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EP 0936771 A2
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(54) Abstract Title
Optical router with identifying signal superposition and feedback control

(57) Optical routing apparatus comprises input waveguides 2 for receiving optical input signals incorporating identifying signals applied by VOAs 4, and beam steering arrangements 5 for directing the input signals towards selected output waveguides 3. A sample of each output signal is tapped off and supplied to a respective photodetector 7. The electrical output signal of the photodetector 7 is supplied to a processor 8 which detects the presence of the required identifying signal in the sample and provides a feedback signal to a steering controller 9. The steering controller 9 controls the steering arrangements 5 in dependence on the feedback signal so as to direct each input signal towards the selected output as determined by detection of the corresponding identifying signal at that output. Such an arrangement enables a selected one of the inputs of an nxn optical switch, for example, to be placed in optical communication with a selected one of the outputs of the switch with optimal beam steering.

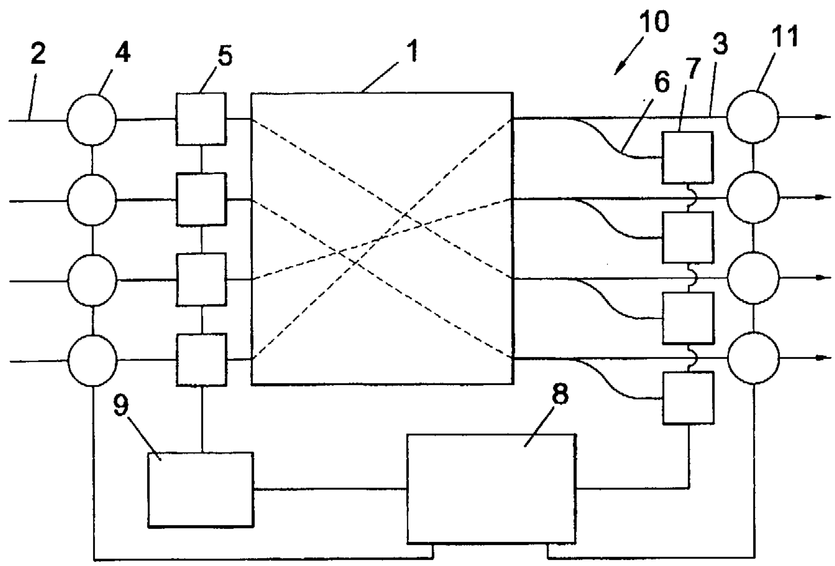

Fig. 1

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

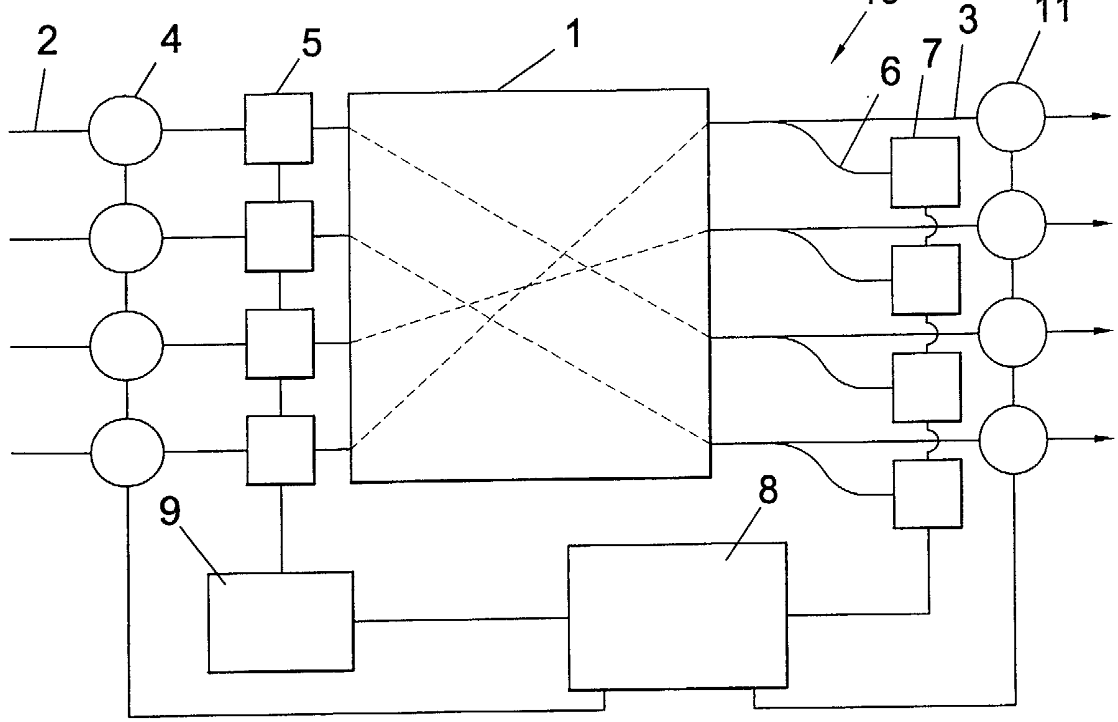
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Fig. 1

