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(54) CONTROL METHOD AND CONTROL APPARATUS OF OPTICAL WAVELENGTH VARIABLE FILTER

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(57) **ABSTRACT**

The present invention aims at providing a control method and a control apparatus for controlling variable selected wavelengths at respective stages with high accuracy and reliability, to obtain desired wavelength characteristics, in a multi-staged band rejection type optical wavelength variable filter. To this end, the optical wavelength variable filter in the present invention has wavelength characteristics formed with a blocking band including a wavelength width according to a deviation amount obtained by deviating respective selected wavelengths from one another of a plurality of optical filter sections that are cascade connected, and the control apparatus for controlling the wavelength characteristics of this optical wavelength variable filter comprises a dropped light monitoring section that takes out to monitor a dropped light to be blocked from passing through at the optical filter section corresponding to the selected wavelength most closest to the center wavelength of the blocking band, among the plurality of selected wavelengths; and a selected wavelength controlling section that adjusts the respective selected wavelengths based on a peak wavelength of the dropped light.

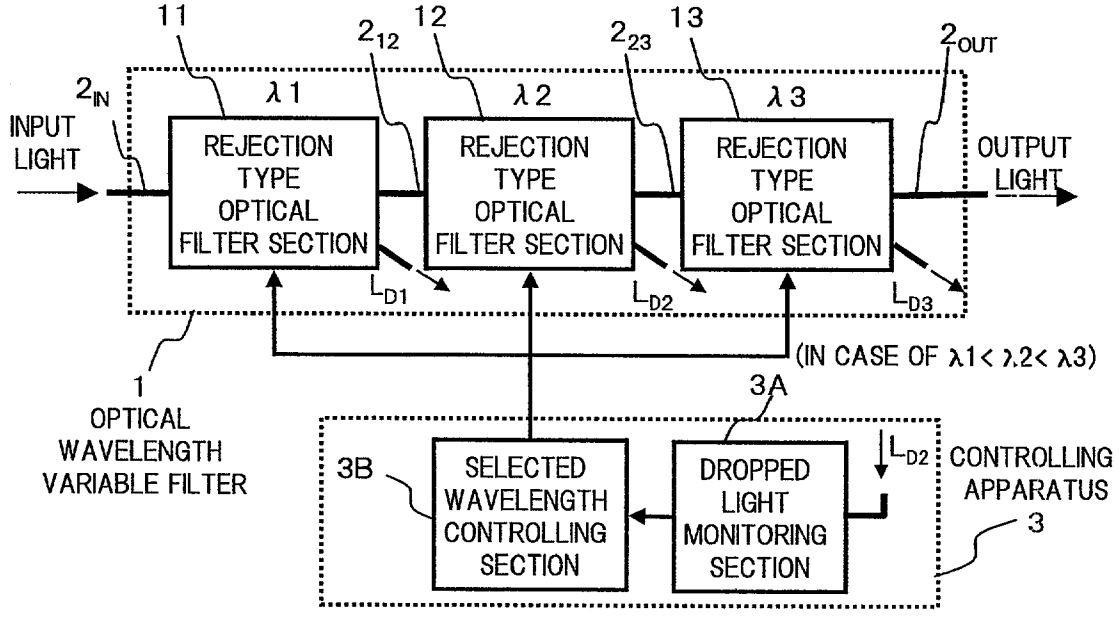


FIG.1

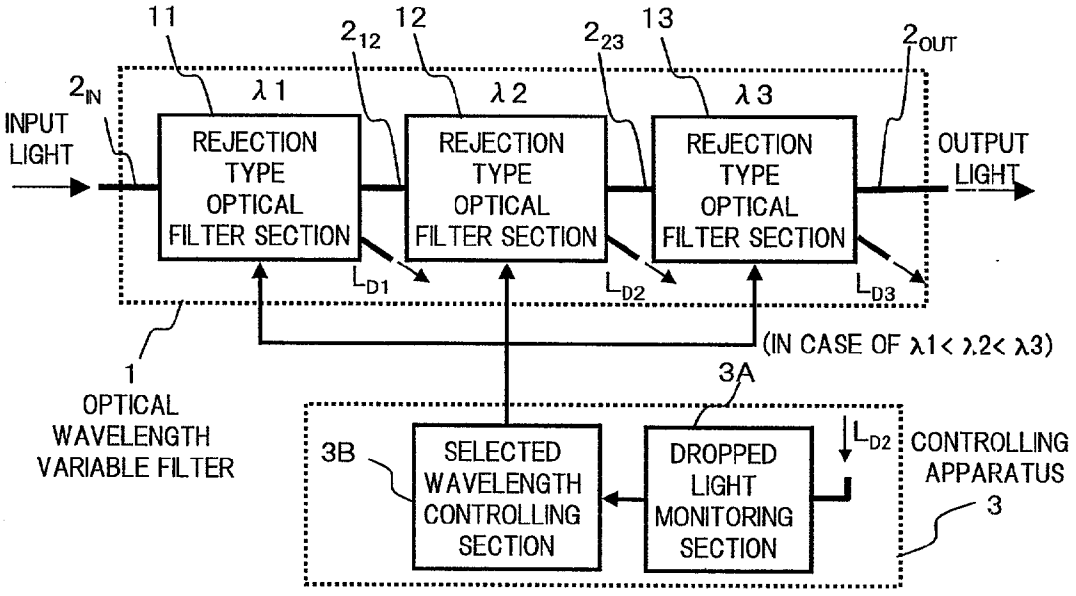


FIG.2A

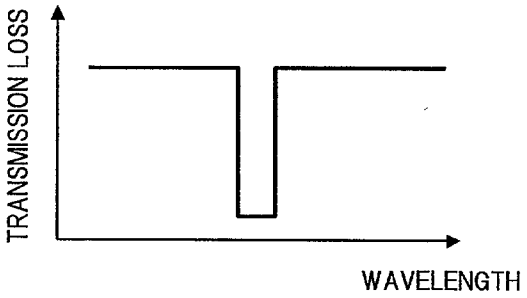


FIG.2B

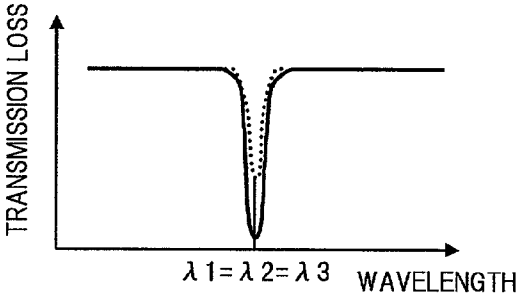


FIG.2C

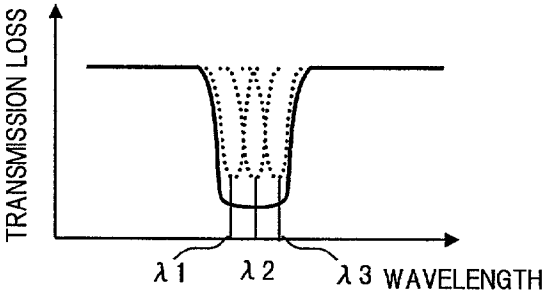


FIG.3

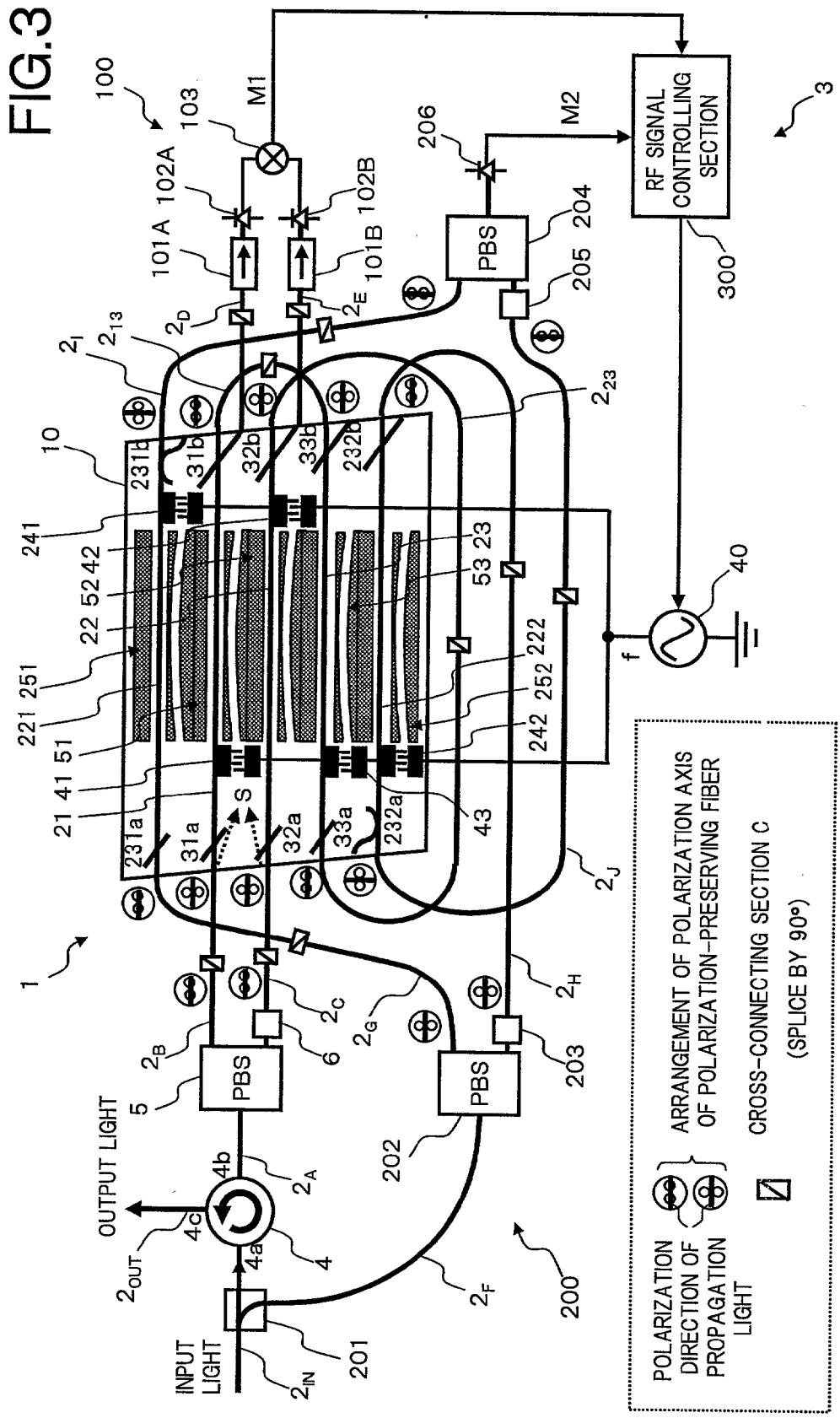

100
103
M1
M2
206
RF SIGNAL CONTROLLING SECTION
3
101A 102A
101B 102B
PBS
204
205
300
2_D
2_E
2_I
2_{13}
2_{23}
10
231b
31b
32b
33b
232b
241
22 52 42
221 251
21 41 51
231a
31a
S
32a
33a
232a
43
53 23
222
252
242
40
f
2_J
2_H
2_G
2_C
2_B
6
5
PBS
PBS
203
202
OUTPUT LIGHT
4b
4c
4a
4
2_A
2_{OUT}
2_F
200
INPUT LIGHT
2_{IN}
201
1
POLARIZATION DIRECTION OF PROPAGATION LIGHT
ARRANGEMENT OF POLARIZATION AXIS OF POLARIZATION-PRESERVING FIBER
CROSS-CONNECTING SECTION C
(SPLICE BY 90°)

