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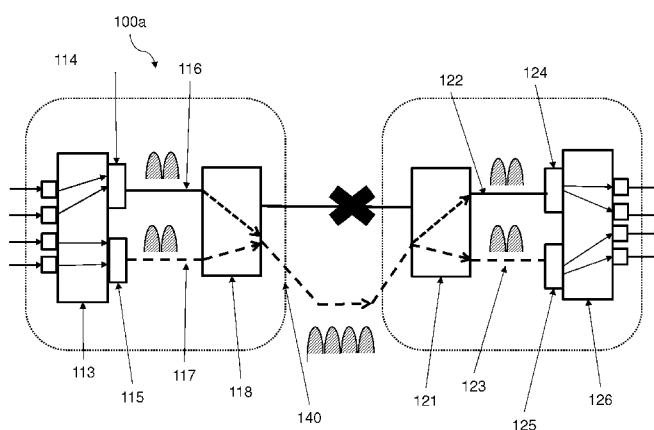


Figure 5

(57) Abstract: A flexible grid optical network in which a first network terminal is connected to a second network terminal using a main optical fibre connection and a protection optical fibre connection, wherein the protection optical fibre connection is longer than the main optical fibre connection. A first optical signal is sent over the main optical fibre connection and comprises one or more flexible grid sub-channels. In the event of a failure of the main optical fibre connection, a second optical signal is sent over the protection optical fibre connection. If the length of the protection optical fibre connection is greater than the reach of the flexible grid sub-channels that comprise the first optical signal then the second optical signal will comprise a greater number of flexible grid sub-channels: these sub-channels will have lower data rates but a longer reach and will provide the necessary capacity over the protection optical fibre connection.

OPTICAL COMMUNICATIONS NETWORK

Field of the Invention

The present invention relates to optical communications networks, and in particular to
5 resilient optical communications, in which data is transmitted over a main route and a
dedicated standby route is available in the event of loss of service or equipment failure.

Background to the Invention

Conventional optical communication networks operate by sending light pulses of a
10 predetermined period, for example such that a pulse represents a '1' and no pulse
represents a '0'. This technique enables signals to be sent at data rates of up to 10
Gbit/s and wavelength division multiplexing (WDM) techniques can be used to send
multiple signals over a single fibre. Dense WDM (DWDM) enables around 80
wavelengths to be used such that a single fibre can potentially carry 0.8Tbit/s of data. In
15 order to enable compatibility between network components from different vendors, the
ITU has specified a grid of wavelengths that are used in DWDM systems (see ITU-T
G.694.1). One of the transmission phenomena present in optical fibres is chromatic
dispersion, which causes the transmitted pulse to spread out, such that it becomes
difficult to recover the transmitted signal at the receiver. The effects of dispersion can
20 be mitigated by installing dispersion compensating modules (DCMs) into the network,
but this adds to the cost and the complexity of the network.

Coherent optical transmission systems are thought to provide the best option for
transmitting data at a rate in excess of 40 Gbit/s. Coherent optical transmission systems
25 are similar to the transmission systems used in wireless systems. Rather than only
turning an optical transmitter on and off to generate a pulse, an optical signal is
modulated, for example in terms of both phase and amplitude, with a data signal. At the
receiver end, coherent detection is used with a local laser oscillator to recover the phase
and amplitude components of the transmitted signals. Dispersion is less of a problem
30 and can be compensated for electronically during the demodulation of the optical signal,
such that Dispersion Compensating Modules (DCMs) are not needed (in fact coherent
optical networks work better without them).

As data transmission rates increase further, for example beyond 100 Gbit/s, then the
35 optical signals required to transmit such data rates may not fit into the 50GHz grid of

wavelengths that are defined in the DWDM specifications. It is preferred, for reasons of flexibility and spectral efficiency, that for such high data rates network operators are able to determine which regions of the optical transmission window are used to transmit specific signals. A single coherent optical signal, for example one having a data rate of 100 Gbit/s or greater, may extend across the 50GHz spectrum window in a conventional 50GHz grid-based network. In comparison, flexible grid networks can transmit higher speed (Tbit/s) optical signals using a wavelength range that is convenient for the network operator. ITU recommendation ITU-T G.694.1 (02/2012) describes the flexible grid, which comprises a number of frequency slots which are defined in terms of the nominal central frequency and the slot width. Appendix I provides example of how such flexible grid networks may be operated.

Figure 1 shows a schematic depiction of a WDM optical communications network 100 in which optical signals are transmitted from a first terminal 110 at a first location to a second terminal 120 at a second location via optical fibre 130. The optical signals will typically comprise 10 Gbit/s signals and WDM techniques are used so that multiple 10 Gbit/s signals can be sent over the optical fibre 130, with each of the signals transmitted using a specified wavelength. It is important that a protection route be provided, in case of equipment failure or an event that causes damage to the optical fibre 130. Figure 1 further shows a protection route which comprises optical fibre 140, which connects the first location 110 to the second location 120 and which is routed via a third location 150. In core networks, the distance between the first and second locations is likely to be of the order of hundreds of kilometres, for example, in UK based networks. In general, the protection route will be longer than the main route, typically more than 30% longer and possibly more than 100% longer. In a current grid-based optical communications network if the length of the protection route is greater than the reach of the transmission system then it will be necessary to install regeneration equipment at the third location; such a requirement is expensive and would be avoided, if possible, by a network operator.

Figure 2 shows a schematic depiction of a flexible grid optical communications network 100', which provides a main optical fibre connection 130 between a first location 110 and a second location 120. A protection route is provided by optical fibre 140, which is routed via third location 150. In this case, the flexible grid network carries a 400Gbit/s superchannel (see below) which comprises 2 x 200Gbit/s sub-channels. If the length of

the protection route is less than the reach of these sub-channels then these signals can be simply transmitted over the protection route from the first location 110 to the second location 120. If the length of the protection route is greater than the reach of the transmission system then it will be necessary to provide opto-electronic regeneration equipment at the third location 150, thus increasing the cost of the network significantly.

Flexible grid optical communications networks are able to operate with a lower frequency separation than that used in grid-based networks, for example a channel separation of as little as 37.5GHz compared to a separation of 50 GHz in grid-based networks. This leads to increased spectral efficiency and allows for the utilisation of fibre infrastructure to be increased by a factor of more than 30%. In a flexible grid optical network, the concept of an optical channel is no longer a single wavelength: instead a single capacity entity can be defined as comprising one or more sub-channels which together form an aggregate optical capacity, which will be referred to as a 'superchannel' in the following discussion. These superchannels can then be configured and managed throughout the optical network infrastructure. Figure 3 shows a schematic depiction of how a 400 Gbit/s superchannel could be formed. Figure 3a shows a superchannel which comprises 4 x 100 Gbit/s sub-channels; Figure 3b shows a superchannel which comprises 2 x 200 Gbit/s sub-channels; and Figure 3c shows a superchannel which comprises a single 400 Gbit/s sub-channel.

