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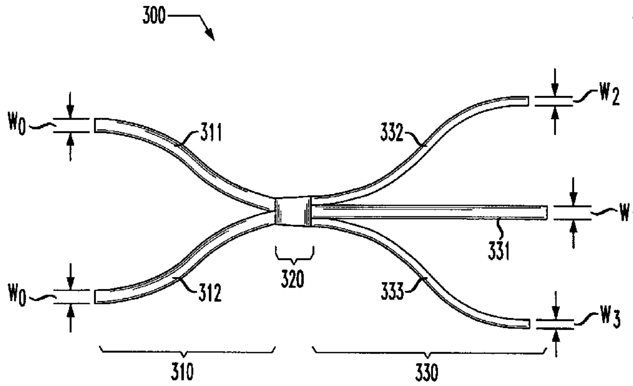
— *with international search report*

*[Continued on next page]*

(54) Title: OPTICAL DEVICE

*A*

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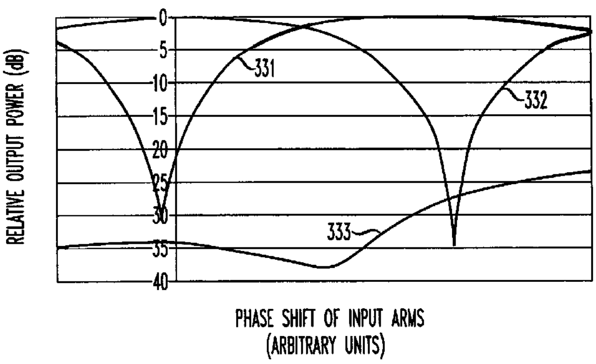


**(57) Abstract:** The present invention provides an optical device comprising first, second, and third waveguides coupled together at an asymmetric X-junction. In a preferred embodiment, the first waveguide has a first width and is coupled to a side of an asymmetric X-junction; the second waveguide is coupled to the first waveguide at the side of the asymmetric X-junction and has a second width less than the first width; and the third waveguide is coupled to the first and second waveguides at the side of the asymmetric X-junction and has a third width that is less than the first width. The present invention further provides an optical transmitter and a method of manufacturing the optical device.

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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

# OPTICAL DEVICE

## TECHNICAL FIELD OF THE INVENTION

The present invention is directed, in general, to an optical device and, more specifically, to a waveguide having a shortened junction length for use with electro-optical waveguides.

## BACKGROUND OF THE INVENTION

As today's optical networks become increasingly more complex and require increased capacity, optical switches are playing an increasingly important role. Optical switches may be used in network protection and restoration as well as other applications. Asymmetric X-junctions have traditionally found significant use in Mach-Zehnder switches, such as modulators.

Referring initially to FIGURE 1A, illustrated is a schematic plan view of a conventional optical device 100 employing an asymmetric X-junction 110 that might be used with electro-optic waveguides. A left (input) side 120 of the conventional asymmetric X-junction 110 comprises two identical wave guides 121, 122 having a common width $W_0$. Each waveguide is assumed to be single mode. A right (output) side 130 of the X-junction 110 is composed of two waveguides 131, 132 of different widths $W_1$, $W_2$, respectively. One who is skilled in the art will recognize that an effective refractive index of a waveguide of one width is different from the effective refractive index of a waveguide of a different width.

A center region 140 of the conventional X-junction 110 is a multi-mode region 140 that couples the left and right sides 120, 130. The conventional X-junction 110 will have a branching angle 141. When input light applied to the input wave guides 121, 122 is both identical in power and has the same phase, a synthesized fundamental mode that couples to the wider waveguide 131 is selectively excited in the multi-mode region 140. In contrast, when input light applied to the identical wave guides 121, 122 has a Pi (π) radians (180°) phase shift, some of the fundamental mode is excited and the extinction ratio is limited. Additionally, a higher mode is excited that couples to the narrower wave guide 132. However, when the mode change is relatively quick, some amount of the input power will couple to the higher mode in the multi-mode region 140 and recombines to both of the waveguides 131, 132 as noise. This higher mode distorts both of the output modes, and as a result, the extinction ratio is limited, which is highly undersirable.

FIGURE 1B schematically illustrates an effective refractive index distribution of the conventional asymmetric X-junction of FIGURE 1A. Because the input light applied to the identical input wave guides 121, 122 is identical in power, the dual input wave guides 121, 122 may be schematically degenerated into a single input 123. Depending upon the phase angle between the dual inputs, the output of the conventional asymmetric X-junction 110 is found in one or both of the output waveguides 131, 132. That is, with a zero phase shift, the higher mode 150 couples 151 to the wider waveguide 131. With a Pi phase shift, the higher mode 150 couples 152 to the narrower waveguide 132.

