(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
27 June 2024 (27.06.2024)

WIPO | PCT

(10) International Publication Number
WO 2024/134137 A1

(51) International Patent Classification:
G02B 6/35 (2006.01) *G02B 6/293* (2006.01)
H04Q 11/00 (2006.01)

(21) International Application Number:
PCT/GB2023/053170

(22) International Filing Date:
08 December 2023 (08.12.2023)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2219364.3 21 December 2022 (21.12.2022) GB

(71) Applicant: **HUBER+SUHNER POLATIS LIMITED** [GB/GB]; 332-2 Cambridge Science Park, Milton Road, Cambridge, Cambridgeshire CB4 0WN (GB).

(72) Inventors: **MONTGOMERY, David James**; c/o HUBER+SUHNER POLATIS LIMITED, 332-2 Cambridge Science Park, Milton Road, Cambridge, Cambridgeshire CB4 0WN (GB). **WILKINSON, Peter John**; c/o HUBER+SUHNER POLATIS LIMITED, 332-2 Cambridge Science Park, Milton Road, Cambridge, Cambridgeshire CB4 0WN (GB).

(74) Agent: **SLINGSBY PARTNERS LLP**; 1 Kingsway, London, Greater London WC2B 6AN (GB).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO,

(54) Title: OPTICAL SWITCH UTILISING ATTENUATION

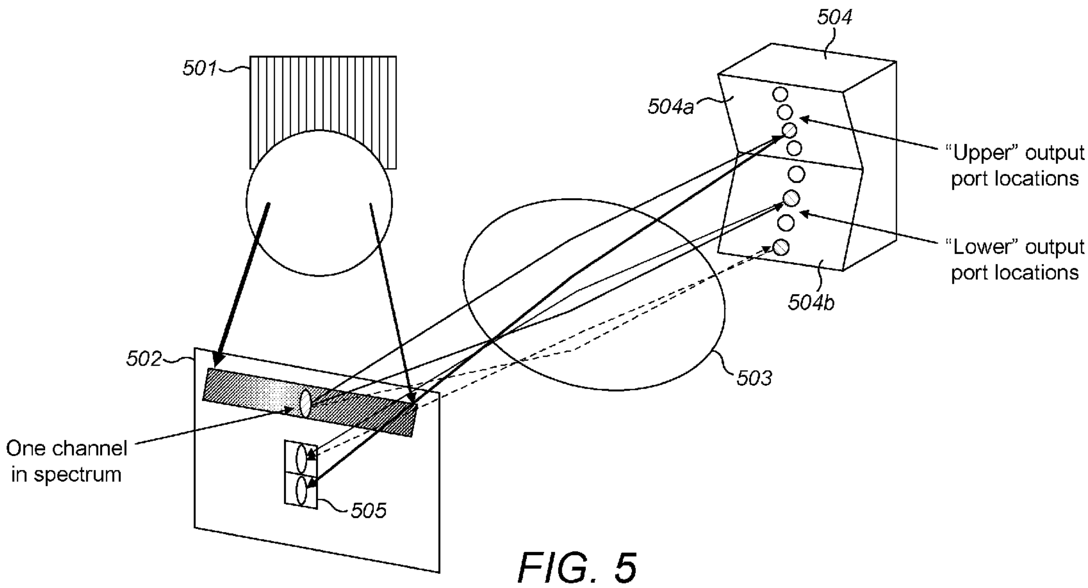

FIG. 5

(57) Abstract: An optical switch comprising an input port and a set of output ports, each input and output port configured to transport an optical signal having at least one component frequency channel. The switch comprises a programmable deflection plane configured to deflect beams of spatially separated frequency channels incident on it from the input port to form a deflected array of beams, and a programmable attenuation plane configured to attenuate beams of spatially separated frequency channels incident on it towards the set of output ports as an attenuated array of beams. The switch also comprises an optical assembly positioned in the optical path between the programmable deflection plane and the programmable attenuation plane, configured to image each component frequency channel of the deflected array of beams to at least two unique positions on the programmable attenuation plane. The at least two unique positions are independent of the deflection applied by the programmable deflection plane.

WO 2024/134137 A1

[Continued on next page]

RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

OPTICAL SWITCH UTILISING ATTENUATION

BACKGROUND

Optical switches are used in optical telecommunication systems to route optical signals through networks. As optical telecommunications systems have become more popular, the quantity of data carried through the networks has increased, putting greater capacity demands on the switches. It is known to use wavelength division multiplexed (WDM) signals to enable each optical fibre in the network to carry multiple data channels, those data channels separated by unique central frequencies and having non-overlapping bandwidths. Wavelength selective switches (WSSs) are used to route WDM signals through the network.

Figure 1 illustrates schematically a known MxN WSS 100. The MxN switch comprises N input ports 101 and M output ports 102. Each port carries multiple data channels. A bank of 1xM WSSs 103 splits the multiplexed signal from each input port into its separate frequency channels. The demultiplexed data channels are then directed to the M output ports. A bank of Nx1 WSSs 104 at the output combines the data channels into a set of multiplexed signals for output via the output ports 102. In this way, the MxN switch is able to redirect any data channel from an input port to any data channel in an output port, subject to the condition that two channels with overlapping frequencies are not routed to the same output port.

Figure 2 illustrates schematically a known switch referred to as an add-drop WSS 200. Add-drop WSS 200 is a special type of WSS in which N input ports 201 are connected to K output ports 202, where K>N. A bank of 1xK WSSs 203 splits the multiplexed signal from each input port into its separate frequency channels. The demultiplexed data channels are then directed to K space switches 204. Each space switch 204 can accept data from any of the 1xK WSSs but can only output data from one of the input ports at a time. The output of each space switch 204 is then output from an output port 202, otherwise known as a drop port. Space switches are simpler to implement that Nx1 switches, and hence the add-drop WSS of figure 2 is preferable to the MxN WSS of figure 1. This is particularly the case when K is much bigger than N, and the data density in the K output ports is much lower than in the N input ports.

Both the WSSs of figure 1 and 2 are reversible. For example, edge reconfigurable optical add-drop multiplexers (ROADM) are used for transferring optical data between core dense wavelength divisional multiplexing (DWDM) and more coarse wavelength division multiplexing (CWDM). An add-drop WSS of the type in figure 2 is used in the "dropping" direction shown in figure 2 to transfer from DWDM to CWDM, and in the reverse "adding" direction (from K drop input ports to N output ports) to transfer from CWDM to DWDM.

Edge ROADMs are related adWSS and MxN switches are often made up of 1xN switches, typically multiple 1xN switches in a single module. Figure 3 illustrates a 1xN switch 300. It has a single input port 301. A 1xN WSS 303 splits the multiplexed signal from the input port into its separate frequency channels. The demultiplexed data channels are directed to N output ports 302. A quad 1xN switch can be used to make a 4x4 optical switch or a 4 degree ROADM. A dual 1xN switch can be used to make an adWSS switch.

The switches shown in figures 1, 2 and 3 are typically implemented by electronic conversion, for example by absorbing light and emitting it again in the desired format. However, electronic conversion has high power requirements and introduces a significant lag in the transmission through the switch. Purely optical methods are preferred because they require much less power than electronic implementations and also enable faster transmission.

However, purely optical methods suffer from crosstalk, where light from one channel propagates to another channel where it is unwanted. Crosstalk can be caused by poor alignment and quality of optics. However, it is also a manifestation of the diffraction of light implemented in the switch. Figure 4 illustrates the outport ports of a typical 1xN system having a one dimensional steering system in which positive and negative deflections are used. The central port 401 is a single input optical fibre. The ports above and below this central port are output ports. The intended output port is port 402. The output port 402 is selected using a diffraction grating to split the light from the input port into a frequency spectrum, and the +1 diffraction order then being deflected by a programmable deflection plane (such as a spatial light modulator (SLM) plane) towards the output port 402. However, other diffraction orders exist. The -1 diffraction order aligns with a different output port 403. This is unwanted crosstalk. Similarly, the -2 diffraction order aligns with a further output port 404. Again, this is unwanted crosstalk.

US 7,826,697, US 2021/0278596 and US 9,429,712 all describe methods of reducing crosstalk by utilising an uneven distribution of output ports. Since the diffraction orders are evenly spaced, distributing the output ports unevenly can reduce the amount of unwanted light reaching each output port. However, distributing the output ports unevenly causes switching complexity and loss of efficiency.

US 10,257,594 describes a method of reducing crosstalk in an optical switch by attenuating the output port images for each individual channel individually at an attenuation SLM plane that lies in the output conjugate optical plane. A large area of the SLM plane is required to perform this attenuation since each port is imaged separately onto the SLM plane.

There is a need for a more compact WSS with improved attenuation of crosstalk achieved by better utilisation of the available area of its constituent SLM planes.

SUMMARY OF THE INVENTION

According to an aspect of the invention, there is provided an optical switch comprising: an input port configured to transport an optical signal having at least one component frequency channel; a set of output ports, each output port configured to transport an optical signal having at least one component frequency channel; a programmable deflection plane configured to deflect beams of spatially separated frequency channels incident on it from the input port to form a deflected array of beams; a programmable attenuation plane configured to attenuate beams of spatially separated frequency channels incident on it towards the set of output ports as an attenuated array of beams; and an optical assembly positioned in the optical path between the programmable deflection plane and the programmable attenuation plane, the optical assembly configured to image each component frequency channel of the deflected array of beams to at least two unique positions on the programmable attenuation plane, those at least two unique positions being independent of the deflection applied by the programmable deflection plane.

The optical assembly may be configured to, for each component frequency channel of the deflected array of beams, image positive diffraction orders onto a first of the at least two unique positions on the programmable attenuation plane, and image negative diffraction orders onto a second of the at least two unique positions on the programmable attenuation plane.

The optical assembly may be at least partially located at the Fourier conjugate plane of the programmable deflection plane, so as to cause a Fourier conjugate image of the programmable deflection plane to be formed on an optical plane of the optical assembly that has a spatial distribution dependent on the deflection applied by the programmable deflection plane.

The optical assembly may be configured to alter the propagation angles of the deflected array of beams incident on it as a function of spatial position in the plane normal to the propagation and dispersion planes.

The optical assembly may be configured to form a Fourier conjugate image of the optical plane of the optical assembly on the programmable attenuation plane.

The at least two unique image positions of each component frequency channel of the deflected array of beams may be separated normal to the dispersion plane in a spatial distribution dependent on the altered propagation angles.

The optical assembly may comprise a faceted mirror.

The optical assembly may comprise an optical microelectromechanical system (MEMS) mirror layer.

The optical assembly may comprise a polarisation element configured to polarise or retard the phase of each component frequency channel of the deflected array of beams in one polarisation axis.

The one polarisation axis may be at 45° to the extraordinary axis of the programmable attenuation plane.

The polarisation element may be a half waveplate.

The optical switch may further comprise a further optical assembly, the further optical assembly at least partially located at the Fourier conjugate plane of the programmable attenuation plane, so as to cause a Fourier conjugate image of the programmable attenuation plane to be formed on an optical plane of the further optical assembly.

The further optical assembly may be configured to alter the propagation angles of the attenuated array of beams incident on it as a function of spatial position in the plane normal to the propagation and dispersion planes, the further optical assembly applying an inverse optical deflection to the optical assembly.

The further optical assembly may comprise a further faceted mirror.

The further optical assembly may comprise a further optical microelectromechanical system (MEMS) mirror layer.

The further optical assembly may comprise a polarisation selection element that propagates only one polarisation phase of the attenuated array of beams towards the set of output ports.

The polarisation selection element may be a 45° sample polariser.

The programmable attenuation plane may be configured to independently control the intensity of optical beams incident at different positions on it.

The programmable attenuation plane may be configured to apply a programmable retardation to the one polarisation axis of the spatially separated frequency channels incident on it.

The programmable deflection plane and the programmable attenuation plane may be different portions of the same spatial light modulator (SLM) device.

The programmable deflection plane and the programmable attenuation plane may be different portions of the same SLM plane.

The optical switch may further comprise a demultiplexer in the optical path between the input port and the programmable deflection plane, the demultiplexer configured to spatially separate the component frequency channels of the optical signal in a dispersion direction normal to the propagation direction of the optical signal.

The optical switch may further comprise a multiplexer in the optical path between the programmable attenuation plane and the set of output ports, the multiplexer configured to combine the spatially separated frequency channels of the attenuated array of beams from the programmable attenuation plane.

The optical switch may further comprise: further input ports, the input port and further input ports forming a set of input ports, each input port of the set of input ports configured to transport an optical signal having at least one component frequency channel; and a gap optic located at the demultiplexer or in the optical path between the demultiplexer and the programmable deflection plane where a coincident image of the optical signals from the set of input ports is formed, the gap optic configured to: (i) propagate the optical signals to the programmable deflection plane; and (ii) deflect the deflected array of beams incident on the gap optic.

The optical switch may further comprise a space optic located in the optical path between the programmable deflection plane and the programmable attenuation plane, the space optic configured to increase the spacing between the spatially separated frequency channels of the deflected array of beams whilst maintaining the beam size of the deflected array of beams.

BRIEF DESCRIPTION OF THE FIGURES

The present invention will now be described by way of example with reference to the accompanying drawings. In the drawings:

Figure 1 illustrates a known MxN WSS;

Figure 2 illustrates a known add-drop WSS;

Figure 3 illustrates a known 1xN WSS;

Figure 4 illustrates crosstalk caused by diffraction in a linear sequence of output ports;

Figure 5 illustrates an optical assembly to split each frequency channel of an input optical signal into two positions on a programmable attenuation plane;

Figure 6 illustrates an arrangement of spectra and channel attenuation areas for a 2-way split of channels on an SLM plane in a quad 1xN arrangement;

Figures 7a and 7b illustrate the optical path of a quad 1xN switch;

Figure 8 illustrates the polarisation of the optical signals incident on the deflection and attenuation areas of an SLM plane;

Figures 9a and 9b illustrate two implementations of space optic 712;

Figure 10 illustrates the layout of an exemplary optical switch;

Figures 11a and 11b illustrate the dispersion and switching planes of an exemplary optical switch;

Figure 12 illustrates a further exemplary optical switch;

Figure 13 illustrates a further exemplary optical switch;

Figure 14 illustrates a further exemplary optical switch; and

Figures 15a and 15b illustrate the optical path of a quad 1xN switch in accordance with the switch of figure 14.

DETAILED DESCRIPTION

The following describes several exemplary optical switches which utilise a programmable deflection plane, a programmable attenuation plane and an optical assembly to optically route light from one or more input ports to a set of output ports. The combination of the functionality of the optical assembly and programmable attenuation plane enables independent control of the brightness of each spectral channel from the input ports. This thereby enables crosstalk to be attenuated.

The described optical switches may be WSSs. In particular, the optical switch may be a one-plane 1xN switch. Alternatively, the optical switch may be a multi 1xN WSS, which consists of multiple independent 1xN WSSs in the same package. The described optical switches may be used as the basis for constructing a ROADM or another architecture for transferring light from core DWDM networks to lower capacity CWDM networks or vice versa. In all the described examples, the switches reduce crosstalk across the whole spectrum for each input port by selectively attenuating each spectral channel independently.

All the examples described herein use optical components to route light through the switches.

Figure 5 introduces the concept of the attenuation crosstalk in a 1xN switch. A reduced set of optical features is shown in figure 5 and described for clarity. Full optical architectures are illustrated and described in the subsequent examples.

In figure 5, the optical signal from the input port is split into its component frequency channels by a dispersion device 501. Each channel may have the same size beam image. Alternatively, the channels may have differently sized beam images, for example through the use of flexible frequency standards. A spectrum of this optical signal is imaged on a programmable deflection plane 502 which is a portion of an SLM plane. The programmable deflection plane applies a holographic beam deflection to the spectrum of channels incident on it. The deflection angle applied to each channel is independent of that applied to the other channels. Each channel may be deflected by a different angle.