Table 1 below shows illustrative data for the different data rates and reaches that can be expected for different modulation formats that are likely to be deployed in the next few years. The table is illustrative, and should not be viewed as an absolute statement of capabilities. It should be noted that as the number of bits per symbol and/or the baud rate (or speed) are increased the expected Optical Signal to Noise Ratio (OSNR) requirements increase dramatically, with a corresponding decrease in network reach. It should be noted that the net baud rate is the actual data rate excluding overhead for FEC (Forward Error Correction) coding. Other examples of configurations could be described (e.g. using a fixed modulation format and varying transponder baud-rates) but for the purpose of the following description we confine ourselves to the examples described in Table 1. As the only constraint on a sub-channel is that the width of its frequency slot is a multiple of 12.5GHz (see section 7 of ITU-T G.694.1 (02/2012)) then it will be understood that it will be possible to define many different superchannels and sub-channels. As will be clear from the following discussion, the present invention is not

limited by the capacity, or other characteristics, of a superchannel or by those of the one or more sub-channels which comprise a superchannel.

Modulation Format	Bits per symbol (Single/Dual polarisation)	Net Baud-rate (GBaud)	Data rate (Gbit/s)	Typical OSNR requirement (dB)	Reach (km)
QPSK	2/4	25	100	12	2000
QPSK	2/4	50	200	17	1000
16-QAM	4/8	25	200	20	600
64-QAM	6/12	33	400	26	150

Table 1: Example characteristics of flexible grid sub-channels

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It can be seen from Table 1 that there are a number of different options available depending on the reach required for a particular optical fibre connection. If a 400 Gbit/s superchannel is required then for the longest connections then it will be necessary to use the superchannel configuration depicted in Figure 3a, of 4 x 100G (QPSK) sub-channels giving a total spectral width of ~150GHz. For a lesser range it would be possible to use the same QPSK modulation format, but with a greater baud rate to form the 400 Gbit/s superchannel from 2 x 200 Gbit/s sub-channels which would occupy approximately 100GHz of spectrum. Ideally, bearing in mind the goal of optimising the efficiency of available fibre capacity and optical spectrum, it would be preferred to exploit more spectrally efficient schemes such as the use of 2 x 200Gbit/s (16-QAM) sub-channels (Figure 3b) which takes up a spectral width of ~75GHz, but owing to its lesser reach (~600km) this would not be feasible for long reach applications. For short distance applications, perhaps on the order of 100-200km, then the preferred option would be the example illustrated in Figure 3c, which illustrates an example where the superchannel would comprise a single sub-channel of 400Gbit/s, based on 64-QAM modulation, having a spectral width of ~50GHz.

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The above discussion illustrates the new paradigm in realising a given capacity, where sub-channels of differing modulation formats and/or Baud-rates could be used to define the capacity of a superchannel. In general, this presents a challenge in realising resilient solutions, where the main and protection route will be significantly different, both in terms of distance and/or the quality of the optical link. For example, for a similar distance the

link could have worse optical characteristics such as fibre loss and number of node or ROADMs transits. In the following description of the invention, it is stated that the protection link is longer than the main link, however, the arguments also apply to a protection link which may not necessarily be longer, but has poorer optical transmission quality as described above.

Vizcaíno *et al*, "*Protection in optical transport networks with fixed and flexible grid: Cost and energy efficiency evaluation*", Optical Switching and Networking, vol 11 (2014), pp 55-71 discuss a number of issues relating to the use of flexible grid networks. In particular, it is disclosed that a different modulation format may be used for working and protection paths in a network.

Summary of the Invention

According to a first aspect of the present invention, there is provided a flexible grid optical communications network comprising: a first terminal at a first location; a second terminal at a second location; a first optical fibre connection between the first and the second location; and a second optical fibre connection between the first location and the second location, the second optical fibre connection being longer than the first optical fibre connection wherein, in use, the network is configured to: transmit a first optical signal from a first optical transponder over the first optical fibre connection, the first optical signal comprising one or more flexible grid sub-channels, wherein in the event of a failure; the first optical transponder is configured to transmit a second optical signal over the second optical fibre connection, the second optical signal comprising one or more flexible grid sub-channels; a second optical transponder is activated to transmit a third optical signal over the second optical fibre connection, the third optical signal comprising one or more flexible grid sub-channels wherein the one or more flexible grid sub-channels which comprise the first optical signal are different from the one or more flexible grid sub-channels which comprise the second optical signal.

The difference between the first optical signal and the second optical signal may take one or more different forms. The modulation format used to generate the one or more flexible grid sub-channels which comprise the first optical signal may be different from the modulation format used to generate the one or more flexible grid sub-channels which comprise the second optical signal. The data rate of the one or more flexible grid sub-channels which comprise the first optical signal may be different from the data rate of the

one or more flexible grid sub-channels which comprise the second optical signal. The baud rate of the one or more flexible grid sub-channels which comprise the first optical signal may be different from the baud rate of the one or more flexible grid sub-channels which comprise the second optical signal. The second optical signal may comprise a greater number of flexible grid sub-channels than the first optical signal.

The length of the protection fibre connection may be greater than that of the main fibre connection such that it is not possible to transmit the same sub-channels over the main and the protection fibre connections. By transmitting a different set of sub-channels over the protection fibre connection it is possible to provide the desired amount of capacity. Providing resilience in this way is less spectrally efficient but avoids the significant expense of having to provide signal re-generation in the protection fibre connection.

According to a second aspect of the present invention, there is provided a transmitter for use in a flexible grid optical communications network, the transmitter comprising: a plurality of interfaces, a first optical transponder, a second optical transponder and an optical multiplexer; the transmitter being configured such that, in use, the first optical transponder receives a first plurality of data signals from the interfaces and modulates the data signals to generate a first optical signal comprising one or more flexible grid sub-channels, the first optical signal being routed by the optical multiplexer over a first optical fibre connection; such that in the event of a failure, the transmitter is configured such that, in use; the first optical transponder receives a second plurality of data signals from the interfaces and modulates the data signals to generate a second optical signal comprising one or more flexible grid sub-channels, the second optical transponder receives a third plurality of data signals from the interfaces and modulates the data signals to generate a third optical signal comprising one or more flexible grid sub-channels, the second optical signal and the third optical signal being routed by the optical multiplexer over a second optical fibre connection, wherein the one or more flexible grid sub-channels which comprise the first optical signal are different from the one or more flexible grid sub-channels which comprise the second optical signal.

