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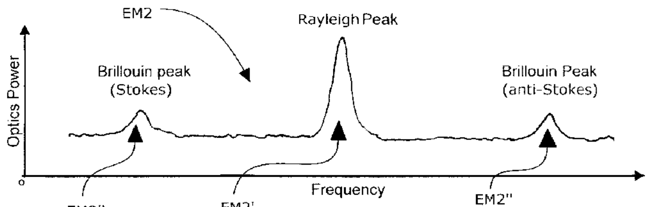

FIG.A

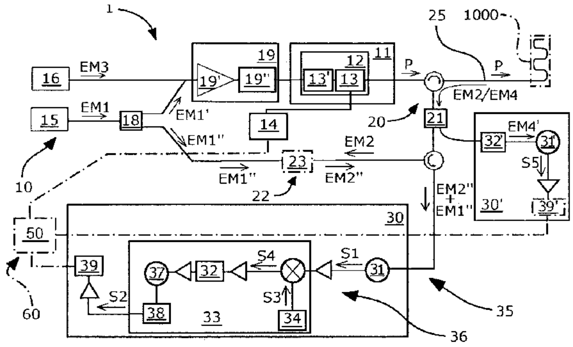

FIG. 1

(57) Abstract: Optoelectronic measuring apparatus (1) (100) comprising emitting means (10) (110) suitable, in use, to generate and modulating the optics power of a plurality of trains (P) comprising a plurality of first electromagnetic pulses presenting a first given frequency and a first duration which can be determined substantially at- will; an optical transmission group (20) (120) for the first electromagnetic pulses comprising a waveguide (25) (125); a detecting group (30,30') (130) suitable, in use, to sample the time-variation of at least an optical feature of at least an electromagnetic radiation (EM2) (EM8); each radiation (EM2) (EM8) having interacted with at least a said train (P) through given Brillouin scattering phenomena at least one portion of said waveguide (25) (125).

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OPTOELECTRONIC MEASURING APPARATUS FOR DISTRIBUTED PHYSICAL CHARACTERISTIC

DESCRIPTION

The present invention relates to a measuring apparatus. In particular, the present invention relates to a measuring apparatus of the optoelectronic type. More in particular, the present invention relates to an optoelectronic measuring apparatus, which can be used to monitor physical characteristics of an architectonic or engineering structure.

BACKGROUND TO THE INVENTION

In the civil engineering sector, and in particular in the field of the construction of structures of great dimensions, such as for example bridges, dams or oil pipelines, the use is well known of measuring apparatuses to monitor continuously structural and/or functional parameters of these structures. In particular, these measuring apparatuses are commonly used to control the trend over time of the temperature or of the strain, i.e. of the relative deformation or elongation, of the respective structure. In more detail, these measuring apparatuses are suitable to give information of local nature, and they can be therefore used to monitor, as a function of the time, the temperature or the strain associated with a plurality of portions and/or of components of the engineering structure to be monitored.

Among the measuring apparatuses used to monitor the status of engineering or architectonic structures, the optoelectronic devices based upon optical fibres have a great significance. In particular, these apparatuses normally comprise an electronic measuring device, provided with an optical fibre probe presenting high extension, usually in the order of a few tens of kilometres. In use, this optical fibre is coupled stably to, and maintained substantially into contact with, portions or components of the engineering structure, whose respective physical parameters shall be monitored. For example, this optical fibre can run along the pipes of an oil pipeline, or it can be immersed in a concrete pillar of a building, so that it can be used to display the local trend of the temperature or of the strain of these elements.

At this point it should be noted that these measuring instruments based upon optical fibres can be subdivided in various types depending upon both the physical quantity/ies they are suitable to measure and the physical principle used to detect this quantity/these quantities. For example, both measuring apparatuses based upon the so-called spontaneous scattering or spontaneous Brillouin scattering, an optical effect commonly indicated by the acronym SPBS, and measuring apparatuses based upon the so-called stimulated scattering or stimulated Brillouin scattering, commonly indicated by the acronym SBS, are well known.

In particular, the measuring apparatuses based upon SPBS are provided with an optical source, for example a laser, suitable to emit, along the respective optical fibre, a plurality of light pulses presenting a duration in the order of a ten of nanoseconds. In use, these light pulses travel along the optical fibre of the probe for all the respective extension, and are subjected, at each segment of this optical fibre, to a process of partial anelastic backscattering, precisely known as Brillouin scattering.

Without the need for deepening the physical mechanisms originating the radiation backscattered by the fibre, it should be noted that, for each electromagnetic Brillouin component, both the optical power and the difference between its own frequency and the carrier frequency of the respective original light pulse depend upon both the temperature and the strain of the portion of optical fibre, wherein the anelastic interaction occurred, which originated this Brillouin component.

It is therefore known that, by monitoring over time both the optical power and the frequency of at least a Brillouin component (Stokes or Anti-Stokes) it is possible to obtain the local temperature and strain of each portion of optical fibre and thus of the respective structural element (pillar, tube, etc.), with which it is coupled.

This technique, which allows measuring the spatial distribution along an optical fibre of at least one given physical quantity by analysing an elastically or anelastically backscattered optical signal, is called Optical Time Domain Reflectometry (OTDR) and represents a development of the common OTDR techniques, which are based upon the elastic backscattering of light and are commonly used to measure the signal loss along the optical fibres used in telecommunications.

An example of an optoelectronic measuring apparatus based upon the Brillouin scattering of light pulses transmitted along a respective optical fibres is described in the scientific article written by Mrs. Sally Maughan *et al* published in 2001 in the volume 12 of the journal "Measurements Science and Technology" (pages 834-842). This article, which is hereunder indicated as Doc1 and whose teachings shall be considered an integral part of the present patent application, presents a device designed for measuring, along an optical fibre of various tens of kilometres, the trend over time of both the local temperature and the local strain of this optical fibre, wherein the term "local" refers to a spatial resolution, which can vary from a minimum of about 1 m to 15-20 m.

However, it should be noted that the device described in the above mentioned article provides for the use of high-power laser pulses, which are necessary to perform measures presenting an acceptable signal-to-noise ratio and being thus reliable. The optoelectronic measuring unit of the measuring device must be therefore provided with highly expensive elements such as, for example, a high peak power laser, for example in the order of hundreds of mW, and at least one pair of optical amplifiers. It is therefore clearly apparent that a so designed measuring device will present such a high cost to prevent the use thereof in the field of the ordinary civil engineering and to limit the use thereof almost exclusively to the field of the specialised research centres or for the safeguard of special engineering structures, such as for example undersea railway tunnels or space stations. Furthermore, the use of high peak power lasers causes a greater wear of the optical components of the measuring apparatus, and it can entails problems as regards the reliability over time of these components, of the laser source and, therefore doubts about the reliability of the performed measures.

Alternatively, it is possible to use measuring apparatuses based upon SBS, wherein each respective optoelectronic measuring device comprises a pair of optical sources, for example lasers, suitable to emit a respective first and second electromagnetic radiations propagating in opposite directions along a common optical fibre. In particular, a first source with reduced optical power emits continuously over time a first substantially monochromatic probe radiation, whilst a second source emits a respective second electromagnetic radiation, which counter-propagates relative to the first radiation along the same optical fibre, in the form of high optical power pulses presenting a given duration, typically in the order of the nanosecond. In more detail, the frequency of the first radiation can be adjusted and it can be set so as to trigger phenomena of optical amplification based upon the stimulated Brillouin effect, wherein the first and the second electromagnetic radiation are suitable to exchange with each other fractions of their respective optical energy. In other words, without deepening the principles of the quantum optics, upon which this phenomenon is based, similarly to what occurs in the phenomena of stimulated emission, upon which the laser effect is based, a fraction of the second electromagnetic pumping radiation backscattered due to the stimulated Brillouin effect is suitable to give part of its own optical energy to the first electromagnetic probe radiation, which will be therefore amplified. Consequently, the gain curve describing, as a function of time, this effect of optical amplification, is linked, as it is well known, both to the temperature and to the strain associated to the various portions of the optical fibre, which are responsible for the SBS of the second electromagnetic pumping radiation. By monitoring the trend over time of this gain curve it is therefore possible to obtain information on the temperature and on the strain associated with these portions of optical fibre and therefore with the architectonical or engineering structure, to which it is stably coupled. This technique, which allows measuring the spatial distribution, along an optical fibre, of at least one given physical quantity by analysing at least one optical signal transmitted through this optical fibre, is called Optical Time Domain Analysis or OTDA. It should be noted that, relative to the measuring techniques based upon SPBS, the techniques based upon SBS, even if more effective from the application point of view, present different characteristics and are in particular affected by some disadvantages. In particular, the performances of measuring are limited by the presence of effects of depletion of the optical pump and by non-linear effects such as the instability in the modulation of the probe radiations (Modulation Instability) when the peak power of this latter achieves particularly high values. These effects cause distortions in the acquired OTDA traces, limiting the signal-to-noise ratio of the acquired signals, and therefore the spatial resolution and the accuracy of the performed measurements of temperature and deformation.

Therefore, in view of the above description, the problem of having available an optoelectronic measuring apparatus, which is suitable, in use, to measure contemporaneously the change over time both of the local temperature and of the local strain of an engineering or architectonical structure, is currently solved in a dissatisfactory manner and represents an interesting challenge for the Applicant, which has the object of providing a measuring apparatus, which is at the same time economical and reliable.

In particular, in view of the state of the art described above, it would be desirable to have available an economical and reliable optoelectronic measuring apparatus based upon the SPBS or upon the SBS inside an optical fibre of low frequency electromagnetic pulses, which present an accuracy and a quality of measurement which can be compare with that obtained through measuring apparatuses functioning with high power laser pulses and, at the same time, a greater reliability over time.

SUMMARY OF THE PRESENT INVENTION

The present invention relates to a measuring apparatus. In particular, the present invention relates to a measuring apparatus of the optoelectronic type. More in particular, the present invention relates to an optoelectronic measuring apparatus, which can be used to monitor physical characteristics of an architectonic or engineering structure.

The object of the present invention is to provide a measuring apparatus, which allows the disadvantages described above to be solved, and which is suitable to satisfy a plurality of requirements that to date have still not been addressed, and therefore suitable to represent a new and original source of economic interest and capable of modifying the current market of measuring apparatuses.

According to the present invention, a measuring apparatus is provided, whose main characteristics will be described in at least one of the appended claims.

A further object of the present invention is to provide a measuring method, which can be validly used to monitor continuously physical characteristics of a given body.

According to the present invention, a measuring method is provided, whose main characteristics will be described in at least one of the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

Further characteristics and advantages of the measuring apparatus according to the present invention will be more apparent from the description below, set forth with reference to the accompanying drawings, which illustrate some non-limiting examples of embodiment, in which identical or corresponding parts of the device are identified by the same reference numbers. In particular:

- figure A illustrates a spectrum of backscattering of a monochromatic electromagnetic radiation transmitted along an optical fibre;
- figure 1 is a schematic block view of a first preferred embodiment of a measuring apparatus according to the present invention;
- figure 2 illustrates a second preferred embodiment of figure 1;
- figure 3 illustrates diagrams of the optical power associated with electromagnetic pulse trains generated, in use, inside the measuring apparatus according to the present invention;
- figure 4 illustrates a frequency spectral decomposition of an electric signal associated with an electromagnetic radiation generated through spontaneous Brillouin effect, and a numerical reconstruction of the variation along an optical fibre of a frequency spectrum of this electromagnetic

Brillouin radiation;

- figure 5 illustrates a third preferred embodiment of figure 1;
- figure 6 illustrates, in enlarged scale, a detail extracted from figure 5;
- figure 7 illustrates a third preferred embodiment of figure 1;
- figure 8 illustrates a fourth preferred embodiment of figure 1; and
- figure 9 illustrates diagrams of the optical power associated with electromagnetic pulse trains generated, in use, inside the measuring apparatus according to the present invention.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

In figure 1 number 1 indicates, in its entirety, a measuring apparatus of the optoelectronic type, which can be used to monitor continuously over time physical characteristics of a given body 1000. In particular, as it will be clearly apparent from the description below, the measuring apparatus 1 is preferably suitable to measure locally the temperature and the relative elongation, or strain, of the body 1000, which can comprise, for instance, an architectonical or engineering structure such as a bridge or a skyscraper, but also an oil platform or a pipeline. At this end, the measuring apparatus 1 is provided with a probe 25 presenting a given extension L, which, in use, is arranged into contact with the body 1000 and allows to carry out local measurements of the physical properties of this body, i.e. measurements suitable to give information about the physical characteristics of limited portions of the body 1000. Therefore, by using a probe 25 presenting an extension L adequately commensurate with the dimensions of the body 1000, it will be possible to know a physical status of the entire body 1000 by monitoring, for instance, the local temperature and/or the local strain of a plurality of contiguous portions of the body 1000.

With particular reference to figure 1, the measuring device 1 comprises an emitting group 10 associated with or provided with a first electromagnetic source 15, suitable to produce continuously a first substantially monochromatic electromagnetic radiation EM1 and presenting a first carrier frequency F and a given optical power I0 constant over time.

At this point, it should be noted that hereinafter reference will be made to a first electromagnetic source 15 comprising a laser 15 of the known type, for example an external cavity laser or a distributed feedback laser (DFB), suitable to generate an electromagnetic radiation presenting preferably, but without limitation, a first given frequency F in the order of 193 THz. However, it should be noted that this design choice has a purely arbitrary character, and it does not represent a limit to the generality of the present invention, whose respective measuring apparatus 1 can be designed so as to use electromagnetic sources of different type.

Similarly, it should be noted that hereinafter the terms generally used in the field of optics will be used, without however being limited to the field of the visible light, but, on the contrary, each term related to the optics has been interpreted in its widest meaning and, therefore, taking into account each electromagnetic radiation, which substantially respect the laws of the wave optics and/or of the geometric optics, for example, electromagnetic radiations in the infrared range.

With reference to figure 1, it should be noted that the emitting group 10 comprises a first optical element 18, suitable to subdivide the first electromagnetic radiation EM1 in a first fraction EM1' and in a second fraction EM1'', presenting respectively optical powers I0′ e I0′′. By way of example, this first optical element 18 can comprise an optocoupler, or optical coupler, suitable to serve as beam splitter. At this point, the first fraction EM1' is sent to an amplifying device 19 suitable, in use, to amplify the optical power I0' of the first fraction EM1' until a given peak value, preferably in the order of the tens of mW. In particular, the amplifying device 19 preferably comprises an optical amplifier 19', for example an EDFA amplifier based upon an erbium doped optical fibre, connected in series with a first band - pass optical filter 19'' presenting a given pass band, for example of 0.5 nm, to filter noise originated during the amplification process. However, it should be highlighted that, if the laser 15 presents a peak power sufficiently high for all the required applications, the presence of the amplifying device 19 is not strictly necessary and, as illustrated in figure 2, it can be omitted so as to reduce production and maintenance costs of the measuring apparatus 1.

With reference to figure 1 again, the emitting group 10 comprises a modulation device 11 designed so as to receive the first fraction EM1' and suitable, in use, to modulate the variation over time of the respective optical power of the fraction, so as to generate at least a train P of first electromagnetic pulses P'. These first pulses P' are substantially monochromatic, present the same carrier frequency F as the first electromagnetic radiation EM1, present a first given duration D' and can be emitted in sequence by the emitting group 10 substantially continuously. In use, each train P of first electromagnetic pulses P' presents a second given duration D1, during which up to a first given number N of first pulses P' can be emitted. In particular, the trains P are generated periodically according to a given period T and, as it will be better described below, they all comprise preferably the same number of first pulses P'.

With reference to figure 1, the modulation device 11 comprises an optoelectronic modulation unit 12 connected to a first control unit 14, which can be used to adjust the trend over time of the optical power I associated to each train P and therefore suitable to determine the first duration D', the optical power and the first given number N that are associated to the first electromagnetic pulses P'.

At this end, the first control unit 14 can preferably comprise a programmable wave-form generator or, alternatively, it can be interfaced with, or implemented through, a computer 50 suitable, in use, to send reference wave-forms to the modulation unit 12, according to which to modulate over time the optical power I associated to each train P. In more detail, the modulation unit 12 comprises preferably, but without limitation, a Mach-Zehnder interferometer 13, coupled in series to a polarisation controller 13' and connected to the first control unit 14 to modulate over time the optical power I associated with the pulses P according to respective reference wave forms.