The subsequent path of one channel is depicted in figure 5. The deflected beams pass through an optical assembly comprising a conjugate lens 503 and a faceted mirror 504. The conjugate lens 503 forms the Fourier conjugate image of the spectral plane on the faceted mirror. The faceted mirror 504 is located at the Fourier conjugate plane of the programmable deflection plane. The faceted mirror shown in figure 5 is a V-wedge shape which has two non-parallel mirror surfaces 504a and 504b. Positive diffraction orders, i.e. those aligned with the “upper” output ports above 401 on figure 4 are directed on one of these mirror surfaces 504a. Negative diffraction orders, i.e. those aligned with the “lower” output ports below 401 on figure 4 are directed to the other of the mirror surfaces 504b. Mirror surface 504a alters the angle of propagation of the deflected beams for the upper ports by a fixed angle. Mirror surface 504b alters the angle of propagation of the deflected beams for the lower ports by a fixed angle. The fixed angular deflection applied by the mirror surface 504a is different to the fixed angular deflection applied by the mirror surface 504b. A wedge angle can be defined as the angle subtended by the mirror surface to the normal to the optical axis. Mirror surface 504a applies a negative angle to the deflected beams for the upper ports which is equal to twice the wedge angle. Mirror surface 504b applies a positive angle to the deflected beams for the lower ports which is equal to twice the wedge angle.

The deflected beams for the upper ports and the lower ports return back to a programmable attenuation plane 505 portion of the SLM plane via the conjugate lens 503. Thus, the upper and lower ports are imaged on the SLM in the spectral plane. The upper ports are imaged onto the programmable attenuation plane in a different position to the lower ports. The programmable attenuation plane 505 applies a controllable attenuation to different positions on the programmable attenuation plane. The attenuation is applied to all channels simultaneously. In the case of figure 5, the programmable attenuation plane 505 is configured to cause the upper port images to be deflected to the output ports with no attenuation, and to attenuate the lower port images. The crosstalk from the -1 and -2 diffraction orders is thereby attenuated, whilst propagating the +1 diffraction order to the output port. The programmable attenuation plane 505 utilises polarisation to achieve the attenuation. This will be discussed in more detail in the full examples that follow. The polarisation optics that apply the polarisation are not shown in figure 5, but are in the figures that follow.

Thus, the arrangement of figure 5 manipulates the angles of the output port beams in the Fourier conjugate plane at the faceted mirror 504 before reimaging on the programmable attenuation plane 505 portion of the SLM plane. This enables ports to be grouped for attenuation, for example by grouping according to diffraction order. The ports in each group are attenuated equally. Compared to an arrangement which images each port individually on a programmable attenuation plane portion of an SLM plane, the same reduction in crosstalk is achieved whilst utilising far less space on the SLM plane.

Figure 5 illustrates grouping the ports into two, i.e. upper ports and lower ports. However, there may be more than two groups. There may be as many groups as there are output ports. The facet angle on the wedge mirror determines the position of each group on the attenuation plane.

Figure 6 illustrates an SLM plane 600 for a quad 1xN switch utilising the optical layout of figure 5. Four spectra are stacked vertically on the programmable deflection plane portion of the SLM plane. The beams 601 of one of the spectra are illustrated. Two circular spots 602 for each channel for each of the four spectra are illustrated on the programmable attenuation plane portion of the SLM plane.

Figures 7a and 7b illustrate the detailed optical path of light as it is routed through the components of an exemplary quad 1xN switch which attenuates crosstalk through use of a programmable attenuation plane and an optic such as a faceted mirror. Figure 7a illustrates the path in the switching plane, i.e. the y axis shown is the switching axis and the z axis is the optical axis. Figure 7b illustrates the optical path in the dispersion plane, i.e. the x axis shown is the dispersion axis and the z axis is the optical axis. Thus, figure 7b illustrates an orthogonal plane to figure 7a. Figures 7a and 7b illustrate a sequential layout of the optical path. Elements shown multiple times may be the same optical element. The optical elements may be ordered in a different sequence to that shown in figures 7a and 7b.

The optical switch of figures 7a and 7b comprises a set of input ports 701 (in this example four), which interface externally to the switch. Each input port comprises one or more optical fibres. Each port transports an optical signal having at least one component data channel. Each channel transports data. Each channel has a frequency band which has a different centre frequency to the other channels of that port. The channels of a port may have the same or different bandwidths. The bandwidths of the channels of a port are non-overlapping. As will be described below, each channel from each input port 701 may be routed to any output port 726 associated with that input port 701.

Light beams pass from the input ports 701 through a polarisation compensation system 702. This corrects for uncertain polarisation from the input optical fibres. The polarisation compensation system 702 may comprise a birefringent crystal and a patterned retarder. The light beams then pass through a single fan lens which images the light to a coincident circular focus point 727.

Next an anamorphic converter 703 is used to convert the circular beams at the input circular focus point 727 to elongated beams focused at input anamorphic focus point 728. A large beam size improves the efficiency of the hologram zones in the switching axis y on the programmable deflection plane 709. However, a narrow width in the dispersion axis x enables the spectra to fit onto the programmable deflection plane and also maximises passband performance. Hence the anamorphic converter is used to increase the length of the light beam in the switching axis and reduce the length of the light beam in the dispersion axis, leading to the non-circular elongated shape of the light beam. The anamorphic converter 703 may comprise two anamorphic lenses. Alternatively, the anamorphic converter 703 may comprise four cylindrical lenses.

Next, the beams pass through a cylindrical lens 704. Cylindrical lens 704 has power normal to the dispersion axis. Next, the beams pass through a 4F imaging system. The 4F imaging system comprises two lenses 705 and 708 separated by a demultiplexer 706 at the Fourier plane of lenses 705 and 708. The demultiplexer 706 spatially separates the component frequency channels of the optical signal beams incident on it to form a set of dispersed optical signal beams. In other words, each optical signal from an input port is spread into its frequency spectrum by the demultiplexer 706. Thus, the demultiplexer 706 acts to demultiplex each optical signal into its component frequency channels in a dispersion direction normal to the propagation direction of the optical signal. The waist of the beam at the demultiplexer 706 normal to the dispersion plane is significantly less than in the dispersion plane, and the beams are coincident for all input ports. The demultiplexer 706 is a dispersion device, such as a diffraction grating.

A gap optic 707 may be located at the demultiplexer. Alternatively, the gap optic 707 may be located elsewhere in the optical path between the demultiplexer and the programmable deflection plane 709. The gap optic 707 is located where a coincident image of the optical signals from the input ports is formed. Thus, the gap optic 707 may be located at the anamorphic focus 728 or the circular focus 727. Thus, the gap optic 707 allows the propagation of the dispersed optical signals from the demultiplexer to the programmable deflection plane 709 unimpeded. The gap optic 707 may be implemented as a mirror with an aperture in it. The dispersed optical signals travel unimpeded through the aperture. Different optics may be used between the gap optic 707 and the programmable deflection plane 709 as long as those optics supply a Fourier conjugate function in the switching plane of the programmable deflection plane 709.

The programmable deflection plane 709 is positioned in the optical path of the set of dispersed optical signals such that the set of dispersed optical signal beams form spectra on the programmable deflection plane 709. In the example of figures 7a and 7b, four input ports 701 are illustrated, each of which forms a spectrum on the programmable deflection plane 709. Those spectra will appear with anamorphic beam waists as shown on figure 6. Each spectrum forms an array of beams of the component data channels of the input port which are imaged on the programmable deflection plane 709, each beam being a data channel. The programmable deflection plane 709 applies a programmable deflection to each beam of the array of beams individually to form a deflected array of beams. The degree of deflection applied to each beam is so as to change the angle of that beam to direct its data channel on a path towards a selected one of the output ports 726. The deflection applied by the programmable deflection plane 709 is reconfigurable. Thus, a controller providing a control signal to the programmable deflection plane 709 may change the deflection applied by the programmable deflection plane 709 to each individual beam of the spectra from each input port, so as to output the desired channels to the desired ports.

The programmable deflection plane 709 may be an SLM plane. The SLM plane may be implemented by a liquid crystal on silicon (LCoS) device. Alternatively, the programmable deflection plane may be implemented by a MEMS mirror device. In this example, the MEMS mirror device programmable deflection plane is a separate component to the LCoS device of the programmable attenuation plane.

The deflected array of beams from the programmable deflection plane 709 propagates through a 4F imaging system. The 4F imaging system comprises two lenses 708 and 729 separated by gap optic 707 at the Fourier plane of lens 708. The deflected beams reach the gap optic 707 before the multiplexer 706. The gap optic deflects the deflected array of beams. The gap optic 707 is located at the output port conjugate plane. The 4F imaging system forms an image of the spectral plane at a plane marked X in figure 7a.

Next, the deflected array of beams may propagate to an anamorphic converter 711. The anamorphic converter 711 converts the deflected array of beams from an anamorphic shape to a circular shape. The circular shaped deflected array of beams is focussed at a plane 730. Plane 730 is the spectral-imaging conjugate plane. Removing the anamorphic image ratio from the beams reduces the area required on the programmable attenuation plane. The anamorphic converter 711 is not required in the optical switch of figures 7a and 7b and may be omitted. If omitted, the beam spot shape on the programmable attenuation plane will match the beam spot shape of the spectra on the programmable deflection plane, i.e. elongated in the switching axis. The optical switch will still function but a larger area is needed on the programmable attenuation plane to accommodate the anamorphic shaped beam spots.

To maximise use of the SLM plane for the programmable deflection plane, the beam positions on the programmable deflection plane are as close to each other as possible. The space allocated between the beam images on the programmable deflection plane may be 1.5 times the width of the image. When each beam is subsequently imaged into at least two positions on the programmable attenuation plane, to avoid those images overlapping, space is usefully introduced between the deflected array of beams. A space optic 712 is located at the plane 730. This is in the optical path between the programmable deflection plane and the programmable attenuation plane. The space optic 712 increases the spacing between the spatially separated frequency channels of the deflected array of beams whilst maintaining the beam size of the deflected array of beams. Thus, the beams are not magnified by the space optic. The space optic 712 may be omitted from the switch if the space allocated between the beam images on the programmable deflection plane is sufficient to avoid overlapping of the images on the programmable attenuation plane.

The expanded spectra then propagate through a Fourier 4F lens 713 to an optical assembly. The optical assembly comprises a polarisation element 714. The polarisation element 714 polarises or retards the phase of each component frequency channel of the deflected array of beams in one polarisation axis. That polarisation axis may be at 45° to the extraordinary axis of the programmable attenuation plane 710. The polarisation element may be a half waveplate at 22.5° to the light polarisation. This causes a rotation of the light polarisation plane of 45°. Alternatively, the polarisation element may cause each component frequency channel of the deflected array of beams to become circularly polarised.

Although depicted between the lens 713 and the optic 715 in the optical path in figures 7a and 7b, the polarisation element 714 may be located at any position in the optical path between the programmable deflection plane 709 and the programmable attenuation plane 710.

The optical assembly also comprises an optic 715 to image each component frequency channel of the deflected array of beams to at least two unique positions on the programmable attenuation plane 710. The optic 715 is located at the focus plane of the lens 713. That optic is located at the Fourier conjugate plane of the programmable deflection plane, so as to cause a Fourier conjugate image of the programmable deflection plane to be formed on an optical plane of the optical assembly that has a spatial distribution dependent on the deflection applied by the programmable deflection plane. The optic alters the propagation angles of the deflected array of beams incident on it as a function of spatial position in the plane normal to the propagation and dispersion planes. The optic applies a constant angle correction. The optic may, for example, image each component frequency channel of the deflected array of beams onto two or more unique positions on the programmable attenuation plane, the location of those unique positions being independent of the deflection applied by the programmable deflection plane 709. The unique positions for each component frequency channel are separated normal to the dispersion plane in a spatial distribution dependent on the altered propagation angles. In the case that two unique image positions are formed for each component frequency channel of the deflected array of beams, the optic may image positive diffraction orders onto a first unique position on the programmable attenuation plane, and image negative diffraction orders onto a second unique position on the programmable attenuation plane.

The optic 715 may comprise, for example, a faceted mirror. That faceted mirror may be a V-shaped wedge mirror as described above with reference to figure 5. The faceted mirror may have a facet for every output port beam image. If a constant angle correction is applied, then the unique images on the spectral plane of the programmable attenuation plane are coincident. Thus, for each frequency channel, any combination of ports may be grouped and attenuated together.

Alternatively, the optic 715 may comprise an active device, for example an optical microelectromechanical system (MEMS) mirror layer. That MEMS mirror layer may be in one or two dimensions. The grouping of ports may be actively chosen depending on the chosen output port, further minimising crosstalk. Another exemplary active device which may be used as the optic 715 is an LCoS. This may be the same LCoS as is used to implement the programmable deflection plane 709 and the programmable attenuation plane 710. In this case, the polarisation element 714 is located after the LCoS 715 in the optical path. In other words, the polarisation element 714 is positioned between the LCoS 715 and the programmable attenuation plane 710.

The optical assembly further comprises a conjugate lens 716 through which the deflected array of beams from the optic 715 propagates. The conjugate lens 716 forms a Fourier conjugate image of the optical plane of the optic 715 on the subsequent programable attenuation plane 710. Thus, the spectral plane is imaged onto the programmable attenuation plane 710.

The programmable attenuation plane 710 attenuates the beams of spatially separated frequency channels incident on it to form an attenuated array of beams. The programmable attenuation plane 710 independently controls the intensity of the optical beams incident at different positions on its surface. It may do this by applying a programmable retardation to the polarisation axis of the spatially separated frequency channels incident on its surface.

The programmable attenuation plane 710 may be an SLM plane. The SLM plane may be implemented by a liquid crystal on silicon (LCoS) device. The SLM plane may be implemented by a transmissive liquid crystal device. The programmable deflection plane and the programmable attenuation plane may be different portions of the same SLM device. The programmable deflection plane and the programmable attenuation plane may be different portions of the same SLM plane.

Figure 8 illustrates a single LCoS plane which incorporates both the programmable deflection plane 709 and the programmable attenuation plane 710. For the hologram deflection applied by the programmable deflection plane 709, the polarisation direction of the incident dispersed optical signals is aligned with the extraordinary refractive index axis of the LCoS. This enables the phase of the incident dispersed optical signals to be retarded controllably as a function of spatial position. For the attenuation applied by the programmable attenuation plane 710, the polarisation direction of the incident dispersed optical signals is preferably aligned at 45° to the extraordinary refractive index axis of the LCoS, and at 45° to the ordinary refractive index axis of the LCoS. The extraordinary refractive index of the LCoS changes with voltage, thus the voltage of the LCoS is controlled so as to shift the phase of the dispersed optical signals incident on the programmable attenuation plane. In other words, the LCoS is controlled to retard one polarisation axis of the light incident on it by a controllable amount.

A polarisation selection element 720 is subsequently used in the optical path between the programmable attenuation plane and the output ports. The polarisation selection element 720 applies the attenuation to the array of beams incident on it by propagating only one polarisation phase of the array of beams towards the set of output ports 726. For example, the polarisation selection element 720 may be a 45° sample polariser which samples the brightness of each channel of the attenuated array of beams.

The image of the beams on the programmable attenuation plane may be small, for example less than a pixel in size. This is very different to the programmable deflection plane. To switch between 32 locations, approximately 400-500 pixels normal to the dispersion axis may be used to allow fine control of the beam deflection based on hologram formation. By comparison, the height of the attenuation dots 602 may be 10 pixels per attenuation spot pair per spectral channel. Thus, as shown on figure 6, the space utilised by the programmable attenuation plane on the LCoS is much smaller than the space utilised by the programmable deflection plane on the LCoS. The programmable attenuation plane individually retards the polarisation components of each of the two images for each channel of each spectrum.

The attenuated array of beams propagates from the programmable attenuation plane 710 to a Fourier 4F lens 718 which images the attenuated array of beams on a further optical assembly. That further optical assembly comprises an optic 719 located at the Fourier conjugate plane of the programmable attenuation plane, thereby forming a Fourier conjugate image of the programmable attenuation plane on the optical plane of the optic 719. The optic 719 applies an inverse optical deflection to the optic 715. The optic 719 alters the propagation angles of the beams incident on it as a function of spatial position in the plane normal to the propagation and dispersion planes. Suitably, the optic 719 applies a constant angle correction which removes the constant angle correction previously applied by the optic 715. Alternatively, the optic 719 in combination with other subsequent optics, may overall apply a constant angle correction which removes the constant angle correction previously applied by the optic 715. Alternatively, the optic 719 may apply an angle correction which is different to the inverse of optic 715. Alternatively, optic 719 may be omitted if subsequent optics use the angle correction applied by optic 715.