According to a third aspect of the present invention, there is provided a receiver for use in a flexible grid optical communications network, the receiver comprising: an optical multiplexer, a first optical transponder, a second optical transponder and a plurality of interfaces; the receiver being configured such that, in use; the optical multiplexer

receives a first optical signal comprising one or more flexible grid sub-channels from a first optical fibre connection and routes the first optical signal to the first optical transponder; the first optical transponder demodulates first optical signal to generate a plurality of data signals, the plurality of data signals being routed to the plurality of interfaces wherein in the event of a failure, the first optical multiplexer receives a second optical signal comprising one or more flexible grid sub-channels from a second optical fibre connection and the second optical multiplexer receives a third optical signal comprising one or more flexible grid sub-channels from the second optical fibre connection wherein the one or more flexible grid sub-channels which comprise the first optical signal are different from the one or more flexible grid sub-channels which comprise the second optical signal.

According to a fourth aspect of the present invention, there is provided a method of operating a flexible grid optical communications network, the method comprising the steps of; method of operating a flexible grid optical communications network, the method comprising the steps of; a) modulating a plurality of electrical data signals to generate a first optical signal comprising one or more flexible grid sub-channels; b) transmitting the first optical signal from the first terminal to a second terminal over a first optical fibre connection; c) demodulating the first optical signal to generate a plurality of electrical data signals; the method being characterised by further comprising the steps of: d) in the event of a fault modulating a plurality of electrical data signals to generate a second optical signal comprising one or more flexible grid sub-channels, wherein the one or more flexible grid sub-channels which comprise the first optical signal are different from the one or more flexible grid sub-channels which comprise the second optical signal; and e) transmitting the second optical signal from the first terminal to the second terminal over a second optical fibre connection.

Brief Description of the Figures

In order that the present invention may be better understood, embodiments thereof will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 shows a schematic depiction of a grid-based optical communications network;

Figure 2 shows a schematic depiction of a flexible grid optical communications network;

Figure 3 shows a schematic depiction of how a superchannel could be formed;

Figure 4 shows a schematic depiction of a flexible grid optical communications network according to a first embodiment of the present invention;

Figure 5 shows a schematic depiction of the flexible grid optical communications network according to a first embodiment of the present invention in a failure state; and

Figure 6 shows a schematic depiction of a number of different superchannels used in a flexible grid optical communications network.

Detailed Description of Embodiments

Figure 4 shows a schematic depiction of a flexible grid optical communications network 100a according to a first embodiment of the present invention. The communications network comprises a first terminal 110 at a first location and a second terminal 120 at a second location, the first terminal being connected to the second terminal by a main optical fibre connection 130. The network 100a further comprises a protection optical fibre connection 140, which has a different routing between the first and second terminals, such that the length of the protection fibre connection 140 is significantly greater than that of the main fibre connection 130. Data is received from multiple client circuits (for example, in this case 4 x 100GE) as respective electrical signals at input client interfaces 112. A first electrical switch 113 connects each of the client circuits to a first optical transponder 114, which is used to generate a 400Gbit/s optical superchannel. In the present example the superchannel will comprise 2 x 200 Gbit/s sub-channels, which are created using a 16-QAM modulation scheme. The superchannel is transmitted over a first optical link 116 to a first multiplexer 118. The first multiplexer 118 is a flexible grid reconfigurable optical add/drop multiplexer (ROADM) which is configured to send the superchannel to the main optical fibre connection 130. The superchannel is received at the second location by a second multiplexer 121, which is also a flexible grid ROADM. The superchannel is transmitted over second optical link 122 to a second optical transponder 124. The second optical transponder demodulates the 2 x 200 Gbit/s sub-channels to recover the four 100GE signals, which the second electrical switch 126 switches to respective output client interfaces 127. The output client interfaces 127 are each connected to respective output

client circuits 128 such that the 100GE signals can be transmitted onwards. In normal operation no data is sent over the protection route, as the protection route is only operational in the event of some form of network failure.

5 Figure 5 shows a schematic depiction of the communications network 100a according to a first embodiment of the present invention when the main fibre connection 130 has failed, for example due to the cable being accidentally severed during road works. As the length of the protection optical fibre connection 140 is substantially greater than the length of the main optical fibre connection 130 then it is not possible to transmit the
10 400Gbit/s superchannel over the protection fibre channel using 2 x 200Gbit/s sub-channels. When the fibre break is detected then a number of different actions are taken. The first switch 113 is re-configured to route two of the 100GE signals to the first optical transponder 114 and to route the other two 100GE signals to the third optical transponder 115. The first optical transponder 114 is reconfigured to generate a second optical signal
15 comprising 2 x 100Gbit/s sub-channels from the two received 100GE signals, for example using QPSK modulation. These 2 x 100GB sub-channels are then sent over optical link 116 to the first multiplexer 118. The third optical transponder 115 is activated such that it generates a third optical signal comprising 2 x 100Gbit/s sub-channels from the two received 100GE signals, which are then sent to the first multiplexer 118 via the
20 third optical link 117. The first multiplexer 118 routes all of the 4 x 100Gbit/s sub-channels over the protection optical fibre 140 such that a 400Gbit/s superchannel is transmitted.

The 400Gbit/s superchannel will be received at the second terminal 120 and the second
25 multiplexer 121 will separate the received 4 x 100Gbit/s sub-channels such that the 2 x 100 Gbit/s sub-channels generated by the first optical transponder are routed to the second optical transponder 124 via the second optical link. Similarly, the 2 x 100 Gbit/s sub-channels generated by the third optical transponder 115 are routed to the fourth optical transponder 125 via a fourth optical link 123. The third and fourth optical
30 transponders 124, 125 will demodulate the received 100 Gbit/s sub-channels to recreate the contents of the 100GE signals, which are then switched by second switch 126 to the appropriate client interface 127.

The switch from operating over the main fibre connection 130 (i.e. operating as described
35 above with reference to Figure 4) to the protection fibre protection 140 (i.e. operating as

described above with reference to Figure 5) is likely to have a recovery time of a few seconds, which will lead to a loss of data. This time delay is caused by the need to reconfigure the first optical transponder from a first modulation format to a second modulation format, for example from 16-QAM to QPSK, and to re-route the signal on to the protection path via the ROADM. Once the fault on the main optical fibre connection 130 has been repaired then it is possible to reverse the above process, such that all of the 100GE signals are switched to the first optical transponder; that the first optical transponder generates 2 x 200Gbit/s sub-channels to form a 400Gbit/s superchannel which is then sent over the main fibre connection.

