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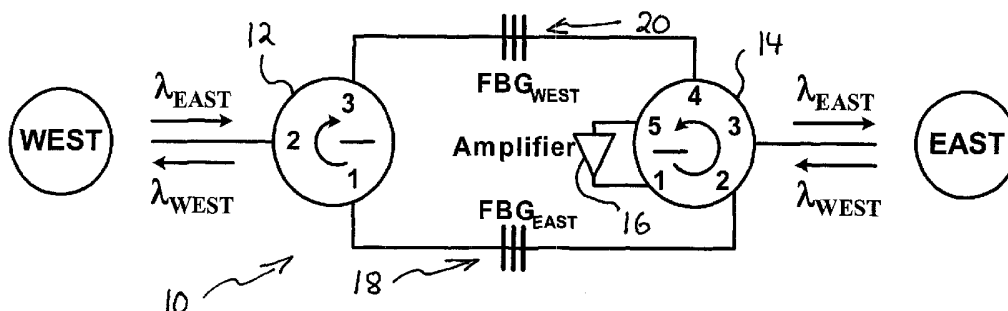
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(54) Title: IMPROVED OPTICAL AMPLIFIER AND/OR ADD/DROP STRUCTURE



(57) **Abstract:** A bi-directional optical amplifier structure (10) is disclosed, the structure comprising a blocking, multi-port optical circulator (MOC) structure (12, 14), a unidirectional amplifier unit (16) optically connected in series between a first and second ports of the MOC structure, a first reflection filter (20) optically connected in series between a third and a fourth ports of the MOC structure and a second reflection filter (18) optically connected in series between a fifth and a sixth ports of the MOC structure. The amplifier structure (10) is arranged such that a first optical signal (λ_{EAST}) entering through a seventh port of the MOC structure passes through the first reflection filter (20) prior to being amplified in the amplifier unit (16) and is reflected at the second reflection filter (18) prior to exiting the amplifier structure (10) at an eighth port of the MOC structure, and such that a second optical signal (λ_{WEST}) entering through the eighth port of the MOC structure is reflected at the first reflection filter (20) prior to being optically amplified in the amplifier unit (16) and passes through the second reflection filter (18) prior to exiting the amplifier structure (10) at the seventh port. A bi-directional add/drop structure is also disclosed

Improved Optical Amplifier and/or Add/Drop Structure

Field of the invention

The present invention relates broadly to an optical amplifier and/or add/drop structure for use in e.g. single-fibre bi-directional wavelength division multiplexing (WDM) networks, to
5 a method of bi-directionally amplifying optical signals, and to a method of bi-directionally adding/dropping optical signals.

Background of the invention

There is a trend in the design of bi-directional WDM networks that optical signals travel along single-fibre connections in both directions. Typically, different groups of wavelengths
10 propagate in opposite directions. The allocation of propagation directions to individual wavelengths may e.g. be interleaved in the spectral domain, i.e. adjacent wavelengths within the spectral domain propagate in opposite directions, resulting in symmetric traffic conditions. Alternatively, different wavelength bands in the spectral domain may propagate in opposite directions, resulting in either symmetric or asymmetric traffic conditions depending on the
15 relevant widths of the respect wavelength bands.

Where the optical signals require amplification between e.g. adjacent network nodes of the WDM network, bi-directional optical amplifier (BOA) structures are required in-line in individual single-fibre bi-directional fibre connections. Typically, such bi-directional amplifier structures utilise two amplifier units connected in parallel between two multi-port optical
20 circulators (MOCs). The two MOCs are utilised to direct traffic travelling in opposite directions along the single-fibre connection into the different parallel connections between the two MOCs.

Bi-directional optical add/drop amplifiers (BOADA) may be implemented as an extension of a bi-directional amplifier structure. For example, two bi-directional amplifiers or two uni-directional amplifiers to boost the optical signal power together with an NxN array
25 waveguide grating or two MOCs disposed between them can be used to add/drop wavelengths.

Where amplification is not required, such prior art structures may also be implemented as optical add/drop structures only, i.e. omitting the two bi-directional or two uni-directional amplifiers to boost the optical signal power.

In at least preferred embodiment, the present invention seeks to provide an improved bi-directional amplifier structure and/or add/drop structure.

Summary of the invention

In the summary of invention and the claims, components of the same name have been
5 identified as e.g. “first”, “second”, “third” etc. This is intended to mean “first identified”,
“second identified”, “third identified” etc. rather than being intended to define a total number of
the same components in individual embodiments of the invention. For example, where an
embodiment is defined with MOCs having a first, a second and a fifth port, this does not define
that there must be a third and a fourth port. In other words, in such an embodiment each MOC
10 has at least 3 ports.

In accordance with a first aspect of the present invention there is provided a bi-directional optical amplifier structure comprising a blocking, multi-port, optical circulator (MOC) structure, a unidirectional amplifier unit optically connected in series between a first and second ports of the MOC structure, a first reflection filter unit optically connected in series
15 between a third and a fourth ports of the MOC structure, and a second reflection filter optically
connected in series between a fifth and a sixth ports of the MOC structure, the amplifier
structure being arranged, in use, such that a first optical signal entering through a seventh port
of the MOC structure passes through the first reflection filter prior to being amplified in the
amplifier unit and is reflected at the second reflection filter prior to exiting the amplifier
20 structure at an eighth port of the MOC structure, and such that a second optical signal entering
through the eighth port of the MOC structure is reflected at the first reflection filter prior to
being amplified in the amplifier unit and passes through the second reflection filter prior to
exiting the amplifier structure at the seventh port.

In one embodiment, the amplifier structure further comprises a third reflection filter
25 having the same filter response as the first reflection filter and being connected to a ninth port of
the MOC structure, and the amplifier structure is arranged, in use, such that the second signal is
reflected at the third reflection filter after having been amplified in the amplifier unit and prior
to exiting the amplifier structure. In such an embodiment, the amplifier structure may further
comprise a light absorber element connected in series after the third reflection filter to prevent
30 re-entering of light transmitted through the third reflection filter into the ninth port of the MOC
structure.

The amplifier unit may comprise a dispersion compensation module. In one embodiment, the dispersion compensation module is connected in series between two unidirectional amplifier elements of the amplifier unit. The dispersion compensation module may comprise a dispersion compensation fibre (DCF).

- 5 The amplifier unit may comprise one or more uni-directional amplifier elements. The amplifier elements may be in the form of fibre amplifiers. The fibre amplifiers may comprise erbium doped fibre (EDF).

The amplifier unit may comprise one or more pump lasers.

- 10 In one embodiment, the amplifier structure further comprises at least one fourth reflection filter connected in series between a tenth and an eleventh ports of the MOC structure for add/drop operation, and the amplifier structure is arranged, in use, such that the first and second signals pass through the at least one fourth reflection filter prior to exiting the amplifier structure, such that signal portions reflected at the at least one fourth reflection filter exit the amplifier structure at a twelfth port of the MOC structure, and such that a third optical signal
15 entering at a thirteenth port of the MOC structure is reflected at one of the fourth reflection filters, whereby the third signal is added to the first or second signals prior to the first or second signals exiting the amplifier structure.

- 20 In an another embodiment, the amplifier structure comprises at least one fifth reflection filter connected in series between a fourteenth and a fifteenth ports of the MOC structure, and at least one sixth reflection filter connected in series between a sixteenth and a seventeenth ports of the MOC structure, and the amplifier structure is arranged, in use, such that the first and second signals pass through the at least one fifth and sixth reflection filters respectively prior to exiting, such that reflected portions of the first and second signals exit at an eighteenth and nineteenth ports respectively, and such that a fourth and a fifth signal entering at a twentieth and
25 a twenty first ports of the MOC structure respectively are reflected at one of the fifth and sixth reflection filter respectively, whereby they are added to the first and second signals respectively prior to the first and second signals exiting the amplifier structure.

The reflection filters may comprise tuneable reflection filters, whereby band and/or wavelength allocations in the amplifier structure are reconfigurable.

In one embodiment, the amplifier structure comprises an optical switch associated with each of the fourth reflection filters and arranged, in use, such that the associated fourth reflection filter is selectively by-passable, whereby an add/drop configuration of the amplifier structure is reconfigurable.

5 The amplifier structure may further comprise an optical demultiplexer and an optical multiplexer connected at the twelfth and thirteenth port of the MOC structure respectively. In one embodiment, the demultiplexer and the multiplexer are connected to the twelfth and thirteenth ports respectively via a further optical switch arranged, in use, such that the demultiplexer and multiplexer are by-passable to selectively disable the add/drop functionality.

10 The MOC structure may be implemented as a single, blocking MOC, or as two or more interconnected blocking MOCs. Where the MOC structure is implemented as two interconnected MOCs, the circulation directions in the two interconnected MOCs are preferably opposite.

