled fibers as in Fig. 14 several pairs of poled fiber may be arranged in series, i.e. a plurality of pairs of said first waveguides and said second waveguides are arranged in series. Each subsequent poled fiber pair is again arranged on its own cylindrical support body like the first pair. Thus, the voltage sensor may consist of a series of individual modules which in certain applications may give enhanced design flexibility.

Each of the two waveguides or sensing fibers 10a, 10b may be composed of several individual poled fiber segments joint by 0°-splices (optionally with one or two short pm-fiber sections in between the segments, as described above, if they are needed to facilitate the splicing). This approach may be chosen if the maximum fiber length that can be poled is limited, e.g. due to the maximum length of electrode wires or liquid electrode material which can be inserted in the fiber holes.

Instead of an integrated phase modulator a piezoelectric modulator may be used (see e.g. Ref. [3]). Commonly, piezoelectric modulators are used in combination with open-loop detection.

Alternatively to the detection with nonreciprocal phase modulation and a Faraday rotator, a polarimetric detection scheme as described e.g. in Ref. [3]

or in US 5936395 may be employed. Operation of the poled fiber sections in transmission or reflection is possible.

A single light source may be used for several sensors, e.g. for a combination of three sensors in a three-phase high voltage apparatus. The depolarized light is then split by several fiber couplers onto the three sensor channels, for example by a 1:3-coupler followed by a parallel arrangement of three 2:1 couplers. The photodiodes are then at the free exits of the 2:1 couplers. All examples and figures are given for exemplary purpose only and shall neither delimit the claims nor the independent use of preferably features of the invention.

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List of reference numbers

1: control unit
3: light source
2a, 2b: unpoled pm fiber sections
4: phase modulator
5: light detector
6: signal processor
7: pm fiber coupler
8: feed fiber
9: Faraday rotator
10a, 10b: sensing fibers
12a, 12b, 12c: splices
13: pm fiber coupler
12, 14: 90° splices
15: mirror
21: fiber polarizer
22: pm fiber lead
23: splice
25: holes
26: cladding
27, 27a, 27b: core
28: in-frozen field
30: holder
31: longitudinal axis of the holder
32: holder surface
33: carrier
33′: flexible support strip
34: grooves
35: insulation housing
35a: sheds
36: metal flanges
37: composite insulator tube
38: solid insulation material
39: corona rings
40: suspension cables

CLAIMS

1. A high voltage measurement device comprising

a holder (30) for being arranged between two potentials,

a first waveguide being transversally poled in a first poling direction and a second waveguide being transversally poled in a second direction, wherein said waveguides are of identical type and are arranged parallel to each other, wherein each waveguide is adapted to carry at least one optical mode having two orthogonal light polarization directions, and wherein said first and second waveguides are commonly supported on said holder (30) with said first and said second poling directions (y) being anti-parallel, and

a coupling (12) between said first and said second waveguides, wherein said coupling (12) exchanges said polarization directions of said mode.

2. The high voltage measurement device of claim 1, wherein said holder (30) comprises a rod having a longitudinal axis (31) and wherein said first and said second waveguide are wound along a helical path around said axis (31) with said first and said second poling directions not being orthogonal to said longitudinal axis (31).

3. The high voltage measurement device of claim 2, wherein a mutual distance of said first and second waveguides is smaller than a pitch of said helical path.

4. The high voltage measurement device of any of the claims 2-3, wherein said holder (30) has a cylindrical surface (32) around said longitudinal axis (31), and said first and said second waveguide are wound around said surface (32).

5. The high voltage measurement device of any of the preceding claims, wherein said first waveguide

comprises a core (27) of a first fiber (10a) and said second waveguide comprises a core (27) of a second fiber (10b).

6. The high voltage measurement device of claim 5, wherein said first and said second fiber (10a, 10b) are arranged adjacent to each other, and in particular wherein said first fiber (10a) and said second fiber (10b) are glued or welded to each other.

7. The high voltage sensor of any of the claims 5-6, wherein said first and said second fiber (10a, 10b) are of identical design.

8. The high voltage measurement device of claim 5, wherein said first and said second fiber (10a, 10b) are mounted to opposite sides of a common carrier (33, 33'), wherein said carrier (33, 33') is mounted to said holder (30), and in particular wherein said carrier is helically wound around said holder (30).

