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(57) Claim

1. An optical isolator which passes optical signals of one wavelength band in one direction of travel and passes optical signals of another wavelength band in the opposite direction of travel.

5. An optical isolator as claimed in claim 1, wherein said one wavelength band comprises first and second wavelength bands and said another wavelength band comprises said second wavelength band, said isolator inhibiting the passage of signals of said first wavelength band in said opposite direction.

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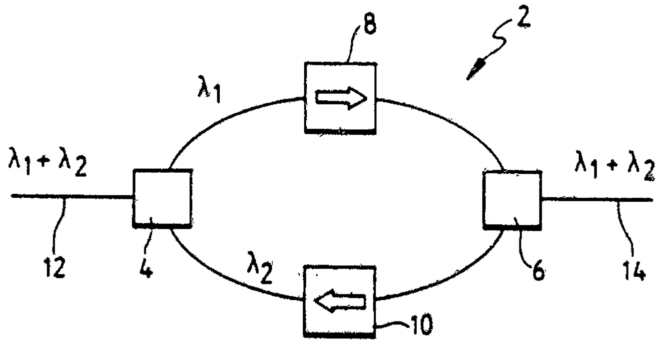

(57) Abstract

An optical isolator (2, 50, 70, 202, 250, 260, 300, 320, 370, 390, 402) which passes optical signals of one wavelength band in one direction of travel and passes optical signals of another wavelength band in the opposite direction of travel.

AN OPTICAL ISOLATOR AND AN OPTICAL TELECOMMUNICATIONS SYSTEM

The present invention relates to an optical isolator and also to an optical telecommunications system.

Back reflections of communication signals are a significant problem in optical telecommunications systems. The reflections may be generated at junctions between optical system components and induce noise and distortion, which can significantly reduce and deteriorate the performance of a component and the system. The reflections are an acute problem in systems which include a gain element, such as an amplifier, yet also cause difficulties in passive systems.

Optical isolators have been employed to inhibit reflections. Optical amplifiers such as rare earth doped optical fibre and semiconductor optical amplifiers are sensitive to back reflections, which may be generated at the input and output ends of the amplifier. Reflections which travel back into the amplifier may be amplified and increase the error rate of the system or can cause the amplifier to randomly oscillate or begin to lase. To prevent oscillations or gain fluctuations occurring in the amplifier, isolators are usually employed at at least one end of an amplifier. Isolators are configured to allow optical signals to pass therethrough in one direction, but prevent or inhibit signals travelling in the opposite direction. An isolator may include a Faraday rotator and a polariser and be constructed so as to have a flat wavelength characteristic, as described in Kazuo Shiraishi and Shorjiro Kawakami, "Cascaded optical isolator configuration having high-isolation characteristics over a wide temperature and wavelength range", Optics Letters, Vol. 12, No. 7, July 1987, pages 462 to 464. A flat characteristic is considered advantageous so an isolator is able to pass a wide range of wavelengths in one direction and inhibit a similar wide range of wavelengths in the opposite direction.

In view of the difficulties caused by back reflections and the need to inhibit them with unidirectional isolators, gain elements are restricted to operating on signals transmitted in one direction. This imposes an increased cost burden on a system when gain is required in both directions of transmission on an optical fibre line.

Furthermore, analysis of and fault location for an optical system may be performed from a remote location using optical time domain reflectometry (OTDR) techniques, whereby a test signal is transmitted into the system and the return signals produced by reflection of the test signal are analysed to determine particular characteristics of the system. For instance, a break in the transmission path caused by a fibre fault will produce a strong reflection and the time taken to receive the reflection after transmitting the test signal provides an indication as to the location of the fault. In systems which include optical isolators that inhibit back reflections, OTDR cannot be performed, unless separate optical paths are provided to avoid the isolators and return the test signal reflections. This is a problem which is encountered in both active and passive optical systems. Additional optical fibres, couplers or circulators may be used to provide the optical paths for the reflections but this significantly increases the cost and complexity of the system.

The present invention provides an optical isolator which passes optical signals of one wavelength band in one direction of travel and passes optical signals of another wavelength band in the opposite direction of travel.

Preferably said isolator inhibits the passage of signals of said another wavelength band travelling in said one direction,and inhibits the passage of signals of said one wavelength band travelling in said opposite direction.

Preferably said one wavelength band comprises first and third wavelength bands and said another wavelength band comprises a second wavelength band and said third wavelength band, and the signals of said first wavelength band of said one wavelength band are inhibited from travelling in said opposite direction and the signals of said second wavelength band of said another wavelength band are inhibited from travelling in said one direction.

Preferably said first and second wavelength bands are communications bands and said third wavelength band is used to perform analysis on an optical system including said isolator.

Preferably said one wavelength band comprises first and second wavelength bands and said another wavelength band comprises said second wavelength band, said isolator inhibiting the passage of signals of said first wavelength band in said opposite direction.

The present invention further provides an optical system comprising an amplifier and a bidirectional isolator disposed at an end of said amplifier. Preferably bidirectional isolators are disposed at each end of said amplifier.

The present invention also provides an optical telecommunications system including isolator means which inhibits reflections in at least one communications channel of a first wavelength band but allows signals of an additional channel of a second wavelength band to pass therethrough in both forward and reverse directions.

The additional channel may advantageously be used for OTDR and/or fault location.

The present invention also provides an optical telecommunications system including isolator means which inhibits reflections of optical signals in a first communications channel of a first wavelength band in one direction and inhibits reflections of optical signals in a second communications channel of a second wavelength band in the opposite direction.

Preferred embodiments of the present invention are hereinafter described, by way of example only, with reference to the accompanying drawings, wherein:

Figure 1 is a schematic diagram of a first preferred embodiment of a bidirectional isolator;

Figure 2 is a graph of a wavelength transmission characteristic of an amplifier;

Figure 3 is a schematic diagram of a rare earth amplifier with two bidirectional isolators;

Figure 4 is a schematic view of a second preferred embodiment of a bidirectional isolator;

Figure 5 is a block diagram of the components of a preferred bidirectional isolator;

Figure 6 is a detailed block diagram of part of the isolator of Figure 5;

Figure 7 is a diagram illustrating transmission of components of an optical signal through the forward direction of the isolator of Figure 5;

Figure 8 is a diagram illustrating transmission of components of an optical signal transmitted in the backward direction in the isolator of Figure 5;

Figure 9 is a diagram illustrating transmission of the components of an optical signal in the backward direction of the isolator when effected by temperature or wavelength variations;

Figure 10 is a diagram of an optical system which uses an additional fibre and a coupler or circulator to provide an optical path for reflections of a test signal;

Figure 11 is a fourth preferred embodiment of an optical isolator;

Figure 12 is a graph of a transmission characteristic for an element of an optical system;

Figure 13 is a block diagram of a fifth preferred embodiment of an optical isolator;

Figure 14 is a block diagram of a sixth preferred embodiment of an optical isolator;

Figure 15 is a schematic diagram of a seventh preferred embodiment of an optical isolator;

Figure 16 is a block diagram of and ray diagrams for an eighth preferred embodiment of an optical isolator;

Figure 17 is a block diagram of and ray diagrams for a ninth preferred embodiment of an optical isolator;

Figure 18 is a block diagram of and ray diagrams for a tenth preferred embodiment of an optical isolator; and

Figure 19 is a block diagram of and polarisation diagrams for an eleventh preferred embodiment of an optical isolator.

A first bidirectional isolator 2, as shown in Figure 1, includes two wavelength sensitive elements 4 and 6, a forward isolator part 8, and a backward isolator part 10. The isolator parts 8 and 10 are connected parallel between the elements 4 and 6. The wavelength elements 4 and 6 are connected to respective optical fibre lines 12 and 14 which carry optical signals on two wavelength bands λ_1 for one direction, the forward direction, and λ_2 for the opposite direction, the backward or reverse direction. Allocating forward and reverse wavelength transmission bands which do not overlap allows the isolator 2 to separately isolate the signals of the different bands using the forward and backward parts 8 and 10. The bands may be chosen based on the transmission characteristic of a component, such as an amplifier, which is to be used with the isolator 2. For example, the transmission characteristic 20 of an amplifier may be as shown in Figure 2 where the vertical axis 22 is a measure of light intensity transmitted and the horizontal axis 24 is a measure of the frequency of the transmitted signals. The characteristic 20 may be divided, as represented by the line 26 into two wavelength regions, with one region λ_1 being allocated for forward travelling signals and the other region λ_2 being allocated for signals travelling in the opposite direction.

