Description

This invention relates to optical test apparatus, and in particular to apparatus for detecting and monitoring losses and/or faults in optical fibres.

It is well known that faults in optical fibres can be located by an optical time domain reflectometer (OTDR). An OTDR launches a pulse of light into a fibre, and backscattered light is monitored for abrupt changes indicative of a loss or fault. The distance of the loss or fault from the launch end of the fibre can be determined from the time interval between launch and return of the backscattered peak. Once a period of time sufficient to receive all detectable backscattered light has passed, a further pulse may be launched into the fibre. The pulse width may be varied for different dynamic range or resolution requirements. Thus, for a given amplitude, an increase in the pulse width enables a greater length of fibre to be monitored, that is to say it increases the dynamic range of the OTDR. The dynamic range of an OTDR is the loss after which an event, backscatter or reflection can still be detected.

The OTDR is, therefore, an extremely useful item of optical test equipment; since, from connection to a single end of an optical fibre network, the location of losses and reflections can be determined, and their amplitude measured, to a high degree of accuracy. For loss measurements, both point losses and end-to-end fibre or network losses can be measured. In duplex networks, the amplitude of any reflections is important, since these may cause crosstalk. Using wavelength division multiplexing (WDM) techniques, it is also possible to take these measurements at a particular wavelength whilst the network is carrying data at another wavelength.

Until recently, high dynamic range OTDRs have primarily been reauired for use on long (>75km) submarine systems. In order to achieve the dynamic range required, the width of the output pulse is increased so that more power is launched into the fibre. This has the effect of reducing the spatial resolution (that is to say the minimum distance between which events can be distinguished). Typically, a 10μs pulse would result in a splice loss appearing 2km in length. For long-haul systems, where events are few and far between, this resolution is sufficient.

With the advent of Passive Optical Networks (PONs) which are short (<10km) in length, but high in loss (25dB), a requirement for a high resolution (<10m), high dynamic range (>25dB backscatter), OTDR is apparent. Currently available OTDRs which have the necessary spatial resolution fall short on dynamic range. Thus the Ando 7110C, with a 50ns pulse width (10m resolution), has a backscatter dynamic range of 15dB; and the Anritsu 910C, with a 100ns pulse width (20m resolution), has a backscatter dynamic range of 18dB. It should be noted that these dynamic range figures are obtained by measuring the loss of the fibre which can be seen from the point nearest to the OTDR to the point where the peak of the noise floor is reached after about 10 minutes of trace averaging. In practice, depending on the measurement to be taken, the usable dynamic range may be up to 3dB less. Furthermore from JP-A-6154421 the use of an optical switch is known to restrict the width of rejected pulses.

The present invention provides an optical test apparatus comprising an OTDR, an optical amplifier and an optical switch, the OTDR having a transmitter for launching light pulses into a test fibre along a first light path, and a receiver for receiving backscattered light from the test fibre along a second light path, the optical amplifier being positioned in the first light path for amplifying the light pulses, and the optical switch being positioned in the first light path between the optical amplifier and the test fibre, whereby there is provided timing means for synchronising the operation of the optical switch so that the switch is open only so as to pass light pulses launched by the OTDR and amplified by the optical amplifier.

An OTDR can launch successive single pulses or successive bit-streams into a fibre for backscattering monitoring, and the term "light pulses" as used in this specification should be taken to include both of these possibilities.

The optical amplifier may be a fibre amplifier or may be constituted by first and second fibre amplifiers in series.

In a preferred embodiment, the or each fibre amplifier is constituted by a length of doped optical fibre and a pump laser, the pump laser being connected to the length of doped optical fibre via a wavelength division multiplex coupler. Advantageously, the output of the or each pump laser is centred on 1,490nm.

The optical switch is effective to prevent power from spontaneous emissions and the pump laser(s) reaching the test fibre at times other than when the OTDR is launching a pulse.

In another preferred embodiment, the first fibre amplifier, which is adjacent to the OTDR is constituted by a length of erbium-doped optical fibre and a pump laser, the pump laser being connected to the length of erbium-doped optical fibre via a wavelength division multiplex coupler; and the second fibre amplifier is constituted by a length of erbium-doped optical fibre and two pump lasers, the pump lasers being connected to opposite ends of the length of erbium-doped optical fibre via respective wavelength division multiplex couplers.

Advantageously, the output of each of the pump lasers is centred on 1,490nm, the power of the pump laser associated with the first fibre amplifier is 25mW, and the power of each of the two pump lasers associated with the second fibre amplifier is 55mW.

Preferably, the erbium-doped optical fibre of the first fibre amplifier has a length of 17m, a core diameter of 5μm and a doping level of 1100ppm; and the erbium-doped optical fibre of the second fibre amplifier has a length of 23m, a core diameter of 6μm and a doping level of 1100ppm.

A lithium niobate switch may be positioned in the first light path between the two fibre amplifiers.

Preferably, the or each fibre amplifier is associated with a respective optical isolator.

In a preferred embodiment, the optical switch is an acousto-optic switch. Conveniently, the acousto-optic switch is driven by a radio frequency driver whose output frequency is such as to set up an acoustic wave in the switch. Alternatively, the optical switch is laser amplifier, preferably a multiple quantum well device. In this case, the laser amplifier may constitute the optical amplifier as well as the optical switch.

Preferably, the timing means includes a square wave generator and a pulse generator. Where the optical switch and the optical amplifier are separate items, the square wave generator and the pulse generator may be positioned between the OTDR and the optical switch, the arrangement being such that the launching of a light pulse by the OTDR triggers the square wave generator to output a square wave, the trailing edge of which triggers the pulse generator which, in turn, triggers the optical switch, the period of the square wave being such as to match the delay between the launch of the light pulse by the OTDR and the arrival of that pulse at the optical switch, this delay being due to the presence of the optical amplifier. Where the optical switch is an acousto-optic switch, the square wave generator and the pulse generator are positioned between the OTDR and the radio frequency driver.

