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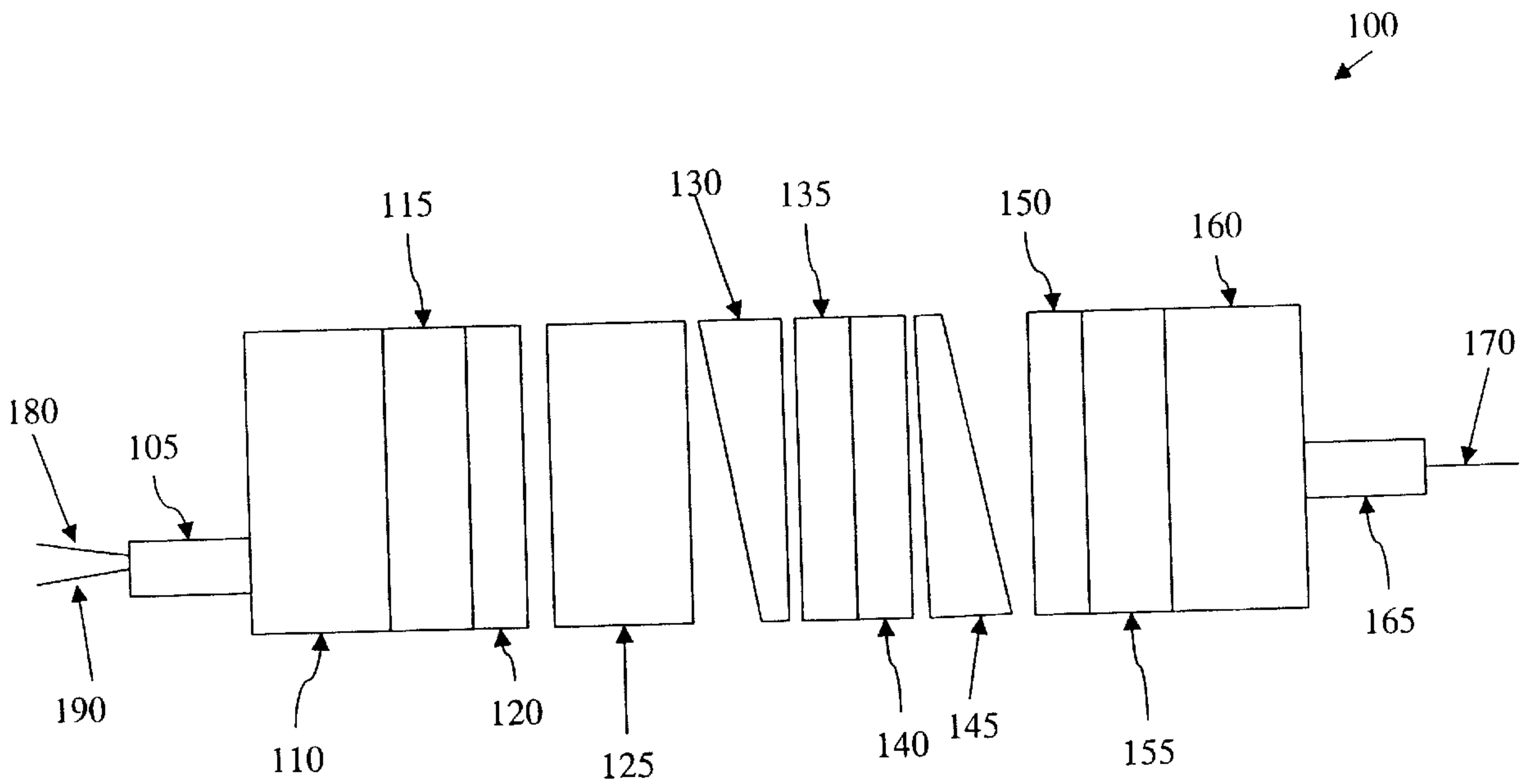

(57) **Abrégé/Abstract:**
An optical circulator having a dual fiber collimator and a single fiber collimator is described. The circulator provides a non-reciprocal functionality that directs input signals from a first fiber of the dual fiber collimator to the single fiber collimator. Input signals from the single fiber collimator are directed to a second fiber of the dual fiber collimator. The circulator includes birefringent wedges that change the angle of signals from the single fiber collimator to direct the signals to the second fiber of the dual fiber collimator. Because the circulator includes two collimators rather than three collimators, the circulator is more compact than a circulator having three collimators.