15 In accordance with a second aspect of the present invention there is provided a bi-directional add/drop structure comprising a blocking MOC structure, at least one first reflection filter connected in series between a first and a second ports of the MOC structure for add/drop operation, the add/drop structure being arranged, in use, such that a first optical signal entering through a third port of the MOC structure passes through the at least one first reflection filter prior to exiting the add/drop structure at a fourth port of the MOC structure, and such that a
20 second optical signal entering through the fourth port of the MOC structure passes through the at least one first reflection filter in the same direction as the first signal prior to exiting the add/drop structure at the third port, and such that signal portions reflected at the at least one first reflection filter exit the add/drop structure at a fifth port of the MOC structure, and such that a
25 third optical signal entering at a sixth port of the MOC structure is reflected at one of the first reflection filters, whereby the third signal is added to the first or second signals prior to the first or second signals exiting the add/drop structure.

30 In one embodiment, the add/drop structure comprises a second reflection filter connected in series between a seventh and an eighth ports of the MOC structure, and a third reflection filter connected in series between a ninth and a tenth ports of the MOC structure, and the add/drop structure is arranged, in use, such that the first optical signal passes through the second reflection filter prior to passing through the at least one first reflection filter and is then

reflected at the third reflection filter prior to exiting the add/drop structure, and such that the second optical signal is reflected at the second reflection filter prior to passing through the at least one first reflection filters and then passes through the third reflection filter prior to exiting the add/drop structure.

5 In another embodiment, the add/drop structure comprises a second reflection filter connected in series between a seventh and an eighth ports of the MOC structure, and a third reflection filter, having the same filter response as the second reflection filter, connected in series between a ninth and a tenth ports of the MOC structure, and the add/drop structure is arranged, in use, such that the first optical signal passes through the second reflection filter prior
10 to passing through the at least one first reflection filter and then passes through the third reflection filter prior to exiting the add/drop structure, and such that the second optical signal is reflected at the second reflection filter prior to passing through the at least one first reflection filter and is then reflected at the third reflection filter prior to exiting the add/drop structure.

In accordance with a third aspect of the present invention there is provided a method of
15 bi-directionally amplifying optical signals, the method comprising the steps of passing a first optical signal through a first reflection filter prior to amplifying the first signal using and then reflecting the first signal at a second reflection filter, reflecting a second optical signal at the first reflection filter prior to amplifying the second optical signal and then passing the second optical signal through the second reflection filter.

20 In accordance with a fourth aspect of the present invention there is provided a method of bi-directionally adding/dropping optical signals, the method comprising the steps of passing a first optical signal through at least one first reflection filter, passing a second optical signal through the at least one first reflection filter in the same direction as the first signal, whereby signal portions reflected at the at least one first reflection filter are dropped, and reflecting a
25 third optical signal at one of the first reflection filters, whereby the third signal is added to the first or second signals.

Brief description of the drawings

Preferred embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings.

30 Figure 1 is a schematic diagram illustrating a BOA embodying the present invention;

Figure 2 is a schematic diagram illustrating another BOA embodying the present invention;

Figure 3 is a schematic diagram illustrating another BOA embodying the present invention;

5 Figure 4 is a schematic diagram illustrating another BOA embodying the present invention;

Figure 5 is a schematic diagram illustrating a BOADM embodying the present invention;

Figure 6 is a schematic diagram illustrating another BOADM embodying the present invention;

10 Figure 7 is a schematic diagram illustrating another BOADM embodying the present invention;

Figure 8 is a schematic diagram illustrating another BOADM embodying the present invention;

15 Figure 9 is a schematic diagram illustrating another BOADM embodying the present invention;

Figure 10 is a schematic diagram illustrating another BOADM embodying the present invention;

Figure 11 is a schematic diagram illustrating another BOADM embodying the present invention.

20 **Detailed description of the embodiments**

Fig. 1 shows the schematic diagram of a BOA 10 embodying the present invention. The device has the flexibility to be used in a bidirectional network with any wavelength arrangements/assignments. The example embodiment shown in Fig. 1 utilises wavelength set λ_{EAST} for the Eastbound direction and wavelength set λ_{WEST} for the Westbound direction. The BOA 10 consists of one 3-port optical circulator (OC) 12 and one 5-port OC 14, a
25 unidirectional optical amplifier 16 (e.g. Erbium-doped fibre amplifier (EDFA)), and two sets of FBGs 18, 20 (FBG_{EAST} and FBG_{WEST}) corresponding to wavelengths λ_{EAST} and λ_{WEST} , respectively. The 3-port and 5-port OCs 12, 14 are conventional OCs, which means that the

path from port 3 to port 1 in the 3-port OC 12 and the path from port 5 to port 1 in the 5-port OC 14 are blocked.

The Eastbound signals enter port 2 of the 3-port OC 12 and go through to port 4 of the 5-port OC 14. The undesired Rayleigh backscattered signals accompanying the Eastbound signals are reflected by FBG_{WEST} 20 and are dumped into port 3 of the 3-port OC 12. These signals are blocked from going to port 1 due to the characteristic of the OC 12. The Eastbound signals come out of port 5 of the 5-port OC 14 and are amplified by the optical amplifier 16. The amplified signals then enter port 1 of the 5-port OC 14. After coming out of port 2 of the OC 14, the Eastbound signals are reflected back to port 2 by FBG_{EAST} 18 and are then routed to port 3 of the 5-port OC 14, exiting the BOA 10.

The Westbound signals enter port 3 of the 5-port OC 14 and are then routed to port 4. The desired Westbound signals are then reflected back to port 4 by FBG_{WEST} 20. The undesired signals accompanying the Westbound signals such as Rayleigh backscattered light and amplified spontaneous emission (ASE) noise pass through FBG_{WEST} 20 and are dumped into port 3 of the 3-port OC 12. The Westbound signals are then routed to port 5 of the 5-port OC 14 and are amplified by the optical amplifier 16 before entering port 1. The amplified Westbound signals come out of port 2 of the 5-port OC 14 and pass through to port 1 of the 3-port OC 12. Finally, the Westbound signals are routed to port 2 of the 3-port OC 12, exiting the BOA 10.

It will be appreciated that in the BOA 10 both the Eastbound and Westbound signals pass through the optical amplifier 16 in the same direction, thus enabling a BOA embodying the present invention which utilised only one uni-directional optical amplifier.

By having different FBGs 18, 20 in FBG_{EAST} and FBG_{WEST}, asymmetric traffic conditions can be accommodated by the BOA 10. It will further be appreciated by a person skilled in the art that both FBG_{EAST} and FBG_{WEST} can be designed/chosen to meet desired travel direction characteristics for any wavelength, including an interleaved channel bidirectional network traffic design. The use of OC port pairs 4-5 and 1-2 in the 5-port OC 14 effectively works as isolators before and after the unidirectional optical amplifier 16. For example, the unidirectional EDFA can then be constructed using only Erbium-doped fibre, pump laser(s) (not shown), and WDM coupler(s) (not shown) and no external isolators are required. The EDFA structure will be illustrated in a later figure.

In the BOA 10 structure shown in Fig. 1, the amplified Eastbound signals are filtered by FBG_{EAST} 18 before leaving the device. Therefore, the Eastbound signals at the output of BOA 10 are clean of out-of-band ASE noise. However, the Westbound signals are not filtered after being amplified and hence contain ASE noise. If multiple BOA 10 devices are used in a network, the ASE noise accompanying the Westbound signals does not present any problem since it will be filtered out at the next BOA before the Westbound signals are amplified. This ensures that the ASE noise does not accumulate throughout the network. A modified BOA 21 device embodying the present invention to accommodate the filtering of ASE noise accompanying the Westbound signals is shown in Fig. 2. In this device, an extra FBG_{WEST} 22 is placed at port 2 of a 4-port OC 24. The other end of the extra FBG_{WEST} 22 is connected to a light absorber 26 to prevent reflections. The light absorber 26 can e.g. be an isolator, a FC/APC connector, or a light scattering/deflecting terminator. The 4-port OC 24 replaces the 3-port OC 12 shown in Fig. 1. The operation of the BOA 21 is similar to that of BOA 10 except that the amplified Westbound signals are filtered by FBG_{WEST} 22 before exiting the device at port 3 of the 4-port OC 24.

The 3-port and 5-port OCs 12, 14 used in BOA 10 can be combined into a single 8-port OC 32. The new BOA 30 is shown in Fig. 3. In a similar fashion, the 4-port and 5-port OCs 24, 14 used in BOA 21 can be combined into a single 9-port OC 42. The new BOA 40 is shown in Fig. 4.

By incorporating wavelength add-drop functionality, the BOA 10 structure shown in Fig. 1 can be modified to become a novel BOADM structure. The new structure 50 is schematically shown in Fig. 5. The BOADM 50 consists of two 6-port OCs 52, 54, a unidirectional optical amplifier 56, two sets of FBGs 58, 60 (FBG_{EAST} and FBG_{WEST}) corresponding to wavelength sets λ_{EAST} and λ_{WEST} , respectively, and a number of FBGs e.g. 62, 64 corresponding to the add/drop channels. In this case, FBG₁ 62 corresponds to wavelength λ_1 added/dropped in the Eastbound direction and FBG₂ 64 corresponds to wavelength λ_2 added/dropped in the Westbound direction.