In another preferred embodiment, a respective timing means is provided for controlling the supply of current to the or each pump laser, whereby the or each pump laser operates substantially only when a light pulse is passing through the associated length of erbium-doped optical fibre, and the optical switch is constituted by the fibre amplifier(s). In this case, the or each timing means may include a square wave generator and a pulse generator, the or each timing means being such that the launching of a light pulse by the OTDR triggers the respective square wave generator to output a square wave, the trailing edge of which triggers the associated pulse generator which, in turn, triggers the supply of current to the associated pump laser, the period of the square wave being such as to match the delay between the launch of the light pulse by the OTDR and the arrival of that pulse at the associated length of erbium-doped optical fibre.

Advantageously, means are provided for continuously varying the width of the output pulse of the or each pulse generator, whereby the width of the light pulses launched into the test fibre can be continuously varied. Consequently, the pulse generator can be used to control the resolution of the apparatus. As this control is continuously variable, an optimum dynamic range/resolution trade-off can be obtained for the fibre under test.

The apparatus may further comprise a length of optical fibre positioned in the first light path between the amplifier(s) and the acousto-optic switch, the length of said optical fibre being such as to provide a delay in the optical light path between the OTDR and the acousto-optic switch to compensate for electrical delays occurring in the electrical path from the OTDR to the radio frequency driver.

An optical test apparatus constructed in accordance with the invention will now be described in greater detail, by way of example, with reference to the accompanying drawings, in which: -

Fig 1. is a schematic representation of the apparatus;

Fig 2. is a schematic representation of a fibre amplifier forming part of the apparatus;

Fig 3. is a graphical representation showing the effect of an acousto-optic switch forming part of the apparatus;

Fig 4. is a graphical representation illustrating the timing of the acousto-optic switch;

Fig 5 is a graphical representation illustrating the spectrum of the OTDR laser forming part of the apparatus and the spectrum of the amplifier gain;

Fig 6 is a schematic representation of an apparatus not claimed.

Referring to the drawings, Fig 1 shows an Anritsu MW910C OTDR mainframe 1 with a 1550nm MW939 plug-in unit. The plug-in unit of the OTDR 1 includes a Fabry-Perot laser 2 and an avalanche photodiode (APD) receiver 3. The OTDR 1 is basically unmodified, apart from minor changes which are necessary to gain access to the plug-in unit, and in particular to the laser 2 and the receiver 3. The laser 2 launches 40ns or 100ns pulses of light at 1550nm into a length of fibre 4 under test, via a fibre branch line 5; and the receiver 3 monitors backscattered light from the test fibre, via a fibre branch line 6. The branch lines 5 and 6 are connected to the test fibre 4 by an optical coupler 7.

The branch line 5 includes a pair of fibre amplifiers 8, each of which is associated with an optical isolater 9 and, via a WDM coupler 10, a pump laser 11. The branch line 5 also includes, "downstream" of the amplifiers 8, a length of delay fibre 12 and an acousto-optic switch 13 which has a 30dB extinction ratio. The switch 13

is constituted by a crystal whose refractive index is altered as a result of the mechanical strain accompanying the passage of an acoustic wave through the crystal. Such a switch is a very fast-acting switch. Each fibre amplifier 8 is constituted (see Fig. 2) by a length of erbium-doped fibre 8a which is coupled into the branch line 5 by splices 8b. The first erbium-doped fibre 8a has a length of 17m, a core diameter of 5μm and a doping level of 1100ppm (BTRL Batch No. 398.004). The second erbium-doped fibre 8a has a length of 23m, a core diameter of 6μm and a doping level of 1100ppm (BTRL Batch No. 309.201). Each WDM coupler 10 has four legs, two of which are spliced into the branch line 5, the pump laser 11 being connected to another leg of the WDM coupler, and the remaining leg of the WDM coupler having a termination 12a. In use, each pump laser 11 is maintained at a constant temperature of 19°C by means of a Peltier cooler. The output of each pump laser 11 is centred on 1490nm, which is the optimum pumping wavelength of the associated fibre amplifier 8. The optical isolator 9 "upstream" of the first amplifier 8 prevents power from the pump laser 11 reaching (and possibly damaging) the OTDR laser 2. The isolator 9 "upstream of the second amplifier 8 prevents the amplified spontaneous emission (ASE) from this amplifier from partially saturating the first amplifier 8 which would reduce its gain. Each isolater 9 has a loss of approximately 2.5dB. Super physical contact (PC) connectors are used to connect all the components of the branch line 5 together, and also to connect the coupler 7 to the test fibre 4. The super PC connectors are used to reduce reflections to a minimum, thereby decreasing the risk of the amplifiers 8 lasing, and also reducing the reflection of transmitted OTDR pulses from the connector between the coupler 7 and the test fibre 4, which may saturate the receiver 3. Alternatively, and preferably, the PC connectors could be replaced by splices.

The acousto-optic switch 13 is effective to prevent ASE and pump laser power being launched into the test fibre 4 at times other than when the OTDR laser 2 is launching a pulse. The effect of the switch 13 is shown in Fig. 3. Thus, Fig 3a shows the normal output of the OTDR 1, and Fig. 3b shows the normal amplified output, in which ASE and pump laser power give rise to a large amount of noise, indicated generally by the reference numeral 14. If the ASE and pump laser power were launched into the test fibre 4 between OTDR pulses at a sufficiently high level, backscattered noise would limit any increase in the dynamic range of the OTDR 1 which results from the increased power due to the amplification of the amplifiers 8, were it not for the effect of the acousto-optic switch 13. Indeed, as the power of the pump laser 11 is increased to give an increase in power transmitted into the test fibre 4, the noise level would, in the absence of the switch 13, increase to such a level as to saturate the receiver 3 of the OTDR 1 as shown in Fig. 3b and make it unusable. This noise problem is overcome, as shown in Fig 3c, by ensuring that the switch 13 is timed to be open only so as to pass amplified pulses from the OTDR laser 2, and so as to be closed at all other times, thereby preventing all other emissions reaching the test fibre 4 in the intervening periods between the passage of amplified pulses. As spontaneous and pump laser emissions do not reach the test fibre 4 between OTDR pulses, the power of the transmitted pulses can be increased, whilst maintaining a narrow pulse width, thereby ensuring that the OTDR 1 has a high dynamic range and a good spatial resolution. This does mean, however, that the amplified pulses are composed of the OTDR laser spectrum, spontaneous emission and pump emission, but this does not matter as the spectrum of the output pulse is unimportant for OTDR purposes.

