

WAVELENGTH-INDEPENDENT AMPLIFIER APPARATUS AND METHOD OF OPERATION

The invention relates to a wavelength-independent amplifier apparatus and a
5 method of operation of the apparatus. The invention relates to amplification of light signals having any wavelength in a range of wavelengths in the C-band. The invention has particular, but not exclusive, application with bi-directional erbium-doped fibre amplifiers.

10 Numerous devices and techniques have been proposed for the bi-directional amplification of light signals. Conventional unidirectional or half duplex transmission requires two fibres for transmit and receive as shown in Figure 1. Each fibre usually requires one optical amplifier (OA) for signal amplification. Based on this conventional layout, an increase in the network capacity will lead to increased
15 numbers of fibres used as well as the number of optical amplifiers. This situation can be solved by using a bidirectional or full duplex transmission as shown in Figure 2.

Previous endeavours in bi-directional amplification include, for example, United States Patent No. 7,346,280 which discloses wavelength division multiplexing (WDM)
20 techniques that combine long haul (LH), and ultra long haul (ULH) optical communication capabilities on the same fibre but in opposite directions in different bands. In addition to using Erbium-doped fibre amplifier (EDFA) amplification for both the LH and ULH bands, the ULH signal is also subjected to distributed Raman amplification. A conventional/long band pump module provides coherent optical
25 energy which is coupled into the transmission fibre via a four-port optical circulator and a fibre Bragg grating is configured to reflect optical energy at the pump wavelengths and allows transmission of optical energy at other wavelengths. The Raman pump energy is thus inserted into the fibre transmission in a counter-propagating direction relative to the ULH signal to be amplified. In this design a high
30 power laser pump is need as a Raman pump.

In this design, the purpose of the circulator is to circulate the pump signal used. A four-port circulator is used not only to circulate the ULH signal to a C-band EDFA but also to provide circulation for a C-band pump module and Raman distributed amplification. Thus, the ULH signal is subjected to amplification twice. The techniques in this document therefore use two types of amplifier, EDFA and Raman. The system also uses a pump reflector to reflect the C-band signal while letting LH signal be passed into the span.

10 United States Patent No. 5,815,308 provides a bidirectional optical amplifier device comprising two optical amplifiers and a bidirectional frequency tunable reflection attenuator (FTRA) coupled between the first and the second optical amplifiers. The FTRA is used to control the direction of the signals' propagation.

15 United States Patent No. 5,452,124 discloses a device using a four-port wavelength-division multiplexing (WDM) filter and a single erbium-doped optical amplifier (EDFA) to implement a dual wavelength bi-directional optical amplifier. The purpose of WDM filters is to couple multiple wavelengths into and out of the transmission fiber as well as the EDFA. However, the uses of WDM filter results in a fixed
20 wavelength transmission. It means that if the WDM filter is for wavelength, λ_1 and λ_2 while other wavelengths are not allowed to pass through the filter.

Such techniques are usually operable with a limited number of wavelengths only since the functionality of a WDM is to combine several wavelengths into a single
25 fibre. A dedicated wavelength is usually assigned to each of the input ports of such devices. For example 1x2 WDM, means signal λ_1 of a first wavelength enters a first port and signal λ_2 of a second wavelength enters a second port. However, if a signal λ_3 of a third wavelength which is not in the specification of the WDM passes through the WDM device, the performance for this signal will be downgraded. The insertion
30 loss will increase and this will contribute to a higher noise figure in the amplifier. This

also will degrade the capability of signal λ_3 for propagation of the full-duplex bi-directional signal, since the amplified signal will be decreased due to the insertion loss.

- 5 The invention is defined in the independent claims. Some optional features of the invention are defined in the dependent claims.

Use of the apparatus and method as set out in the independent claims allows for a broader range of wavelengths in the C-band to be amplified. As there is no need for
10 a wavelength filter deployed in the apparatus, then the apparatus can operate across a range of wavelengths, not being limited to, say, two wavelengths as in the typical prior art. Thus, bi-directional transmission in order to increase network capacity and reduce the number of fibres used may be realised across a broader range of wavelengths. Use of the apparatus can provide full duplex signal
15 amplification using, for example, erbium-doped fibre amplifiers when the two light signals are propagated concurrently. The design is substantially wavelength independent, subject to the wavelength of the or each light signal being in the C-band.

