



(86) Date de dépôt PCT/PCT Filing Date: 1998/01/05

(87) Date publication PCT/PCT Publication Date: 1998/07/30

(45) Date de délivrance/Issue Date: 2002/08/06

(85) Entrée phase nationale/National Entry: 1999/06/28

(86) N° demande PCT/PCT Application No.: US 1998/006809

(87) N° publication PCT/PCT Publication No.: 1998/033289

(30) Priorité/Priority: 1997/01/08 (780,291) US

(51) Cl.Int.<sup>6</sup>/Int.Cl.<sup>6</sup> H04J 14/00, H04B 10/00

(72) Inventeurs/Inventors:

WU, KUANG-YI, US;

LIU, JIAN-YU, US

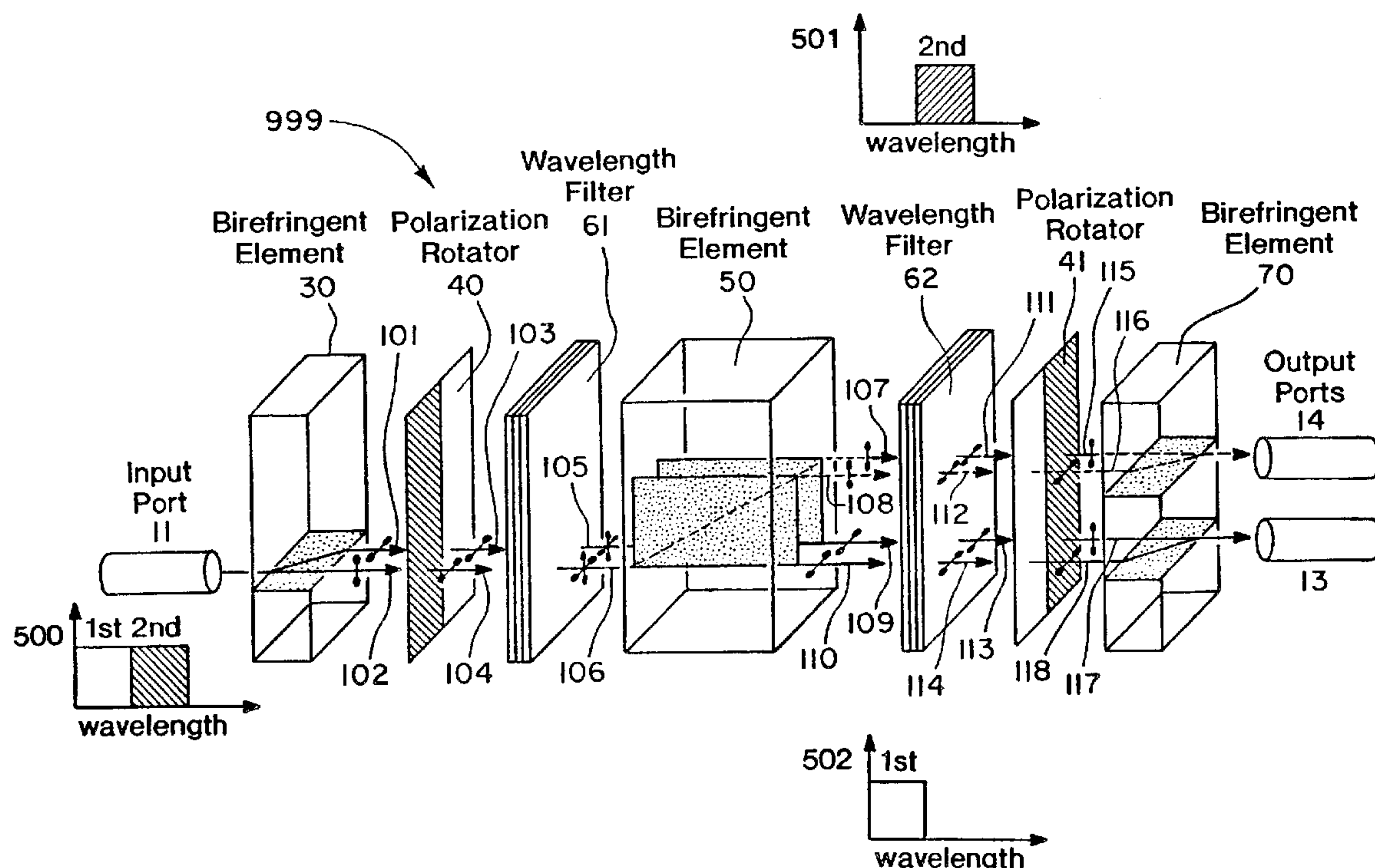
(73) Propriétaire/Owner:

CHORUM TECHNOLOGIES LP, US

(74) Agent: BORDEN LADNER GERVAIS LLP

(54) Titre : ROUTEUR A COMMUTATION DE LONGUEURS D'ONDE

(54) Title: SWITCHABLE WAVELENGTH ROUTER



(57) Abrégé/Abstract:

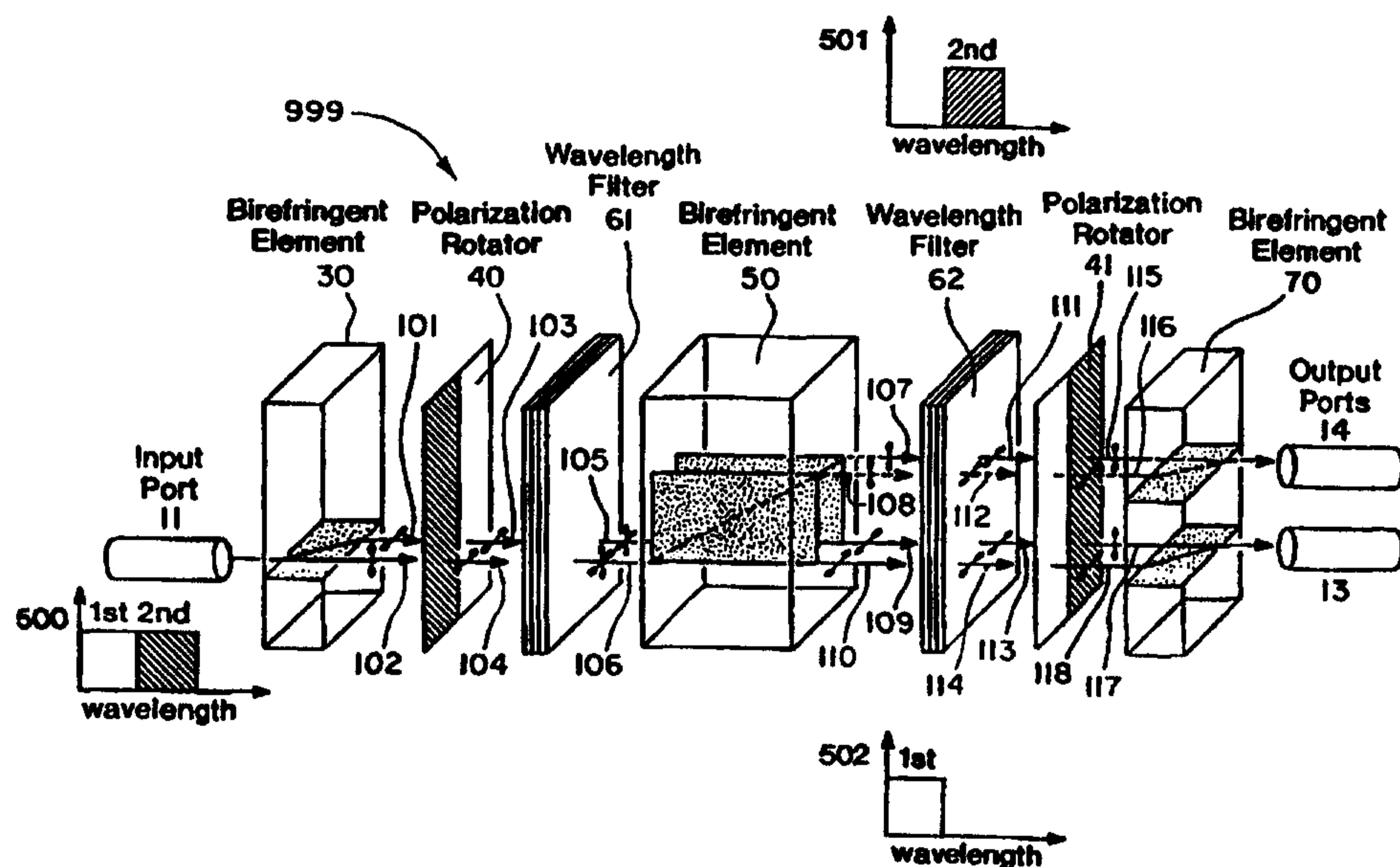
A switchable wavelength router (999) having an input port (11) for the incoming WDM signal (500) and two output ports (13, 14) for de-multiplexing the WDM signals (500). The router (999) divides the received optical signals into divided optical signals (101, 102) comprising a subset of the channels and spatially positions the divided optical signals in response to a control signal applied to the router (999). For example, the router (999) can divide a received WDM signal (500) into two subsets that are either single channel or WDM signals. Multiple routers (999) can be cascaded to form a  $2^n$  switchable wavelength router, where  $n$  is the number of stages of wavelength routers.