9. The high voltage sensor of claim 8 wherein said first and said second fiber (10a, 10b) are mounted in recesses on opposite sides of said carrier (33').

10. The high voltage measurement device of any of the claims 1-4, wherein said first and said second waveguides comprise two cores (27a, 27b) of a common fiber.

11. The high voltage measurement device of any of the preceding claims, wherein said holder (30) is arranged in an insulation housing (35), wherein said insulation housing (35) carries a plurality of circumferential sheds (35a), wherein said waveguides are arranged between said holder (30) and said insulation housing (35).

12. The high voltage measurement device of claim 11 wherein said sheds are arranged at an outside of an insulator tube (37), in particular of fibre-reinforced resin, and wherein said waveguides are arranged between said holder (30) and said insulator tube (37).

13. The high voltage measurement device of any of the preceding claims, further comprising

a control unit (1) for sending light at least once through said first waveguide, said coupling (12) and said second waveguide and being adapted to measure a phase delay suffered between

- light waves that travel through said first waveguide with a polarization along the first poling direction and through said second waveguide with a polarization perpendicular to said second poling direction and

- light waves that travel through said first waveguide with a polarization perpendicular to said first poling direction and through the second waveguide with a polarization along said second poling direction.

14. The high voltage measuring device of claim 13, further comprising at least one Faraday rotator (9) arranged between said control unit (1) and said fibers, and in particular wherein said Faraday rotator (9) rotates light by 45° for each pass.

15. The high voltage measuring device of any of the preceding claims, wherein said first and said second waveguide extend parallel to each other.

16. The high voltage measuring device of any of the preceding claims, comprising a plurality of pairs of said first waveguides and said second waveguides arranged in series.

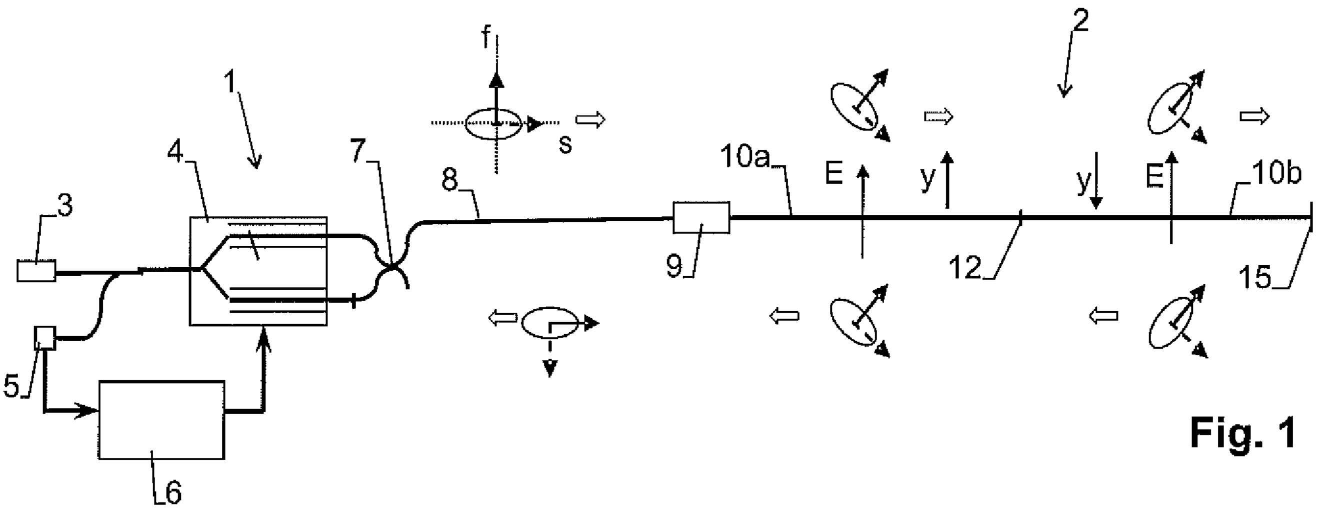
1
2
3
4
5
6
7
8
9
10a
10b
12
15
f
s
E
y
y
E