FIG.4

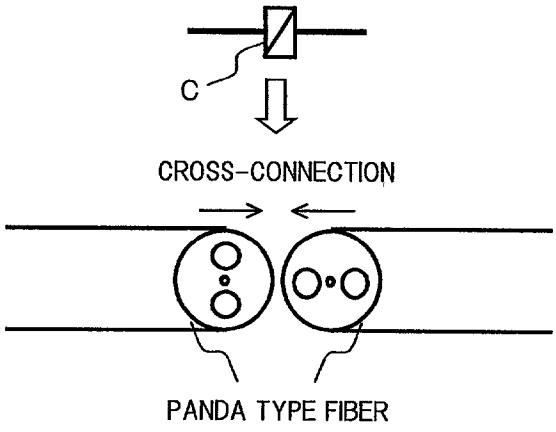

C
CROSS-CONNECTION
PANDA TYPE FIBER

FIG.5

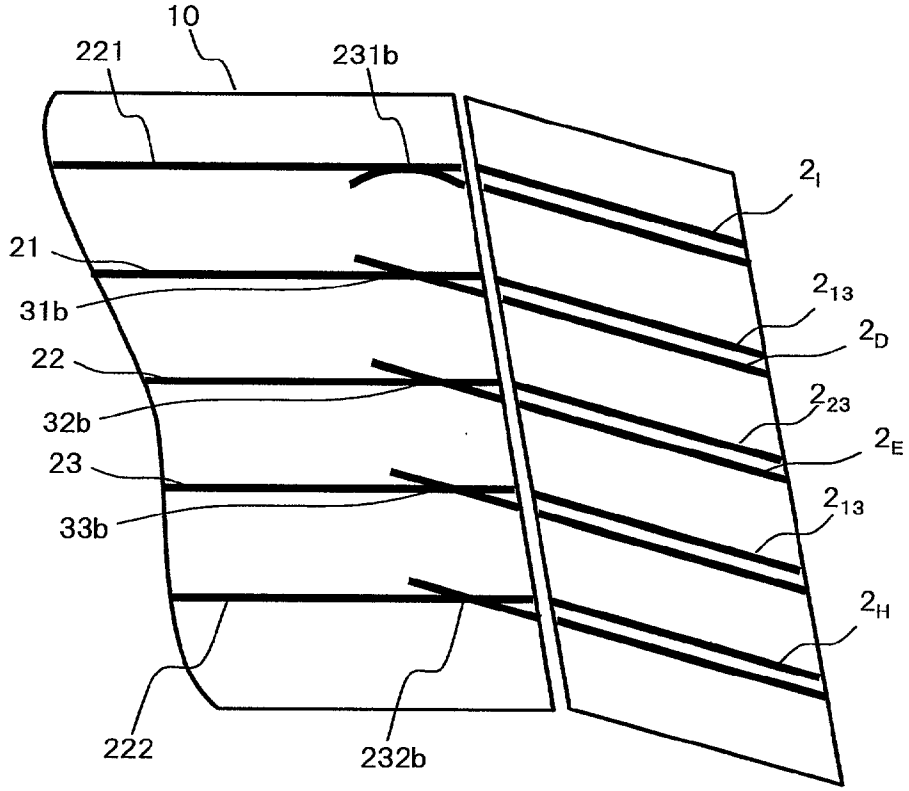

10
221
231b
21
31b
22
32b
23
33b
222
232b
2_I
2_{13}
2_D
2_{23}
2_E
2_{13}
2_H

FIG.6

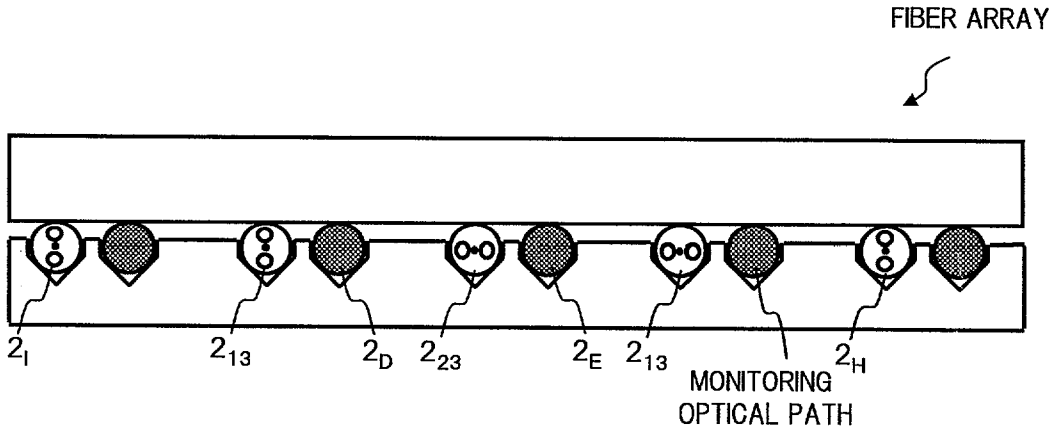

FIBER ARRAY
2_I
2_{13}
2_D
2_{23}
2_E
2_{13}
2_H
MONITORING OPTICAL PATH

FIG.7

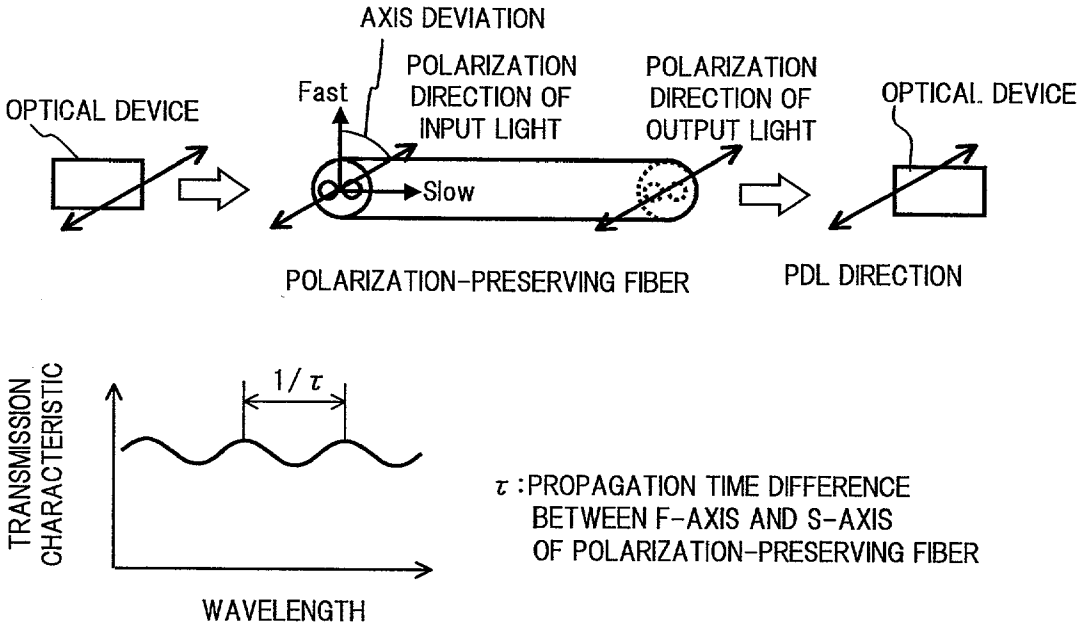

AXIS DEVIATION
OPTICAL DEVICE
Fast
POLARIZATION DIRECTION OF INPUT LIGHT
POLARIZATION DIRECTION OF OUTPUT LIGHT
OPTICAL DEVICE
Slow
POLARIZATION-PRESERVING FIBER
PDL DIRECTION
TRANSMISSION CHARACTERISTIC
1/τ
WAVELENGTH
τ :PROPAGATION TIME DIFFERENCE BETWEEN F-AXIS AND S-AXIS OF POLARIZATION-PRESERVING FIBER

FIG.8

PROPAGATION DIRECTION OF LIGHT AND SAW	WAVELENGTH Λ OF SAW SENSED BY LIGHT
STATIC (ACOUSTIC VELOCITY = 0)	Λ_0 PROPAGATION DIRECTION OF LIGHT
FORWARD DIRECTION	Λ_+ PROPAGATION DIRECTION OF SAW
REVERSE DIRECTION	Λ_- PROPAGATION DIRECTION OF SAW