At this point, with reference to figure 3, it should be noted that the optical power associated to each train P will be modulated according to a code C, preferably of the binary type, so as to associate to each train P a word, written according to this code C, that for the sake of simplicity will be indicated hereinafter with the same letter P. In particular, according to this binary code C, to each electromagnetic train P' a bit is associated so that each word P is composed exactly by a first given number N of characters.

Therefore, with reference to figure 3 again, the optical power I associated to each train P will present, according to the time, a stepped profile, wherein to each relative minimum and to each relative maximum one or more bit will be associated, presenting respectively the binary values 1 and 0. In particular, it should be noted that the minima of the optical power I can be equal to zero, as illustrated in figure 3a, or they can present a non null value, as illustrated in figure 3b, however hereinafter the term "train P of electromagnetic pulses" will be used to indicate, in its entirety, only a single physical entity presenting a second duration D1 even if this, as illustrated in figure 3a, is divided into a plurality of distinct packets due to the presence of a bit with binary value 0, or, in other words, of first pulses P' with null optical power. Furthermore, it should be noted that each first pulse P', even if it maintains the respective first duration D', can be of the NRZ, i.e. non-return to zero, type, as illustrated in figures 3a and 3b, or of the RZ, i.e. return to zero, type, as illustrated in figure 3c. In more detail, the pulses of the NRZ type present a constant optical power for all the respective first duration D', whilst the pulses RZ present an optical power different than zero, or anyway different than a base value associated to a bit equal to zero, only for a given fraction of the first duration D', for example 20% or 50%, as illustrated in figure 3c. In this regard it should be noted that the use of a train of first pulses P' of the RZ type allows obtaining same amplification or optical Brillouin depletion value for each bit inside the code words, and therefore, as no normalisations are required, it is much more effective from the application point of view.

At this point, it should be useful to highlight that to each train P are associated, for example, 127 or 255 bits, and therefore respectively 127 or 255 first pulses P', and that each word P has been coded according to the code C, known as Simplex code. However, it should be noted that this choice does not represent a limit to the present invention, which can be correctly implemented also by using binary codes C of different type, for example, although without limitation, Golay codes.

Therefore, in view of the above description, it is clearly apparent that the emitting group 10 is suitable to emit in a periodic manner trains P of first electromagnetic pulses P', whose optical power I is modulated so as to associate to each train P a respective word P of the given code C containing a first given number N of bits.

With reference to figure 1 again, the measuring apparatus 1 comprises an optical transmission group 20 provided with the probe 25 and designed so as to receive each train P and to transmit it along the probe 25. In particular, the probe 25 comprises a wave guide 25 suitable to transmit each train P for all the respective linear extension L. In more detail, for example with reference to each preferred embodiment wherein the first frequency F is contained within the infrared electromagnetic spectrum, the wave guide 25 can comprise, without limitation, a first optical fibre 25.

At this point it should be noted that the phenomenon is well known, wherein, when an electromagnetic pulse is transmitted along a respective wave guide, each segment of this latter interacts with this electromagnetic pulse, backscattering a small fraction of the respective optical energy. In particular, this backscattering phenomenon can be interpreted as the superimposition of a phenomenon of elastic scattering, wherein a fraction of the electromagnetic radiation transmitted along the wave guide is backscattered without any variation in the respective carrier frequency, with a phenomenon of anelastic scattering, wherein the electromagnetic radiation is diffused after having been subjected to at least a variation in its carrier frequency.

Therefore, in use, sending a first train P of first electromagnetic pulses P' along the first optical fibre 25 generates a second electromagnetic radiation EM2, formed by the superimposition of all the fractions of this train P which are backscattered from respective portions of the first optical fibre 25 as the pulse travels along the linear extension L of this first optical fibre 25. In particular, this second radiation will present a first component EM2' elastically scattered and therefore centred on the first carrier frequency F and at least a second component EM2'' presenting a second given frequency FB.

At this point it should be noted that, during each backscattering process, a plurality of distinct anelastic scattering phenomena can occur, to each of which the creation will be associated of a different second electromagnetic component EM2'' of the second radiation EM2, and each of these components will present a respective frequency different from the first frequency F. However, hereinafter only the second components EM2'' will be taken into consideration, generated from that phenomena of optical backscattering known as "spontaneous Brillouin effect", or SPBS, that, as illustrated in figure A, entail, at the first optical order, the creation of two second components EM2'' of the second electromagnetic radiation EM2, presenting respective second frequencies FB arranged in a manner spectrally symmetric relative to the first carrier frequency F.

At this point it should be noted that hereinafter with the term "spontaneous Brillouin effect" reference will be made to any anelastic scattering phenomenon, which can be interpreted, according to the quantum physics, as an interaction between the photons that form the first electromagnetic pulses P and acoustic photons, which propagate along the wave guide 25. Furthermore, as it is clearly apparent from figure A, the second components EM2'', which are respectively indicated as Stokes and anti-Stokes components, present a greater spectral width and a significantly lower optical power than the first elastically backscattered first component EM2', which is commonly indicated as Rayleigh component.

At this point it is very important to note that the emission of each second radiation EM2 through backscattering will present a third duration D2 substantially double than the time necessary for each train P to cross the first optical fibre 25 along all the respective given extension L. Therefore, with first electromagnetic pulses P' presenting a first given duration D' in the order of the ten of nanoseconds and with a first optical fibre 25 presenting a given extension L in the order of the tens of kilometres, the third duration D2 of emission of each second electromagnetic radiation EM2 will present a value in the order of hundreds of nanoseconds. Consequently, the third duration D2 presents a value which can be about ten thousand times greater than the value of the first duration D' and therefore the emission of each second electromagnetic radiation EM2 can be interpreted as an emission phenomenon substantially continuous over time relative to the periodic emission of the first pulses P'. In addition, in view of the above description, it should be noted that the period T of time, which separates the emission of each two consecutive trains P will present a value twice greater than the third duration D2, so that the second radiation EM2 generated by a given train P does not superimpose the second radiation EM2 generated by the subsequent train P.

At this point, as it is clearly apparent also from Doc1, to which reference shall be made for any further explanation, it should be noted that the value of each second frequency FB and of the optical power IB associated to a respective second Brillouin component EM2'' depends upon the local temperature and the local strain of the portion of first optical fibre 25, which has generated this component during a respective backscattering phenomenon. By analysing the second frequency FB and the optical power IB associated to at least one second Brillouin component EM2'' over a time interval presenting a duration D2, it is therefore possible to identify the linear spatial distribution of temperature and strain along the first optical fibre 25. In particular, the mathematical formulae and the empiric parameters which link the characteristics of each second Brillouin component to the linear spatial distribution of temperature and strain along a first optical fibre 25 are well known and illustrated also in the cited Doc1, and therefore it is not necessary to report them herein.

In view of the above description, and as it will be better explained hereunder, the measuring apparatus 1 according to the present invention is therefore suitable to monitor contemporaneously the local distribution of temperature and strain of a body 1000 through the measurement of the frequency and of the optical power associated to at least one electromagnetic component of a train P backscattered through Brillouin scattering.

At this point, with reference to figure 1 again, it should be noted that the transmission group 20 comprises an optical device 22 suitable, in use, to superimpose the second fraction EM1'' of the first electromagnetic radiation EM1 to at least a second component EM2'' of the second electromagnetic radiation EM2. In particular, the optical device 22 comprises preferably a second optical filter 23, suitable to select exclusively a second Brillouin component EM2'' from the respective second radiation EM2 to mix it with the second fraction EM1''. In more detail, this second optical filter 23 can preferably comprise a band-reflection grating or FBG, designed so as to be passed by the second fraction EM1'' (coming from the left in figure 1) and to reflect only a second Brillouin component EM2'', i.e. to reflect a spectral portion of the second radiation EM2 (coming from the right in figure 1) centred around a second given frequency FB. Furthermore, according to the engineering choices, this optical device 22 can or cannot comprise one or more optical elements of the known type, for example optocouplers or optical circulators, to guide the propagation of the second fraction EM1'' and/or of the second radiation EM2 towards a first detecting group 30 of the measuring apparatus 1. As the function of these optical elements is well known, it has been deemed sufficient to indicate them generically in figures 1, 2, and 5, without assigning them a respective reference number.

At this point, before describing in detail the first detecting group 30, it should be advisable to specify that each second frequency FB is spectrally near to the respective first carrier frequency F. For example, in the example of a first frequency F in the order of 193 THz, the second frequencies FB relating to the second Stokes and anti-Stokes components EM2'' differ from the first carrier frequency F by about ± 11 GHz. In view of the above description, it is therefore clearly apparent that the optical radiation resulting from the superimposition of a second component EM2'' with the respective second fraction EM1' will present a respective electrical intensity, downstream of the photoelectric sensor 31, characterized by interference phenomena modulated according to a third frequency ΔFB substantially identical to the difference between the first frequency F and a second given frequency FB. This third frequency ΔFB is commonly indicated as "frequency shift" of the respective Brillouin component and, as already noted, it is in this example in the order of 11 GHz.

With particular reference to figure 1, the first detecting group 30 comprises a first photoelectric sensor 31, suitable to receive the superimposition of each second component EM2'' with the respective second fraction EM1', to convert it in a respective first electric signal S1, for example an electric voltage signal. This first sensor 31 comprises preferably, although without limitation, a photodiode 31, for example a photodiode of the PIN or APD type, which presents a pass-band greater than the third frequency ΔFB and which is therefore suitable to solve in frequency the modulations of the optical intensity of the radiation incident on it.

In view of the above description it is easy to understand that the first electric signal S1 generated by the photodiode 31 will present beating phenomena modulated according to the third frequency ΔFB and that the spectral characteristics of these beats substantially reflect, unless a scale factor, the spectral characteristics of the second selected Brillouin component EM2''. In other words, the first electric signal S1 can be interpreted, instant by instant, as a spectral image of a component EM2'' centred to a third frequency ΔFB instead that to the respective more high second frequency FB.

Therefore, following the process of optical superimposition performed by the optical device 22, the measurement of the optical power IB and of the second frequency FB of a second Brillouin component EM2'', and of the third frequency ΔFB can be obtained through the analysis of the spectral characteristics of the beats presented by the first electric signal S1.

In particular, with reference to the example of a first frequency F in the order of 190 THz and at a third frequency ΔFB of about 11GHz, the process of optical superimposition of a second component EM2'' with the second fraction EM1'' of the first carrier radiation EM1 and the subsequent conversion made by the first sensor 31 allows to translate the spectrum of the second selected Brillouin component EM2'' from the range of the infrared radiation to the range of microwaves. This method of analysis of a high-frequency signal is known with the name of "measurement" or "coherent detection" and presents the following advantages: first of all, the spectrum of the quantity to be analysed is translated to lower frequency, and this allows using more economical photoelectric sensors 31 presenting a lower pass-band. Furthermore, it should be noted that each second Brillouin component EM2'' presents a very reduced optical power relative to the optical power associated to the respective train P and therefore, if a direct optical measurement is performed, this component risks being below the detection limit of the firs sensor 31 or producing a measurement characterised by a very bad signal-to-noise ratio. Vice versa, the superimposition between each second component EM2'' and a respective second carrier fraction EM1'' of greater optical power allows to make an electromagnetic radiation incident on the first sensor 31, the radiation being provided with an optical power sufficient to originate a measurement, and therefore a first electric signal S1, presenting a high signal-to-noise ratio. Briefly, the set of the optical device 22 and of the first photoelectric sensor 31 can be therefore interpreted as a first opto-electronic coherent detection device 35, which can be used to detect spectral characteristics of a second given component EM2'' of the second electromagnetic radiation EM2.

With reference to figure 1 again, the first detection group 30 comprises a frequency selector 33 connected at the output to the first sensor 31 to take the first electric signal S1, and suitable, in use, to emit a second electric signal S2, almost continuous and presenting, instant by instant, a value of voltage and/or electric current directly proportional to the average spectral amplitude of a respective given single spectral band BS of the first electric signal S1 presenting a respective given spectral width LS. In this regard it should be clarified that, hereinafter, "average spectral amplitude of a given band BS" indicates the integral in frequency, along the respective given spectral width LS, of the amplitude of that spectral portion of the first electric signal S1 associated to this given band BS. In this regard, understanding the concept of average spectral amplitude of a band BS can be facilitated by observing figure 4a, which illustrates a frequency spectrum of a first given signal S1 subdivided into a plurality of respective given bands BS. In particular, from a graphic point of view, the average spectral amplitude of each band BS is, instant by instant, substantially proportional to the respective area of its own frequency spectrum, an example of which relating to a generic instant is illustrated in figure 4.

In particular, the frequency selector 33 can be adjusted and it allows selecting each time the frequency on which is centred the given spectral band BS of the first signal S1 to be isolated. Therefore, the frequency selector 33 can be used to discretise each frequency spectrum of each first signal S1 by subdividing it in a second given number M of given spectral bands BS, of which it will be possible to analyse, independently one of the other, the changes over time of the respective average spectral amplitudes. In more detail, it should be noted that the frequency selector 33 is preferably of the programmable type and it allows varying the second given number M, the given spectral width LS of each spectral band BS and the spectral position of each given spectral band BS, so as to regulate the resolution and the speed of performing the spectral analysis which can be performed through the first detecting group 30, for example, to adapt it to the calculation speed of the computer 50. In any case, the second given number M, the given spectral width LS of each spectral band BS and the spectral position of each given spectral band BS are mutually correlated parameters and the respective values are selected, in use, so that the frequency selector 33 is always suitable to scan a frequency interval sufficiently wide to contain completely each frequency spectrum of the first signal S1. In fact, it should be noted that each second Brillouin component EM2'', and therefore each respective first signal S1, presents an intrinsic spectral width, typically· in the order of tens of MHz, and this signal is suitable to vary, also by many tens of MHz, its frequency position depending upon the temperature and the strain of the various portions which compose the first optical fibre 25. Therefore, in use, the frequency selector 33 will be always suitable to scan a frequency interval presenting a width comprised, for example, between the tens of KHz and the hundreds of MHz.

The frequency selector 33 comprises preferably, although without limitation, an electric oscillator 34, whose carrier frequency can be tuned substantially at will about the third frequency ΔFB. This electric oscillator 34 produces an harmonic third electric signal S3, which is mixed to the first signal S1 to generate a fourth electric signal S4 sent to a third band-pass filter 32 presenting a given pass-band substantially identical to the spectral width LS of the given spectral band BS which one desires to select. In use, the pass-band of the third filter 32 is spectrally fixed, constant over time and centred around a frequency value significantly lower than the third frequency ΔFB, for example in the order of some MHZ. Therefore, in use, this filter 32 will select only that component of the fourth signal S4, and therefore of the first signal S1, which presents beats modulated according respective frequencies falling within its own pass-band. At this point, by varying each time the carrier frequency of the third signal S3 generated by the electric oscillator 34, it will be possible to select the fourth signal S4 so as to select through the third filter 32 a given number M of spectral bands of the fourth signal S4 to produce a complete, but discrete, spectral and time (or equivalently in distance) reconstruction of the first electric signal S1 and therefore of the second optical Brillouin component EM2'' associated thereto.

In view of the above description it is clearly apparent that the functioning principle of the frequency selector 33 is conceptually the same as that of the first opto-electronic coherent detection device 35 and therefore this frequency selector 33 can be interpreted as a second electric coherent detection device 36. It should be furthermore noted that, at reduced costs, the above illustrated configuration gives to the frequency selector 33 an operative speed greater than the electric spectrum analysers currently marketed, which are generally inadequate for the present application.

At this point, each signal exiting from the third filter 32 is sent to a second electric sensor 37 suitable, in use, to convert it into a second electric signal S2 almost continuous and proportional to the average spectral amplitude of the respective spectral band BS selected by the first signal S1. This second sensor 37 can preferably and economically comprise a current rectifier 37 connected in series to a fourth low-pass filter 38, suitable to remove from each second signal S2 electric noise generated from the conversion/rectification process performed by the second sensor 37.

Lastly, it should be noted that the first detection group 30 can comprise, as the case may be, one or more electronic amplifiers of the known type, which therefore in figures 1, 2, and 5 have been generically illustrated without specific reference numbers; these amplifiers can be introduced or not, in the case the intensity of at least one of the electric signals S1-S4 is not sufficient to obtain measurements presenting an adequate signal-to-noise ratio.