ABSTRACT

An optical circulator having a dual fiber collimator and a single fiber collimator is described. The circulator provides a non-reciprocal functionality that directs input signals from a first fiber of the dual fiber collimator to the single fiber collimator. Input signals from the single fiber collimator are directed to a second fiber of the dual fiber collimator. The circulator includes birefringent wedges that change the angle of signals from the single fiber collimator to direct the signals to the second fiber of the dual fiber collimator. Because the circulator includes two collimators rather than three collimators, the circulator is more compact than a circulator having three collimators.

OPTICAL CIRCULATORS

FIELD OF THE INVENTION

The invention relates to optical communications devices. More particularly, the invention relates to an optical circulator for use with, for example, optical communications networks.

BACKGROUND OF THE INVENTION

An optical circulator is a passive, non-reciprocal optical device that can be found in many applications, for example, optical amplifiers, dispersion compensation devices, and bi-directional optical communications systems. Because optical circulators are common components in many optical networks and devices, it is desirable to have reliable and compact circulators in order to reduce the size and cost of the networks and devices. However, current optical circulators may not be as compact and reliable as possible.

For example, the circulator disclosed in U.S. Patent No. 4,650,289 has an input or output port on each or four sides. Such a configuration requires optical fibers to be run in several directions in order to access the circulator. Thus, the circulator disclosed by U.S. Patent No. 4,650,289 does not provide a compact and efficient device when multiple circulators are included in the device.

More compact optical circulators have been developed. For example, U.S. Patent No. 5,204,771 discloses an optical circulator having ports on two sides. The optical circulator of U.S. Patent No. 5,204,771 thus provides a more compact circulator that can be used more efficiently with multiple circulators. However, an improved optical circulator can be provided.

SUMMARY OF THE INVENTION

Optical circulators are disclosed. In one embodiment, a polarization independent optical circulator comprises:

a first port for directing an optical signal to a second port, the second port for directing an optical signal to a third port;

polarization diversity means associated with the first, second and third ports for dividing the optical signal into two subbeams and for combining two subbeams of light by polarization, and for rotating a polarization of at least one subbeam; and

means for aligning the signal from the second port with the third port to pass optical signals traveling in the first direction having a first polarization without changing an optical path of the signals, and to change an angle of the optical path for signals traveling in the second direction having a second orthogonal polarization including:

a first birefringent wedge;

a second birefringent wedge; and

a half wave plate and a non-reciprocal rotator between the first birefringent wedge and the second birefringent wedge.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is illustrated by way of example, and not by way of limitation in the figures of the accompanying drawings in which like reference numerals refer to similar elements.

Figure 1 illustrates a side view of one embodiment of an optical circulator.

Figure 2 is a forward light path through an circulator as illustrated in Figure 1.

Figure 3 is a backward light path through an optical circulator as illustrated in Figure 1.

DETAILED DESCRIPTION

An optical circulator is described. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the invention. It will be apparent, however, to one skilled in the art that the invention can be practiced without these specific details. In other instances, structures and devices are shown in block diagram form in order to avoid obscuring the invention.

Reference in the specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

An optical circulator having a dual fiber collimator and a single fiber collimator is described. The circulator provides a non-reciprocal functionality that directs input signals from a first fiber of the dual fiber collimator to the single fiber collimator. Input signals from the single fiber collimator are directed to a second fiber of the dual fiber collimator. The circulator includes birefringent wedges that change the angle of signals from the single fiber collimator to direct the signals to the second fiber of the dual fiber collimator. Because the circulator includes two collimators rather than three collimators, the circulator is more compact than a circulator having three collimators.

Figure 1 illustrates a side view of one embodiment of an optical circulator. The polarization states of the components described with respect to Figure 1 are described in greater detail below with respect to Figures 2 and 3.

In one embodiment, circulator 100 includes dual-port (or dual fiber) collimator 105 and single-port (or single fiber) collimator 165. In one embodiment, both dual port collimator 105 and single port collimator 165 include a collimating assembly having a GRIN lens to collimate the light. Other types of lenses can also be used, or pre-collimated light can be received.