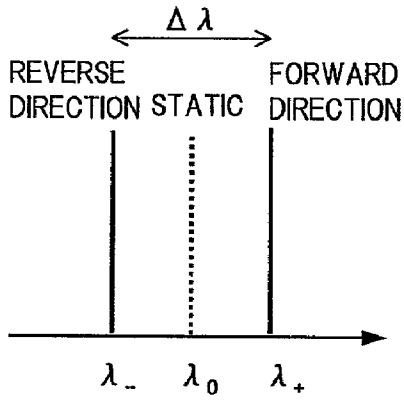


FIG.9A FIG.9B FIG.9C

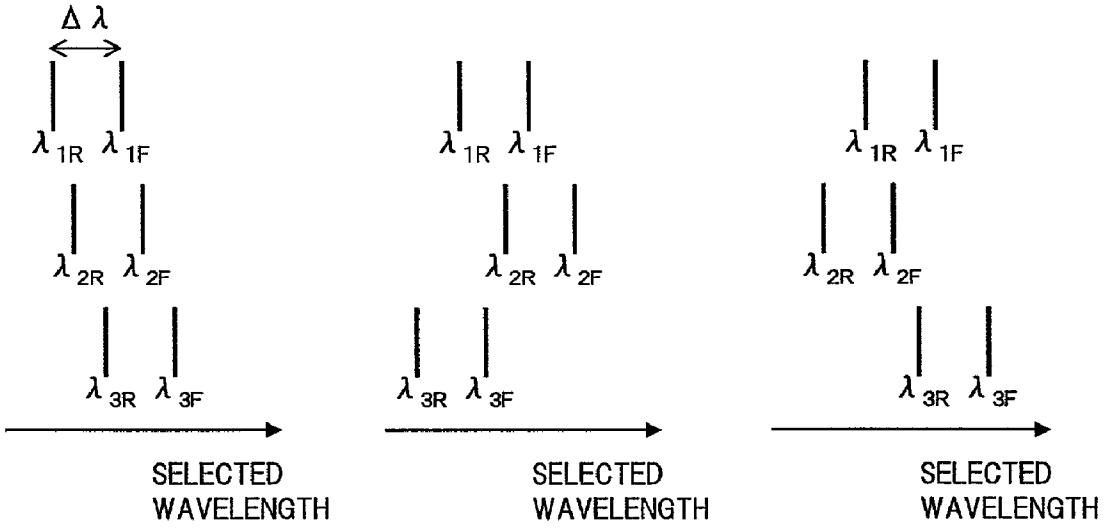


FIG.9D

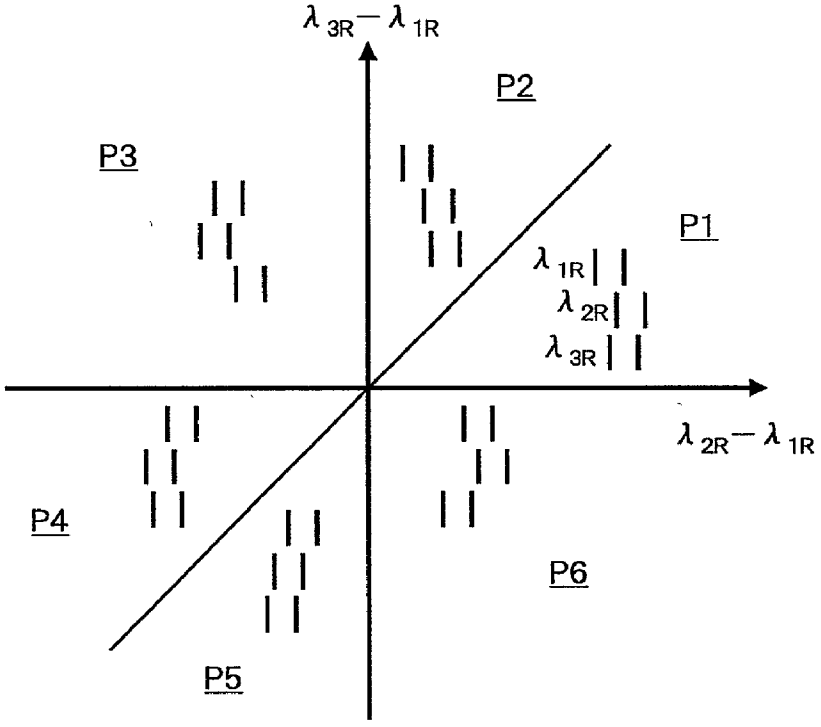


FIG.10

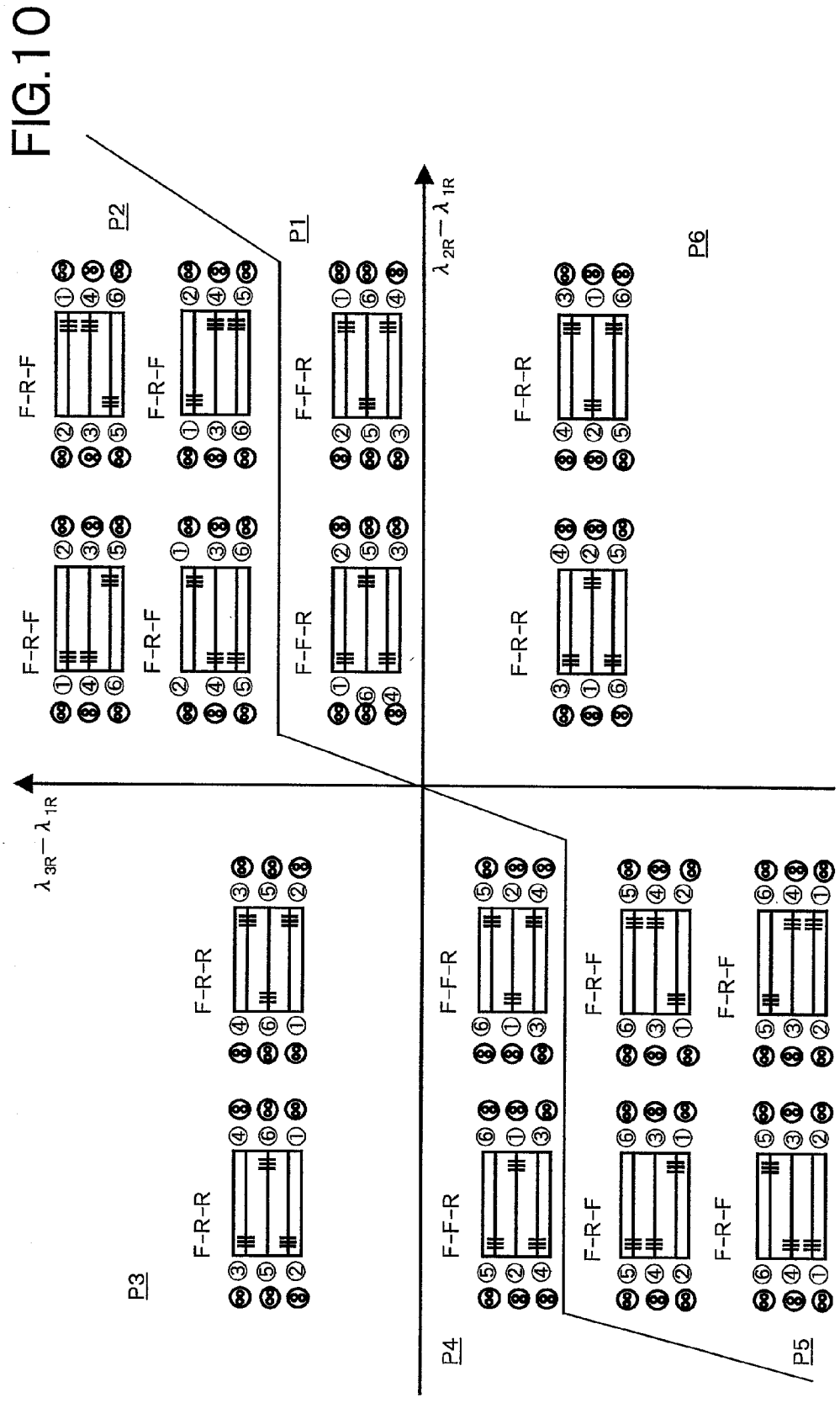
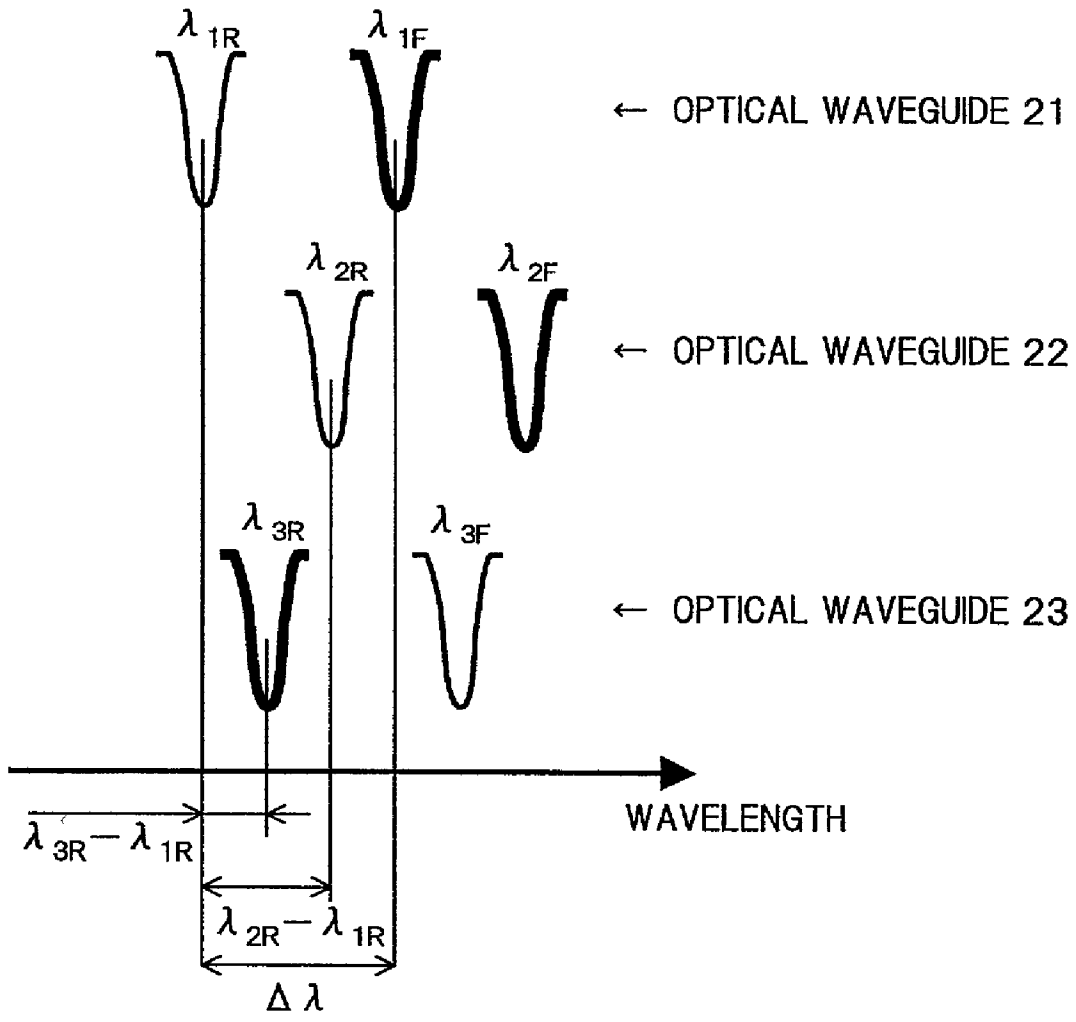

P1
P2
P3
P4
P5
P6
F-R-F
F-F-R
F-R-R
$\lambda_{2R}-\lambda_{1R}$
$\lambda_{3R}-\lambda_{1R}$

FIG.11


λ 1R
λ 1F
← OPTICAL WAVEGUIDE 21
λ 2R
λ 2F
← OPTICAL WAVEGUIDE 22
λ 3R
λ 3F
← OPTICAL WAVEGUIDE 23
WAVELENGTH
λ 3R − λ 1R
λ 2R − λ 1R
Δ λ

CONTROL METHOD AND CONTROL APPARATUS OF OPTICAL WAVELENGTH VARIABLE FILTER

BACKGROUND OF THE INVENTION

[0001] (1) Field of the Invention

[0002] The present invention relates of a control technique of an optical wavelength variable filter to be utilized in various equipments for optical communication, in particular, to a control method and a control apparatus for controlling wavelength characteristics of a band rejection type optical wavelength variable filter.

[0003] (2) Related Art

[0004] There have been demanded developments of optical communication systems and optical signal processing systems capable of constructing networks of large capacities and ultra-long distance with an explosive increase of IP data communication demand. In a transmission system adopting a wavelength-division multiplexing (WDM) transmission as a basic technique thereof, it is possible to realize the large capacity transmission and easily perform the division-multiplication with the wavelength as a unit, so that the construction of flexible optical networks that performs multiplication-division of different kinds of services at optical levels, such as, optical cross-connecting (OXC), optical add/drop multiplexing (OADM) and the like. Therefore, the development and manufacturing of transmission apparatus and signal processing apparatus using the above system have been remarkably made.