Therefore, in view of the above description, the frequency selector 33 can be also interpreted as an electric spectrum analyser 33 with high operative speed and therefore suitable to allow, substantially in real time, a full spectral analysis of each first electric signal S1 associated to a

Brillouin optical component.

With reference to figures 1, 2, and 5, the first detection group ·30 comprises preferably an analog-to-digital converter 39 suitable, in use, to receive and digitalise each second electric signal S2 exiting from the frequency selector/spectrum analyser 33. Once it has been digitalised by the converter 39, each second signal S2 can be acquired by the computer 50 which, as it will be better explained hereunder, is suitable to process these data in order to reconstruct a spectrum of the second Brillouin component EM2'' and to decode information coded in this spectrum, according to the given code C, during the phase of modulation of the first pulses P'. Therefore, the computer 50 is suitable both to control the/to act as, first control unit 14 for controlling the coding of the words P, and to act as decoder 60 of the information coded in each first signal S1 according to the given code C.

At this point, with reference to figure 1 again, it should be noted that the emitting group 10 comprises a second electromagnetic source 16, for example a wide-band laser, suitable to produce continuously a third electromagnetic radiation EM3 preferably centred on the same carrier frequency F of the first electromagnetic radiation EM1. In use, this third radiation EM3 is sent to the modulation device 11 alternatively to the first electromagnetic radiation EM1 so as to be modulated in the form of second pulses p'' presenting an optical power and a duration given and constant over time.

Each second pulse p'' is transmitted along the first optical fibre 25 so as to generate a respective fourth electromagnetic radiation EM4 backscattered by at least a portion of this optical fibre 25. Clearly, each fourth radiation EM4 will present at least one third Rayleigh component EM4', generated by the elastic backscattering of the third electromagnetic radiation EM3. Furthermore, it should be specified that the process of emission of each electromagnetic radiation EM4 presents a fourth duration D4, which is substantially identical to the third duration D2 of emission of each second radiation EM2. At this point, each fourth radiation EM4 is sent to a second optical element 21 associated to the optical transmission group 20 and suitable, in use, to act as beam splitter and therefore suitable to send a given fraction of each fourth electromagnetic radiation EM4 to a second detecting group 30'. This second detecting group 30' comprises a fourth pass-band optical filter 32' designed so as to select exclusively each third Rayleigh component EM4' and to send it to a third sensor 31' which comprises, for example, a photodiode 31' of the PIN type and is suitable to convert each third component EM4' into a respective fifth electric signal S5 representing the variation over time, and therefore the linear distribution along the first optical fibre 25, of the optical power associated to this third component EM4'. Each electric signal S5, after having been amplified, as the case may be, through an electric amplifier of the known type, for example of the TIA type, is sent to a second analog-to-digital converter 39', so as to be acquired by the computer 50. In case, if one desires to increase the signal-to-noise ratio with which the variation over time of each third Rayleigh component EM4' is measured, it is possible to send in succession a plurality, also a numerous plurality, of second pulses P'' and statistically weight the respective electric signals S5 which have been acquired.

At this point it should be noted that knowing at least one trace presenting a fourth duration D4 and illustrating the variation over time of the Rayleigh radiation backscattered along the first optical fibre 25 allows normalising the data relating to each second Brillouin component EM2'' so as to take into account phenomena of optical attenuation which normally occur along any wave guide/first optical fibre 25. This normalisation procedure is well known and can be performed, for instance, by the computer 50 by applying numerically the so-called Landau-Placzek ratio or "L-P ratio" between the signals acquired by the first detecting group 30, and subsequently processed, and at least a respective fifth signal S5 acquired by the second detecting group 30'.

At this point, it should be specified that modifications and variants can be made to the measuring apparatus described and illustrated herein, without however departing from the protective scope of the present invention.

For example, figure 2 illustrates a second preferred embodiment of the measuring apparatus 1, wherein a second source 16 is not provided usable for measuring the Rayleigh component, but the first substantially monochromatic source 15 is used both to generate each train P of first pulses P' and each second pulse p''.

In this regard it should be noted that the transmission of substantially monochromatic pulses along an optical fibre can generate phenomena known as "coherent Rayleigh noise", due to phenomena of self-interference between the radiation sent along this optical fibre and the radiation (almost) elastically backscattered from distinct portions of the optical fibre. The presence of coherent noise does not interfere with the measurement of the backscattered Brillouin components, but makes the measurement of the Rayleigh component associated to the second pulses P'' difficult and therefore in this second preferred embodiment, the emitting group 10 is provided with a second control unit 17, controlled, as the case may be, by the computer 50 and suitable to adjust the power, and as the case may be the frequency, of emission of the first source/laser 15 to originate dithering phenomena which can be used to minimise this coherent Rayleigh noise until values lower than the percentage point of the emitted optical power and therefore substantially negligible.

In more detail, the first source 15, in use, maintains an emission optical power constant and substantially identical during the emission of each train P, whilst the emission optical power will be modulated by the second control unit 17 every time second pulses p'' must be generated, finalised to measure the intensity of the third Rayleigh component EM4'. Alternatively, it is possible to reduce the effect of the coherent Rayleigh noise on the measurement of the intensity of the Rayleigh radiation backscattered from the first optical fibre/probe 25, by mutually mediating algebraically the intensities of a plurality of third components EM4' generated by the backscattering of second pulses P'' emitted with carrier frequencies slightly different from each other, so as to minimise the contribution of the peaks of coherent Rayleigh noise on the evaluation of the intensity of the Rayleigh radiation associated to each train P.

Figure 2 furthermore illustrates a second configuration of the transmission group 20 relative to that illustrated in the first preferred embodiment of figure 1. In particular, in this second configuration, the optical device 22 does not comprise a band-reflecting filter 22 to perform the mixing of the second fraction EM1'' with a single second Brillouin component EM2'', but the second fraction EM1'' is optically superimposed together with a second electromagnetic radiation EM2 backscattered from the first optical fibre 25 by means of a third optical element 26 suitable to act as optical coupler. It should be noted that this configuration is simpler and more economical than the configuration illustrated in figure 1, but it can be validly used only when the optical power associated to the first Rayleigh component EM2' is substantially negligible relative to the optical power associated to the second fraction EM1'' of the first electromagnetic radiation EM1. In any case it should be noted that the presence of a second source 16 and the absence of the second filter 22 are mutually distinct characteristics which can be implemented or not, independently one of the other in each measuring apparatus 1 according to the present invention.

Lastly, in figure 5 a third preferred embodiment is illustrated of the measuring apparatus 1, which presents a further variant of the optical transmission group 20, wherein the optical device 22 comprises an optical frequency changer 24, which is suitable, in use, to receive the second fraction EM1'' and to emit a fifth electromagnetic radiation EM5 presenting a fourth carrier frequency F', spectrally arranged between the first carrier frequency F of the first radiation EM1 and the second frequency FB of a second Brillouin component EM2''. For example, with reference to the case of a first frequency F of 193 THz and a third frequency ΔFB of 11 GHz, the fourth frequency F' can present a frequency shift relative both to the first frequency F and to a second given frequency FB in the order, for example, of 5-6 GHZ. With reference to figure 5 again, it is possible to note that the fifth radiation EM5 generated by the optical frequency changer 24 is optically superimposed to the second radiation EM2 coming from the first optical fibre 25, so that the first electric signal S1 associated to this optical superimposition presents, downstream of the first sensor 31, beats, whose respective third frequency ΔFB is substantially identical to the difference between the fourth frequency F' and the second frequency FB of a second given Brillouin component EM2''.

At this point it is clearly apparent that the smaller this difference, the smaller both the pass-band required for the first sensor 31 associated to the detecting group 30 and the carrier frequency of the third electric signal S3 generated by the electric oscillator 34. Therefore, it is possible to state that the use of an optical frequency changer 24 allows measuring characteristics of a second Brillouin component EM2'' using a more economical coherent detection group 30 designed for low frequencies and that can therefore present a lower operative speed relative to the detection group 30 implemented in the previous embodiments of the measuring apparatus 1. At this point it can be advisable to highlight that the optical frequency changer 24 can comprise preferably, although without limitation, a high-speed phase modulator LN, or a high-speed acousto-optic modulator. Alternatively, as illustrated in figure 6, the optical frequency changer 24 can comprise a second optical fibre 24', stably maintained at a given and constant temperature and subjected to a given and constant strain, and a fifth optical band-pass filter 24'' designed to select an optical band centred in the reference value of a given Brillouin component generated by the scattering of the second fraction EM1'' inside the second optical fibre 24'. Therefore, in use, the optical frequency changer will be suitable to generate a fifth radiation EM5, which presents a fourth carrier frequency F' substantially identical to a reference frequency for this given Brillouin component. Consequently, each first signal S1 associated to the superimposition of a second Brillouin component EM2'' with the fifth radiation EM5 will present low-frequency beats, for example in the order of tens or hundreds of KHz, and therefore easily and economically detectable. In particular, the second optical fibre 24' is preferably produced with a material at least partially different from that of the first optical fibre 25, so that the fourth frequency F' does not generate interference phenomena with the second frequency FB of each second Brillouin component EM2''.

Alternatively, a fourth embodiment of the apparatus 1 is possible, wherein the frequency changer 24 is arranged at the input, at the output or associated to the modulation device 11 so that each first pulse P' is emitted with a carrier frequency different relative to the first frequency F of the first radiation EM1 emitted from the first laser source 15. In particular, each first pulse P' will be emitted with such a frequency that the second frequency FB of each respective given second Brillouin component EM2'' will be near the first frequency F of the first fraction EM1' and therefore the value of the difference thereof, i.e. the respective third frequency ΔFB, will be reduced and preferably in the order of the tens or hundreds MHz, similarly to what occurs in the above mentioned third preferred embodiment of the measuring apparatus 1.

At this point, after having illustrated a plurality of preferred embodiments and variants of the measuring apparatus 1, it should be mentioned that the present invention also relates to a measuring method which can be performed through the apparatus 1 and is suitable to measure the linear distribution of at least one physical quantity, for example the temperature and/or the strain, along all the linear extension of the probe/first optical fibre 25.

First of all, this method comprises in particular the phase of generating a first electromagnetic radiation EM1 through a first source 15, followed by a phase of modulating the optical power associated to at least one fraction of this first electromagnetic radiation EM1 through an adequate modulation device 11, so as to generate a plurality of trains P of first pulses P'; these trains P are emitted periodically and present a respective second duration D1, which is substantially equivalent to the product of each first duration D' of each first pulse P' and the first given number N. In more detail, the phase of modulating the optical power associated to at least one fraction of the first radiation EM1 comprises the phase of associating to each train P a respective word P coded according to a given code C, preferably of the binary type.

Then the phase follows of transmitting each train P along a probe 25 of given extension L and the phase of receiving, for each train P, a substantially continuous second electromagnetic radiation EM2 backscattered, both elastically and anelastically due to spontaneous Brillouin effect, by at least one portion of the probe 25.

At this point, the measuring method according to the present invention comprises at least a phase of measuring the variation over time of the optical power IB and of the third frequency ΔFB associated to at least one second given Brillouin component EM2'' of a given second radiation EM2 to obtain from this analysis a measurement of the temperature and/or of the strain associated to each portion of the probe 25. This phase of measuring the variation over time of the optical power IB and of the third frequency ΔFB associated to at least one second given component EM2'' comprises first of all a phase of mixing this second given Brillouin component EM2'' with a further given electromagnetic radiation so that the resulting radiation presents, downstream of the first photoelectric sensor 31, a respective electric power modulated substantially according to a third frequency ΔFB substantially equivalent to the difference between the first frequency F and a second frequency FB.

As illustrated above, this further given electromagnetic radiation can be a fraction of the first radiation EM1 or a fifth radiation EM5 generated by an optical frequency changer 24 starting from a fraction of the first radiation EM1.

At this point, the phase of measuring the variation over time of the optical power IB and of the third frequency ΔFB associated to at least one second given component EM2'' comprises a phase of converting the superimposition of this second given Brillouin component EM2'' with a respective further electromagnetic radiation into a first electric signal S1 through a first photoelectric sensor 31, followed by a phase of analysing the variation over time of the frequency spectrum of this first signal S1 by means of the second electric coherent detection device 36. In more detail, as illustrated above, this phase of analysing the variation over time of the frequency spectrum of the first signal S1 comprises the phase of discretising this frequency spectrum by subdividing it into a second given number M of given spectral bands BS, to each of which a trace OTDR will be associated, and the phase of converting each of these spectral bands into a respective second electric signal S2, preferably of the digital type, which represents the variation over time of the average spectral amplitude of the respective spectral band BS.

In particular, the phase of discretising the frequency spectrum of the first electric signal S1 comprises the cyclical repetition by a given number M of times of a phase of mixing this first signal S1 with a third harmonic carrier signal S3 generated by an oscillator 34 which can be adjusted in frequency to obtain a fourth electric signal S4, followed by a phase of tuning this fourth electric signal S4 relative to the pass-band of a second filter 37 to select a given spectral band of this fourth electric signal S4.

At this point, without representing a limit to the present invention, it should be noted that the phase of converting each of the spectral bands BS in a respective second electric signal S2 can be performed in succession for a given number K of times, at the end of which a phase can be performed of mediating statistically a third given number K of these electric signals S2 to obtain an average signal S2 presenting a signal-to-noise ratio significantly higher. Just by way of example, the third given number K can be in the order of the thousand or tens of thousand.

At this point, the phase of measuring the variation over time of the optical power IB and of the third frequency ΔFB associated to at least one second given component EM2'' of a second given radiation EM2 comprises a phase of numerically reconstructing through a computer 50 the variation over time of the frequency spectrum of this second component EM2'' starting from the digital electrical signals S2 relating to the spectral bands BS of the first signal S1 corresponding to this second component EM2''. In particular, this phase of numerically reconstructing the variation over time of the frequency spectrum of this second component EM2'' comprises the cyclical repetition for a given number of times of a phase of interpolating a given frequency spectrum of the second given component EM2''. In more detail, each phase of interpolating a given frequency spectrum is performed by interpolating with a continuous mathematic function, for example a Lorenz function, a second given number M of experimental points, each of which is associated to a respective spectral band BS. Furthermore, it should be noted that each spectrum reconstructed through interpolation is associated to a given time instant associated to the time of flight of the second radiation EM2 and, therefore, based upon the functioning principles of the OTDR, each spectrum reconstructed through interpolation can be associated to a given linear distance measured along the probe 25. In this regard it can be useful to observe figure 4b, which illustrates an example of frequency spectrum of a second Brillouin component EM2'' reconstructed through interpolation of the experimental points associated to the second electric signals S2.

Therefore, in view of the above description, the set of the phase of discretising the frequency spectrum of a first electric signal S1 in a plurality of spectral bands BS, of the phase of converting each of these spectral bands in a respective second electric signal S2 of the digital type, and of the phase of numerically reconstructing the variation over time of the frequency spectrum of a second given component EM2'', can be interpreted as a phase of performing a digital sampling of the variation over time of this frequency spectrum of a second component EM2'' to allow subsequent operations of numerical-statistical processing and/or operations of decoding information/OTDR traces coded inside this frequency spectrum.

Lastly, the phase of measuring the variation over time of the optical power IB and of the third frequency ΔFB associated to at least one second given component EM2'' comprises a phase of obtaining through the numerical reconstruction of the frequency spectrum of this second component EM2'', a first and a second numerical functions F1 and F2, which represent respectively the trend of the optical power IB and of the third frequency ΔFB as a function of time. This phase can be performed by assigning to each instantaneous value of the optical power IB, and therefore to each point of the first numerical function F1, the integral of the Lorenz function which better interpolates the frequency spectrum of the respective signal S1 in that given instant, as the case may be, by normalising through the use of the Landau-Placzek ratio.

Similarly, it will be possible to assign to each instantaneous value of the third frequency ΔFB, and therefore to each point of the second numerical function F2, the frequency associated to the maximum of the Lorenz function which better interpolates the frequency spectrum of the respective signal S1 in that given instant

At this point, the measuring method according to the present invention comprises a phase of decoding information contained in a fourth number Q of these first and second numerical functions F1 and F2 and originally associated to a given number Q of distinct words P transmitted preferably in succession through respective trains P of first electromagnetic pulses P'.

It should be noted that processes for coding/decoding trains of electromagnetic pulses, in particular infrared, are already known and used in the telecommunication field for example for measuring signal losses along optical fibres.

However, as it will be better illustrated hereunder, these coding methods are not correctly applied in the field of sensors based upon Brillouin scattering phenomena of electromagnetic pulses sent along respective probes/wave guides.