For simplicity of description, collimator 105 is described as having an input port and an output port. The circulator of Figure 1 directs optical signals from the input port of collimator 105 to collimator 165. Signals input to collimator 165 are directed to the output port of collimator 105. Circulator 100 thus provides non-reciprocal functionality for signals input to collimators 105 and 165.

Collimator 105 is optically coupled to optical displacement or walk-off crystal 110. In one embodiment, walk-off crystal 110 is a 45° walk-off crystal that splits the input signal from collimator 105 into two polarized optical signals and separates the two polarized signals by a predetermined distance. Because walk-off crystal 110 is a 45° walk-off crystal, the two polarized beams include a first beam having a 45° orientation and a second beam have a -45° orientation.

In one embodiment, half wave plate 115 changes the polarization of one of the two polarized signals by 90°. Half wave plate 115 has an azimuth angle of 45° with respect to optical signals passing from walk-off crystal 110 to Faraday rotator 120. Faraday rotator 120 rotates both polarized signals 45° in the counterclockwise direction.

Walk-off crystal 125 changes the path of polarized signals passing from collimator 165 to collimator 105, but does not change the path of polarized signals passing from collimator 105 to collimator 165. Birefringent wedge 130 similarly does not affect signals passing from collimator 105 to collimator 165. Birefringent wedge 130 changes the angle of signals passing from collimator 165 to collimator 105. In one embodiment, birefringent wedge 130 change the angle of signals passing from collimator 165 to 105 in the range of 1° and 5° (e.g., 1.8°); however, other angles can also be used. The angle directs optical signals from collimator 165 to the output fiber of collimator 105.

Faraday rotator 135 rotates both polarized optical signals by 45° in the counterclockwise direction. In one embodiment, half wave plate 140 has an azimuth angle in the range of 15° to 25° (e.g., 22.5°) with respect to optical signals passed from Faraday rotator 135 to birefringent wedge 145; however, other azimuth angles can also be used.

Birefringent wedge 145 does not change the angle of signals from collimator 105 to collimator 165, but birefringent wedge 145 does change the angle of signals from collimator 165 to collimator 105. In one embodiment, birefringent wedge 145 change the angle of signals passing from collimator 165 to 105 in the range of 1° and 5° (e.g., 1.8°); however, other angles can also be used.

Both polarized optical signals pass through half wave plate 150. In one embodiment, half wave plate 150 has an azimuth angle in the range of 15° to 25° (e.g., 22.5°); however, other azimuth angles can also be used. One of the optical signals passes through half wave plate 155. In one embodiment, half wave plate 155 has an azimuth angle in the range of 40° to 50° (e.g., 45°); however, other azimuth angles can also be used. Walk-off crystal 160 combines the two polarized optical signals. Collimator 165 receives the combined optical signal.

Optical signals input to collimator 165 are directed to a second port of collimator 105 by circulator 100. Walk-off crystal 160 separates the input signal into two polarized optical signals. Half wave plate 155 rotates one of the two polarized optical signals. Half wave plate 150 rotates both of the polarized optical signals.

Birefringent wedge 145 angles the two polarized optical signals passing from collimator 165 to collimator 105 to change the respective optical paths. Half wave plate 140 and Faraday rotator 135 both rotate the two polarized optical signals. Birefringent wedge 130 angles the two polarized optical signals. The group of optical elements including birefringent wedge 145, half wave plate 140, Faraday rotator 135 and birefringent wedge 130 operate to align input signals from collimator 165 with the output port of collimator 105.

Thus, optical signals that pass through circulator 100 are offset by a predetermined distance based on the direction in which the optical signals travel. The offset, in combination with the operation of half wave plates and Faraday rotators directs the optical signals between input and output ports to provide a non-reciprocal circulator function.

Figure 2 is a forward light path through an optical circulator as illustrated in Figure 1. Figure 2 illustrates the effects of the element described on the optical signal(s) described. In other words, the elements of Figure 2 indicate the orientation of the optical signals at the output of the respective circulator elements. For example, illustration of a half wave plate indicates the orientation of one or more optical signals after passing through the half wave plate.

Input port 200 receives an optical input signal. In one embodiment, input port 200 is a dual-fiber collimator; however, other configurations can also be used. For example, two adjacent modified or non-modified collimators can also provide input port 200. The dashed line in input port 200 corresponds to an output port, for example, of a dual-fiber collimator. The optical signal received through input port 200 includes both horizontally polarized and vertically polarized components.