It will be appreciated that in the BOADM 50 embodying the present invention pass the uni-directional optical amplifier 56 on the one hand and the number of FBGs e.g. 62, 64 in the same direction.

The operation of BOADM 50 is very similar to that of BOA 10 except for the add/drop operation of channels at wavelengths λ_1 and λ_2 . The drop channels at wavelengths λ_1 and λ_2 are reflected by FBG₁ 62 and FBG₂ 64, respectively, and exit port 3 of the first 6-port OC 52. The add channels at wavelengths λ_1 and λ_2 enter the device via port 1 of the second 6-port OC 54 and are reflected by FBG₁ 62 and FBG₂ 64 to join the other channels through the device.

This BOADM 50 structure only has a single add port and a single drop port for all add/drop channels in both directions. This saves the number of OC ports and fibres required for the add/drop operation. Other advantages of BOA 10 are still retained in this BOADM 50.

Fig. 6 shows a detailed implementation of a BOADM 60 embodying the present invention. The optical amplifier 62 can be constructed using Erbium-doped fibre 64, two pump lasers 66, 68, and two WDM couplers 70, 72. The OC ports act as isolators for the unidirectional optical amplifier 62 so there is no need for external isolators to be included in the device. The amplifier 62 can also comprise any other gain medium. An additional FBG_{WEST} 74 is also placed at port 5 of a 7-port OC 76. This additional FBG_{WEST} 74 works in the same way as that described in BOA 21. The 7-port OC 76 replaces the 6-port OC 52 (Figure 5). A demultiplexer (DEMUX) 78 can be used at the drop port to separate the drop channels and a multiplexer (MUX) 80 or a coupler can be used at the add port to combine the add channels together. FBG₁ 82 and FBG₂ 84 can be made tunable to facilitate add/drop reconfigurability in the network. If FBG₁ 82 and FBG₂ 84 are at their nominal Bragg wavelengths, the drop channels are dropped and the add channels at the same wavelengths can enter the device as explained before, otherwise if FBG₁ 82 and FBG₂ 84 are tuned outside their nominal Bragg wavelengths the drop channels are not dropped and pass through the device. The tunability of FBG₁ and FBG₂ can be achieved via thermal or strain tuning.

Fig. 7 shows another embodiment of a BOADM 100. In this structure, optical switches (OSWs) 102, 104 are used to provide reconfigurability instead of tunable gratings. If the OSW 102, 104 is in the bar state, the channel at the corresponding FBG 106, 108 is not dropped and passes through the device. If the OSW 102, 104 is in the cross state, that channel is dropped and an add channel at the same wavelength can enter the device.

Fig. 8 shows another embodiment of a BOADM 120. BOADM 120 facilitates the reconfigurability of a whole band of channels instead of individual wavelength channels. FBG₁ 122 and FBG₂ 124 are band-reflecting devices. If the OSW 126 is in the bar state, the band of

channels pass through the device unaffected. Otherwise, they are dropped to the drop port and can be separated using a DEMUX 128. The add channels can enter the device in a similar manner as described in BOADM 50 (Figure 5) via a MUX 130. It will be appreciated by the person skilled in the art that in other embodiments, FBG₁ and FBG₂ may be designed/chosen to be channel-reflecting devices, where the bi-directional traffic in the network is e.g. an interleaved channels traffic design. In such embodiments, through suitable switching of a switch corresponding to OSW 126, the groups of channels can either pass through the device unaffected, or be dropped.

Another embodiment of a BOADM 140 is shown in Fig. 9. In this structure, a dispersion compensation fibre (DCF) module 142 is inserted between two unidirectional optical amplifiers 144, 146 to facilitate dispersion compensation in the system.

Another embodiment of a BOADM 160 is shown in Fig. 10. The operation of BOADM 160 is very similar to that of BOA 10 (Figure 1) except that the signals before leaving the device pass through additional FBGs 162, 164 for add/drop operation. Therefore, for each OC 166, 168, we require four more ports compared to that of BOA 10 (Figure 1). Overall, BOADM 160 requires one 7-port 166 and one 9-port OCs 168. In the BOADM 160 structure shown in Fig. 9, the channel at wavelength λ_1 is added/dropped in the Eastbound direction and the channel at wavelength λ_2 is added/dropped in the Westbound direction.

A feature of BOADM 160 compared to BOADM 50 (Figure 5) is that it requires a higher number of ports to achieve the add/drop operation. Consequently, it is expected to be more expensive and has a higher insertion loss than BOADM 50 (Figure 5).

Another embodiment of a BOADM 180 is shown in Fig. 11. BOADM 180 consists of one 5-port and one 7-port OCs 182, 184, two sets of FBG_{WEST} 186 corresponding to the wavelength set travelling in the Westbound direction, and a number of FBGs e.g. 188, 190 (FBG₁ and FBG₂) corresponding to the add/drop wavelengths. The operation of BOADM 180 is different from that of BOADM 50 (Figure 5) and is briefly described here.

The Eastbound signals enter port 4 of the 5-port OC 182 and pass through to port 6 of the 7-port OC 184. The signals are then amplified by the optical amplifier 192 and are routed to port 2 of the 7-port OC. The channel at λ_1 is reflected and exits the device at port 3 of the 7-port OC 184. Other channels pass through the FBGs 188, 190 and are then routed to port 3 of

the 5-port OC. The add channel at λ_1 enters port 1 of the 5-port OC 182 and is then reflected by FBG₁ 188 and joins other through Eastbound channels. The Eastbound channels then pass from port 3 of the 5-port OC 182 to port 4 of the 7-port OC 184 and exit BOADM 180 at port 5 of the 7-port OC 184.

5 The Westbound signals enter port 5 of the 7-port OC 184 and are then routed to port 6 of the 7-port OC 184. The signals are then reflected by FBG_{WEST} 186 and are amplified by the optical amplifier and are routed to port 2 of the 7-port OC 184. The channel at λ_2 is reflected and exits the device at port 3 of the 7-port OC 184. Other channels pass through the FBGs 188, 190 and are then routed to port 3 of the 5-port OC. The add channel at λ_2 enters port 1 of the 5-
10 port OC 182 and is then reflected by FBG₂ 190 and joins other through Westbound channels. The Westbound channels are then routed to port 3 of the 5-port OC 182 and are reflected by FBG_{WEST} 186 back to port 3. Finally, the Westbound channels exit the BOADM 180 at port 4 of the 5-port OC 182.

15 Overall, the preferred embodiments aim at low-cost and good-performance implementation of BOAs and BOADMs for any type of traffic condition.

By employing different FBGs in the FBG_{EAST} and FBG_{WEST} sets in embodiments of the invention, any types of traffic conditions in the bidirectional single-fibre networks can be accommodated. This emphasises the device's good flexibility and good scalability.

20 Embodiments of the invention employ a single unidirectional amplifier to provide amplification for bidirectional signals. This reduces the cost and improves the device performance in terms of reflection prevention and noise figure compared to the implementation technique using two unidirectional amplifiers or a single bidirectional amplifier element.

25 Embodiments of the invention utilise OC ports to prevent reflections and hence removes the need of external isolators in the amplifier implementation. This further emphasises the low cost advantage of such embodiments.

Embodiments of the invention provide a single add port and a single drop port for bidirectional signals, which reduces the number of OC ports compared to other conventional structures. Moreover, the use of single add and drop ports facilitate the waveband and/or wavelength channels add/drop operation.

Embodiments of the invention efficiently remove Rayleigh backscattered light and out-of-band ASE noise in the input signals by utilising OC ports and FBGs.

Embodiments of the invention provide clean and ASE-free amplified output signals also by using OC ports and FBGs.

5 Embodiments of the invention provide dynamic reconfigurability of wavelength channels and/or waveband by using optical switches or tunable FBGs.

Embodiments of the invention incorporate a single unidirectional amplifier element to provide amplification for bidirectional signals in BOA or BOADM structures.

10 Embodiments of the invention use OCs and FBGs to add/drop wavelengths in unidirectional mode, which results in low crosstalk.

Embodiments of the invention can accommodate any asymmetric traffic, i.e. the number of wavelengths assigned for each direction can differ from each other. This is a strong merit in IP-centric network.

15 The positions of the wavelengths can be changed by simply changing the FBGs. Using this property, all the wavelengths can be arranged so that the total optical bandwidth is reduced for effective use of wavelength resources or to fit to the bandwidth of the amplifier used.

20 It will be appreciated by the person skilled in the art that numerous modifications and/or variations may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

In the claims that follow and in the summary of the invention, except where the context requires otherwise due to express language or necessary implication the word “comprising” is used in the sense of “including”, i.e. the features specified may be associated with further features in various embodiments of the invention.