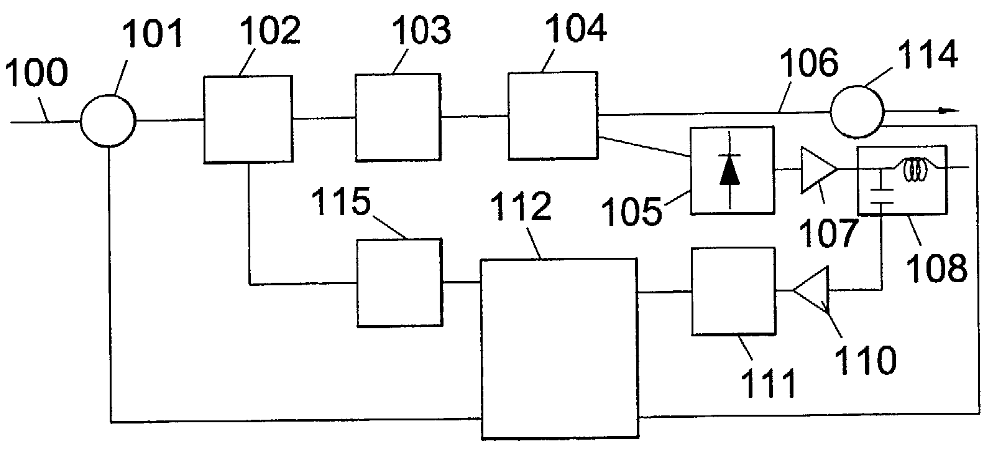
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Fig. 3