**PCT**WORLD INTELLECTUAL PROPERTY ORGANIZATION  
International Bureau

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

(51) International Patent Classification <sup>6</sup> : H04J 14/00, H04B 10/00	<b>A3</b>	(11) International Publication Number: <b>WO 98/33289</b> (43) International Publication Date: 30 July 1998 (30.07.98)
(21) International Application Number: PCT/US98/06809 (22) International Filing Date: 5 January 1998 (05.01.98) (30) Priority Data: 780,291 8 January 1997 (08.01.97) US (71) Applicant: MACRO-VISION COMMUNICATIONS, INC. [US/US]; 5490 Conestoga Court, Boulder, CO 80301 (US). (72) Inventors: WU, Kuang-Yi; 4720 Shoup Place, Boulder, CO 80303 (US). LIU, Jian-Yu; 4395 Grinnell Avenue, Boulder, CO 80303 (US). (74) Agents: CARSON, W., Scott et al.; Dorr, Carson, Sloan & Birney, P.C., 3010 E. 6th Avenue, Denver, CO 80206 (US).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, GM, GW, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).  <b>Published</b> <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>  (88) Date of publication of the international search report: 5 November 1998 (05.11.98)

(54) Title: SWITCHABLE WAVELENGTH ROUTER



## (57) Abstract

A switchable wavelength router (999) having an input port (11) for the incoming WDM signal (500) and two output ports (13, 14) for de-multiplexing the WDM signals (500). The router (999) divides the received optical signals into divided optical signals (101, 102) comprising a subset of the channels and spatially positions the divided optical signals in response to a control signal applied to the router (999). For example, the router (999) can divide a received WDM signal (500) into two subsets that are either single channel or WDM signals. Multiple routers (999) can be cascaded to form a  $2^n$  switchable wavelength router, where  $n$  is the number of stages of wavelength routers.

## SWITCHABLE WAVELENGTH ROUTER

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention.

5 The present invention relates, in general, to communication systems, and more particularly, to a switchable wavelength router for wavelength division multiplex (WDM) optical communications.

#### 2. Statement of the Problem.

10 Optical wavelength division multiplexing has gradually become the standard backbone network for fiber optic communication systems. WDM systems employ signals consisting of a number of different wavelength optical signals, known as carrier signals or channels, to transmit information on optical  
15 fibers. Each carrier signal is modulated by one or more information signals. As a result, a significant number of information signals may be transmitted over a single optical fiber using WDM technology.

20 Despite the substantially higher fiber bandwidth utilization provided by WDM technology, a

number of serious problems must be overcome, for example, multiplexing, demultiplexing, and routing optical signals, if these systems are to become commercially viable. The addition of the wavelength domain increases the complexity for network management because processing now involves both filtering and routing. Multiplexing involves the process of combining multiple channels (each defined by its own frequency spectrum) into a single WDM signal. Demultiplexing is the opposite process in which a single WDM signal is decomposed into individual channels. The individual channels are spatially separated and coupled to specific output ports. Routing differs from demultiplexing in that a router spatially separates the input optical channels into output ports and permutes these channels according to control signals to a desired coupling between an input channel and an output port.

The Applicants' U.S. Patent Nos. 5,724,165 and 5,867,291 (Kuang-Yi Wu et al.) teach two independent methods for high performance signal routing (Patent No. 5,724,165) and wavelength de-multiplexing (Patent No. 5,867,291). In Patent No. 5,724,165, new structures for realizing optical switches (routers) are disclosed that achieve very high extinction ratio operation. However, these switches are wavelength independent. In Patent No. 5,867,291, a system is disclosed to provide the functions of wavelength de-multiplexing and routing. However, this single stage

design relies primarily on the filter design. The transmission function of the filter has to be close to an ideal square flat-top to realize the desired low crosstalk operation.

5           In this patent application, we combine the two architectures and concepts presented in the above-cited patents to create a switchable wavelength router. This new structure employs double stage filters that can obtain a better  
10       (purified) pass-band transmission, and incorporates a fault-tolerant structure (similar to that disclosed in Patent No. 5,724,165) that results in low crosstalk between channels.

SUMMARY OF THE INVENTION

The present invention involves a switchable wavelength router having an input port for the incoming WDM signal and a two output ports for de-  
5 multiplexing the WDM signals. The router divides the received optical signals into divided optical signals comprising a subset of the channels and spatially positions the divided optical signals in response to a control signal applied to the router.  
10 For example, the router can divide a received WDM signal into two subsets that are either single channel or WDM signals. Multiple routers can be cascaded to form a  $2^n$  switchable wavelength router, where  $n$  is the number of stages of wavelength  
15 routers.

More specifically, a first birefringent element decomposes the WDM optical signal into two spatially separated beams having orthogonal polarizations. A first polarization rotator  
20 selectably rotates the polarization of one of the beams to match the polarization of other beam, based on an external control signal. A wavelength filter (e.g., stacked waveplates) provides a polarization-dependent optical transmission function such that  
25 the first beam decomposes into third and fourth orthogonal beams, and the second beam decomposes into fifth and sixth orthogonal beams. The third and fifth beams carry a first spectral band at a first polarization and the fourth and sixth beams  
30 carry a second spectral band at an orthogonal polarization. A second birefringent element

5

spatially separates these four beams into four horizontally polarized and vertically polarized components. A second polarization rotator rotates the polarizations of the beams so that the third and fifth beams are orthogonally polarized and the fourth and sixth beams are orthogonally polarized. A third birefringent element recombines the third and fifth beams containing the first spectral band which is coupled to the first output port, and also recombines the fourth and sixth beams containing the second spectral band which is coupled to the second output port.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIGS. 1a and 1b are block diagrams illustrating the functionality of the optical router in accordance with the present invention.

5        FIGS. 2a and 2b are simplified schematic diagrams illustrating a double stage switchable wavelength router in accordance with the present invention.

10       FIGS. 3a and 3b are simplified schematic diagrams illustrating a single stage switchable wavelength router in accordance with the present invention.

15       FIGS. 4a and 4b are graphs showing experimental results using three lithium niobate waveplates in the filter design. In figure 4a, spectra of the output port #1 are recorded before and after switching. Figure 4b shows the corresponding spectra of the output port #2 before and after switching. The spectra are roughly equally separated and are  
20       ready for further spectral slicing.

25       FIG. 5 is a graph showing a design of asymmetric spectra where the narrower one can be used as an add/drop port, whereas the wider spectrum can pass the rest of WDM signals back to the network.

FIG. 6 is a graph showing a design of a switchable wavelength router to cover the 1310 and 1550 nm wavelengths. A better than -50 dB crosstalk between both channels is obtained with this design.

**DETAILED DESCRIPTION OF THE INVENTION****1. Overview.**

The present invention both demultiplexes (i.e., spectrally separates) and routes (i.e., spatially permutes) a wavelength division multiplexed (WDM) optical signal. FIGS. 1a and 1b are block diagrams illustrating the general functionality of the present invention. A WDM signal 500 consists of multiple channels, with each channel having its own range of wavelengths or frequencies. As used herein, the terms "channel" or "spectral band" refer to a particular range of frequencies or wavelengths that define a unique information signal. Each channel is usually evenly spaced from adjacent channels, although this is not necessary. Uneven spacing may result in some complexity in design, but, as will be seen, the present invention can be adapted to such a channel system. This flexibility is important in that the channel placement is driven largely by the technical capabilities of transmitters (i.e., laser diodes) and detectors and so flexibility is of significant importance.

The WDM signal 500 is input using conventional optical signal coupling techniques to the input port of the switchable wavelength router 999. By switching the control signal between two control states (e.g., on and off), the router 999 generates two unique output signals at its output ports, where the input WDM spectrum is split into two bands 501 and 502. One is denoted as the first band 501

(i.e., the shorter wavelength in FIG. 1a) and the other is denoted as the second band 502 (i.e., the longer wavelength in FIG. 1a). The two spectral bands are routed to the output ports according to the control state, as depicted in FIGS. 1a and 1b. The two output spectra can be symmetric or asymmetric depending on the functionality required by the WDM system. For optical channel demultiplexing, symmetric spectra at the two output ports are usually preferred. In addition, a second stage wavelength router with a narrower spectral response can be cascaded after the outputs of the first stage to further splice the spectra and produce even narrower spectral bandwidths. In an asymmetric spectra design, the wavelength router can be used as an add/drop filter for a WDM network node. Here, a specific optical channel can be added or dropped through the narrower band of the asymmetric spectra of the wavelength router, while the rest of the channels continue past the wavelength router through the wider complementary spectrum. This allows WDM signals enter or leave the network as they travel within the WDM network.

## 2. Double stage router.

FIG. 2a and FIG. 2b are schematic diagrams illustrating the two control states of a double-stage wavelength router 999. The wavelength router 999 is under binary control from a control bit and hence has two control states. The router 999 serves to separate channels of the wavelength spectrum

applied to an input port 11 and determines which of two output ports 13, 14 are coupled to each of the channels.

5 In FIG. 2a and FIG. 2b, the bold solid lines indicate optical paths that contain the full spectrum of channels in the WDM input signal 500. Solid thin lines indicate optical paths of signals containing a first subset of channels labeled as the first spectral band. Thin dashed lines indicate the  
10 optical channels carrying a second subset of channels referred to as the second spectral band. It is important to understand that each of the subsets may comprise more than one channel and may itself be a WDM signal although having a smaller  
15 bandwidth than the original WDM signal 500. Each of the optical paths is further labeled with either a horizontal double-headed line indicating horizontal polarization, or a vertical double-headed line indicating vertical polarization, or both horizontal  
20 and vertical double-headed lines indicating mixed horizontal and vertical polarizations in the optical signal at that point.