Fig. 1

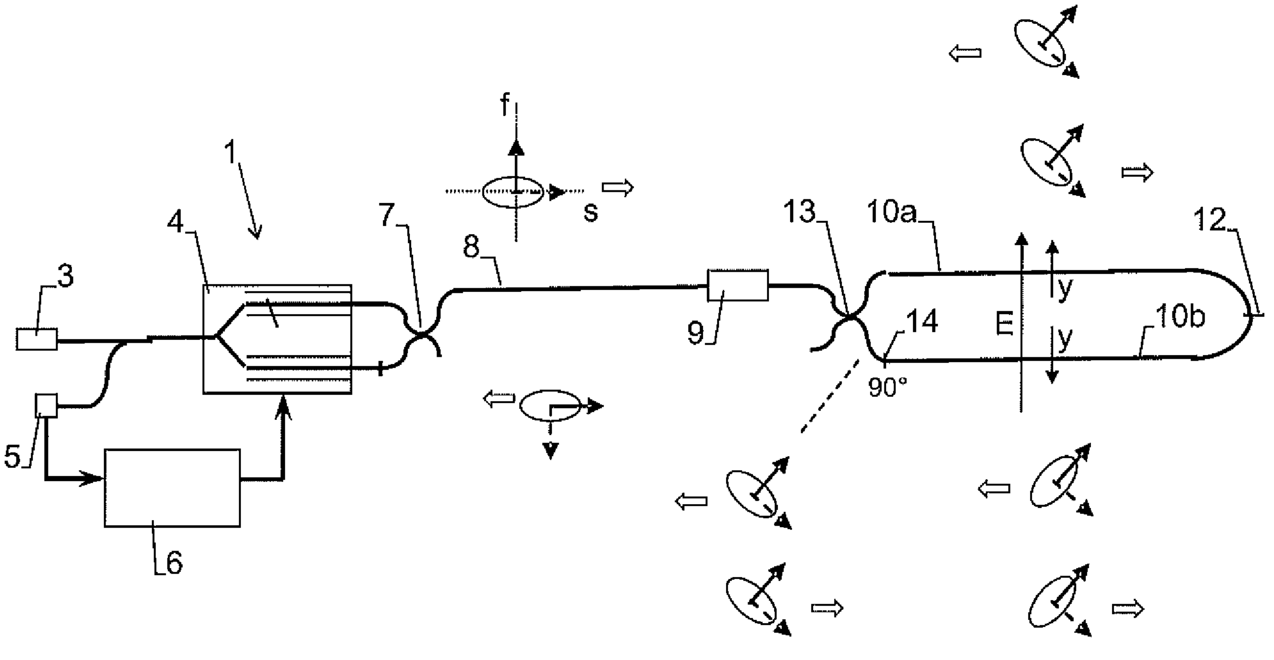
1
3
4
5
6
7
8
9
13
10a
12
14
10b
90°
f
s
E
y
y