The preceding discussion has focussed on superchannels comprised from identical sub-channels which are contiguously arranged in the frequency spectrum. It should be understood that this is not necessary. Figure 6 shows a schematic depiction of a number of different superchannels used in a flexible grid network. Superchannel 10a comprises four 100Gbit/s sub-channels which are arranged contiguously. Superchannel 10b comprises a single 400Gbit/s sub-channel. Superchannel 10c also comprises four 100Gbit/s sub-channels but the sub-channels are arranged non-contiguously in the frequency spectrum. Superchannel 10d is also arranged non-contiguously but comprises one 200Gbit/s sub-channel and two 100 Gbit/s sub-channels. The exploitation of non-contiguous superchannel formats gives significant flexibility and spectral efficiency benefits in the allocation of capacity, particularly when trying to ensure that equivalent capacities are available on both the main and protection links. This is particularly important when links have been in operation for some time and are well utilised.

The preceding discussion has focussed on a scenario in which the superchannel transmitted over the main fibre connection differs from the superchannel transmitted over the protection fibre channel. This difference may be in terms of the modulation format used in generating the sub-channels (for example 16QAM vs. QPSK), the number of sub-channels forming the superchannel (for example 2 vs. 4) and changing the data rate used for the sub-channels (for example decreasing from 200 Gbit/s to 100 Gbit/s). The baud rate used is another parameter which can be varied in order to achieve a protection superchannel having the same capacity as the main superchannel.

For example, if the main link is 500km long and the capacity requirement is 200Gbit/s then the superchannel will preferably comprise a single 200Gbit/s 16-QAM modulated sub-channel (see Table 1 above). If the protection route has a length of 750km then the protection superchannel will comprise a single 200Gbit/s QPSK modulated sub-channel.

5 Thus, although both the main and the protection superchannels have the same number of sub-channels and the sub-channels both have the same data rate there is a difference in the modulation format used to generate the sub-channels.

Furthermore, if the capacity required for a route is 600Gbit/s then the main superchannel may comprise a 400Gbit/s sub-channel and a 200Gbit/s sub-channel. The protection route may be longer than the main route such that the protection superchannel comprises 3 x 200Gbit/s sub-channels. It will be seen that the protection superchannel uses the same modulation format and also the same data rate as is used in one of the sub-channels used in the main superchannel. However, there is a difference in the

10 number of sub-channels that are used to form the main and the protection superchannels.

In a further example, if the capacity required for a route is 500Gbit/s then the main superchannel may comprise a 400Gbit/s sub-channel and a 100Gbit/s sub-channel. The protection superchannel may comprise a 300Gbit/s sub-channel and a 200Gbit/s sub-channel. It can be seen that the protection superchannel has the same number of sub-channels as the main superchannel but that there is a difference in the data rates of the sub-channels in the main and protection superchannels. This difference in data rates is caused by a change in modulation formats and/or baud rate.

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In a yet further example, if the capacity for a route is 400Gbit/s and the main superchannel comprises 2 x 200Gbit/s sub-channels, each of the sub-channels being generated using QPSK modulation with a baud rate of 50Gbaud, then the protection sub-channel may comprise 4 x 100 Gbit/s sub-channels, each of the sub-channels being generated using QPSK modulation with a baud rate of 25Gbaud. In this case, the modulation format is unchanged but the protection superchannel comprises a greater number of sub-channels than the main superchannel and the sub-channels have a different data rate.

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The preceding discussion has focussed on sending a protection signal which has a different composition of sub-channels from that of the main signal because the additional length of the protection route does not allow an identical signal to be transmitted. It will be understood that the determining factor in whether or not the sub-channels which form the main signal can be transmitted over the second link is whether the optical SNR required by the protection link is at an acceptable level. It may be that the geographical length of the protection link is only slightly longer than that of the main route but if the attenuation of the fibre is slightly higher in the protection route, or if the protection route features more ROADMs, fibre splices, optical connectors, etc. then the loss in the protection link will be significantly greater than that of the main link, which may lead to the optical SNR of the protection link falling below the required level for successful network operation.

The preceding discussion has described the client data being received as 100GE circuits. It will be understood that the client data could be received as electrical signals in other formats, for example 10GE, 40GE, etc. Furthermore, the client data may be received as an optical signal, for example as OTU4, OUT, etc., signals, without departing from the teaching of the present invention.

The invention provides a flexible grid optical network in which a first network terminal is connected to a second network terminal using a main optical fibre connection and a protection optical fibre connection, wherein the protection optical fibre connection is longer than the main optical fibre connection. A first optical signal is sent over the main optical fibre connection and comprises one or more flexible grid sub-channels. In the event of a failure of the main optical fibre connection, a second optical signal is sent over the protection optical fibre connection. If the length of the protection optical fibre connection is greater than the reach of the flexible grid sub-channels that comprise the first optical signal then the second optical signal will comprise a greater number of flexible grid sub-channels: these sub-channels will have lower data rates but a longer reach and will provide the necessary capacity over the protection optical fibre connection.

CLAIMS

- 5 1. A flexible grid optical communications network comprising: a first terminal at a first location; a second terminal at a second location; a first optical fibre connection between the first and the second location; and a second optical fibre connection between the first location and the second location, the second optical fibre connection being longer than the first optical fibre connection wherein, in use, the network is configured to:
- 10 transmit a first optical signal from a first optical transponder over the first optical fibre connection, the first optical signal comprising one or more flexible grid sub-channels, wherein in the event of a failure;
- the first optical transponder is configured to transmit a second optical signal over the second optical fibre connection, the second optical signal comprising one or more
- 15 flexible grid sub-channels;
- a second optical transponder is activated to transmit a third optical signal over the second optical fibre connection, the third optical signal comprising one or more flexible grid sub-channels
- 20 wherein the one or more flexible grid sub-channels which comprise the first optical signal are different from the one or more flexible grid sub-channels which comprise the second optical signal.
2. A flexible grid optical communications network according to Claim 1, wherein the modulation format used to generate the one or more flexible grid sub-channels which
- 25 comprise the first optical signal is different from the modulation format used to generate the one or more flexible grid sub-channels which comprise the second optical signal.
3. A flexible grid optical communications network according to Claim 1 or Claim 2, wherein the data rate of the one or more flexible grid sub-channels which comprise the
- 30 first optical signal is different from the data rate of the one or more flexible grid sub-channels which comprise the second optical signal
4. A flexible grid optical communications network according to Claim 3, wherein the baud rate of the one or more flexible grid sub-channels which comprise the first optical

signal is different from the baud rate of the one or more flexible grid sub-channels which comprise the second optical signal

5. A flexible grid optical communications network according to any of Claims 1 to 4,
5 wherein the second optical signal comprises a greater number of flexible grid sub-channels than the first optical signal.