- 20 The invention will now be described, by way of example only, and with reference to the accompanying drawings in which:

Figure 1 is a block diagram illustrating conventional unidirectional or half duplex transmission;

- 25 Figure 2 is block diagram illustrating conventional bidirectional or full duplex transmission;

Figure 3 is a block diagram illustrating a wavelength-independent amplifier apparatus for amplifying light signals in a range of wavelengths;

- Figure 4 is a flow diagram illustrating a process of operation of the apparatus for a
30 first signal λ_1 ; and

Figure 5 is a flow diagram illustrating a process of operation of the apparatus for a first signal λ_2 .

Turning now to Figure 3, a wavelength-independent amplifier apparatus for
 5 amplifying light signals in a range of wavelengths in the C-band comprises, principally, a fibre amplifier stage 10, a first optical circulator 1 and a second optical circulator 5.

First optical circulator 1 receives a first light signal Tx1 from a first optical fibre (not
 10 shown). First light signal Tx1 is of a first wavelength λ_1 in the C-band and propagates in a first direction indicated by the arrow (left-to-right as shown in Figure 3). Second optical circulator 5 receives a second light signal Tx2 from a second optical fibre (not shown). Second light signal Tx2 is of a second wavelength λ_2 in the C-band and propagates in a second direction indicated by the arrow (right-to-left as shown in
 15 Figure 3). Thus, the first direction is "opposite" the second direction, and bi-directional amplification in full duplex communication is realised. The apparatus is wavelength-independent in the C-band and is capable of amplifying light signals having any wavelength in the range of wavelengths, with the proviso that the first wavelength is different from the second wavelength, a requirement for full duplex
 20 communication. Thus, as the amplifier apparatus can operate without a wavelength selective filter (as required by the typical prior art systems discussed above), all wavelengths in the range of wavelengths can be propagated and amplified within the apparatus, thus removing a serious limitation with the prior art. One suitable range of wavelengths in the C-band is 1525nm to 1565nm.

25 After receiving the first light signal Tx1 at a first port (e.g. port 2) of first optical circulator 1, first light signal Tx1 is then propagated from a second port (e.g. port 3) of first optical circulator 1 to an input of fibre amplifier stage 10, where first light signal Tx1 is amplified to produce an amplified first light signal. The apparatus then
 30 propagates the amplified first light signal from an output of the fibre amplifier stage

10 to a third port (e.g. port 1) of second optical circulator 5 for continued propagation Rx2 in the first direction from a first port (e.g. port 2) of second optical circulator 5.

- 5 Additionally (and which may be effected concurrently), after receiving the second signal Tx2 at a first port (e.g. port 2) of second optical circulator 5, second signal Tx2 is then propagated from a second port (e.g. port 3) of second optical circulator 5 to an input of fibre amplifier stage 10, where second signal Tx2 is amplified to produce an amplified second light signal. The apparatus then propagates the amplified
- 10 second light signal from an output of the fibre amplifier stage 10 to a third port (e.g. port 1) of first optical circulator 1 for continued propagation Rx1 in the second direction from a first port (e.g. port 2) of first optical circulator 1.

- Placement of the optical circulators 1, 5 at either end of the amplifier apparatus
- 15 control the signal propagation direction into, through, and out of the amplifier apparatus. Thus, when compared with typical WDM techniques noted above, a greater range of wavelengths can pass through the apparatus without excessive attenuation at wavelengths other than the principal wavelengths of the prior art devices. Also, the optical circulators direct the appropriate signal to the correct
- 20 direction of amplification, from left to right or right to left and separates the propagated signal from Tx1 to Rx1 and Tx2 to Rx2

The operation of the apparatus of Figure 3 is also illustrated with reference to Figures 4 and 5.

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- In the example of Figure 3, fibre amplifier stage 10 comprises first and second erbium-doped fibre amplifiers 4, each of which has a laser diode pump 3 to provide the required pumping action to the amplifiers 4. As is known, the laser diode pump 3 has its own controller board. It is controlled by varying current to the controller
- 30 board. The LD is a laser diode with an optical signal at certain wavelength, (in the

example of Figure 3, 980nm) and its level of power can be increased or decreased according to the current input. It is called pump laser diode because this source assists the amplification in a way that it provided energy to doped fibre ions in order for the ions to move to a higher energy level. This stage is important for photon
 5 amplification. However, it is to be noted that the techniques disclosed herein are not limited to use with erbium-doped fibre amplifiers, but may be used with any type of fibre amplifier suitable for operation in the C-band.

Further, and also in the example of Figure 3, the first optical circulator 1 and the
 10 second optical circulator 5 are three-port optical circulators. The optical circulators are suitable for use in the C-band,

Furthermore, it is not necessary to provide two fibre amplifiers 4, as a single fibre amplifier may be used as a bi-directional optical amplifier for each direction.
 15 However, with such an arrangement, the amplifier will saturate more easily. This is because the concentration of ions in the fibre used as the amplifier are used twice as quickly when compared with use of separate fibre amplifiers, one for each direction of propagation.