Claims

1. A bi-directional optical amplifier structure comprising:

- a blocking, multi-port optical circulator (MOC) structure;

5 - a unidirectional amplifier unit optically connected in series between a first and second ports of the MOC structure;

- a first reflection filter unit optically connected in series between a third and a fourth ports of the MOC structure, and

- a second reflection filter optically connected in series between a fifth and a sixth ports of the MOC structure,

10 the amplifier structure being arranged, in use, such that a first optical signal entering through a seventh port of the MOC structure passes through the first reflection filter prior to being amplified in the amplifier unit and is reflected at the second reflection filter prior to exiting the amplifier structure at an eighth port of the MOC structure, and

15 such that a second optical signal entering through the eighth port of the MOC structure is reflected at the first reflection filter prior to being optically amplified in the amplifier unit and passes through the second reflection filter prior to exiting the amplifier structure at the seventh port.

2. An amplifier structure as claimed in claim 1, wherein the amplifier structure further comprises:

20 - a third reflection filter having the same filter response as the first reflection filter and being connected to a ninth port of the MOC structure, and

the amplifier structure is arranged, in use, such that the second signal is reflected at the third reflection filter after having been amplified in the amplifier unit and prior to exiting the amplifier structure.

25 3. An amplifier structure as claimed in claim 2, wherein the amplifier structure further comprises a light absorber element connected in series after the third reflection filter to prevent re-entering of light transmitted through the third reflection filter into the ninth port of the MOC structure.

4. An amplifier structure as claimed in any one of the preceding claims, wherein the amplifier unit comprises a dispersion compensation module.

5. An amplifier structure as claimed in claim 4, wherein the dispersion compensation module is connected in series between two unidirectional amplifier elements of the amplifier unit.

6. An amplifier structure as claimed in claims 4 or 5, wherein the dispersion compensation module comprises a dispersion compensation fibre (DCF).

7. An amplifier structure as claimed in any one of the preceding claims, wherein the amplifier unit comprises one or more uni-directional amplifier elements.

8. An amplifier structure as claimed in claim 7, wherein the amplifier elements are in the form of fibre amplifiers.

9. An amplifier structure as claimed in claim 8, wherein the fibre amplifiers comprise erbium doped fibre (EDF).

10. An amplifier structure as claimed in any one of the preceding claims, wherein the amplifier unit comprises one or more pump lasers.

11. An amplifier structure as claimed in any one of the preceding claims, wherein the amplifier structure further comprises:

- at least one fourth reflection filter connected in series between a tenth and an eleventh ports of the MOC structure for add/drop operation, and

the amplifier structure is arranged, in use, such that the first and second signals pass through the at least one fourth reflection filter prior to exiting the amplifier structure,

such that signal portions reflected at the at least one fourth reflection filter exit the amplifier structure at a twelfth port of the MOC structure, and

such that a third optical signal entering at a thirteenth port of the MOC structure is reflected at one of the fourth reflection filters, whereby the third signal is added to the first or second signals prior to the first or second signals exiting the amplifier structure.

12. An amplifier structure as claimed in any one of claims 1 to 10, wherein the amplifier structure comprises:

- at least one fifth reflection filter connected in series between a fourteenth and a fifteenth ports of the MOC structure for add/drop operation, and

- at least one sixth reflection filter connected in series between a sixteenth and a seventeenth ports of the MOC structure for add/drop operation,

5 and the amplifier structure is arranged, in use, such that the first and second signals pass through the at least one fifth and sixth reflection filters respectively prior to exiting, and such that reflected portions of the first and second signals exit at an eighteenth and nineteenth ports respectively, and

10 such that a fourth and a fifth signal entering at a twentieth and a twenty first ports of the MOC structure respectively are reflected at one of the fifth and sixth refraction filters respectively, whereby they are added to the first and second signals respectively prior to the first and second signals exiting the amplifier structure.

13. An amplifier structure as claimed in any one of the preceding claims, wherein the reflection filters comprise tuneable reflection filters, whereby band and/or wavelength
15 allocations in the amplifier structure are reconfigurable.

14. An amplifier structure as claimed in claim 11, wherein the amplifier structure comprises an optical switch associated with each of the fourth reflection filters and arranged, in use, such that the associated fourth reflection filter is selectively by-passable, whereby an add/drop configuration of the amplifier structure is reconfigurable.

20 15. An amplifier structure as claimed in claims 11 or 14, wherein the amplifier structure further comprises an optical demultiplexer and an optical multiplexer connected at the twelfth and thirteenth port of the MOC structure respectively.

25 16. An amplifier structure as claimed in claim 15, wherein the demultiplexer and the multiplexer are connected to the twelfth and thirteenth ports respectively via a further optical switch arranged, in use, such that the demultiplexer and multiplexer are by-passable to selectively disable the add/drop functionality.

17. An amplifier structure as claimed in any one of the preceding claims, wherein the MOC structure is implemented as a single, blocking MOC, or as two or more interconnected blocking MOCs.

18. An amplifier structure as claimed in claim 17, wherein the MOC structure is implemented as two interconnected MOCs, and the circulation directions in the two interconnected MOCs are opposite.

19. A bi-directional add/drop structure comprising:

5 - a blocking MOC structure,

- at least one first reflection filter connected in series between a first and a second ports of the MOC structure for add/drop operation,

the add/drop structure being arranged, in use, such that a first optical signal entering through a third port of the MOC structure passes through the at least one first reflection filter prior to exiting the add/drop structure at a fourth port of the MOC structure, and

such that a second optical signal entering through the fourth port of the MOC structure passes through the at least one first reflection filter in the same direction as the first signal prior to exiting the add/drop structure at the third port, and

such that signal portions reflected at the at least one first reflection filter exit the add/drop structure at a fifth port of the MOC structure, and

such that a third optical signal entering at a sixth port of the MOC structure is reflected at one of the first reflection filters, whereby the third signal is added to the first or second signals prior to the first or second signals exiting the add/drop structure.

20. An add/drop structure as claimed in claim 19, wherein the add/drop structure comprises:

- a second reflection filter connected in series between a seventh and an eighth ports of the MOC structure, and

- a third reflection filter connected in series between a ninth and a tenth ports of the MOC structure,

and the add/drop structure is arranged, in use, such that the first optical signal passes through the second reflection filter prior to passing through the at least one first reflection filter and is then reflected at the third reflection filter prior to exiting the add/drop structure, and

such that the second optical signal is reflected at the second reflection filter prior to passing through the at least one first reflection filters and then passes through the third reflection filter prior to exiting the add/drop structure.

21. An add/drop structure as claimed in claim 19, wherein the add/drop structure
5 comprises:

- a second reflection filter connected in series between a seventh and an eighth ports of the MOC structure, and

- a third reflection filter, having the same filter response as the second reflection filter, connected in series between a ninth and a tenth ports of the MOC structure,

10 and the add/drop structure is arranged, in use, such that the first optical signal passes through the second reflection filter prior to passing through the at least one first reflection filter and then passes through the third reflection filter prior to exiting the add/drop structure, and

such that the second optical signal is reflected at the second reflection filter prior to passing through the at least one first reflection filter and is then reflected at the third reflection
15 filter prior to exiting the add/drop structure.

22. A method of bi-directionally amplifying optical signals, the method comprising the steps of:

- passing a first optical signal through a first reflection filter prior to
- amplifying the first signal using and then
- 20 - reflecting the first signal at a second reflection filter,
- reflecting a second optical signal at the first reflection filter prior to
- amplifying the second optical signal and then
- passing the second optical signal through the second reflection filter.