Referring now to FIGURE 2 with continuing reference to FIGURES 1A and 1B, illustrated are switching response curves as a function of phase shift of a conventional 1X2 Mach-Zehnder interferometer. That is, the switching response shown is that of a conventional symmetric Y-junction input side coupled to a conventional asymmetric X-junction output side. Waveguides comprising titanium-diffused, lithium niobate are suitable for this device. One who is skilled in the art is familiar with the design and operation of Mach-Zehnder modulators. A device exhibiting these characteristics will have a multi-mode region 140 (FIGURE 1A) of very short physical size. As there are essentially no straight waveguides in the multi-mode region, the extinction ratio (relative output power) is limited to between about -16 dB (narrow waveguide 132) and about -20 dB (wide waveguide 131). In order to conventionally increase the limits of the extinction ratio, the multi-mode region 140 may be formed as a relatively long, *e.g.*, about 1 cm, straight, waveguide section having a small branching angle 141, *i.e.*, ≤0.2°. However, customer requirements now require a small form or packaging factor with an integrated power monitor. Therefore, a long, straight waveguide section is often antithetical to customer requirements.

Accordingly, what is needed in the art is an optical device that has a shortened junction length and overcomes the deficiencies found in the conventional devices as discussed above.

**SUMMARY OF THE INVENTION**

To address the above-discussed deficiencies of the prior art, the present invention provides an optical device comprising first, second, and third waveguides coupled together at an asymmetric X-junction. In an advantageous embodiment, the first waveguide has a first width and is coupled to a side of an asymmetric X-junction; the second waveguide is coupled to the first waveguide at the side of the asymmetric X-junction and has a second width less than the first width; and the third waveguide is coupled to the first and second waveguides at the side of the asymmetric X-junction and has a third width that is less than the first width. The present invention further provides an optical transmitter and a method of manufacturing the optical device.

The foregoing has outlined preferred and alternative features of the present invention so that those skilled in the art may better understand the detailed description of the invention that follows. Additional features of the invention will be described hereinafter that form the subject of the claims of the invention. Those skilled in the art should appreciate that they can readily use the disclosed conception and specific embodiment as a basis for designing or modifying other structures for carrying out the same purposes of the present invention. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the invention.

**BRIEF DESCRIPTION OF THE DRAWINGS**

For a more complete understanding of the present invention, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIGURE 1A illustrates a schematic plan view of a conventional optical device employing an asymmetric X-junction as might be used with electro-optic waveguides;

FIGURE 1B schematically illustrates an effective refractive index distribution of the conventional asymmetric X-junction of FIGURE 1A;

FIGURE 2 illustrates switching response curves as a function of phase shift of a conventional 1X2 Mach-Zehnder interferometer;

FIGURE 3A illustrates a plan view of an optical device constructed according to the principles of the present invention;

FIGURE 3B schematically illustrates an effective refractive index distribution of the asymmetric X-junction of FIGURE 3A constructed according to the principles of the present invention;

FIGURE 3C illustrates switching response as a function of phase shift of a 1X2 Mach-Zehnder interferometer with an output region constructed according to the principles of the present invention;

FIGURE 4 illustrates a plan view of one embodiment of a 1x2 Mach-Zehnder modulator constructed according to the principles of the present invention;

FIGURE 5 illustrates a plan view of one embodiment of a 2x2 Mach-Zehnder modulator constructed according to the principles of the present invention; and

FIGURE 6 illustrates a plan view of one embodiment of an optical transmitter constructed according to the principles of the present invention.

## DETAILED DESCRIPTION

Referring now to FIGURE 3A illustrated is a plan view of an optical device 300 constructed according to the principles of the present invention. For this discussion, the optical device 300 comprises an input region 310, a center region 320, and an output region 330. Of course, the functions of input and output could also be reversed with region 330 being an input region and region 310 being an output region. The input region 310 comprises first and second input waveguides 311, 312 having a common width $W_0$. The output region 330 comprises first, second and third output waveguides 331, 332, 333 having first, second and third widths $W_1$, $W_2$, $W_3$ respectively. In one embodiment, the second and third widths $W_2$, $W_3$ are less than the first width W1. In a preferred embodiment, the waveguide widths have the following relationships: $W_3 < W_2 < W_0 < W_1$.

The center region 320 comprises a junction 320 of the first and second input waveguides 311, 312 and the first, second and third output waveguides 331, 332, 333. Because the waveguides 311, 312, 331, 332, 333 have different widths as described above, the junction 320 may be termed an asymmetric X-junction. The center region 320, which may also be referred to herein as a mutli-mode region, is a region that facilitates interaction of light applied to the first and second input waveguides 311, 312. In a preferred embodiment, the first and second input waveguides 311, 312 and the first, second and third output waveguides 331, 332, 333 can be formed by conventional process techniques and may be comprised of a titanium-diffused, lithium niobate material. However, one who is skilled in the art will recognize that other materials having suitable optical properties may also be used.