The wavelength sensitive elements 4 and 6, which may be prisms, dichroic mirrors, holograms, dichroic couplers or gratings, split incoming signals on the lines 12 and 14 into two paths. One path is for signals of wavelength band λ_1 which as passed to the forward isolator part 8 and the second path is for signals of wavelength band λ_2 which are passed to the backward isolator part 10. The forward isolator part 8 only transmits signals travelling from first wavelength element 4 to the second wavelength element 6 and cancels signals received from the second wavelength element 6. Similarly, the backward isolator part 10 only transmits signals travelling from the second wavelength element 6 to the first wavelength element 4, and cancels signals travelling from the first wavelength element 4. Signals received from the isolator parts 8 and 10 at the elements 4 and 6 are combined and outputted on the lines 12 and 14. Therefore the isolator 2 cancels reflections of the wavelength band λ_1 travelling in the reverse direction and cancels reflections of the wavelength band λ_2 travelling in the forward direction.

A bidirectional isolator 2 which is wavelength sensitive over the transmission or gain range of an amplifier can be advantageously employed at at least one end 28 or 30 of the amplifier 32. Performance of the amplifier 32, such as a fibre amplifier doped with Erbium, is enhanced if an isolator 2 is placed at each end 28 and 30, as shown in

Figure 3. The isolator 2 may also be placed at other strategic locations in an optical system. The amplifier 32 can be pumped in both directions by a forward laser diode 34 and a reverse laser diode 36 which are both optically connected to the respective ends 28 and 30 of the amplifier 32 by respective optical couplers 42 and 44. The isolators 2 are placed between the couplers 42 and 44 and input/output fibre lines 38 and 40 to the amplifier 32. The amplifier 32 can therefore advantageously be used to amplify both signals of wavelength band λ_1 travelling in the forward direction from the line 38 to the line 40 and signals of wavelength band λ_2 travelling in the reverse direction from the line 40 to the line 38. The bidirectional isolators 2 prevent any reflections at the ends 28 and 30 of wavelength band λ_1 or λ_2 from entering the amplifier 32 and generating gain fluctuations or causing the amplifier 32 to oscillate or lase.

A second configuration for a bidirectional isolator is illustrated in Figure 4. The second bidirectional isolator 50 includes two directional elements 52 and 54 in place of the wavelength sensitive elements 4 and 6. The isolator parts 8 and 10 are replaced by optical filters 56 and 58. The first directional element 52 has three ports 59, 60 and 62 and signals received on the first port 59 are passed to the second port 60, whereas signals received on the third port 62 are outputted on the first port 59. The first optical fibre line 12 is connected to the first port 59 of the first directional element 52, and the filters 56 and 58 are connected to the second and third ports 60 and 62, respectively. The second directional element 54 also has three ports 64, 66 and 68 and the first port 64 passes signals received thereon to the second port 66 and signals received on the second port 66 are passed to the third port 68. The second optical fibre line 14 is connected to the second port 66 of the second directional element 54, and the filters 56 and 58 are connected to the first port 64 and the third port 68, respectively. Therefore signals travelling in the forward direction on the first line 12 to the second line 14 are passed through the isolator 50 via the first filter 56, and signals travelling in the reverse direction are passed via the second filter 58. The directional elements 52 and 54 may be constructed from optical isolators or 3 or 4 port optical circulators, of the type described in Yohji Fujii, "High-isolation polarisation-independent optical circulator coupled with single-mode fibers", Journal of Lightwave Technology, Vol. 9, No. 4, April 1991, pages 456 to 460. The first filter 56 inhibits signals of the wavelength band λ_2 and passes signals of the wavelength band λ_1, whereas the second filter 58 inhibits signals of the wavelength band λ_1 and passes signals of the band λ_2. The filters may be band pass or high or low pass filters, as desired. The first filter 56 ensures signals of the band λ_2 are not allowed to continue to travel in the forward direction, and the second filter 58 ensures signals of the wavelength band λ_1 are not allowed to continue to travel in the reverse direction.

A third bidirectional isolator 70, as shown in Figure 5, advantageously comprises a single device or assembly. The isolator 70 includes two wavelength selective elements 74 and 76, two spatial walk-off polarisers (SWP) 78 and 80, a polarisation dependent isolator 82 and three judiciously placed half-wave plates 84, 86 and 88. The wavelength selective elements 74 and 76 may be the same as the elements 4 and 6 of the first isolator 2 and are connected to first and second optical fibre lines 12 and 14, respectively. The lines 12 and 14 carry signals of the forward wavelength band λ_1 and the reverse wavelength band λ_2 which are split by the elements 74 and 76 into two paths, the forward path 90 and the backward path 92. The polarisers 78 and 80 then split the signals on the two paths 90 and 92 into four paths, two paths 94 and 96 for the band λ_1 and two paths 98 and 100 for the λ_2 band signals. The polarisers 78 and 80 break the signals of the paths 90 and 92 into two polarised orthogonal components for transmission on the paths 94 and 96 or 98 and 100, respectively.

The half-wave plates 84, 86 and 88 rotate a polarised component by 90°. Assuming horizontal components travel on the paths 94 and 98 and vertical components travel on the paths 96 and 100, the first half-wave plate 84 rotates the vertical components of the λ_1 band signals and the horizontal components of the λ_2 band signals between the first polarisers 78 and the isolator 82. The second and third half-wave plates 86 and 88 rotate the horizontal components of the λ_1 band signals and the vertical components of the λ_2 band signals between the isolator 82 and the second polariser 80.

The isolator 82, as shown in Figure 6, includes for each wavelength band λ_1 90 and λ_2 92 three polarisers 101, 102 and 104, and two Faraday rotators 106 and 108 disposed between respective pairs of the polarisers 101 and 102, 102 and 104. The operation of the isolator 82 is hereinafter described with reference to the λ_1 band paths 94 and 96, but it should be understood the description also applies to the λ_2 band paths

98 and 100, except the positions of the first and third polarisers 101 and 104 are swapped. The same rotators 106 and 108 and second polariser 102 may be used for both λ_1 and λ_2 paths 90 and 92.

For the forward direction, the signal is first split by the SWP 78 into two components, a vertical component 110 and a horizontal component 112, as shown in Figure 7. The first component 110 is rotated 90° by the half-wave plate 84 so the component 110 is now polarised in the same plane as the second component 112. Both components are allowed to pass by the first polariser 101 to the first Faraday rotator 106, as the first polariser 101 is a horizontal polariser. Both of the Faraday rotators 106 and 108 are configured to rotate incoming optical waves clockwise by 45° regardless of the direction from which they are received. Accordingly the first rotator 106 rotates both the first and second components by 45° in the clockwise direction so the components could be said to oscillate at 135° or 315° polarisation, as shown in Figure 7. The second polariser 102 only allows signals oscillating at the 135° and 315° polarisation to pass, and the components 110 and 112 therefore move unchanged to the second Faraday rotator 108 where they are rotated to be placed in the vertical plane. The third polariser 104 is a vertical plane polariser and allows the components to pass to the second SWP 80 where they are recombined. Before recombination, the second component 112 is rotated 90° by the second half-wave plate 86 so as to return to the horizontal plane. Therefore the λ_1 band signals placed on the path 90 at the output of the second SWP 80 are substantially the same as that received at the input of the first SWP 78.

For λ_1 band signals travelling in the reverse direction, the two components 110 and 112 are separated by the second SWP 80, and the second component 112 is rotated by the half-wave plate 86 into the vertical plane, as shown in Figure 8. The two components 110 and 112, being in the vertical plane, are passed by the third polariser 104 to the second Faraday rotator 108 where they are rotated in a clockwise direction so as to be at 45° or 225° polarisation. The components 110 and 112 of the λ_1 band signals are then cancelled by the second polariser 102, as they do not include components polarised in the 135° to 315° plane.