The optic 719 may comprise, for example, a faceted mirror such as the V-shaped wedge mirror described above with reference to figure 5. In this case, the faceted mirror 719 is an inverse faceted mirror relative to the faceted mirror 715. Alternatively, the optic 719 may comprise an optical microelectromechanical system (MEMS) mirror layer.

The optic 719 may be omitted from the switch. The optic 719 enables the output ports 726 to be in a similar configuration to the input ports 701.

Following the optical correction at the further optical assembly, the beams are sampled at polariser 720, then inverted in the dispersion plane by inverter 721. The inverted beams are then incident on a multiplexer 722. The multiplexer combines the spatially separated frequency channels, which then propagate through Fourier lens 723. The inverter 721 may be omitted from the switch. For example, if the multiplexer 722 is a diffraction grating having an opposite order to the order of the diffraction grating 706, then the inverter 721 may be omitted. The multiplexer 722 may be the same physical component as the demultiplexer 706.

The multiplexed beams are then coupled to the output ports 726 by coupling lenses 724. Polarisation compensation system 725 couples the coupling lenses 724 to the output ports 726 to correct for uncertain polarisation to the output optical fibres. The polarisation compensation system 725 may comprise a birefringent crystal and a patterned retarder.

Each port of the set of output ports 726 comprises optical fibres which interface with the external environment outside the switch.

The optical components of the 1xN WSS between the input ports and the programmable deflection plane may be different to those described with reference to figures 7a and 7b. For example, different optical components may be used if coincident images from the input ports are formed at the demultiplexer, those coincident images being more extended in the dispersion plane than orthogonal to it.

Although shown in the optical path directly after the optic 719 in figures 7a and 7b, the polarisation selection element 720 may be located anywhere in the optical path between the programmable attenuation plane 710 and the polarisation converter 725. If the grating 722 is polarisation dependent, then the polarisation selection element is located between the optic 719 and the grating 722. In this case, additional polarisation rotation optics may be located between the polarisation selection element 720 and the grating 722 to align the light beams to an optimum polarisation condition for the grating 722. These additional polarisation rotation optics may be, for example, a half wave plate. Figures 9a and 9b illustrate two exemplary implementations of space optic 712. Figure 9a is a linear prism array. It is located in the spectral plane. It comprises a pair of parallel refractive surfaces for each spectrum at a different and increasing angle to the normal to the dispersion plane. The light beam reaching the first of the pair of surfaces refracts away from the centre and is re-collimated by the second of the pair of surfaces. The spacing between light beams output from the linear prism array is greater than those input to the linear prism array. However, the individual light beams themselves are not magnified. The beam size of each remains the same.

Figure 9b illustrates an alternative implementation of the space optic 712. It comprises a multi-element micro-lens array and a large lens. There are the same number of micro-lenses in the array as there are input ports/spectra. Figure 9b illustrates four micro-lenses to match the four input ports of the switch of figure 7a. The micro-lenses are spaced away from each light beam optical axis. Thus, the light beam input to each micro-lens is deflected onto a large lens. The large lens collimates the diverging light beams from the micro-lenses, thereby outputting light beams which are spaced apart compared to those input to the micro-lenses. However, the individual light beams themselves are not magnified. The beam size of each remains the same.

Although figure 9b illustrates a micro-lens array, an alternative approach would be to use an array of pairs of parallel mirrors, each pair of parallel mirrors at an angle to the other pairs of parallel mirrors. This arrangement would achieve the same optical deflection as described above with respect to the micro-lens array.

Figure 10 illustrates an optical layout implementation of the optical path shown in figures 7a and 7b. Figure 10 illustrates the dispersion plane, i.e the x axis shown is the dispersion axis and the z axis shown is the optical axis. The optical layout to achieve the routing of the optical beams from the input ports 701 to the demultiplexer 706 is not shown. This may be achieved by any known set of optics. Similarly, the optical layout to achieve the routing of the optical beams from the multiplexer 722 to the output ports is not shown. This may be achieved by any known set of optics as long as the gap optic 707 plane is a conjugate Fourier transform of the LCoS plane in the switching axis. An example arrangement of the routing from the input ports to the demultiplexer 706 and from the multiplexer 722 to the output ports is shown in figures 7a and 7b.

Light from the input ports is demultiplexed at grism 706. The light is then imaged via 4F lens 708 onto the programmable deflection plane 709. The light is deflected from the programmable deflection plane 709 back through the 4F lens 708 onto gap optic 707. The gap optic 707 may be a mirror with an aperture in it as described with respect to figures 7a and 7b. The light is reflected by the gap optic 707, and a further mirror 1001, then through lens 729 to anamorphic converter 711. The anamorphic converter 711 converts the light beam shape from an elongated beam shape back to a circular shape.

Light beams output from the anamorphic converter 711 pass through space optic 712 which increases the space between the spectra without magnifying the beams. The light then passes through 4F lens 713, then polarisation element 714 to optic 715. The 4F lenses 729 and 713 together are in a 4F arrangement to image the output ports from the gap optic 707 to the optic 715. Although shown as lenses 729 and 713, the same optical path may be achieved through use of other optical components, such as mirrors.

Polarisation element 714 may comprise a half waveplate at 22.5°. The polarisation element 714 rotates the polarisation of the incident light beams by 45°. This has the effect of causing the LCoS to act as a polarisation rotator (for the programmable attenuation plane) rather than as a hologram (for the programmable deflection plane).

Optic 715 splits each component frequency channel of the beams input to it into the number of unique positions to be imaged on the programmable attenuation plane 710. For example, the optic 715 may be a wedge mirror which splits each component frequency channel of each beam input to it into two, so as to cause two images on the subsequent programmable attenuation plane at unique positions. As described above, these two images may correspond to a wanted upper port spot (for the positive diffraction orders) and an unwanted lower port spot (for the negative diffraction orders).

Following the optic 715, the light beams are directed via mirror array 1002 through a conjugate lens 716 to programmable attenuation plane 710. Conjugate lens 716 forms a Fourier conjugate image of the optical plane of optic 715 on the programmable attenuation plane. Thus, the spectral plane is imaged onto the programmable attenuation plane 710.

After attenuation at the programmable attenuation plane 710, the light beams pass back through conjugate lens 716 and are directed by mirror array 1002 onto optic 719. Optic 719 applies the inverse of optic 715. Thus, in the case that optic 715 is a wedge mirror, optic 719 is an inverse wedge mirror. The light beams then propagate to polarisation selection element 720, which may be a 45° sample polariser as previously described.

From the polarisation selection element 720, the light beams pass through inverter 721 which orientates the spectra for subsequent multiplexing at grism 722, following which the light beams are transmitted to the output ports. The inverter 721 is used if the output grism 722 is the same as the input grism 706. However, the inverter 721 may be omitted if the output grism 722 is different to the input grism 706, and in particular if the output grism 722 has the opposite diffraction order to the input grism 706.

Figure 10 illustrates a single LCoS panel which comprises two areas, one for the programmable deflection plane 709 and one for the programmable attenuation plane 710. The LCoS panel is positioned flat parallel to the dispersion plane. It is preferable to illuminate the LCoS panel normally in order to minimise angular variations and optimise the operation of the LCoS SLM. A 45° mirror or prism 1003 is positioned so as to deflect light from the 4F lens 708 normally onto the programmable deflection plane 709, and also to deflect light from the programmable deflection plane 709 back to the 4F lens 708. A 45° mirror or prism 1004 is positioned so as to deflect light from the conjugate lens 716 normally onto the programmable attenuation plane 710, and also to deflect light from the programmable attenuation plane 710 back to the conjugate lens 716. In the arrangement shown in figure 10, the light beam from the 4F lens 708 towards the LCoS panel is in an opposing direction to the light beam from the conjugate lens 716 towards the LCoS panel. Thus, the mirror/prism 1003 and the mirror/prism 1004 are oriented back-to-back in a V-shaped arrangement. Although figure 10 illustrates a single LCoS panel, two separate SLMs could instead be used. However, using the same SLM panel for both the programmable deflection plane and the programmable attenuation plane optimises area utilisation on the SLM panel since the area used for the attenuation is significantly less than the area used for the deflection.

The programmable attenuation plane 710 retards one axis of the incident attenuation spot, which is subsequently attenuated by the polarisation selection element 720. Instead, an LCoS deflection scheme or MEMS with a beam stop may be used.

Although gap optic 707 is depicted in figure 10, it may be omitted. For example, in the case that the SLM panel housing the programmable deflection plane is not illuminated normally, the deflection from the SLM panel follows a different path away from the demultiplexer 706. In this scenario, the gap optic 707 is not required to prevent the deflected light from the programmable deflection plane from falling incident on the demultiplexer.

Although space optic 712 is depicted in figure 10, it may be omitted. For example, if there is only one spectrum, then the space optic is not required. As another example, if there is sufficient space between the spectral images in the spectral plane on the programmable deflection plane such that the number of required unique spots on the programmable attenuation plane for each spectral beam can be formed without overlapping each other, then the space optic is not required. However, allowing sufficient space on the programmable deflection plane comes at the cost of not efficiently using the LCoS SLM area.

Although optic 719 is depicted in figure 10, it may be omitted. For example, the output port positions and/or optics between the programmable attenuation plane and the output ports may be modified to accommodate the range of angles observed at the output port plane.

As shown on figure 10, the long axis of the switch of figure 10 is four times the main 4F Fourier lens focal length. There is one focal length F between the grating 706 and the lens 708, another focal length F between the lens 708 and the programmable deflection plane 709, another focal length F between the lens 716 and the programmable attenuation plane 710, and another focal length F between the lens 716 and the mirror array 1002. This layout is large for high spectral bands or low dispersion gratings.

Figures 11a and 11b illustrate a further optical layout implementation of the optical path shown in figures 7a and 7b. Figure 11a illustrates the path in the dispersion plane, i.e. the x axis shown is the dispersion axis and the z axis is the optical axis. Figure 11b illustrates the path in the switching plane. i.e. the y axis shown is the switching axis and the z axis is the optical axis. Thus, figure 11b illustrates an orthogonal plane to figure 11a.

In figures 11a and 11b, the optical switch uses an LCoS SLM which is incident from the same direction for both the programmable deflection plane portion of the SLM and the programmable attenuation plane portion of the SLM. Mirrors 1102, 1103 and 1201 are used to direct the optical path in a loop around the LCoS SLM. This enables a more compact arrangement than that described with reference to figure 10. As can be seen on figure 11b, the incident beam from the input ports, the reflection from the gap optic 707, the incident beam on the programmable attenuation plane 710 and the output ports are at different heights in the switching plane, i.e. perpendicular to the dispersion plane. This enables a fan-in approach for the quad 1xN switch to the demultiplexer 706 using optical structures such as those described with respect to figures 7a and 7b between the input ports 701 and the demultiplexer 706.

Light from the input ports is demultiplexed at diffraction grating 706. A mirror array 1101 positioned in the optical path between the diffraction grating 706 and the LCoS SLM is shown in more detail in figure 11b. The dispersed light beams pass through the aperture in mirror 707, through 4F lens 708, and onto the programmable deflection plane 709 of the LCoS SLM. The light beams are deflected back through the 4F lens 708, and are incident on the mirror 707 which deflects them to a further 4F lens 729, following which they pass through polarisation element 714. Next the light beams are deflected from mirror 1102 to keep the optical path compact around the LCoS SLM, inverted by inverter 711, and then passed through space optic 712. From there, the light beams are deflected from mirror 1103 to keep the optical path compact around the LCoS SLM, passed through 4F lens 713, and are then split into two or more by optic 715. The light beams then pass through inverter 721, following which they are reflected from flat mirror 1201 sitting above the diffraction grating 706 in the switching plane. The light beams are consequently made incident to the programmable attenuation plane of the LCoS SLM through Fourier lens 708 from an upper angle, causing them to be reflected back through the Fourier lens 708 beneath the mirror 707 to fall incident on polarisation selection element 720 and then optic 719 before meeting the diffraction grating 706. By imaging the light beams from an upper angle through Fourier lens 708 onto the programmable attenuation plane, the images are formed below the programmable deflection plane as the LCoS is in the Fourier plane of lens 708. The reflected beams pass back through lens 708 and an inverted image of the mirror 1201 is formed at the optic 719. The diffraction grating 706 multiplexes the light beams and outputs them to the output ports.

The Fourier lens 708 incident on the LCoS panel is used for both the light beams incident on the programmable deflection plane and the light beams incident on the programmable attenuation plane. Thus, the same Fourier lens is used for both lens 708 and lens 716 in figures 7a and 7b.

Some of the optical components in figures 11a and 11b are in a different sequential order to those shown in figures 7a and 7b. This does not affect the light beams which are output to the output ports. For example, polarisation element 714 is positioned before anamorphic converter 711 in figures 11a and 11b, whereas it comes after anamorphic converter 711 in figures 7a and 7b. The order of these components is not important. The light beams output from the combination of the polarisation element 714 and the anamorphic converter 711 are the same regardless of which comes first in the optical path. Inverter 721 is in the optical path before programmable attenuation plane 710 in figures 11a and 11b, whereas it is after the programmable attenuation plane 710 in figures 7a and 7b. The optic 719 follows the polariser 720 in the optical path of figures 11a and 11b, whereas the polariser 720 follows the optic 719 in the optical path of figures 7a and 7b.

Figure 12 illustrates a further optical layout implementation of the optical path shown in figures 7a and 7b. In this layout, mirrors are used to reduce the overall size of the arrangement compared to the layout of figure 10. Specifically, 4F dispersion axis cylindrical mirrors are used to reduce the overall size of the layout by half compared to figure 10 to twice the main 4F Fourier lens focal length. These mirrors replace transmission lenses described in figures 7a and 7b. The mirrors have the same focal length as the transmission lenses. The mirrors may be fabricated from a single block element through which the other optical elements are added. This aids tolerance. An LCoS for implementing the programmable deflection and attenuation planes, and all the non-lens optics are located in a central area of the switch, and are surrounded by the mirrors which direct the light beams onto the centralised optical components in the correct sequence.

Light from the input ports passes to demultiplexer 706 by any known method for a 1xN switch. The demultiplexer 706 may be implemented by a grism. The grism is a combination of a diffraction grating and a prism assembly. The prism assembly makes the dispersed spectra more linear across the frequency spectrum for imaging on the LCoS. From there the light is reflected by 4F dispersion axis cylindrical mirror 1201 to programmable deflection plane 709. The light beams deflected from programmable deflection plane 709 are reflected by mirror 1201 to mirror 707, where they are reflected to 4F dispersion axis cylindrical mirror 1202.

From mirror 1202, the light beams pass through 4F steering axis cylindrical lens 1203, then through polarisation element 714, are reflected from 4F dispersion axis cylindrical mirror 1204, propagate through space optic 712, and through further 4F steering axis cylindrical lens 1205 to optic 715. The two 4F dispersion axis cylindrical mirrors 1202 and 1204 have power only in the dispersion axis. The two 4F steering axis cylindrical lenses 1203 and 1205 have power only in the steering/switching axis. Mirrors 1202 and 1204 together with lenses 1203 and 1205 act as an anamorphic 4F arrangement. Their focal length is chosen so as to change the shape of the light beams from elongate to circular. Alternatively, their focal length may be chosen so as to change the shape of the light beams from elongate to any other aspect ratio. This anamorphic 4F arrangement focuses the light beams on the optic 715. Space optic 712 acts only in the switching plane. Space optic 712 is thus positioned at the Fourier plane of the two 4F steering axis cylindrical lenses 1203 and 1205.

Optic 715 directs the light beams to 4F dispersion axis cylindrical mirror 1206 which reflects the light beams onto the programmable attenuation plane 710. The light beams from the programmable attenuation plane 710 reflect from 4F dispersion axis cylindrical mirror 1207 to optic 719. From optic 719, the light beams reflect from inverter mirror 1208, then pass through sample polariser 720, and are reflected from mirror 1209 onto multiplexer 722. Multiplexer 722 may be a grism. Grism 722 is rotated relative to grism 706. Thus, this arrangement does not require the inverter 721 shown in figures 7a and 7b.

The polarisation element 714 is in a different position in the optical path in figure 12 than in the optical path of figures 7a and 7b. Specifically, polarisation element 714 is before space optic 712 in figure 12, whereas it is located after it in figures 7a and 7b. The order of these components is not important, and does not affect the light beams output to the output ports. The polarisation element 714 may instead come before the space optic in figure 12.