Referring now to FIGURE 3B, with continuing reference to FIGURE 3A, schematically illustrated is an effective refractive index distribution of the asymmetric X-junction of FIGURE 3A constructed according to the principles of the present invention. To realize a higher extinction with a shorter junction 320, the third waveguide 333 has been added that has a preferred width $W_3$ that is less than either the first width $W_1$, or the second width $W_2$. Consequently, the higher mode 341 generated in the multi-mode region 320 couples to the narrowest waveguide, *i.e.*, the third output waveguide 333 having a width $W_3$, and does not affect the output of the first and second output waveguides 331, 332 thereby eliminating noise from the first and second output waveguides 331, 332. Thus, the first output waveguide 331 may function as a power waveguide, and the second output waveguide 332 may function as a power monitor waveguide. The third waveguide 333 may therefore be considered a control waveguide that adjusts or enhances the extinction ratio of the optical device 300.

FIGURE 3C illustrates switching response as a function of phase shift of a 1X2 Mach-Zehnder interferometer with an output region constructed according to the principles of the present invention. One who is skilled in the art is familiar with the design and operation of Mach-Zehnder modulators. Furthermore, a Mach-Zehnder modulator may also be used for optical switching and therefore be termed a Mach-Zehnder switch. As described above, the higher mode couples to the narrow waveguide 333 and therefore the output on the first and second output waveguides 331, 332 remains clean. As can be seen, the representative extinction ratio for both the first and second output waveguides 331, 332 is now greater than -30 dB, an increase of over 50 percent of the extinction ratio achievable with the conventional interferometer of FIGURE 1A.

Referring now to FIGURE 4, illustrated is a plan view of one embodiment of a 1x2 Mach-Zehnder modulator 400 constructed according to the principles of the present invention. The Mach-Zehnder modulator 400 comprises a standard Y-junction input side 410, a control region 420, and an asymmetric X-junction output side 430. The standard Y-junction input side 410 has a single optical input waveguide 411, a branching region 412, and dual modulating waveguides 413, 414. The control region 420 has first and second electrodes 421, 422 proximate extensions 423, 424 of the dual modulating waveguides 413, 414, respectively. The dual modulating waveguides 413, 414 are further coupled at a junction/tapered waveguide 425. In this embodiment, the optical input waveguide 411, dual waveguides 413, 414 and extensions 423, 424 have a single common width $W_0$. First, second and third output waveguides 431, 432, 433 having widths $W_1$, $W_2$, $W_3$ exit the junction/tapered waveguide 425. The first output waveguide 431 is a power output waveguide, the second output waveguide 432 is a power monitor waveguide and third output waveguide 433 is a power control or enhancement waveguide.

The present invention may also be used on an input side of a Mach-Zehnder modulator. Referring now to FIGURE 5, illustrated is a plan view of one embodiment of a 2x2 Mach-Zehnder modulator 500 constructed according to the principles of the present invention. The Mach-Zehnder modulator 500 comprises an asymmetric X-junction input side 510, a control region 520, and an asymmetric X-junction output side 530. In this embodiment, the asymmetric X-junction input side 510 has first, second, and third input waveguides 511, 512, 513, a branching region 514, and dual modulating waveguides 515, 516. The control region 520 has first and second electrodes 521, 522 proximate extensions 523, 524 of the dual waveguides 515, 516, respectively. The dual modulating waveguides 515, 516 are further coupled at a junction/tapered waveguide 525. In this embodiment, the dual modulating waveguides 515, 516 and extensions 523, 524 have a single common width $W_0$. First, second and third output waveguides 531, 532, 533 having widths $W_1$, $W_2$, $W_3$ exit the junction/tapered waveguide 525. The first output waveguide 531 is a power output waveguide, the second output waveguide 532 is a power monitor waveguide and third output waveguide 533 is a power control or enhancement waveguide. In a preferred embodiment, the waveguide widths have the following relationships: $W_3 < W_2 < W_0 < W_1$.

Referring now to FIGURE 6, illustrated is a plan view of one embodiment of an optical transmitter 600 constructed according to the principles of the present invention. The optical transmitter 600 comprises an optical source 610, a standard Y-junction input side 620, a control region 630, and an asymmetric X-junction output side 640. In a preferred embodiment, the optical source 610 may be a laser 610. The optical source 610 is optically coupled to and provides light to an input waveguide 621 that branches to dual modulating waveguides 631, 632, that are located adjacent to and controlled by first and second electrodes 622, 623 of a 1x2 Mach-Zehnder modulator 650 as described above with reference to FIGURE 4. The Mach-Zehnder modulator 650 has first, second and third output waveguides 641, 642, 643 analogous to the first, second and third output waveguides 431, 432, 433 of FIGURE 4. In a preferred embodiment, the first output waveguide 641 is a power waveguide, the second output waveguide 642 is a power monitor waveguide and the third output waveguide 643 is a control waveguide. One who is skilled in the art will readily apply the principles of the present invention to the asymmetric X-junction output side 640 of the optical transmitter 600. In an alternative embodiment, the input waveguide 621 may be replaced with first, second and third input waveguides as described above with reference to FIGURE 5. In a preferred embodiment, the waveguide widths have the following relationships: $W_3 < W_2 < W_0 < W_1$. Furthermore, in a preferred embodiment, the first waveguide is a power waveguide, the second waveguide is a power monitor waveguide and the third waveguide is a control waveguide.