Yet further, in the example of Figure 3, the amplifier apparatus comprises a first optical isolator 2a for isolating the first optical circulator 1 from noise from fibre amplifier stage 10. Alternatively (or additionally), first optical isolator 6a isolates second optical isolator 5 from noise from the fibre amplifier stage 10. So, when fibre amplifier stage 10 includes one or more fibre amplifier, the (or each) first optical
 25 isolator is provided to suppress the backward amplified stimulated emission (ASE) from the fibre amplifier from interfering with the signal propagating from either of optical circulators 1, 5 to the fibre amplifier stage. The provision of the or each first optical isolator 2a, 6a obviates the possibility of breakdown of isolation between ports in the circulators 1, 5. If the ASE was high enough to overcome the isolation
 30 value between the ports, there would, otherwise, be leakage between ports.

Also in the example of Figure 3, the amplifier apparatus comprises a second optical isolator 6b for isolating the fibre amplifier stage from noise from first optical circulator 1. Alternatively (or additionally), second optical isolator 2b isolates the
5 fibre amplifier stage 10 from noise from the second optical circulator 5. The or each second optical isolator 2b, 6b, protects the circulators from forward ASE from the fibre amplifier stage.

Further, the isolators also function to block any signal leakage from Tx1 to Rx1 from
10 propagating into Tx2 and Rx2 path. If any such signal leakage is not blocked, it will cause interference.

It will be appreciated that the invention has been described by way of example only. Various modifications may be made to the techniques described herein without
15 departing from the spirit and scope of the appended claims. The disclosed techniques comprise techniques which may be provided in a stand-alone manner, or in combination with one another. Therefore, features described with respect to one technique may also be used and presented in combination with another technique.

Claims

1. A wavelength-independent amplifier apparatus for amplifying light signals in a range of wavelengths in the C-band, the apparatus comprising:
 - 5 a fibre amplifier stage;
 - a first optical circulator for receiving a first light signal of a first wavelength propagating in a first direction;
 - a second optical circulator for receiving a second light signal of a second wavelength propagating in a second direction; wherein
 - 10 the wavelength-independent apparatus is arranged to amplify light signals having any wavelength in the range of wavelengths, the first wavelength being different from the second wavelength, and wherein the first direction is opposite the second direction; and wherein
 - the apparatus is arranged for the fibre amplifier stage to amplify the first light
 - 15 signal thereby to produce an amplified first light signal and for the amplified first light signal to be propagated to the second optical circulator for continued propagation in the first direction; and
 - the apparatus is arranged for the fibre amplifier stage to amplify the second light signal thereby to produce an amplified second light signal and for the amplified
 - 20 second light signal to be propagated to the first optical circulator for continued propagation in the second direction.
2. The apparatus of claim 1 wherein the first optical circulator and the second optical circulator are three-port optical circulators.
- 25 3. The apparatus of claim 1 or claim 2 further comprising a first optical isolator for isolating the first optical circulator or the second optical circulator from noise from the fibre amplifier stage.

4. The apparatus of any preceding claim, further comprising a second optical isolator for isolating the fibre amplifier stage from noise from the first optical circulator or the second optical circulator.
5. A method of amplifying light signals across a range of wavelengths in the C-band, the method being implemented in a wavelength-independent amplifier apparatus, and comprising:
 - receiving a first light signal of a first wavelength propagating in a first direction at a first optical circulator;
 - 10 receiving a second light signal of a second wavelength propagating in a second direction at a second optical circulator; wherein
 - the wavelength-independent amplifier apparatus is arranged to amplify light signals having any wavelength in the range of wavelengths, the first wavelength being different from the second wavelength, and wherein the first direction is
 - 15 opposite the second direction; the method further comprising
 - amplifying the first light signal in a fibre amplifier stage thereby to produce an amplified first light signal, and propagating the amplified first light signal to the second optical circulator for continued propagation in the first direction; and
 - amplifying the second light signal in the fibre amplifier stage thereby to
 - 20 produce an amplified second light signal and propagating the amplified second light signal to the first optical circulator for continued propagation in the second direction.
6. The method of claim 5 wherein the first optical circulator and the second
 - 25 optical circulator are three-port optical circulators.
7. The method of claim 5 or claim 6 further comprising using a first optical isolator to isolate the first optical circulator or the second optical circulator from noise from the fibre amplifier stage.

8. The method of any of claims 5 to 7 further comprising using a second optical isolator to isolate the fibre amplifier stage from noise from the first optical circulator or the second optical circulator.