Fig. 2

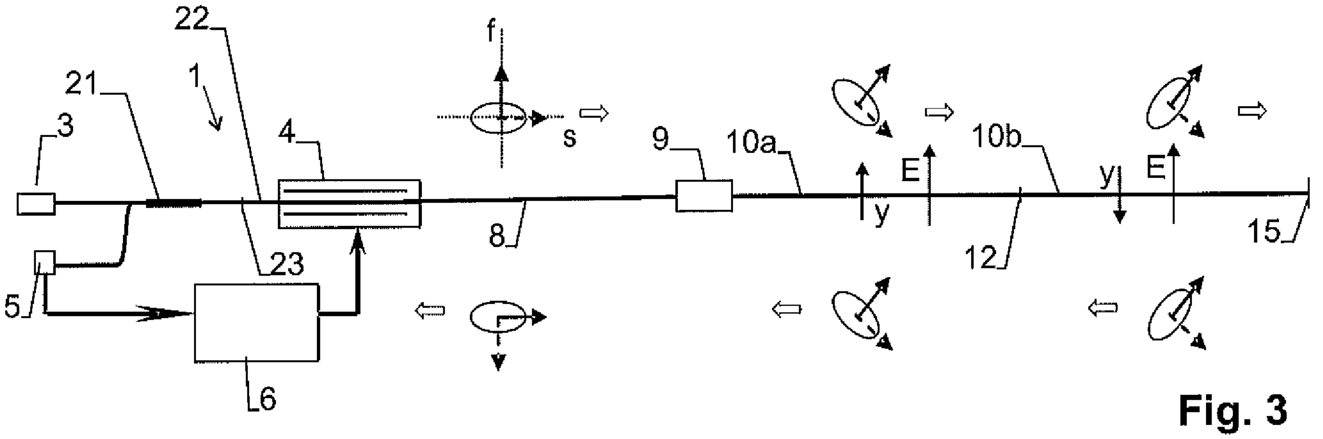

Fig. 3

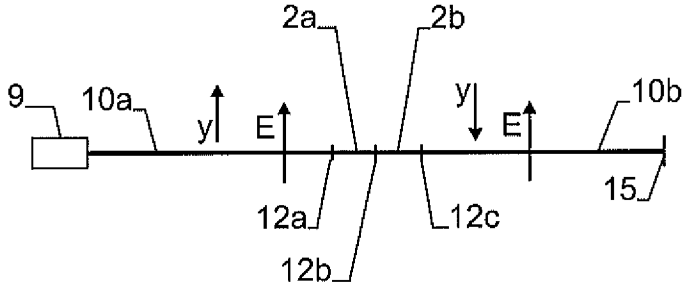

Fig. 4

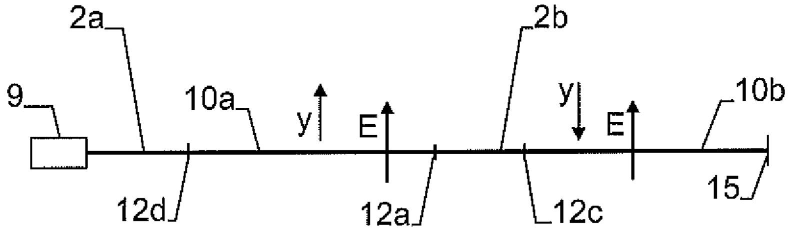

Fig. 5

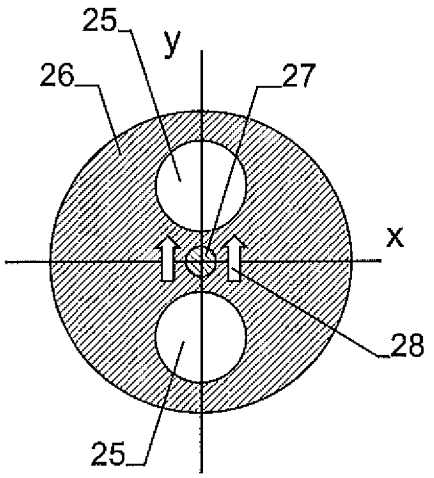

Fig. 6

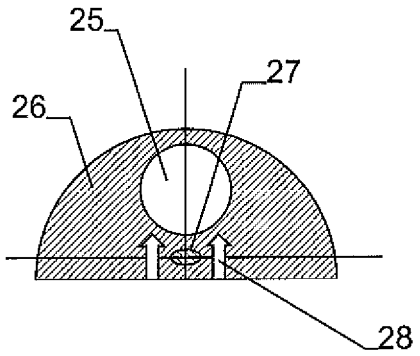

Fig. 7