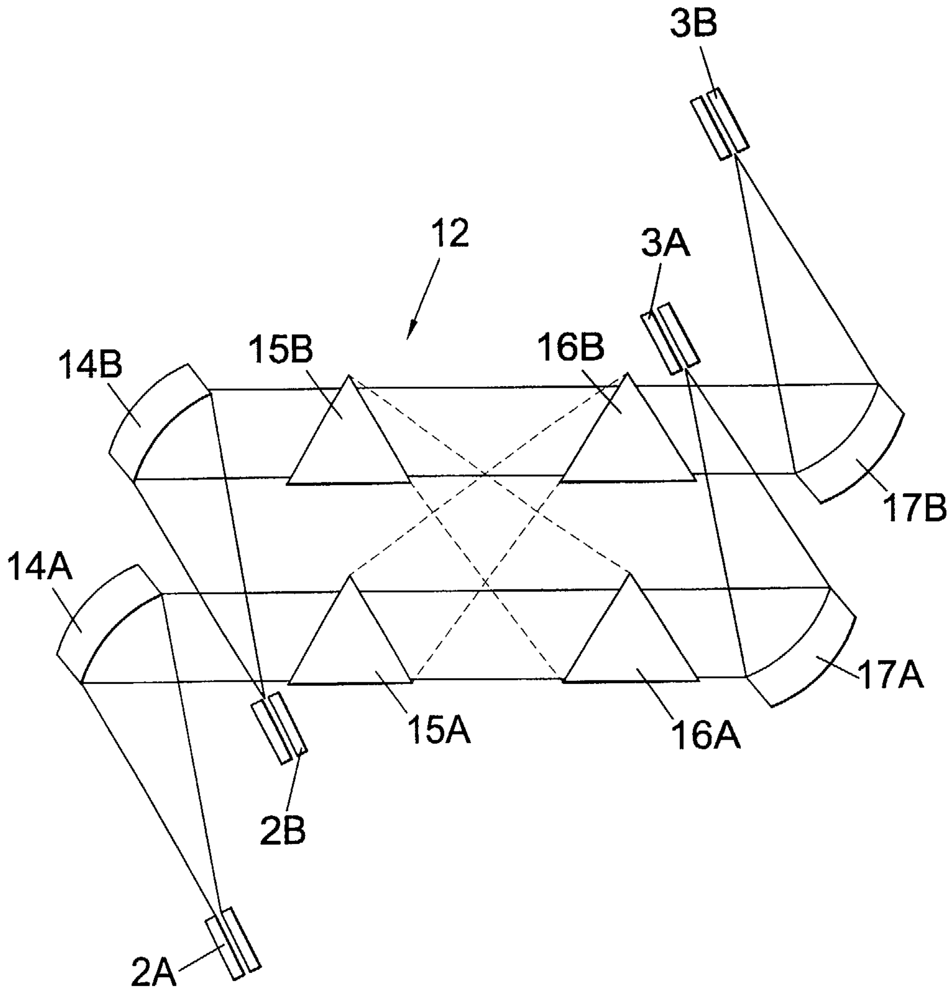

Fig. 2

"Optical Routing Apparatus"

The present invention relates to optical routing apparatus, and is concerned more particularly, but not exclusively, with an arrangement for controlling the routing of signals through an optical nxn switch. However the invention is also applicable to the routing of optical signals through other types of optical device, such as optical routers and interleavers, for example.

Various types of integrated optical switch are known. Most of these make use of interference effects to provide selective communication between one or more light inputs and one or more light inputs. Copending International Patent Application No. PCT/GB01/00880 (P63/64) describes an optical switch comprising a slab waveguide, one or more input waveguides for directing light into the slab waveguide, one or more output waveguides for receiving light from the input waveguides after it has travelled through the output waveguide, and adjustment means for adjusting the refractive index of one or more refracting portions of the slab waveguide through which the light travels so as to refract the light as it passes therethrough, whereby transmission of light between the input and output waveguides can be selectively controlled. The or each refracting portion is preferably triangular so as to function in the manner of a prism. Furthermore the adjustment means is preferably a heater which serves to adjust the refractive index of the refracting portion by heating it.

Furthermore it is known to modulate optical transmission signals with low-frequency tone signals. US 5485299 discloses a supervisory facility for an optical communications system which serves to detect a low-level intensity modulated tone which has previously been added to the transmitted signal and which can be recovered to provide direct measurement of received light level using a WDM/SKEW coupler in a co-pumping or bi-pumping configuration. US 5654816 discloses monitoring apparatus in which the power of each channel is determined after each stage of optical amplification by monitoring the ratio between the power of the added tone and the total output power. The use of such superimposed low-frequency tone signals is also disclosed in US 5745270 and US 5969833.

It is an object of the invention to provide optical routing apparatus which incorporates effective means for controlling the direction of the optical beam bridging the selected input and output waveguides.

According to the present invention there is provided optical routing apparatus comprising input means for receiving at least one optical input signal incorporating an identifying signal, beam steering means for directing the input signal towards one of a plurality of outputs, sampling means for tapping off a sample of the optical output signal received by each of the outputs, detection means for detecting the identifying signal in the sample of each output signal sampled by the sampling means and for providing an electrical output signal, processing means for determining from the electrical output signal the proportion of the identifying signal in the sample of the output signal received by a selected one of the outputs and for providing a feedback signal, and feedback control means for controlling the beam steering means in dependence on the feedback signal received from the processing means so as to direct the input signal towards the selected output.

Such an arrangement enables a selected one of the inputs of an nxn optical switch, for example, to be placed in optical communication with a selected one of the outputs of the switch with optimal beam steering.

Whilst it is possible for the identifying signal to be applied to the input signal at some point upstream of the input means, in most applications the routing apparatus includes identifying means for applying the identifying signal to the input signal, the identifying means preferably comprising some form of modulating means, for example a variable optical attenuator (VOA), for modulating the input signal so as to apply the identifying signal to the input signal. In most practical applications the input means comprises a plurality of inputs for receiving a corresponding plurality of input signals, and the identifying means, such as a respective VOA associated with each input, is arranged to apply a different identifying signal to each input signal.