The WDM signal 500 enters the first  
25 birefringent element 30 that spatially separates horizontal and vertically polarized components of the WDM signal 500. The first birefringent element 30 consists of a material that allows the vertically polarized portion of the optical signal to pass through without changing course because they are  
30 ordinary waves in the birefringent element 30. In contrast, horizontally polarized waves are

10

redirected at an angle because of the birefringent walk-off effect. The angle of redirection is a well-known function of the particular materials chosen. Examples of materials suitable for construction of the birefringent element include calcite, rutile, lithium niobate, YVO<sub>4</sub> based crystals, and the like. The horizontally polarized component travels along a path 101 as an extraordinary signal in the first birefringent element 30 while the vertically polarized component 102 travels as an ordinary signal and passes through without spatial reorientation. The resulting signals 101 and 102 both carry the full frequency spectrum of the WDM signal 500.

Both the horizontally and vertically polarized components 101 and 102 are coupled to a switchable polarization rotator 40 under control of a control bit. The polarization rotator 40 consists of two sub-element rotators that form a complementary state, i.e., when one turns on the other turns off. The rotator 40 selectively rotates the polarization state of either signal 101 or 102 by a predefined amount. In the preferred embodiment, the rotator 40 rotates the signals by either 0° (i.e., no rotation) or 90°. For example, the polarization rotator 40 can be a twisted nematic liquid crystal rotator, ferroelectric liquid crystal rotator, pi-cell based liquid crystal rotator, magneto-optic based Faraday rotator, acousto-optic or electro-optic based polarization rotator. Commercially available rotators based on liquid crystal technology are

preferred, although other rotator technologies may be applied to meet the needs of a particular application. The switching speed of these elements ranges from a few milliseconds to nanoseconds, and therefore can be applied to a wide variety of systems to meet the needs of a particular application. These and similar basic elements are considered equivalents and may be substituted and interchanged without departing from the spirit of the present invention.

FIG. 2a illustrates the control state in which the signal 102 is rotated by  $90^\circ$  so that both signals 103, 104 exiting the rotator 40 have a horizontal polarization. FIG. 2b illustrates the second control state in which the polarization of the signal 101 is rotated by  $90^\circ$  so that both optical signals 103, 104 exiting the rotator 40 have a vertical polarization. Again, at this stage, both the horizontal and vertical components contain the entire frequency spectrum of channels in the WDM signal 500.

The stacked waveplates element 61 is a stacked plurality of birefringent waveplates at selected orientations that generate two eigen states. The first eigen state carries a first sub-spectrum with the same polarization as the input, and the second eigen state carries a complementary sub-spectrum at the orthogonal polarization. The polarization of the incoming beam and the two output polarizations form a pair of spectral responses, where (H, H) and (V, V) carry the first part of the input spectrum

12

and (H, V) and (V, H) carry the complementary (second) part of the input spectrum, where V and H are vertical and horizontal polarization, respectively.

5           This may be better understood by comparing  
FIGS. 2a and 2b. With horizontal polarizations 103,  
104 input to the stacked waveplates element 61 as  
shown in FIG. 2a, orthogonal vertical and horizontal  
polarizations are generated with the first spectral  
10 band residing in horizontal polarization and the  
second spectral band residing in vertical  
polarization. With vertical polarizations 103, 104  
input to the stacked waveplates element 61 as shown  
in FIG. 2b, orthogonal vertical and horizontal  
15 polarizations are generated with the first spectral  
band residing in vertical polarization and the  
second spectral band residing in horizontal  
polarization.

For wavelength demultiplexing applications, the  
20 stacked waveplates element 61 has a comb filter  
response curve with a substantially flat top or  
square wave spectral response. For WDM optical  
channel add/drop applications, the stacked  
waveplates element 61 has an asymmetric filter  
25 response.

Returning to FIG. 2a, the pairs of optical  
responses 105, 106 output by the stacked waveplates  
element 61 are coupled to a second birefringent  
element 50. This birefringent element 50 has a  
30 similar construction to the first birefringent  
element 30 and spatially separates the horizontally

13

and vertically polarized components of the input optical signals 105 and 106. As shown in FIG. 2a, the optical signals 105, 106 are broken into vertically polarized components 107, 108 containing the second spectral band and horizontally polarized components 109, 110 containing the first spectral band. Due to the birefringent walk-off effect, the two orthogonal polarizations that carry first spectral band 109, 110 in horizontal polarization and second set spectral band 107, 108 in vertical polarization are separated by the second birefringent element 50.

Following the second birefringent element 50, the optical elements on the input side of the second birefringent element 50 can be repeated in opposite order, as illustrated in FIGS. 2a and 2b. The second stacked waveplates element 62 has substantially the same composition as the first stacked waveplates element 61. The horizontally polarized beams 109, 110 input to the second stacked waveplates element 62, are further purified and maintain their polarization when they exit the second stacked waveplates element 62. On the other hand, the vertically polarized beams 107, 108 experience a  $90^\circ$  polarization rotation and are also purified when they exit the second stacked waveplates element 62. The  $90^\circ$  polarization rotation is due to the fact that the vertically polarized beams 107, 108 carry the second spectral band and therefore are in the complementary state of element 62. At the output of the stacked waveplates

14

element 62, all four beams 111, 112 and 113, 114 have horizontal polarization. However, the spectral bands defined by the filter characteristics of the stacked waveplates elements 61,62 are separated with the second spectral band 501 on top and the first spectral band 502 below.

To recombine the spectra of the two sets of beams 111, 112 and 113, 114, a second polarization rotator 41 and a second birefringent element 70 are used. Again, the second rotator 41 has two sub-elements that intercept the four parallel beams 111 - 114. The two sub-elements of the second rotator 41 are set at a complementary state to the first rotator 40, i.e. when the first rotator 40 is turned on/off, the second rotator 41 is turned off/on. In the case of Fig. 2a, the polarization of beams 111 and 113 is rotated by  $90^\circ$ , and beams 112 and 114 are passed without change of polarization. This results an orthogonal polarization pair 115, 116 and 117, 118 for each spectral band at the output of the second rotator 41. Finally, a second birefringent element 70 re-combines the two orthogonal polarizations 115, 116 and 117, 118 using the walk-off effect to produce two spectra that exit at ports 14 and 13, respectively. This completes the first operational state of the switchable wavelength router 999.

FIG. 2b shows the other control state in which the two polarization rotators 40 and 41 have switched to their complimentary states, i.e. from on to off, or off to on, in contrast to their states

15

shown in FIG. 2a. The full spectrum 500 is first divided by polarization into two orthogonal states, i.e. vertical and horizontal polarization as indicated at 101 and 102, by the first birefringent element 30. The first polarization rotator 40 is now set to have the output polarizations 103 and 104 both vertical. After passing through the first stacked waveplates element 61, two orthogonal polarizations (i.e., horizontal and vertical) that carry second and first spectral bands are generated, respectively. In this state of operation, horizontal polarization is used to carry the second spectral band, and vertical polarization is used to carry the first spectral band of the WDM spectrum 500. The two spectral bands are then spatially separated by the second birefringent element 50 with vertical polarization 107, 108 going upward and horizontal polarization 109, 110 passing through without deviation. This, therefore, separates the two spectral bands according to their polarizations.

The resulting four beams 107 - 110 enter the second stacked waveplates element 62 for further spectral purification. Another important role of element 62 is its polarization rotation for the second spectral band. Remember that the stacked waveplates elements 61, 62 have two eigen states. With regard to the first band, the vertically polarized beams 107, 108 remain unchanged by element 62. However, with regard to the second spectral band, the horizontally polarized beams 109 and 110 are rotated by  $90^\circ$  as they pass through element 62

because they are in the complementary state of the stacked waveplate 62. At the output of element 62, all polarizations become vertical, as indicated by beams 111, 112 for the first spectral band and beams 113, 114 for the second spectral band in FIG. 2b. To recombine the two sub-spectra, a second polarization rotator 41 and third birefringent element 70 are used, as previously discussed. In the case of FIG. 2b, the second rotator 41 is set to rotate the polarizations of beams 112 and 114 by  $90^\circ$  and to pass beams 111 and 112 without rotation. The resulting beams 115 - 118 are recombined by the third birefringent element 70 and exit to ports 14 and 13 for the first and second spectral bands, respectively.

### 3. Single stage router.

A simplified version of the double stage wavelength router using a single stage switchable wavelength router is shown in FIGS. 3a and 3b, for the two states of operation. Two changes have been made with this structure in contrast to the double stage design shown in FIGS. 2a and 2b. The second stacked waveplates element 62 in FIGS. 2a and 2b has been removed and the second polarization rotator 41 has been replaced with a passive polarization rotator with two sub-elements to intercept the beams 108 and 109, as shown in FIGS. 3a and 3b.

The single stage wavelength router operates in substantially the same manner as the double stage router until the beams 107 - 110 exit the second

17

birefringent element 50. At the output of the second birefringent element 50, the divided first and second spectral bands are carried by two sets of orthogonally polarized beams 107,108 and 109,110, respectively. The positions of the first and second spectral bands depend on the polarization state of the beams 103 and 104. If the first spectral band is horizontally polarized by the first rotator 40, it will exit at the lower output port 13 and the second spectral band will exit at the upper output port 14. If the first spectral band is vertically polarized by the first rotator 40, it will exit at the upper output port 14 and the second spectral band will exit at the lower output port 13. Because of the birefringent walk-off effect in the second birefringent element 50, the vertically polarized light beams 107, 108 deviate from their original paths and travel upward, whereas the horizontally polarized beams 109, 110 pass through element 50 without changing their directions. The two pairs of beams 107, 108 and 109, 110 exiting the second birefringent element 50 have the same polarization but different frequencies.