Thus, several embodiments of an optical device have been described that employ an asymmetric X-junction having three waveguides as either an input or output. It has been shown how the third waveguide functions to couple with and isolate the higher mode that would otherwise cause noise on the conventional outputs.

Although the present invention has been described in detail, those skilled in the art should understand that they can make various changes, substitutions and alterations herein without departing from the spirit and scope of the invention in its broadest form.

**WHAT IS CLAIMED IS:**

1. An optical device, comprising:

a first waveguide having a first width and coupled to a side of an asymmetric X-junction;

a second waveguide coupled to said first waveguide at said side of said asymmetric X-junction and having a second width less than said first width; and

a third waveguide coupled to said first and second waveguides at said side of said asymmetric X-junction and having a third width less than said first width.

2. The optical device as recited in Claim 1 wherein said first, second and third waveguides are each output waveguides or are each input waveguides.

3. The optical device as recited in Claim 1 further comprising first and second modulating waveguides coupled to said first, second and third waveguides at said X-junction and an electrode located adjacent each of said first and second modulating waveguides.

4. The optical device as recited in Claim 1 wherein said first waveguide is a power waveguide, said second waveguide is a power monitor waveguide and said third waveguide is a control waveguide.

5. The optical device as recited in Claim 1 wherein said optical device is a Mach-Zehnder modulator.

6. The optical device as recited in Claim 1 wherein said third width is less than said second width.

7. The optical device as recite in Claim 1 further including an optical source coupled to said first waveguide.

8. A method of manufacturing an optical device, comprising:

forming a first waveguide having a first width;

coupling a second waveguide to said first waveguide at a side of an asymmetric X-junction, said second waveguide having a second width less than said first width; and

coupling a third waveguide to said first and second waveguides at said side of said asymmetric X-junction, said third waveguide having a third width less than said first width.

9. The method as recited in Claim 8 wherein said first, second and third waveguides are each output waveguides or are each input waveguides.

10. The method as recited in Claim 8 further comprising coupling first and second modulating waveguides to said first, second and third waveguides at said X-junction, and further comprising locating an electrode adjacent each of said first and second modulating waveguides.

11. The method as recited in Claim 8 wherein forming a first waveguide includes forming a power waveguide, and wherein coupling a second waveguide includes coupling a power monitor waveguide, and wherein coupling a third waveguide includes coupling a control waveguide.

12. The method as recited in Claim 8 wherein said

optical device is a Mach-Zehnder modulator.

13. The method as recited in Claim 8 wherein coupling a third waveguide includes coupling a third waveguide wherein said third width is less than said second width.

14. The method as recited in Claim 8 further including coupling an optical source to said first waveguide.

15. An optical transmitter, comprising:

an optical source; and

a modulator optically coupled to said optical source and, including:

a first waveguide having a first width and coupled to a side of an asymmetric X-junction;

a second waveguide coupled to said first waveguide at said side of said asymmetric X-junction and having a second width less than said first width; and

a third waveguide coupled to said first and second waveguides at said side of said asymmetric X-junction and having a third width less than said first width.

16. The optical transmitter as recited in Claim 15 wherein said first, second and third waveguides are each output waveguides or are each input waveguides.

17. The optical transmitter as recited in Claim 15 further comprising first and second modulating waveguides coupled to said first, second and third waveguides at said X-junction and an electrode located adjacent each of said first and second modulating waveguides.

18. The optical transmitter as recited in Claim 15 wherein said third width is less than said second width and said first waveguide is a power waveguide, said second waveguide is a power monitor waveguide and said third waveguide is a control waveguide.

19. The optical transmitter as recited in Claim 15 wherein said optical source is optically coupled to said modulator by an input waveguide.

20. The optical transmitter as recited in Claim 15 wherein said optical source a laser.

*FIG. 1A*
(PRIOR ART)