Whilst the identifying means preferably comprises some type of attenuating means, such as variable optical attenuators, other types of attenuating means may also be used, such as attenuators based on Mach-Zender interferometers (MZIs).

The apparatus can be integrated in a waveguide-based optical chip, such as a silicon-on-insulator optical chip or indium phosphide optical chip for example.

According to another aspect of the invention there is provided an optical device comprising identifying means for applying identifying signals to a series of optical input signals, optical processing means for processing the input signals to produce at least one output signal utilising the identifying signals to differentiate the input signals from one another, and identifying signal cancellation means for cancelling the identifying signals from said at least one output signal.

This aspect of the invention is applicable to a wide range of optical devices, and is not applicable only to optical routing apparatus. The combination of the identifying means and the identifying signal cancellation means, which are preferably fabricated on a common chip, enables a wide range of optical processing steps to be performed, whilst ensuring that the identifying signals are removed at the output of the device so that these identifying signals do not adversely affect operation downstream of the device. It is possible to conceive of a wide range of optical devices, including optical attenuators and optical monitoring devices, in which the application of such tone signals within the device would provide a number of advantages in use.

For example, the processing means may comprise routing means for directing each of said input signals towards a selected one of a plurality of outputs in dependence on the applied identifying signal to produce corresponding output signals. In an alternative embodiment the processing means may comprise input means for receiving a multichannel input signal incorporating at least one identifying signal providing channel identification information, sampling means for tapping off a sample of the input signal from the input means, detection means for detecting the identifying signal in the sample of the input signal obtained by the sampling means and for providing an electrical output signal indicative of the identifying signal, and demultiplexing means for demultiplexing the input signal to produce a plurality of output channel signals.

For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:

Figure 1 is a schematic diagram of an exemplary embodiment of optical routing apparatus in accordance with the invention;

Figure 2 is a schematic diagram of a beam steering arrangement which may be used in the embodiment of Figure 1; and

Figure 3 is a block diagram of a control circuit which may be used in the embodiment of Figure 1.

The embodiment of Figure 1 is in the form of an integrated optical chip 10 incorporating an nxn optical switch 1 having four input waveguides 2 and four output waveguides 3, and respective VOA elements 4 for modulating identifying signals onto input signals applied to the input waveguides 2. Additionally the optical chip 10 incorporates a beam steering arrangement 5 associated with each input waveguide 2 for directing the light inputted along that waveguide to any selected one of the output waveguides 3, and an optical tap device 6 and associated pin diode 7 for tapping off a sample of the optical output signal from each output waveguide 3 and supplying an RF electrical output signal to a feedback processor 8. The processor 8 in turn supplies an electrical control signal to a beam steering controller 9 which controls the beam steering arrangements 5 in dependence on the control signal so as to place each input waveguide 2 in optical communication with the required output waveguide 3. The output signals leaving the device along the output waveguides 3 are passed to VOA elements 11 which cancel the identifying signals applied to these output signals.

Generally the embodiment of Figure 1 can be adapted to have n inputs to the switch for receiving n input signals, with n different tone frequencies being applied to the input signals, and capable of being switched relative to n outputs. The identifying signals are preferably low frequency tone signals, typically in the form of sine waves, although other types of identifying signal, such as a digital identification code in an n-bit repeating pattern, may also be used. The optical tap device 15 can comprise either a tap coupler integrated on the chip or a conventional optical fibre tap.

Figure 2 shows a possible steering arrangement which may be used in such an optical switch having n input waveguides 2A, 2B, ... which can be switched to any one of n output waveguides 3A, 3B, …, Figure 2 showing only two input waveguides and only two output waveguides in order to render the figure easier to read. n is equal to 4 in the embodiment of Figure 1, although it should be appreciated that n may be any number up to a hundred or more.

Referring to Figure 2, the first input waveguide 2A is positioned at the focus of an input parabolic mirror 14A, and the light from the input waveguide 2A is collimated by the mirror 14A and directed towards a first prism portion 15A within a slab waveguide 12. If the refractive index of the first prism portion 15A is the same as the refractive index of the surrounding slab waveguide 12, the light passes through the first prism portion 15A to a second prism portion 16A. If the refractive index of the second prism portion 16A is the same as the refractive index of the surrounding slab waveguide 12, the light passes through the second prism portion 16A to an output parabolic mirror 17A which focuses the light on the output waveguide 3A which is positioned at the focus of the mirror 17A.