[0005] In these apparatuses, there are used many optical function devices, such as, an optical wavelength filter that separates a signal light for each wavelength, and the like. Specifically, the optical wavelength filter is used, for example, for the wavelength switching in the OXC and OADM, the separation of each wavelength at a receiving section, the ASE cutting, and the like.

[0006] By forming the above mentioned optical wavelength filter on a substrate made of SiO_2, $LiNbO_3$ and the like, it becomes possible to achieve the high functions, down-sizing, integration, reduction of electricity, and reduction of cost. Further, in a case where a plurality of optical wavelength filters are cascade connected, it is possible to achieve the narrow transmission band and the improvement of suppression ratio between other channels during used as band-pass type optical wavelength filters, and also it becomes possible to achieve the improvement of extinction ratio during used as band-rejection type optical wavelength filters (notch filters).

[0007] However, in such optical wavelength filters adopted with multi-staged structure, there is caused a problem in that the wavelength setting at respective stages needs to be controlled with high accuracy, since filter characteristics fluctuate due to a change in temperature or a change with time lapse. Further, since there is a possibility that the wavelength of light to be input to the optical wavelength filters fluctuates due to a change in environment, the function for controlling the wavelength setting as mentioned above is indispensable to the optical wavelength filters.

[0008] In particular, in the optical wavelength filter of band rejection type to be used in the OXC, OADM and the like, if the light of wavelength that should have passed through is erroneously blocked, the services to the users are suspended. An occurrence of such a situation should be avoided. In order to avoid such a situation, a wavelength controlling technique for variably controlling the wavelength (selected wavelength) of light to be blocked from passing through at each stage, with high accuracy and reliability, shall be important.

SUMMARY OF THE INVENTION

[0009] The present invention has been achieved in view of the above problems, and an object of the present invention is to provide, in an optical wavelength variable filter of band rejection type structured in multi-stages by cascade connecting a plurality of optical filter sections, a control method and a control apparatus for controlling with high accuracy and reliability selected variable wavelengths at respective stages, to obtain desired wavelength characteristics.

[0010] In order to achieve the above object, the present invention provides a control method of wavelength characteristics of an optical wavelength variable filter of band rejection type including a plurality of optical filter sections each blocking a light corresponding to a selected wavelength from passing through, the optical filter sections being cascade connected to be in a multi-staged structure, wherein, when the optical wavelength variable filter has wavelength characteristics formed with a blocking band including a wavelength band according to a deviation amount obtained by deviating respective selected wavelengths from one another of the plurality of optical filter sections, a dropped light to be blocked from passing through at the optical filter section corresponding to the selected wavelength most closest to the center wavelength of the blocking band, among the respective selected wavelengths, is taken out to be monitored, and the respective selected wavelengths are adjusted based on a peak wavelength of the monitored dropped light, to control the wavelength characteristics.

[0011] Further, according to the present invention, a control apparatus of wavelength characteristics of an optical wavelength variable filter of band rejection type including a plurality of optical filter sections each blocking a light corresponding to a selected wavelength from passing through, the optical filter sections being cascade connected to be in a multi-staged structure, wherein, when the optical wavelength variable filter has wavelength characteristics formed with a blocking band including a wavelength band according to a deviation amount obtained by deviating respective selected wavelengths from one another of the plurality of optical filter sections, said control apparatus comprises a monitoring section that takes out to monitor a dropped light to be blocked from passing through at the optical filter section corresponding to the selected wavelength most closest to the center wavelength of the blocking band, among the respective selected wavelengths, and a controlling section that adjusts the respective selected wavelengths based on a peak wavelength of the dropped light monitored by the monitoring section, to control the wavelength characteristics.

[0012] According to the control method and control apparatus of an optical wavelength variable filter as mentioned above, in the band rejection type optical wavelength variable filter of multi-staged structure, the dropped light to be blocked from passing through at the optical filter section

corresponding to the selected wavelength most closest to the center wavelength of the blocking band among the selected wavelengths at respective stages is taken out to be monitored, so that the peak wavelength of the dropped light can be detected stably. Thus, it becomes possible to control the selected wavelengths at the respective optical filter sections with high accuracy and reliability. In this way, even if the setting of filters or the wavelength of input light fluctuates under an influence of a change in temperature, a change with time lapse or the like, the selected wavelengths at respective stages are adjusted following such a fluctuation, and thus it becomes possible to obtain desired wavelength characteristics stably.

[0013] Further objects, features and advantages of the present invention will become more apparent from the following description of preferred embodiments when read in conjunction with the accompanying drawings.

BRIEF EXPLANATION OF THE DRAWINGS

[0014] **FIG. 1** is a block diagram showing an embodiment of a control apparatus of an optical wavelength variable filter according to the present invention;

[0015] **FIG. 2** is a conceptual diagram for explaining filter characteristics of an optical wavelength variable filter of band rejection type, in which **FIG. 2A** shows ideal filter characteristics, **FIG. 2B** shows filter characteristics of when the selected wavelengths are coincident with one another in a multi-staged structure, and **FIG. 2C** shows filter characteristics of when the selected wavelengths are different from one another;

[0016] **FIG. 3** is a block diagram showing a more specific embodiment of a control apparatus of an optical wavelength variable filter according to the present invention;

[0017] **FIG. 4** is a diagram for explaining the cross-connection of connecting optical paths in the optical wavelength variable filter of **FIG. 3**;

[0018] **FIG. 5** is a diagram showing one example of the end face shape of a substrate in the optical wavelength variable filter of **FIG. 3**;

[0019] **FIG. 6** is a diagram showing one example of fiber array structure connected to the substrate end face in the optical wavelength variable filter of **FIG. 3**;

[0020] **FIG. 7** is a diagram for explaining inter-polarization-mode interference of a polarization-preserving fiber;

[0021] **FIG. 8** is a diagram for explaining the selected wavelength Doppler shift in AOTF;

[0022] **FIG. 9** is a diagram for explaining the deviation of selected wavelengths inherent to the substrate on which three-staged AOTFs are integrated, in which **FIG. 9A** to **FIG. 9C** are exemplary diagrams of wavelength deviation patterns, and **FIG. 9D** is a diagram showing a typical wavelength deviation pattern;

[0023] **FIG. 10** is a schematic view arranging optimum connection relationships in view of an influence of selected wavelength Doppler shift and the like, according to the wavelength deviation patterns in **FIG. 9**; and

[0024] **FIG. 11** is a diagram showing relationships among the selected wavelengths at respective stages set in the optical wavelength variable filter in **FIG. 3**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0025] Embodiments of the present invention will be described based on the drawings.

[0026] **FIG. 1** is a block diagram showing an embodiment of a control apparatus of an optical wavelength variable filter according to the present invention.

[0027] In **FIG. 1**, an optical wavelength variable filter **1** has a three-staged structure in which, for example, three optical filter sections of band rejection type **11**, **12** and **13** are cascade connected via connecting optical paths $\mathbf{2}_{12}$ and $\mathbf{2}_{23}$. Herein, an input optical path $\mathbf{2}_{IN}$ that guides an input light from the outside to the optical filter section **11** at first stage, and an output optical path $\mathbf{2}_{OUT}$ that guides an output light from the optical filter section **13** at third stage to the outside, are connected to the optical wavelength variable filter **1**, respectively. Variable selected wavelengths **λ1**, **λ2** and **λ3** are set to the optical filter sections **11**, **12** and **13** at respective stages, respectively, and the light corresponding to each of the selected wavelengths **λ1**, **λ2** and **λ3** is blocked from passing through, out of the light being propagated through each stage.

[0028] A control apparatus **3** adopted to the optical wavelength variable filter **1** includes, for example, a dropped light monitoring section **3**A that takes out to monitor one of dropped lights L_{D1}, L_{D2}, and L_{D3} blocked from passing through, in the optical filter sections **11**, **12** and **13** at respective stages, and a selected wavelength controlling section **3**B that adjusts the selected wavelengths **λ1**, **λ2** and **λ3** of the optical wavelengths variable filter **1** to control wavelength characteristics, based on the monitoring result at the dropped light monitoring section **3**A. The setting of dropped lights to be monitored by the dropped light monitoring section **3**A will be described later.

[0029] Here, the basic setting for the selected wavelengths **λ1**, **λ2** and **λ3** of the optical wavelength variable filter **1** will be described hereinafter.

[0030] Generally, for the characteristics of the band rejection type optical wavelength filter, for example, as shown in the conceptual diagram of **FIG. 2**A, it is an ideal to have a filter characteristic that is changed in rectangular, namely, a change in transmissivity from the passing band to the blocking band is steep and also the blocking band has a required width. The multi-staged structure with a plurality of optical filter sections being cascade connected is useful as means for achieving the realization of such a filter characteristic. The optical wavelength filter having a filter characteristic with an excellent extinction ratio can be obtained, as the number of stages is increased.

[0031] When the multi-staged structure as mentioned above is applied, if the wavelengths of lights at the respective stages, that are blocked from passing through, are all coincident, as shown in the conceptual diagram of **FIG. 2**B, since the transmissivity becomes minimum at one point, the width of blocking band becomes narrower. For the blocking band of the rejection type optical wavelength filter, a required width needs to be ensured, considering the conditions of, for example, the wavelength width of optical signal corresponding to the spectrum width of light source such as laser, errors in setting or controlling of optical wavelength filter, or the unstable wavelength of light source. Therefore,

according to the filter characteristics as shown in **FIG. 2**B, it becomes impossible to block the passing of optical signal of desired wavelength even in a case a slight variation is caused in the setting of the optical signal wavelength or the setting of filter.

[**0032**] Therefore, the band rejection type optical wavelength variable filter to which the control system according to the present invention is applied, adopts the wavelength setting, as a premise, to ensure a required width of blocking band by deviating the selected wavelengths at respective stages from one another, as shown in **FIG. 2C**. That is, in the optical wavelength variable filter with the selected wavelengths at respective stages being deviated from one another, the transmission wavelength characteristics at respective stages shown by dotted line are overlapped to one another, so that the transmission wavelength characteristics shown by solid line can be obtained as the entire filter. In the transmission wavelength characteristics of the entire filter is formed with a blocking band having a wavelength width corresponding to a deviation amount between selected wavelengths at respective stages.

[**0033**] Specifically, in the optical wavelength variable filter **1** of **FIG. 1**, for example, it is assumed that the selected wavelengths at respective stages are deviatedly set in advance so as to have a relationship in length of $\lambda 1<\lambda 2<\lambda 3$, and there is formed a blocking band having a wavelength width corresponding to a deviation amount between the selected wavelength $\lambda 1$ and the selected wavelength $\lambda 3$.