The rotations performed by the Faraday rotators 106 and 108 may be subject to temperature or wavelength shifts. For example, if the second Faraday rotator 108 is operating at a point shifted from its peak characteristic due to temperature or wavelength fluctuations then the backward travelling polarisation components 110 and 112 may not be precisely aligned to 45° or 225° when outputted by the rotator 108. Therefore there will be a small polarisation component 114 of each of the components 110 and 112 which is at 135° or 315° which is passed by the second polariser 102, as illustrated in Figure 9. This small component 114 of each of the components 110 and 112 is rotated by the first Faraday rotator 106 so as to then be aligned with the vertical plane. The components are then cancelled by the first polariser 101 which only allows horizontal components to pass therethrough.

Alternatively if temperature or wavelength shifts are not a sufficient problem the polarisers 100 and 104 can be simply omitted.

The cascade structure of the isolator 82 and the arrangement of the half-wave plates 84, 86 and 88 of the bidirectional isolator 70 ensure the isolator 70 inhibits signals of wavelength band λ_1 travelling in the reverse direction and signals of the λ_2 band travelling in the forward direction through the isolator 70. Even with fluctuations due to temperature or variations of the signal wavelength, the bidirectional isolator 70 is able to attenuate undesired reflections by typically 40 to 60 dB.

An optical system 201, as shown in Figure 10, includes a transmission line formed of optical fibres 203 and an optical isolator 205. The isolator 205 allows signals travelling on the line in the forward direction 207 to pass therethrough but inhibits the signals, including reflections, travelling in the reverse direction 209. If a fault 211 has occurred in the transmission line, location of the fault may be determined using OTDR techniques by using a remote laser diode light source 213 connected to the line to launch a test pulse into the line in the forward direction 207. The reflection of the test pulse in the reverse direction 209 caused by the fault 211, however, cannot be received from the transmission line at the location of the source 213, as the isolator 205 inhibits the reflection. Therefore, an optical coupler or circulator 215 is placed ahead of the isolator 205 to receive the reflection and couple it to a separate optical path provided by an additional optical fibre 217. The optical fibre 217 routes the reflection back to the location of the source 213 so as to be received by a photodetector 219. OTDR techniques, as described in Mitsuhiro Tateda and Tsuneo Horiguchi, "Advances in optical time-domain reflectometry", Journal of Lightwave Technology, Vol. 7, No. 8, August 1989, pages 1217 to 1224 and in Yukio Horiuchi et al., "Novel coherent heterodyne optical time domain reflectometry for fault localization of optical amplifier submarine cable systems", IEEE Photonics Technology Letters, Vol. 2, No. 4, April 1990, pages 291 to 293, can then be used to analyse the signal produced by the photodetector 219 to determine the location of the fault 211. As discussed previously, having to provide the optical coupler 215 and the additional fibre 217 significantly increases the complexity and the cost of the system 201, particularly when a number of isolators 205 are employed in the system and the location of the source 213 and the photodetector 219 are a large number of kilometres from the locations of the isolators.

A fourth optical isolator 202, as shown in Figure 11, includes a first directional element 204 connected to one optical fibre 206 and a second directional element 208 connected to another optical fibre 210, and an optical filter 212. The first directional element 204 includes three ports and is configured so that the signals received on a first port 214 connected to the fibre 206 are outputted on a second port 216 and the signals received on a third port 218 are outputted on the first port 214. The second directional element 208 also has three ports and the signals received on a first port 220 are outputted on a second port 222 connected to the fibre 210, and the signals received on the fibre 210 at the second port 222 are outputted on a third port 224. The filter 212 is connected between the third ports 218 and 224 of the directional elements 204 and 208, and the second port 216 of the first directional element 204 is connected to the first port 220 of the second directional element 208. The directional elements 204 and 208 may be constructed from optical isolators or 3 or 4 port optical circulators, of the type described in Yohji Fujii, "High-isolation polarisation-independent optical circulator coupled with single-mode fibers", Journal of Lightwave Technology, Vol. 9, No. 4, April 1991, pages 456 to 460.

All optical signals travelling in the forward direction, from the first optical fibre 206 to the second optical fibre 210, are allowed to travel through the isolator 202 via the first and second ports 214, 216, 220, 222 of the directional elements 204 and 208.

However, in the reverse direction, from the optical fibre 210 to the optical fibre 206, only those signals of a wavelength not filtered out by the filter 212 are allowed to pass through the isolator 202. The filter 212 may comprise a high, low or band pass filter, as desired.

A transmission characteristic 230 of an optical system, or of an element of the system, such as an amplifier, may be as shown in Figure 12 where the vertical axis 232 represents the intensity of light transmitted and the horizontal axis 234 represents the frequency of the light transmitted. Wavelength bands within the range of the characteristic 230 can be advantageously selected for at least one communication channel and an additional channel for analytical purposes. The additional channel need only comprise a narrow band and it is preferably selected to be a band which will not be amplified significantly by or interfere with the gain characteristics of amplifiers in the system. For example, if the transmission characteristic 230 is that of a rare earth amplifier, then two wavelength bands, λ_1 236 and λ_2 238 may be selected for two communication channels and a narrow band λ_3 240 selected at the edge of the characteristic 230 for the additional channel. By including the isolator 202 in the system, the filter 212 can be configured to inhibit reflections of the communications band λ_1 and λ_2 but allow transmission of signals of the analysis band λ_3. Hence, the isolator 202 is unidirectional, as desired, with respect to each of the communications band λ_1 and λ_2 but allows test signals of the λ_3 band to be transmitted through the isolator 202 from the fibre 206 to the second fibre 210 and then reflected back through the isolator 202 in the reverse direction. The reflected signals of the λ_3 band can then be used to perform OTDR. Hence, OTDR can be performed on an optical system which includes the isolator 202 and gain elements, without requiring additional optical paths to be established with couplers or circulators and additional fibre.

A fifth isolator 250, as shown in Figure 13, is bidirectional and similar to the fourth isolator 202, except it includes a second filter 252 between the second port 216 of the first directional element 204 and the first port 220 of the second directional element 208. Also the filter 212 is configured differently to pass signals of a wider wavelength range. Both filters 212 and 252 may comprise notch filters, a low/high pass filter combination, a notch/low pass filter combination or a notch/high pass filter combination.

If the transmission characteristic 230 applies, the first filter 212 is configured to allow the wavelength bands λ_2 and λ_3 to pass whereas the second filter 252 passes only the first communication band λ_1 and the analysis band λ_3. Therefore the isolator 250 only allows the signals of the first communication channel 236 to travel in the forward direction from the first optical fibre 206 to the second optical fibre 210, and in the reverse direction, only allows the second communication channel 238 to travel from the second fibre 210 to the first fibre 206. Both filters 212 and 252 allow the signals of the analysis band λ_3 to pass so OTDR can be performed on systems including the isolator 250 using test signals having a wavelength within the λ_3 band.

A sixth optical isolator 260, as shown in Figure 14, is able to perform the same function as the fifth optical isolator 250 but advantageously it comprises a single device or assembly, which does not include fibre to connect the components. The isolator 260 includes two wavelength selective elements 262, two spatial walk-off polarisers (SWPs) 264, a polarisation dependent isolator 266, a transparent medium 268 and three half-wave plates 270. The wavelength selective elements 262 are connected respectively to the first and second fibres 206 and 210 and split the signals received on the fibres 206 and 210 into three paths, one path 271 for the signals of the analysis band λ_3, a second path 272 for signals of the first communication band λ_1 and a third path 274 for signals of the second communication band λ_2. The wavelength selective elements may comprise prisms, dichroic mirrors, holograms, dichroic couplers or gratings. The SWPs 264, the half-wave plates 270 and the isolator 266 are configured and arranged to process signals on the second and third paths 72 and 74 in the same manner as the third bidirectional isolator 70 described previously with reference to Figures 5 to 9. The isolator 260 only allows signals on the λ_1 path 272 to pass from the first optical fibre 206 to the second optical fibre 210, and similarly, only allows signals on the λ_2 path 274 to pass from the second optical fibre 210 to the first optical fibre 206. Signals on the λ_3 path 271 are passed directly between the wavelength selective elements 262 by the transparent medium 268. The medium 268 has a refractive index selected to receive signals on the path 271 from one of the wavelength selective elements 262, pass the signals along the medium 268 past the SWPs 264 and the isolator 266, and then direct the signals onto the appropriate point of incidence on the other wavelength selective element 262. The bidirectional isolator 260 therefore inhibits reflections of the communications bands λ_1

and λ_2 but allows reflections of the analysis band λ_3 to pass therethrough so OTDR can be performed on a system including the isolator 260.