Walk-off crystal 205 separates the input signal into two polarized light signals separated by a predetermined distance. In the embodiment of Figure 2, one signal is illustrated as being disposed above and to the right of the original position of the input signal; however, other separations can also be provided by walk-off crystal 205. Half wave plate 210 rotates one of the polarized light signals 90° counterclockwise. The two polarized optical signals then have the same polarization.

Faraday rotator 215 rotates both polarized optical signals 45° counterclockwise so that both signal are horizontally polarized. Alternative components can be used to generate two horizontally polarized optical signals corresponding to the input signal. for example, two split FR, one for pos 45 one for neg 45. Walk-off crystal 220 operates on non-horizontally polarized optical signals. Thus, the horizontally polarized optical signals are passed by walk-off crystal 220. Similarly, birefringent wedge 225 does not affect horizontally polarized light.

Faraday rotator 230 is a non-reciprocal component that rotates both polarized optical signals 45° counterclockwise. Half wave plate 240 is a reciprocal component that rotates both polarized optical signals 45° clockwise. Birefringent wedge 245 does not affect horizontally polarized light, so the horizontally polarized light output by half wave plate 240 is input to half wave plate 250.

Half wave plate 250 is a reciprocal component that rotates the two polarized optical signals 45° clockwise. Half wave plate 255 rotates one of the polarized optical signals 90° clockwise. Walk-off crystal 260 combines the two polarized optical signals to a single output signal corresponding to the input signal received at input port 200. The output signal is output to output port 265. In one embodiment, output port 265 is a single-fiber collimator; however, other components can also be used.

Figure 3 is a backward light path through an optical circulator as illustrated in Figure 1. As with Figure 2, Figure 3 illustrates the effects of the element described on the optical signal(s) described. However, because signals are traveling in the opposite direction in Figure 3 (e.g., collimator 165 to collimator 105, in Figure 1), the illustrations of Figure 3 refer to the opposite side of the respective components as compared to Figure 2.

Input port 300 receives an optical input signal. In one embodiment, input port 300 is a single fiber collimator, as described above; however, other components can also be used to provide input signals to the circulator. Walk-off crystal 305 separates the input signal into two polarized optical signals. Half wave plate 310 rotates one of the two polarized signals 90° counterclockwise. Half wave plate 315 rotates both of the polarized optical signals 45° counterclockwise.

The combination of components including birefringent wedge 320, half wave plate 325, Faraday rotator 330, and birefringent wedge 335 change the angle of the optical signals that pass from input port 300 to output port 340. In one embodiment, the angle is 3.8°, however, other angles can also be used. The angle is determined based on the distance between the adjacent input and output ports (e.g., the distance between the centers of the input and output fibers of dual-fiber collimator 105) and the focal distance between birefringent wedge 335 and output port 340. In one embodiment, the distance, d, between the ports is 125 μm and the focal distance, f, is 2000 μm; however, other distances can also be used.

Half wave plate 325 rotates the two polarized optical signals 45° counterclockwise and Faraday rotator 330 rotates the two polarized optical signals 45° further counterclockwise.

In the foregoing specification, the invention has been described with reference to specific embodiments thereof. It will, however, be evident that various modifications and changes can be made thereto without departing from the broader spirit and scope of the invention. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

CLAIMS

What is claimed is:

1. A polarization independent optical circulator comprising:

a first port for directing an optical signal to a second port, the second port for directing an optical signal to a third port;

polarization diversity means associated with the first, second and third ports for dividing the optical signal into two subbeams and for combining two subbeams of light by polarization, and for rotating a polarization of at least one subbeam; and

means for aligning the signal from the second port with the third port to pass optical signals traveling in the first direction having a first polarization without changing an optical path of the signals, and to change an angle of the optical path for signals traveling in the second direction having a second orthogonal polarization including:

a first birefringent wedge;

a second birefringent wedge; and

a half wave plate and a non-reciprocal rotator between the first birefringent wedge and the second birefringent wedge.

2. The optical circulator as defined in claim 1, wherein the polarization diversity means comprises:

a walkoff crystal for dividing the signal passing from one of the first port and the second port into subbeams having orthogonal polarizations, and for combining subbeams having orthogonal polarizations passing to one of the second port and the third port; and

a half wave plate for rotating the polarization of one of the subbeams to match the polarization of the other passing from one of the first port and the second port, and for rotating one of the subbeams to be orthogonal to the other passing to one of the second port and the third port.