[**0034**] For the optical wavelength variable filter **1** set with the selected wavelengths $\lambda 1$ to $\lambda 3$ at respective stages as described above, in the control apparatus **3**, the selected wavelength positioned most closest to the center wavelength of the blocking band, among the selected wavelengths $\lambda 1$ to $\lambda 3$ at respective stages, that is, the selected wavelength $\lambda 2$ in the above example, is taken notice, the dropped light L_{D2} to be blocked from passing through by the optical filter section **12** at second stage corresponding to the selected wavelength $\lambda 2$ is taken out, to be monitored by the dropped light monitoring section **3**A, and the monitoring result is transmitted to the selected wavelength controlling section **3**B. Then, in the selected wavelength controlling section **3**B, a peak wavelength of the dropped light L_{D2} is detected based on the monitoring result from the dropped light monitoring section **3**A, and a wavelength deviation amount to the previously set selected wavelength $\lambda 2$ is obtained, so that the selected wavelengths $\lambda 1$ to $\lambda 3$ at respective stages are adjusted in accordance with the wavelength deviation amount.

[**0035**] In this way, in the dropped light monitoring section **3**A of the control apparatus **3**, the dropped light L_{D2} corresponding to the selected wavelength $\lambda 2$ most closest to the center wavelength of the blocking band is selectively monitored. Thus, it becomes possible to judge reliably an actual filter characteristic of the optical wavelength variable filter **1**. That is, each of the optical signals of respective wavelengths input to the optical wavelength variable filter **1** has the wavelength width corresponding to the spectrum width of light source, and is likely to fluctuate by an influence of unstable wavelength of the light source. Such optical signals are dropped at the optical filter sections **11** to **13** at respective stages. If the dropped light from the optical filter section of which selected wavelength is positioned at the end of the blocking band (in the above example, dropped light L_{D1} or L_{D3}) is monitored, the wavelength of the dropped light reaches a wavelength region where the transmissivity is steeply changed, so that the level of the dropped light to be monitored by the dropped light monitoring section **3**A is greatly changed. Thus, there is a possibility that the peak wavelength of the dropped light cannot be detected accurately. In order to realize the stable peak wavelength detection by avoiding such a situation, it is useful to take out to monitor the dropped light corresponding to the selected wavelength most closest to the center wavelength of the blocking band.

[**0036**] Even if the setting of filter or the wavelength of input light fluctuates by an influence of a change in temperature, a change with time lapse or the like, the selected wavelengths $\lambda 1$ to $\lambda 3$ at respective stages are adjusted following the fluctuation, by controlling with high accuracy and reliability the selected wavelengths $\lambda 1$ to $\lambda 3$ at respective stages of the optical wavelength variable filter **1** by the control apparatus **3**. Thus, it is possible to realize stably a desired filter characteristic.

[**0037**] In the above embodiment, there has been shown the optical wavelength variable filter **1** of a three-staged structure by cascade connecting three optical filter sections **11** to **13**. However, it is also possible to apply the control technique of the present invention to an optical wavelength variable filter of a multi-staged structure by cascade connecting four or more optical filter sections.

[**0038**] Next, there will be described a more specific embodiment of a control apparatus of an optical wavelength variable filter according to the present invention. In the following, the consideration is made on a control apparatus of a band rejection type optical wavelength variable filter embodied by cascade connecting three optical filter sections on the same substrate, as one example.

[**0039**] **FIG. 3** is a plan view showing the constitution of the optical wavelength variable filter and control apparatus thereof according to the above embodiment. Components same as those in the above embodiment are denoted by the same reference numerals.

[**0040**] In the optical wavelength variable filter **1** shown in **FIG. 3**, for example, three acousto-optic tunable filters (AOTF) formed on the same substrate **10** are connected to one another by means of connecting optical paths $\mathbf{2}_{13}$ and $\mathbf{2}_{23}$, as optical filter sections **11** to **13**. Optical input and output portions of the connected AOTFs on the same substrate **10** are connected to the input optical path $\mathbf{2}_{IN}$ and the output optical path $\mathbf{2}_{OUT}$ by using an optical circulator **4**, a polarization beam splitter (PBS) **5**, a polarization rotating section **6** and connecting optical paths $\mathbf{2}_A$, $\mathbf{2}_B$, $\mathbf{2}_C$, so that the three AOTFs on the substrate **10** are cascade connected in a loop.

[**0041**] The control apparatus **3** to be applied to the above optical wavelength variable filter **1**, for example, comprises a first monitoring section **100**, a second monitoring section **200** and an RF signal controlling section **300**. The first monitoring section **100** corresponding to the dropped light monitoring section **3**A shown in **FIG. 1**, monitors a dropped light blocked from passing through by a required AOTF, so as to perform a tracking control of the selected wavelengths in the respective AOTFs cascade loop connected on the

substrate **10**. The second monitoring section **200**, at the starting, the alteration of setting or the like of the optical wavelength variable filter **1**, in order to previously detect a control value of the AOTFs cascade loop connected on the substrate **10**, monitors the lights passed through monitoring AOTFs on the substrate **10**, that operates in accordance with the parameter same as for the AOTFs. The RF signal controlling section **300** controls RF signals to be given to the respective AOTFs based on the monitoring results of the first and second monitoring sections **100** and **200**, to control the operation states of AOTFs. The RF signal controlling section **300** has a function equivalent to the selected wavelength controlling section **3**B shown in **FIG. 1**.

[**0042**] The substrate **10** is constituted such that five optical waveguides **21**, **22**, **23**, **221** and **222** substantially parallel with one another are formed on a substrate material made of, for example, $LiNbO_3$. The optical waveguides **21** to **23** are used for the main signal, and the optical waveguides **221** and **222** are used for the second monitoring section **200**. The respective optical waveguides **21**, **22**, **23**, and **221**, **222** are provided with polarization beam splitters (PBS) **31***a*, **31***b*, **32***a*, **32***b*, **33***a*, **33***b*, and **231***a*, **231***b*, **232***a*, **232***b*, respectively, at both end portions thereof. Also, the substrate **10** is formed with interdigital transducers (IDT) **41**, **42**, **43**, and **241**, **242**, and SAW guides **51**, **52**, **53**, and **251**, **252**, corresponding to the optical waveguides **21**, **22**, **23**, and **221**, **222**, respectively.

[**0043**] As the respective PBSs **31***a*, **31***b*, **32***a*, **32***b*, **33***a* and **33***b* for main signal, it is possible to use, for example, PBSs of crossing waveguide type and the like. Here, input and output ports of the PBSs positioned at the crossing sides of the crossing waveguides are connected to the optical waveguides, respectively, so that the respective PBSs are constituted to be of TE mode transmission type. Further, as the respective PBSs **231***a*, **231***b*, **232***a* and **232***b* for the second monitoring section **200**, it is possible to use, for example, PBSs of crossing waveguide type and the like. However, herein, input and output ports of the PBSs **231***a* and **232***b* positioned at the crossing sides of the crossing waveguides are connected to the optical waveguides, respectively, so that the PBSs **231***a* and **232***b* are constituted to be of TE mode transmission type, while input and output ports of the PBSs **231***b* and **232***a* positioned at the bar sides of the crossing waveguides are connected to the optical waveguides, respectively, so that the PBSs **231***b* and **232***a* are constituted to be of TM mode transmission type.

[**0044**] The respective IDTs **41** to **43**, **241** and **242** are applied commonly with a signal of required frequency f generated by an RF signal generating circuit **40**, to generate surface acoustic waves (SAW), respectively. Note, as will be described later, positions of the respective IDTs **41** to **43**, **241** and **242** are preferably set such that relationships between the propagation directions of SAWs and the propagation directions of lights within the corresponding optical waveguides are those taking into account of influences of selected wavelength Doppler shift and the like.

[**0045**] The SAW guides **51** to **53**, **251** and **252** are those for propagating respective SAWs generated at the IDTs **41** to **43**, **241** and **242** through the optical waveguides **21** to **23**, **221** and **222**, respectively. Here, a case is shown where, for example, SAW guides of directional coupling type formed in required shape by Ti diffusion are used, as the SAW guides **51** to **53**, **251** and **252**.

[**0046**] In the AOTF using the SAW guides of directional coupling type, SAWs generated at the IDTs are directionally coupled by the SAW guides of required shape, so that SAWs most strongly interfere the light being propagated through the optical waveguide in the vicinity of the center of mode conversion area. Thus, it is possible to achieve the suppression of side lobe level in the filter characteristics of AOTF. Note, in the SAW guides shown in **FIG. 3**, curving shapes are adopted in order to directionally couple SAWs in accordance with a further desired function. In this way, it becomes possible to suppress further effectively the side lobe level.

[**0047**] Here, the case is shown where the AOTF using the SAW guides of directional coupling type is used. However, the present invention is not limited thereto, and it is possible to use AOTF and the like formed with SAW guides of thin film type on the optical waveguides. Further, for the AOTF using the SAW guides of thin film type, the arrangement may be such that the longitudinal direction of each SAW guide is inclined by a required amount to the axial direction of the optical waveguide so that the propagation axis of SAW and the optical axis cross each other at an inclined angle. By adopting such an arrangement, the intensity of surface acoustic wave sensed by the light is weighted in the longitudinal direction. Thus, it becomes possible to achieve the suppression of side lobe level.

[**0048**] The optical circulator **4** is a typical optical component that includes at least three ports **4***a*, **4***b* and **4***c*, and transmits the light only in a direction from the port **4***a* to port **4***b*, from the port **4***b* to port **4***c*, and from the port **4***c* to port **4***a*. This optical circulator **4** is connected with the input optical path $\mathbf{2}_{IN}$, the connecting optical path $\mathbf{2}_{A}$ to be connected to a PBS **5**, and the output optical path $\mathbf{2}_{OUT}$, at the port **4***a*, port **4***b*, and port **4***c*, respectively.

[**0049**] The PBS **5** splits an input light sent from the port **4***b* of the optical circulator **4** via the connecting optical path $\mathbf{2}_{A}$ into two polarization lights with polarization planes thereof being orthogonal to each other, to output one of the two polarization lights to one end of the connecting optical path $\mathbf{2}_{B}$, while outputting the other polarization light to one end of the connecting optical path $\mathbf{2}_{C}$. The other end of the connecting optical path $\mathbf{2}_{B}$ is connected to the PBS $\mathbf{31}_{a}$ positioned on the optical waveguide **21** of the substrate **10**, and the other end of the connecting optical path $\mathbf{2}_{C}$ is connected to the PBS **32***a* positioned on the optical waveguide **22** of the substrate **10**. Also, herein, a polarization rotating section **6** is inserted onto the connecting optical path $\mathbf{2}_{C}$. The polarization rotating section **6** has a function for rotating the polarization plane of the other polarization light split by the PBS **5** by 90 degrees.

[**0050**] The PBS **31***b* positioned on the optical waveguide **21** of the substrate **10** is connected to the PBS **33***b* positioned on the optical waveguide **23** by the connecting optical path $\mathbf{2}_{13}$. Further, the PBS **32***b* positioned on the optical waveguide **22** of the substrate **10** is connected to the PBS **33***a* positioned on the end portion of the optical waveguide **23** by the connecting optical path $\mathbf{2}_{23}$. Thus, the three AOTFs for main signal on the substrate **10** are cascade connected iri a loop between the input optical path $\mathbf{2}_{IN}$ and the output optical path $\mathbf{2}_{OUT}$.