As mentioned above, the timing of the acousto-optic switch 13 is critical. The switch 13 is driven by its own radio frequency (RF) driver 15, which converts a transistor-transistor logic (TTL) input signal to a switched RF output whose frequency is such as to set up an acoustic wave in the switch. However, since the fibre amplifiers 8 introduce a delay into the arrival of a pulse at the switch 13, due to the time it takes for the light pulse to travel the length of each erbium-doped fibre 8a, the switch driver 15 cannot be directly coupled to the drive circuitry of the OTDR laser 2. Instead, as shown in Fig. 1, an output is taken from the OTDR laser 2 to trigger a square wave generator 16. This in turn triggers a pulse generator 17, whose output is connected to the driver 15 of the acousto-optic switch 13.

Fig. 4 illustrates the switch timing sequence. Thus, an output pulse of the OTDR laser 2 (see Fig. 4a) triggers the square wave generator 16, the trailing edge of the output square wave (see Fig. 4c) of which is used to trigger the pulse generator 17 (see Fig. 4d). The output of the pulse generator 17 then triggers the switch 13 via the driver 15. By adjusting the period of the square wave, the delay between the OTDR laser pulse (see Fig. 4a) and the amplified pulse (see Fig. 4b) can, in theory, be matched. In practice, because of electrical delays in the switch path (that is to say the path from the OTDR laser 2 to the switch driver 15), matching is still not exact. This is the reason for the length of delay fibre 12 in the branch line 5. This delay fibre 12 has a length of a few hundred metres, which is sufficient to provide a delay in the optical signal path to compensate for electrical delays in the switch path. If necessary, the width of the output pulse of the pulse generator 17 can be adjusted to match (or be narrower than) the width of the amplified pulse. Consequently, the width of the output pulse, and hence the resolution of the OTDR 1, can be controlled by the switch 13. The only limiting factors here are the rise time of the switch 13, and the bandwidth of the receiver 3. Acousto-optic switches are available with rise times as low as a few nanoseconds which is adequate for a high resolution instrument. If

necessary, the receiver 3 could also be changed to obtain the required bandwidth for high resolution operation.

In use, the laser 2 of the OTDR 1 emits a pulse with a peak output power of 14dBm (25mW). The dynamic range (without the amplification of the branch line 5) for pulse widths of 40ns and 100ns is 16dB and 18dB respectively (giving a spatial resolution of 20m and 8m respectively). However, by amplifying the pulses on the branch line 5, a pulse power of 27dBm (500mW) is launched into the fibre 4, and this 13dB power increase should, in theory, result in a 6.5dB increase in the dynamic range for each pulse width providing the noise at the receiver 3 is not increased, since the pulse will encounter the loss of the fibre twice, once in each direction. The measured dynamic range of the apparatus shown in Fig. 1 is 22.5dB and 24.5dB respectively for the 40ns and 100ns pulse widths (for which the spatial resolutions remain 20m and 8m respectively). Thus, the apparatus of the invention gives an increased dynamic range for an OTDR whilst maintaining high resolution.

Figure 5 is a comparison of the spectrum A of the laser 2 and the spectrum B of the gain of the amplifier constituted by the two fibre amplifiers 8. As will be apparent, the laser spectrum A (which has a broad spectral width of about 40nm) lies entirely within the amplifier gain spectrum B. In other words, the gain characteristics of the amplifier are such that the entire output spectrum of the laser 2 is amplified. The use of the fibre amplifiers 8 thus permits the use of a relatively cheap Fabry-Perot laser. This is to be contrasted with known OTDRs whose amplifiers have narrow bandwidths, thereby requiring the use of expensive distributed feed back (DFB) lasers. Moreover, because the laser spectrum A lies well within the amplifier gain spectrum B, there is a wide tolerance of laser wavelengths that can be used. As it is difficult to manufacture a Fabry-Perot laser with a pre-determined output, this wavelength tolerance permits tolerances on the outputs of Fabry-Perot lasers to be accomodated, thereby permitting the use of cheaper Fabry-Perot lasers than would otherwise have been the case.

It will be apparent that modifications could be made to the apparatus described above. Thus, by increasing the power of the fibre amplifiers 8, the optical power launched into the test fibre 4 can be increased to about 33dBm (2W). Above this level, problems tend to arise if connectors are not kept spotlessly clean, so this is probably the highest practical launch power. To achieve such a launch power level, a peak amplifier output of 48dBm (63W) is required due to the losses (about 15dB) in the optical components the delay fibre 12, (the acousto-optic switch 13, and the coupler 7) "downstream" of the amplifiers 8. It is, of course, possible to replace the fibre amplifiers 8 by a single fibre amplifier of a suitable rating, or to use three or more fibre amplifiers. It would also be possible to use one or more semiconductor amplifiers in place of the fibre amplifiers.

The apparatus described above could be further improved by using a receiver having a higher sensitivity. Two possibilities are to use photon counting techniques or an optical receiver having an integral pre-amplifier. Also, where narrower pulse widths are used to achieve a higher resolution, the receiver circuitry would need to be extensively revised to increase the bandwidth to that required. In this connection, two options exist to decrease the output pulse width. First, by using the acousto-optic switch 13, and second by modifying the pulse generation circuitry in the OTDR 1. To use the switch 13, the collimated beam entering the switch crystal would need to be focused, since the rise time of the switch is related to the time it takes the acoustic wave to traverse the beam. Where a 400μm collimated beam is used, a rise time of about 20ns results. If the beam were focused, then the rise time could be reduced to a few nanoseconds. This is required if the pulse is to be reduced to a period of less than 10ns. Modifying the pulse generation circuitry is potentially a relatively simple task, though the bandwidth of the pulse amplification circuitry is unknown but likely to be too low. The problems of receiver and pulse generator bandwidth can, however, be overcome by using a specifically-designed, high resolution OTDR.