A seventh bidirectional isolator 300 to handle the three bands λ_1, λ_2 and λ_3 comprises, as shown in Figure 15, a four port circulator 302 and two reflective filters 304 and 306. The circulator 302 is configured so that light incident on the first port 308 is transmitted to and output from the second port 310, light incident on the second port 310 is transmitted to and output from the third port 312, light incident on the third port 312 is transmitted to and output from the fourth port 314, and light incident on the fourth port 314 is transmitted to and output from the first port 308. The first port 308 is connected to a first optical fibre 316, and the third port 312 is connected to a second optical fibre 318. The first communication band λ_1 236 is used for signals travelling in a forward direction from the first fibre 316 to the second fibre 318, and the second communication band λ_2 238 is used for signals travelling in the reverse direction from the second fibre 318 to the first fibre 316. Signals of the analysis band λ_3 240 are allowed to travel in each direction. The first reflective filter 304 is connected to the second port 310 and is configured to reflect signals within the first communication band λ_1 and the analysis band λ_3 but not signals of the second communication band λ_2. Therefore λ_1 and λ_3 signals received on the first port 308 are reflected by the first filter 304 and redirected back into the second port 310 so as to be output from the third port 312 on the second fibre 318. The signals of the second communication band λ_2 received on the first port 308 are output from the second port 310 and are not returned to the port 310 by the first filter 304.

The second filter 306 is connected to the fourth port 314 and reflects signals within the second communication band λ_2 and the analysis band λ_3 but not the first communication band λ_1. Accordingly, λ_2 and λ_3 signals received on the third port 312 are reflected by the second filter 306 and returned to the fourth port 314 and outputted on the first fibre 316 at the first port 308. The signals of the λ_1 band received on the third port 312 are output on the fourth port 314 but are not returned to the port 314 by the second filter 306. The isolator 300 ensures any reflections in the λ_1 or λ_2 bands dissipate via the fourth port 314 or second port 310, respectively.

An eighth isolator 320, as shown in Figure 16, is a single device or assembly which is configured to perform the same function as the seventh isolator 300. The isolator 320 includes first and third ports 322 and 324 connected to respective graded refractive index (GRIN) lenses 327 which are used to collimate light to be received by the ports 322 and 324 so that the beam width is a predetermined size. The beam width to be handled by the assembly 320 determines the size of the assembly. In some instances the beam width and assembly may be thin enough that the lenses 327 are not required. The second and fourth ports 323 and 325 have the reflective filters 304 and 306 respectively affixed thereto. Between the first and third ports 322 and 324 and the second and fourth ports 323 and 325, the isolator 320 comprises an in-line or series assembly of a first spatial walk-off polariser (SWP) 326, a first half-wave plate arrangement 328, a second SWP 330, a Faraday and optical rotator 332, a third SWP 334, a second half-wave plate arrangement 336, and a fourth SWP 340. The first and second SWPs 326 and 330 have an SWP function 342 where incident light is split into two polarisation components, horizontal and vertical, and the horizontal component diverges or is walked upward with respect to the vertical component, which is allowed to pass without directional change. In Figures 16, 17 and 18 vertical components are illustrated by a dashed line 344 and horizontal components are illustrated by a dotted line 346. The second and third SWPs 334 and 340 have an SWP function 348 which walks the incident horizontal component downwards, and the vertical component is allowed to pass without directional change.

The half-wave plate arrangements 328 and 336 are each divided into upper, middle and lower sections 350, 352 and 354, respectively. The upper and lower sections 350 and 354 each include a half-wave plate which inflicts a 90° polarisation rotation on incident polarised light, and the middle section 352 includes a transmissive medium, which allows light to pass unaltered. The first and second ports 322 and 323 are aligned with the lower sections 354 and the third port 324 and the fourth port 325 are aligned with the middle sections 352. The Faraday and optical rotator 332 includes a Faraday rotator which performs a clockwise 45° rotation on all incident polarised light regardless of the direction of travel. The rotator 332 also includes an optical rotator which is connected in series with the Faraday rotator and performs a clockwise 45° rotation on incident light travelling in the reverse direction from the second and fourth ports 323 and

325 to the first and third ports 322 and 324 and an anticlockwise 45° rotation on light travelling in the forward direction from the first and third ports 322 and 324 to the second and fourth ports 323 and 325. Therefore light travelling in the forward direction through the rotator 332 is outputted from the rotator unchanged, whereas light travelling in the reverse direction is rotated by 90° by the rotator 332.

Figure 16 includes four ray diagrams 356, 358, 360 and 362 which illustrate the path taken by light through the isolator 320 when incident on each of the four ports 322, 323, 324 and 325, respectively. With regard to the first ray diagram 356, light incident on the first port 332 is separated into a horizontal component and a vertical component which are directed by the first SWP 326 to the middle section 352 and the lower section 354 of the first half-wave plate arrangement 328, respectively. The vertical component is rotated into a horizontal plane by the lower half-wave plate section 354, and the second SWP 330 walks both components up a section to the rotator 332. The third SWP 334 walks both components down to the second half-wave plate arrangement 336 which allows one component to pass through the middle section 352 and the other component to pass through the lower section 354, which returns the lower component to a vertical polarisation. The fourth SWP 340 walks the upper horizontal component down to the second port 323 so as to be combined with the lower vertical component. With reference to the second ray diagram 358, light reflected by the first filter 304 at the second port 323 returns via the same path to the rotator 332 at which both incident components are rotated 90° to have a vertical polarisation. The second SWP 330 allows the two vertically polarised components to simply pass therethrough so as to be incident respectively on the upper section 350 and the middle section 352 of the first half-wave plate arrangement 328. The upper component passed through the upper section 350 is rotated so as to now be polarised horizontally, and this horizontal component is walked down by the first SWP 326 to meet the other vertically polarised component at the third port 324.

Light incident on the third port 324 is split, as shown in the third ray diagram 360, into an upper horizontal component and a vertical component, with the horizontal component being walked up to the upper section 350 of the first half-wave plate arrangement 328 so as to be rotated into the vertical plane. The two vertically polarised components pass unchanged through the second SWP 330, the rotator 332 and the third SWP 334 until the upper component reaches the upper section 350 of the second half-wave plate arrangement 336 at which it is rotated into the horizontal plane. The upper horizontally polarised component is then walked down by the fourth SWP 340 so as to be incident on the fourth port 325 with the other component which passes through the entire assembly 320 without alteration. Light reflected at the fourth port 325 by the second filter 306 returns via the same path until the rotator 332 rotates both components from a vertical polarisation to a horizontal polarisation. Both components are then walked down by the second SWP 330 so as to impinge on the middle section 352 and the lower section 354, respectively, of the first half-wave plate arrangement 328. The component which passes through the lower section 354 is rotated by 90° so as to be vertically polarised and is passed directly by the first SWP 326 to the first port 322. The horizontally polarised component which emerges from the middle section 352 of the first half-wave plate arrangement 328 is walked down by the first SWP 326 to the first port 322.

A ninth isolator 370, as shown in Figure 17, provides an alternative assembly for performing the function of the seventh isolator 300. The isolator 370 has essentially the same configuration as the eighth isolator 320, except the fourth SWP 340 is omitted and the second half-wave plate arrangement 336 is arranged between the second SWP 330 and the rotator 332. The first port 322 is now aligned with the middle sections 352 and the third port 324 is aligned with the upper sections 350 of the half-wave plate arrangements 328 and 336. The second port 323 is aligned with the middle sections 352, but the fourth port is split into two sections 325a, which is aligned with the upper sections 350, and 325b which is aligned with the lower sections 354. The SWPs 326, 330 and 334 also have different SWP functions, in that the first two SWPs 326 and 330 have a function 370 which walks horizontally polarised components down and the third SWP 334 has a function 374 which walks horizontally polarised components up a section. The assembly 370 saves an SWP 340 and only requires the addition of extra reflective element in the split port 325a, 325b.