[**0051**] The connecting optical paths $\mathbf{2}_{B}$, $\mathbf{2}_{C}$, $\mathbf{2}_{13}$ and $\mathbf{2}_{23}$ are polarization-preserving fibers, and here, for example, PANDA type fibers are used. However, the structure of

polarization-preserving fiber is not limited to the PANDA type fiber, and it is possible to adopt a known structured fiber. Further, each of the connecting optical paths 2_B, 2_C, 2_{13} and 2_{23} includes a cross-connecting section C spliced by rotating the polarization axis substantially by 90 degrees as shown in **FIG. 4**, and suppresses an influence due to the deviation of polarization axis of when connecting an optical device having polarization dependence by the polarization-preserving fiber, as described later.

[**0052**] Moreover, the first monitoring section **100** connected to the substrate **10** comprises an optical isolator **101**A and a light receiver **102**A for monitoring a dropped light from the lights sequentially passing in one direction through the respective AOTFs cascade loop connected to one another, an optical isolator **101**B and a light receiver **102**B for monitoring a dropped light from the lights sequentially passing in the other direction through the respective AOTFs cascade loop connected to one another, and a circuit **103** that adds up output signals photo-electrically converted by the light receivers **102**A and **102**B, to output a monitor signal M1.

[**0053**] Here, an input port of the optical isolator **101**A is connected to a TM mode output port of the PBS **31***b* on the substrate **10** via a connecting optical path 2_D, while an input port of the optical isolator **101**B is connected to a TM mode output port of the PBS **32***b* on the substrate **10** via a connecting optical path 2_E. Note, it is assumed that a position for monitoring the dropped signal for the light in each direction is set to an AOTF stage wherein the selected wavelength is positioned most closest to the center wavelength of blocking band, as in the case of the dropped light monitoring section **3**A in the above embodiment.

[**0054**] Further, the second monitoring section **200** connected to the substrate **10** includes an optical coupler **201** on the input optical path 2_{IN} that branches a part of the input light by a required branching ratio (for example, 10:1 and the like), a PBS **202** that polarization splits the branched light from the optical coupler **201** to send the split lights to the respective monitoring AOTFs on the substrate **10**, a PBS **204** that multiplexes the polarization lights passed through the monitoring AOTFs on the substrate **10**, and a light receiver **206** that converts the monitor light multiplexed by the PBS **204** into an electrical signal, to thereby output a monitor signal M2.

[**0055**] The PBS **202** splits the branched light sent from the optical coupler **201** via a connecting optical path 2_F into two polarization lights with polarization planes thereof being orthogonal to each other, and outputs one of the polarization lights to one end of a connecting optical path 2_G, while outputting the other polarization light to one end of a connecting optical path 2_H. The other end of the connecting optical path 2_G is connected to a PBS **231***a* positioned on the optical waveguide **221** of the substrate **10**, and the other end of the connecting optical path 2_H is connected to a PBS **232***b* positioned on the optical waveguide **222** of the substrate **10**. Also, herein, a polarization rotating section **203** is inserted onto the connecting optical path 2_H. The polarization rotating section **203** has a function for rotating the polarization plane of the other polarization light split by the PBS **202** by 90 degrees.

[**0056**] The PBS **204** multiplexes the polarization lights with polarization planes thereof being orthogonal to each other, passed through the monitoring AOTFs on the substrate **10** to be sent via respective connecting optical paths 2_I and 2_J, to output the multiplexed light to the light receiver **206**. Specifically, a TM mode light output from a PBS **231***b* on the optical waveguide **221** of the substrate **10** is input to the PBS **204** through the connecting optical path 2_I, and at the same time, a TM mode light output from a PBS **232***a* on the optical waveguide **222** of the substrate **10** passes through the connecting optical path 2_J and is rotated with polarization plane thereof by 90 degrees at a polarization rotating section **205**, to be input to the PBS **204**.

[**0057**] For the respective connecting optical paths 2_D, 2_E, 2_G, 2_H, 2_I and 2_J used in the first and second monitoring sections **100** and **200**, for example, optical paths of polarization-preserving type such as PANDA type fiber are used, and each optical path includes, in the vicinity of the center in the longitudinal direction, the cross-connecting section C of the same structure as in the above mentioned **FIG. 4**.

[**0058**] It is preferable that two end faces opposite to each other of the substrate **10**, to which the respective optical paths for main signal and for monitoring are connected, are inclined by required angles so as to reduce an influence of reflected light at the faces connected with the respective optical paths, for example, as shown in **FIG. 5**. Also, it is preferable that the optical fibers to be connected to each of the substrate end faces are structured in a fiber array, for example, as shown in **FIG. 6**. Note, the optical fibers provided in parallel to the respective connecting optical paths 2_{13} and 2_{23} in **FIG. 6**, are for extracting the dropped lights and the like to be blocked from passing through by the AOTFs at respective stages. An arrangement for the polarization axes of the polarization-preserving fibers within the fiber array is desirable to be set, considering the symmetry with a fiber array connected to the substrate end face on the opposite side, so that the kinds of the both side fiber arrays are the same.

[**0059**] In the optical wavelength variable filter **1** having the above mentioned constitution, the input light propagated through the input optical path 2_{IN} is sent to the PBS **5** via the optical circulator **4** and the connecting optical path 2_A, and split into two polarization lights orthogonal to each other, to be output to the connecting optical paths 2_B and 2_C, respectively. The polarization light output to the connecting optical path 2_C is rotated with polarization plane thereof by 90 degrees by the polarization rotating section **6**, to be aligned with the polarization direction of the polarization light output to the connecting optical path 2_B. Then, the respective polarization lights propagated through the connecting optical paths 2_B and 2_C are given to the PBSs **31***a* and **32***a* on the substrate **10**, respectively, as the TE mode lights. Note, in **FIG. 3**, the polarization directions of propagated lights are indicated together with the cross section of arrangement of polarization axes of the PANDA type fibers, so that the polarization directions of propagated lights at the respective portions on the optical paths cascade loop connected can be clearly understood.

[**0060**] The TE mode light given to the PBS **31***a* passes therethrough and is propagated through the optical waveguide **21** toward the PBS **31***b*. At this time, SAW generated as a result that the RF signal of frequency f from the RF signal generating circuit **40** is applied to the IDT **41**, is guided along the optical waveguide **21** by the SAW guide

51, to be propagated in the same direction (forward direction) as the propagated light within the optical waveguide **21**. Due to the acousto-optic effect by this SAW, only the light of wavelength corresponding to the frequency of SAW (selected wavelength) out of the TE mode light being propagated within the optical waveguide **21**, is mode converted into a TM mode light. Then, the lights of respective modes reach the PBS **31***b*, the TE mode light of wavelengths different from the selected wavelength (non-selected wavelengths), that has not been mode converted, passes through the PBS **31***b* to be output to the connecting optical path $\mathbf{2}_{13}$, while the mode converted TM mode light of selected wavelength is branched by the PBS **31***b* as a dropped light, to be sent to the optical isolator **101**A of the first monitoring section **100**.

[**0061**] The TE mode light output to the connecting optical path $\mathbf{2}_{13}$ passes through the PANDA type fiber that is spliced by 90 degrees in the vicinity of the center in the longitudinal direction, to be sent to the PBS **33***b* on the optical waveguide **23**. At this time, a periodic wavelength dependence loss or polarization mode dispersion (PMD) due to inter-polarization-mode interference caused in the PANDA type fiber, and a polarization dependence loss (PDL) caused in the PBS on the substrate **10** and the like are offset in front of and behind the 90 degree splice point, to be suppressed.

[**0062**] Here, there will be described the inter-polarization-mode interference caused within the optical paths of polarization-preserving type.

[**0063**] In a case where a plurality of optical devices each having polarization dependence are connected by polarization-preserving fiber or the like, it is an ideal to perform the connection by completely coinciding the polarization axis (Fast axis, Slow axis) directions of the polarization-preserving fiber with the axis direction of polarization light to be input/output to/from the optical devices. However, in the actual connection of the polarization-preserving fiber with the optical devices, it is difficult to completely coincide the axis directions with each other and thus, certain axis deviation cannot be avoided.

[**0064**] If the axis deviation as mentioned above is caused, as shown in **FIG. 7**, the inter-polarization-mode interference of the polarization-preserving fiber is caused, resulted in the periodic wavelength dependence loss in the transmission characteristics of optical devices. The period of this periodic wavelength dependence loss becomes $1/\tau$, if a difference between the propagation times of Fast axis and Slow axis of the polarization-preserving fiber is τ. Such a periodic wavelength dependence loss due to the inter-polarization-mode interference of the polarization-preserving fiber causes a change in level of transmission light in an optical filter of band rejection type according to the wavelength, to lead characteristic deterioration.

[**0065**] Therefore, in the present optical wavelength variable filter **1**, by splicing the PANDA type fiber by rotating the polarization axis thereof by 90 degrees in the vicinity of the center of the connecting optical path in the longitudinal direction, the respective directions of Fast axis and Slow axis are switched in front of and behind the splicing point, so that the polarization light to be propagated through the connecting optical path is propagated through the respective polarization axes for substantially equal distances. Thus, the influence by the above mentioned periodic wavelength dependence loss, PMD or PDL shall be offset.

[**0066**] The TE mode light sent to the PBS **33***b* on the substrate **10** passes therethrough and is propagated within the optical waveguide **23** toward the PBS **33***a*. At this time, SAW generated at the IDT **43** and guided by the SAW guide **53** is propagated in a reverse direction to the propagated light within the optical waveguide **23**. Due to the acoust-optic effect by this SAW, only the light corresponding to the selected wavelength out of the TE mode light being propagated through the optical waveguide **23** is mode converted into a TM mode light. Then, when the lights of respective modes reach the PBS **33***a*, the TE mode light of non-selected wavelengths, that has not been mode converted, passes through the PBS **33***a* to be output to the connecting optical path $\mathbf{2}_{23}$, while the mode converted TM mode light of selected wavelength is branched by the PBS **33***a*.

[**0067**] The TE mode light output to the connecting optical path $\mathbf{2}_{23}$ is sent to the PBS **32***b* on the optical waveguide **22** while the periodic wavelength dependence loss and the like thereof being suppressed by passing the PANDA type fiber having the cross-connecting section C, in the same manner as when passed through the connecting optical path $\mathbf{2}_{13}$.

[**0068**] The TE mode light sent to the PBS **32***b* passes therethrough and is propagated within the optical waveguide **22** toward the PBS **32***a*. At this time, SAW generated at the IDT **42** and guided by the SAW guide **52** is propagated in a forward direction to the propagated light within the optical waveguide **22**. Due to the acoust-optic effect by this SAW, only the light corresponding to the selected wavelength out of the TE mode light being propagated through the optical waveguide **22** is mode converted into a TM mode light. The TE mode light of non-selected wavelengths, that has not been mode converted, passes through the PBS **32***a* to be output to the connecting optical path $\mathbf{2}_{C}$, while the mode converted TM mode light of selected wavelength is branched by the PBS **32***a*. The TE mode light output to the connecting optical path $\mathbf{2}_{C}$ is rotated with the polarization plane thereof by 90 degrees by the polarization rotating section **6** on the connecting optical path $\mathbf{2}_{C}$ and then returned to the PBS **5**.