Alternatively light from the first input waveguide 2A may be switched to the output waveguide 3A by altering the refractive index of the first prism portion 15A by heating so as to refract the light towards a third prism portion 16B associated with the second output waveguide 3B. The third prism portion 16B is controlled to refract the light to a parabolic mirror 17B which focuses the light on the second output waveguide 3B which is positioned at the focus of the mirror 17B. Thus light from the input waveguide 2A can be directed by the components 14A, 15A, 16B and 17B towards the second output waveguide 3B in this switching mode.

Similarly light may be directed from the second input waveguide 2B by way of the components 14B, 15B, 16B and 17B towards the second output waveguide 3B when the refractive index of the second prism portion 15B is the same as the refractive index of the surrounding slab waveguide 12, or alternatively, in another switching mode in which the refractive index of the second prism portion 15B is altered by heating, light from the second input waveguide 2B may be directed by way of the components 14B, 15B, 16A and 17A towards the first output waveguide 3A. Each of the prism portions 15A, 15B ... is provided with a steering heater deposited on the upper surface of the slab waveguide, for example in the form of a series of resistance heating elements formed by narrow lines of conductive material distributed over the prism portion, for effecting the required change in the refractive index of the prism portion to steer the light beam towards the required output waveguide.

In the above described embodiment a closed loop feedback processor is used to control the beam steering controller, and Figure 3 is a block diagram of a possible control circuit which may be used to effect such control. One optical path through the apparatus is shown in order to simplify the diagram, although it will be understood that in practice other optical paths and their associated control circuits will be provided.

Referring to Figure 3, an optical signal is applied to an input waveguide 100 and passes through a VOA 101 which is supplied with electrical power having an AC component at a particular frequency f_i. The frequency f_i corresponds to the identifying tone frequency referred to above. Additionally a DC component may be utilised to set the average attenuation of the optical signal. The AC component is used for subsequent control and signal processing as already discussed. The optical signal is then supplied to one input of the nxn optical switch 103. The corresponding steering arrangement for guiding the light beam towards a selected output waveguide 106 is shown at 102. An optical tap device 104 diverts a small proportion of the light out of the main output waveguide 106 to a photodetector 105. The resulting detection currents outputted by the photodetector 105 are converted to voltage by an amplifier 107, and a demodulator 108 separates the DC average photocurrent from the AC photocurrent. The AC signal from the demodulator 108 incorporating the applied tone frequency is supplied to the feedback control circuitry.

The optical signal leaves the device through the output waveguide 106, and a VOA 114 is provided to apply a tone frequency f_i of opposite polarity so as to cancel the tone frequency applied to the optical signal, with the result that further processing of the optical signal downstream of the device is not adversely affected by the presence of such a tone frequency. The purpose of the feedback control circuitry is to control the guiding of the light beam through the switch 103 in order to ensure that the light beam is accurately guided towards the required output waveguide to minimise light losses, and so as to allow for accurate switching of the light beam between output waveguides when required.

The signal from the demodulator 108 is passed through a further amplifier 110 and is then digitised by an analogue-to-digital converter 111 to supply a digital byte output signal proportional to the analogue signal outputted by the amplifier 110 at regular intervals, typically 100k Samples/s, to a central control processor 112. The processor 112 receives a waveform of samples and operates on this waveform to measure the amplitude of the frequency component at the identifying tone frequency f_i. This can be extracted by Fast Fourier Transform (FFT) or other methods from the waveform without detriment to the signal quality provided that the frequency component to be extracted is of sufficient amplitude, even in the presence of noise and other tones to an extent determined by the control parameters of the device.

Generally the feedback control is effected so as to ensure that the required light beam is received at the relevant output by detection of the corresponding identifying tone frequency f_i , and so as to maximise the total light received at thatoutput so as to ensure that the light beam is directed as accurately as possible towards the required output waveguide. Optionally further control measures may be adopted to speed up the steering settling time and prevent unnecessary hunting of the light beam relative to the output position. For example, the processor may be adapted to determine the signal strength and level of the identifying frequency f_i in the sample of the output signal received by the selected output relative to the level of the other identifying frequencies in that sample and also the signal strengths and levels of the identifying frequencies in the samples of all the output signals received. In this way it is possible to estimate the level of crosstalk interference in the sample of the output signal received and to compensate for such crosstalk, so that the steering control settles on the final position of the beam with the minimum number of output samples having to be taken over the shortest possible time. Alternatively the processor may be adapted to compare the signal strength and level of the identifying frequency f_i in the sample of the output signal received by the selected output to values in a lookup table providing an indication of the signal strength and the level of the identifying frequency f_i applied to the input signal. The processor may also be adapted control the level of the identifying frequency f_i applied to the input signal to provide a required level of the identifying frequency f_i at the output.