6. A flexible grid optical communications network according to any of Claims 1 to 5,
10 wherein the network is configured to transmit the second optical signal over the second optical fibre connection in the event of a failure in the first fibre connection.

7. A flexible grid optical communications network according to any of Claims 1 to 6,
15 wherein the one or more flexible grid sub-channels which comprise the third optical signal are different from the one or more flexible grid sub-channels which comprise the second optical signal.

8. A flexible grid optical communications network according to any of Claims 1 to 6,
20 wherein the one or more flexible grid sub-channels which comprise the third optical signal are the same as the one or more flexible grid sub-channels which comprise the second optical signal.

9. A transmitter for use in a flexible grid optical communications network, the
transmitter comprising: a plurality of interfaces, a first optical transponder, a second
optical transponder and an optical multiplexer; the transmitter being configured such that,
25 in use, the first optical transponder receives a first plurality of data signals from the interfaces and modulates the data signals to generate a first optical signal comprising one or more flexible grid sub-channels, the first optical signal being routed by the optical multiplexer over a first optical fibre connection; such that in the event of a failure, the transmitter is configured such that, in use;

30 the first optical transponder receives a second plurality of data signals from the interfaces and modulates the data signals to generate a second optical signal comprising one or more flexible grid sub-channels,

the second optical transponder receives a third plurality of data signals from the
interfaces and modulates the data signals to generate a third optical signal comprising
35 one or more flexible grid sub-channels,

the second optical signal and the third optical signal being routed by the optical multiplexer over a second optical fibre connection, wherein the one or more flexible grid sub-channels which comprise the first optical signal are different from the one or more flexible grid sub-channels which comprise the second optical signal.

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10. A receiver for use in a flexible grid optical communications network, the receiver comprising: an optical multiplexer, a first optical transponder, a second optical transponder and a plurality of interfaces; the receiver being configured such that, in use; the optical multiplexer receives a first optical signal comprising one or more flexible grid sub-channels from a first optical fibre connection and routes the first optical signal to the first optical transponder; the first optical transponder demodulates first optical signal to generate a plurality of data signals, the plurality of data signals being routed to the plurality of interfaces

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wherein in the event of a failure, the first optical multiplexer receives a second optical signal comprising one or more flexible grid sub-channels from a second optical fibre connection and the second optical multiplexer receives a third optical signal comprising one or more flexible grid sub-channels from the second optical fibre connection wherein the one or more flexible grid sub-channels which comprise the first optical signal are different from the one or more flexible grid sub-channels which comprise the second optical signal.

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11. A method of operating a flexible grid optical communications network, the method comprising the steps of;

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a) modulating a plurality of electrical data signals to generate a first optical signal comprising one or more flexible grid sub-channels;

b) transmitting the first optical signal from the first terminal to a second terminal over a first optical fibre connection;

c) demodulating the first optical signal to generate a plurality of electrical data signals; the method being characterised by further comprising the steps of:

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d) in the event of a fault modulating a plurality of electrical data signals to generate a second optical signal comprising one or more flexible grid sub-channels, wherein the one or more flexible grid sub-channels which comprise the first optical signal are different from the one or more flexible grid sub-channels which comprise the second optical signal; and

e) transmitting the second optical signal from the first terminal to the second terminal over a second optical fibre connection.