3. The optical circulator as defined in claim 2 further including a non-reciprocal rotator for rotating a polarization of both subbeams to a first polarization traveling in a first direction from the first port to the second port, and for rotating the polarization of the beams traveling in a second direction from the second port to the third port for combining within the polarization diversity means;

4. The optical circulator as defined in claim 3 further including a walk-off crystal for wedge to pass optical signals traveling in the first direction having a first polarization without changing an optical path of the signals, and to change an angle of the optical path for signals traveling in the second direction having a second orthogonal polarization, after passing through the means for aligning the signal.

5. The optical circulator of claim 4 wherein the non-reciprocal rotator comprises a Faraday rotator.

6. The optical circulator of claim 5 further including a polarization rotator for rotating a polarization of both subbeams to a second polarization traveling in the second direction prior to passing through a means for aligning the signal, and for rotating the polarization of the beams traveling in the first direction for combining within the polarization diversity means.

7. The optical circulator of claim 1 wherein the first birefringent wedge and the second birefringent wedge change the optical path by an angle of between 1° and 5° with respect to a corresponding input optical signal.

8. The optical circulator of claim 7 wherein the angle is 1.8°.

9. The opitcal circulator of claim 8, wherein the first port and the third port comprise separate ports of a single dual-fiber collimator.

10. The optical circulator of claim 5 wherein the Faraday rotator is rotatatable to tune the optical circulator.

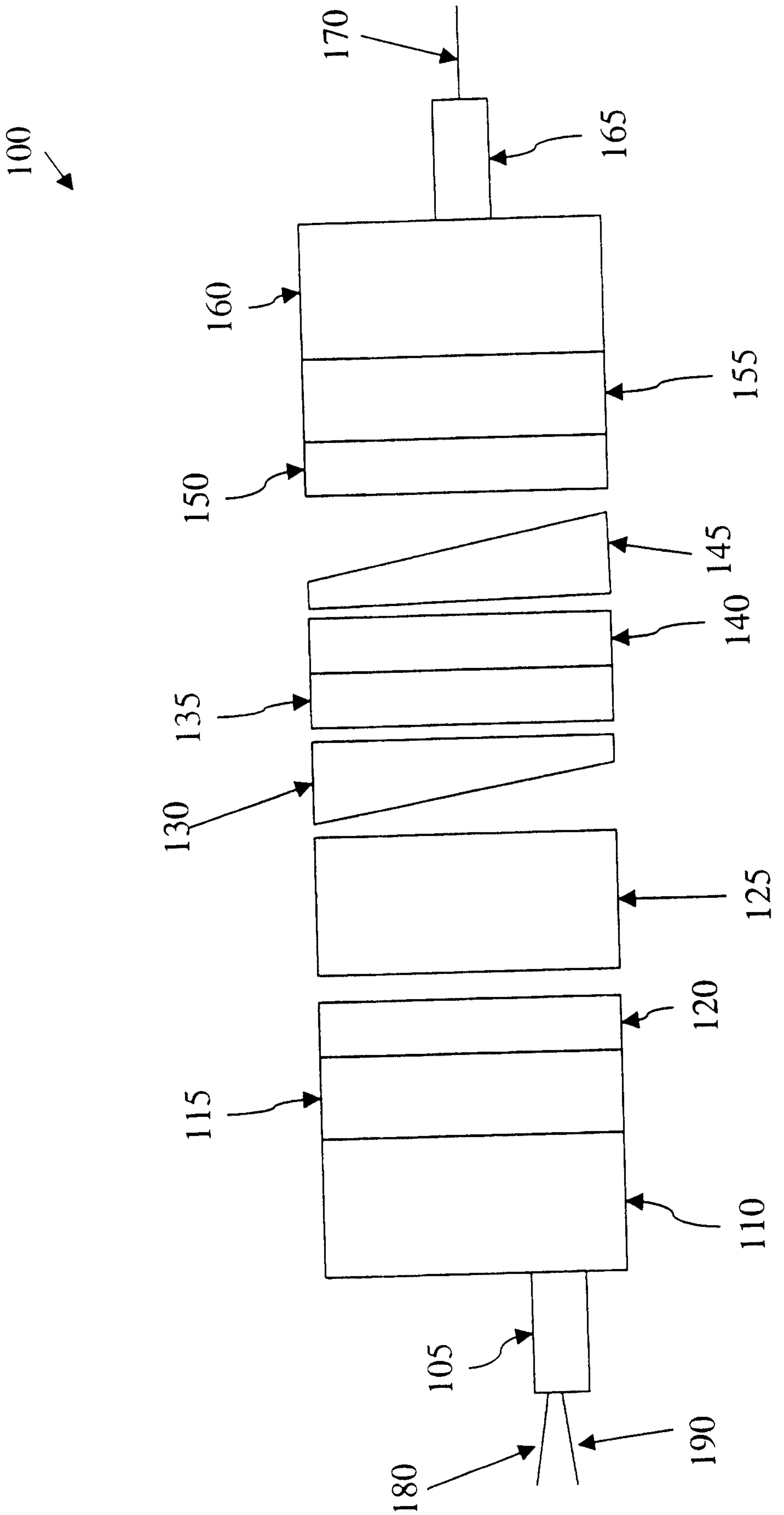
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Fig. 1