As these coding/decoding methods are known, it is not deemed advisable to deepen the issue, but reference is made to respective technical literature, for example to the article "using Simple Codes to Improve OTDR Sensitivity" by M.D. Jones, published in volume 15, no. 7 of 7 July 1993 of the journal "IEEE Photonics Technology Letters".

In any case, independently of the type of code C used, it should be noted that the result of the phase of decoding information contained in a fourth given number Q of first and second numerical functions relating respectively to the optical power IB and to the third frequency ΔFB is that of generating a third and a fourth numerical functions F1' and F2' which represent respectively measurements of the variation over time of the optical power IB and of the third frequency ΔFB; these measurements associated to the third and to the fourth numerical functions F1' and F2' are not influenced, as the first and second functions F1 and F2, by the presence of the original modulation of optical power of the trains P, and they are furthermore characterised by a signal-to-noise ratio, with equal spatial resolution, significantly better than the signal-to-noise ratio associated to the single measurements relating to the first and second functions F1 and F2. In particular, with reference to a first carrier frequency F of 193 THz, the improvement in the signal-to-noise ratio in the measurement of the optical power IB due to the use of words P of simplex codes of 127 bits is in the order of 7.5dB.

At this point it should be noted that the present measuring method also comprises a phase of normalising the third numerical function F1' relative to the variation over time of the optical power associated to a respective third Rayleigh component EM4', so that the values of the third numerical function F1' take into account phenomena of optical attenuation of the wave guide 25. In particular this phase of normalising the third numerical function F1' is preceded by a phase of optically filtering at least one third component EM4' of a fourth given radiation EM4, and by a phase of converting, through a third photoelectric sensor 31', this first component EM2' in a fifth electric digital signal S5, whose intensity is substantially proportional, instant by instant, to the optical power associated to the respective third Rayleigh component EM4'.

Lastly, the measuring method according to the present invention comprises the phase of calculating the linear distribution of the temperature and of the strain associated with the probe 25, and therefore with respective contiguous portions of the body 1000, applying to the third and fourth numerical functions F1' and F2' empirical formulae, known and cited also in Doc1.

The characteristics of the measuring method according to the present invention will be apparent from the above description and do not require further explanations; however it would be advisable to present some further advantages resulting from the use of the techniques for coding/decoding the optical power associated to the trains P of first electromagnetic pulses P'.

At this end it is important to highlight that it is well known in the field of the traditional OTDR that time, and therefore spatial, accuracy of the measurements of a Brillouin component generated by a given electromagnetic pulse is inversely proportional to the first duration D' of this pulse. For example, for a radiation with carrier frequency of 190

THZ, at a duration of the pulses of 10 ns a linear spatial resolution in the order of a meter can be associated. On the other hand, the signal-to-noise ratio associated to measurements of the optical power and of the frequency of a Brillouin component, and therefore to the measurements of temperature and strains, increases as the optical power increases associated to each pulse, or pulse train, transmitted along the wave guide. Therefore, with the same optical power supplied by the source, the only way to improve the signal-to-noise ratio of the performed measurements seems to be the increase in the duration of each pulse/train of pulses to increase the respective optical energy thereof, but this choice clearly reduces the spatial accuracy of the measurements of temperature and strain. On the other hand, the hypothesis of increasing the optical power supplied by the electromagnetic source entails high costs for producing and maintaining the measuring apparatus that, on the contrary, are to be minimised.

In this scenario, the use of a coding process, which associated a word P of code C to each train P of first electromagnetic pulses P' is a possible solution. In fact, it should be noted that, in this way, to each train P an optical energy will be associated substantially equivalent to the sum of the optical energies of all the first non-null pulses P', i.e. representing a bit of value 1. In particular, with reference to the codes of the Simplex type, these bit are (for a sufficient great number of bits and at least greater than 10) a number substantially equal to the half of the first given number N, and therefore, in the case of N=127, these bits will be in the order of the tens. Therefore, each train P will present an optical energy sufficient to allow measurements of the optical power IB and of the third frequency ΔFB characterised by a good signal-to-noise ratio. Furthermore, the use of the decoding techniques during the phase of analysing the spectrum associated to the Brillouin components allows decoupling the different optical contributions which form each second component EM2'' and which are respectively related to the backscattering of each single first pulse P' associated to a respective train P. In other words, the use of coding/decoding techniques allows to given to each measurement of temperature and/or strain performed by the apparatus 1 both the high spatial resolution associated to a single first pulse P' presenting a short first duration D' and, contemporaneously, the high signal-to-noise ratio associated to a train P presenting a respective optical energy substantially equivalent to the sum of the optical energies associated to all the first pulses P'/bits which forma each word P.

At this point it should be noted that the use of these coding/decoding techniques, which represents the characterising and most innovative aspect of the present invention, can be also applied in a optoelectronic measuring apparatus based upon the Stimulated Brillouin Scattering, or SBS, such as that illustrated in figures 7 and 8, wherein number 100 indicates in its entirety a measuring apparatus of the optoelectronic type, which can be used to monitor continuously over time the temperature and the elative elongation of the given body 1000. The measuring apparatus 100 is provided with a probe 125 presenting a given extension L, which, in use, is arranged into contact with the body 1000 so as to perform a function substantially equivalent to that of the probe 25 previously described. Always with particular reference to figure 7 again, the measuring device 100 comprises an emitting group 110 associated with or provided with a given electromagnetic source 115, suitable to produce continuously a sixth given substantially monochromatic electromagnetic radiation EM6, presenting a first carrier frequency G and a given optical power J0 constant over time.

At this point, it should be noted that hereinafter reference will be made to a given electromagnetic source 115 comprising a laser 115 of the known type, for example an external cavity laser or a distributed feedback laser (DFB), and suitable to generate an electromagnetic radiation presenting preferably, although without limitation, a given fifth frequency G in the order of 193 THz. However, it should be noted that this design choice has a purely arbitrary character, and it does not represent a limit to the generality of the present invention, whose respective measuring apparatus 100 can be designed so as to use electromagnetic sources of different type. With reference to figure 7, it should be noted that the emitting group 110 comprises a first optical element 118, suitable to subdivide the sixth electromagnetic radiation EM6 in a third fraction EM6' and in a fourth fraction EM6'', presenting respectively optical powers J0′ and J0′′. By way of example, this first optical element 118 can comprise an optocoupler, or optical coupler, suitable to serve as beam splitter. In this regard it should be noted that the first optical element 118 is designed so as to subdivide the given optical power J0 of the sixth radiation EM6 so that the third fraction EM6' presents a respective optical power J0' significantly higher than the optical power J0'' associated to the fourth fraction EM6''. By way of example, the third fraction EM6' will present preferably an optical power J0' comprised between the 80% and the 90% of the optical power J0, whilst to the fourth fraction EM6'' a remaining optical power J0'' will be associated, in the order of the 5-20% of the optical power J0 of the sixth radiation EM6.

At this point, the third fraction EM6' is sent to an amplifying device 119 suitable, in use, to amplify the optical power J0' of the third fraction EM6' until a given peak value, preferably in the order of the tens of mW. In particular, the amplifying device 119 preferably comprises an optical amplifier 119', for example an EDFA amplifier based upon an erbium doped optical fibre, connected in series with a first band-pass optical filter 119'' presenting a given pass band, for example of 0.5 nm, to filter noise originated during the amplification process. However, it should be highlighted that, if the laser 115 presents a peak power sufficiently high for all the required applications, the presence of the amplifying device 119 is not strictly necessary and, as illustrated in figure 8, it can be omitted so as to reduce production and maintenance costs of the measuring apparatus 1.

With reference to figure 7 again, the emitting group 110 comprises a first modulation device 111 designed so as to receive the third fraction EM6' and suitable, in use, to modulate the variation over time of the respective optical power of the fraction, so as to generate at least a train P of first electromagnetic pulses P'. These first pulses P', similarly to what described with reference to the measuring apparatus 1, are substantially monochromatic, present the same carrier frequency G as the sixth electromagnetic radiation EM6, present a first given duration D' and can be emitted in sequence by the emitting group 110 substantially continuously. In use, each train P of first electromagnetic pulses P' presents a second given duration D1, during which up to a fifth given number N' of first pulses P' can be emitted. In particular, the trains P are generated periodically according to a given period T and, as it will be better described below, they all comprise preferably the same number of first pulses P'.

With reference to figure 7, the first modulation device 11 comprises an optoelectronic modulation unit 12 connected to a first control unit 114, which can be used to adjust the trend over time of the optical power I1 associated to each train P and therefore suitable to determine the first duration D', the optical power and the fifth given number N' that are associated to the first electromagnetic pulses P'.

At this end, the first control unit 114 can preferably comprise a programmable wave-form generator or, alternatively, it can be interfaced with, or implemented through, a computer 150 suitable, in use, to send reference wave-forms to the modulation unit 112, according to which to modulate over time the optical power I1 associated to each train P. In more detail, the modulation unit 112 comprises preferably, but without limitation, a Mach-Zehnder interferometer 113, coupled in series to a first polarisation controller 113' and connected to the first control unit 114 to modulate over time the optical power JI associated with the trains P according to respective reference wave forms.

Therefore, in view of the above description, the set of the given electromagnetic source 115, of the first optical element 118, of the first modulation device 111 and of the optical amplifying device 119, if any, can be interpreted as a third electromagnetic source 115' suitable, in use, to emit a seventh electromagnetic radiation EM7. Substantially pulsed, monochromatic and presenting a respective sixth frequency G1 substantially identical to the fifth frequency G of the sixth radiation EM6. Consequently, hereinafter the third fraction EM6' exiting from the first modulation device 111, and therefore from the third source 115', will be indicated as a seventh electromagnetic radiation EM7 composed by a plurality of trains P of first pulses P'. In this regard it should be noted that, even if it allows obtaining a seventh radiation EM7 with high monochromatism and time definition, the technical solution of arranging the amplifying device 119 upstream of the first modulation device 111 is completely arbitrary and it must be considered substantially equivalent to the solution, not shown, of interposing this amplifying device 119 between the output of the first modulation device 111 and the probe 125.

At this point, with reference to figure 9, it should be noted that the optical power associated to each train P will be modulated according to a code C, preferably of the binary type, so as to associate to each train P a word, written according to this code C, that for the sake of simplicity will be indicated hereinafter with the same letter P. In particular, according to this binary code C, to each electromagnetic pulse P' a bit is associated so that each word P is composed exactly by a fifth given number N' of characters.

Therefore, with reference to figure 9 again, the optical power J associated to each train P will present, according to the time, a stepped profile, wherein to each relative minimum and to each relative maximum one or more bit will be associated, presenting respectively the binary values 1 and 0. It should be noted that each consideration previously made with reference to figure 3, identically applies to figure 9 and to the present case of a measuring apparatus 100 based upon the SBS and therefore it is not necessary to repeat these considerations, and reference shall be made to what previously illustrated as regards the value of the optical power of the pulses P' and the type of these latter.

Therefore, in view of the above description, it is clearly apparent that the third source 115' is suitable, in use, to emit in a periodic manner trains P of first electromagnetic pulses P', whose optical power J1 is modulated so as to associate to each train P a respective word P of the given code C containing a fifth given number N' of bits.

Again with reference to figure 7, the emitting group 10 comprises a second modulation device 117, designed so as to receive the fourth fraction EM6'' and suitable, in use, to adjust at least one respective frequency of propagation along the probe 125. In particular, the second modulation device 117 comprises a, electro-optical (EOM) modulator 117' connected to a wave-form generator 116 suitable, in use, to generate sixth electric sinusoidal signals S6 oscillating with a frequency in the order of GigaHertz. In more detail, this wave-form generator 116 can preferably, although without limitation, comprise a *microwave synthesizer* which, for the sake of practicality, will be indicated with the same number. In use, the electro-optical modulator 117' is suitable to generate in the fourth fraction EM6'' two optical signals presenting respective seventh subcarrier frequencies G2 spectrally arranged in a symmetric manner relative to the fifth carrier frequency G.

In this regard it should be noted that each seventh subcarrier frequency G2 of the fourth fraction EM6'' can be varied continuously by means of the electro-optical modulator 117' based upon the sixth sinusoidal signal S6 emitted by the *microwave synthesizer 16* whose respective eighth frequency ΔG is substantially equivalent to the absolute value of the difference between the fifth carrier frequency G and a seventh subcarrier frequency G2. Therefore, the second modulation device 117 can be interpreted as a first optical frequency changer 117 of the fourth fraction EM6''. At this point, the fourth fraction EM6'' exiting from the electro-optical modulator 177' and presenting a fifth carrier frequency G and two seventh subcarrier frequencies G2, is sent to an optical filtering device, indicated schematically in figure 7 as a single optical filter 117'', which is suitable, in use, to filter the carrier signal and one of the two subcarriers so as to send to the probe 125 a seventh electromagnetic radiation EM7 presenting as carrier frequency a seventh given frequency G2. Therefore, in view of the above description, the set of the electromagnetic source 115, of the first optical element 118 and of the second modulation device 117 can be interpreted as a fourth electromagnetic source 115'' suitable, in use, to emit continuously over time a seventh electromagnetic radiation EM7 substantially monochromatic and presenting a reduced optical power, typically lower than the optical power J0'', and a respective seventh carrier frequency G2.

With reference to figure 7 again, the measuring apparatus 1 comprises an optical transmission group 20 provided with the probe 25 and designed so as to receive both each train P of the seventh radiation EM7, and transmit it along the probe 25 according to a first direction, and the seventh radiation EM7 and to transmit it along this probe 25 according to a second direction opposite to the first direction. In particular, the probe 125 comprises a wave guide 125 suitable to transmit the seventh and the eighth electromagnetic radiation EM7 and EM8 along all the respective linear extension L. In more detail, for example with reference to each preferred embodiment wherein the fifth frequency G is contained within the infrared electromagnetic spectrum, the wave guide 125 can comprise, without limitation, a first optical fibre 125.

At this point it should be noted that it is well known that, when a wave guide is crossed by a first high optical power radiation and by a second radiation, which counter-propagates relative to the first one, stimulated Brillouin scattering phenomena can occur, which can be interpreted as phenomena of optical amplification according to which the two radiations are able to exchange mutually a fraction of the respective energy. In particular, this phenomenon of optical amplification occurs only when the second radiation presents a frequency substantially identical to a Brillouin frequency associated to a fraction of the first radiation backscattered by the wave guide. In fact, only the substantial identity of these two frequencies allows a process of stimulated emission, according to which a fraction of the photons of the first radiation backscattered by the wave guide are emitted in phase with the photons of the second radiation and become substantially part of this latter.

Therefore, in use, sending a train P of first electromagnetic pulses P' along the optical fibre 125 can cause the amplification, or the depletion, of the optical power J2 associated to the eighth electromagnetic radiation EM8 when the seventh frequency G2 associated to this latter is substantially identical to a ninth Brillouin frequency GB associated to a fifth fraction EM8' backscattered from at least one portion of the optical fibre 125. In other words, this optical amplification phenomenon will occur at each portion of the optical fibre 125 when it is crossed by a train P of the seventh electromagnetic radiation EM7 and when the eighth frequency ΔG is substantially identical to the Brillouin *frequency shift* ΔGB, i.e. the difference between the fifth frequency G and the ninth Brillouin frequency GB associated with this portion of optical fibre 125. In fact, it should be noted that each ninth frequency GB generated by the Brillouin scattering of the seventh radiation EM7 by means of a given portion of the optical fibre 125 is specifically associated to this portion as function of the local temperature and strain of the portion, as illustrated in the article "*Brillouin Gain spectrum Characterization in Single-Mode Optical Fibres*" by Marc Niklès *et al.* published on volume 15, No.10 of the "*Journal of lightwave technology*" of October 1997, which will be indicated hereinafter as Doc2.

Therefore, by analysing over time the trend of the optical power J2 of the eighth electromagnetic radiation EM8 exiting from the optical fibre 15 according to the eight frequency ΔG of the *microwave synthesizer* 116 used to generate this eight radiation EM8, it is possible to define the linear spatial distribution of temperature and strain along the first optical fibre 125. In particular, the mathematic formulae and the empiric parameters linking the gain curve associated with the optical power J2 and the linear spatial distribution of temperature and strain along the optical fibre 125 are well known and illustrated in the cited document Doc2.