The current supply to the heater of the beam steering arrangement 102 is adjusted by an adjustment circuit 115 in dependence on output signals received from the processor 112 so as to ensure that each light beam is guided along a direction which ensures detection of a corresponding tone frequency of maximum amplitude on the appropriate output waveguide 106. The processor 112 also supplies electrical control signals to the VOA 101 and the VOA 114 so as to match the frequency of the identifying tone signal initially applied by the VOA 101 and the frequency of the cancelling tone signal subsequently applied by the VOA 114.

In an optional development the VOA 114 is controllable by the processor 112, in response to detection signals outputted by the photodetector 105, to compensate for the effects of time varying components of the input signals and/or to compensate for the effects of polarisation dependent losses (PDL). In a further optional development the VOA 114 may be controlled to simultaneously (i) cancel the tone signal and/or compensate for other signal features and (ii) apply a new tone signal to the output signal for use in subsequent processing of the signal.

The processor 112 determines, from the signal strengths of the sampled output signals and the associated tone frequencies, the guided positions of the light beams relative to the output waveguides, and supplies control signals to the steering controller to effect control of each steering arrangement to ensure that each light beam is accurately directed towards the required output waveguide by heating the prism portions with the heaters where necessary. Such determination is carried out after sampling the outputs over a sampling window, and this procedure is preferably repeated over several sampling windows before any adjustment to the steering is effected. To deal with any likely drift which may occur with time after the initial steering directions have been set, the processor preferably includes a dither sub-routine in which a displacement signal is applied to the steering controller to displace the light beam from the output waveguide by a small amount, and in which the sampled output signals are then monitored to determine whether this has resulted in an increase or a decrease in the signal strength of the corresponding output signal. Depending on the result of this comparison, the steering controller is actuated to cause the corresponding steering arrangement to guide the beam to a position in which it is accurately directed towards the selected output waveguide. This iterative control process may be continued for as many cycles as is necessary to obtain the required accuracy of control.

In practice the current supplied to the beam steering arrangement 102 may be caused to vary at a slow frequency f_{i2}, or may be first increased and then decreased in small increments, so as to allow the iterative control process to hunt for the steering position providing a maximum value of the detected tone frequency f_i.

Variations of this control process are included within the scope of this invention. For example, feedback control may be applied in each duty cycle with the iterative control process being maintained for as long as the same light routing path is to be maintained. Only when switching to a new routing path is required is the iterative control process discontinued to enable the steering controller to guide the beam to the required new position after which the iterative feedback process is reapplied to direct the beam towards the new position with the required accuracy.

It will be appreciated that the inputs of the switch are identified by sinusoidal tones of different frequencies, and the control of the steering arrangements associated with these inputs can be effected concurrently by use of such a control procedure utilising the corresponding photodetector output signals.

CLAIMS:

1. Optical routing apparatus comprising input means for receiving at least one optical input signal incorporating an identifying signal, beam steering means for directing the input signal towards one of a plurality of outputs, sampling means for tapping off a sample of the optical output signal received by each of the outputs, detection means for detecting the identifying signal in the sample of each output signal sampled by the sampling means and for providing an electrical output signal, processing means for determining from the electrical output signal the presence of the identifying signal in the sample of the output signal received by a selected one of the outputs and for providing a feedback signal, and feedback control means for controlling the beam steering means in dependence on the feedback signal received from the processing means so as to direct the input signal towards the selected output.

2. Apparatus according to claim 1, further comprising identifying means for applying the identifying signal to the input signal.

3. Apparatus according to claim 2, wherein the identifying means comprises modulating means for modulating the input signal so as to apply the identifying signal to the input signal.

4. Apparatus according to claim 3, wherein the modulating means comprises a variable optical attenuator (VOA).

5. Apparatus according to claim 3 or 4, wherein the identifying means is adapted to apply an identifying signal in the form of a pilot tone to said input signal.