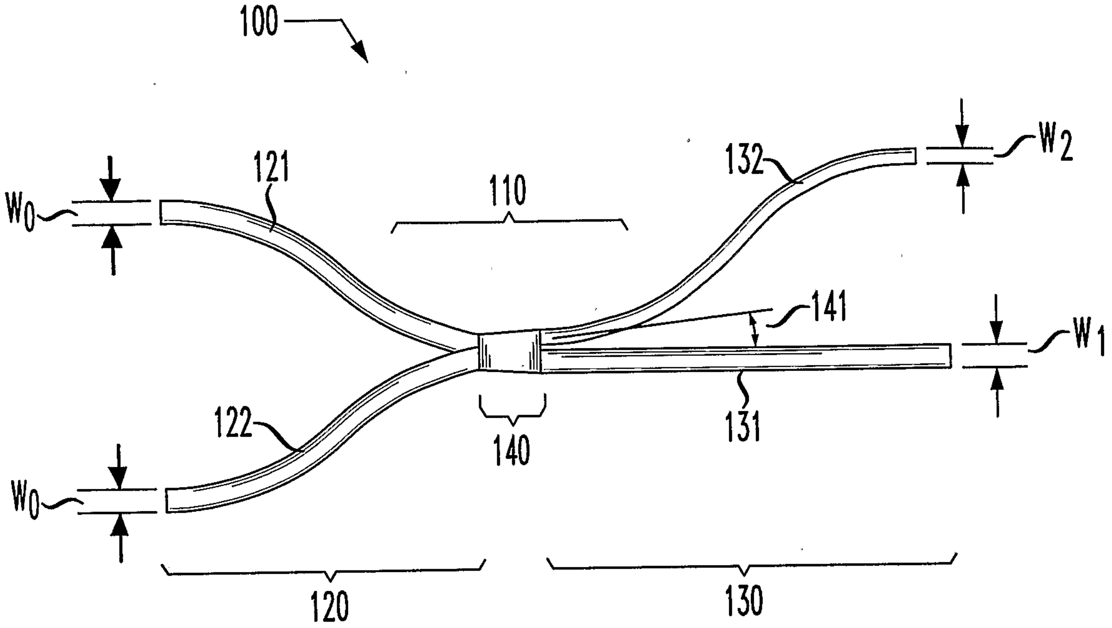



*FIG. 1B*
(PRIOR ART)

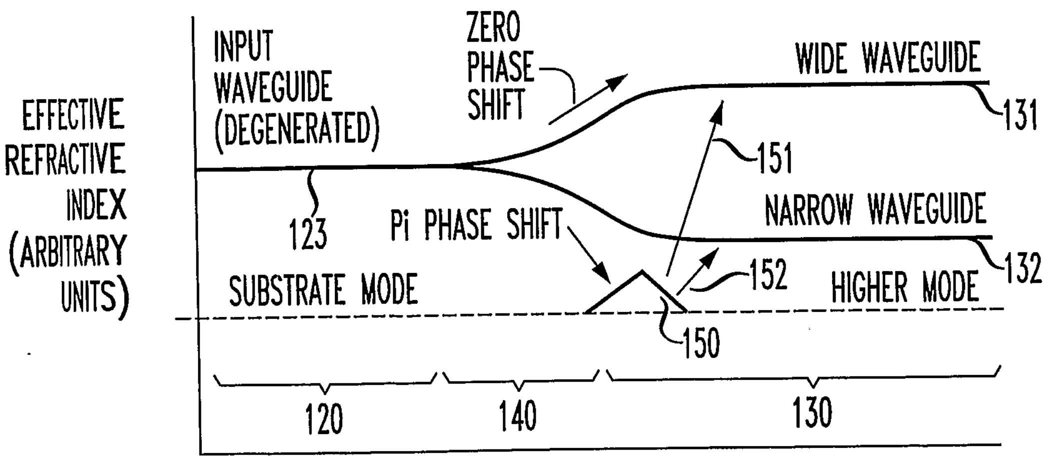


*FIG. 2*
(PRIOR ART)