It would also be possible to alter the amplification properties of the fibre amplifiers 8 by varying the concentrations of erbium doping. The length of fibre 8a used for these amplifiers 8 depends upon the power of the associated pump lasers 11, and can vary between 10 and 25m for pump laser outputs varying between 15 and 90mW. Similarly, the operating wavelength of each pump depends upon the properties of the fibre amplifier with which it is associated.

In a further modification, a filter could be positioned between the acousto-optic switch 13 and the coupler 7 to reduce pump power reaching the test fibre 4, and to narrow the spontaneous output of the fibre amplifiers 8. In this case, the Fabry-Perot laser 2 could be replaced by a DFB laser, if a very narrow spectral width output is required.

In a particularly advantageous modification, a lithium niobate switch, which operates on the Mach-Zehnder principle, is positioned in the branch line 5 between the two amplifiers 8. Timing and driver circuitry - similar to that used to time the switch 13 (i.e. a square wave generator, a pulse generator and a switch driver) - is provided to time the lithium niobate switch so that only amplified pulses are transmitted to the second amplifier. This is to prevent the ASE from the first amplifier causing population inversion in the second amplifier, which would reduce the pump energy stored and thus the gain which can be extracted. A third optical isolator may be provided between the second amplifier 8 and the acousto-optic switch 13, this isolator being effective to

prevent the output of the second amplifier being reflected back into that amplifier, which would reduce its gain.

In this modified arrangement, the first amplifier is pumped (using a 25mW pump laser) towards the source to minimise the ASE energy arriving at the second amplifier. The second amplifier is pumped bidirectionally, thereby improving its amplification. This bidirectional pumping is achieved by using two 55mW pump lasers, one at each end of the associated fibre amplifier, each of the pump lasers being connected to the fibre amplifier via a respective WDM coupler. In this case, all three pump lasers are semiconductor laser diodes which operate at a wavelength of 1490nm. For a pulse width of 100ns, and a pulse repetition period of 1.6ms, the OTDR has a distance range of 144km. Without any input to the second amplifier, the mean ASE output (measured "upstream" of the acousto-optic switch 13) is 5mW. This equates to a total energy output of 8μJ per repetition period. The energy contained in the amplified pulse - which has a peak optical power of 100 W (again measured "upstream" of the switch 13) - is 10μJ, which is comparable to the total ASE energy. This suggests that the gain of the second amplifier is just saturating. The insertion loss of the switch 13 and the coupler 7 reduce the peak optical power to 2W (33dBm). The dynamic range of the OTDR modified in this way is, therefore, theoretically 9.5dB higher than the 18dB of the "standard" OTDR (i.e. without the amplication in the branch line 5). In practice, however, coupler losses reduce the dynamic range of the modified instrument to 26dB. For 3ns pulses, the dynamic range of the modified instrument is 14dB (instead of 4dB for the "standard" instrument).

It would, of course, be possible to operate each of the fibre amplifiers (no matter how many are present) with bidirectional pumping. Bidirectional pumping for the first of two or more amplifiers is, however, of doubtful value, as there is usually no need for additional power at this stage. Indeed, too much power at such an amplifier can be disadvantageous in that it tends to cause deposits on the PC connectors "downstream" thereof.

In a further modified arrangement, the acousto-optic switch 13 could be replaced by a semiconductor laser amplifier, and in particular a multiple quantum well device (which can handle the high input power that occur). In this case, the laser amplifier is turned on and off in sychronism with the arrival and departure of light pulses from the OTDR. An advantage of using a laser amplifier in place of the acousto-optic switch is that the gain of a laser amplifier will generally be ≧1, so it constitutes a lossless switch. This is to be compared with a loss of about 7dB for an acousto-optic switch. This means that the amplification stages upstream of the switch are not so critical. Indeed, if the laser amplifier has sufficient gain, the fibre amplifiers 8 are no longer required, and the laser amplifier acts both as an optical amplifier and an optical switch. Such an arrangement is shown in Figure 6, in which like reference numerals are used for like parts, and the reference numeral 13′ indicates the multiple quantum well semiconductor laser amplifier which constitutes both an optical amplifier and an optical switch. In this case, the square wave generator 16 is used to trigger the pulse generator 17 which, in turn, triggers the laser amplifier 13′.

It would also be possible to pulse the current to the two pump lasers 11, so that the two fibre amplifiers act as optical switches. Each pump laser 11 would then have its own timing switch constituted by a square wave generator and a pulse generator. This modification should work satisfactorily for wide (~200ns) pulses, but may encounter problems with narrow pulses (~3ns). For example, problems may occur in controlling the pump lasers, and with decays after the pump lasers are switched off.

Claims

1. An optical test apparatus comprising an OTDR (1), an optical amplifier (3) and an optical switch (13), the OTDR having a transmitter (2) for launching light pulses into a test fibre (4) along a first light path (5), and a receiver (3) for receiving backscattered light from the test fibre along a second light path (6), the optical amplifier being positioned in the first light path for amplifying the light pulses, and the optical switch being positioned in the first light path between the optical amplifier and the test fibre, whereby there is provided timing means (15, 16, 17) for synchronising the operation of the optical switch so that the switch is open only so as to pass light pulses launched by the OTDR and amplified by the optical amplifier.

2. Apparatus as claimed in claim 1, wherein the optical amplifier is a fibre amplifier (8).

3. Apparatus as claimed in claim 1, wherein the optical amplifier is constituted by first and second fibre amplifiers (8) in series.

4. Apparatus as claimed in claim 2 or claim 3, wherein the or each fibre amplifier (8) is constituted by a length of erbium-doped optical fibre (8a) and a pump laser (11), the pump laser being connected to the length of erbium-doped optical fibre via a wavelength division multiplex coupler (10).

prevent the output of the second amplifier being reflected back into that amplifier, which would reduce its gain.