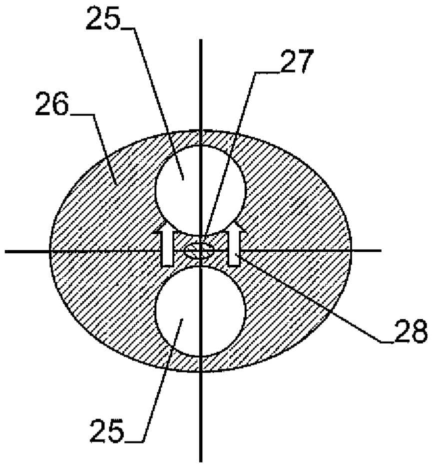

Fig. 8

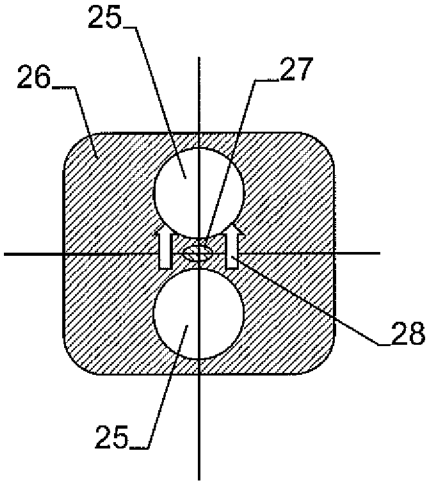

Fig. 9

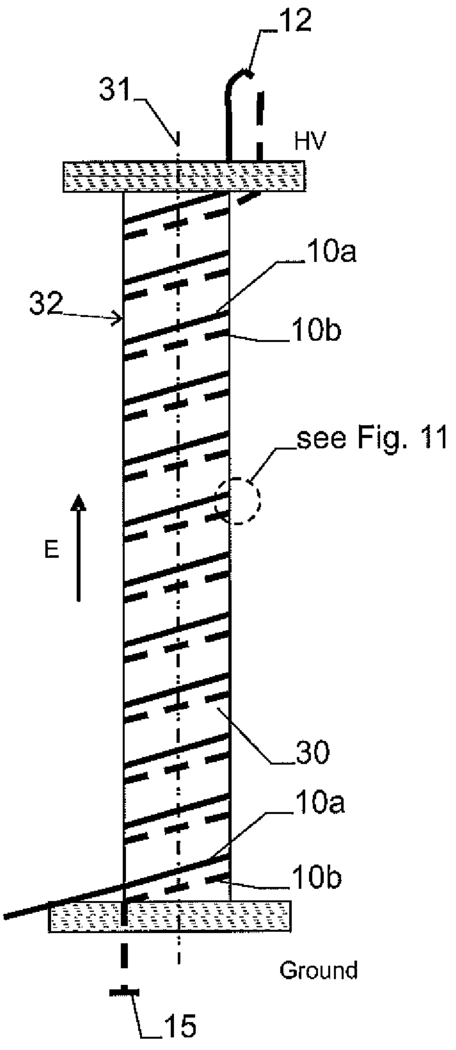
12
31
HV
10a
32
10b
see Fig. 11
E
30
10a
10b
Ground
15

Fig. 10

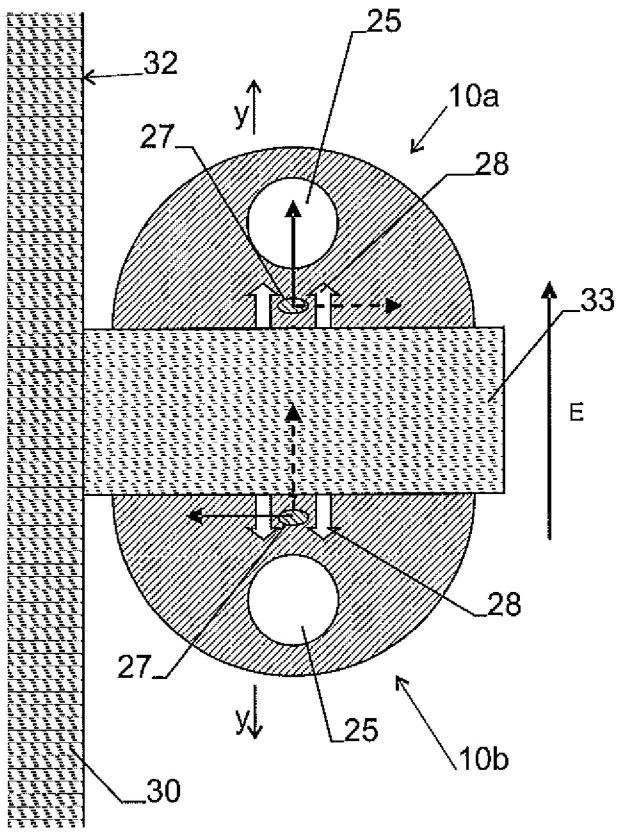
25
32
y
10a
27
28
33
E
28
27
y
25
10b
30