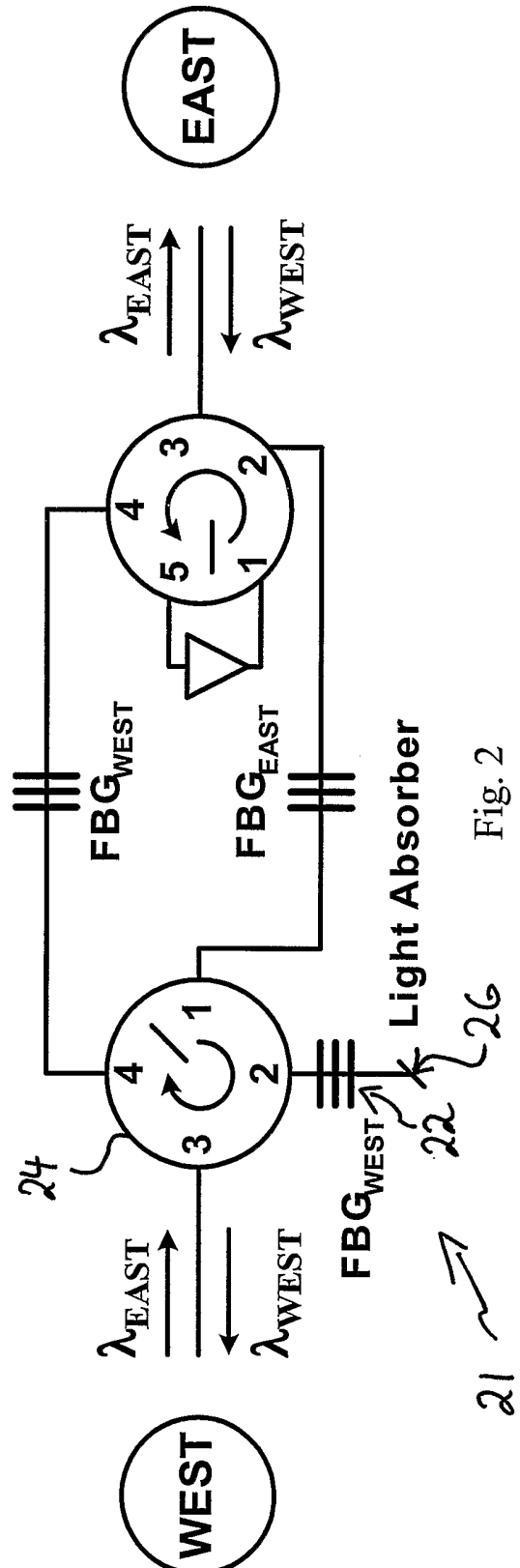
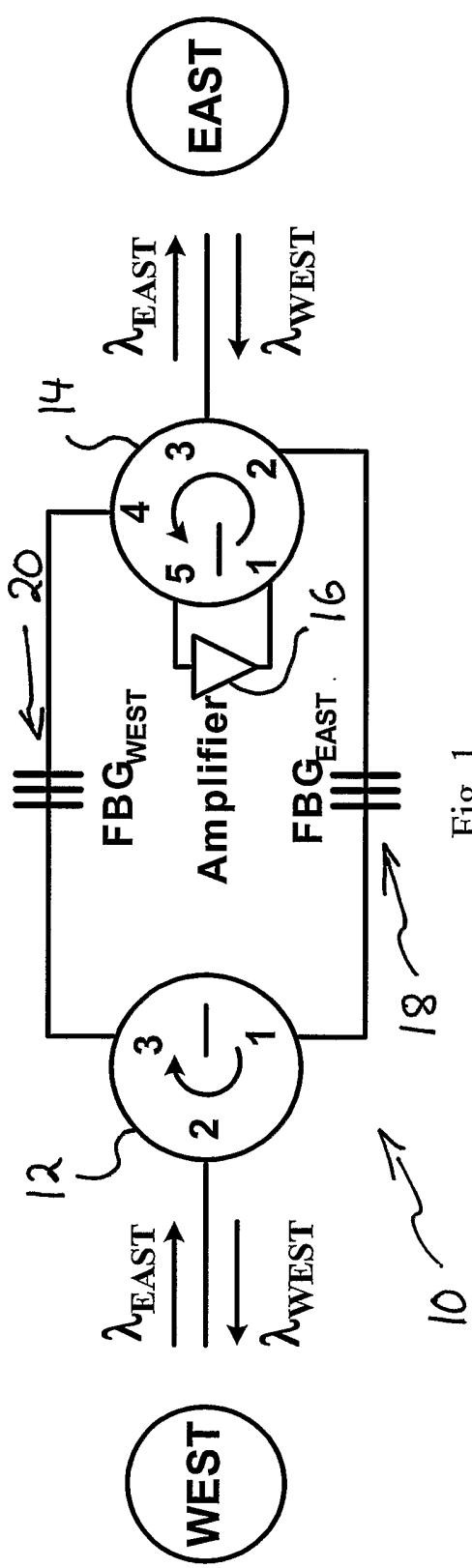
23. A method of bi-directionally adding/dropping optical signals, the method
25 comprising the steps of:

- passing a first optical signal through at least one first reflection filter,
- passing a second optical signal through the at least one first reflection filter in the same direction as the first signal,

whereby signal portions reflected at the at least one first reflection filter are dropped,
and

- reflecting a third optical signal at one of the first reflection filters,

whereby the third signal is added to the first or second signals.