In this modified arrangement, the first amplifier is pumped (using a 25mW pump laser) towards the source to minimise the ASE energy arriving at the second amplifier. The second amplifier is pumped bidirectionally, thereby improving its amplification. This bidirectional pumping is achieved by using two 55mW pump lasers, one at each end of the associated fibre amplifier, each of the pump lasers being connected to the fibre amplifier via a respective WDM coupler. In this case, all three pump lasers are semiconductor laser diodes which operate at a wavelength of 1490nm. For a pulse width of 100ns, and a pulse repetition period of 1.6ms, the OTDR has a distance range of 144km. Without any input to the second amplifier, the mean ASE output (measured "upstream" of the acousto-optic switch 13) is 5mW. This equates to a total energy output of 8μJ per repetition period. The energy contained in the amplified pulse - which has a peak optical power of 100 W (again measured "upstream" of the switch 13) - is 10μJ, which is comparable to the total ASE energy. This suggests that the gain of the second amplifier is just saturating. The insertion loss of the switch 13 and the coupler 7 reduce the peak optical power to 2W (33dBm). The dynamic range of the OTDR modified in this way is, therefore, theoretically 9.5dB higher than the 18dB of the "standard" OTDR (i.e. without the amplication in the branch line 5). In practice, however, coupler losses reduce the dynamic range of the modified instrument to 26dB. For 3ns pulses, the dynamic range of the modified instrument is 14dB (instead of 4dB for the "standard" instrument).

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In a further modified arrangement, the acousto-optic switch 13 could be replaced by a semiconductor laser amplifier, and in particular a multiple quantum well device (which can handle the high input power that occur). In this case, the laser amplifier is turned on and off in sychronism with the arrival and departure of light pulses from the OTDR. An advantage of using a laser amplifier in place of the acousto-optic switch is that the gain of a laser amplifier will generally be ≧1, so it constitutes a lossless switch. This is to be compared with a loss of about 7dB for an acousto-optic switch. This means that the amplification stages upstream of the switch are not so critical. Indeed, if the laser amplifier has sufficient gain, the fibre amplifiers 8 are no longer required, and the laser amplifier acts both as an optical amplifier and an optical switch. Such an arrangement is shown in Figure 6, in which like reference numerals are used for like parts, and the reference numeral 13′ indicates the multiple quantum well semiconductor laser amplifier which constitutes both an optical amplifier and an optical switch. In this case, the square wave generator 16 is used to trigger the pulse generator 17 which, in turn, triggers the laser amplifier 13′.

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Claims

1. An optical test apparatus comprising an OTDR (1), an optical amplifier (3) and an optical switch (13), the OTDR having a transmitter (2) for launching light pulses into a test fibre (4) along a first light path (5), and a receiver (3) for receiving backscattered light from the test fibre along a second light path (6), the optical amplifier being positioned in the first light path for amplifying the light pulses, and the optical switch being positioned in the first light path between the optical amplifier and the test fibre, whereby there is provided timing means (15, 16, 17) for synchronising the operation of the optical switch so that the switch is open only so as to pass light pulses launched by the OTDR and amplified by the optical amplifier.

2. Apparatus as claimed in claim 1, wherein the optical amplifier is a fibre amplifier (8).

3. Apparatus as claimed in claim 1, wherein the optical amplifier is constituted by first and second fibre amplifiers (8) in series.

4. Apparatus as claimed in claim 2 or claim 3, wherein the or each fibre amplifier (8) is constituted by a length of erbium-doped optical fibre (8a) and a pump laser (11), the pump laser being connected to the length of erbium-doped optical fibre via a wavelength division multiplex coupler (10).

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5. Apparatus as claimed in claim 4, wherein the output of the or each pump laser (11) is centred on 1,490nm.

6. Apparatus as claimed in claim 3, wherein the first fibre amplifier (8), which is adjacent to the OTDR (1), is constituted by a length of erbium-doped optical fibre and a pump laser (11), the pump laser being connected to the length of erbium-doped optical fibre via a wavelength division multiplex coupler (10); and the second fibre amplifier (8) is constituted by a length of erbium-doped optical fibre (8a) and two pump lasers (11), the pump lasers being connected to opposite ends of the length of erbium-doped optical fibre via respective wavelength division multiplex couplers.

7. Apparatus as claimed in claim 6, wherein the output of each of the pump lasers (11) is centred on 1,490nm, the power of the pump laser associated with the first fibre amplifier (8) is 25mW, and the power of each of the two pump lasers associated with the second fibre amplifier (8) is 55mW.

8. Apparatus as claimed in any one of claims 4 to 7 when appendant to claim 3, wherein the erbium-doped optical fibre (8a) of the first fibre amplifier (8) has a length of 17m, a core diameter of 5μm and a doping level of 1100ppm.

9. Apparatus as claimed in any one of claims 4 to 8 when appendant to claim 3, wherein the erbium-doped optical fibre (8a) of the second fibre amplifier (8) has a length of 23m, a core diameter of 6μm and a doping level of 1100ppm.

10. Apparatus as claimed in any one of claims 3 to 9, wherein a lithium niobate switch is positioned in the first light path (5) between the two fibre amplifiers (8).

11. Apparatus as claimed in any one of claims 4 to 10, wherein each fibre amplifier 8) is associated with a respective optical isolator (9).

12. Apparatus as claimed in any one of claims 1 to 11, wherein the optical switch (13) is an acousto-optic switch.

13. Apparatus as claimed in claim 12, wherein the acousto-optic switch (13) is driven by a radio frequency driver (15) whose output frequency is such as to set up an acoustic wave in the switch.

14. Apparatus as claimed in any one of claims 1 to 11, wherein the optical switch (13) is a laser amplifier.

15. Apparatus as claimed in claim 14, wherein the laser amplifier (13) is a multiple quantum well device.

16. Apparatus as claimed in either of claims 14 and 15 when appendant to claim 1, wherein the laser amplifier consitutes the optical amplifier (8) as well as the optical switch (13).

17. Apparatus as claimed in any one of claims 1 to 16, wherein the timing means includes a square wave generator (16) and a pulse generator (17).

18. Apparatus as claimed in claim 17 when appendant to any one of claims 13 to 15, wherein the square wave generator (16) and the pulse generator (17) are positioned between the OTDR (1) and the optical switch (13), the arrangement being such that the launching of a light pulse by the OTDR triggers the square wave generator to output a square wave, the trailing edge of which triggers the pulse generator which, in turn, triggers the optical switch, the period of the square wave being such as to match the delay between the launch of the light pulse by the OTDR and the arrival of that pulse at the optical switch.