[**0069**] The respective selected wavelengths to be mode converted at the respective optical waveguides **21** to **23** are slightly different from one another, due to the selected wavelength Doppler shift to be described in the following, or inherent wavelength deviation caused by variations in manufacturing process of the substrate **10**, even in a constitution where the RF signal is applied commonly to the IDTs **41** to **43**.

[**0070**] Here, the selected wavelength Doppler shift will be described.

[**0071**] The selected wavelength Doppler shift is a phenomenon in which the wavelengths of the light to be polarization mode converted become different from one another due to the acousto-optic effect, depending on a relationship between the propagation direction of light within the optical waveguide and that of SAW transmitted along that optical waveguide. This phenomenon is caused by the same theory as that of typically known Doppler shift, and in the above case, it can be considered that the wavelength (frequency) of SAW viewed from the light is changed. Accordingly, for example, as shown in **FIG. 8**, if the propagation direction of light is the same forward direction as the propagation direction of SAW, the wavelength of

SAW sensed by the light becomes longer. On the contrary, if the propagation direction of light is the reverse direction to the propagation direction of SAW, the wavelength of SAW sensed by the light becomes shorter. The selected wavelength λ in a case of influenced by such a Doppler shift, can be represented by the following equation (1);

$$\lambda = \frac{\lambda_0}{1 - v/c} \tag{1}$$

[0072] wherein λ_0 is the selected wavelength in a case where SAW is static, v is a speed of SAW, and c is an average speed of light in the optical waveguide.

[0073] Accordingly, a selected wavelength difference Δλ caused by whether the propagation directions of the light and SAW are forward directions or reverse directions can be represented by the following equation (2).

$$\Delta\lambda = 2 \cdot \lambda_0 \cdot \frac{v/c}{1 - (v/c)^2} \tag{2}$$

[0074] In the optical wavelength variable filter **1** of rejection type with three AOTFs cascade loop connected as shown in **FIG. 3**, the selected wavelengths in the AOTFs at respective stages are different from one another due to the inherent wavelength deviation caused by variations in manufacturing process of the substrate **10** in addition to the selected wavelength difference Δλ due to the above mentioned selected wavelength Doppler shift. The wavelength deviation caused by variations in manufacturing process, for example, is inherently caused in individual substrates due to manufacturing errors in width of the optical waveguides **21** to **23** at respective stages.

[0075] Since the wavelength characteristics of the optical wavelength variable filter **1** is regarded, as a premise, to ensure a required width of the blocking band by slightly deviating the selected wavelengths of AOTFs at respective stages from one another, as shown in **FIG. 2**C, herein the wavelength deviation inherent to the substrate caused by variations in manufacturing process is considered and also the selected wavelength difference Δλ due to the selected wavelength Doppler shift is utilized, to realize the setting of selected wavelengths deviated from one another as described above.

[0076] Specifically, when the selected wavelengths corresponding to the respective optical waveguides **21**, **22**, **23** when SAWs of the same frequency f are given in the forward directions to the propagated lights are made λ_{1F}, λ_{2F} and λ_{3F}, while the selected wavelengths corresponding to the respective optical waveguides **21**, **22**, **23** when SAWs of the same frequency f are given in the reverse directions to the propagated lights are made λ_{1R}, λ_{2R} and λ_{3R}, there occurs various patterns in the wavelength deviation inherent to the substrate caused by variations in manufacturing process, as shown in **FIG. 9A** to **FIG. 9**C, for example. Such wavelength deviation patterns of the three staged AOTFs can be classified into six patterns P1 to P6 as shown in **FIG. 9D** when the values of λ_{2R}-λ_{1R} are put on the horizontal axis and the values of λ_{3R}-λ_{1R} are put on the transverse axis with the selected wavelength λ_{1R} as the reference.

[0077] In order to realize the selected wavelengths that are slightly deviated among the respective stages as shown in **FIG. 2**C, it is required to determine optimum combinations of the wavelength deviation of the patterns P1 to P6, with the wavelength difference due to the selected wavelength Doppler shift. When determining the optimum combinations, it is desired to consider the condition that the connection relationship in which such kinds of fiber arrays as explained in **FIG. 6** can be made same on the both ends of the substrate **10**, and the connection relationship of the input and output for suppressing an influence by stray light as described in the following, are satisfied at the same time.

[0078] In a case where a plurality of optical devices integrated on the same substrate are connected to be used, most of the input light from a substrate input section passes through the optical devices, however, as shown by an arrow in dotted line in **FIG. 3, a** part of the input light is emitted into the substrate to be propagated as the stray light S. This stray light S is likely to be coupled to an output section bypassing the optical devices, thereby causing deterioration of extinction ratio and the like.

[0079] In order to effectively suppress such a leakage phenomenon of the stray light S from the input side to the output side, for example, in a case where a plurality of optical devices on the same substrate are cascade connected to be used, such a connection relationship is preferable that both ends of optical path passing through all of optical devices are positioned on the same end face of the substrate. By realizing such a connection relationship, the stray light S from the input side is hardly to be coupled to the light being propagated within the optical path on the output side.

[0080] The optimum combinations satisfying all the conditions of the above mentioned selected wavelength Doppler shift and the like, including the connection relationship of input and output for suppressing the above influence by the stray light, can be determined corresponding to the respective patterns P1 to P6 in **FIG. 9**D, and the combination results are shown in **FIG. 10**.

[0081] In **FIG. 10**, the numerals **1** to **6** indicated at both ends of the substrate show the connecting orders of AOTFs at respective stages. Further, characters such as "F-F-R" (forward-forward-reverse) indicated at the upper part of the substrate show the propagation direction of SAW relative to the light being propagated through the optical waveguide positioned at the upper stage of the substrate in the figure, the propagation direction of SAW relative to the light being propagated through the optical waveguide positioned at the middle stage of the substrate, and the propagation direction of SAW relative to the light being propagated through the optical waveguide positioned at the lower stage of the substrate, in this sequence. Further, arrangements of respective polarization axes of when the respective PANDA type fibers connected to the both ends of the substrate are made fiber arrays of same kind, are shown on the right and left sides of the substrate.

[0082] The constitution of the optical wavelength variable filter shown in **FIG. 3** specifically illustrates the connection relationship corresponding to the pattern P1 in **FIG. 10**. For the selected wavelength Doppler shift, the arrangement of

the IDTs **41**, **43** and **42** at the respective stages are set so that, to the light given via the connecting optical path 2_B, the propagation direction of SAW in the AOTF of the first stage corresponding to the optical waveguide **21** is the forward direction, the propagation direction of SAW in the AOTF of the second stage corresponding to the optical waveguide **23** is the reverse direction, and the propagation direction of SAW in the AOTF of the third stage corresponding to the optical waveguide **22** is the forward direction. In the AOTFs at respective stages, since the RF signal of the same frequency is given to the IDTs, the wavelength difference due to the selected wavelength Doppler shift corresponding to the above equation (2) is caused between the selected wavelengths at the first and third stages, and the selected wavelength at the second stage. Thus, by combining the wavelength difference with the inherent wavelength deviation of the pattern P1, it becomes possible to realize the filter characteristic as shown in **FIG. 2C**.

[**0083**] In the optical wavelength variable filter **1**, the TE mode light given from the PBS **5** to the PBS **32***a* of the substrate **10** via the connecting optical path 2_C and the polarization rotating section **6** passes through the AOTFs at respective stages sequentially, in reverse to the TE mode light given to the PBS **31***a* of the substrate **10** via the connecting optical path 2_B, namely, passes sequentially through the optical waveguide **22**, PBS **32***a*, connecting optical path 2_{23}, PBS **33***a*, optical waveguide **23**, PBS **33***b*, connecting optical path 2_{13}, PBS **31***b*, optical waveguide **21** and PBS **31***a*, to be output to the connecting optical path 2_B, and is returned to the PBS **5** under the polarization state just as is without polarization plane thereof rotated. In this reverse propagation of the polarization light, the mode converted TM mode light corresponding to the selected wavelength when being propagated through the optical waveguide **22**, is branched by the PBS **32***b* as the dropped light, to be sent to the optical isolator **101**B of the first monitoring section **100**.

[**0084**] The respective polarization lights with polarization planes thereof being orthogonal to each other, returned to the PBS **5** via the connecting optical paths 2_B and 2_C, are multiplexed by the PBS **5** and thereafter sent to the optical circulator **4** via the connecting optical path 2_A, to be output to the output optical path 2_{OUT} after passing from the port **4***b* to the port **4***c*.

[**0085**] As mentioned above, when the polarization lights from the connecting optical paths 2_B and 2_C are propagated in bi-directions through the three staged AOTFs cascade loop connected on the substrate **10**, the stray light S generated from each of the PBSs **31***a* and **32***a* at the one end of each of the optical waveguides **21** and **22** is propagated toward the end face on the opposite side to the optical input side of the substrate **10**. However, since the connecting optical paths 2_B and 2_C are connected to the PBSs **31***a* and **32***a* positioned on the same end face of the substrate **10**, respectively, the leakage phenomenon of the stray light from the input side to the output side is suppressed.

[**0086**] Moreover, in the optical wavelength variable filter **1**, the dropped lights branched by the PBSs **31***b* and **32***b*, pass through the optical isolators **101**A and **101**B of the first monitoring section **100**, to be converted into electrical signals at the light receivers **102**A and **102**B, respectively, and further are added up by the circuit **103** to be sent to the RF signal controlling section **300** as the monitor signal M1. In the RF signal controlling section **300**, the peak wavelengths of the dropped lights are detected based on the monitor signal M1, and an amount of wavelength deviation to the previously set control value (selected wavelength) is obtained based on the monitoring result by the second monitoring section **200**.

[**0087**] In the RF signal controlling section **300**, as a method for detecting the peak wavelengths of the dropped lights based on the monitor signal M1, for example, a method to add dithering to the frequency f of RF signal to be applied commonly to the IDTs **41** to **43** at the respective stages, is suitable. Specifically, in a case where the frequency f of RF signal is set to, for example, 170 MHz, 4 kHz or the like is set as the frequency Δf of the dithering, and the RF signal of which frequency fluctuates within a range of f±Δf is applied to each of the IDTs **41** to **43**. Thus, the selected wavelengths to be mode converted in the AOTFs at the respective stages fluctuate corresponding to the frequency Δf of the dithering. Accordingly, the monitor signal M1 to be monitored by the first monitoring section **100** includes frequency components corresponding to the dithering. Thus, it becomes possible to detect the peak wavelengths of the actually dropped lights by utilizing the detected frequency components.