The passive polarization rotator 41 is patterned to rotate polarization only in the areas that intercept beams 108 and 109. Therefore, at the output of the rotator 41, orthogonally polarized pairs of beams 115, 116 and 117, 118 are produced for both the first and second spectral bands. These beams 115 - 118 are then recombined by the third birefringent element 70 and exit to ports 13 and 14.

The single stage switchable wavelength router has the advantages of requiring fewer components as compared to the double stage router. However, its spectral purity is not as good as the double stage router. It will depend on the applications and requirements of a specific WDM network, whether the single stage or the double stage wavelength router is preferred.

One advantage of the present invention is that routing is accomplished while conserving substantially all optical energy available in the WDM signal 500. That is to say, regardless of the polarization of the signals in WDM signal 500 both the horizontal and vertically polarized components are used and recombined at output ports 13, 14 resulting in very low loss through router 999.

Each set of birefringent waveplates 61, 62 is oriented at an unique optic axis angle with respect to the optical axis of polarization rotator 40. As mentioned earlier, the spectral design for the stacked waveplates elements 61 and 62 is dependent on the applications required by the WDM network. In the following, we list three different designs that can be used with current WDM systems. The first example uses stacked waveplates with equally separated sub-spectra centered at 1533 and 1557 nm wavelength. In the second case, asymmetric sub-spectra are produced by the stacked waveplates. This design can be used for an add/drop optical filter application. The third one is designed to cover the two transmission windows of fiber optics

networks at 1310 and 1550 nm wavelengths. In this case, the center wavelengths of 1310 and 1550 nm can be interchangeably routed to either output port.

#### Example 1

5           Three lithium niobate ( $\text{LiNbO}_3$ ) waveplates having a thickness of 1 mm have been stacked together to form a flat-top, equally divided spectrum, as shown in Fig. 4, with channel crosstalk under 30 dB. The experimental results are based on  
10           the double stage switchable wavelength router. This out-performs existing filter technologies, such as using multi-layer dielectric coatings, where a 20 dB crosstalk is generally obtained. Because of the equal spectra design at the two output ports, this  
15           type of switchable wavelength router can be further cascaded. With "n" stages of routers cascaded, a total of  $2^n$  output ports result. These  $2^n$  ports can have their output spectra permuted according to n control signals to create a programmable wavelength  
20           router.

#### Example 2

Figure 5 shows an asymmetric spectrum design, where one output port carries a much narrower spectral width compared to the other port. This  
25           design can be applied to a WDM network when there is a need to add or drop part of the optical channels at an optical exchange node. The add/drop filter can be either passive or active, depending on system design and requirements. The switching element,  
30           i.e. the switchable polarization rotator arrays, can

20

be replaced by two passive halfwave plates at each corresponding position of the polarization rotator, such that one of the ports is always designated as the add/drop port. The rest of the optical channels pass through the wavelength router and continue to propagate along the WDM network.

### Example 3

As shown in Fig. 6, the present invention can be further extended to farther apart spectra to cover two operational wavelength windows centered at 1310 and 1550 nm for fiber optic communications. Several techniques (e.g., fiber fusion and multi-layer coating techniques) have been widely used in the industry to perform this task. However, the current design provides lower crosstalk and a switchable characteristic, which are valuable from the system's point of view.

The above disclosure sets forth a number of embodiments of the present invention. Other arrangements or embodiments, not precisely set forth, could be practiced under the teachings of the present invention and as set forth in the following claims.

**WE CLAIM:**

1. A method for switching wavelength division multiplexed (WDM) optical signals comprising the steps of:

5 providing a first input/output (I/O) port for receiving the WDM optical signal;

providing a second I/O port;

providing a third I/O port;

10 spatially decomposing the WDM optical signal received from said first I/O port into first and second beams having orthogonal polarizations with respect to each other;

rotating the polarization of said first beam to substantially match the polarization of said second beam;

15 demultiplexing said first and second beams of same polarization through a first wavelength filter having a polarization dependent optical transmission function such that said first beam decomposes into third and fourth beams with their polarizations  
20 orthogonal to each other, and said second beam decomposes into fifth and sixth beams with their polarizations orthogonal to each other, wherein said third and fifth beams carry a first predetermined spectral band at a first polarization and said  
25 fourth and sixth beams carry a second predetermined spectral band at a second polarization, wherein said first and second spectral bands are substantially complementary and said first and second polarizations are orthogonal;

30           spatially routing said third, fourth, fifth and sixth beams based upon their polarizations;

          passing said routed third, fourth, fifth and sixth beams through a second wavelength filter having substantially the same transmission function as said first wavelength filter, wherein second  
35           wavelength filter rotates said third, fourth, fifth, and sixth beams back to the same polarization state as said second beam before it enters said first wavelength filter;

40           rotating the polarizations of said fifth and sixth beams such that they are orthogonal to said third and fourth beams;

          spatially recombining said third and fifth beams containing said first spectral band, and  
45           spatially recombining the said fourth and sixth beams containing said second spectral band; and

          coupling said first spectral band to said second I/O port and said second spectral band to said third I/O port.

2.   The method of claim 1 wherein the step of spatially decomposing the WDM optical signal uses a first birefringent element.

3.   The method of claim 1 wherein the step of routing said third, fourth, fifth, and sixth beams uses a second birefringent element.

4. The method of claim 1 wherein the step of recombining said third, fourth, fifth, and sixth beams uses a third birefringent element.

5. The method of claim 1 wherein the step of rotating the first beam further comprises passing said first and second beams through a configurable rotator array having:

5 (a) a first area for rotating the polarization of said first beam; and

(b) a second area for passing said second beam.

6. The method of claim 1 wherein the step of rotating the polarization of said fifth and sixth beams comprises passing said third, fourth, fifth and sixth beams through a configurable rotator array having:

5 (a) a first area for rotating the polarization of said fifth and sixth beams; and

(b) a second area for passing said third and fourth beams.

7. The method of claim 1 wherein said first wavelength filter comprises a stacked plurality of birefringent waveplates with each waveplate oriented in a predetermined direction.

8. The method of claim 1 wherein said second wavelength filter comprises a stacked plurality of

24

birefringent waveplates with each waveplate oriented in a predetermined direction.

9. A method for switching wavelength division multiplexed (WDM) optical signals comprising the steps of:

5 providing a first input/output (I/O) port for receiving the WDM optical signal;

providing a second I/O port;

providing a third I/O port;

10 spatially decomposing the WDM optical signal received from said first I/O port into first and second beams having orthogonal polarizations with respect to each other;

rotating the polarization of said first beam to substantially match the polarization of said second beam;

15 demultiplexing said first and second beams of same polarization through a wavelength filter having a polarization dependent optical transmission function such that said first beam decomposes into third and fourth beams with their polarizations  
20 orthogonal to each other, and said second beam decomposes into fifth and sixth beams with their polarizations orthogonal to each other, wherein said third and fifth beams carry a first predetermined spectral band at a first polarization and said  
25 fourth and sixth beams carry a second predetermined spectral band at a second polarization, wherein said first and second spectral bands are substantially complementary and said first and second

polarizations are orthogonal;

30       spatially routing said third, fourth, fifth,  
and sixth beams based upon their polarizations;  
rotating the polarizations of said third,  
fourth, fifth, and sixth beams such that said third  
and fifth beams are orthogonally polarized and said  
35       fourth and sixth beams are orthogonally polarized;  
spatially recombining said third and fifth  
beams containing said first spectral band, and  
spatially recombining the said fourth and sixth  
beams containing said second spectral band; and  
40       coupling said first spectral band to said  
second I/O port and said second spectral band to  
said third I/O port.

10. The method of claim 9 wherein the step of  
spatially decomposing the WDM optical signal uses a  
first birefringent element.

11. The method of claim 9 wherein the step of  
routing said third, fourth, fifth, and sixth beams  
uses a second birefringent element.

12. The method of claim 9 wherein the step of  
recombining said third, fourth, fifth, and sixth  
beams uses a third birefringent element.

13. The method of claim 9 wherein said wavelength  
filter comprises a stacked plurality of birefringent  
waveplates with each waveplate oriented in a  
predetermined direction.

14. The method of 9 wherein the step of rotating the first beam further comprises passing said first and second beams through a configurable rotator array having:

5 (a) a first area for rotating the polarization of said first beam; and

(b) a second area for passing said second beam.

15. The method of claim 9 wherein the step of rotating the polarization of said fifth and sixth beams comprises passing said third, fourth, fifth and sixth beams through a configurable rotator array having:

5

(a) a first area for rotating the polarization of said fifth beams;

(b) a second area for rotating the polarization of said sixth beam;

10 (c) a third area for passing said third beam without rotation; and

(b) a fourth area for passing said fourth beam without rotation.