19. Apparatus as claimed in claim 18 when appendent to claim 13, wherein the square wave generator (16) and the pulse generator (17) are positioned between the OTDR (1) and the radio frequency driver (15).

20. Apparatus as claimed in any one of claims 4 to 11, wherein a respective timing means is provided for controlling the supply of current to the or each pump laser (11), whereby the or each pump laser operates substantially only when a light pulse is passing through the associated length of erbium-doped optical fibre (8a), and wherein the optical switch (13) is constituted by the fibre amplifier(s).

21. Apparatus as claimed in claim 20, wherein the or each timing means includes a square wave generator (16) and a pulse generator (17), the or each timing means being such that the launching of a light pulse

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by the OTDR (1) triggers the respective square wave generator to output a square wave, the trailing edge of which triggers the associated pulse generator which, in turn, triggers the supply of current to the associated pump laser (11), the period of the square wave being such as to match the delay between the launch of the light pulse by the OTDR and the arrival of that pulse at the associated length of erbium-doped optical fibre (8a).

22. Apparatus as claimed in claim 17, claim 18, claim 19 or claim 21, wherein means are provided for continuously varying the width of the output pulse of the or each pulse generator (17), whereby the width of the light pulses launched into the test fibre (4) can be continuously varied.

23. Apparatus as claimed in claim 19, further comprising a length of optical fibre positioned in the first light path (15) between the amplifier(s) (8) and the acousto-optic switch (13), the length of said optical fibre being such as to provide a delay in the optical light path between the OTDR (1) and the acousto-optic switch (13) to compensate for electrical delays occuring in the electrical path from the OTDR to the radio frequency driver (15).

Patentansprüche

1. Optisches Prüfgerät, mit einem OTDR (1), einem optischen Verstärker (8) und einem optischen Schalter (13), wobei das OTDR einen Sender (2), der die Lichtimpulse in eine Prüffaser (4) längs eines ersten Lichtweges (5) einkoppelt, sowie einen Empfänger (3) enthält, der von der Prüffaser längs eines zweiten optischen Weges (6) zurückgestreutes Licht empfängt, wobei der optische Verstärker im ersten Lichtweg angeordnet ist, um die Lichtimpulse zu verstärken, und der optische Schalter im ersten Lichtweg zwischen dem optischen Verstärker und der Prüffaser angeordnet ist, wobei eine Einrichtung (15, 16, 17) vorgesehen ist, die den Betrieb des optischen Schalters in der Weise synchronisiert, daß der Schalter nur offen ist, um Lichtimpulse durchzulassen, die vom OTDR eingekoppelt und vom optischen Verstärker verstärkt werden.

2. Gerät nach Anspruch 1, bei dem der optische Verstärker ein Faserverstärker (8) ist.

3. Gerät nach Anspruch 1, bei dem der optische Verstärker durch einen ersten und einen zweiten Faserverstärker (8), die in Serie geschaltet sind, gebildet ist.

4. Gerät nach Anspruch 2 oder Anspruch 3, bei dem der oder jeder Faserverstärker (8) durch ein Stück einer mit Erbium dotierten Lichtleitfaser (8a) und durch einen Pumplaser (11) gebildet ist, wobei der Pumplaser an das Stück der mit Erbium dotierten Lichtleitfaser über einen Wellenlängenmultiplex-Koppler (10) angeschlossen ist.

5. Gerät nach Anspruch 4, bei dem der Ausgang des oder der Pumplaser (11) bei 1,490 nm zentriert ist.

6. Gerät nach Anspruch 3, bei dem der erste Faserverstärker (8), der an das OTDR (1) angrenzt, durch ein Stück einer mit Erbium dotierten Lichtleitfaser sowie durch einen Pumplaser (11) gebildet ist, wobei der Pumplaser an das Stück der mit Erbium dotierten Lichtleitfaser über einen Wellenlängenmultiplex-Koppler (10) angeschlossen ist; und der zweite optische Verstärker (8) durch ein Stück einer mit Erbium dotierten Lichtleitfaser (8a) sowie durch zwei Pumplaser (11) gebildet ist, wobei die Pumplaser an gegenüberliegende Enden des Stücks der mit Erbium dotierten Lichtleitfaser über entsprechende Wellenlängenmultiplex-Koppler angeschlossen sind.

7. Gerät nach Anspruch 6, bei dem der Ausgang jedes Pumplasers (11) bei 1,490 nm zentriert ist, wobei die Leistung des dem ersten Faserverstärker (8) zugehörigen Pumplasers 25 mW beträgt und die Leistung jedes zweiten Pumplasers, die dem zweiten Faserverstärker (8) zugehören, 55 mW beträgt.

8. Gerät nach irgendeinem der Ansprüche 4 bis 7 in Verbindung mit Anspruch 3, bei dem die mit Erbium dotierte Lichtleitfaser (8a) des ersten Faserverstärkers (8) eine Länge von 17 m, einen Kerndurchmesser von 5 µm und einen Dotierungsgrad von 1100 ppm besitzt.

9. Gerät nach irgendeinem der Ansprüche 4 bis 8 in Verbindung mit Anspruch 3, bei dem die mit Erbium dotierte Lichtleitfaser (8a) des zweiten Faserverstärkers (8) eine Länge von 23 m, einen Kerndurchmesser

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von 6 µm und einen Dotierungsgrad von 1100 ppm besitzt.

10. Gerät nach irgendeinem der Ansprüche 3 bis 9, bei dem im ersten Lichtweg (5) zwischen den zwei Faserverstärkern (8) ein Lithium-Niobat-Schalter angeordnet ist.

11. Gerät nach irgendeinem der Ansprüche 4 bis 10, bei dem jeder Faserverstärker (8) mit einem entsprechenden optischen Isolator (9) verbunden ist.

12. Gerät nach irgendeinem der Ansprüche 1 bis 11, bei dem der optische Schalter (13) ein akustooptischer Schalter ist.

13. Gerät nach Anspruch 12, bei dem der akustooptische Schalter (13) durch einen Funkfrequenztreiber (15) getrieben wird, dessen Ausgangsfrequenz derart ist, daß im Schalter eine Schallwelle erzeugt wird.