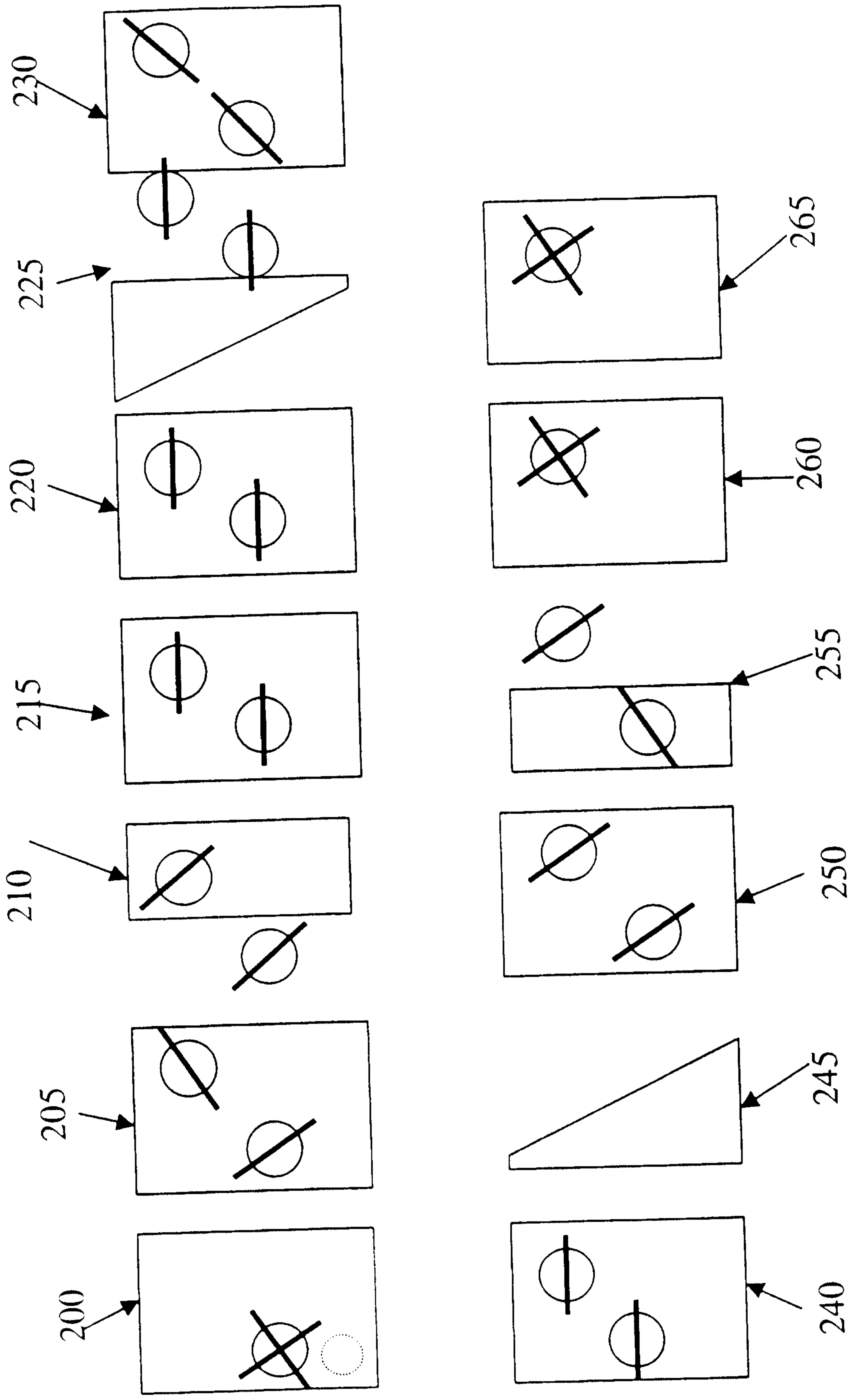


Fig. 2