16. A switchable wavelength router comprising:

a first birefringent element for receiving an WDM optical signal and decomposing said WDM optical signal into a first beam and a second beam that have orthogonal polarizations and are spatially separated;

5

10 a first polarization rotator having a first  
control state in which the polarization of said  
first beam is rotated to substantially match the  
polarization of said second beam, and a second  
control state in which the polarization of said  
second beam is rotated to substantially match the  
polarization of said first beam; the control state  
15 of said first polarization rotator being switchable  
by an external control signal;

a wavelength filter coupled to receive said  
first and second beams from said first polarization  
rotator, said wavelength filter having a  
20 polarization dependent optical transmission function  
such that the said first beam decomposes into third  
and fourth beams with their polarizations orthogonal  
to each other, and said second beam decomposes into  
fifth and sixth beams with their polarizations  
25 orthogonal to each other, wherein said third and  
fifth beams carry a first predetermined spectral  
band at a first polarization and said fourth and  
sixth beams carry a second predetermined spectral  
band at a second polarization, wherein said first  
30 and second spectral bands are substantially  
complementary and said first and second  
polarizations are orthogonal;

a second birefringent element for spatially  
separating said third, fourth, fifth, and sixth  
35 beams into four horizontally polarized and  
vertically polarized components;

a second polarization rotator for rotating the  
polarizations of said third, fourth, fifth, and

sixth beams such that said third and fifth beams are  
40 orthogonally polarized and said fourth and sixth  
beams are orthogonally polarized; and

a third birefringent element for receiving said  
third, fourth, fifth, and sixth beams from said  
second polarization rotator, spatially recombining  
45 said third and fifth beams containing said first  
spectral band, and spatially recombining said fourth  
and sixth beams containing said second spectral  
band.

17. The router of claim 16 wherein said first  
polarization rotator further comprises:

a first area for rotating the polarization of  
said first beam in said first control state, and  
5 passing said first beam without rotation in said  
second control state; and

a second area for passing said second beam  
without rotation in said first control state, and  
rotating the polarization of said second beam in  
10 said second control state.

18. The router of claim 16 wherein said  
second polarization rotator further comprises:

(a) a first area for rotating the polarization  
of said fifth beam;

5 (b) a second area for rotating the  
polarization of said sixth beam;

(c) a third area for passing said third beam  
without rotation; and

PCT/US9 8 / 06809  
IPRA/US 00 JUL 1998

29

10 (b) a fourth area for passing said fourth beam  
without rotation.

19. The router of claim 16 wherein said wavelength filter comprises a stacked plurality of birefringent waveplates with each waveplate oriented in a predetermined direction.