Fig. 11

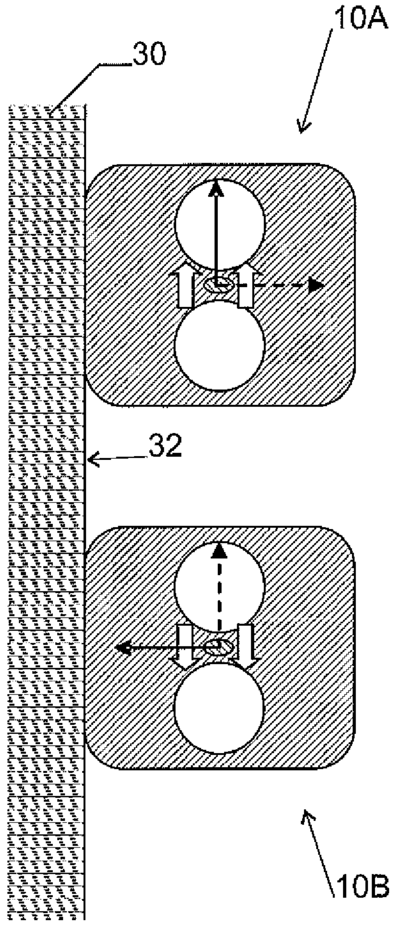

Fig. 12

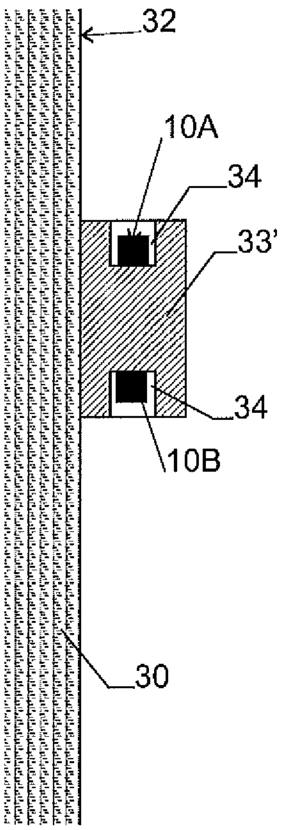

Fig. 13

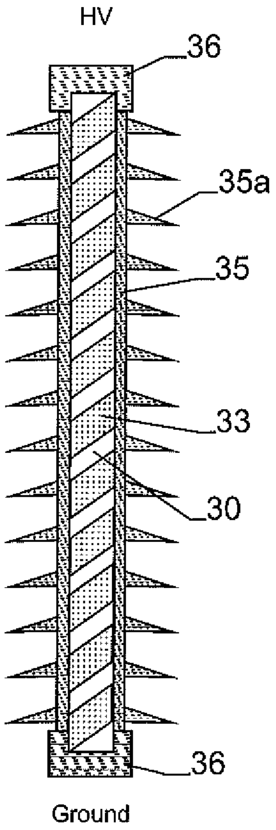

Fig. 14

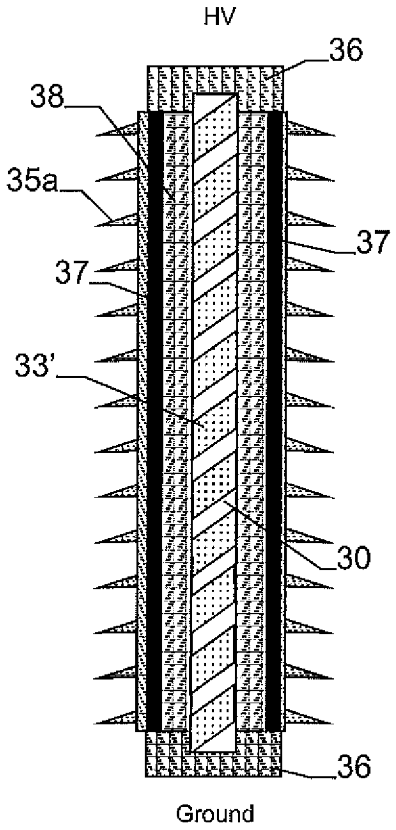

Fig. 15

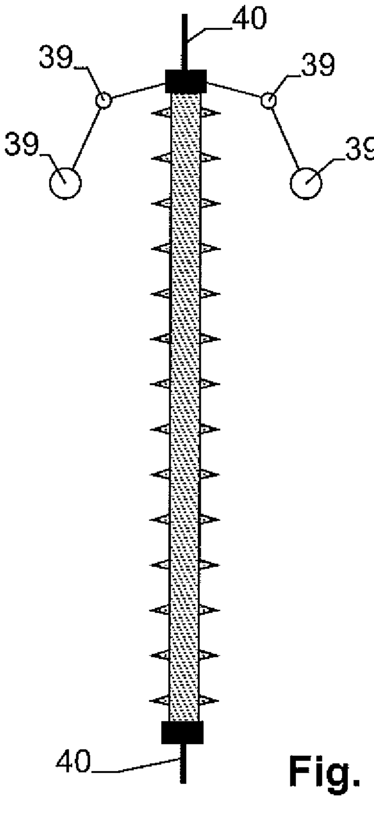

Fig. 16

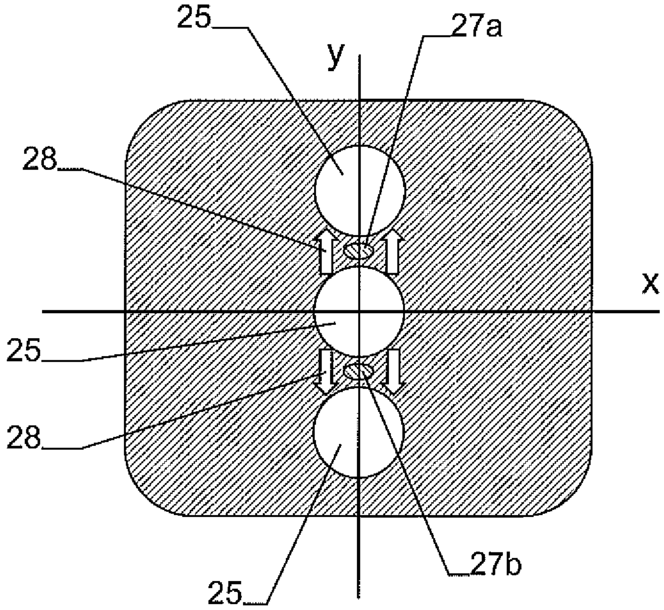

Fig. 17

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/055879

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01B9/02 G01R15/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01B G02B G01R

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 03/023320 A (UNIV SYDNEY [AU]; HAYWOOD JOHN [AU]) 20 March 2003 (2003-03-20) abstract; figure 1 page 2, paragraph 1 - page 7, paragraph 1	1-16
E	WO 2008/077256 A (ABB RESEARCH LTD [CH]; BOHNERT KLAUS [CH]; FRANK ANDREAS [CH]; BRAENDL) 3 July 2008 (2008-07-03) abstract; figure 6 page 12, line 11 - line 21	1-16
A	WO 00/19217 A (HONEYWELL INC [US]) 6 April 2000 (2000-04-06) abstract; figure 2	1-16

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☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search 5 March 2009	Date of mailing of the international search report 19/03/2009
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Ernst, Monika

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/055879

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	BOHNERT K ET AL: "Temperature and Vibration Insensitive Fiber-Optic Current Sensor" JOURNAL OF LIGHTWAVE TECHNOLOGY, IEEE SERVICE CENTER, NEW YORK, NY, US, vol. 20, no. 2, 1 February 2002 (2002-02-01), XP011030114 ISSN: 0733-8724 page 267, column 2, paragraph 4 - page 269, column 1, last paragraph -----	1-16
A	WO 97/01100 A (ASEA BROWN BOVERI [SE]; UNIV SYDNEY [AU]; BJARME MARGARETA [SE]; BASSE) 9 January 1997 (1997-01-09) abstract; figure 1 page 3, line 15 - line 24 -----	1-16
A	EP 1 418 452 A (ABB RESEARCH LTD [CH]) 12 May 2004 (2004-05-12) abstract; figures 1-3 -----	1-16
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A	US 5 625 737 A (SAITO MASAMI [US]) 29 April 1997 (1997-04-29) abstract; figure 2 -----	8,9

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Information on patent family members

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PCT/EP2008/055879

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