Figure 13 illustrates a further optical layout implementation of the optical path shown in figures 7a and 7b. In this layout, mirrors are placed strategically to reduce the overall size of the arrangement compared to the layouts of figures 10 and 12. Specifically, flat mirrors and 4F dispersion axis cylindrical mirrors are used to reduce the overall size of the layout by approximately four times compared to figure 10 to approximately one times the main 4F Fourier lens focal length in both directions. The optical path is weaved around the optical structures through the use of mirrors to maintain the required path lengths. The mirror arrangement is more compact than that of figure 12.

Light beams pass from the input ports 701 through any suitable known optical elements to steering cylindrical lens 704, and from there to grism 706 via 4F dispersion axis cylindrical mirror 1301. Light diffracted by grism 706 passes through an aperture in mirror 707, reflects off flat mirror 1302, then reflects off 4F dispersion axis cylindrical mirror 1303, then reflects off flat mirror 1304 to programmable deflection plane 709.

The light beams deflected from programmable deflection plane 709 are reflected by flat mirror 1304, then reflected by 4F dispersion axis cylindrical mirror 1303 to flat mirror 1302, which reflects them onto mirror 707. From mirror 707, the light beams reflect back onto flat mirror 1302, then through 4F steering axis cylindrical lens 1203 onto 4F dispersion axis cylindrical mirror 1305, then through space optic 712 and 4F steering axis cylindrical lens 1205 to flat mirror 1306. The two 4F dispersion axis cylindrical mirrors 1303 and 1305 have power only in the dispersion axis. The two 4F steering axis cylindrical lenses 1203 and 1205 have power only in the steering/switching axis. Mirrors 1202 and 1204 together with lenses 1203 and 1205 act as an anamorphic 4F arrangement. Space optic 712 acts only in the switching plane. Space optic 712 is thus positioned at the Fourier plane of the two 4F steering axis cylindrical lenses 1203 and 1205.

The light beams are reflected from flat mirror 1306 through polarisation element 714 to flat mirror 1307, where they are reflected to 4F dispersion axis cylindrical mirror 1308, and from there to optic 715. The light beams propagate from optic 715 to 4F dispersion axis cylindrical mirror 1309, and from there to flat mirror 1310 and onto the programmable attenuation plane 710. The light beams output from the programmable attenuation plane 710 propagate back to flat mirror 1310, then onto 4F dispersion axis cylindrical mirror, then to optic 719, and from there to flat mirror 1311, inverter lens 721, flat mirrors 1312, 1313, 1314 and 1315, then through inverter lens 721 to flat mirrors 1315 and 1317 then onto grism 722. The multiplexed light from grism 722 passes to flat mirrors 1318, 1319, 1320, then through 4F lens 723, onto flat mirrors 1321 and 1322 before passing through sample polariser 720 and onto the output ports 726. Multiplexers 706 and 722 implemented by grisms use the same order. No inverter is required.

Figure 14 illustrates an optical layout of a 1xN switch which utilises a polarising beamsplitter in addition to control of the polarisation of light leaving and returning to the multiplexer in order to use several optical elements twice in the optical path through the switch. Thus the switch comprises fewer optical components in total compared to the previously described embodiments. The use of fewer components, along with strategic use of mirrors, enables the overall size of the switch to be reduced by approximately four times compared to figure 10 to approximately one times the main 4F Fourier lens focal length in both directions. Where the optical path passes through an optical component twice, once in each direction, any tolerance misalignment applied to the light on passage through the optical component in one direction is corrected on passage through the optical component in the other direction. Figures 15a and 15b illustrate the detailed optical path of light as it is routed through the layout of figure 14. Figure 15a illustrates the path in the switching plane, i.e. the y axis shown is the switching axis and the z axis is the optical axis. Figure 15b illustrates the optical path in the dispersion plane, i.e. the x axis shown is the dispersion axis and the z axis is the optical axis. Thus, figure 15b illustrates an orthogonal plane to figure 15a. Figures 15a and 15b illustrate a sequential layout of the optical path.

In figures 14 and 15, polarisation is expressed as S or P orthogonal plane polarisation. Circular polarisation is expressed as C. An arbitrary circular or plane polarisation created by the LCoS is expressed as E. An unpolarised state is expressed as U.

Unpolarised light from the input ports 1401 passes through polarisation compensation 1402 that polarises the light in the S direction. S polarisation is the optimum polarisation for the programmable deflection plane 1415. The light beams pass through anamorphic converter 1403 that converts each beam size from circular to elongated. The light beams then pass through steering cylindrical lens 1404 that has power only in the steering axis. The light beams are redirected by flat mirror 1405 to 4F dispersion axis cylindrical mirror 1406. Mirror 1406 only has power in the dispersion axis. It acts as a dispersion 4F Fourier lens. The light beams are redirected by flat mirror 1407, through 4F steering axis cylindrical lens 1408, and are reflected by flat mirror 1409 to demultiplexer 1410. The demultiplexer may be a grism with a diffraction grating. The grism is optimised for S-polarised light.

The demultiplexed light beams are reflected from flat mirror 1411 to polarising beamsplitter 1412. Polarising beamsplitter transmits S polarisation and reflects P polarisation. The light beams entering the polarising beamsplitter 1412 are S-polarised, so are transmitted through beamsplitter 1412 unimpeded. From the beamsplitter 1412, the light beams pass through patterned half wave plate 1413. This performs the same function as the aperture mirror 707 described in previous embodiments. The light beams from the beamsplitter pass through the patterned half wave plate 1413 unimpeded. The light beams thus pass through still S-polarised and are deflected by flat mirror 1414 towards the programmable deflection plane 1415 on the LCoS via 4F dispersion axis cylindrical mirror 1417 and 4F steering axis cylindrical lens 1419. Flat mirrors 1416, 1418 and 1420 are used to direct the light beams onto the mirror 1417, lens 1419 and LCoS 1415 respectively.

The 4F dispersion axis cylindrical mirrors 1406 and 1417 have power only in the dispersion axis. The Fourier plane is aligned with the grating layer 1410. The 4F steering axis cylindrical lenses 1408 and 1419 have power only orthogonal to the dispersion plane. Their Fourier plane is aligned with the patterned half wave plate 1413.

The LCoS acts as a programmable deflection plane and deflects the spectra incident on it according to each channel. The LCoS extraordinary axis direction (controllable phase) is in the S polarisation direction. The light beams deflected from the LCoS are then propagated back via flat mirror 1420 and lens 1419 to mirror 1417 and are reflected off mirror 1414 to impact the patterned half wave plate 1413.

The patterned half wave plate 1413 changes the polarisation of the light beams to P polarisation. The light beams then pass to beamsplitter 1412 which reflects the light beams causing them to propagate to flat mirror 1414 where they are reflected towards 4F steering axis cylindrical lens 1421. The light beams then are reflected from 4F dispersion axis cylindrical mirror 1422, which focusses the light to flat mirror 1424 via space optic 1423. The light beams are then redirected by flat mirror 1424 and flat mirror 1425 through 4F steering axis cylindrical lens 1426 to 4F dispersion axis cylindrical mirror 1427 which focusses the light beams on faceted mirror 1428. 4F steering lenses 1421 and 1426 have power only in the steering direction. 4F cylindrical mirrors 1422 and 1427 have power in the dispersion direction. Lenses 1421 and 1426 and mirrors 1422 and 1427 as a whole constitute an anamorphic converter. Space optic 1423 is positioned in the steering axis Fourier plane.

Faceted mirror 1428 is at the Fourier plane of 4F dispersion axis cylindrical mirrors 1427 and 1429. Mirrors 1427 and 1429 image the spectral plane onto the attenuation part 1432 of the LCoS. Mirrors 1427 and 1429 may additionally have power in the steering axis. From faceted mirror 1428, the light beams propagate to mirror 1429, then flat mirror 1430 which deflects the light beams to the programmable attenuation plane 1432 via quarter wave plate 1431. Quarter wave plate 1431 changes the polarisation of the light to C polarisation. Thus, the light beams are circularly polarised when they meet the programmable attenuation plane 1432 of the LCoS. Illumination on the programmable attenuation plane is normal to and from the LCoS plane. This optimises LCoS performance and minimises losses.

The LCoS programmable attenuation plane 1432 alters the polarisation of the light input to it to a controllable elliptical polarisation E that is a sum of different amounts of S and P polarisation. The light beams output from the programmable attenuation plane 1432 then propagate back through all the optic components in reverse to beamsplitter 1412. The part of the light beam in the S-polarisation state is transmitted through beamsplitter 1412 to the diffraction grating 1410. The diffraction grating 1410 multiplexes this light and sends it via flat mirrors 1404 and 1433, through 4F Fourier lens 1434, via flat mirror 1435 to outport ports

1436. The part of the light beam in the P-polarisation state is reflected from the beamsplitter through to the patterned half waveplate where it is rotated to S-polarisation. The light beam then propagates a reverse path past the LCoS programmable deflection plane. The light beam then passes back to the beamsplitter 1412. It passes through the aperture of the patterned half wave plate 1413 unretarded. It is subsequently reflected from mirror 1411 then through grism 1410, then back to the input port. A known optic is included in the optical path prior to the input ports to prevent this from propagating into the input port. That known optic also removes zero order reflections from all the optical elements including from the LCoS. All of these unwanted signals are lost at this point.

The divergence point for the light incident on the diffraction grating 1410 is at the diffraction grating 1410 and above the beamsplitter for the returning light beams. This causes a small spatial chromatic aberration in the output beam. Correction optics, such as an output anamorphic telescope, or higher numerical aperture output optics may be used to correct this.

The examples described herein have optical components in a sequential order in optical switches. However, it will be understood that the same optical effect may be achieved by modifying the sequential layout of some of the optical components. Thus, the optical components within each switch may be in a different order in the optical path to those shown and described.

The 1xN optical switches described herein may be packaged utilising the same SLMs in groups to form ROADM and related adWSS structures.

The example 1xN optical switches described herein enable independent control of crosstalk for each spectral channel for one or more 1xN WSS devices in a single package. They also enable full and independent attenuation control for each spectral channel for one or more 1xN WSS devices in a single package. Attenuation and crosstalk can be reduced to within the noise floor of the device.

The example 1xN optical switches described herein are operable with flexible spectrum bandwidths and broad spectral bands. Light signals from broad spectral bands in particular suffer wavelength dependent brightness variation from the reposes of ROADMs previously propagated through and in the amplification spectrum. High variation lowers detection accuracy. By controlling spectral attenuation as described herein, the variation in wavelength dependent brightness can be reduced.

The examples described are for 1D switching, however it will be understood that the principle is adaptable for 2D operation.

The programmable deflection planes and programmable attenuation planes described herein may be SLM planes. The SLM plane may be a MEMS mirror array. The SLM plane may be an LCoS device. Alternatively, the SLM plane may be another local configuration device capable of applying a deflection to a channel from the input, and capable of changing the polarisation of beams incident on it.

In the examples described herein the programmable deflection plane and programmable attenuation plane are incorporated onto a single SLM device. This utilises fewer components, reduces control complexity and hence cost compared to if the programmable deflection plane and programmable attenuation plane are on separate SLM devices. Alternatively, the programmable deflection plane and programmable attenuation plane may be on separate SLM devices.

In the examples described herein, optical components are used to route data through the described switches. There is no absorption and re-emission of light, thereby avoiding the lag associated with transmitting data through electronical switches. The optical components also have lower power consumption than equivalent electronical implementations.

The examples described herein incorporate a diffraction grating or grism. However, any demultiplexer which demultiplexes light signals into spatially separated data channels may be used instead of a diffraction grating in any of the examples. Similarly, any multiplexer which multiplexes spatially separated data channels into multiplexed light signals may be used instead of a diffraction grating in any of the examples. Any suitable optical dispersion device may be used as a multiplexer and/or a demultiplexer.

Lenses and other optical components described herein as single structures may be implemented using assemblies having a plurality of components which achieve the same optical effect. Examples of such assemblies are: achromatic doublets, achromatic triplets, Cook doublets, telescopes and microscopes for imaging lenses. The lenses described herein may be implemented using other optics with the same optical power. For example, a curved mirror may be used as a lens. For example, multiple lens elements, mirrors, mirror arrays, catadioptric systems, holographic optical elements or diffractive optical elements may be used as a lens. Separate elements, for example 4F lenses, with the same optical properties can be arranged as separate passes through or from a single physical element. Cylindrical mirrors may be replaced by a lens and a flat mirror.

The applicant hereby discloses in isolation each individual feature described herein and any combination of two or more such features, to the extent that such features or combinations are capable of being carried out based on the present specification as a whole in the light of the common general knowledge of a person skilled in the art, irrespective of whether such features or combinations of features solve any problems disclosed herein, and without limitation to the scope of the claims. The applicant indicates that aspects of the present invention may consist of any such individual feature or combination of features. In view of the foregoing description it will be evident to a person skilled in the art that various modifications may be made within the scope of the invention.

CLAIMS

1. An optical switch comprising:

an input port configured to transport an optical signal having at least one component frequency channel;

a set of output ports, each output port configured to transport an optical signal having at least one component frequency channel;

a programmable deflection plane configured to deflect beams of spatially separated frequency channels incident on it from the input port to form a deflected array of beams;

a programmable attenuation plane configured to attenuate beams of spatially separated frequency channels incident on it towards the set of output ports as an attenuated array of beams; and

an optical assembly positioned in the optical path between the programmable deflection plane and the programmable attenuation plane, the optical assembly configured to image each component frequency channel of the deflected array of beams to at least two unique positions on the programmable attenuation plane, those at least two unique positions being independent of the deflection applied by the programmable deflection plane.

2. An optical switch as claimed in claim 1, wherein the optical assembly is configured to, for each component frequency channel of the deflected array of beams, image positive diffraction orders onto a first of the at least two unique positions on the programmable attenuation plane, and image negative diffraction orders onto a second of the at least two unique positions on the programmable attenuation plane.

3. An optical switch as claimed in claim 1 or 2, wherein the optical assembly is at least partially located at a Fourier conjugate plane of the programmable deflection plane, so as to cause a Fourier conjugate image of the programmable deflection plane to be formed on an optical plane of the optical assembly that has a spatial distribution dependent on the deflection applied by the programmable deflection plane.

4. An optical switch as claimed in any preceding claim, wherein the optical assembly is configured to alter the propagation angles of the deflected array of beams incident on it as a function of spatial position in the plane normal to the propagation and dispersion planes.

5. An optical switch as claimed in claim 3 or claim 4 when dependent on claim 3, wherein the optical assembly is configured to form a Fourier conjugate image of the optical plane of the optical assembly on the programmable attenuation plane.

6. An optical switch as claimed in claim 4, or claim 5 when dependent on claim 4, wherein the at least two unique image positions of each component frequency channel of the deflected array of beams are separated normal to the dispersion plane in a spatial distribution dependent on the altered propagation angles.

7. An optical switch as claimed in any preceding claim, wherein the optical assembly comprises a faceted mirror.

8. An optical switch as claimed in any of claims 1 to 6, wherein the optical assembly comprises an optical microelectromechanical system (MEMS) mirror layer.

9. An optical switch as claimed in any preceding claim, wherein the optical assembly comprises a polarisation element configured to polarise or retard the phase of each component frequency channel of the deflected array of beams in one polarisation axis.

10. An optical switch as claimed in claim 9, wherein the one polarisation axis is at 45° to the extraordinary axis of the programmable attenuation plane.

11. An optical switch as claimed in claim 9 or 10, wherein the polarisation element is a half waveplate.

12. An optical switch as claimed in any preceding claim, further comprising a further optical assembly, the further optical assembly at least partially located at the Fourier conjugate plane of the programmable attenuation plane, so as to cause a Fourier

conjugate image of the programmable attenuation plane to be formed on an optical plane of the further optical assembly.

13. An optical switch as claimed in claim 12 when dependent on claim 4, wherein the further optical assembly is configured to alter the propagation angles of the attenuated array of beams incident on it as a function of spatial position in the plane normal to the propagation and dispersion planes, the further optical assembly applying an inverse optical deflection to the optical assembly.

14. An optical switch as claimed in claim 13, wherein the further optical assembly comprises a further faceted mirror.

15. An optical switch as claimed in claim 13, wherein the further optical assembly comprises a further optical microelectromechanical system (MEMS) mirror layer.