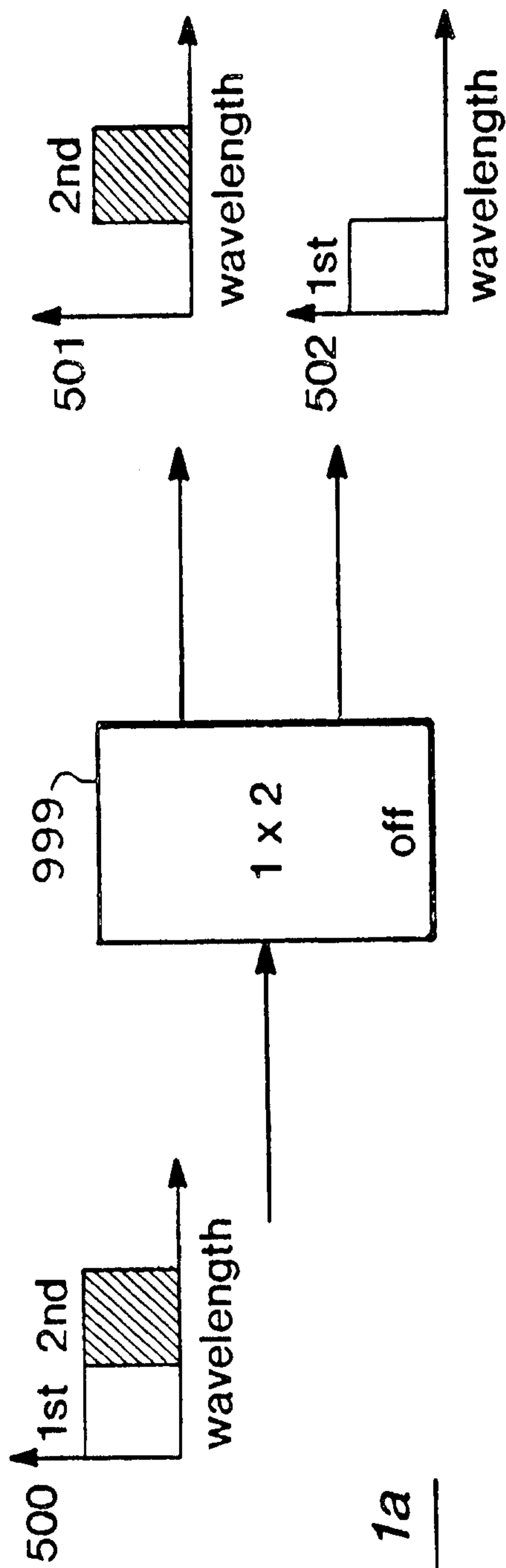


Fig. 1a

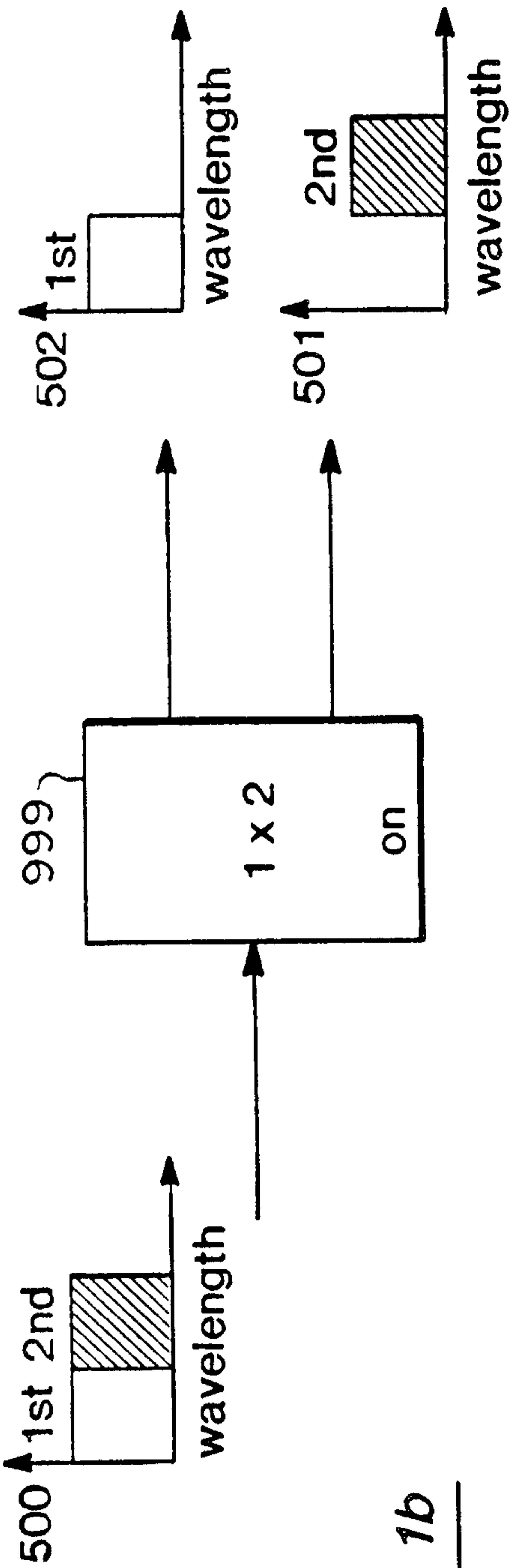


Fig. 1b

2/8

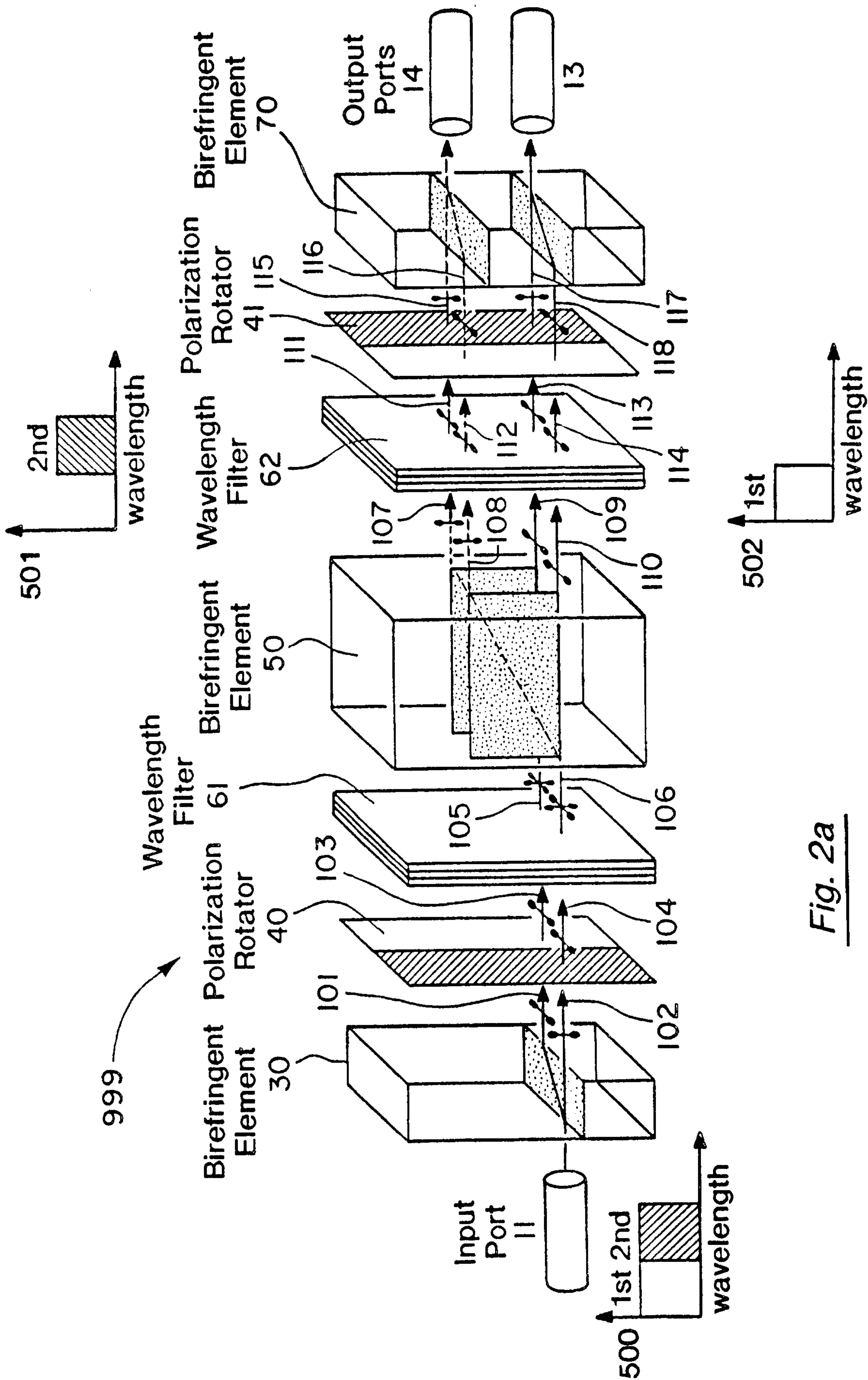