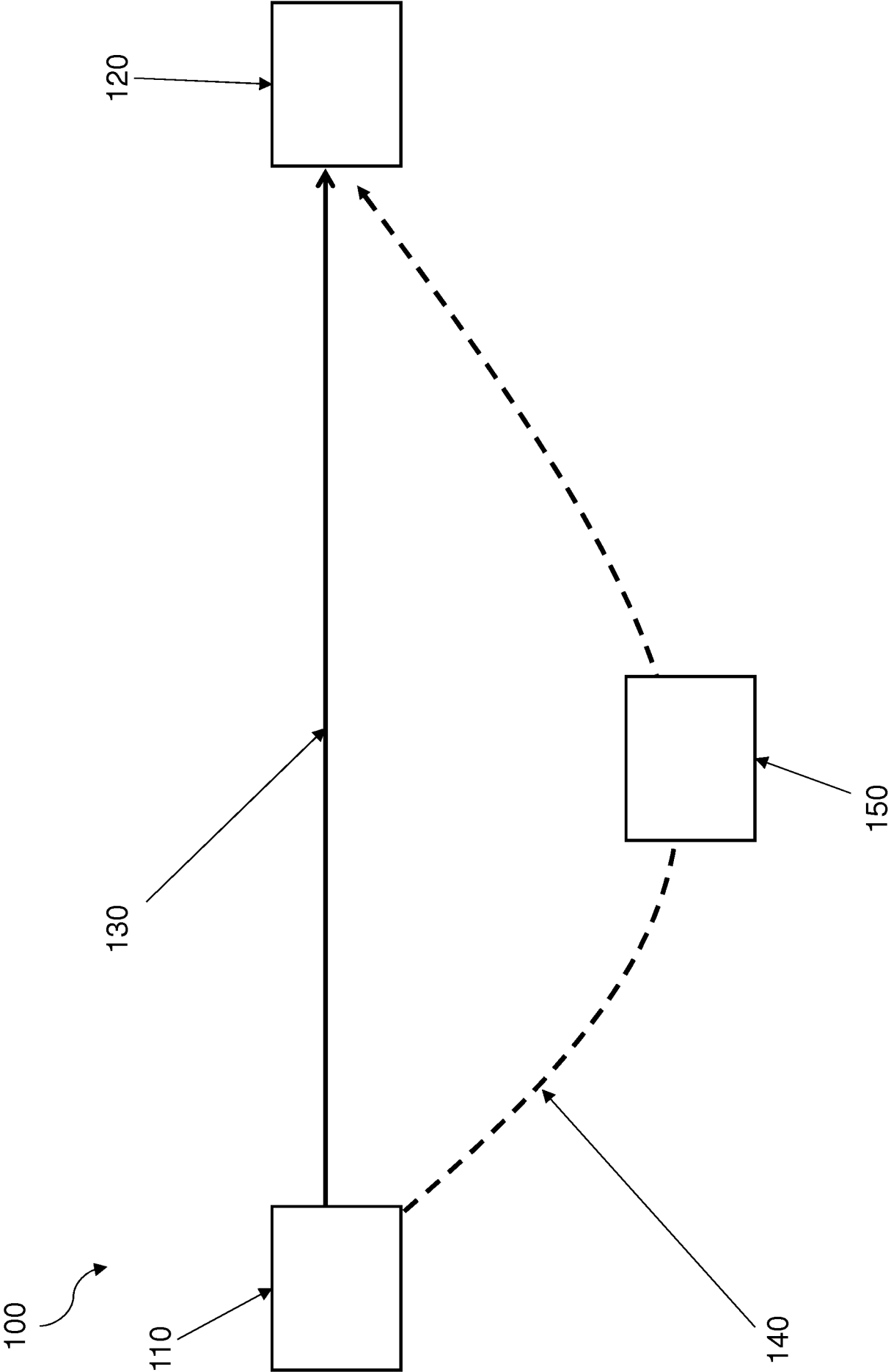


Figure 1

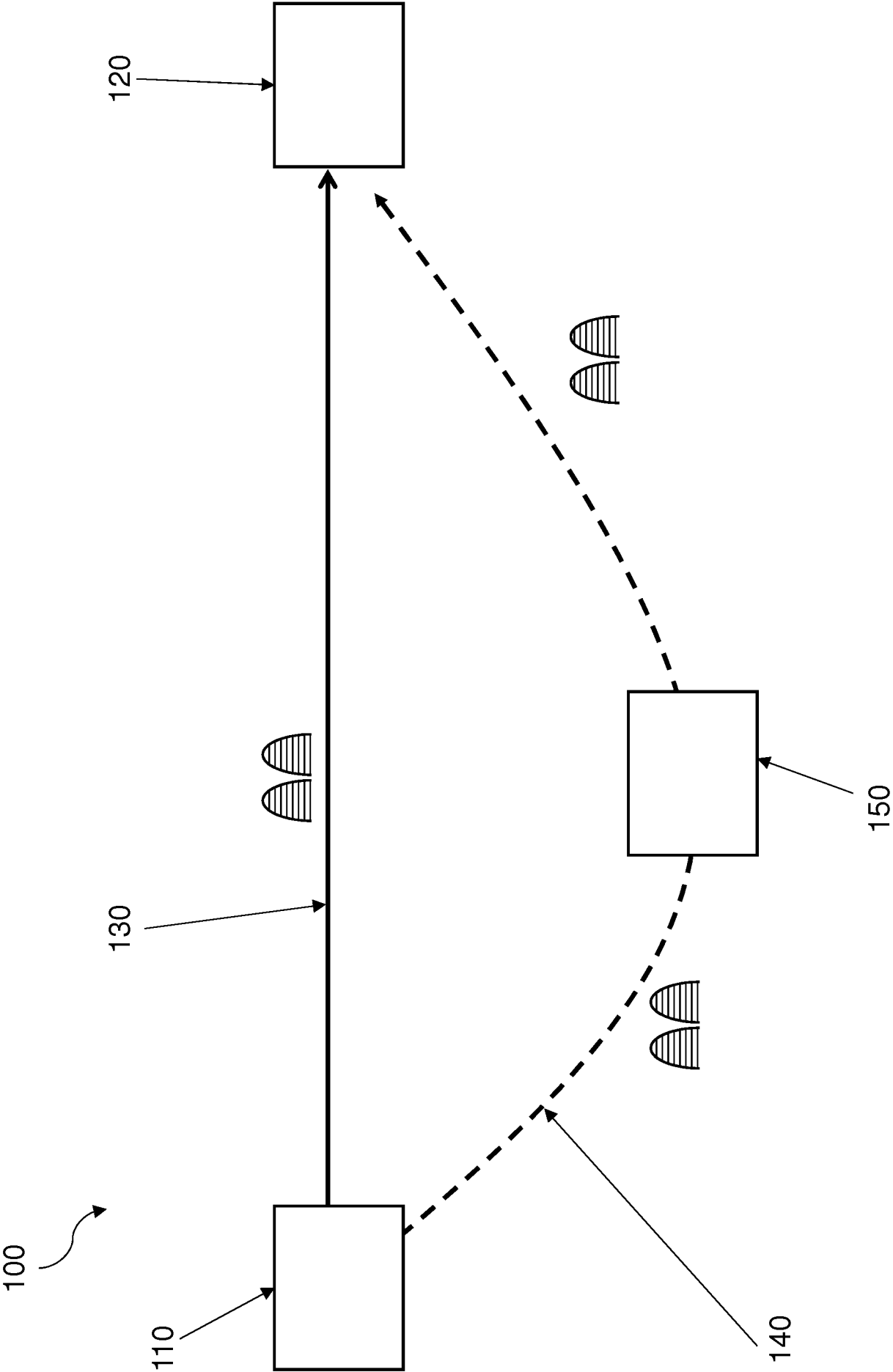


Figure 2

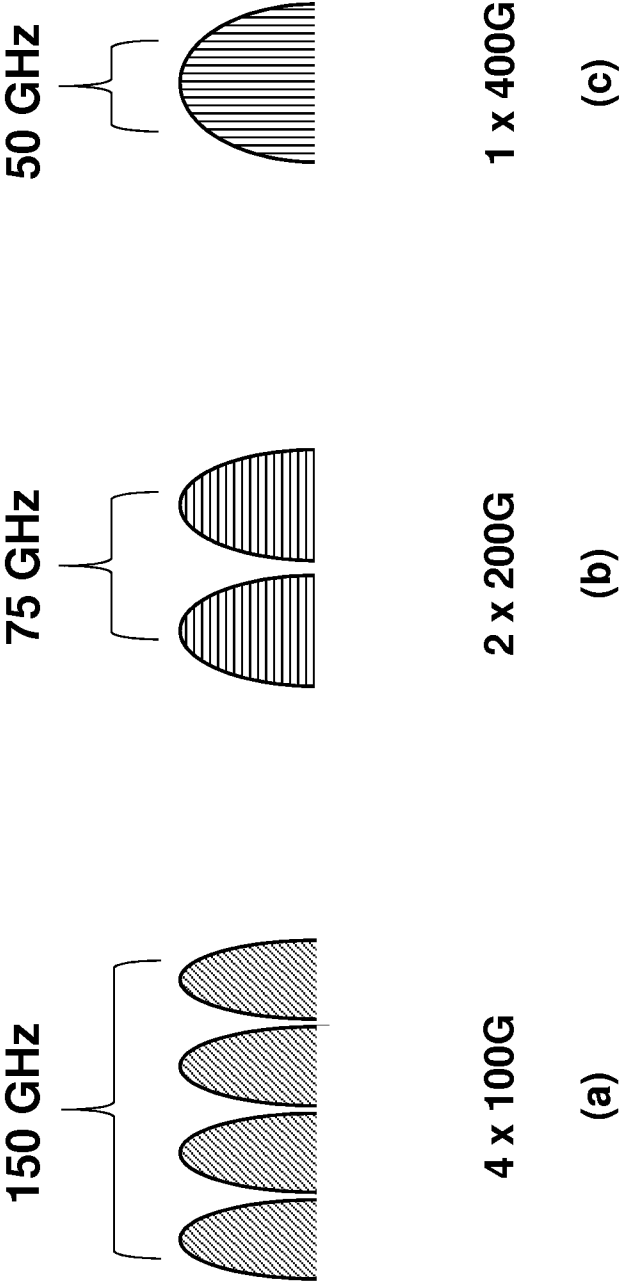


Figure 3

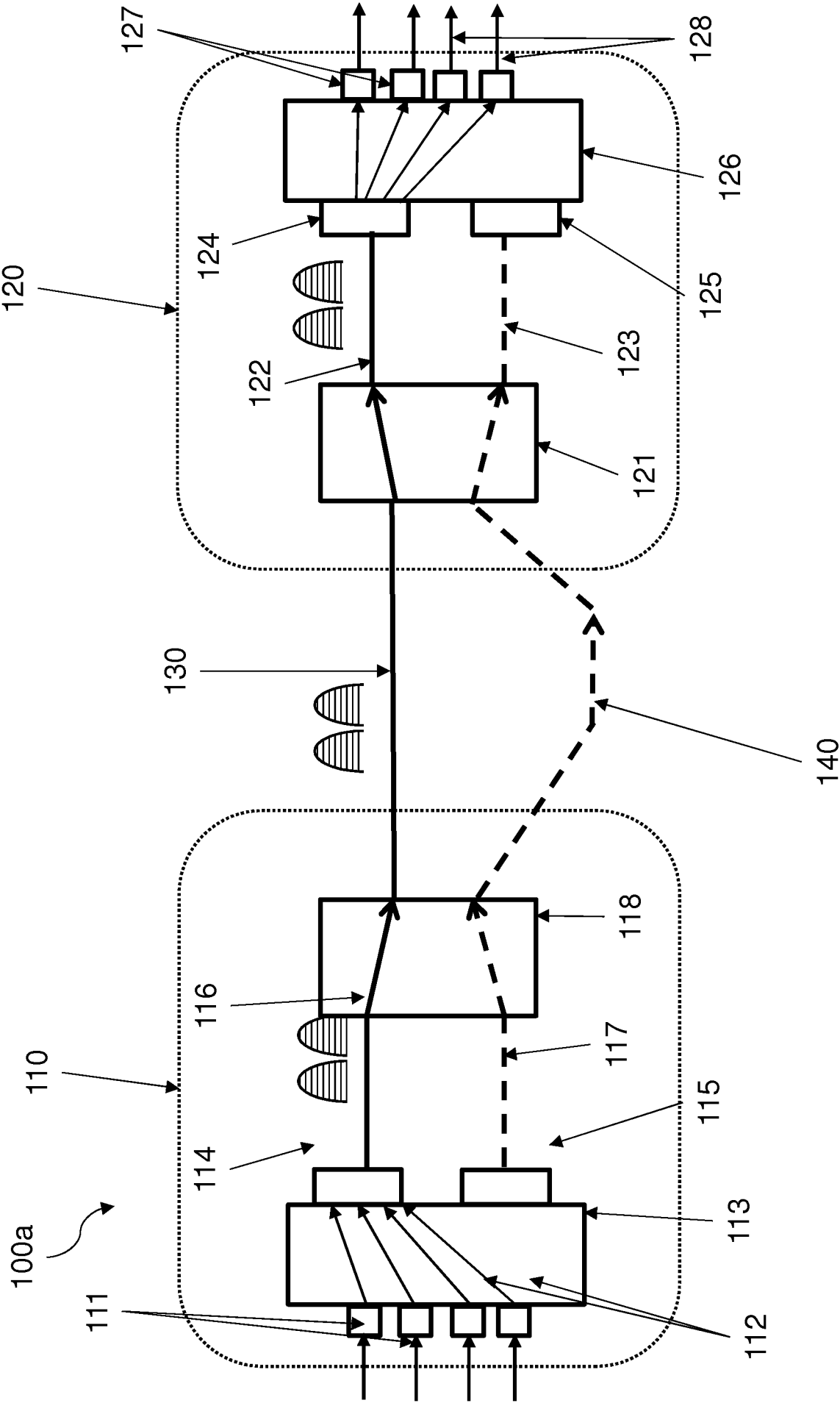


Figure 4

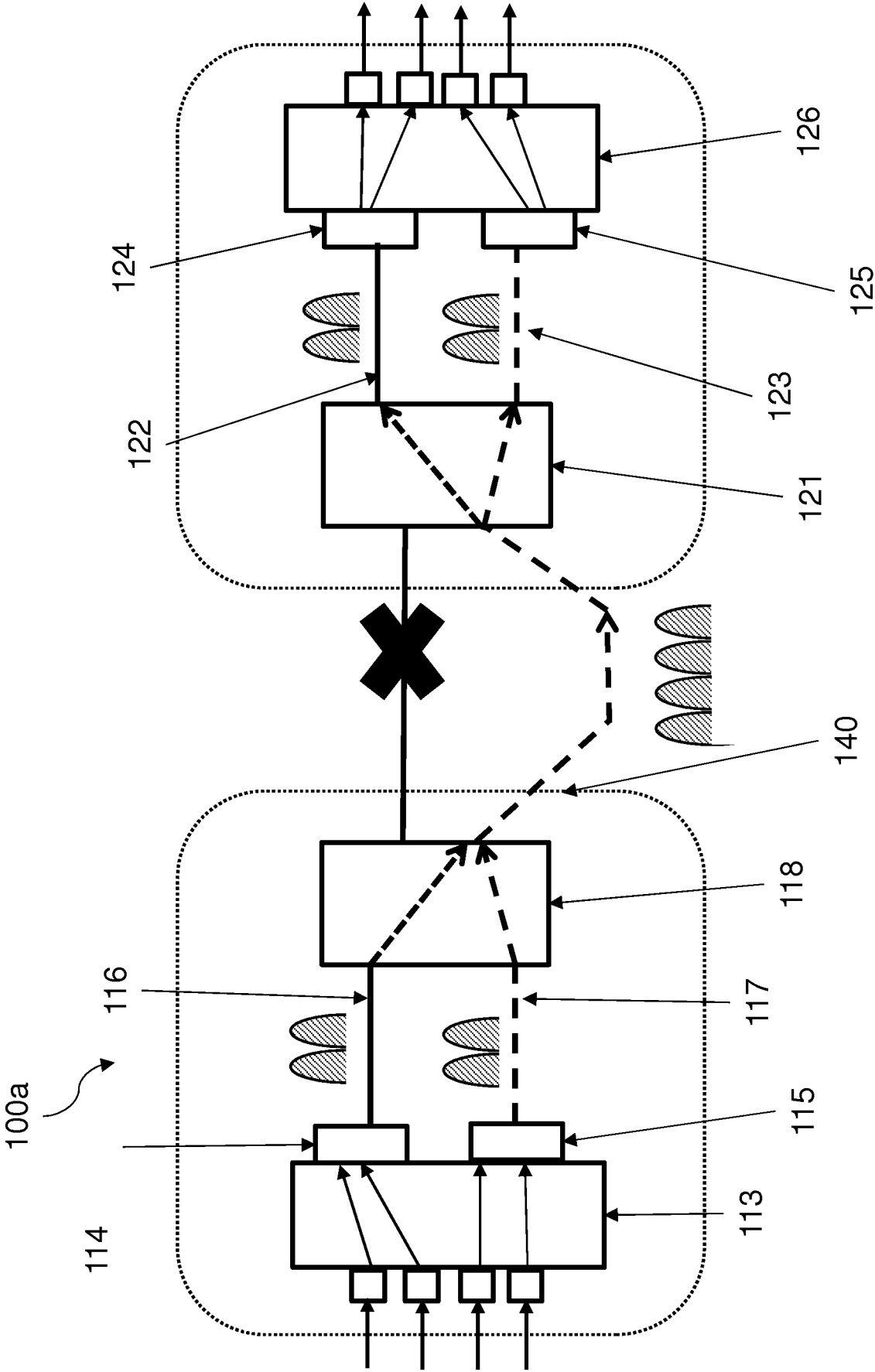


Figure 5

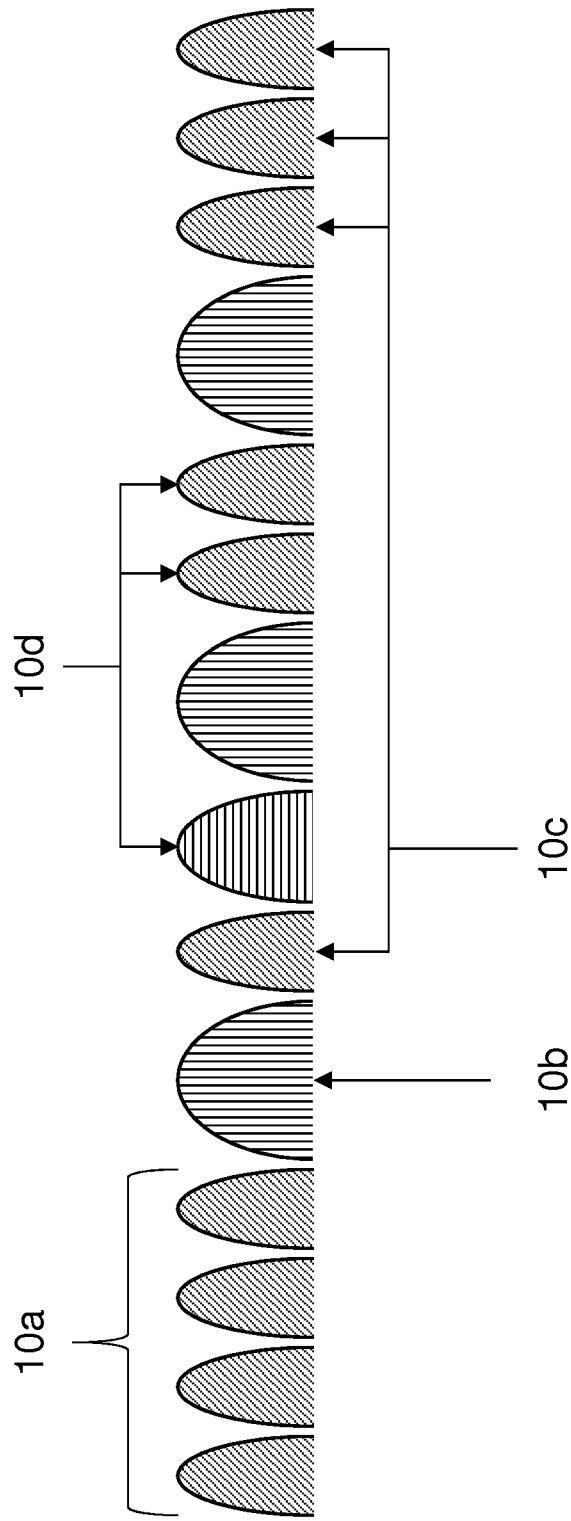


Figure 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/056937

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04J14/02
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04J

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)

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	"Protection in optical transport networks with fixed and