Figure 17 includes four ray diagrams 376, 378, 380 and 382 which illustrate the paths taken by light through the assembly 370 for each port, respectively. With reference to the first ray diagram 376, light incident on the first port 322 is separated into a vertically polarised component which is passed to the middle section 352 of the first half-wave plate arrangement 328 and a horizontally polarised component which is walked down to the lower section 354. The lower section 354 polarises the lower component into a vertical polarisation which is then returned to a horizontally polarised component by the lower section 354 of the second half-wave plate arrangement 336. The horizontally polarised component is then walked up by the third SWP 334 to meet the other component, which is unchanged throughout the assembly 370, at the second port 323. Light reflected at the second port 323 by the first reflective filter 304 returns via the SWP 334 to the rotator 332 and is rotated by 90° into an upper horizontally polarised component and a lower vertically polarised component. The lower component is rotated into a horizontal polarisation by the lower section 354 of the second half-wave plate arrangement 336 and then both components are walked up by the second SWP 330 to the upper section 350 and the middle section 352, respectively, of the first half-wave plate arrangement 328. The upper component is rotated by the upper section 350 of the first half-wave plate arrangement 328 into a vertical polarisation and passed by the first SWP 326 to the third port 324. The other horizontally polarised component is walked up by the first SWP 326 to the third port 324.

With reference to the third ray diagram 380, light incident on the third port 324 travels the same path as that for the second ray diagram 378 until it reacnes the rotator 332. At the rotator 332, the upper horizontally polarised component is aligned with the middle sections 352 and is not rotated by the rotator 332, nor is the lower vertically polarised component which is aligned with the lower sections 354. The third SWP 334 passes the vertically polarised component directly to the port 325b, and the horizontally polarised component is walked up by the third SWP 334 to the port 325a. Light reflected at the port sections 325a and 325b by second reflective filters 306 returns via the same path to the rotator 332 at which the upper horizontal component is polarised vertically and the lower vertically polarised component becomes polarised horizontally. The lower component is then changed to a vertical polarisation by the lower section 354 of the second half-wave plate arrangement 336 and the two components are passed by the second SWP 330 into the first half-wave plate arrangement 328 at which the lower section 354 changes the polarisation of the lower component again to a horizontal polarisation. The first SWP 326 then walks the horizontally polarised component up to the first port 322 to meet the vertically polarised component.

A tenth isolator 390, as shown in Figure 18, provides a further alternative assembly for performing the function of the seventh isolator 300. The isolator 390 has the same assembly as the eighth isolator 320, except the third SWP 334 is omitted and the second half-wave plate arrangement is replaced by a complementary half-wave plate arrangement 392 where the upper and lower sections 350 and 354 include a transmissive medium and only the middle section 352 includes a half-wave plate. This provides a significant half-wave plate saving. The configuration of the first half-wave plate arrangement 328 is constructed by boring a hole through a half-wave plate which is the same size as the arrangement, whereas the second arrangement 392 only requires a half-wave plate which is one third of the size of that of the first arrangement 328. The second port 323 is aligned with the middle section 352 and the fourth port is again split into two sections 325a, aligned with upper section 350, and 325b, aligned with the lower section 354.

Figure 18 includes four ray diagrams 394, 396, 398 and 400 which illustrate the paths taken by light incident on each of the four ports, respectively, of the isolator 390. With reference to the first diagram 394, light incident on the first port 322 follows the same path as that of the diagram 356 of Figure 16 until the upper and lower components leave the rotator 332 and are incident on the upper and middle sections 350 and 352 of the second half-wave plate arrangement 392. The upper component passes unchanged and is then walked down by the SWP 340 to the second port 323. The lower component is rotated by 90° by the middle section 352 so as to have a vertical polarisation and is then passed directly to the second port 323. Light reflected at the second port 323 passes back to the rotator 332 via the same path and at the rotator 332 the two horizontally polarised components are rotated so as to be vertically polarised. The two components then follow the same path as the second diagram 358 of Figure 16 to the third port 324. With reference to the third ray diagram 398, light incident on the third port 3 follows the same path as the third ray diagram 360 of Figure 16 until reaching the half-wave plate arrangement 390 in which the upper vertically polarised component is passed directly to the port 325a, and the lower vertically polarised component is rotated by the middle section 352 and then walked down by the SWP 340 to the lower port 325b. Light reflected at the ports 325a and 325b returns via the same path to the rotator 332 at which the vertically polarised components are rotated so as to become horizontally polarised components. The components then follow the same path to the first port 322 as described previously with reference to the fourth ray diagram 362 of Figure 16.

An eleventh isolator, as shown in Figure 19, provides a further alternative assembly to perform the function of the seventh isolator 300. The isolator 402 has the same configuration as the ninth isolator 370, except the third SWP 334 is replaced by a SWP combination 404 which includes a first SWP for walking down light polarised in a first diagonal plane 406, and then a second SWP which walks up light polarised in an orthogonal second diagonal plane 408, as shown in Figure 19. Also the rotator 332 does not include the optical rotator and consists of a single 45° Faraday rotator. Figure 19 includes four polarisation diagrams 410, 412, 414 and 416 which illustrate the various polarisation states which exist at each interface of the components 326, 328, 330, 336, 332 and 404 for light incident on each of the ports, respectively. The diagrams comprise a plurality of interface cross-sections. The diagrams illustrate that the first and second SWPs 326 and 330 walk the vertically polarised components instead of the horizontal components as for Figure 17. Light travels within the isolator 402 in the same manner as for the isolator 370 of Figure 17 between the GRIN lenses 327 and the rotator 332, except where shown as being horizontally polarised the light is now vertically polarised and vice versa.

With reference to the first diagram 410 for light incident on the first port 322, the horizontal component aligned with the middle section 352 is rotated 45° by the rotator 332 to be polarised in the first diagonal plane 406, whereas the vertical component aligned with the lower section 354 is rotated so as to be polarised in the second diagonal plane 408. The two components are then walked by the SWP combination 404 so as to be brought together and incident on the second port 323. Light reflected from the second port returns via the same path and the rotator 332 rotates the upper first diagonal component 406 so as to be vertically polarised, and the second diagonal component 408 so as to be horizontally polarised. With reference to the third polarisation diagram 414, the rotator 332 receives an upper vertically polarised component aligned with the middle second 352, and a lower horizontally polarised component aligned with the lower section 354. The upper component is rotated so as to become polarised in the second diagonal plane 408, and the lower component is rotated so as to become polarised in the first diagonal plane 406. The SWP combination 404 then walks both components 406 a. 408 apart from one another so as to be respectively incident on the port sections 325a and 325b. Light reflected from the port sections 325a and 325b return via the same path when the SWP combination 404 walks the two components 408 and 406 towards one another and the upper component is then rotated by the rotator 332 so as to be polarised in the horizontal plane and the lower component is rotated so as to be polarised in the vertical plane.

The isolator assemblies 320, 370, 390 and 402 are all compact in line devices which do not consume a considerable amount of space and are efficient.

All of the spatial walk-off polarisers described previously can be produced from calcite which is cut in a predetermined manner to give the desired walk-off and polarisation effects. All of the half-wave plates may be cut from quartz. Faraday rotators are normally constructed from YIG, which is Yttrium based, or BIG, which is based on Bismuth substituted YIG.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. An optical isolator which passes optical signals of one wavelength band in one direction of travel and passes optical signals of another wavelength band in the opposite direction of travel.

2. An optical isolator as claimed in claim 1, wherein said isolator inhibits the passage of signals of said another wavelength band travelling in said one direction,and inhibits the passage of signals of said one wavelength band travelling in said opposite direction.

3. An optical isolator as claimed in claim 2, wherein said one wavelength band comprises first and third wavelength bands and said another wavelength band comprises a second wavelength band and said third wavelength band, and the signals of said first wavelength band of said one wavelength band are inhibited from travelling in said opposite direction and the signals of said second wavelength band of said another wavelength band are inhibited from travelling in said one direction.

4. An optical isolator as claimed in claim 3, wherein said first and second wavelength bands are communications bands and said third wavelength band is used to perform analysis on an optical system including said isolator.