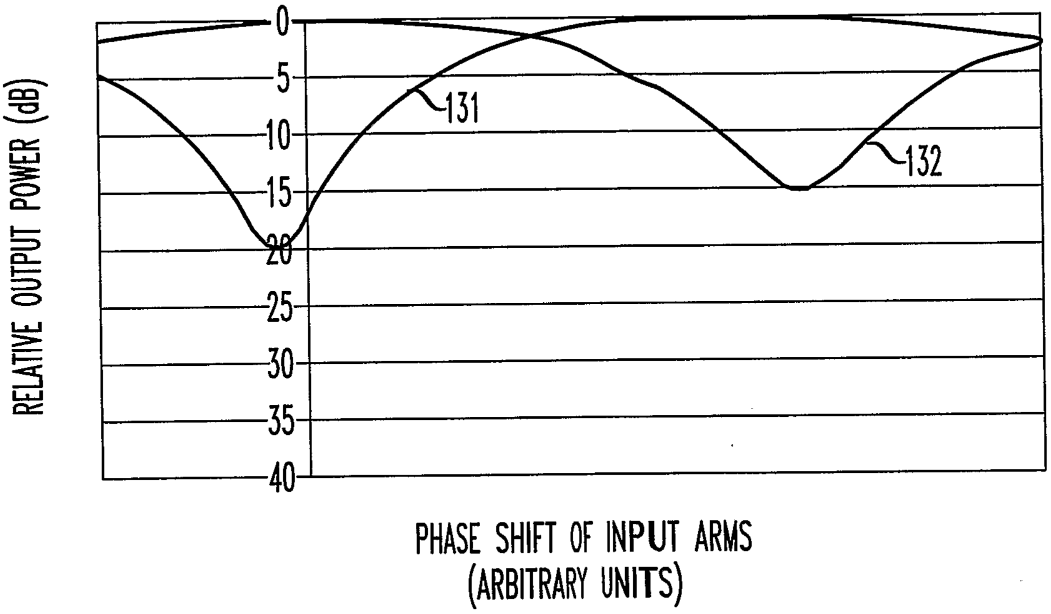
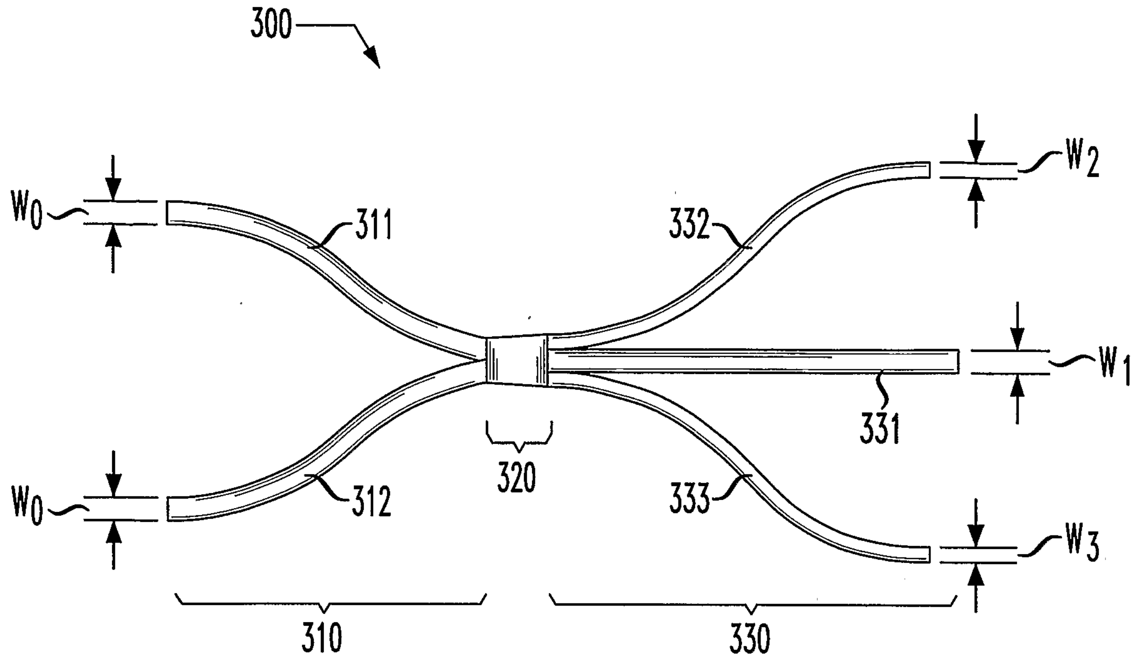


*FIG. 3A*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W2
W1
W3
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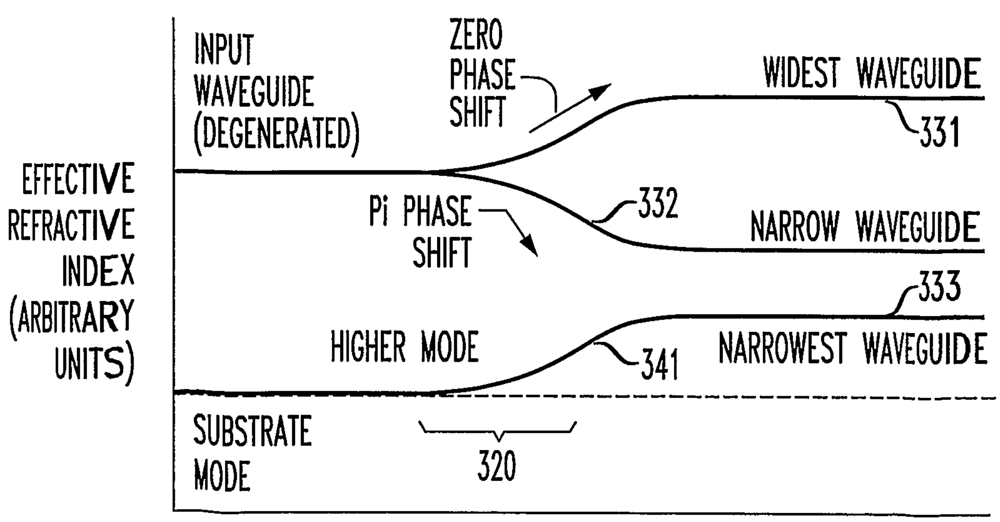
330