16. An optical switch as claimed in any of claims 12 to 15 when dependent on any of claims 9 to 11, wherein the further optical assembly comprises a polarisation selection element that propagates only one polarisation phase of the attenuated array of beams towards the set of output ports.

17. An optical switch as claimed in claim 16, wherein the polarisation selection element is a 45° sample polariser.

18. An optical switch as claimed in any preceding claim, wherein the programmable attenuation plane is configured to independently control the intensity of optical beams incident at different positions on it.

19. An optical switch as claimed in claim 18 when dependent on any of claims 9 to 11, wherein the programmable attenuation plane is configured to apply a programmable retardation to the one polarisation axis of the spatially separated frequency channels incident on it.

20. An optical switch as claimed in any preceding claim, wherein the programmable deflection plane and the programmable attenuation plane are different portions of the same spatial light modulator (SLM) device.

21. An optical switch as claimed in claim 20, wherein the programmable deflection plane and the programmable attenuation plane are different portions of the same SLM plane.

22. An optical switch as claimed in any preceding claim, further comprising a demultiplexer in the optical path between the input port and the programmable deflection plane, the demultiplexer configured to spatially separate the component frequency channels of the optical signal in a dispersion direction normal to the propagation direction of the optical signal.

23. An optical switch as claimed in any preceding claim, further comprising a multiplexer in the optical path between the programmable attenuation plane and the set of output ports, the multiplexer configured to combine the spatially separated frequency channels of the attenuated array of beams from the programmable attenuation plane.

24. An optical switch as claimed in claim 22, or claim 23 when dependent on claim 22, further comprising:

further input ports, the input port and further input ports forming a set of input ports, each input port of the set of input ports configured to transport an optical signal having at least one component frequency channel; and

a gap optic located at the demultiplexer or in the optical path between the demultiplexer and the programmable deflection plane where a coincident image of the optical signals from the set of input ports is formed, the gap optic configured to: (i) propagate the optical signals to the programmable deflection plane; and (ii) deflect the deflected array of beams incident on the gap optic.

25. An optical switch as claimed in any preceding claim, further comprising a space optic located in the optical path between the programmable deflection plane and the

programmable attenuation plane, the space optic configured to increase the spacing between the spatially separated frequency channels of the deflected array of beams whilst maintaining the beam size of the deflected array of beams.

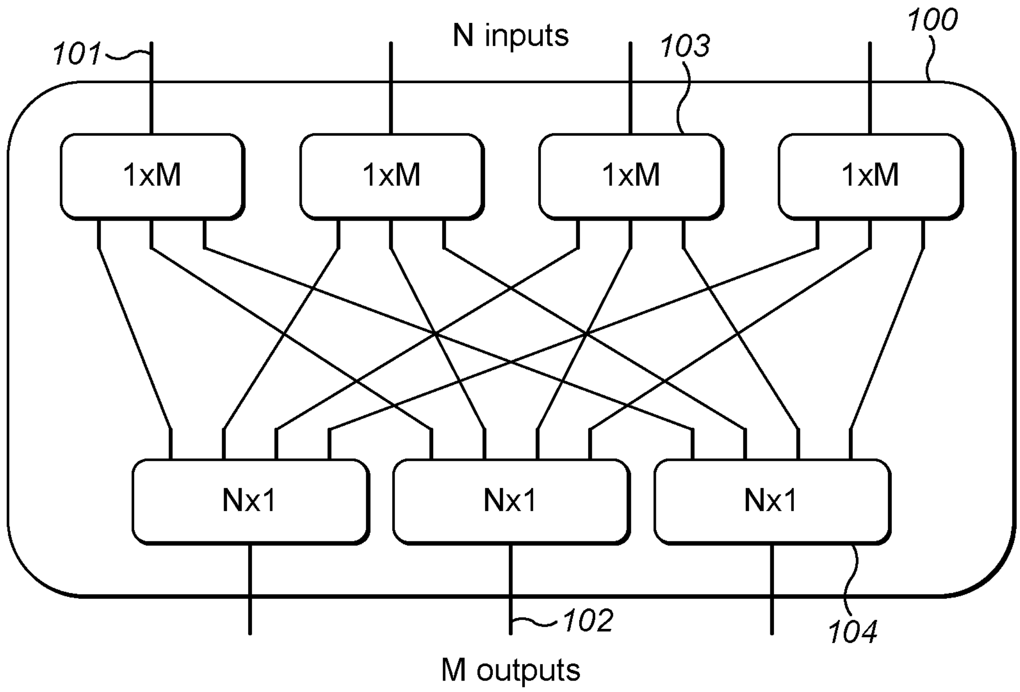
N inputs
101
103
100
1xM
1xM
1xM
1xM
Nx1
Nx1
Nx1
102
104
M outputs

FIG. 1

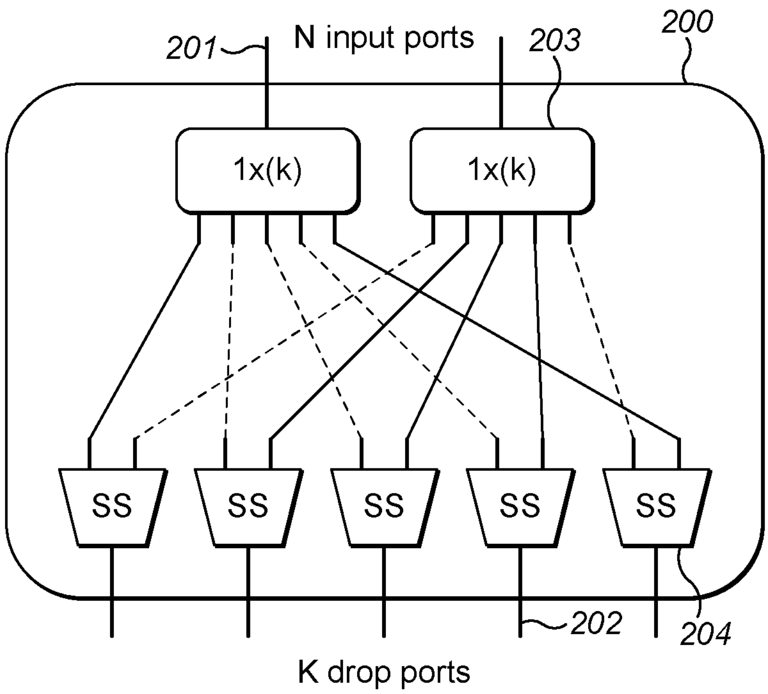
N input ports
201
203
200
1x(k)
1x(k)
SS
SS
SS
SS
SS
202
204
K drop ports

FIG. 2

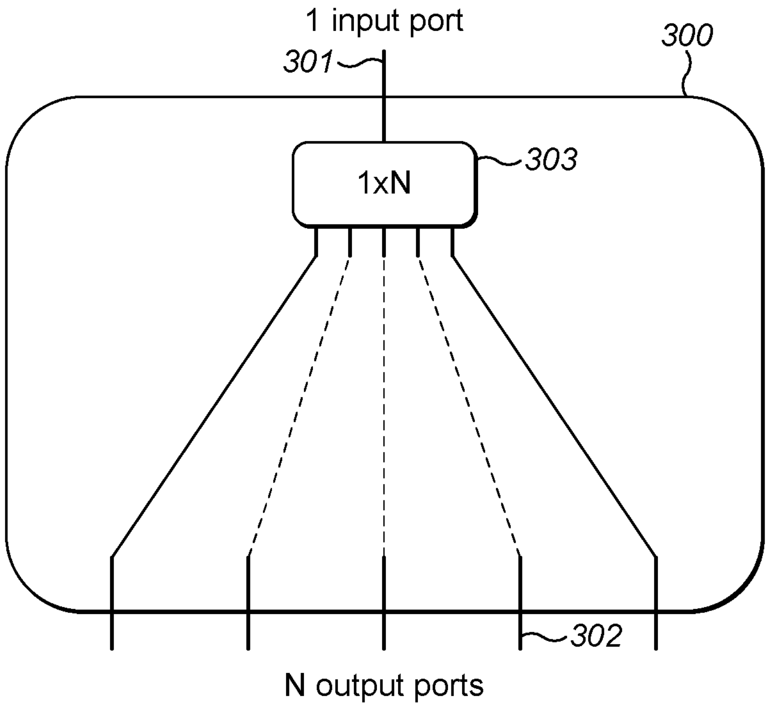
1 input port
300
301
303
1xN
302
N output ports

FIG. 3

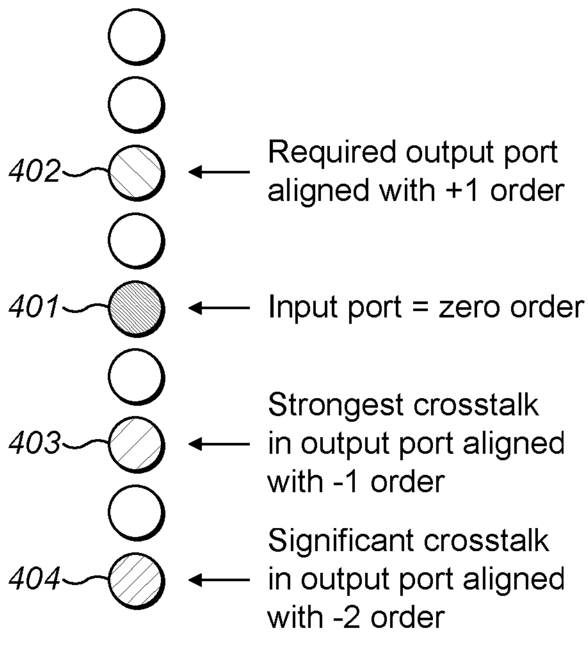
402
Required output port aligned with +1 order
401
Input port = zero order
403
Strongest crosstalk in output port aligned with -1 order
404
Significant crosstalk in output port aligned with -2 order

FIG. 4

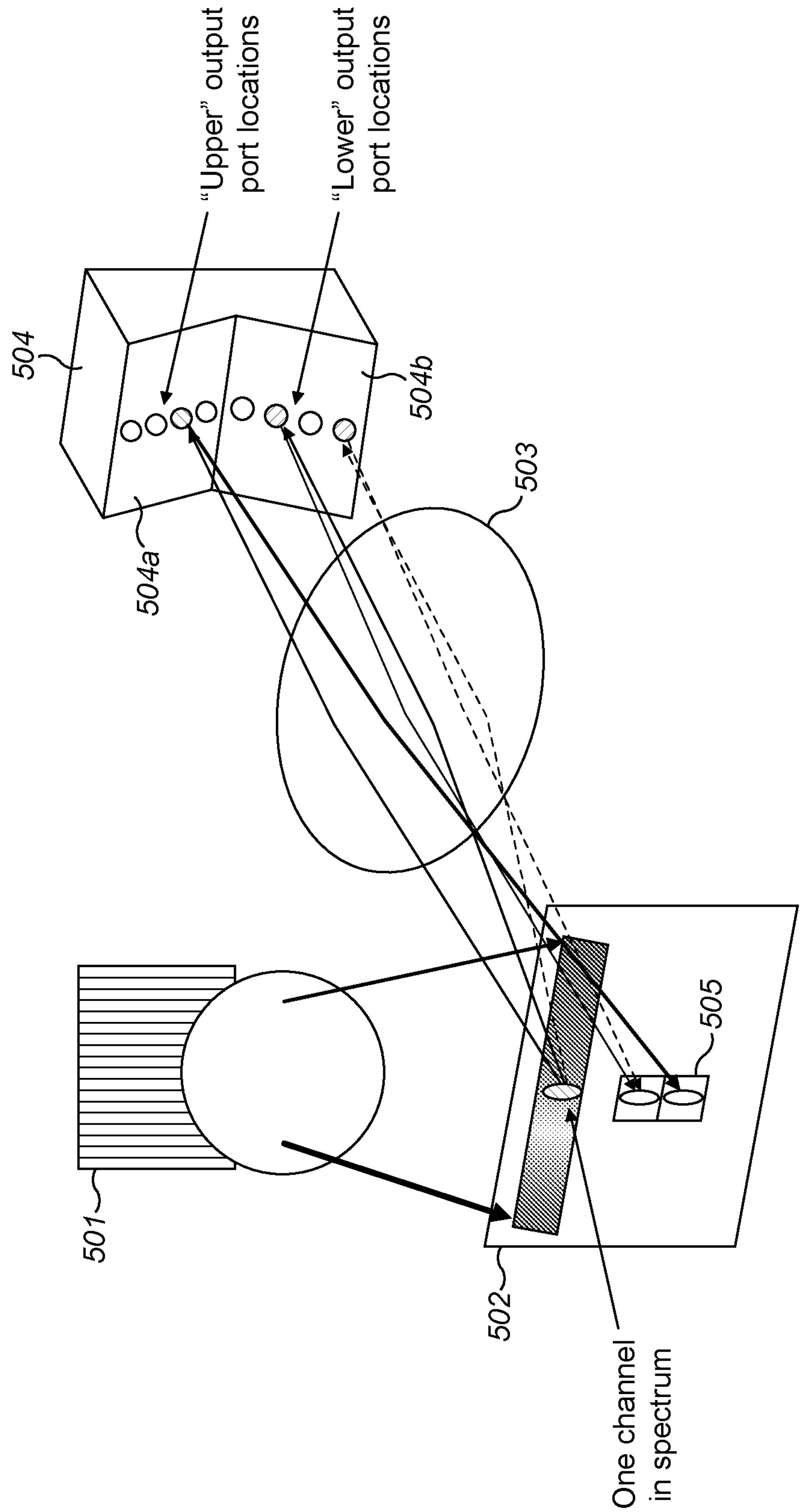
“Upper” output port locations
“Lower” output port locations
504
504a
504b
503
501
502
505
One channel in spectrum