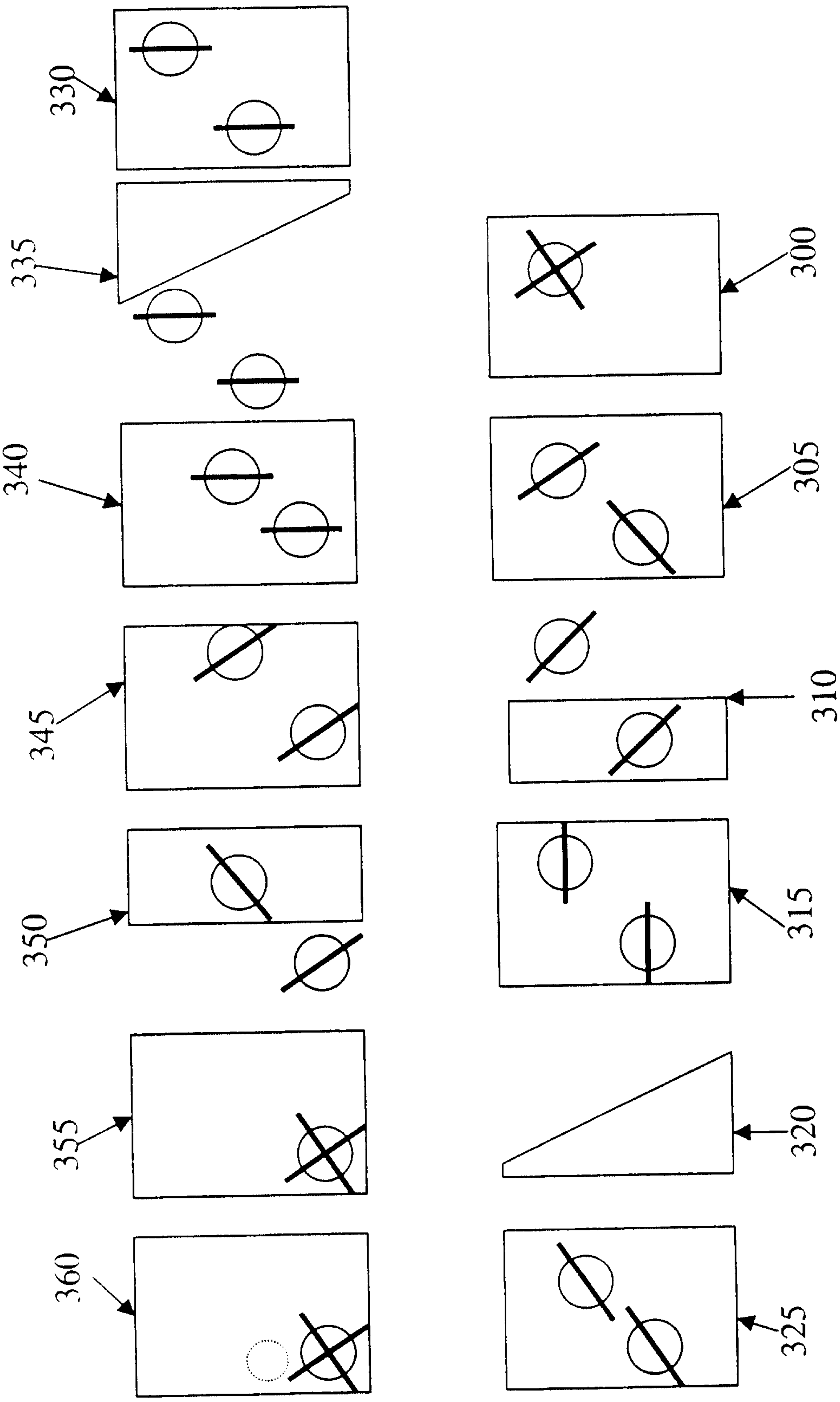
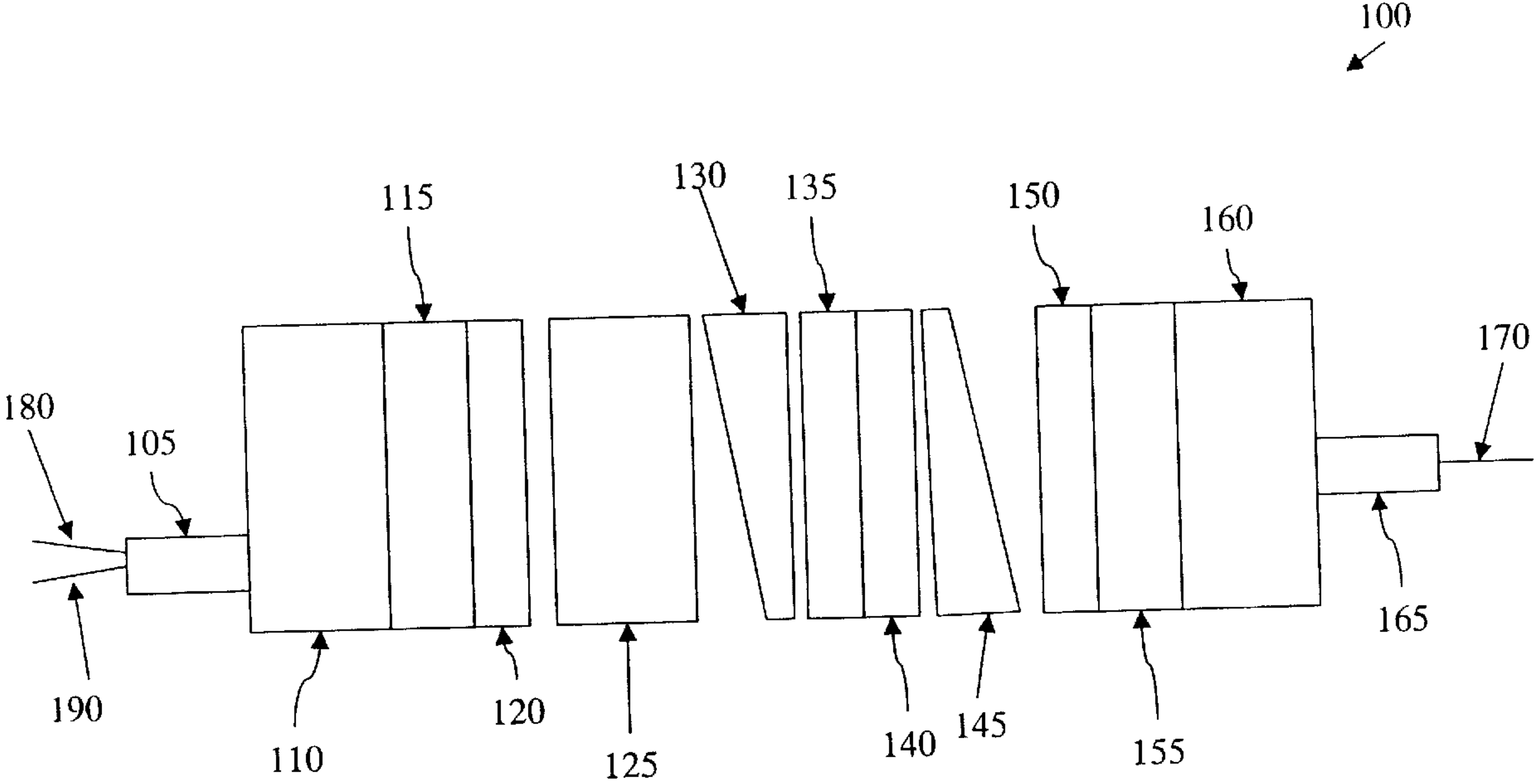


Fig. 3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