*FIG. 3B*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WIDEST WAVEGUIDE
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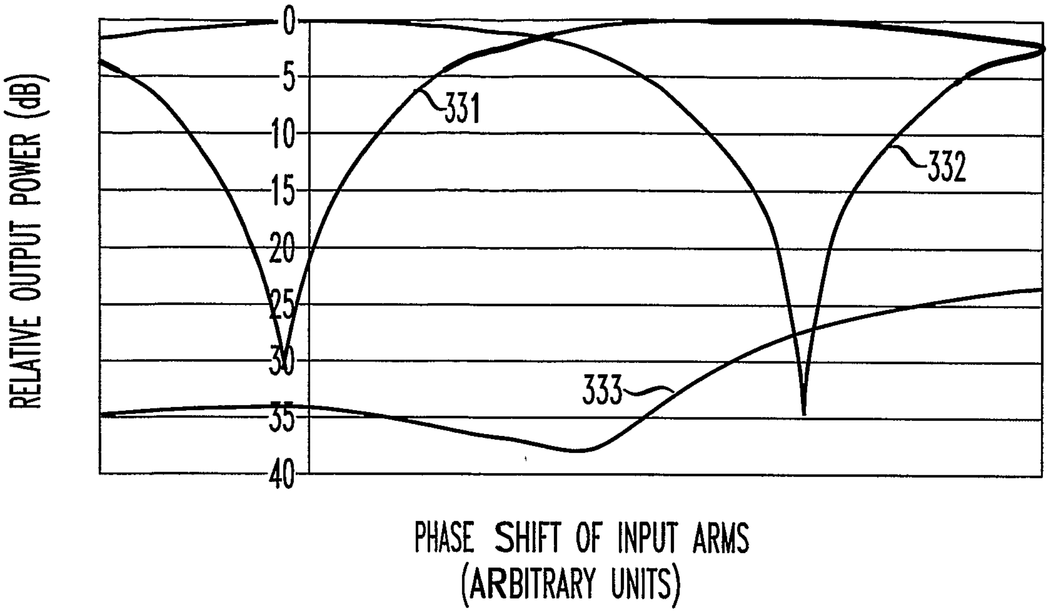
Pi PHASE SHIFT
332
NARROW WAVEGUIDE
333
HIGHER MODE
341
NARROWEST WAVEGUIDE
SUBSTRATE MODE
320

*FIG. 3C*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5
10
15
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331
332
333
PHASE SHIFT OF INPUT ARMS
(ARBITRARY UNITS)

*FIG. 4*

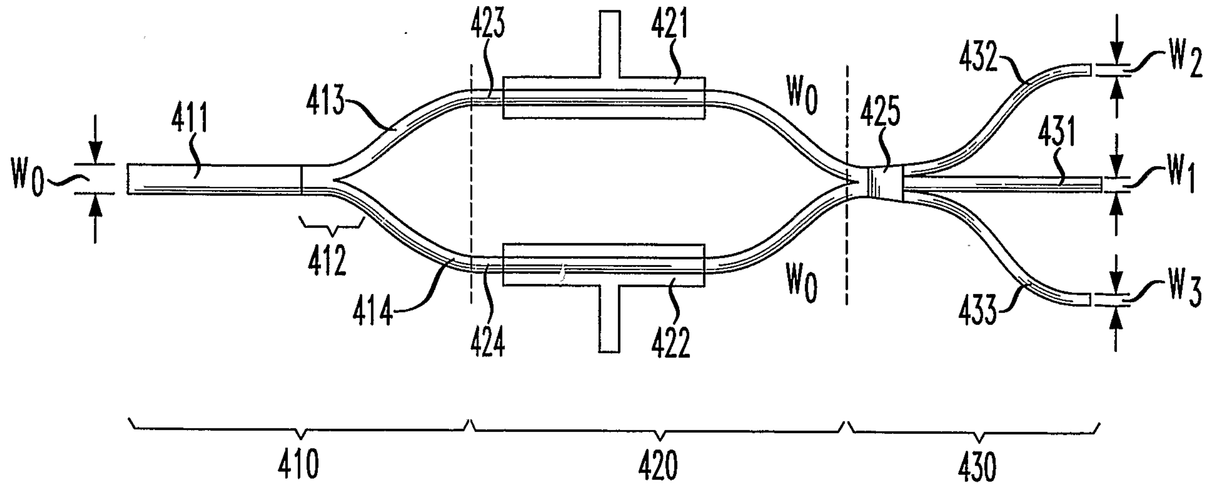
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*FIG. 5*