FIG. 5

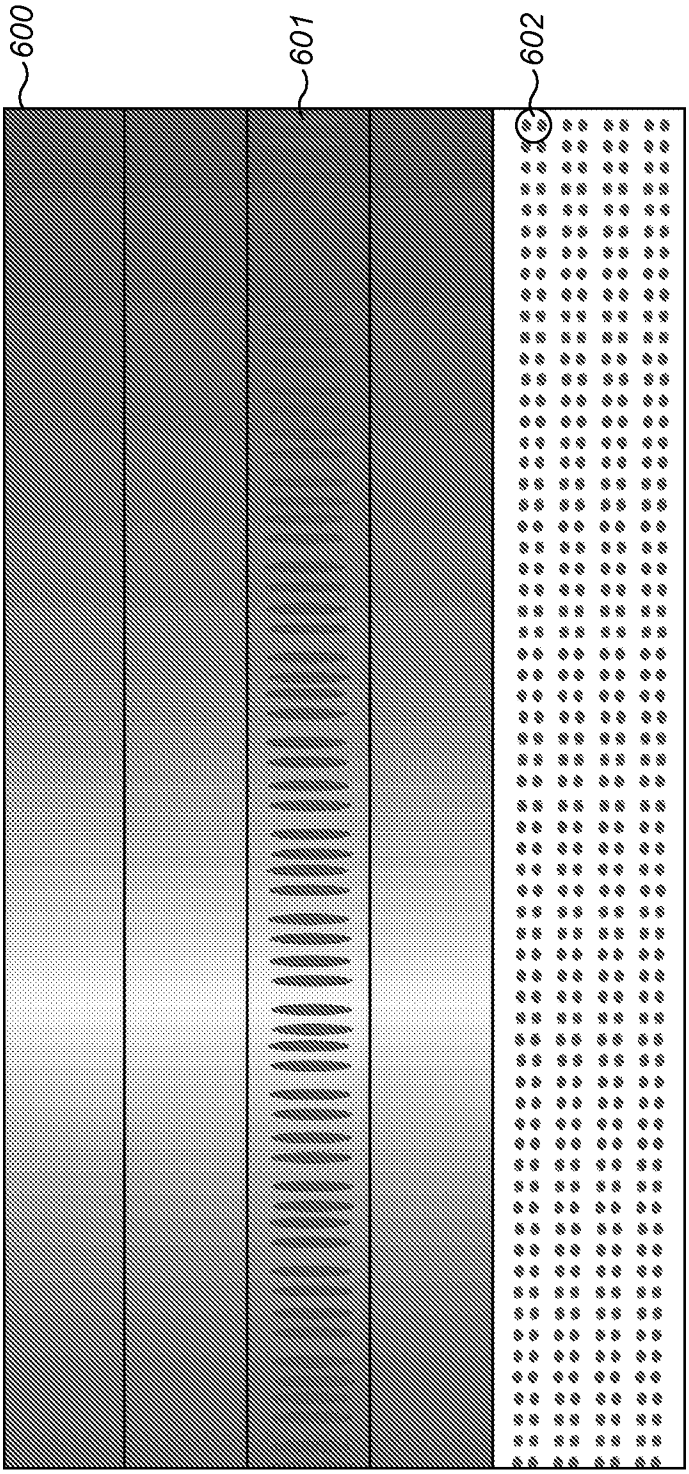

FIG. 6

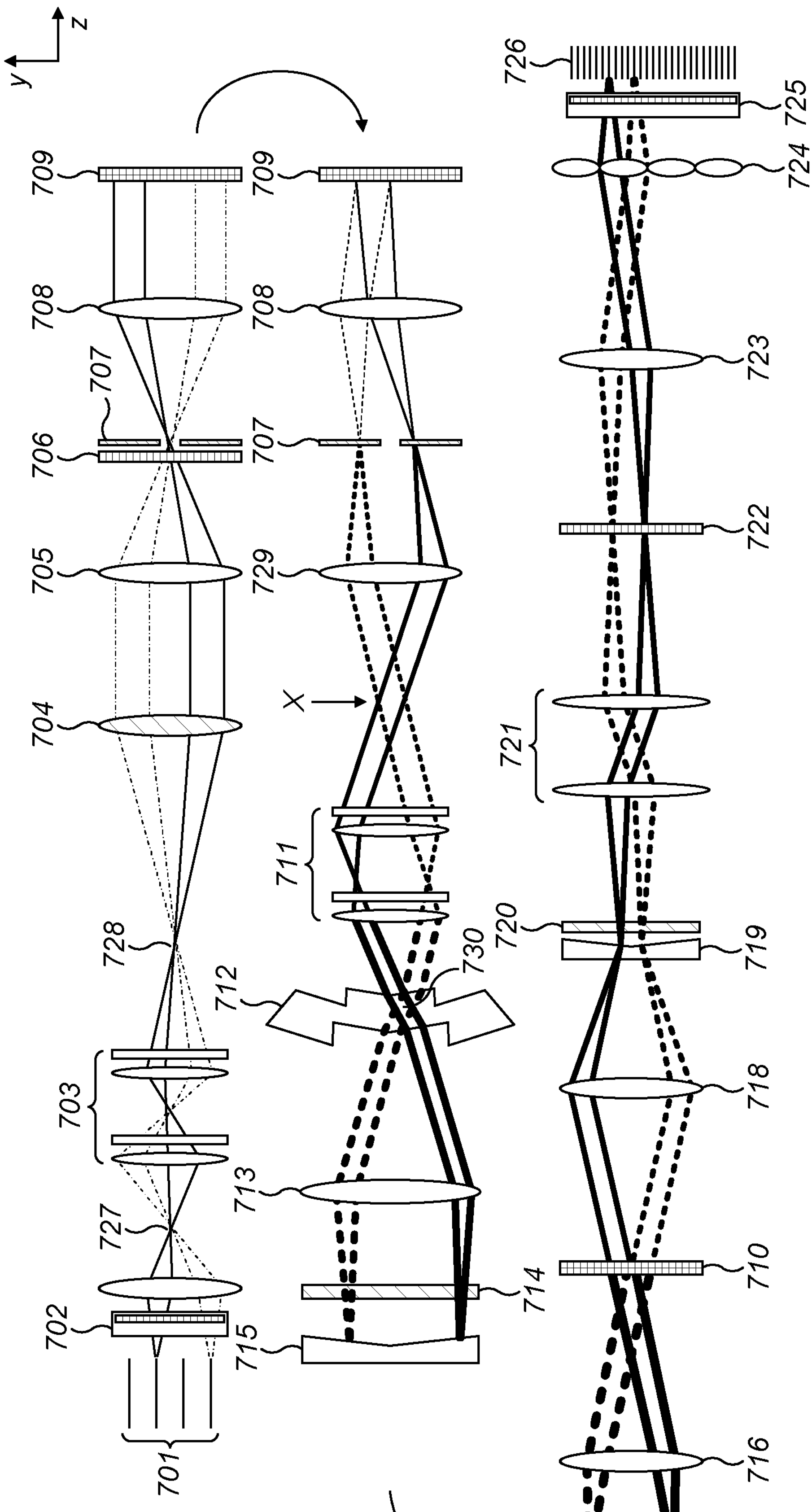
z
y
701
702
727
703
728
704
705
706
707
708
709
709
708
707
729
X
711
730
712
713
714
715
726
725
724
723
722
721
720
719
718
710
716
715

FIG. 7a

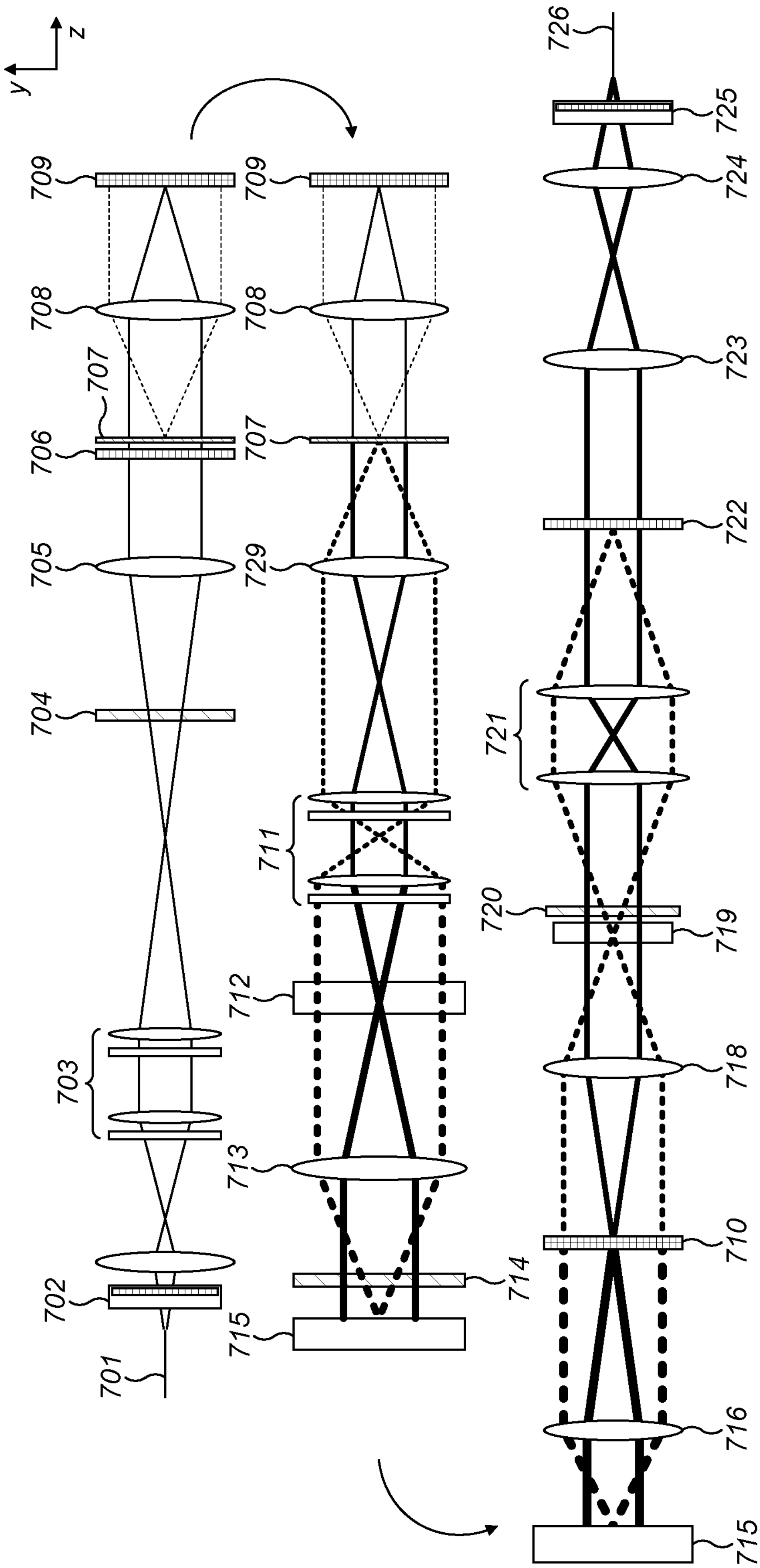
y
z
701
702
703
704
705
706
707
708
709
729
711
712
713
714
715
710
716
718
719
720
721
722
723
724
725
726

FIG. 7b

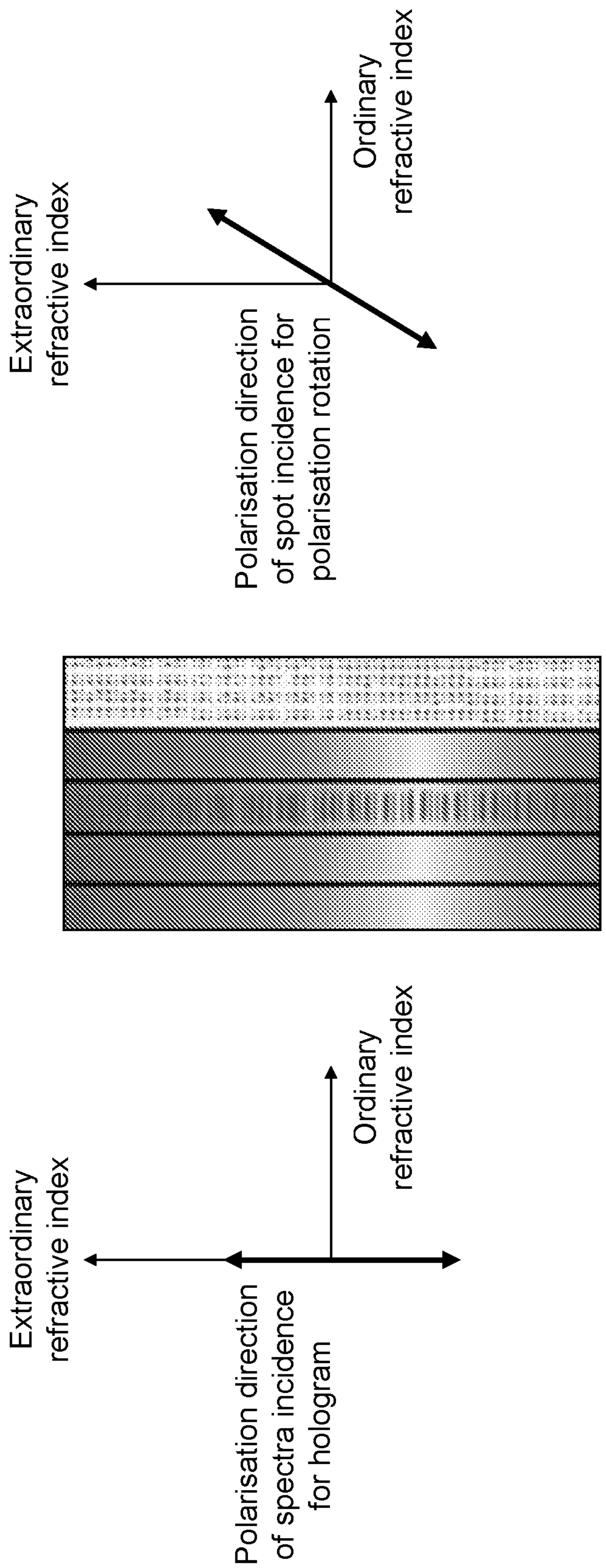
Extraordinary refractive index
Ordinary refractive index
Polarisation direction of spot incidence for polarisation rotation
Extraordinary refractive index
Ordinary refractive index
Polarisation direction of spectra incidence for hologram

FIG. 8

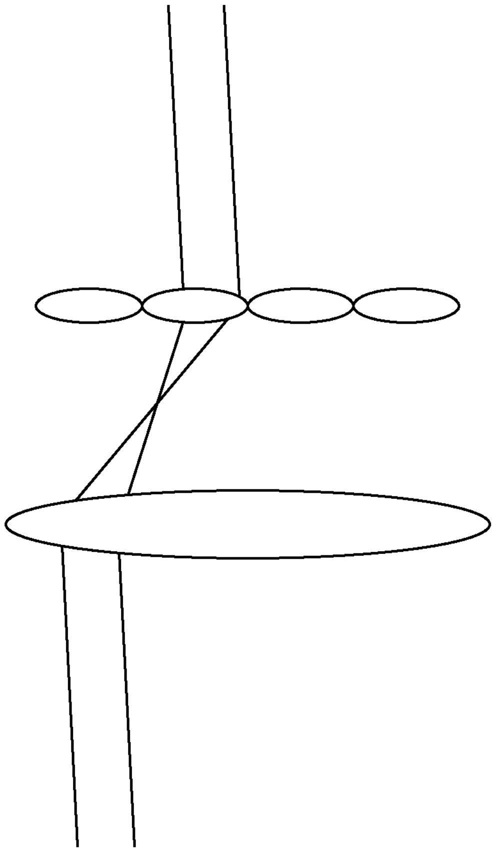

FIG. 9b

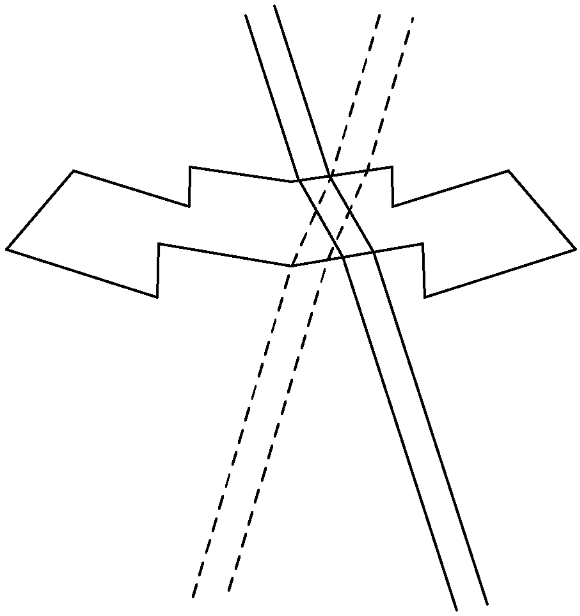

FIG. 9a

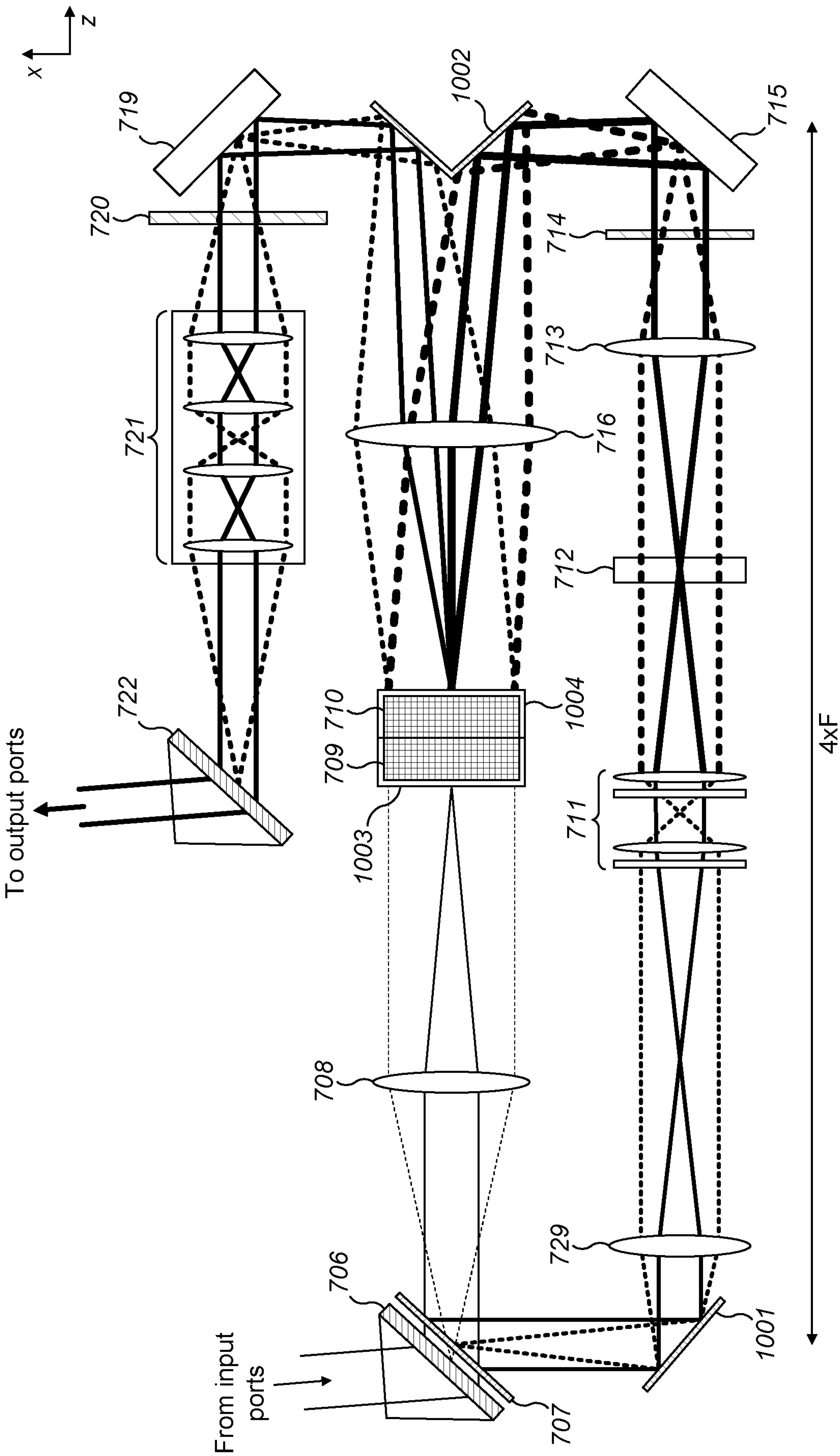
z
x
719
1002
715
720
714
713
721
716
712
722
710
709
1004
1003
711
4xF
To output ports
708
729
706
1001
From input ports
707