Therefore, in view of the above description and as it will be better ·explained below, the measuring apparatus 100 according to the present invention is suitable to monitor contemporaneously the local distribution of temperature and strain of a body 1000 through the measurement of the dependence of the optical power J2 associated to the eight radiation EM8, and therefore of the respective optical gain curve, according to the eight frequency ΔG of the *microwave synthesizer* 116.

At this point it should be noted that hereinafter the term optical amplification due to stimulated Brillouin effect will refer to any phenomenon of optical amplification, which can be interpreted, according to the quantum physics, as a phenomenon of stimulated emission of photons due to an interaction between the photons forming the first electromagnetic pulses P' and the photons forming the eighth electromagnetic radiation EM8 mediated by at least one acoustic phonon which propagate along the wave guide 25. Furthermore, it should be highlighted that in the present patent application the terms "amplification due through SBS" or "gain curve" of a given electromagnetic radiation will be used to indicate or describe in general phenomena of exchange of optical energy, wherein this given electromagnetic radiation can be indifferently subjected both to an increase and to a decrease in its own respective optical power. Therefore, in view of the above description and with particular reference to the terminology commonly used in quantum optics to describe the stimulated emission phenomena, the seventh electromagnetic radiation EM7 is suitable to act as a pumping radiation or "optical pump", whilst the eighth radiation EM8 is suitable to act as probe radiation, or simply "probe", of the linear distribution of temperature and strain along the optical fibre 125.

Again with reference to figure 7, it is advisable to note that the transmission group 20 comprises a depolariser 121 preferably interposed between the optical fibre 125 and the second modulation device 117 to depolarise the eighth probe radiation EM8 in order to maximise the effects of optical amplification due to SBS which occur inside the optical fibre 125. The optical transmission group 120 can furthermore comprise a second optical filter 123 suitable, in use, to act as *optoisolator*, i.e. suitable to prevent the propagation of the seventh radiation EM7 outside the optical fibre 125 in the direction of the fourth electromagnetic source 115''.

With reference to figure 7 again, it is possible to note that the optical transmission group 120 comprises a second optical element 122, for example an optical circulator, interposed between the third source 115' and the optical fibre 125 and suitable, in use, to receive the eighth electromagnetic radiation EM8 exiting from the optical fibre 125, and to send it to an optoelectronic detection group 130 of the measuring apparatus 100. In this regard it should be noted that the second optical element 122 may be suitable to send to the detection group 130 not only the eighth radiation EM8, but also the Rayleigh radiation composed by each fraction of the seventh radiation EM7 which has been backscattered by at least a portion of the optical fibre 125 in a manner non coherent with the eighth probe radiation EM8. However, as it is well known, if there are SBS phenomena these fractions backscattered in a non coherent manner relative to the probe radiation present a respective optical power substantially negligible relative to the optical power associated with the probe radiation which has been subjected to an optical amplification effect due to SBS. On the other hand, if the Rayleigh backscattered radiation presents an optical power which can be compared with that of the eighth probe radiation EM8, it will be possible to filter this Rayleigh backscattered radiation through adequate optical filters known and therefore not illustrated in figure 7.

With particular reference to figure 7, the first detection group 130 comprises a first photoelectric sensor 131 suitable to receive the eighth radiation EM8 to convert it into a respective seventh electric signal S7, for example a signal of electric voltage, substantially proportional to the optical power J2 associated with this probe eight radiation EM8. This first sensor 131 comprises preferably, although without limitation, a photodiode 131, for example of the PIN type, suitable, in use, to measure the trend over time of the optical power J2 and therefore, based upon the OTDA principles, the spatial distribution of this optical power J2 along the extension L of the probe 125. Therefore, as it will be more apparent from the description below, each seventh electric signal S7, normalised as the case may be, can be interpreted as a gain curve of the optical amplification to which the probe radiation EM2 is subjected.

Again with reference to figure 7, the detection group 130 comprises preferably a first analog-to-digital converter 139 suitable, in use, to receive and digitalise each seventh electric signal S7 exiting from the first sensor 131. Once it has been digitalised by the converter 139, each seventh signal S7 can be acquired by the computer 150 which, as it will be better explained hereunder, is suitable to process these data in order to reconstruct the dependence of the trend over time of each gain curve of the eighth radiation EM8 as a function of the ninth frequency ΔG and to decode information coded in this gain curve, according to the given code C, following the interaction with first pulses P'. Therefore, the computer 150 is suitable both to control the/to act as, first control unit 114 for controlling the coding of the words P, and to act as decoder 160 of the information coded in each sixth signal S6 according to the given code C. In addition to this, this computer 150 is also connected to the second waveform generator/microwave synthesizer 116 to regulate, in use, the value of the ninth frequency ΔG.

Lastly, it should be noted that the first detection group 130 can preferably comprise one or more electronic amplifiers of the known type, for instance of the TIA type, and that therefore in figures 7 and 8 they have been generically illustrated without specific reference numbers; these amplifiers can be or cannot be introduced if the intensity of the seventh signal S7 is not sufficient to obtain a correct analog-to-digital conversion and therefore measurements presenting an adequate signal-to-noise ration.

At this point, it should be specified that modifications and variants can be made to the measuring apparatus described and illustrated herein, without however departing from the protective scope of the present invention.

For example, figure 8 illustrates a second preferred embodiment of the measuring apparatus 100 wherein not a single electromagnetic source 115 and a beam splitter are provided, but a fifth and a sixth electromagnetic sources 115''' and 115^{IV} distinct and suitable to generate respective ninth and tenth electromagnetic radiations EM9 and EM10 substantially identical in frequency and optical power to the first and second fractions EM6' and EM6'' illustrated above. Furthermore, it should be noted that the second preferred embodiment illustrated in figure 8 can comprise a second optical frequency changer 124 of the known type, arranged at the input, at the output or associated with the first modulation device 111 and suitable, in use, to vary the sixth carrier frequency G1 of the seventh radiation EM7 so that this sixth radiation G1 is slightly different from the fifth reference frequency G. In this way, the two subcarrier frequencies of the eighth radiation EM8 generated by the second modulation device 117 will not be spectrally symmetric relative to the sixth frequency G1 of the seventh radiation EM7 and therefore the optical amplification phenomena due to SBS can be occur only between the seventh pumping radiation EM7 and a given fraction of the eighth radiation EM8 associated to one of the two subcarrier frequencies. it is clearly apparent that under these experimental conditions, the elimination of one of the two subcarriers by means of the optical filter device 117'' is no necessary, as this subcarrier of the eighth probe radiation EM8 does not interact constructively or destructively with the seventh pumping radiation EM7.

At this point, after having illustrated a plurality of preferred embodiments and variants of the measuring apparatus 1, it should be mentioned that the present invention also relates to a measuring method which can be performed through the apparatus 1 and is suitable to measure the linear distribution of at least one physical quantity, for example the temperature and/or the strain, along all the linear extension of the probe/first optical fibre 125.

In particular this method comprises first of all the phase of generating a third optical pumping electromagnetic fraction EM6' and a fourth electromagnetic probe radiation EM6'' through respectively a third and a fourth electromagnetic sources 115' and 115'' or, alternatively, a fifth and a sixth electromagnetic sources 115''' and 115^{IV}. It is clearly apparent that in the first case this phase of generating a seventh and a eighth radiation EM7 and EM8 will comprise a phase of generating a sixth given electromagnetic radiation EM6 through a given electromagnetic source 115, followed by a phase of subdividing this sixth radiation EM6 into a third and a fourth fractions EM6' and EM6''.

At this point of the measuring method a phase is provided of modulating the optical power J0' associated to the third fraction EM6' through a specific first modulation device 111 so as to generate a seventh electromagnetic pumping radiation EM7 presenting a plurality of trains P of first pulses P'; these trains P are emitted periodically and present a respective second duration D1, which is substantially equivalent to the product of each first duration D' of each first pulse P' and the fifth given number N'. In more detail, the phase of modulating the optical power J0' associated to the third fraction EM6 comprises the phase of associating to each train P a respective word P coded according to a given code C, preferably of the binary type.

Contemporaneously to this phase of modulating the optical power J0' associated with the third fraction EM6', the present method provides for the execution of a phase of modulating at least a fifth frequency G associated with the fourth fraction EM6'' to generate an eighth electromagnetic probe radiation EM8 presenting a respective optical power J2 substantially constant over time and a respective seventh carrier frequency G2, which is different from the sixth frequency G1 of the seventh pumping radiation EM7 by a value substantially equivalent to a ninth frequency ΔG.

At this point, the measuring method according to the present invention provides for a phase of transmitting each train P associated to the seventh radiation EM7 along a probe 125 of given extension L according to a first propagation direction and of transmitting the eighth radiation EM8 along the same probe 125 according to a second propagation direction opposite to the first propagation direction, so that phenomena can be generated of optical amplification due to SBS of the eighth electromagnetic radiation EM8.

This phase of transmitting the seventh and eighth radiations EM7 and EM8 along the probe 125 is followed by a phase of receiving through a detection group 130 an eighth electromagnetic radiation EM8 exiting from the probe 125, which has been potentially subjected to phenomena of optical amplification due to SBS.

At this point, the measuring method according to the present invention comprises at least a phase of measuring the variation s over time of the dependence of a gain curve associated to each respective eighth probe radiation EM8 as a function of the ninth frequency ΔG to obtain from the analysis of these measurements values of the temperature and/or of the strain associated to each portion of the probe 125.

In particular, this phase of measuring the variation over time of the dependence of a gain curve relative to the fourth frequency ΔG comprises first of all a phase of measuring at least a trend over time of the optical power J2 associated to the eighth radiation EM8 exiting from the probe 125 at the emission of a respective train P and for a period of time substantially equivalent to the double of the time necessary to an electromagnetic signal for travelling the given extension L of the probe 125. In fact, in this regard it should be noted that the effect of optical amplification due to SBS can occur starting from the emission of a given train P for the time interval necessary to this train P for travelling the probe 125 for all the respective given extension L; in addition, the eight amplified radiation EM8 will need at the most the same time interval to propagate from an end of the probe 125 to the detection group 130. Therefore, with first electromagnetic pulses P' presenting a first given duration D' in the order of the ten of nanoseconds and with an optical fibre 125 presenting a given extension L in the order of the tens of kilometres, the third duration D2 of emission of each eighth electromagnetic radiation EM8 will present a value in the order of hundreds of nanoseconds. Consequently, the time period T which separates the emission of each two consecutive trains P will present a value double twice greater than the time necessary to an electromagnetic signal for travelling the probe 125 so that no fraction of the eighth electromagnetic radiation EM8, during the respective transmission along the probe 125, can be subjected to two distinct phenomena of optical amplification due to SBS.

At this point, to obtain a measurement of the dependence of each gain curve associated to the eighth radiation EM8 it is necessary to repeat for a discrete plurality of times the phase of measuring the trend over time of the optical power J2 associated with each eighth radiation EM8 by associating to each of these measurements of the power J2 the same code word P, but different value of the ninth frequency ΔG of the microwave synthesizer 116. In this regard it should be specified that the values associated with the ninth frequency ΔG shall be near to the values theoretically admitted for the Brillouin *frequency shift* ΔGB so as to maximise the efficiency of the measurements of the gain curve of the optical amplification due SBS. Therefore, for measuring the dependence of the frequency of each optical gain curve associated to a given word P of code it will be necessary to make a sixth given number M' of measurements of the trend over time of the optical power J2 exiting from the probe 125. Each of these measurements shall be made by maintaining constant the value of the word P coded in each respective train P of first electromagnetic pulses P' and varying step by step the value of the ninth frequency ΔG so that, in the range of the M measurements, this ninth frequency ΔG scans in a preferably uniform manner a frequency interval centred around a theoretical value of the Brillouin *frequency shift* ΔGB. For example, in the case taken as example of a fifth frequency G in the order of 193 THz, the Brillouin *frequency shift* ΔGB is about ± 11 GHz and therefore, in use, the value of the ninth frequency ΔG will be preferably varied between 10.8 e 11.2 GHz with steps in the order of some MHz. Again with reference to the phase of measuring at least one trend over time of the optical power J2 for a given word C of code, it should be noted that, without representing a limit for the present invention, this phase can be performed in succession for a given number K' of times, at the end of which a phase can be performed of mediating statistically a seventh given number K' of measurements of the optical power J2 to obtain an average measurement of the trend over time of the optical power J2 presenting a signal-to-noise ration significantly greater than a single measurement. Merely by way of example, the seventh given number K' can be in the order of the thousand or of the tens of thousand for each given word P and for each given value of the ninth frequency ΔG.

At this point, the phase of measuring the variation over time of the dependence of a gain curve associated with each respective eighth probe radiation EM8 as a function of the ninth frequency ΔG comprises a phase of reconstructing numerically, for each given train/word P, the respective optical gain curve associate with the eighth radiation EM8 through a computer 150. In particular, this phase of numerically reconstructing an optical gain curve associated with the eighth radiation EM8 comprises the cyclical repetition for a given number of times of a phase of interpolating a sixth given number M' of experimental points with a continuous mathematical function, for example a Lorentz function, suitable to describe the trend of the optical gain curve relative to the ninth frequency ΔG. In more detail, each of these experimental points represent a respective value, adequately normalised, of the second optical power J2, which is associated to the respective value of the ninth frequency ΔG set by the microwave synthesizer 16 during the respective phase of transmission of the seventh and eighth electromagnetic radiations EM7 and EM8 along the probe 125.

Furthermore, it should be noted that each of these continuous mathematical functions used for interpolating the experimental points of the gain curve associated with the eighth radiation EM8 is associated to a given time instant of the flight time of the eighth probe radiation EM8 and therefore, according to the functioning principle of the OTDA, each of these functions which reconstruct the dependence of the gain curve from the ninth frequency ΔG can be associated to a given linear distance measured along the probe 125.

Therefore, in view of the above description each phase of numerically reconstructing, for each given train/word P, the respective optical gain curve associated with the eighth radiation EM8 can be interpreted as a phase of performing a digital sampling of the variation over time of this optical gain curve associated to a respective second radiation to allow subsequent operations of numerical-statistical processing and/or operations of decoding information/OTDA traces coded inside this gain curve.

Lastly, each phase of measuring the variation over time of the dependence of a gain curve associated with each respective eighth probe radiation EM8 relative to the ninth radiation ΔG comprises a phase of obtaining from the numerical reconstruction of each of these gain curves associated with the eighth radiation EM8, a fifth and a sixth numerical functions H1 and H2, which represent respectively the trend, as a function of time, of the maximum gain for optical amplification due to SBS and of the respective value of the ninth frequency G for which this optical gain is maximum, i.e. for which the value is maximum of the mathematical function used for the respective interpolation.

At this point, the measuring method according to the present invention comprises a phase of decoding information contained in an eighth number Q' of these fifth and sixth numerical functions H1 and H2 and originally associated to a given eighth number Q' of distinct words P transmitted preferably in succession through respective trains P of first electromagnetic pulses P'.

It should be noted that, contrarily to what illustrated above in the case of a measuring apparatus 1 based upon the spontaneous Brillouin effect, wherein a linear decoding process is used, the present phase of decoding information contained in an eighth number Q' of these fifth and sixth numerical functions H1 and H2 can comprise analysis and decoding methods both of the linear and of the non linear type, in this latter case preferably of the logarithmic type, which is necessary to linearise the effect on each second radiation EM2 by the trains P of the seventh radiation EM7 following the effect of optical amplification generated by the SBS.

In any case, independently of the type of code C used and of the implemented analysis method, it should be noted that the result of the phase of decoding information contained in a given eighth number Q' of fifth and sixth numerical functions H1 and H2 relating respectively to the optical power JB and to the ninth frequency ΔG is that of generating a seventh and an eighth numerical functions H1' and H2', which represent respectively measurements of the variation over time of the maximum of the gain curve and of the respective value of the ninth frequency ΔG; these measurements associated to the seventh and to the eighth numerical functions H1' and H2' are not influenced, as the first and second functions H1 and H2, by the presence of the original modulation of optical power of the trains P, and they are furthermore characterised by a signal-to-noise ratio, with equal spatial resolution, significantly better than the signal-to-noise ratio associated to the single measurements relating to the fifth and sixth functions H1 and H2.

Lastly, the measuring method according to the present invention comprises the phase of calculating the linear distribution of the temperature and of the strain associated with the probe 125, and therefore with respective contiguous portions of the body 1000, applying to the seventh and eighth numerical functions H1' and H2' empirical formulae, for the explanation of which reference shall be made to the already cited scientific documents Doc1 and Doc2.