14. Gerät nach irgendeinem der Ansprüche 1 bis 11, bei dem der optische Schalter (13) ein Laserverstärker ist.

15. Gerät nach Anspruch 14, bei dem der Laserverstärker (13) eine Mehrfachquantentopf-Vorrichtung ist.

16. Gerät nach Anspruch 14 oder 15 in Verbindung mit Anspruch 1, bei dem der Laserverstärker sowohl den optischen Verstärker (8) als auch den optischen Schalter (13) bildet.

17. Gerät nach irgendeinem der Ansprüche 1 bis 16, bei dem die Zeitgebereinrichtung einen Rechteckwellengenerator (16) und einen Impulsgenerator (17) enthält.

18. Gerät nach Anspruch 17 in Verbindung mit irgendeinem der Ansprüche 13 bis 15, bei dem der Rechteckwellengenerator (16) und der Impulsgenerator (17) zwischen dem OTDR (1) und dem optischen Schalter (13) angeordnet sind, wobei die Anordnung derart ist, daß das Einkoppeln eines Lichtimpulses durch das OTDR den Rechteckwellengenerator triggert, um eine Rechteckwelle auszugeben, deren Abstiegsflanke den Impulsgenerator triggert, der seinerseits den optischen Schalter triggert, wobei die Periode der Rechteckwelle derart ist, daß sie an die Verzögerung zwischen dem Einkoppeln des Lichtimpulses durch das OTDR und der Ankunft jenes Impulses beim optischen Schalter angepaßt ist.

19. Gerät nach Anspruch 18 in Verbindung mit Anspruch 13, bei dem der Rechteckwellengenerator (16) und der Impulsgenerator (17) zwischen dem OTDR (1) und dem Funkfrequenztreiber (15) angeordnet sind.

20. Gerät nach irgendeinem der Ansprüche 4 bis 11, bei dem eine entsprechende Zeitgebereinrichtung vorgesehen ist, die die Stromversorgung an den oder jeden Pumplaser (11) steuert, wobei der oder jeder Pumplaser im wesentlichen nur dann arbeitet, wenn durch das zugehörige Stück der mit Erbium dotierten Lichtleitfaser (8a) ein Lichtimpuls läuft, und bei dem der optische Schalter (13) durch den (die) Faserverstärker gebildet ist.

21. Gerät nach Anspruch 20, bei dem die Zeitgebereinrichtung(en) einen Rechteckwellengenerator (16) und einen Impulsgenerator (17) enthält (enthalten), wobei die Zeitgebereinrichtung(en) so beschaffen ist (sind), daß das Einkoppeln eines Lichtimpulses durch das OTDR (1) den entsprechenden Rechteckwellengenerator triggert, um eine Rechteckwelle auszugeben, deren Anstiegsflanke den zugehörigen Impulsgenerator triggert, der seinerseits die Stromzufuhr an den zugehörigen Pumplaser (11) triggert, wobei die Periode der Rechteckwelle derart ist, daß sie an die Verzögerung zwischen dem Einkoppeln des Lichtimpulses durch das OTDR und der Ankunft jenes Impulses am zugehörigen Stück der mit Erbium dotierten Lichtleitfaser (8a) angepaßt ist.

22. Gerät nach Anspruch 17, Anspruch 18, Anspruch 19 oder Anspruch 21, bei dem Einrichtungen vorgesehen sind, die die Breite des Ausgangsimpulses des oder jedes Impulsgenerators (17) kontinuierlich verändern, wobei die Breite des Lichtimpulses, der in die Prüffaser (4) eingekoppelt wird, kontinuierlich verändert werden kann.

23. Gerät nach Anspruch 19, ferner mit einem Stück einer Lichtleitfaser, die im ersten Lichtweg (15) zwischen dem (den) Verstärker(n) und dem akustooptischen Schalter (13) angeordnet ist, wobei die Länge der Lichtleitfaser derart ist, daß im optischen Lichtweg zwischen dem OTDR (1) und dem akustooptischen Schalter (13) eine Verzögerung geschaffen wird, die die elektrischen Verzögerungen kompensiert, die im elektri-

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schen Weg zwischen dem OTDR und dem Funkfrequenztreiber (15) auftreten.

Revendications

1. Un appareil de contrôle optique comprenant un réflectomètre à dimension temporelle optique OTDR (1), un amplificateur optique (8) et un interrupteur optique (13), le réflectomètre OTDR comprenant un émetteur (2) pour lancer des impulsions lumineuses dans une fibre d'essai (4) le long d'un premier trajet lumineux (5), et un récepteur (3) pour recevoir la lumière rétrodiffusée par la fibre d'essai le long d'un second trajet lumineux (6), l'amplificateur optique étant positionné dans le premier trajet lumineux pour amplifier les impulsions lumineuses, et l'interrupteur optique étant positionné dans le premier trajet lumineux, entre l'amplificateur optique et la fibre d'essai, de manière à ménager des moyens de synchronisation (15, 16, 17) pour synchroniser le fonctionnement de l'interrupteur optique afin que l'interrupteur ne soit ouvert que pour laisser passer les impulsions lumineuses lancées par le réflectomètre OTDR et amplifiées par l'amplificateur optique.

2. Appareil selon la revendication 1, dans lequel l'amplificateur optique est un amplificateur à fibre optique (8).

3. Appareil selon la revendication 1, dans lequel l'amplificateur optique est constitué par des premier et second amplificateurs à fibre optique (8), en série.

4. Appareil selon la revendication 2 ou 3, dans lequel le ou chaque amplificateur à fibre optique (8) est constitué par une longueur de fibre optique dopée en erbium (8a) et un laser de pompage (11), le laser de pompage étant relié à la longueur de fibre optique dopée en erbium par l'intermédiaire d'un coupleur à multiplexage par répartition en longueur d'onde (10).