FIG. 10

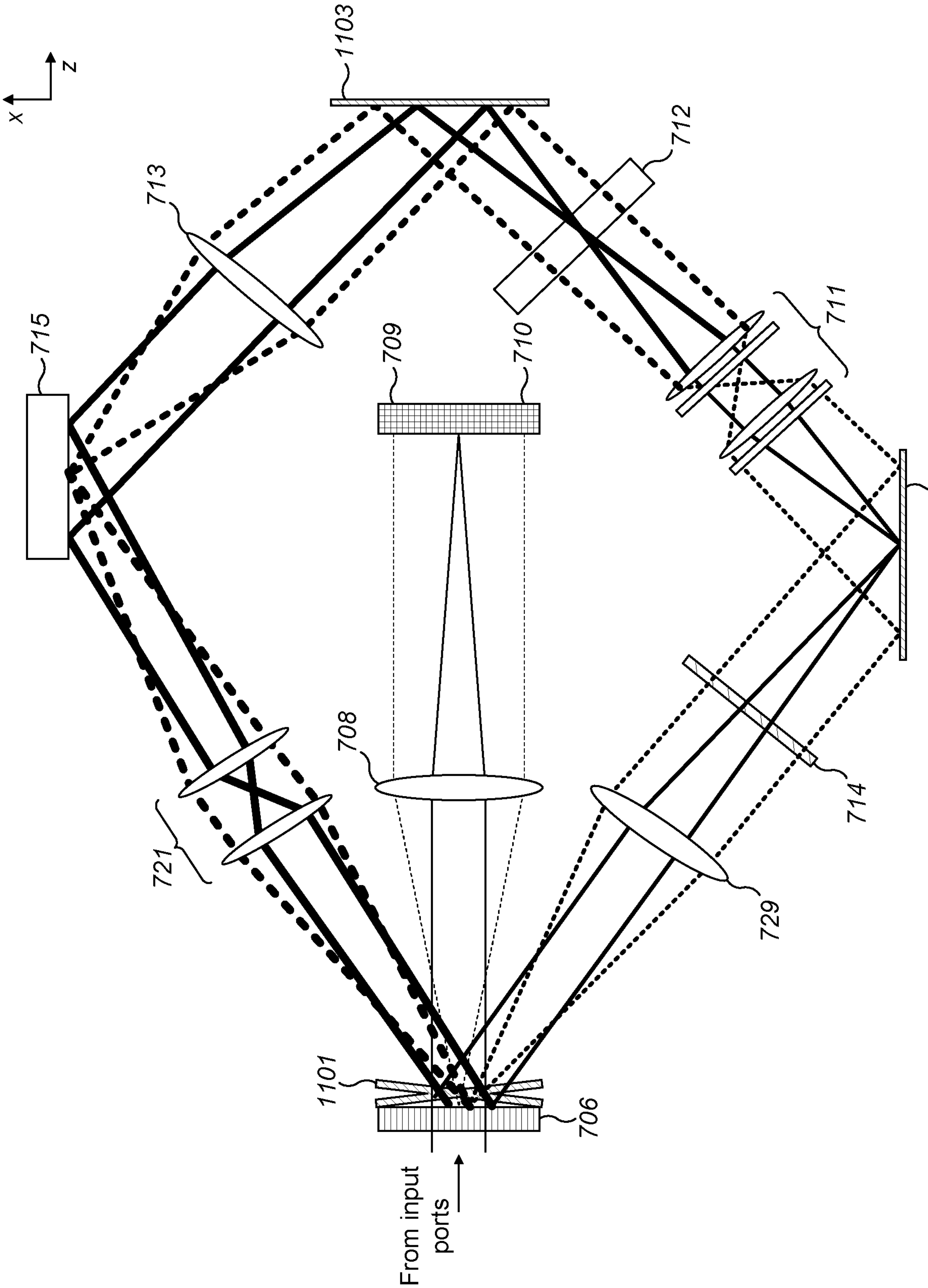
z
x
1103
712
713
711
715
709
710
1102
708
714
721
729
1101
706
From input ports

FIG. 11a

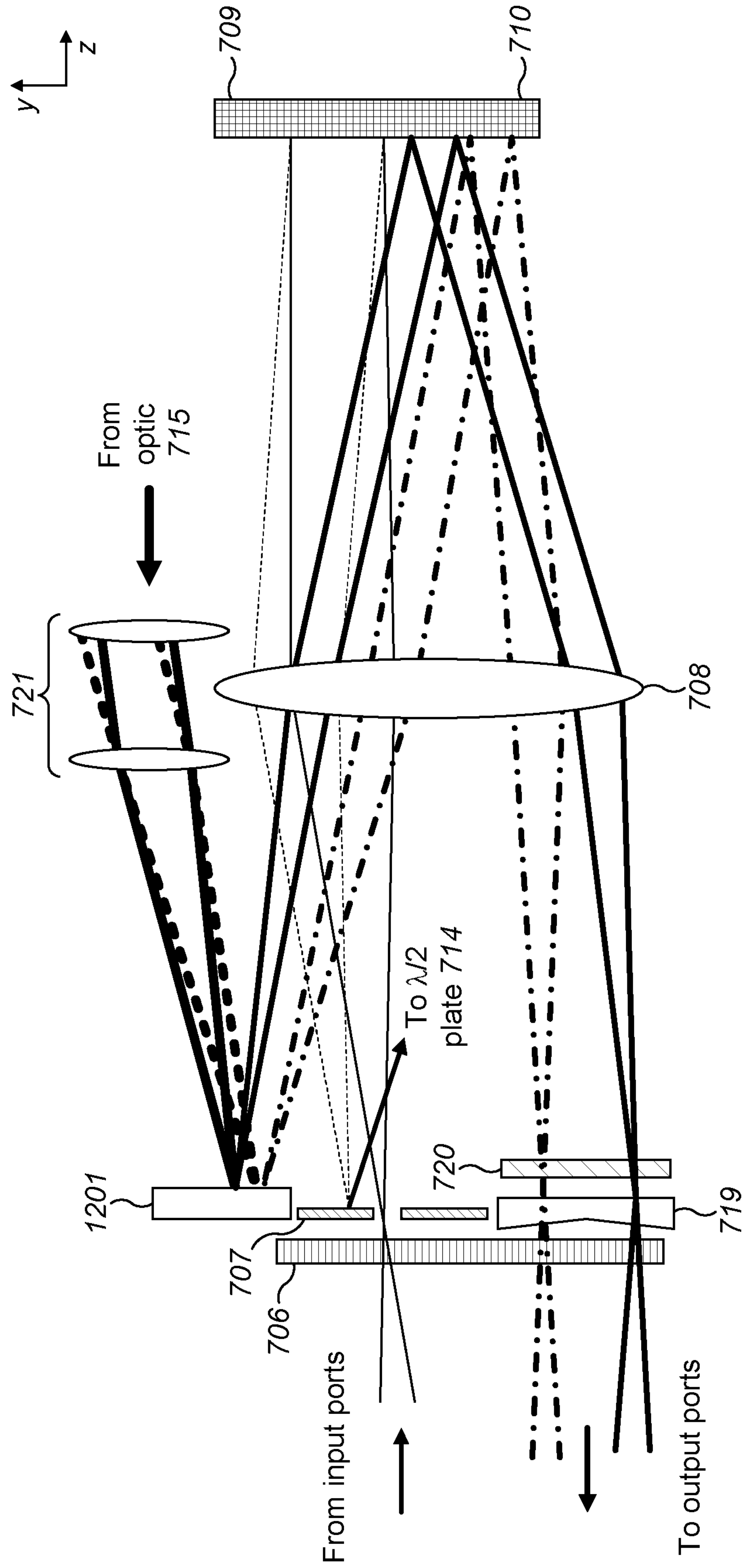
709
710
y
z
From optic 715
721
708
To λ/2 plate 714
1201
707
706
720
719
From input ports
To output ports

FIG. 11b

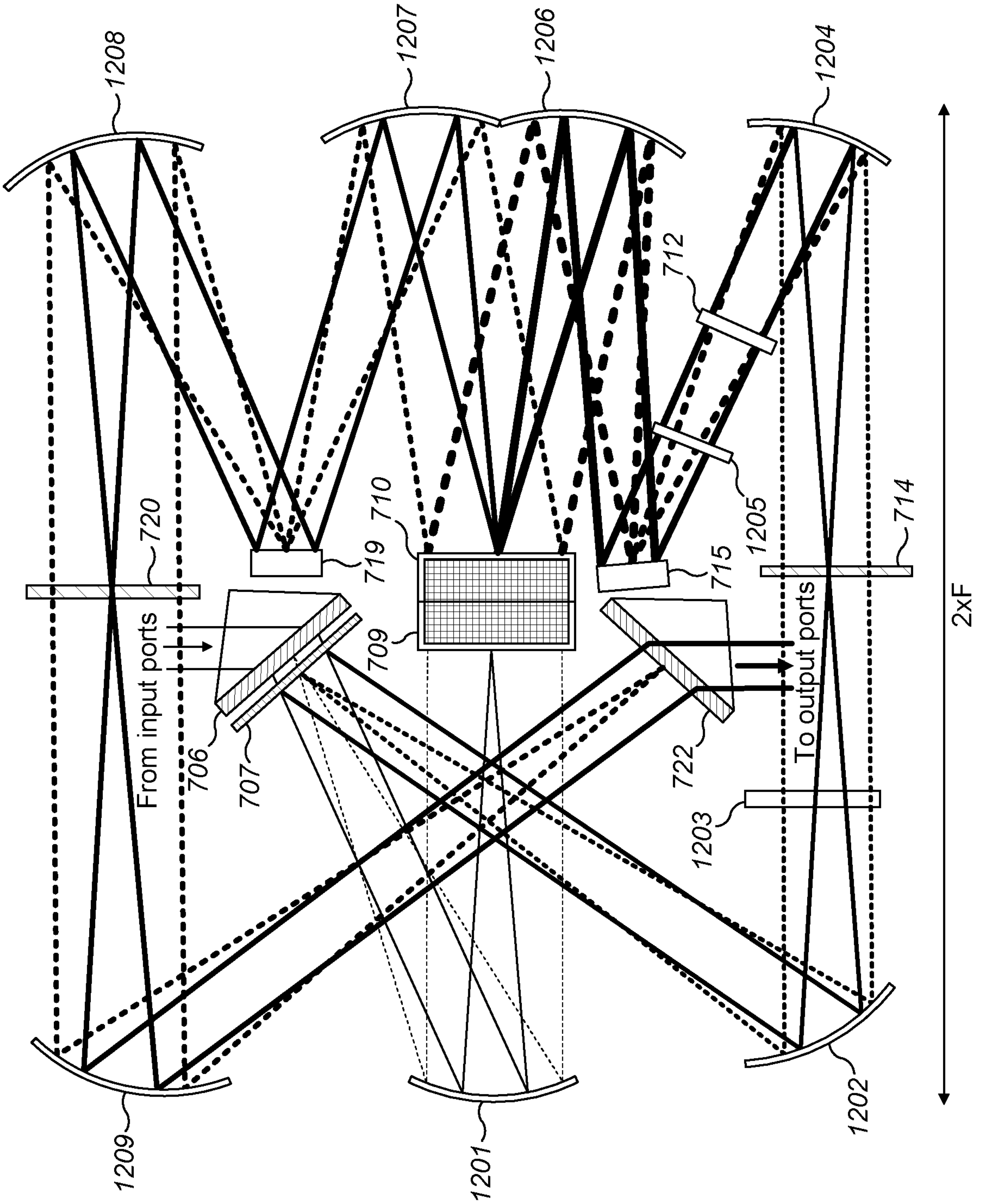
1208
1207
1206
1204
712
720
719
710
709
715
1205
714
From input ports
To output ports
706
707
722
1203
2xF
1209
1201
1202

FIG. 12

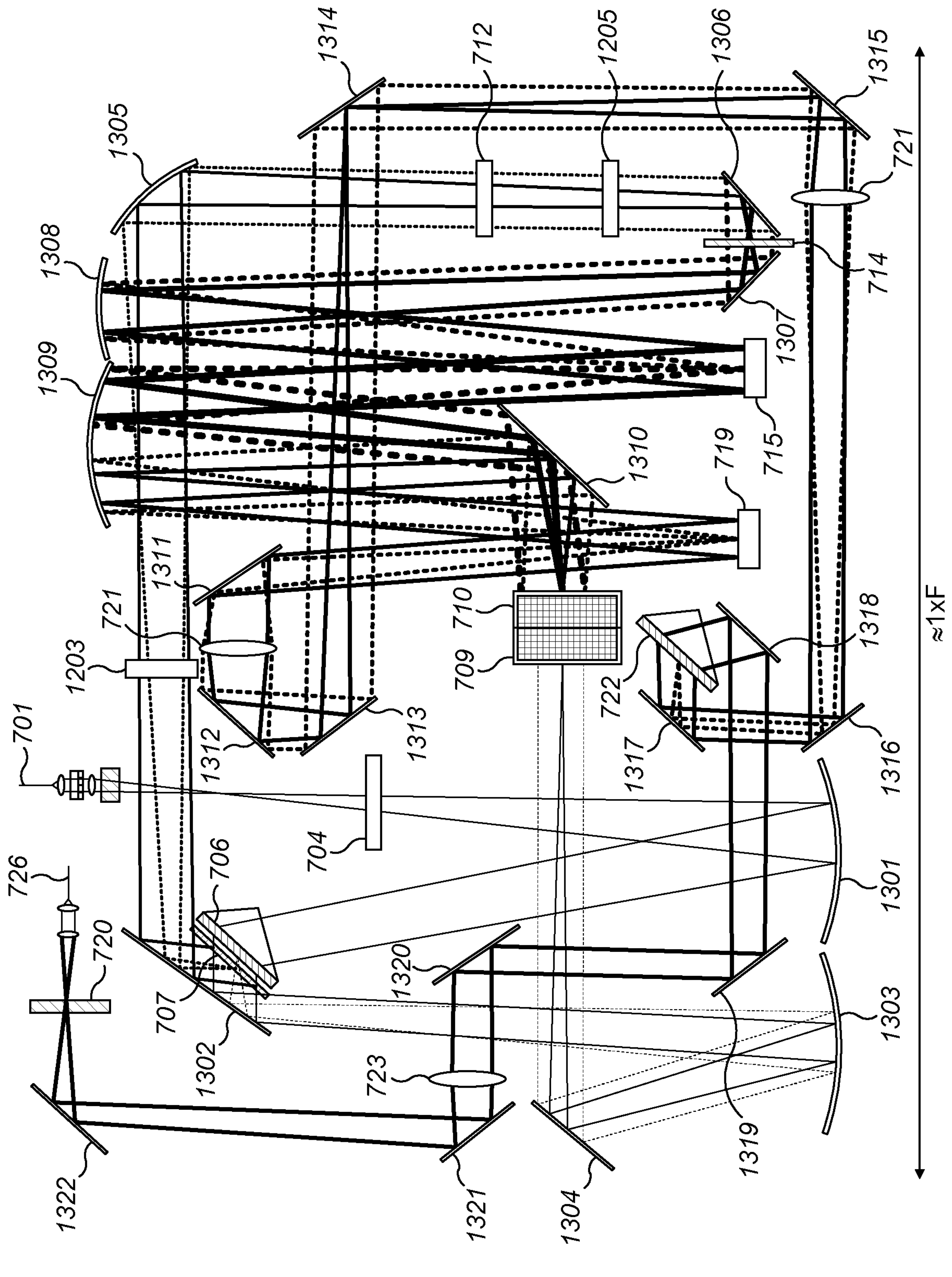
1314
712
1205
1306
1315
1305
721
1308
714
1307
1309
715
1310
719
1311
721
1203
710
709
1318
722
701
1313
1312
1317
1316
704
726
706
1301
720
707
1320
1302
1303
723
1319
1322
1321
1304
≈1xF