5. An optical isolator as claimed in claim 1, wherein said one wavelength band comprises first and second wavelength bands and said another wavelength band comprises said second wavelength band, said isolator inhibiting the passage of signals of said first wavelength band in said opposite direction.

6. An optical isolator as claimed in claim 1 or 2, including first and second wavelength sensitive means for separating incident optical signals into first signals of said one wavelength band and second signals of said another wavelength band and for combining said first and second signals when incident thereon, and first and second isolator means between said wavelength sensitive means, said first isolator means inhibiting the passage of said first signals in said opposite direction, and said second isolator means inhibiting the passage of said second signals in said one direction.

7. An optical isolator as claimed in claim 6, further including a transmissive medium disposed between said wavelength sensitive means, wherein said wavelength sensitive means further separates said incident optical signals into third signals of a further wavelength band and combine said third signals with said first and second signals when incident thereon, said third signals being directed for passage by said transmissive medium.

8. An optical isolator as claimed in claim 6 or 7, wherein said first and second isolator means comprise a series assembly of optical polarisers, optical rotators and Faraday rotators.

9. An optical isolator as claimed in any one of claims 1 to 5, comprising:

first and second three port circulator means, a first port of the first circulator means comprising a first input/output port of the optical isolator and a first port of the second circulator means comprising a second input/output port of the optical isolator, signals of said one wavelength band being passed between a second port of the first circulator means and a third port of the second circulator means; and

optical filter means between a second port of the second circulator means and a third port of the first circulator means and which filters for said another wavelength band.

10. An optical isolator as claimed in claim 9, including a further optical filter means between said second port of said first circulator means and said third port of said second circulator means and which filters for said one wavelength band.

11. An optical isolator as claimed in any one of claims 1 to 5, including four port circulator means, a first and a third port of said circulator means forming a first input/output port and a second input/output port, respectively; and

first and second light reflecting means disposed at a second port and a fourth port, respectively, of said circulator means, said second reflecting means being wavelength selective so as to inhibit reflection of signals of said one wavelength band.

12. An optical isolator as claimed in claim 11, wherein said first reflecting means is wavelength selective so as to inhibit reflection of signals of said another wavelength band.

13. An optical isolator as claimed in claim 11 or 12, wherein said circulator means comprises a series assembly of:

first, second and third spatial walk-off polariser means;

Faraday rotator means disposed between said second and third polariser means;

a first half-wave plate arrangement between the first and second polariser means; and

a second half-wave plate arrangement between the second and third polariser means;

said first and third ports being disposed at an interface of said first polariser means, and said second and fourth ports being disposed at an interface of said third polariser means.

14. An optical isolator as claimed in claim 13, wherein said half-wave plate arrangements comprise upper, middle and lower horizontal sections and said ports are respectively aligned with said sections.

15. An optical isolator as claimed in claim 14, wherein the upper and lower sections of said half-wave plate arrangements comprise half-wave plates, and the middle sections comprise a transmissive medium.

16. An optical isolator as claimed in claim 15, wherein said Faraday rotator means is between said second half-wave plate arrangement and said third polariser means.

17. An optical isolator as claimed in claim 14, wherein said Faraday rotator means is between said second polariser means and second half-wave plate arrangement, and the upper and lower sections of said first half-wave plate arrangement and the middle section of said second half-wave plate arrangement comprise half-wave plates, and the middle section of said first half-wave plate arrangement and the upper and lower sections of said second half-wave plate arrangement comprise a transmissive medium.

18. An optical isolator as claimed in claim 15, further including a fourth spatial walk-off polariser means between said second polariser means and said second half-wave plate arrangement, said Faraday rotator means being disposed between said

second and fourth polariser means.

19. An optical isolator as claimed in claim 16, wherein said third polariser means comprises a first spatial walk-off polariser for walking light polarised in a first diagonal plane in one direction, and a second spatial walk-off polariser for walking light polarised in an orthogonal diagonal plane in a second direction.

20. An optical system comprising an amplifier and an isolator as claimed in any one of the preceding claims at an end of said amplifier.

21. An optical system as claimed in claim 20, wherein said isolator is disposed at each end of said amplifier, and the system transmits optical signals of said one wavelength band in said one direction and optical signals of said another wavelength band in said opposite direction.

22. An optical system as claimed in claim 20 or 21, wherein said amplifier comprises a rare earth doped optical fibre.

23. An optical telecommunications system including isolator means which inhibits reflections in at least one communications channel of a first wavelength band but allows signals of an additional channel of a second wavelength band to pass therethrough in both forward and reverse directions.

24. An optical telecommunications system including isolator means which inhibits reflections of optical signals in a first communications channel of a first wavelength band in one direction and inhibits reflections of optical signals in a second communications channel of a second wavelength band in the opposite direction.

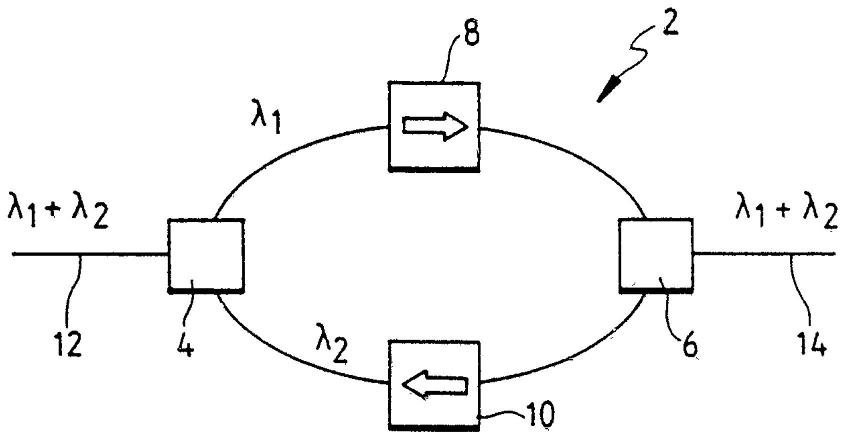
8
2
λ1
λ1 + λ2
λ1 + λ2
12
4
λ2
6
14
10

FIG 1

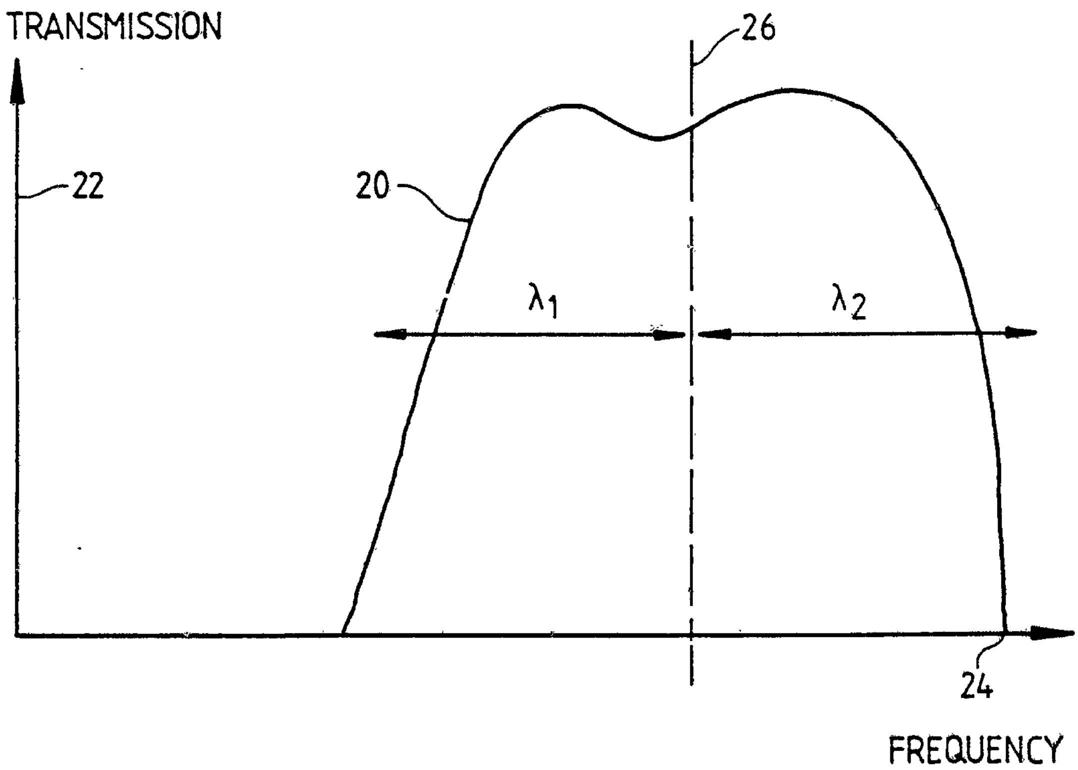
TRANSMISSION
26
22
20
λ1
λ2
24
FREQUENCY