flexible grid: Cost and energy efficiency evaluation", 4 September 2013 (2013-09-04), XP055218998, Retrieved from the Internet: URL: http://ac.els-cdn.com/S1573427713000568/1-s2.0-S1573427713000568-main.pdf?_tid=03fd1e68-6d01-11e5-bb35-00000aabb0f27&acdnat=1444228863_23302c5d37999d82080988ae30ac3e57 [retrieved on 2015-10-07] paragraphs [0001], [05.3]; figures 3,4,5,6,7,11 ----- -/-	1-11



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

27 June 2016

Date of mailing of the international search report

06/07/2016

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Authorized officer

Borsier, Celine

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/056937

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EIRA ANTONIO ET AL: "Multi-objective design of survivable flexible-grid DWDM networks", IEEE/OSA JOURNAL OF OPTICAL COMMUNICATIONS AND NETWORKING, IEEE, USA, vol. 6, no. 3, 1 March 2014 (2014-03-01), pages 326-339, XP011544547, ISSN: 1943-0620, DOI: 10.1364/JOCN.6.000326 [retrieved on 2014-04-03] the whole document -----	1-11
A	US 2014/186020 A1 (HANDELMAN DORON [IL]) 3 July 2014 (2014-07-03) paragraph [0129] - paragraph [0132]; figures 4a,4B,5 -----	1,11

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/056937

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		US 2015270893 A1	24-09-2015