The characteristics of the measuring method according to the present invention will be apparent from the above description and do not require further explanations; however it would be advisable further to highlight some advantages resulting from the use of the techniques for coding/decoding the optical power associated to the trains P of first electromagnetic pulses P'. In particular, the use of these analysis technique based upon the decoding of information optically coded in the eighth probe radiation EM8 allows obtaining measurements of the gain curves associated with this second radiation EM2 presenting a high signal-to-noise ratio. Consequently, the computer 150 is suitable to calculate a linear distribution of the temperature and of the strain along the optical fibre 125 presenting greater accuracy and reliability than the measurements which can be performed with apparatuses according to the prior art.

At this point it should be noted that it is possible to develop a variant of the measuring method based upon the SBs by applying the techniques for coding/decoding illustrated above to pairs of differential pulses. OTDA measurement techniques based upon the analysis of pairs of differential pulses are illustrated in the following scientific articles, which shall be considered an integral part of the present description:

- "Differential pulse-width pair BOTDA for high spatial resolution sensing" by W. Li, X. Bao, Y. Li and L. Cheng, published on "Optics Express" (16) 26 of 2008 at pages 21616-21625;

- "12-km distributed fibre sensor based on differetial pulse-width pair BOTDA" by Y. Dong, X. Bao and W. Li, published in the acts of the "Optical Fibre Sensor Conferences" (article OF101-81) that took place in Edinburgh, Scotland, in 2009.

In these articles it is shown how it is possible to increase the spatial resolution of the OTDA measurement techniques by applying the analysis described above with reference to single OTDA traces to the difference of two OTDA traces obtained by sending two electromagnetic pulses of different duration. However these articles do not take into account the hypothesis of modulating the power of these electromagnetic pulses to associate to each train of pulses a word of a given code C. Therefore, by applying the coding/decoding methods described above to the differences of OTDA traces relating to trains P presenting first pulses P' of different duration, it is possible to obtain a further improvement of the spatial resolution of the measurements of temperature and strain which can be carried out with the measuring apparatus 100.

In particular, relative to the measuring method illustrated above, a variant based upon the analysis of pairs of differential pulses will comprise both a further phase of generating in succession, for each given word P of the given code C, a pair of trains P of first electromagnetic signals P' presenting respective first and fifth durations D' and D'' slightly different from each other, i.e. presenting the same order of magnitude, but not exactly the same value, and a phase of subtracting each from the other the OTDA traces obtained starting from these pairs of trains P of electromagnetic pulses before proceeding with the analysis and decoding the information present in this difference between OTDA traces following the numerical analysis method illustrated above.

Therefore, summarising, it is possible to state that the use of coding/decoding technique in an optoelectronic measuring apparatus based upon spontaneous or stimulated Brillouin scattering of electromagnetic pulses inside an optical fibre allows solving the technical problem illustrated above, i.e. it allows performing, in an economical manner, simultaneous measurements of the linear distribution of strain and temperature along a probe in optical fibre; in particular these measurements, although they are obtained with low power electromagnetic sources, are characterised by such a signal-to-noise ratio and such a spatial resolution that are commonly destined to expensive measuring apparatuses provided with high peak power laser sources.

CLAIMS

1. Measuring apparatus (1)(100) for monitoring at least one given physical· characteristic of a body (1000); said apparatus (1)(100) comprising emitting means (10)(110) suitable, in use, to generate at least a first electromagnetic radiation (EM1)(EM7) presenting at least a train (P) comprising at least one first electromagnetic pulse (P') presenting a given first frequency (F)(G1) and a given first duration (D') which can be determined substantially at will; optical transmission means (20)(120) for transmitting said first electromagnetic pulses (P’) comprising at least one waveguide (25)(125), which presents a given linear extension (L), is couplable, in use, to said body (1000) and is suitable, in use, to transmit at least one said electromagnetic pulse (P') along all the respective said given linear extension (L); detecting means (30,30') (130) suitable, in use, to sample the time-variation of at least an optical feature of at least an electromagnetic second electromagnetic radiation (EM2)(EM8)transmitted by said waveguide (25)(125); each said second electromagnetic radiation (EM2)(EM8) being acquire in input by said detecting means (30,30') (130) after having interacted with at least a said train (P) through given Brillouin scattering phenomena at least one portion of said waveguide (25)(125); characterised in that said emitting means (10)(110) comprise a first modulating device (11)(111) suitable, in use, to modulate the optical power associated with each said first electromagnetic pulse (P'), in order to associate to each said train (P) of said first electromagnetic radiation (EM1)(EM7) a respective word (P) expressed according to a given code (C).

2. An apparatus according to claim 1, characterised in that said emitting means (10) comprise at least one first electromagnetic source (15) which is substantially

monochromatic and suitable, in use, to emit said first electromagnetic radiation (EM1); said modulating device (11) comprising a modulating unit (12) optically connected to said first electromagnetic source (15) and suitable, in use, to modulate over the time the optical power associated with said first electromagnetic radiation (EM1) in order to generate each said train (P) of said first electromagnetic pulses (P').

3. An apparatus according to claim 2, characterised in that said modulating device (11) comprises a control unit (14) connected to said modulating unit (12) and suitable, in use, to adjust at least said given first duration (D′) of each said electromagnetic pulse (P') and a periodicity of emission of said trains (P); said control unit (14) being furthermore suitable, in use, to give reference waveforms to said modulating unit (12) in order to modulate, according to said given code (C), the optical power associated with said first electromagnetic radiation (EM1) and/or each said train (P) of said first electromagnetic pulse (P′).

4. An apparatus according to claim 2 or 3, characterised in that said first electromagnetic source (15) is a first laser (15) suitable to emit infrared radiation and in that said modulating unit (12) comprises an interferometer.

5. An apparatus according to any one of the previous claims, characterised by comprising a first coherent detection device (35) which is optoelectronic and suitable, in use, to monitor the time-variation of an optical power (IB) and a second frequency (FB) associated to each first component (EM2") of said second electromagnetic radiation (EM2): each said first component (EM2′′) being generated by the Spontaneous Brillouin (SpBS) backscattering of a respective said train (P) of said first electromagnetic radiation (EM1) by at least a portion of said waveguide (25).

6. An apparatus according to claim 5, characterised in that

said first coherent detection device (35) comprises a first photoelectric sensor (31) suitable, in use, to convert each electromagnetic· incident radiation into a respective first electric signal (S1); and an optical device (22) suitable to make incident onto said first sensor (31) an optical superposition of a said first component (EM2") of Brillouin with a third electromagnetic radiation (EM1'', EM5) substantially monochromatic and presenting a respective frequency comprised between said first frequency (F) and said second frequency (FB).

7. An apparatus according to claims 2 and 6, characterised in that said optical device (22) comprises an optical frequency changer (24) suitable, in use, to receive a fraction (EM1'') of said first electromagnetic radiation (EM1) in order to generate said third electromagnetic radiation (EM5).

8. An apparatus according to claim 2 and 6, characterised in that said optical device (22) comprises an optical frequency changer (24) interposed between said first electromagnetic source (15) and said modulating device (11) in order to adjust substantially at will the frequency of emission of each said first electromagnetic pulse (P').

9. An apparatus according to any one of claims 6-8, characterised in that said detecting means (30) comprise an electric spectrum analyser (33) presenting a high operating speed in order to analyse substantially in real time the time-variation of the frequency spectrum of each said first electric signal (S1).

10. An apparatus according to claim 9, characterised in that said electric spectrum analyser (33) comprises a second coherent detection device (36) which is electric and suitable, in use, to subdivide the frequency spectrum of each said first electric signal (S1) into a plurality of respective given spectral bands (BS) and to measure the time-

variation of a width of each spectral portion of each said first electric signal (S1) associated with a respective given said spectral band (BS).

11. An apparatus according to claim 10, characterised in that said second coherent detection device (36) comprises an electric band-pass filter (32) presenting a given passband, constant over the time, and suitable, in use, to select each said spectral band (BS); and an adjustable electric oscillator (34) suitable to generate a second electric signal (S3) suitable, in use, to interact with each said first electric signal (S1) in order to generate beating phenomena, whose respective frequency can be tuned substantially at will with respect to the passband of said electric band-pass filter (32) through adjustment of said oscillator (34).

12. An apparatus according to any one of the previous claims, characterised in that said detecting means (30') comprise an optical filter (32') suitable, in use, to select a second Rayleigh component (EM4') of at least a fourth electromagnetic radiation (EM4) emitted by the said waveguide (25), and a second photoelectric sensor (31') to convert each said second component (EM4') into a respective third electric signal (S5); each said second component (EM4') being generated by the elastic backscattering of a respective second electromagnetic pulse (P'') by at least one portion of said waveguide (25).

13. An apparatus according to claim 5 or according to claim 5 and any one of claims 6-12, characterised by being designed so as to be connected to a computer (50) suitable, in use, to act as said control unit (14) to control a modulation, according to said given code (C), of the optical power associated with each said train (P), and/or as decoder (60) for decoding information coded according said given code (C) and transferred by each given first component (EM2'') of Brillouin generated from a respective said train (P)

associated with a respective word (P) of said given code (C).

14. An apparatus according to claim 12 or to claims 12 and 13, characterised in that said emitting means (10) comprise a second electromagnetic source (16) which is broadband and connected to said modulating device (11) to generate each said second pulse (P'') in order to measure the time-variation of the optical power associated with said third component (EM3') of Rayleigh of each said third electromagnetic radiation (EM4).

15. An apparatus according to claim 12 or according to claim 12 and 13, characterised in that said emitting means (10) comprise a second control unit (17) suitable, in use, to adjust an optical power (I0) of emission of said first electromagnetic source (15) to regulate dithering phenomena associated with the emission of said first electromagnetic radiation (EM1).

16. An apparatus according to claim 12 or according to claim 12 and 13, characterised in that said first electromagnetic source (15) is of the frequency adjustable type and in that said emitting means (10) comprise a second control unit (17) suitable, in use, to adjust substantially at will said first frequency (F).

17. Apparatus according to claim 1, characterised in that said emission means (110) are suitable for generating said first and second electromagnetic radiation (EM7,EM8) which, in use, propagate along said waveguide (125) according to respective first and second directions of propagation which are reciprocally opposite; said emitting means (110) comprising a first optical modulation device (117,124,111') suitable, in use, to adjust substantially at will a carrier frequency (G1,G2) of at least one of said first and/or second radiations (EM7)(EM8); said first and second electromagnetic radiations (EM7)(EM8) being suitable, in use, to exchange respective optical energy with each other, interacting

through a process of optical amplification of said second radiation (EM8) based upon respective stimulated Brillouin scattering (SBS) phenomena.

18. An apparatus according to claim 17, characterised in that said emitting means (110) comprise at least a third electromagnetic source (115′) which is substantially monochromatic and suitable, in use, to emit a said first electromagnetic radiation (EM7) presenting a respective second frequency (G1); said second modulation device (11) comprising a modulation unit (112) optically associated with said first electromagnetic source (115′) and suitable, in use, to modulate over time the optical power associated with said first electromagnetic radiation (EM7) so as to generate each said train (P) of said pulses (P′).

19. An apparatus according to claim 18, characterised in that said second modulation device (111) comprises, or is associated with, a control unit (114) connected to said modulation unit (112) and suitable, in use, to adjust at least said first given duration (D′) of each said electromagnetic pulse (P′) and a periodicity of emission of said trains (P); said control unit (114) being furthermore suitable, in use, to provide said modulation unit (12) with reference waveforms so as to modulate, according to said given code (C), the optical power (J1) associated with said first radiation (EM7) and with each said train (P) of electromagnetic pulses (P′).

20. An apparatus according to claim 18 or 19, characterised in that said first modulation device (117) comprises a waveform generator (116) suitable, in use, to generate a fourth electric signal (S6) presenting a respective fourth carrier frequency (ΔG) which can be adjusted substantially at will; and an electro-optical modulator (117′) suitable, in use, to vary a carrier frequency of a respective input optical signal (EM6′′) of value substantially corresponding

to said fourth frequency (ΔG) so as to generate at the output each said second electromagnetic radiation (EM8) presenting a said fifth carrier frequency (G2).

21. An apparatus according to any one of the claims 17-20, characterised in that said emitting means (110) comprise at least one second electromagnetic source (115'') suitable, in use, to emit a said second electromagnetic radiation (EM8) presenting at least one respective fifth carrier frequency (F2) which can be adjusted substantially at will.

22. An apparatus according to claims 20 and 21, characterised in that said first electromagnetic source (15') comprises a first laser (115, 115''') suitable to emit infrared radiation, and in that the fourth source (115') comprises the set of a third laser (115, 115^{IV}), suitable to emit infrared radiation, and of said first modulation device (117); said first modulation device (117) being optically connected to said third laser (15, 15^{IV}) so as to receive at the input each infrared radiation emitted by this latter.

23. An apparatus according to claim 22, characterised in that said second and third lasers (115) coincide with each other, and in that said third and fourth electromagnetic sources (115')(115'') comprise said laser (15) and an optical element (118) suitable, in use, to subdivide each fourth electromagnetic radiation (EM6) emitted by said laser (115) into a first and a second fractions (EM6')(EM6'') presenting respective given first and second optical powers (J0')(J0'').

24. An apparatus according to claim 20 or in claim 20 and in any one of claims 21-23, characterised in that said detecting means (130) are suitable, in use, to measure an optical gain curve associated with each said second radiation (EM8) exiting from said waveguide (125), and to reconstruct the trend over time of the dependence of each said optical gain curve and said fourth frequency (ΔG)

25. An apparatus according to claim 24, characterised in

that it comprises, or it can be associated with, a decoder (160) suitable, in use, to decode information coded according to said given code (C) and transported by each said second radiation (EM8) which has interacted with at least one respective said train (P) of said first radiation (EM7) through stimulated Brillouin scattering (SBS) phenomena.

26. An apparatus according to any one of the previous claims, characterised in that said given code (C) is a binary code of the simplex type.

27. n apparatus according to any one of the previous claims, characterised by being suitable, in use, to measure at the same time both the temperature and the strain associated to a plurality of portions of said body (1000).

28. A measuring method for measuring the spatial distribution of at least one given physical quantity along a waveguide (25)(125) with given linear extension (L); said method comprising at least one phase of transmitting a first electromagnetic radiation (EM1)(EM7) presenting a first frequency (F)(G1) through said waveguide (25)(125); the phase of receiving by means of detecting means (30)(130) at least a second electromagnetic radiation (EM2)(EM8) transmitted through said waveguide (25)(125); each said second electromagnetic radiation (EM2)(EM8) having interacted with said first electromagnetic radiation (EM1)(EM7) through given Brillouin scattering Phenomena at at least a one portion of said waveguide (25)(125) and a phase of measuring the time-variation of at least a n optical feature of said second radiation (EM2)(EM8); characterised in that each said phase of transmitting a said first radiation (EM1)(EM7) along said waveguide (25)(125) is preceded by a phase of modulating the optical power associated with said first electromagnetic radiation (EM1)(EM7) in order to generate at least one respective train (P) of first electromagnetic pulses (P') and to associated each said train (P) with a respective given

word (P) of a given code (C).

29. A method according to claim 28, characterised in that each said phase of modulating the optical power associated with a said first radiation (EM1) comprises the phase of defining a given first duration (D') of each said electromagnetic pulse (P') to vary selectively the spatial resolution associated with each measurement of said spatial distribution of said at least one physical quantity.

30. A method according to claim 28 or 29, characterised in that each one said phase of measuring the time-variation of the optical power (IB) and of a second frequency (ΔFB) substantially equivalent to the difference between said first frequency (F) and a third frequency (FB) associated with a first Brillouin component (EM2'') of said second electromagnetic radiation (EM2); each said first component (EM2'') being generated by a spontaneous Brillouin backscattering phenomena of at least a fraction of each said first electromagnetic radiation (EM1) due to at least a portion of said waveguide (25;)each said phase of measuring the time-variation of the optical power (IB) and of a second frequency (ΔFB) associated to a respective said first component (EM2'') of Brillouin comprising a phase of generating respective first and second numeric functions (F1)(F2) representing the time-variation of said optical power (IB) and of said second frequency (ΔFB); at least one said phase of generating respective first and second numeric functions (F1)(F2) being followed by a phase of decoding information contained inside at least one of said first or second numeric functions (F1)(F2), associated with a respective said given word (P) and coded according said given code (C).