FIG 2

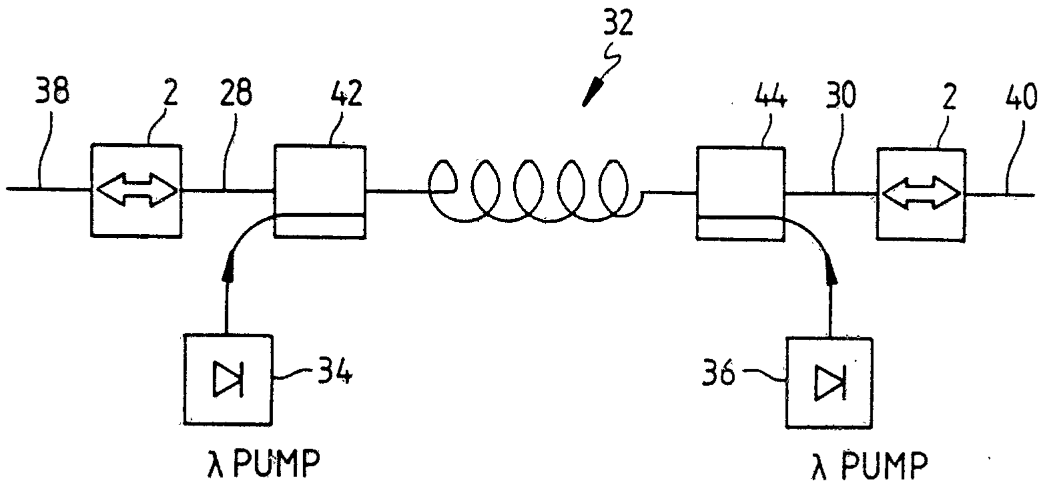

FIG 3

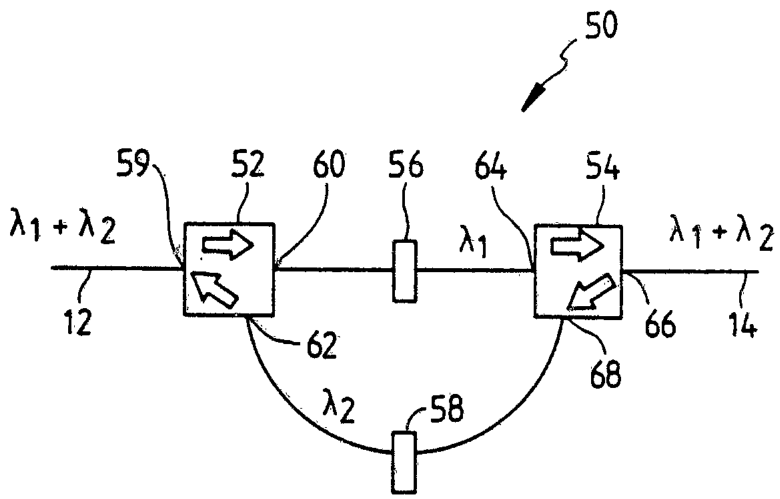

FIG 4

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FIG 5

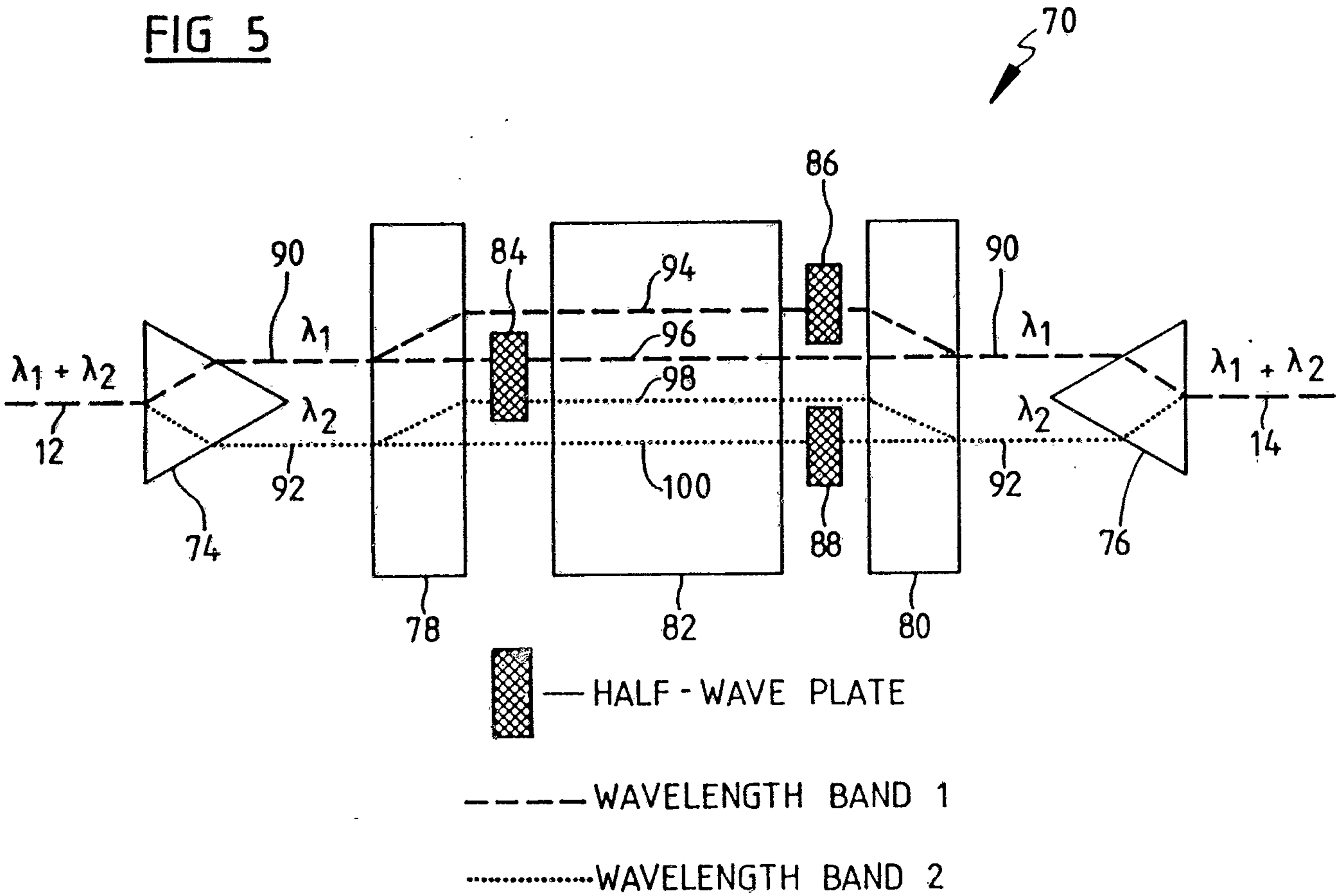
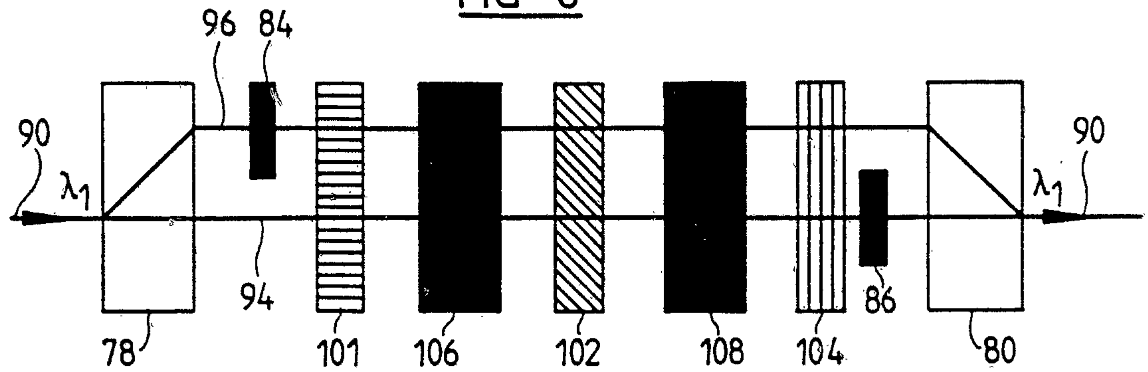