[**0088**] Also, in a case where the dithering is added to the frequency of RF signal as described above, the dropped light is taken out from the AOTF stage corresponding to the selected wavelength most closest to the center wavelength of the blocking band, to monitor the dropped light by the first monitoring section **100**, it is possible to detect reliably the peak wavelength of the dropped light. That is, if the dropped light from the AOTF stage of which selected wavelength is positioned at the end portion of the blocking band is monitored, the wavelength of the dropped light fluctuating by the dithering reaches the wavelength region where the transmissivity is steeply changed, so that the level of dropped light to be monitored by the first monitoring section **100** is largely changed, thereby resulting in a possibility that the peak wavelength of dropped light cannot be accurately detected. However, such a situation can be avoided by taking out the dropped light from the AOTF stage of which selected wavelength is positioned at the center of blocking band, to monitor the dropped light, thereby enabling to realize the stable peak wavelength detection.

[**0089**] In the constitution of **FIG. 3**, the setting of the blocked wavelengths (selected wavelength) corresponding to the optical waveguides **21** to **23** on the substrate **10** is indicated in the relationship as shown in **FIG. 11**. Therefore, for the light given to the substrate **10** via the connecting optical path 2_B and propagated sequentially through the optical waveguides **21**, **23** and **22**, the monitoring is performed on the dropped light in the optical waveguide **21** corresponding to the wavelength λ_{1F} positioned substantially at the center of the blocking band, depending on the relationship of blocking wavelength as shown by a bold line in the figure. Moreover, for the light given to the substrate **10** via the connecting optical path 2_C and propagated sequentially through the optical waveguides **22**, **23** and **21**, the monitoring is performed on the dropped light in the optical waveguide **22** corresponding to the wavelength λ_{2R}, depending on the relationship of blocking wavelength as shown by a thin line in the figure.

[0090] Based on the peak wavelengths of dropped lights detected in the above manner, the wavelength deviation amount to the previously set control value (selected wavelength) is obtained based on the monitoring result by the second monitoring section **200**, and a controlling signal for correcting the frequency of RF signal is generated according to the wavelength deviation amount, to be output to the RF signal generating circuit **40**. Then, in the RF signal generating circuit **40**, in accordance with the controlling signal from the RF signal controlling section **300**, the frequency f of RF signal is corrected, and the corrected RF signal is applied commonly to the IDTs **41** to **43** at the respective stages. Thus, even if the filter characteristic is changed due to a change in temperature, deterioration with time lapse or the like, it becomes possible to block reliably and stably a light desired wavelength from passing through, by tracking and controlling the frequency of RF signal.

[0091] Further, herein, at the starting time or at the alteration of setting, a process for previously detecting the control value of the AOTFs cascade loop connected on the substrate **10** is executed by the RF signal controlling section **300** based on the monitor signal M2 from the second monitoring section **200**. In the second monitoring section **200**, there is monitored the light passed through the monitoring AOTFs that operate in accordance with the same parameter as for the three staged AOTFs cascade connected on the substrate **10**. That is, the branched light from the optical coupler **201** on the input optical path $\mathbf{2}_{IN}$ is polarization split by the PBS **202**. One of the polarization lights is given, as a TE mode light, to the PBS **231***a* on the optical waveguide **221** of the substrate **10** via the connecting optical path $\mathbf{2}_G$, to be propagated within the optical waveguide **221** toward the PBS $\mathbf{231}_b$. At this time, due to the acousto-optic effect of SAW generated at the IDT **241** and propagated through the SAW guide **251**, only the light corresponding to the selected wavelength out of the TE mode light being propagated within the optical waveguide **221** is mode converted into a TM mode light. Then, when the respective mode lights reach the PBS **231***b*, the mode converted TM mode light of selective wavelength passes therethrough and is sent to the PBS **204** via the connecting optical path **21**.

[0092] On the contrary, the other polarization light polarization split by the PBS **202** is rotated with polarization plane thereof by 90 degrees by the polarization rotating section **203**, and then given, as a TE mode light, to the PBS **232***b* on the optical waveguide **222** of the substrate **10** via the connecting optical path $\mathbf{2}_H$, to be propagated within the optical waveguide **222** toward the PBS **232***a*. At this time, due to the acousto-optic effect of SAW generated at the IDT **242** and propagated through the SAW guide **252**, only the light corresponding to the selected wavelength out of the TE mode light being propagated within the optical waveguide **222** is mode converted into a TM light. Then, when the respective mode lights reach the PBS **232***a*, the mode converted TM mode light of selective wavelength passes therethrough, and is rotated with polarization plane thereof by 90 degrees by the polarization rotating section **205** and then sent to the PBS **204** via the connecting optical path $\mathbf{2}_J$.

[0093] In the PBS **204**, the polarization lights with polarization planes being orthogonal to each other from the connecting optical paths $\mathbf{2}_I$ and $\mathbf{2}_J$, are multiplexed to be sent to the light receiver **206**. In the light receiver **206**, the monitor signal from the PBS **204** is converted into an electrical signal, to be output to the RF signal controlling section **300**, as the monitor signal M2.

[0094] In the RF signal controlling section **300**, at the starting time or at the alteration of setting, a controlling signal for sweeping the frequency of RF signal within a required range is generated, to be output to the RF signal generating circuit **40**. Then, the wavelengths of lights actually selected by the monitoring AOTFs on the substrate **10** are detected based on the monitor signal M2 from the second monitoring section **200**, corresponding to the RF signals of respective swept frequencies, and in accordance with the detection result, the RF signal frequency corresponding to a desired selected wavelength is judged to be initially set as a control value for the starting time or the time of alteration of setting.

[0095] The control value set based on the monitor signal M2 from the second monitoring section **200**, is determined in accordance with the wavelengths of lights actually passed through the monitoring AOTFs that operate in accordance with the same control parameter (frequency of RF signal) for the AOTFs cascade connected that process the main signal light, and therefore, can achieve an extremely higher precision, compared with a value obtained by using a monitoring device that operates in accordance with a different control parameter. In the optical wavelength variable filter to be used for the OXC apparatus, OADM apparatus or the like, if the light of wavelength that is needed to pass through, is erroneously blocked, the services to the users are suspended. Therefore, the control parameter requires a high precision in the initial value thereof. Accordingly, it is very useful that the controlling function of RF signal based on the monitoring result by the second monitoring section **200** is provided in the optical wavelength variable filter.

[0096] As described above, according to the control apparatus **3** of the optical wavelength variable filter **1**, in order to perform the tracking control of the selected wavelengths in the respective AOTFs cascade loop connected on the substrate **10**, the dropped light that has blocked from passing through at the AOTF stage corresponding to the selected wavelength most closest to the center wavelength of the blocking band, is monitored. Thus, even if the dropped light fluctuates under the influence of the dithering of RF signal, the unstable wavelength of light source or the like, the peak wavelength of the dropped light can be stably detected, so that the selected wavelengths in the AOTFs at respective stages can be controlled with high accuracy and reliability. Thereby, even if the setting of the respective AOTFs or the wavelength of input light fluctuates under the influence of a change in temperature, a change with time lapse or the like, the selected wavelengths in the AOTFs are adjusted following such a fluctuation. Thus, it is possible to realize stably a desired filter characteristic.

[0097] Note, in the above embodiment, as the respective optical filter sections of the optical wavelength variable filter **1**, the use of AOTF has been described. However, the optical filter sections to be used for the optical wavelength variable filter in the present invention are not limited to AOTF. It is possible to use a known band rejection type optical filter having a variable selected wavelength.

[0098] Moreover, as one example for detecting the peak wavelength of the dropped light, the method to add the dithering to the frequency of RF signal has been descried.

However, the wavelength detecting method of dropped light in the present invention is not limited thereto.

What is claimed is:

1. A control method of wavelength characteristics of an optical wavelength variable filter of band rejection type including a plurality of optical filter sections each blocking a light corresponding to a selected wavelength from passing through, said optical filter sections being cascade connected to be in a multi-staged structure,

wherein, when said optical wavelength variable filter has wavelength characteristics formed with a blocking band including a wavelength band according to a deviation amount obtained by deviating respective selected wavelengths from one another of said plurality of optical filter sections,

a dropped light to be blocked from passing through at the optical filter section corresponding to the selected wavelength most closest to the center wavelength of said blocking band, among said respective selected wavelengths, is taken out to be monitored, and

said respective selected wavelengths are adjusted based on a peak wavelength of said monitored dropped light, to control said wavelength characteristics.

2. A control method of wavelength characteristics of an optical wavelength variable filter according to claim 1,

wherein, when each of said optical filter sections is an acousto-optic tunable filter that blocks the passing of light corresponding to the selected wavelength utilizing the acousto-optic effect based on a surface acoustic wave generated by applying an RF signal to an electrode,

dithering is added to a frequency of the RF signal to be given to each of said acousto-optic tunable filters, the peak wavelength of said dropped light is detected based on a wavelength fluctuation corresponding to said dithering in said monitored dropped light, and the frequency of said RF signal is adjusted according to said detected peak wavelength, to control said wavelength characteristics.

3. A control apparatus of wavelength characteristics of an optical wavelength variable filter of band rejection type including a plurality of optical filter sections each blocking a light corresponding to a selected wavelength from passing through, the optical filter sections being cascade connected to be in a multi-staged structure,

wherein, when said optical wavelength variable filter has wavelength characteristics formed with a blocking band including a wavelength band according to a deviation amount obtained by deviating respective selected wavelengths from one another of said plurality of optical filter sections,

said control apparatus comprises: a monitoring section that takes out to monitor a dropped light to be blocked from passing through at the optical filter section corresponding to the selected wavelength most closest to the center wavelength of said blocking band, among said respective selected wavelengths; and

a controlling section that adjusts said respective selected wavelengths based on a peak wavelength of the dropped light monitored by said monitoring section, to control said wavelength characteristics.

4. A control apparatus of wavelength characteristics of an optical wavelength variable filter according to claim 3,

wherein, when each of said optical filter sections is an acousto-optic tunable filter that blocks the passing of light corresponding to the selected wavelength utilizing the acousto-optic effect based on a surface acoustic wave generated by applying an RF signal to an electrode,

said controlling section adds dithering to a frequency of the RF signal to be given to each of said acousto-optic tunable filters, detects the peak wavelength of said dropped light based on a wavelength fluctuation corresponding to said dithering in said dropped light monitored by said monitoring section, and adjusts the frequency of said RF signal according to said detected peak wavelength, to control said wavelength characteristics.

5. A control apparatus of wavelength characteristics of an optical wavelength variable filter according to claim 3,

wherein said optical wavelength variable filter includes three or more numbers of said optical filter sections.

6. A control apparatus of wavelength characteristics of an optical wavelength variable filter according to claim 3,

wherein said optical wavelength variable filter has a cascade loop connection in which both ends of optical paths passing through said plurality of optical filter sections are connected to each other, and a light is input/output via said connection section.

7. A control apparatus of wavelength characteristics of an optical wavelength variable filter according to claim 6,

wherein said monitoring section monitors a multiplexed light of said dropped light of the light being propagated in one direction and said dropped light of the light being propagated in the other direction, within each of said optical filter sections cascade loop connected.

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