31. A method according to claim 30, characterised by comprising the cyclic execution for a given first number (Q) of times of said phase of measuring the time-variation of the

optical power (IB) and of a second frequency (ΔFB) associated with a respective said first Brillouin component (EM2''); this execution of a given first number (Q) of times of said phase of measuring the time-variation of the optical power (IB) and of a second frequency (ΔFB) being followed by a phase of jointly decoding information coded according to said given code (C) and contained as a whole in a given first number (Q) of said first and/or second numeric functions (F1)(F2) relating to respective said words (P), given and distinct from each other, in order to generate a third and a fourth numeric functions (F1')(F2'), which represent a measure of the time-variation of said optical power (IB) and of said second frequency (ΔFB) presenting a spatial resolution substantially equivalent to that of a measure that can be associated to a single said first electromagnetic pulse (P′) presenting said given first duration (D′).

32. A method according to any one of claims 19-22, characterised in that each said phase of measuring the time-variation of the optical power (IB) and of a second frequency (ΔFB) associated with a said first Brillouin component (EM2'') comprises the phase of analysing the time-variation of the frequency spectrum of said first component (EM2'') through at least one first coherent detection device (35) which is optoelectronic and suitable, in use, to generate a first electric signal (S1) centred on said second frequency (ΔFB) for each said first Brillouin component (EM2'').

33. A method according to claim 32, characterised in that each said phase of analysing the time-variation of the frequency spectrum of a said first Brillouin component (EM2'') is followed by the phase of discretise the frequency spectrum of a respective said first electric signal (S1) into a plurality of given spectral bands (BS) through a second electronic coherent detection device (36) provided with a spectrum analyser (33) with high operating speed.

34. Method according to claim 28 or 29, characterised in that each said phase of transmitting a first electromagnetic radiation (EM7)· comprises a phase of transmitting through said waveguide (125) a said given first electromagnetic radiation (EM7) and a said given second electromagnetic radiation (EM8) presenting respective first and fourth frequencies (G1,G2) and propagate according to mutually opposite directions; and in that each phase of measuring the time-variation of at least an optical feature of said second radiation (EM8) comprises a phase of measuring the time-variation of the dependence of a gain curve associated with each respective said second radiation (EM8) as a function of the difference (ΔG) between said first and fourth frequencies (G1)(G2) so as to obtain, by analysing these measures, values of temperature and/or of strain associated with each portion of said waveguide (125); each said second electromagnetic radiation (EM8) exiting from said waveguide (125) after having been subjected to an optical amplification phenomenon through stimulated Brillouin scattering inside said guide (125) due to the interaction with at least one pulse (P') associated with said first radiation (EM7).

35. A method according to claim 34, characterised by comprising a phase of modulating a carrier frequency of the first and/or second electromagnetic radiations (EM7)(EM8) so as to vary selectively and substantially at will said difference (ΔG) between said first and fourth frequencies (G1)(G2).

36. A method according to claim 34 or 35, characterised in that said phase of measuring the change over time in the dependence of a gain curve associated with each respective said second radiation (EM8) as a function of the difference (ΔG) between said first and second frequencies (G1)(GF2) is substantially equivalent to a phase of measuring the change over time in the dependence of a gain curve associated with

each respective said second radiation (EM8) as a function of a third frequency (ΔG) of a reference signal (S6) of a waveform generator (116) associated with an optical modulation device (117) which can be used to perform said phase of modulating a carrier frequency of the first and/or second electromagnetic radiations (EM7)(EM8) so as to vary selectively and substantially at will said difference between said first and fourth frequencies (G1)(G2).

37. A method according to claim 36, characterised in that each said phase of measuring the change over time in the dependence of a gain curve associated with each respective said second radiation (EM8) as a function of the difference (ΔG) between said first and fourth frequencies (G1)(G2) comprises the repetition for a given second number (M′) of times the phase of associating a given value to the fifth frequency (ΔG) followed by a phase of measuring the trend over time of the optical power (J2) associated with said second radiation (EM8) maintaining said fifth frequency (ΔG) constant.

38. A method according to any one of claims 34-37, characterised in that each said phase of measuring the change over time in the dependence of a gain curve associated with each respective said second radiation (EM8) as a function of the difference (ΔG) between said first and fourth frequencies (G1)(G2) comprises a phase of generating respective fifth and sixth numeric functions (H1)(H2) representing the trend, as a function of time, of the maximum gain of the optical amplification through stimulated Brillouin scattering and of the value of said difference between said first and fourth frequencies (G1)(G2) associated with said maximum of the optical amplification, at least one said phase of generating respective fifth and sixth numeric functions (H1)(H2) being followed by a phase of decoding information contained in at least one of said fifth or sixth numeric functions (H1),(H2),

associated with a respective said given word (P) and decoded according to said given code (C).

39. A method ·according to claim 18, characterised by comprising the cyclical execution for a fourth given number (Q′) of times of said phase of measuring the change over time in the dependence of a gain curve associated with each respective said second radiation (EM8) as a function of the difference (ΔG) between said first and fourth frequencies (G1)(G2); this execution for a given fourth number (Q′) of times of said phase of measuring the change over time in the dependence of a gain curve associated with each respective said second radiation (EM8) as a function of the difference (ΔG) between said first and fourth frequencies (G1)(G2) being followed by a phase of jointly decoding information coded according to said given code (C) and entirely contained in a fourth given number (Q′) of said fifth and/or sixth numeric functions (H1)(H2) related to respective said given words (P) distinct from each other, in order to generate a seventh and a eighth numeric functions (H1')(H2') which represent a measure related to the change over time in the maximum gain of the optical amplification and of the respective value of said difference between said first and second fourth (G1)(G2), and presenting a spatial resolution substantially equivalent to that of a measure which can be associated with an individual said pulse (P) presenting said first given duration (D').

40. A method according to claim 38 or 39, characterised in that each said phase of decoding jointly information coded according to said code (C) comprises a phase of performing a numeric analysis of the non-linear type in order to facilitate subsequent numeric operations for decoding said information coded according to said code (C).

41. A method according to any one of claims 28-40, characterised in that said given code (C) is a binary code of

the simplex type and in that each said train (P) comprises a given fifth number (N)(N′) of said first electromagnetic pulses (P'), which is identical to said given first or fourth number (Q)(Q′).

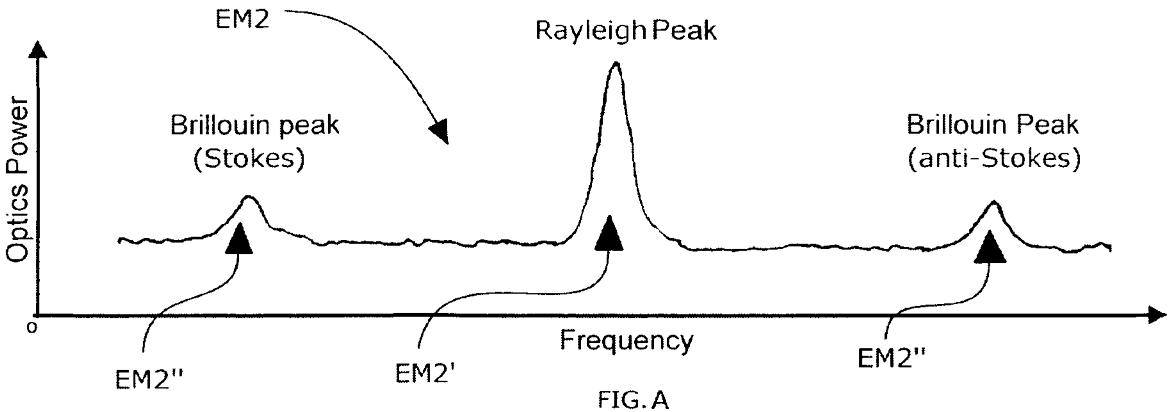


FIG. A

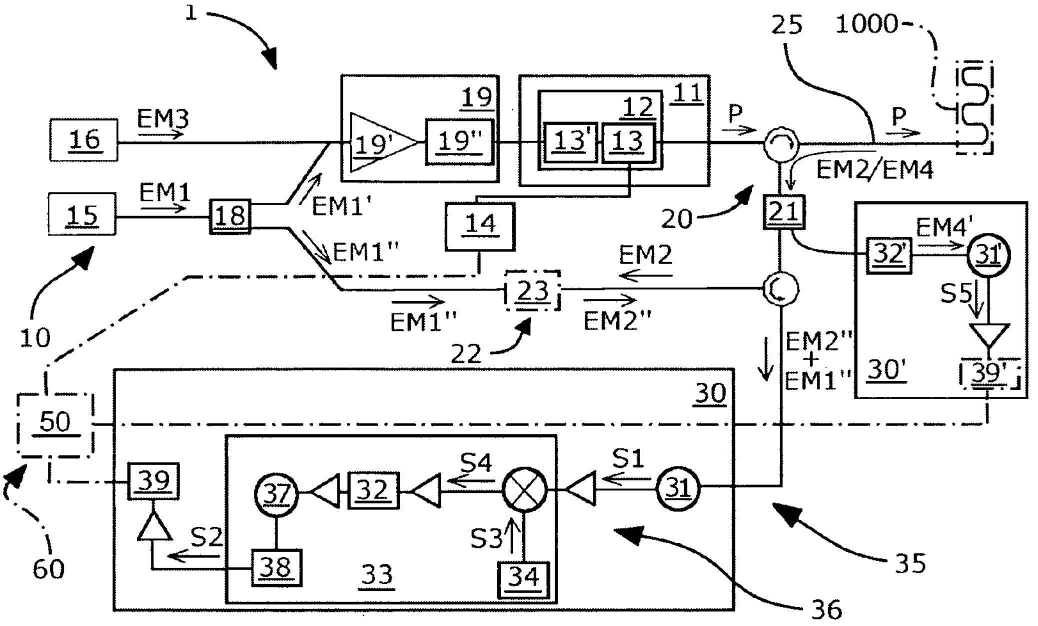


FIG. 1

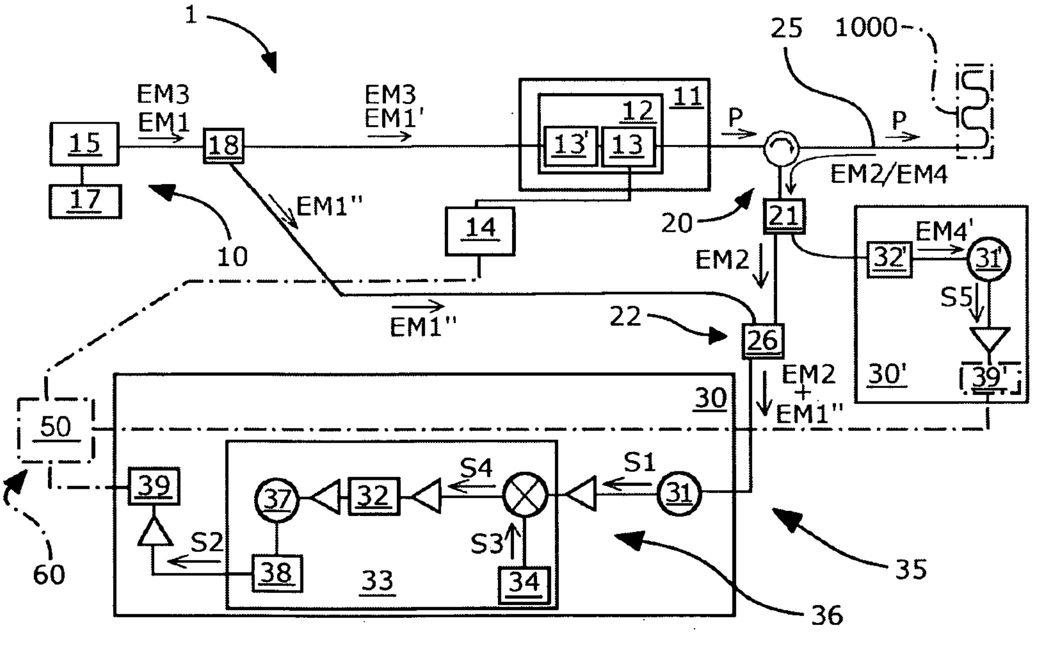


FIG. 2

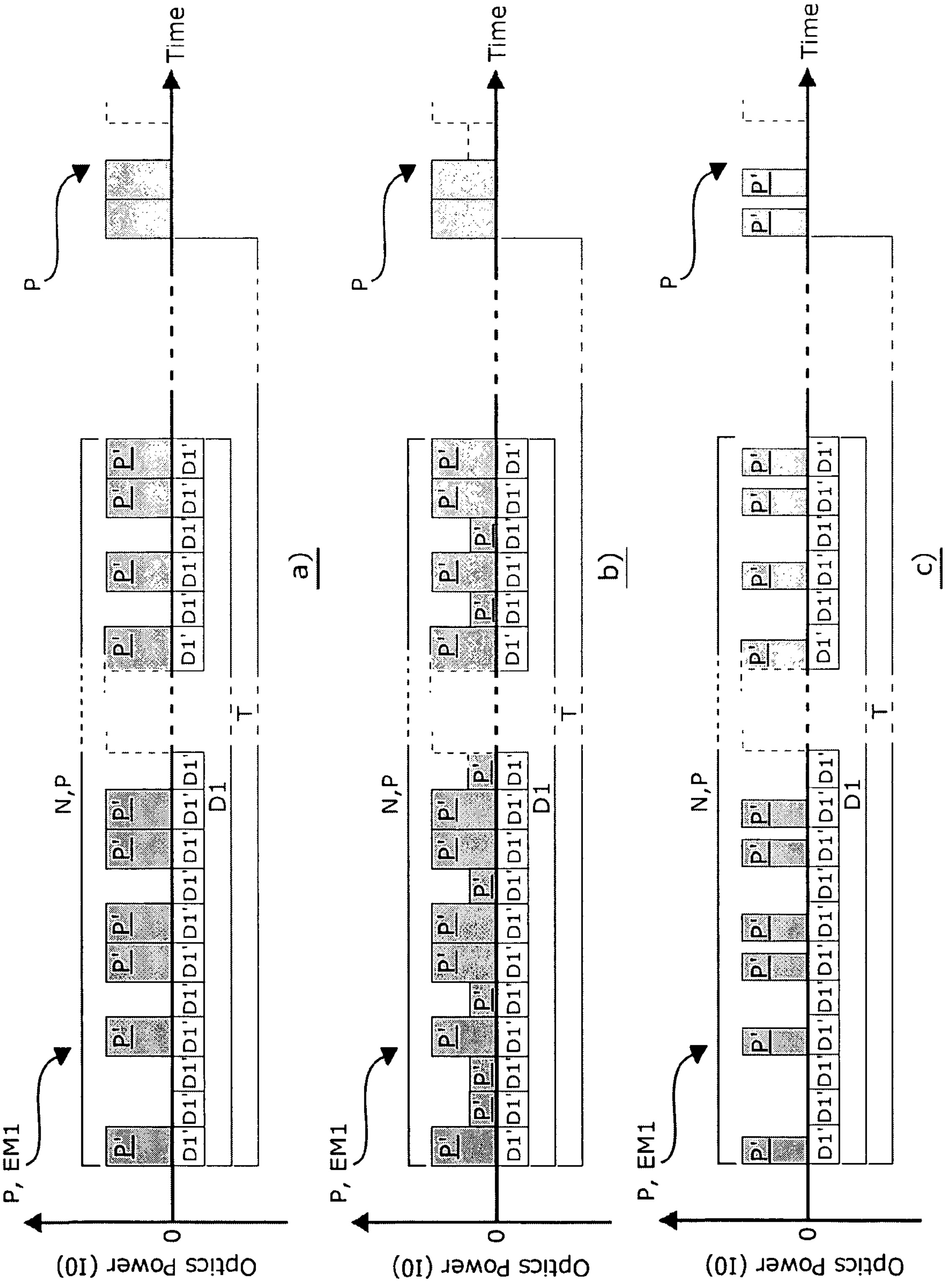
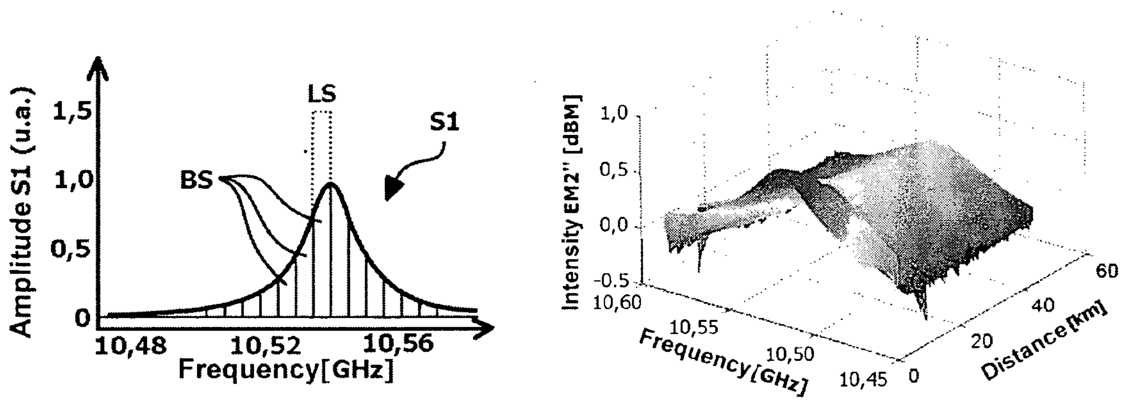