Fig. 2a

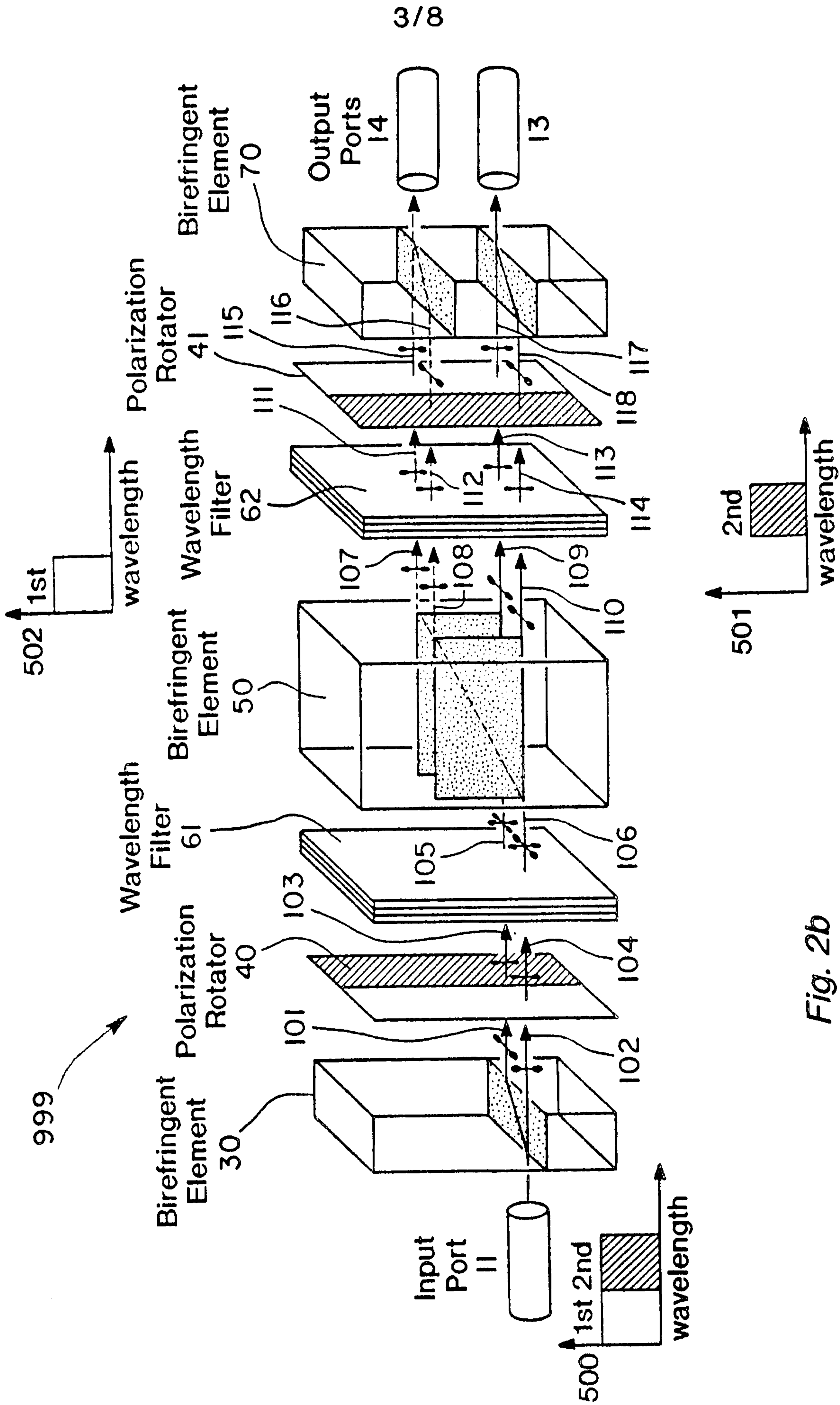


Fig. 2b

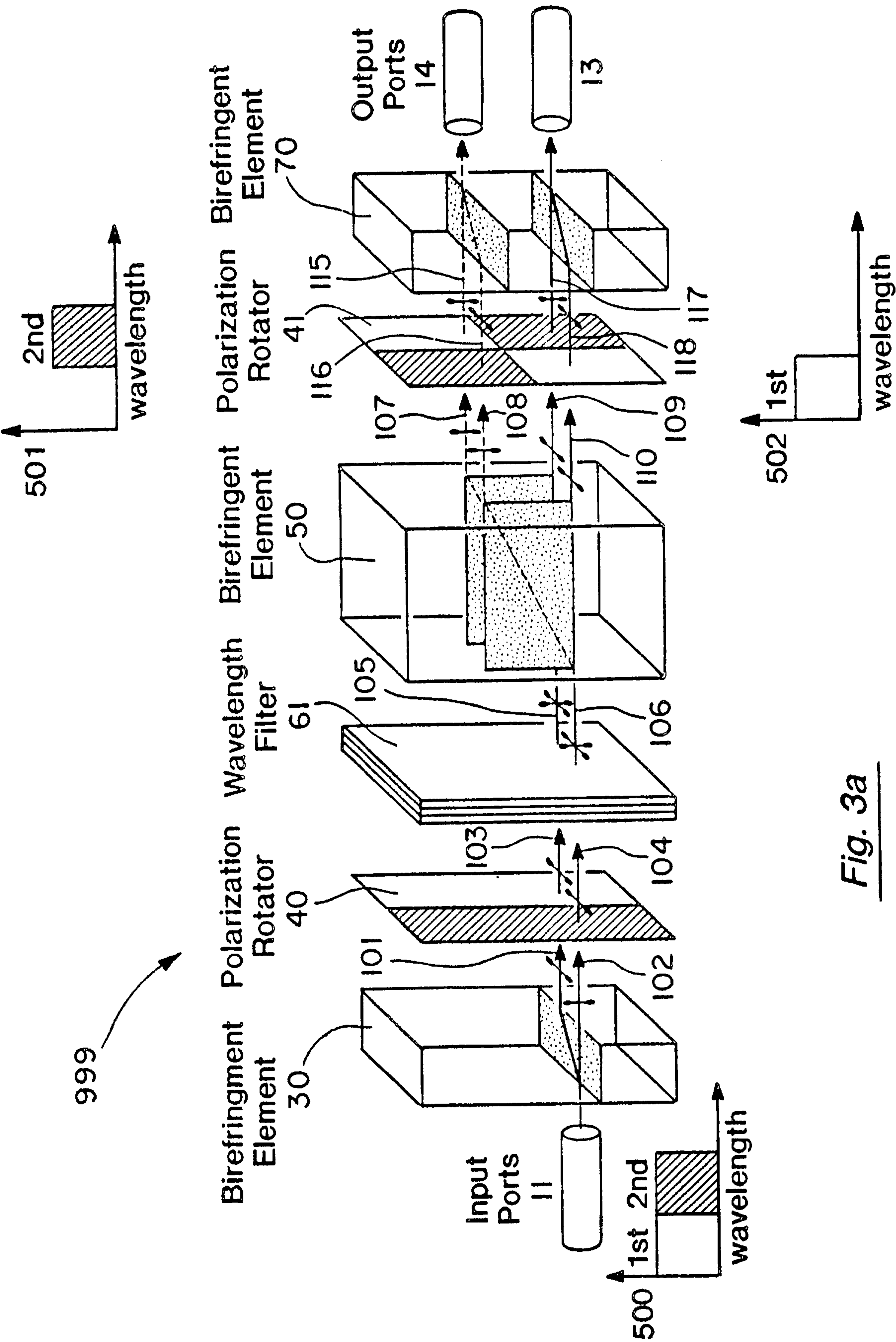
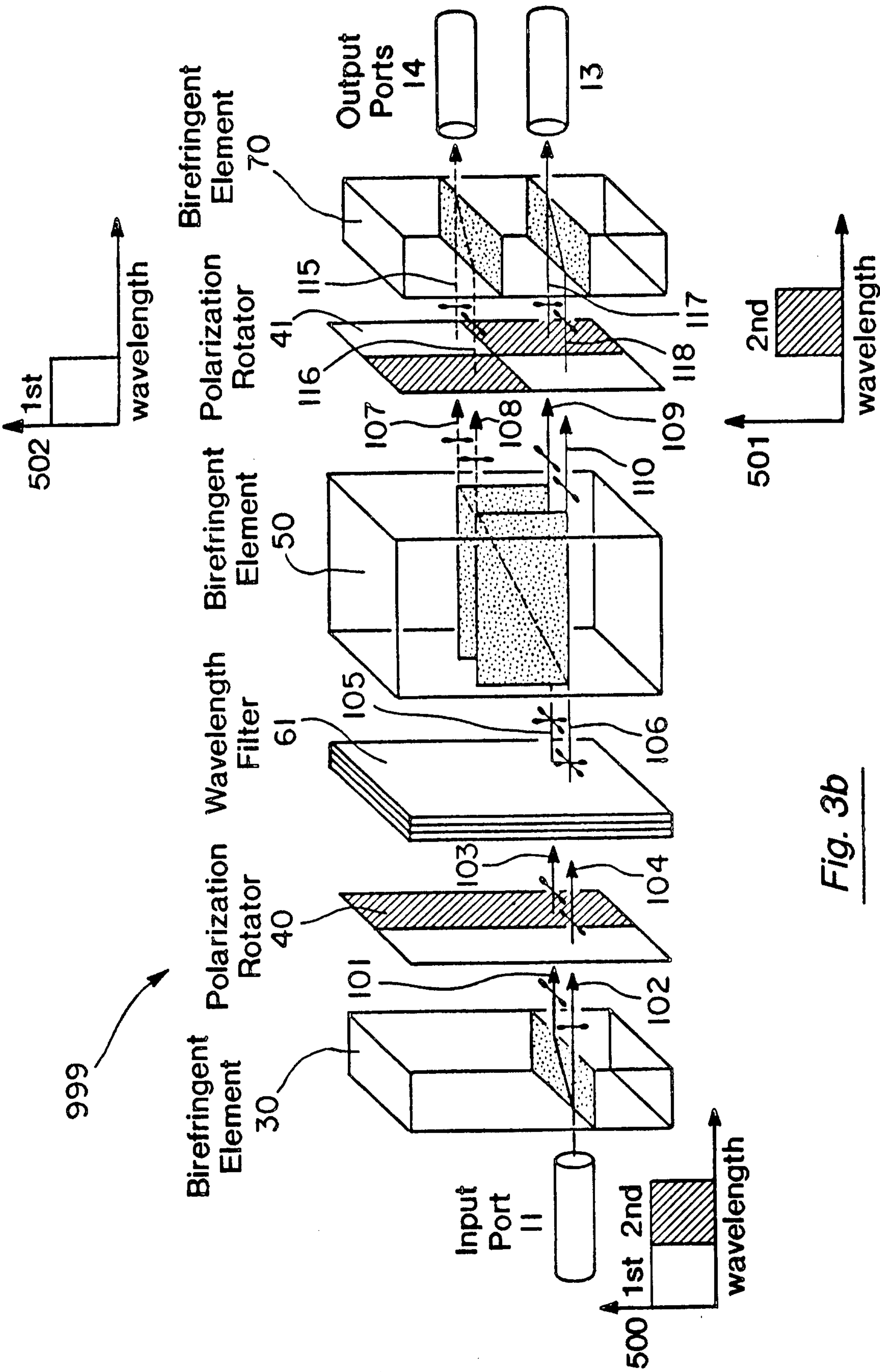