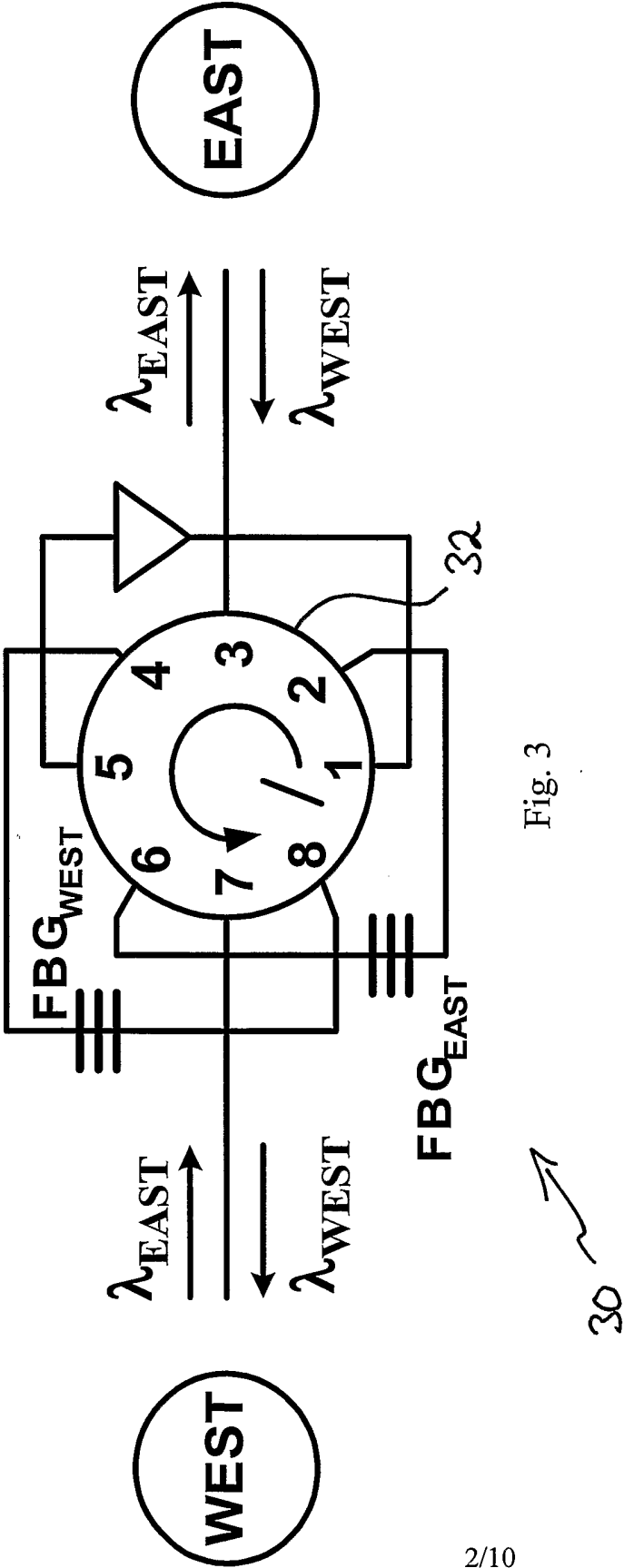


Fig. 3

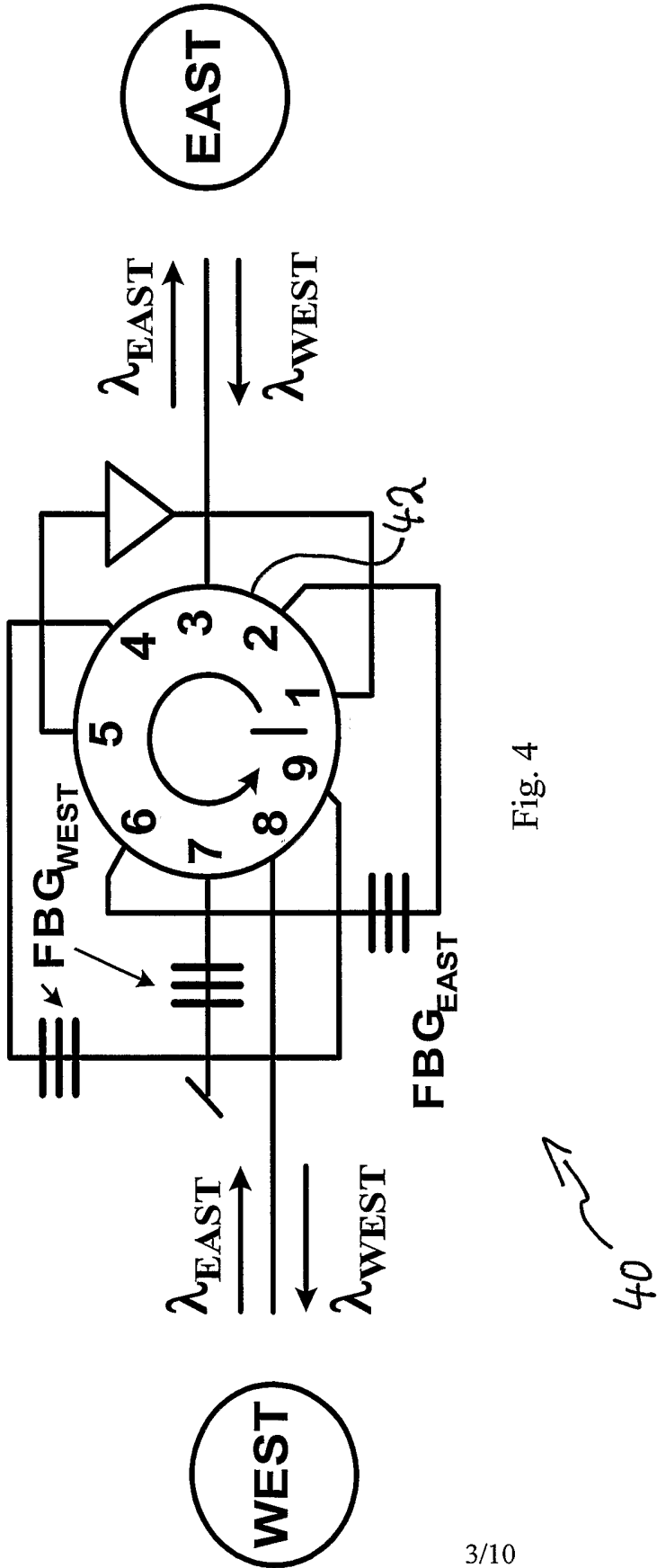


Fig. 4

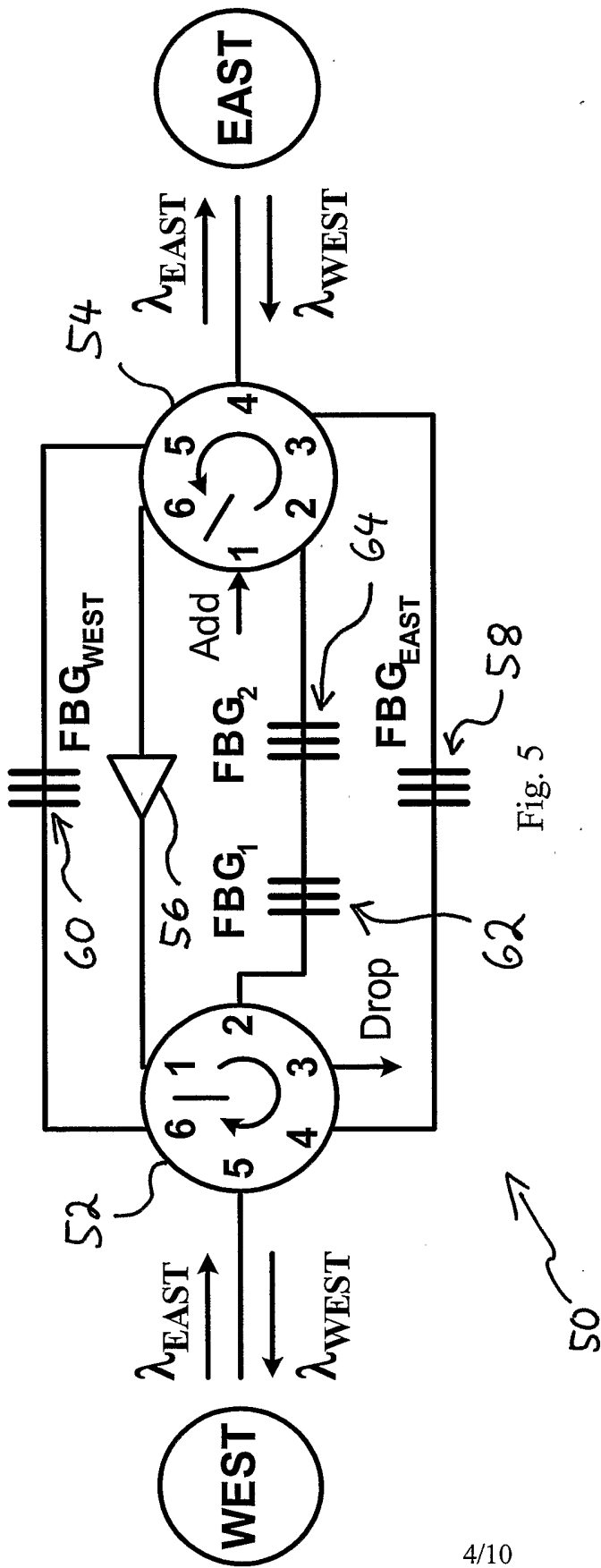


Fig. 5

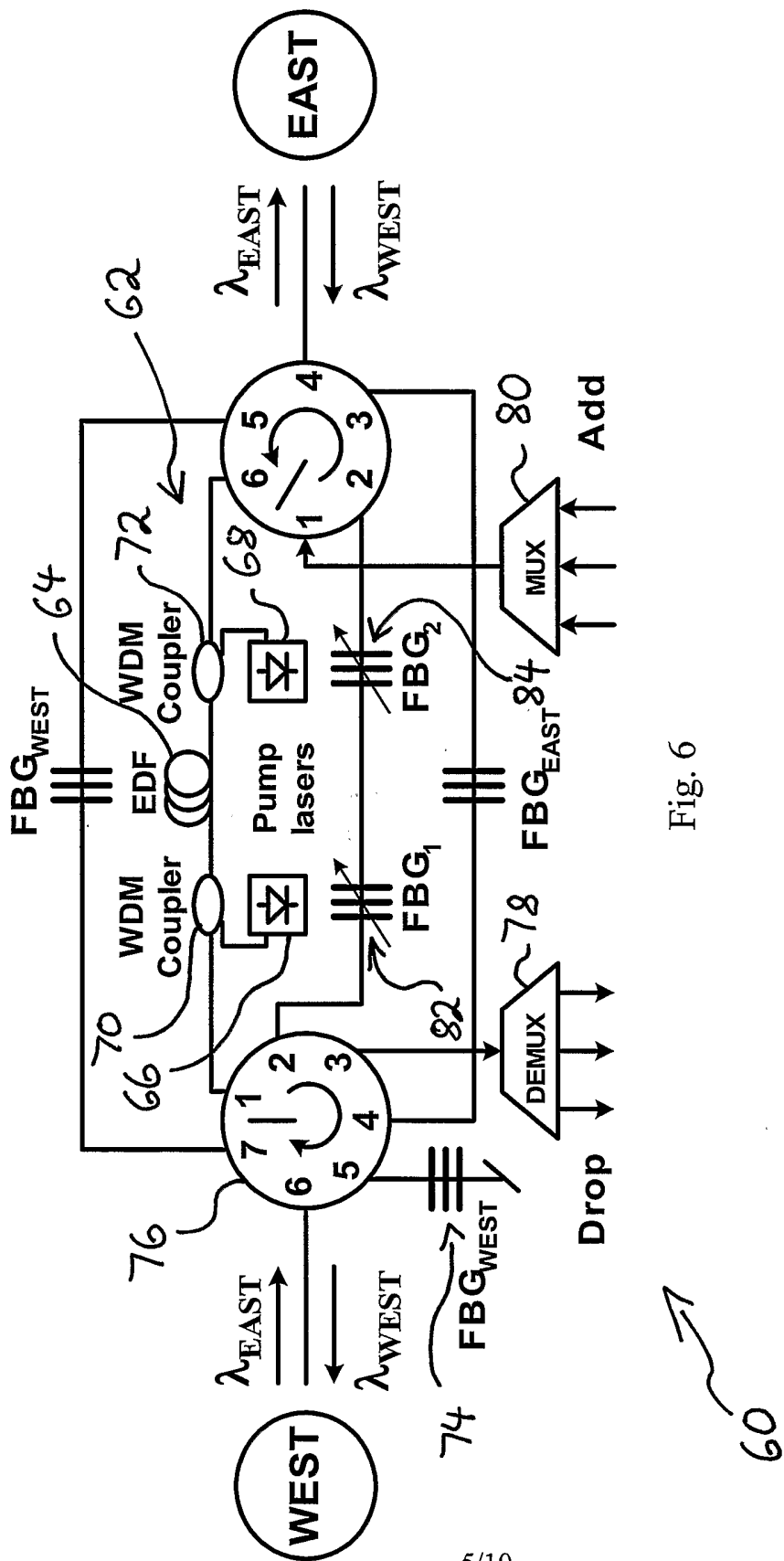


Fig. 6

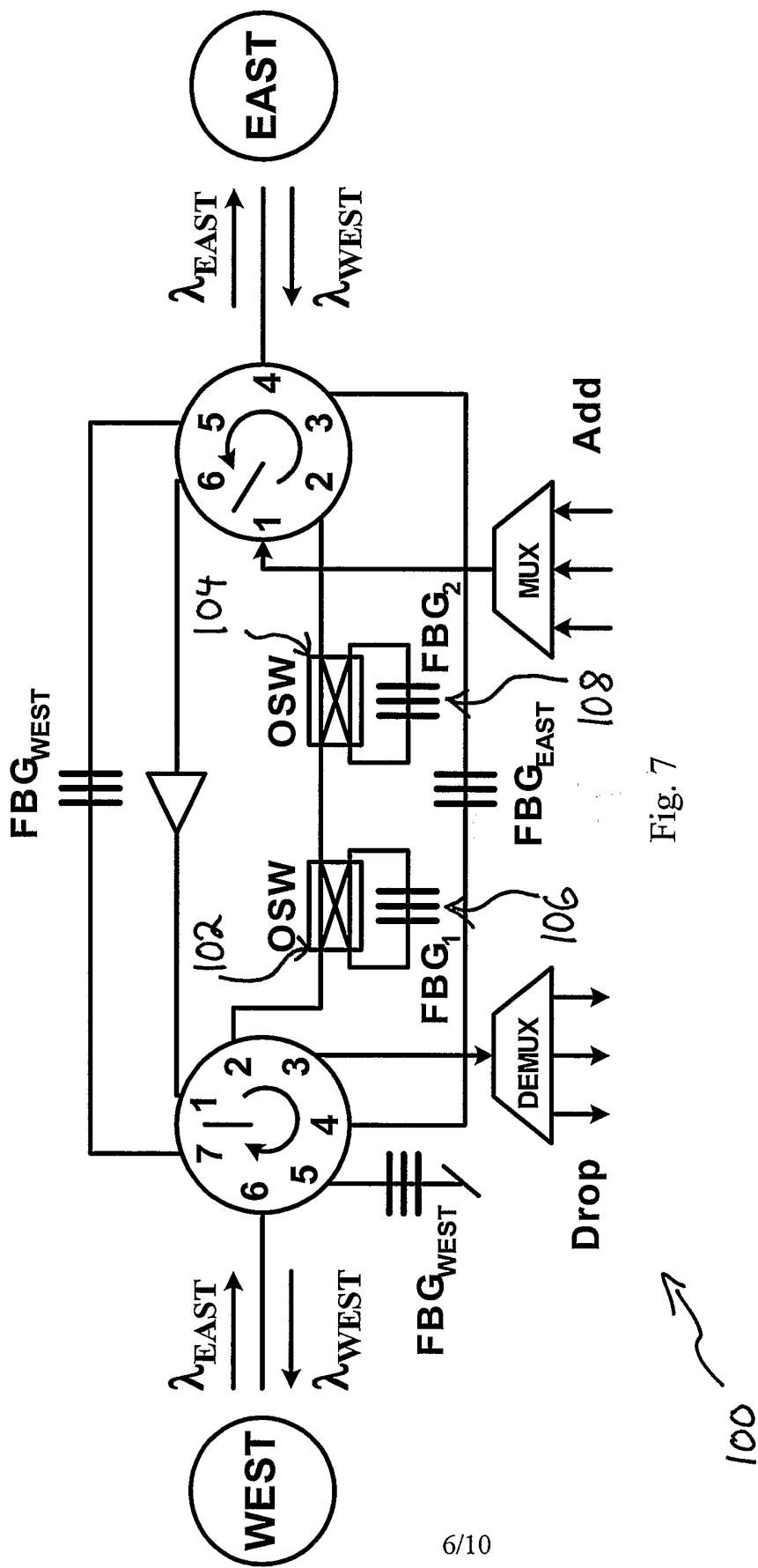


Fig. 7

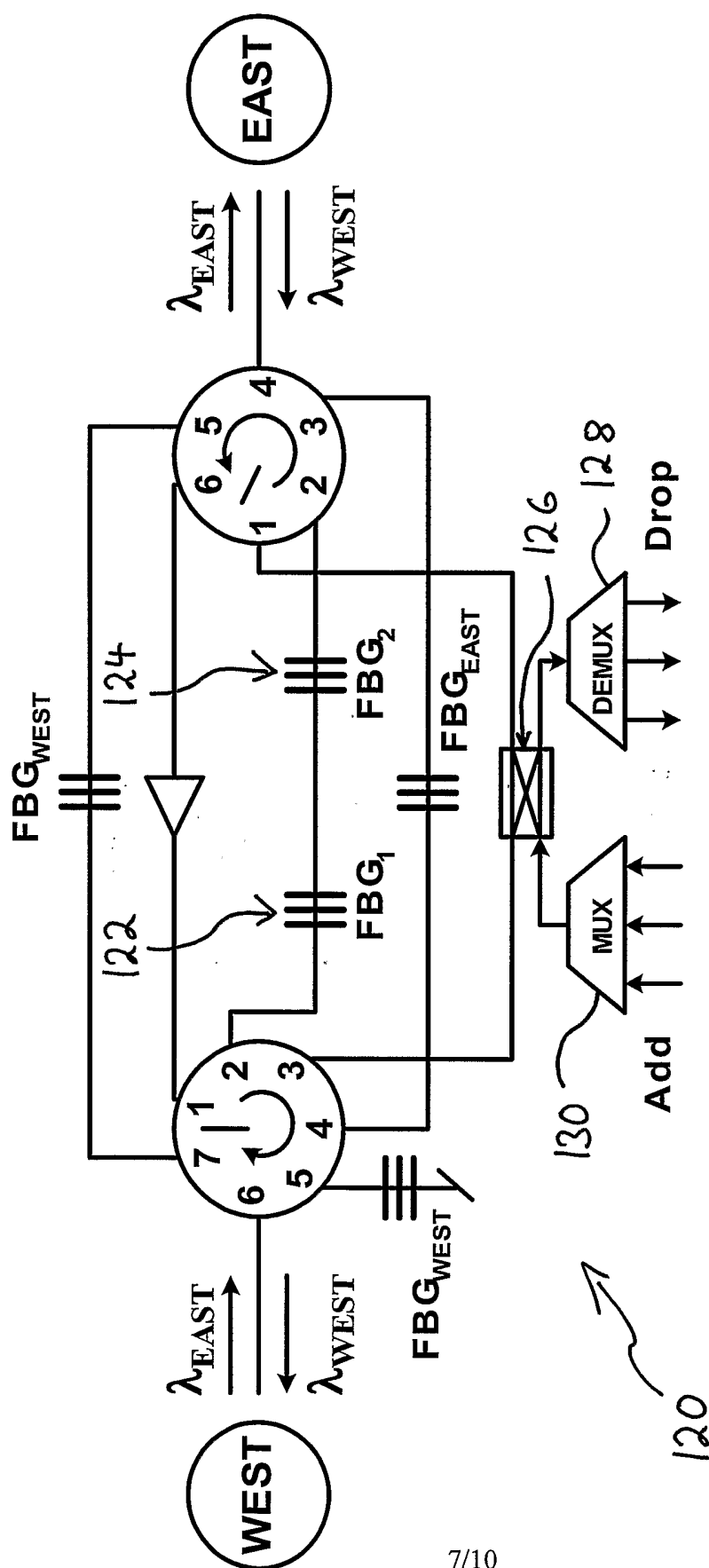


Fig. 8

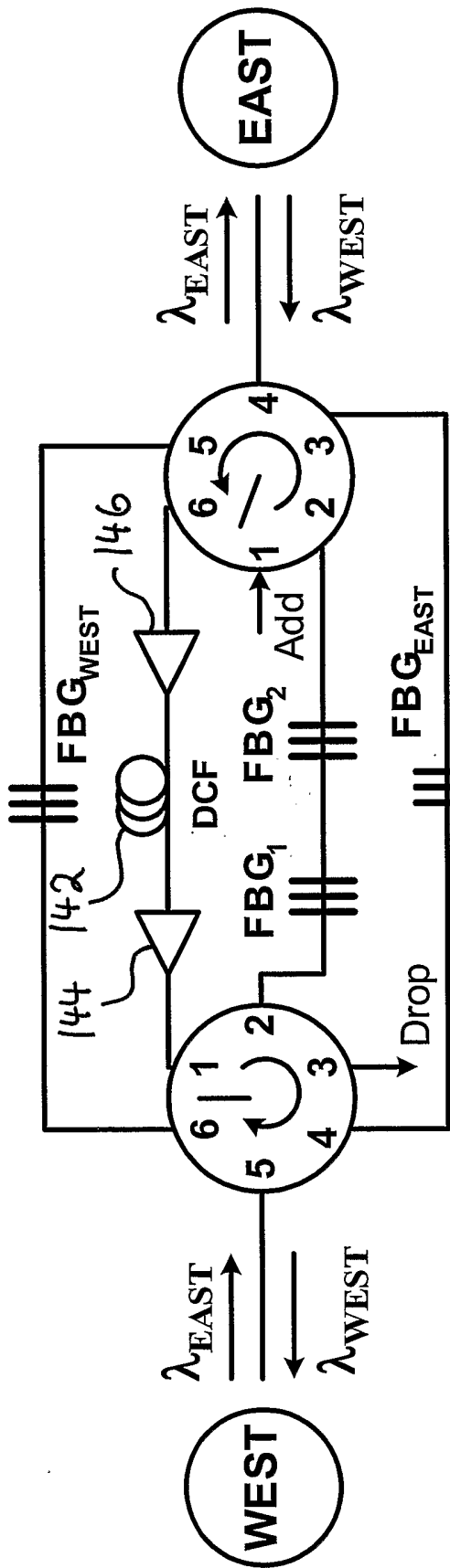


Fig. 9

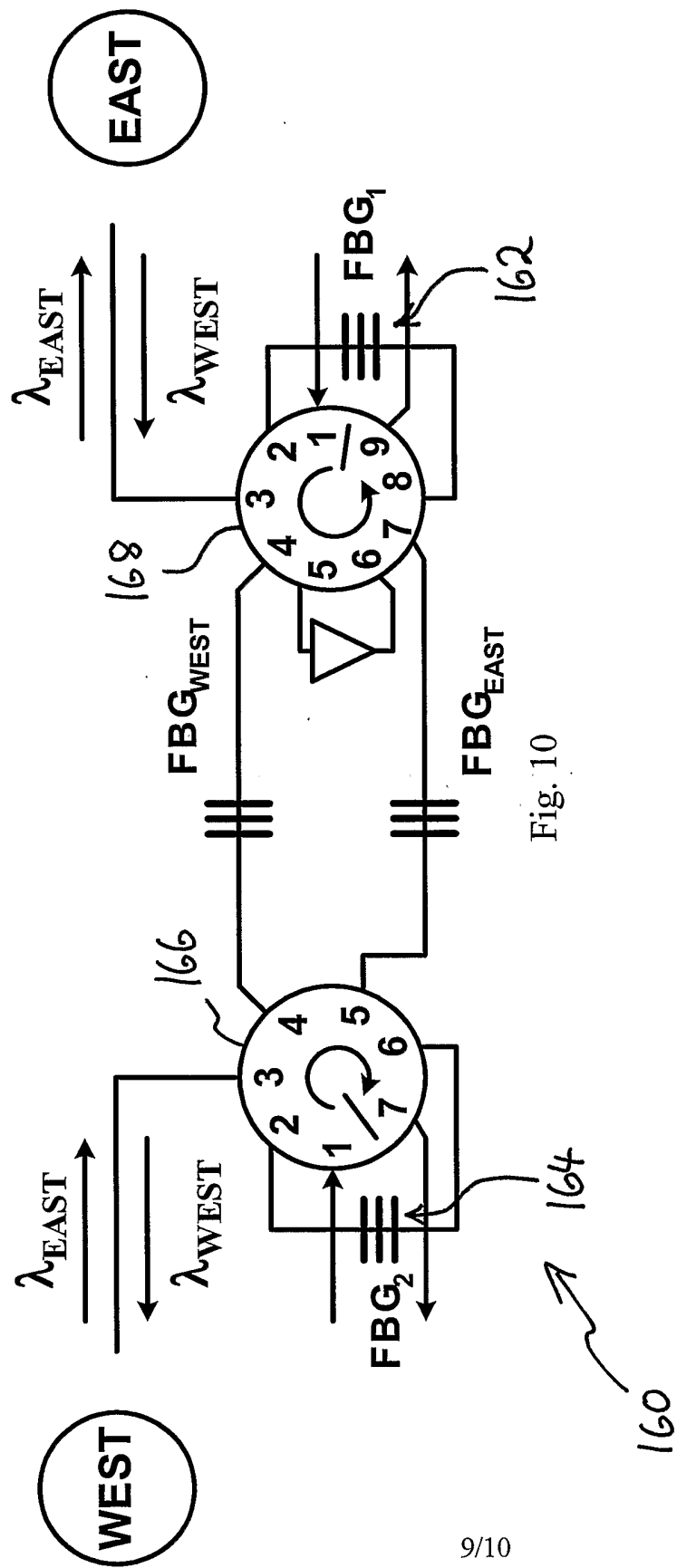


Fig. 10

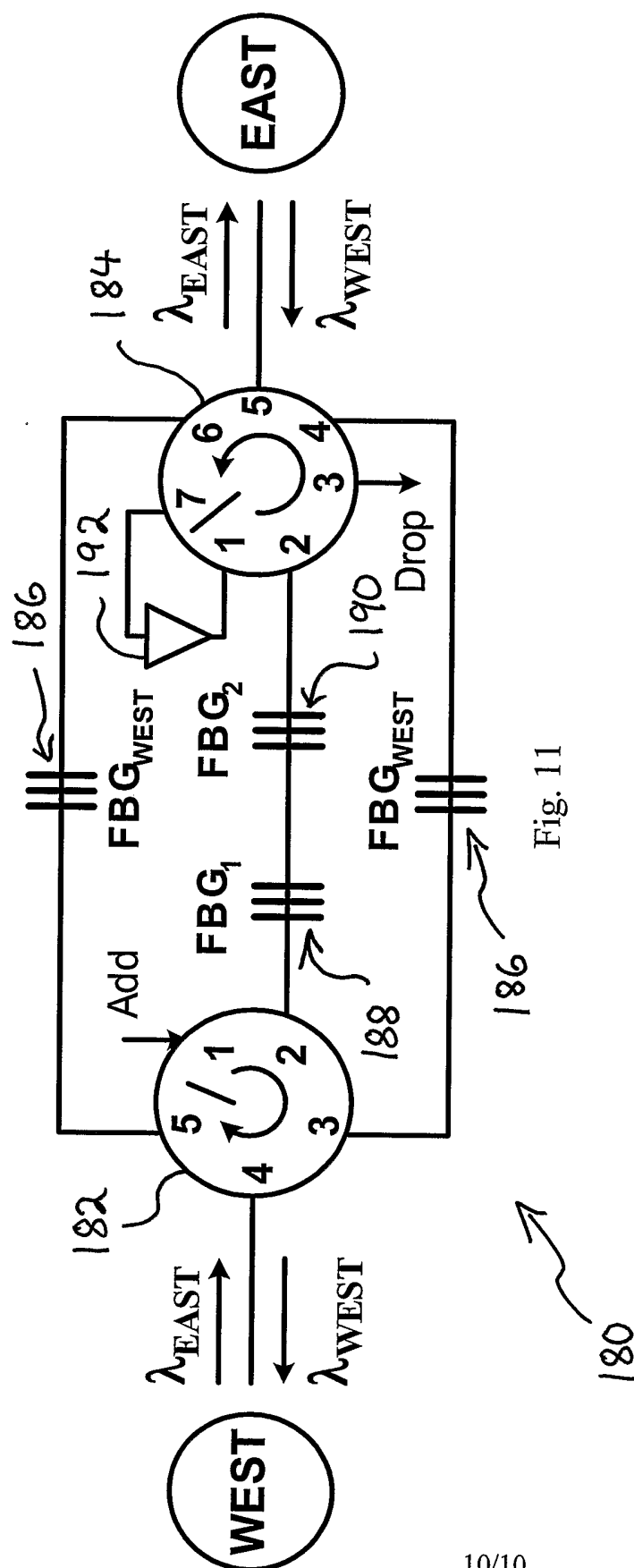


Fig. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU03/01115

A. CLASSIFICATION OF SUBJECT MATTER		
Int. Cl. ⁷ : H04J 14/02, H04B 10/17, 10/24		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
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 practicable, search terms used) DWPI, JAPIO: keywords [circulator?; filter+, grating?; amplifi+; add+, drop+, multiplex+, demultiplex+; (multi+, plurality, several) (4D) (ports, terminals, channels), multiport; bi-directional, two-way, ?WDM]		