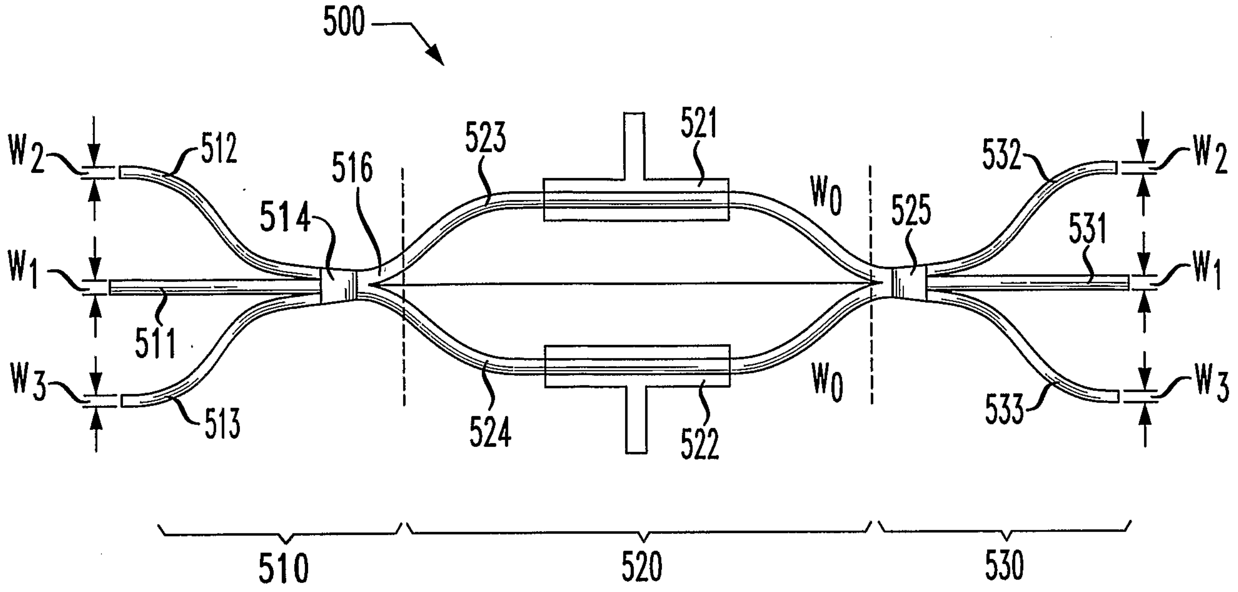
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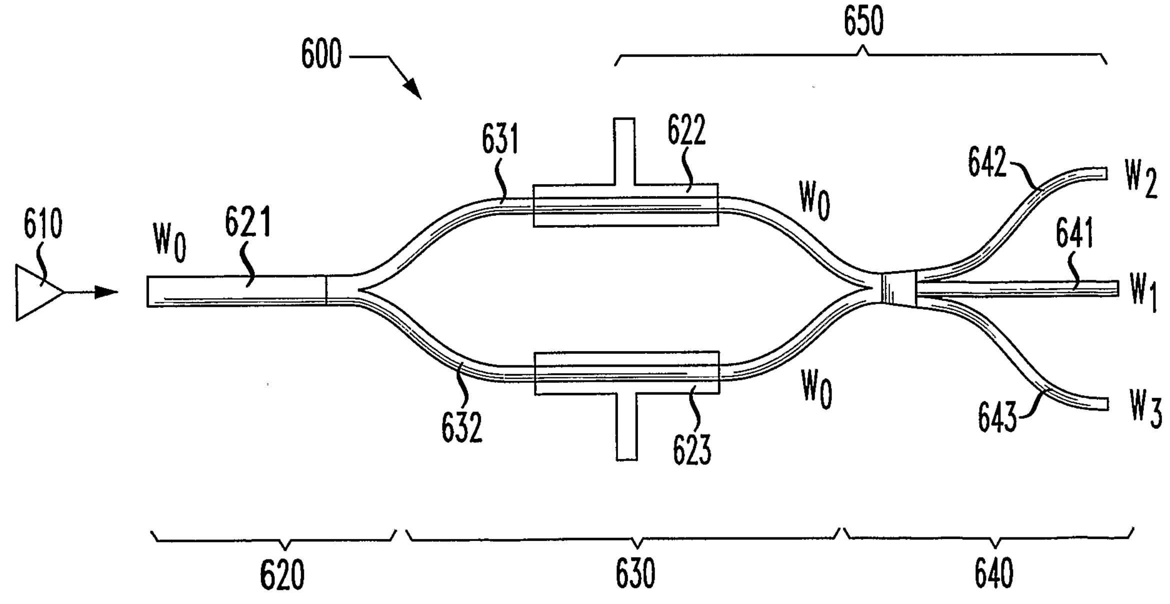
*FIG. 6*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# INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/25215

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 7 G02B6/28 G02B6/12

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, PAJ, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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| X | GB 2 215 482 A (MARCONI GEC LTD) 20 September 1989 (1989-09-20) abstract; figures 5-7 --- | 1-20 |
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| A | US 4 674 827 A (IZUTSU MASAYUKI ET AL) 23 June 1987 (1987-06-23) the whole document --- | 1-20 |
| | -/-- | |

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

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 11 April 2003 | 17/04/2003 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL – 2280 HV Rijswijk<br>Tel. (+31–70) 340–2040, Tx. 31 651 epo nl,<br>Fax: (+31–70) 340–3016 | Verbandt, Y |

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/25215

**C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT**

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**Information on patent family members**

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