5. Appareil selon la revendication 4, dans lequel le ou chaque laser de pompage (11) est centré sur 1490 nm.

6. Appareil selon la revendication 3, dans lequel le premier amplificateur de fibre (8), adjacent au réflectomètre OTDR (1) est constitué par une longueur de fibre optique dopée en erbium et un laser de pompage (11), le laser de pompage étant relié à la longueur de fibre optique dopée en erbium par l'intermédiaire d'un coupleur à multiplexage par répartition en longueur d'onde (10); et le second amplificateur de fibre (8) est constitué par une longueur de fibre optique dopée en erbium (8a) et deux lasers de pompage (11), les lasers de pompage étant connectés aux extrémités opposées de la longueur de fibre optique dopée en erbium par l'intermédiaire des coupleurs à multiplexage par répartition en longueur d'onde respectifs.

7. Appareil selon la revendication 6, dans lequel la sortie de chaque laser de pompage (11) est centrée sur 1490 nm, la puissance du laser de pompage associé au premier amplificateur à fibre (8) est de 15 mW, et la puissance de chacun des deux lasers de pompage associés au second amplificateur de fibre (8) est de 55 mW.

8. Appareil selon l'une quelconque des revendications 4 à 7 lorsqu'elle est dépendante de la revendication 3, dans lequel la fibre optique dopée en erbium (8a) du premier amplificateur de fibre (8) a une longueur de 17 m, un diamètre de coeur de 5 µm et un niveau de dopage de 1100 ppm.

9. Appareil selon l'une quelconque des revendications 4 à 8 lorsqu'elle est dépendante de la revendication 3, dans lequel la fibre optique dopée en erbium (8a) du second amplificateur de fibre (8) a une longueur de 23 m, un diamètre de coeur de 6 µm et un niveau de dopage de 1100 ppm.

10. Appareil selon l'une quelconque des revendications 3 à 9, dans lequel un interrupteur au niobate de lithium est placé dans le premier trajet lumineux (5) entre les deux amplificateurs de fibre (8).

11. Appareil selon l'une quelconque des revendications 4 à 10 dans lequel chaque amplificateur de fibre (8) est associé à un sectionneur optique respectif (9).

12. Appareil selon l'une quelconque des revendications 1 à 11, dans lequel l'interrupteur optique (13) est un interrupteur acoustico-optique.

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13. Appareil selon la revendication 12, dans lequel l'interrupteur acoustico-optique (13) est commandé par une unité de commande à fréquence radioélectrique (15) dont la fréquence de sortie est telle qu'elle établit une onde acoustique dans l'interrupteur.

14. Appareil selon l'une quelconque des revendications 1 à 11, dans lequel l'interrupteur optique (13) est un amplificateur laser.

15. Appareil selon la revendications 14, dans lequel l'amplificateur laser (13) est un dispositif à puits quantique multiple.

16. Appareil selon l'une des revendications 14 ou 15, lorsqu'elle est dépendante de la revendication 1, dans lequel l'amplificateur laser constitue l'amplificateur optique (8) ainsi que l'interrupteur optique (13).

17. Appareil selon l'une quelconque des revendications 1 à 16, dans lequel les moyens de synchronisation comprennent un générateur d'ondes carrées (16) et un générateur d'impulsions (17).

18. Appareil selon la revendications 17, lorsqu'elle est dépendante de l'une quelconque des revendications 13 à 15, dans lequel le générateur d'ondes carrées (16) et le générateur d'impulsions (17) sont disposés entre le réflectomètre OTDR (1) et l'interrupteur optique (13), l'agencement étant tel que le lancement d'une impulsion lumineuse par le réflectomètre OTDR déclenche le générateur d'ondes carrées pour émettre une onde carrée dont le front arrière déclenche le générateur d'impulsions qui, de son côté, déclenche l'interrupteur optique, la durée de l'onde carrée étant telle qu'elle est adaptée à la temporisation entre le lancement de l'impulsion lumineuse par le réflectomètre OTDR et l'arrivée de cette impulsion à l'interrupteur optique.

19. Appareil selon la revendication 18 lorsqu'elle est dépendante de la revendication 13, dans lequel le générateur d'ondes carrées (16) et le générateur d'impulsions (17) sont disposés entre le réflectomètre OTDR (1) et le circuit de commande à fréquence radioélectrique (15).

20. Appareil selon l'une quelconque des revendications 4 à 11, dans lequel des moyens de synchronisation respectifs sont prévus pour commander l'alimentation en courant vers le ou chaque laser de pompage (11), de manière que le ou chaque laser de pompage ne fonctionne essentiellement que lorsqu'une impulsion lumineuse passe dans la longueur de fibre optique dopée en erbium associée (8a), et dans lequel l'interrupteur optique (13) est constitué par le ou les amplificateurs de fibre.

21. Appareil selon la revendication 20, dans lequel le ou chacun des moyens de synchronisation comprend un générateur d'ondes carrées (16) et un générateur d'impulsions (17), le ou chacun des moyens de synchronisation étant tel que le lancement d'une impulsion lumineuse par le réflectomètre OTDR déclenche le générateur d'ondes carrées respectif pour émettre une onde carrée, dont le front arrière déclenche le générateur d'impulsions associé qui, de son côté, déclenche l'alimentation de courant vers le laser de pompage associé (11), la durée de l'onde carrée étant telle qu'elle correspond à la temporisation entre le lancement de l'impulsion lumineuse par le réflectomètre OTDR et l'arrivée de cette impulsion à la longueur de fibre optique dopée en erbium associée (8a).

22. Appareil selon la revendication 17, la revendication 18, la revendication 19 ou la revendication 21, dans lequel il est prévu des moyens pour modifier continuellement la largeur de l'impulsion de sortie du ou de chaque générateur d'impulsions (17), de manière que la largeur des impulsions lumineuses lancées dans la fibre d'essai (4) puisse être modifiée continuellement.

23. Appareil selon la revendication 19, comprenant en outre une longueur de fibre optique disposée dans le premier trajet lumineux (15), entre le ou les amplificateurs (8) et l'interrupteur acoustico-optique (13), la longueur de ladite fibre optique étant telle qu'elle ménage un retard dans le trajet lumineux optique entre le réflectomètre OTDR (1) et l'interrupteur acoustico-optique (13) pour compenser les retards électriques survenant dans le trajet électrique, du réflectomètre OTDR au circuit de commande à fréquence radioélectrique (15).

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