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2321809 A (STC SUBMARINE SYSTEMS LIMITED) 5 August 1998 Page 7 line 20 - page 10 line 4, figures 1, 2	23
X	WO 00/48348 A (NOKIA NETWORKS OY) 17 August 2000 Figure 3	23
X	WO 02/30025 A (THE UNIVERSITY OF MELBOURNE) 11 April 2002 Figure 1	23
A	EP 928081 A (PIRELLI CAVI E SISTEMI S.P.A.) 7 July 1999 Figures 2 & 5	1-18, 22
☒ 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 application or patent 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 October 2003		Date of mailing of the international search report 06 NOV 2003
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustalia.gov.au Facsimile No. (02) 6285 3929		Authorized officer IRINA TALANINA Telephone No : (02) 6283 2203

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU03/01115

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6212000 B (ISHIKAWA) 3 April 2001 Col. 6 lines 1-67, figure 2	1-18, 22
A	US 5812306 A (MIZRAHI) 22 September 1998 Col. 7 line 32 - col. 8 line 45, figure 1	1-18, 22
A	WO 01/88603 A (AVANEX CORP) 22 November 2001 Abstract, figure 20	19-21, 23
P, A	WO 03/005619 A (THE UNIVERSITY OF MELBOURNE) 16 January 2003 The whole document	1-23

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/AU03/01115

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
GB	2321809	EP	0893016	US	6449072	WO	9834364
WO	0048348	AU	25505/00	EP	1151567	FI	990238
		US	2002071156				
WO	0230025	AU	93508/01				
EP	0928081	AU	98172/98	BR	9805736	JP	11266208
		NZ	333528	US	6160660		
US	6212000	FR	2773647	IT	MI990060	JP	11204869
US	5812306	NONE					
WO	0188603	AU	78846/01	US	6538815		
WO	03005619	NONE					
END OF ANNEX							