FIG. 13

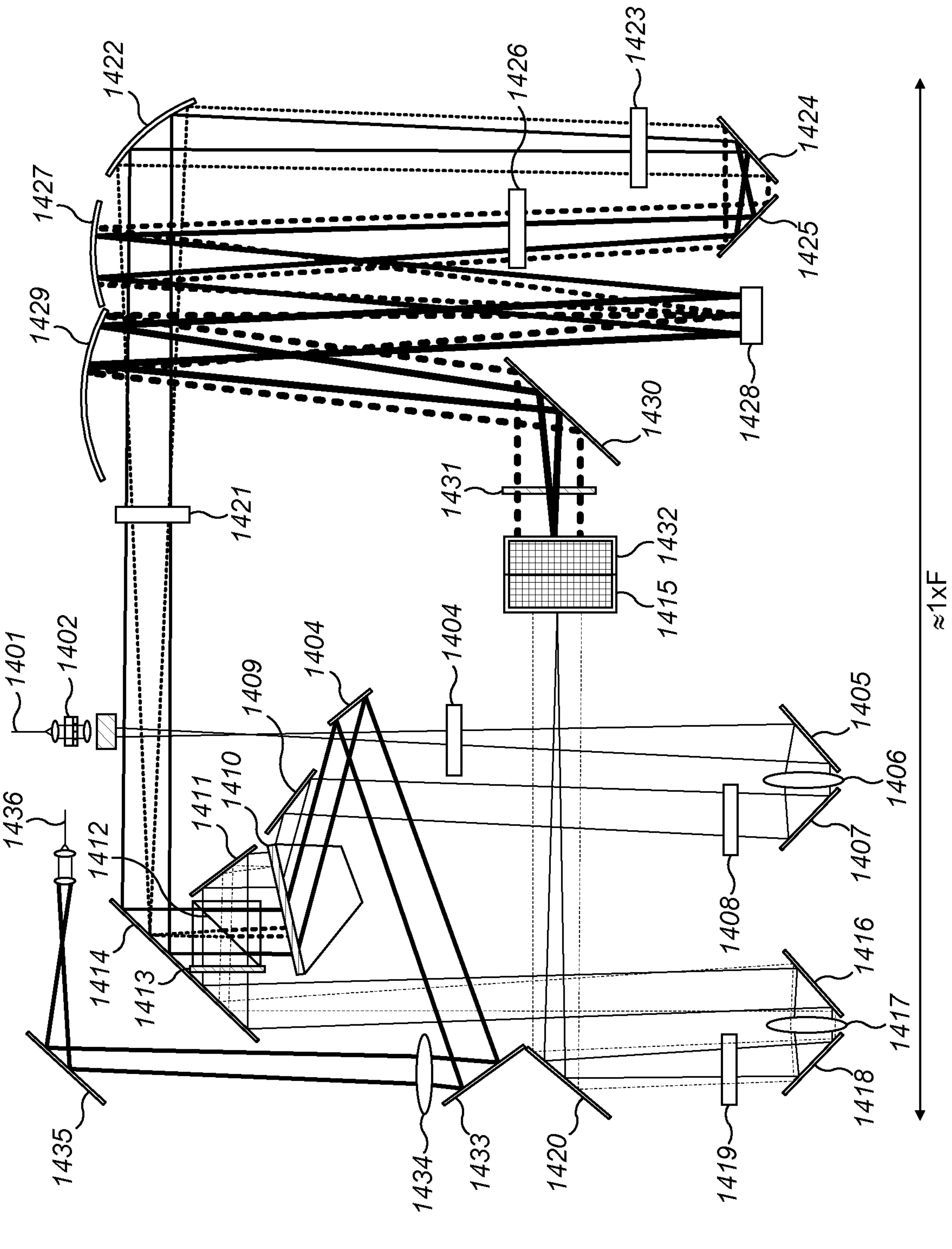
1401
1402
1404
1404
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
≈1xF

FIG. 14

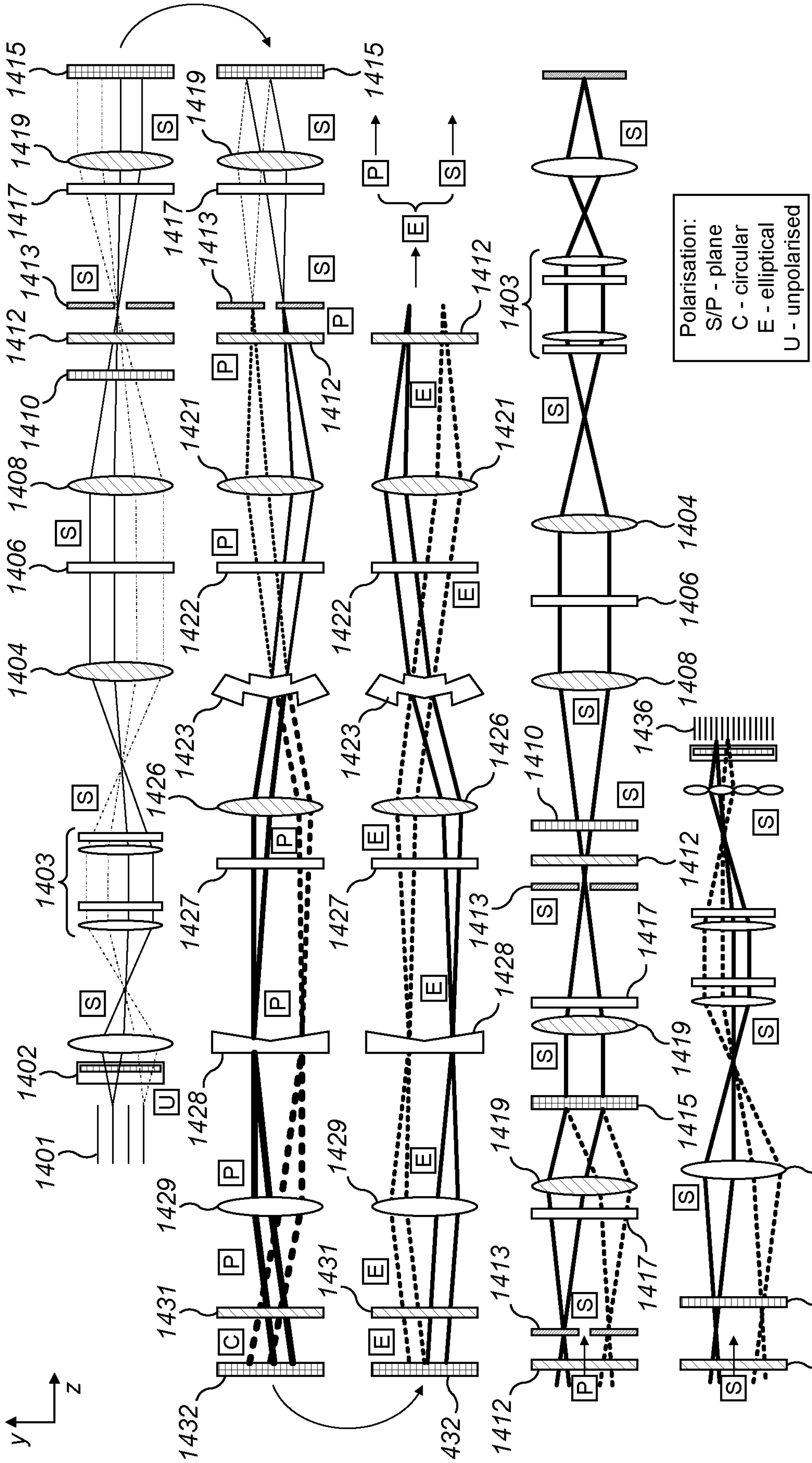
Polarisation:
S/P - plane
C - circular
E - elliptical
U - unpolarised

FIG. 15a

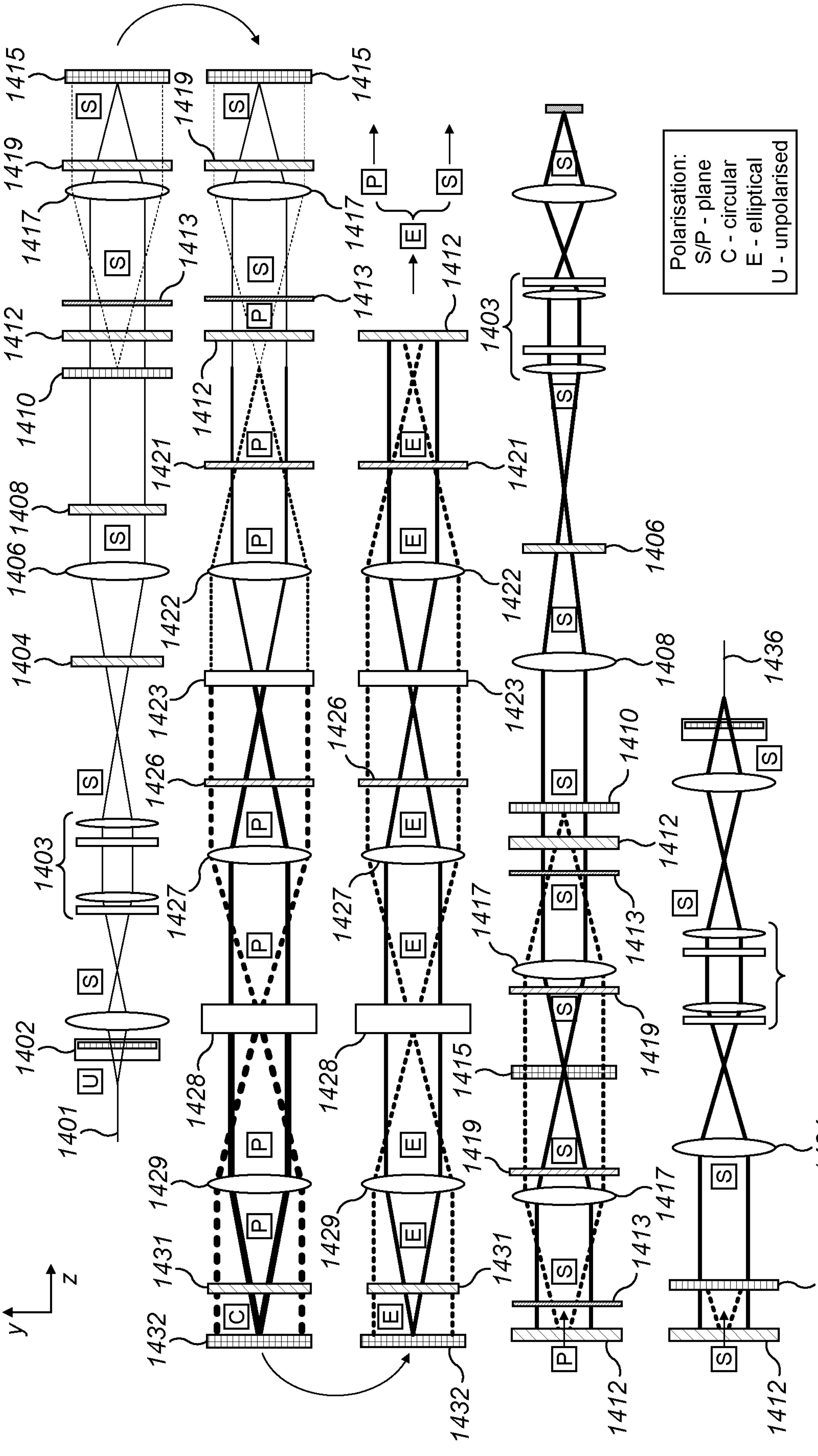
Polarisation:
S/P - plane
C - circular
E - elliptical
U - unpolarised
1401
1402
1403
1404
1406
1408
1410
1412
1413
1415
1417
1419
1421
1422
1423
1426
1427
1428
1429
1431
1432
1434
1436
y
z

FIG. 15b

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2023/053170

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B6/35 H04Q11/00
ADD. G02B6/293

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)
G02B H04Q

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2020/225417 A1 (YAN YUNFEI [CN] ET AL) 16 July 2020 (2020-07-16) paragraphs [0085] - [0116]; figures 4,5	1-25
A	US 2017/075075 A1 (FRISKEN STEVEN JAMES [AU]) 16 March 2017 (2017-03-16)	1-25
A	US 2011/234951 A1 (COHEN GIL [US]) 29 September 2011 (2011-09-29)	1-25
A	US 6 525 863 B1 (RIZA NABEEL A [US]) 25 February 2003 (2003-02-25)	1-25
A	US 2013/070320 A1 (HOLMES MELANIE [GB]) 21 March 2013 (2013-03-21)	1-25
A	US 2002/176151 A1 (MOON JOHN [US] ET AL) 28 November 2002 (2002-11-28)	1-25

-/--

[X] Further documents are listed in the continuation of Box C.

[X] 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	Date of mailing of the international search report
6 February 2024	21/02/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Kapsalis, Alexandros

1

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2023/053170

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 2022/252793 A1 (JIANG GUOMIN [US] ET AL) 11 August 2022 (2022-08-11) -----	1-25

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2023/053170

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 2020225417	A1	16-07-2020	CN	108352921	A	31-07-2018
			EP	3364575	A1	22-08-2018
			ES	2923645	T3	29-09-2022
			US	2018267247	A1	20-09-2018
			US	2020225417	A1	16-07-2020
			WO	2017088115	A1	01-06-2017
US 2017075075	A1	16-03-2017	CN	106416097	A	15-02-2017
			US	2017075075	A1	16-03-2017
			US	2020264379	A1	20-08-2020
			WO	2015134393	A1	11-09-2015
US 2011234951	A1	29-09-2011	NONE			
US 6525863	B1	25-02-2003	NONE			
US 2013070320	A1	21-03-2013	AU	2002321598	A1	18-03-2003
			EP	1466218	A2	13-10-2004
			EP	2508951	A1	10-10-2012
			US	2005018259	A1	27-01-2005
			US	2007035803	A1	15-02-2007
			US	2007268537	A1	22-11-2007
			US	2008145053	A1	19-06-2008
			US	2010209109	A1	19-08-2010
			US	2013070320	A1	21-03-2013
			US	2015177685	A1	25-06-2015
			US	2017102603	A1	13-04-2017
			US	2019219889	A1	18-07-2019
			US	2019243211	A1	08-08-2019
			WO	03021341	A2	13-03-2003
US 2002176151	A1	28-11-2002	CA	2443356	A1	17-10-2002
			EP	1386192	A2	04-02-2004
			US	2002176151	A1	28-11-2002
			WO	02082165	A2	17-10-2002
US 2022252793	A1	11-08-2022	CN	114915367	A	16-08-2022
			KR	20220115537	A	17-08-2022
			US	2022252793	A1	11-08-2022
			US	2023061448	A1	02-03-2023