6. Apparatus according to claim 3, 4 or 5, wherein the feedback control means is adapted to control the modulation applied by the modulating means to the input signal.

7. Apparatus according to any preceding claim, wherein the feedback control means is adapted to periodically actuate the beam steering means so as to change the

direction of the input signal relative to the selected output, and to subsequently control the beam steering means in dependence on the resulting feedback signal received from the processing means so as to direct the input signal towards the selected output.

8. Apparatus according to any preceding claim, wherein the processing means is adapted to monitor the signal strength of the sample of the output signal received by the selected output and to effect feedback control in such a manner as to maximise the detected signal strength.

9. Apparatus according to any preceding claim, wherein the input means comprises a plurality of inputs for receiving a corresponding plurality of input signals, and the identifying means is arranged to apply a different identifying signal to each input signal.

10. Apparatus according to any preceding claim, wherein the sampling means incorporates, for each output, an optical tap device having a main waveguide for conducting the main part of the corresponding optical output signal for ongoing transmission and a tap waveguide for tapping off a relatively small part of the optical output signal.

11. Apparatus according to any preceding claim, wherein the detection means incorporates a pin diode.

12. Apparatus according to any preceding claim, which is formed on a semiconductor optical chip, for example by silicon-on-insulator (SOI) optical chip technology.

13. Apparatus according to any preceding claim, further comprising identifying signal compensation means for cancelling the identifying signal in each output signal.

14. Apparatus according to any preceding claim, further comprising input signal compensation means for compensating for the effects of input signal variations.

15. Apparatus according to any preceding claim 13 or 14, wherein the compensation means comprises modulating means for modulating each output signal so as to provide the required signal compensation.

16. Apparatus according to claim 15, wherein the modulating means is adapted to simultaneously apply a further identifying signal to the output signal.

17. Optical routing apparatus substantially as hereinbefore described with reference to the accompanying drawings.

18. An optical device comprising identifying means for applying identifying signals to a series of optical input signals, optical processing means for processing the input signals to produce at least one output signal utilising the identifying signals to differentiate the input signals from one another, and identifying signal cancellation means for cancelling the identifying signals from said at least one output signal.

19. A device according to claim 18, wherein electrical control means are provided for controlling said identifying means and said identifying signal cancellation means to ensure synchronisation of the operation of said identifying means and said identifying signal cancellation means.

20. A device according to claim 18 or 19, wherein said processing means comprises routing means for directing each of said input signals towards a selected one of a plurality of outputs in dependence on the applied identifying signal to produce corresponding output signals.

21. A device according to claim 18 or 19, wherein said processing means comprises input means for receiving a multichannel input signal incorporating at least one identifying signal providing channel identification information, sampling means for tapping off a sample of the input signal from the input means, detection means for detecting the identifying signal in the sample of the input signal obtained by the sampling means and for providing an electrical output signal indicative of the

identifying signal, and demultiplexing means for demultiplexing the input signal to produce a plurality of output channel signals.

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Application No: GB 0119620.3
Claims searched: 1-16

Examiner: Stephen Brown
Date of search: 10 April 2002

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): H4B (BN)

Int Cl (Ed.7): H04Q: 11 /00; G02B: 26/02.

Other: Online: WPI, EPODOC, JAPIO.

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	EP 0 798 882 A2	(Lucent) See especially the abstract.	-
A	WO 01/53875 A1	(Optical Switch) See especially the abstract and figure 6.	-
A	WO 01/50176 A1	(Dames) See especially the abstract and figure 11a.	-
A	US 5 377 182	(US Army) See especially the abstract and figure 3.	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		

Application No: GB 0119620.3
Claims searched: 18-21

Examiner: Stephen Brown
Date of search: 14 May 2002

Patents Act 1977
Further Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): H4B (BN)

Int Cl (Ed.7): H04Q: 11 /00; G02B: 26/02.

Other: Online: WPI, EPODOC, JAPIO.

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	EP 0 936 771 A2	(Lucent) See especially the abstract and paragraphs 0002 & 0007 to 0009.	18, 20 & 21
A	EP 0 798 882 A2	(Lucent) See especially the abstract.	-
A	US 5 377 182	(US Army) See especially the abstract and figure 3.	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		