Fig. 3a



*Fig. 3b*

6/8

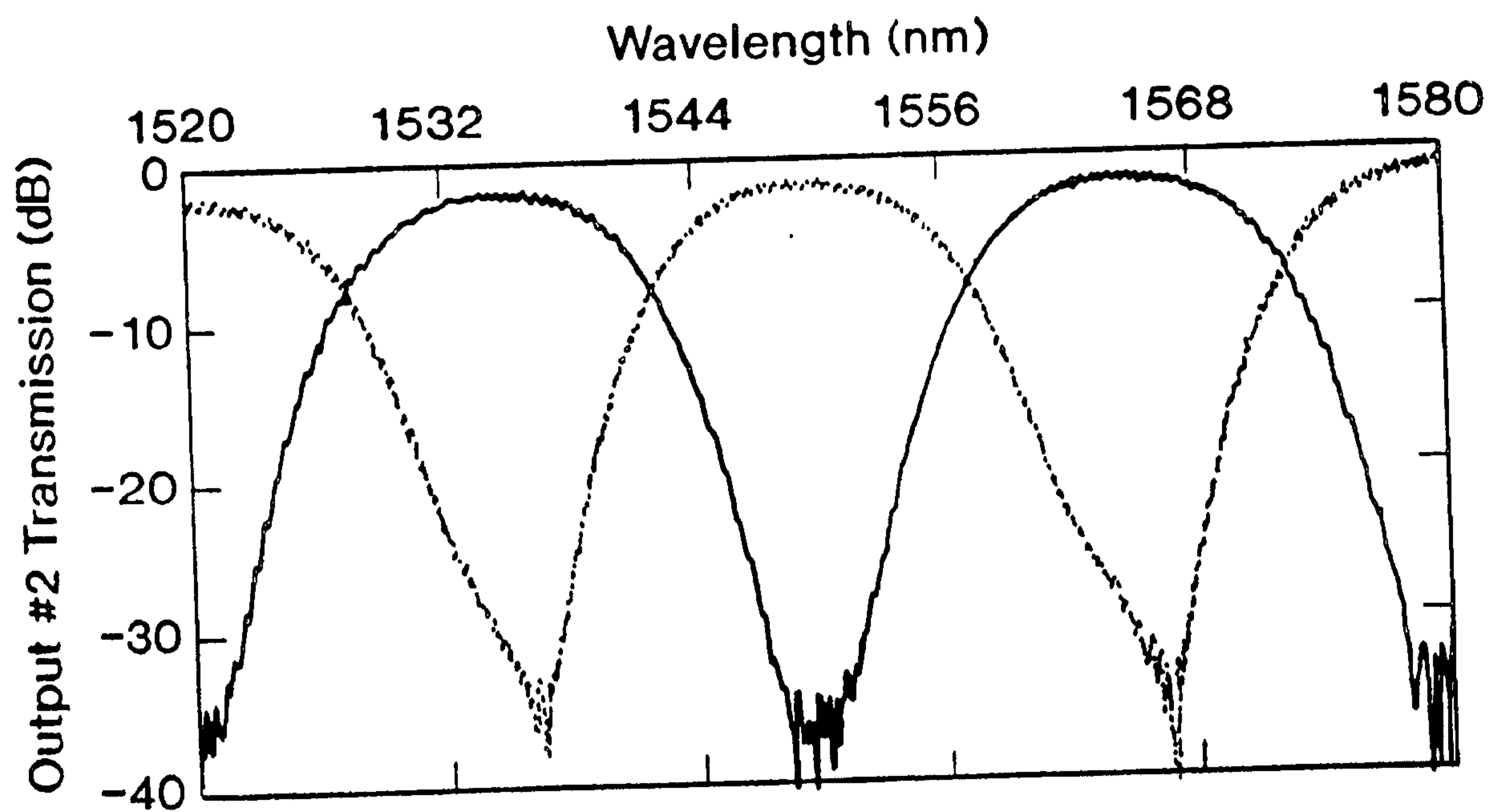
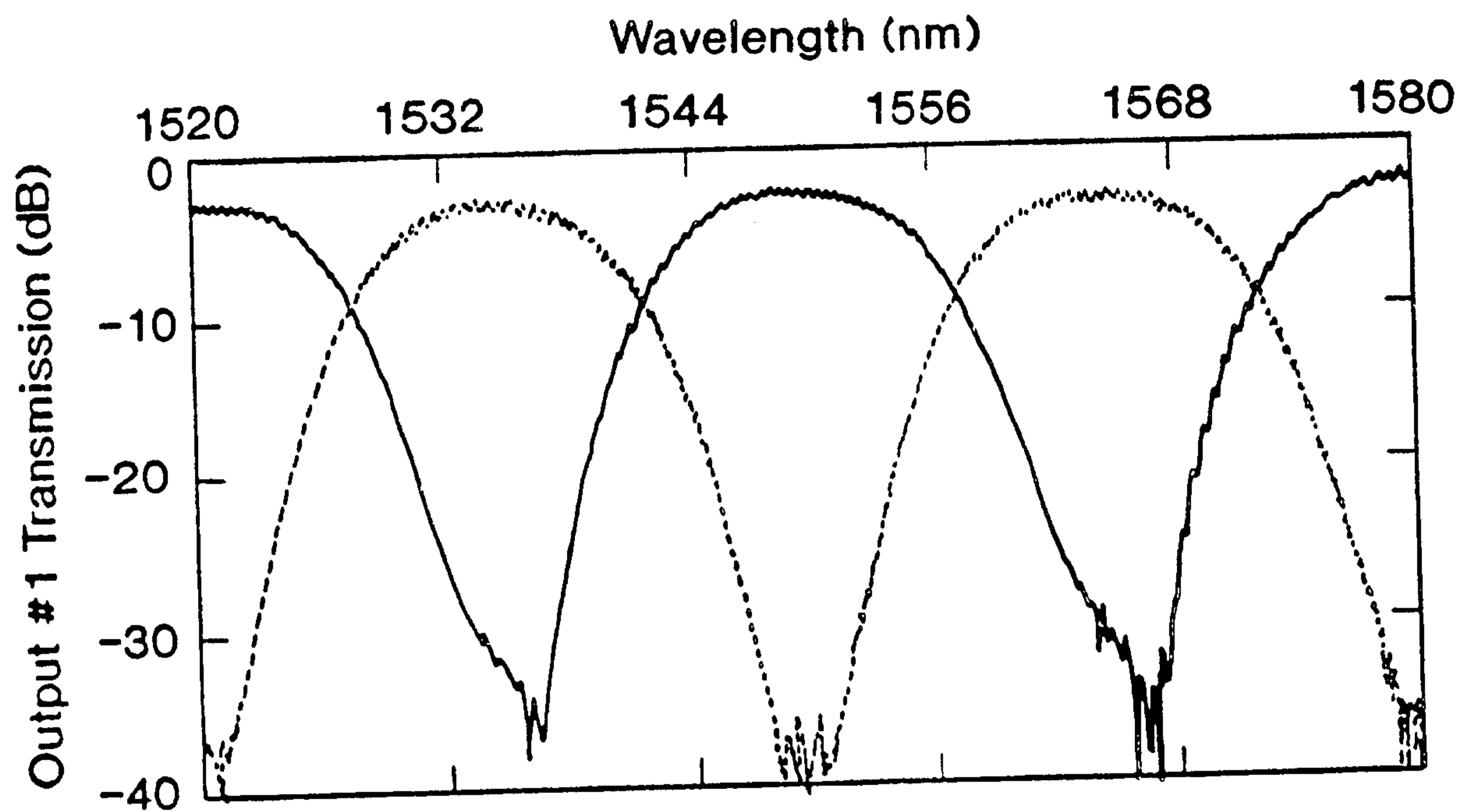
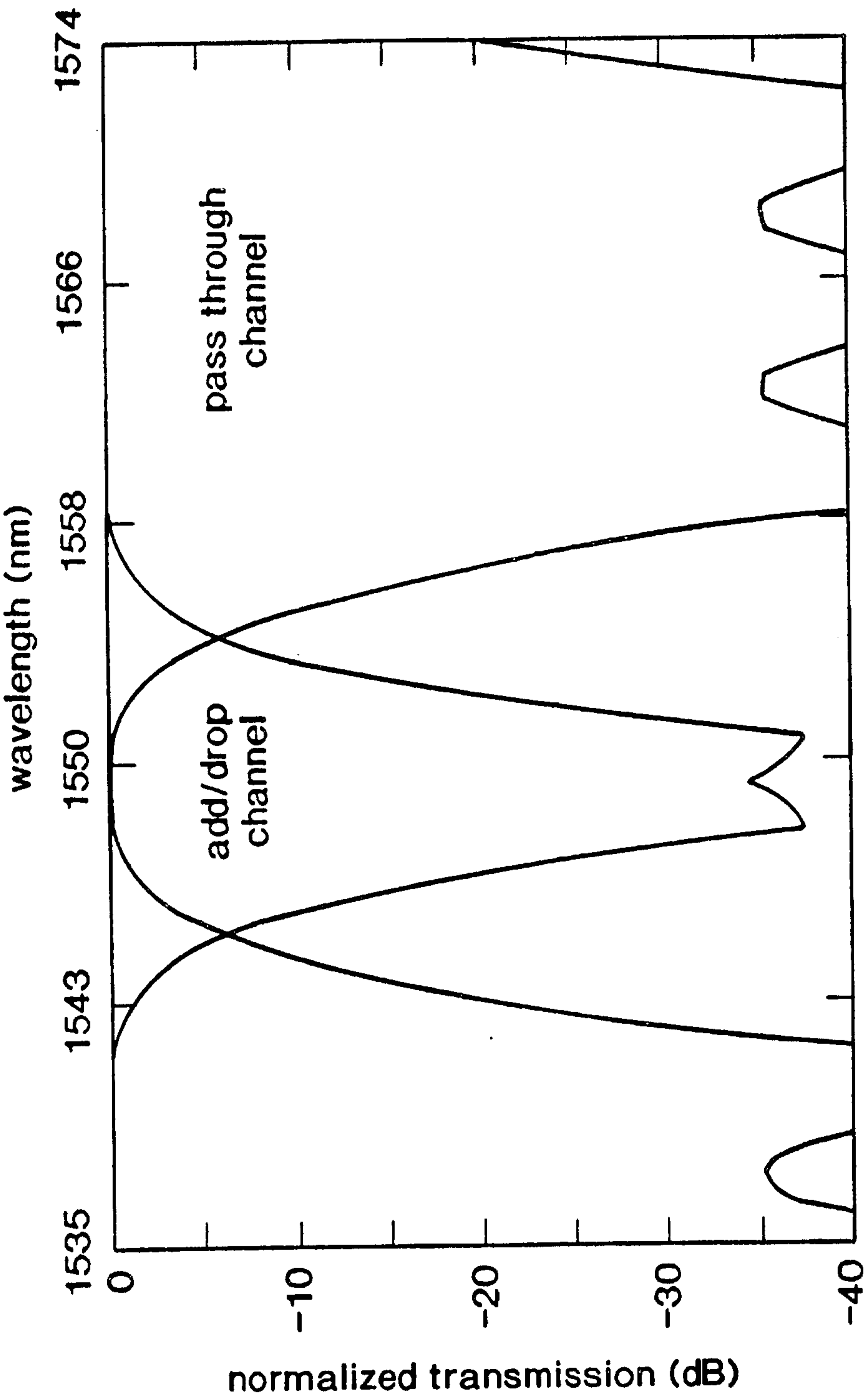
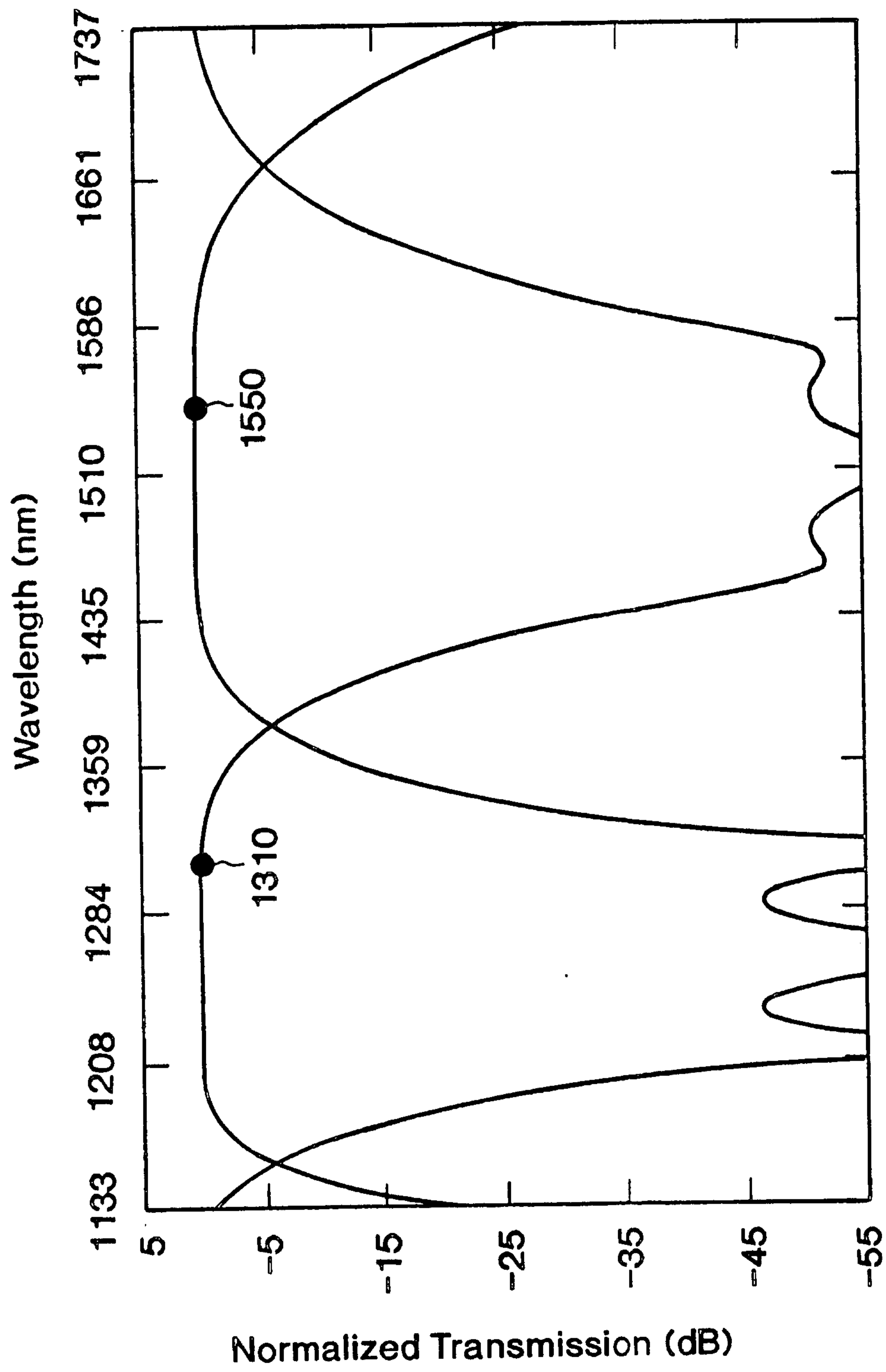
Fig. 4aFig. 4b

Fig. 5



8/8

Fig. 6