FIG.3



a) b)

FIG.4

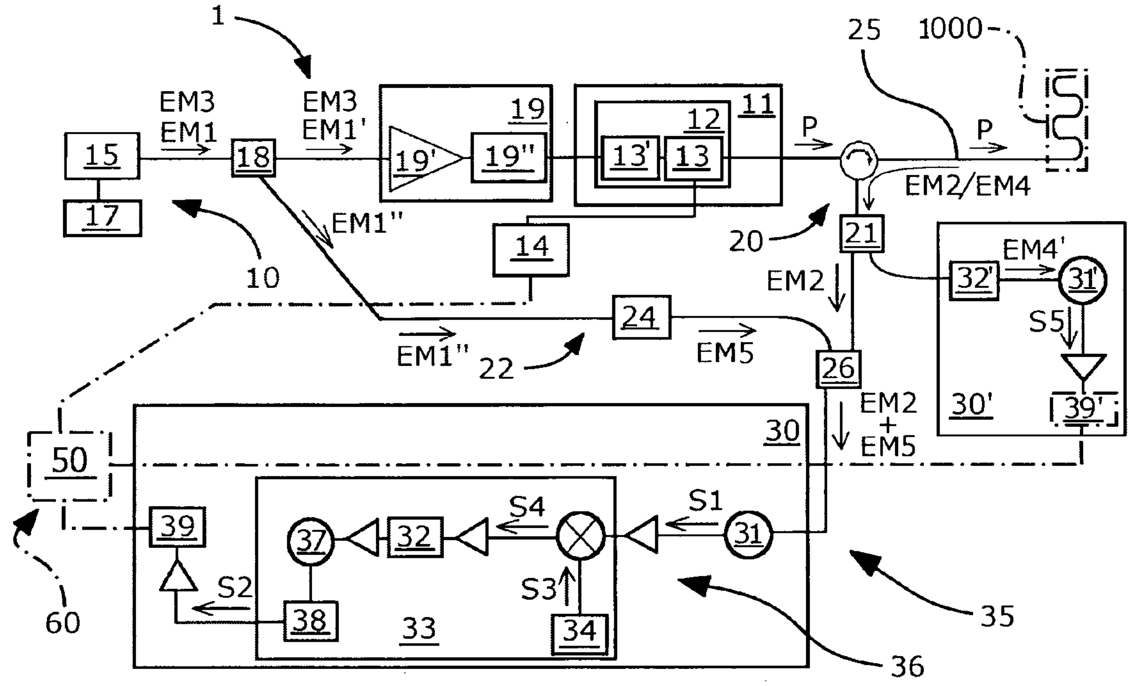


FIG.5

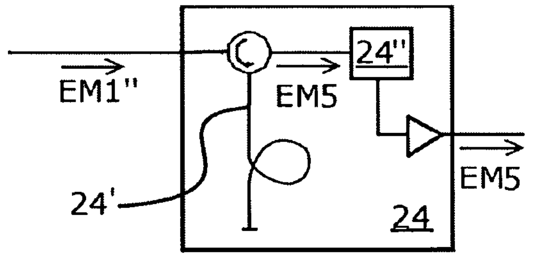
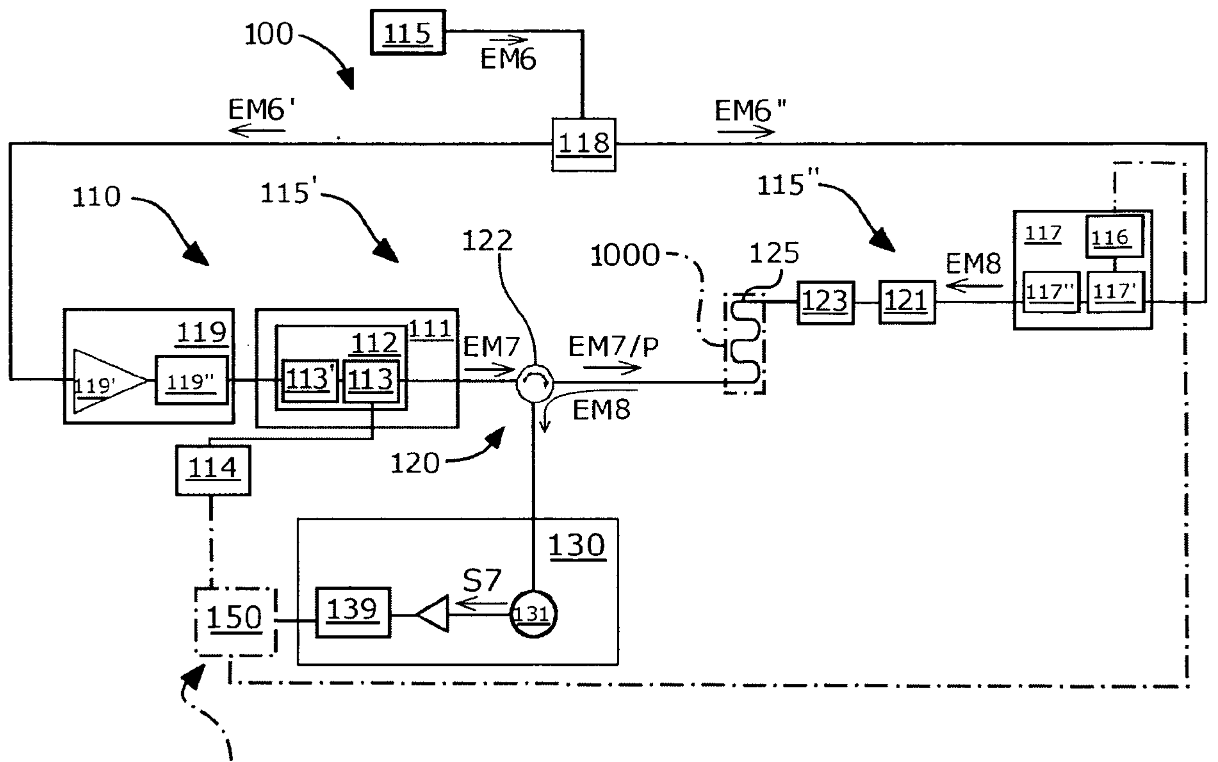


FIG.6


100
115
EM6
EM6'
118
EM6"
110
115'
115"
122
1000
125
123
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EM8
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117"
117'
119
119'
119"
112
111
113'
113
EM7
EM7/P
EM8
114
120
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S7
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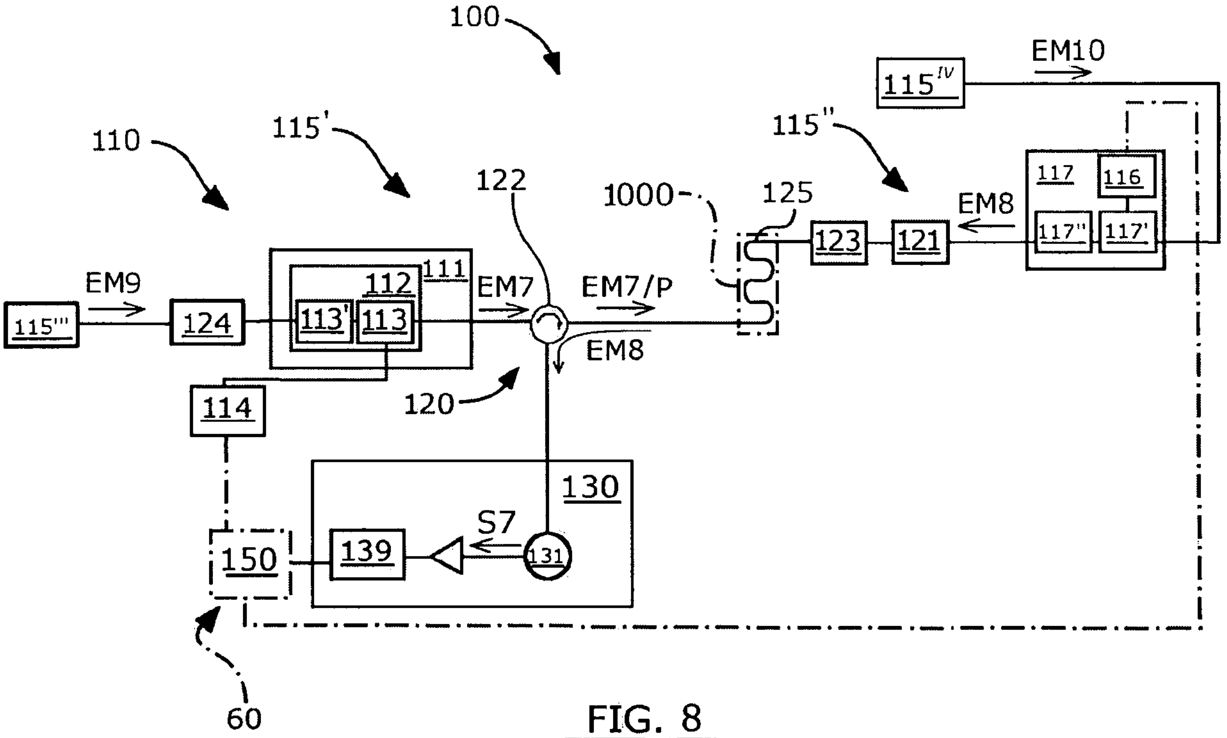
139
131
160

FIG. 7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EM9
115'''
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EM7
EM7/P
EM8
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FIG. 8

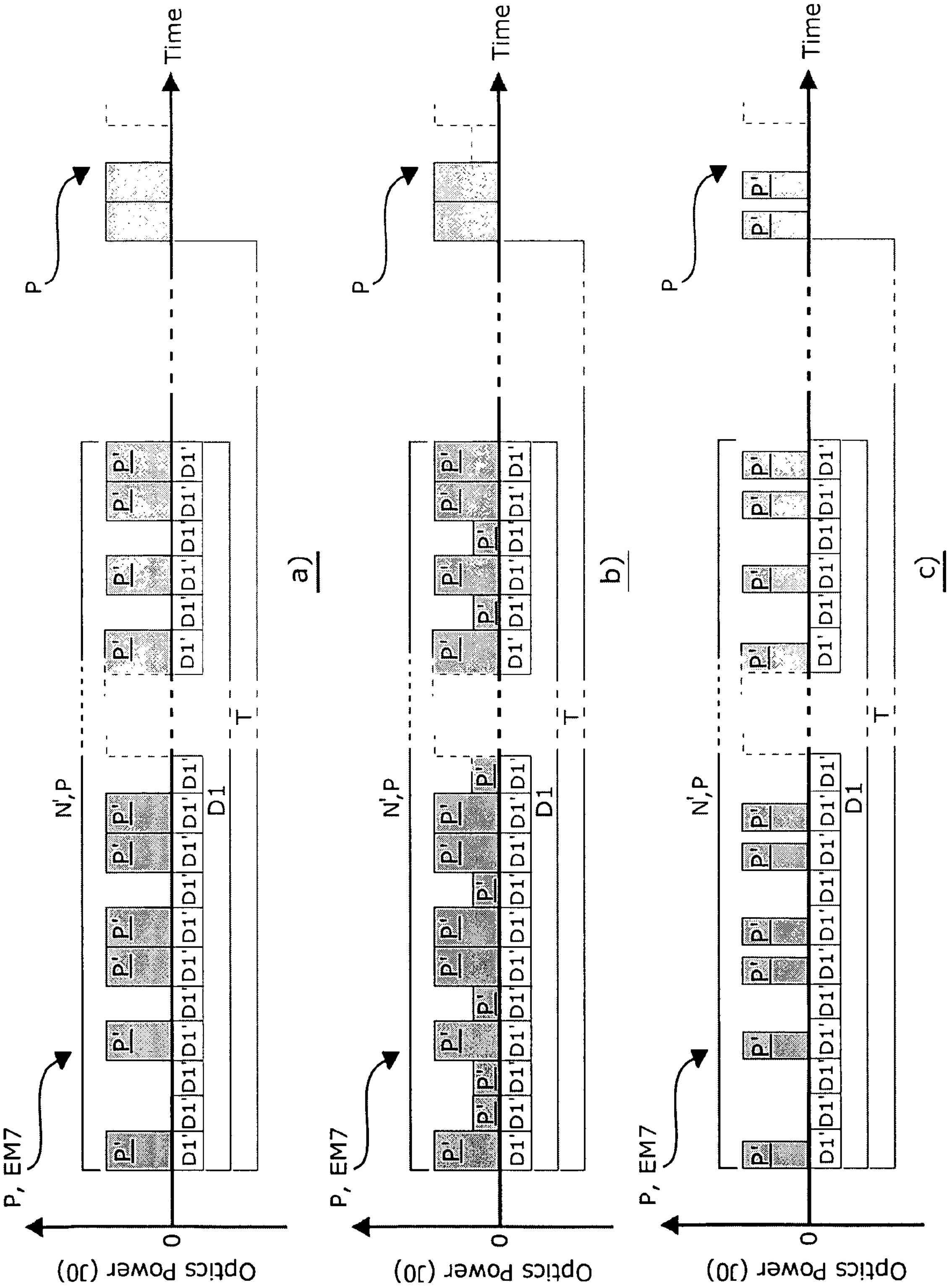

FIG.9

INTERNATIONAL SEARCH REPORT

International application No
PCT/IT2009/000525

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01K11/32 G01L1/24
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01K G01L

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	SOTO M A ET AL: "Brillouin-Based Distributed Temperature Sensor Employing Pulse Coding" 1 March 2008 (2008-03-01), IEEE SENSORS JOURNAL, IEEE SERVICE CENTER, NEW YORK, NY, US, PAGE(S) 225 - 226 , XP011203445 ISSN: 1530-437X the whole document ----- -/--	1-41

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

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"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)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"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.

"&" document member of the same patent family

Date of the actual completion of the international search 28 April 2010	Date of mailing of the international search report 07/05/2010
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 de Bakker, Michiel

3

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SAHU P K ET AL: "Analysis of Brillouin-Based Distributed Fiber Sensors Using Optical Pulse Coding" 24 February 2008 (2008-02-24), OPTICAL FIBER COMMUNICATION/NATIONAL FIBER OPTIC ENGINEERS CONFERENCE, 2008. OFC/NFOEC 2008. CONFERENCE ON, IEEE, PISCATAWAY, NJ, USA, PAGE(S) 1 - 3 , XP031391507 ISBN: 9781557528568 the whole document -----	1-41
X	MARCELO A SOTO ET AL: "30-km spontaneous-Brillouin distributed temperature sensor employing Simplex-coding and low optical input power" 26 October 2008 (2008-10-26), SENSORS, 2008 IEEE, IEEE, PISCATAWAY, NJ, USA, PAGE(S) 282 - 285 , XP031375074 ISBN: 9781424425808 the whole document -----	1-41
X	GB 2 243 210 A (EVERARD JEREMY KENNETH ARTHUR) 23 October 1991 (1991-10-23) page 5, line 11 - page 7, line 15 figure 6 -----	1,28
X	JP 2007 033183 A (SHIBAURA INST OF TECHNOLOGY; NTT INFRANET CO LTD) 8 February 2007 (2007-02-08) abstract; figure 16 paragraphs [0057] - [0061] -----	1-41

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IT2009/000525

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
GB 2243210	A	23-10-1991	NONE	
JP 2007033183	A	08-02-2007	NONE	