70
86
90
84
94
90
λ1
96
λ1
λ1 + λ2
98
λ1 + λ2
λ2
λ2
12
92
100
92
14
74
88
76
78
82
80
HALF - WAVE PLATE
WAVELENGTH BAND 1
WAVELENGTH BAND 2

FIG 6



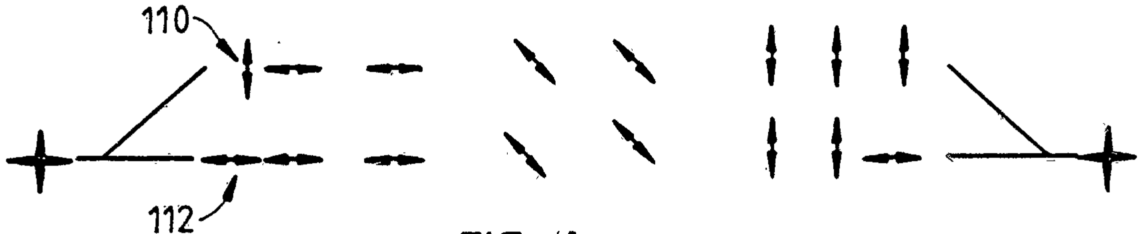


FIG 7

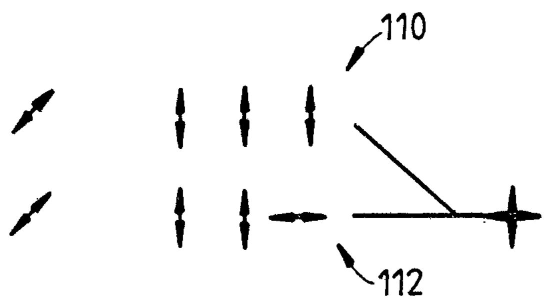


FIG 8

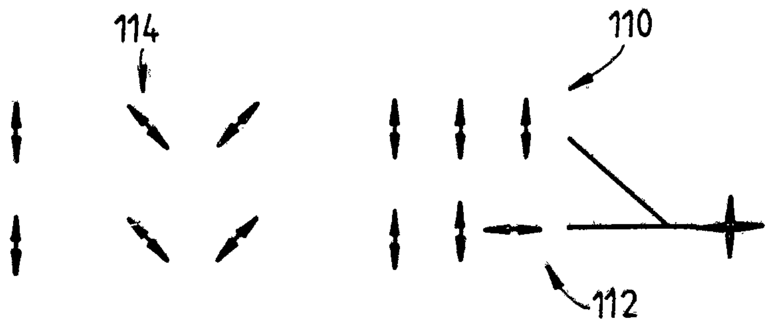


FIG 9

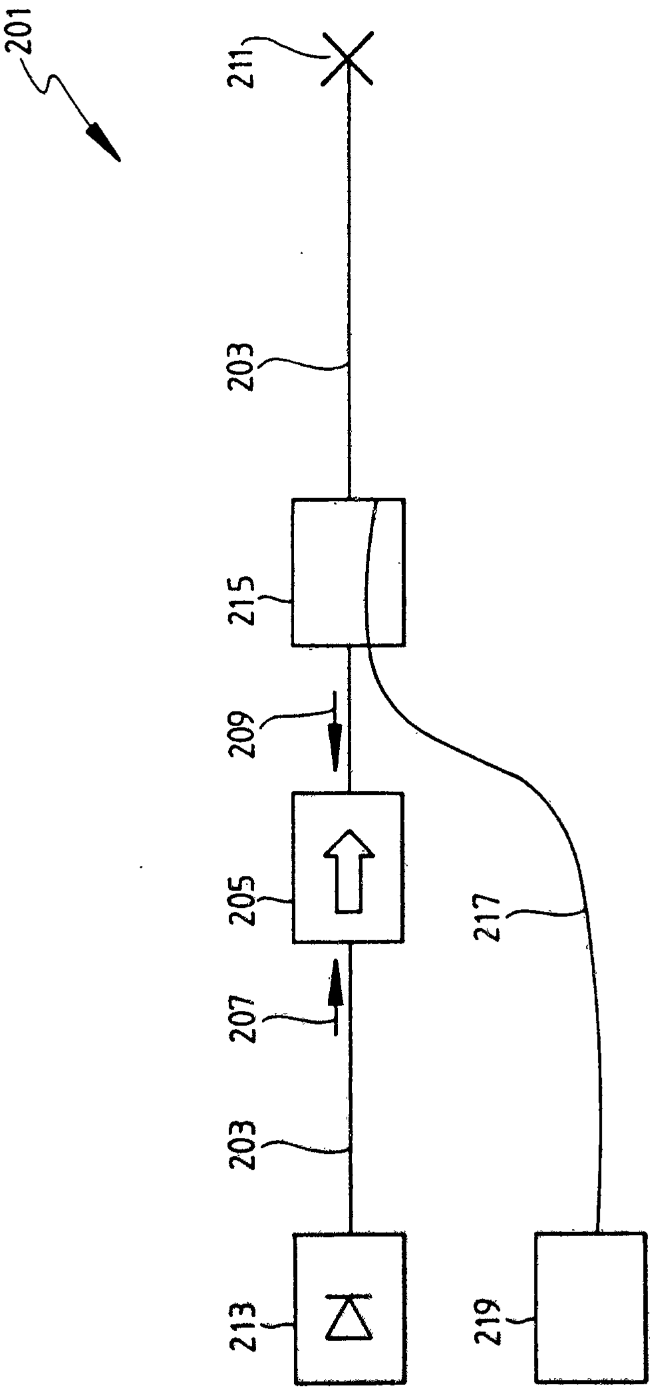


FIG 10

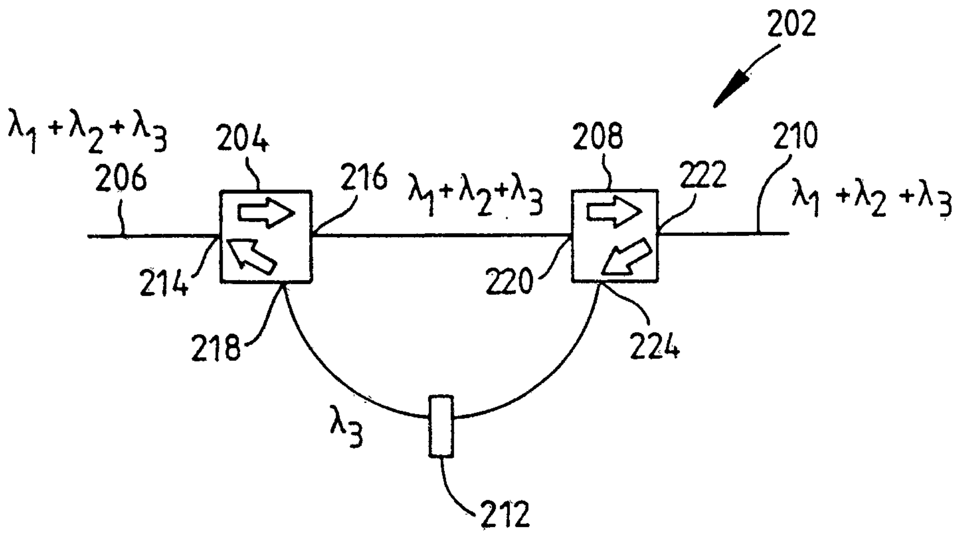

202
λ1 + λ2 + λ3
204
206
216
λ1 + λ2 + λ3
208
222
210
λ1 + λ2 + λ3
214
220
218
224
λ3
212

FIG 11

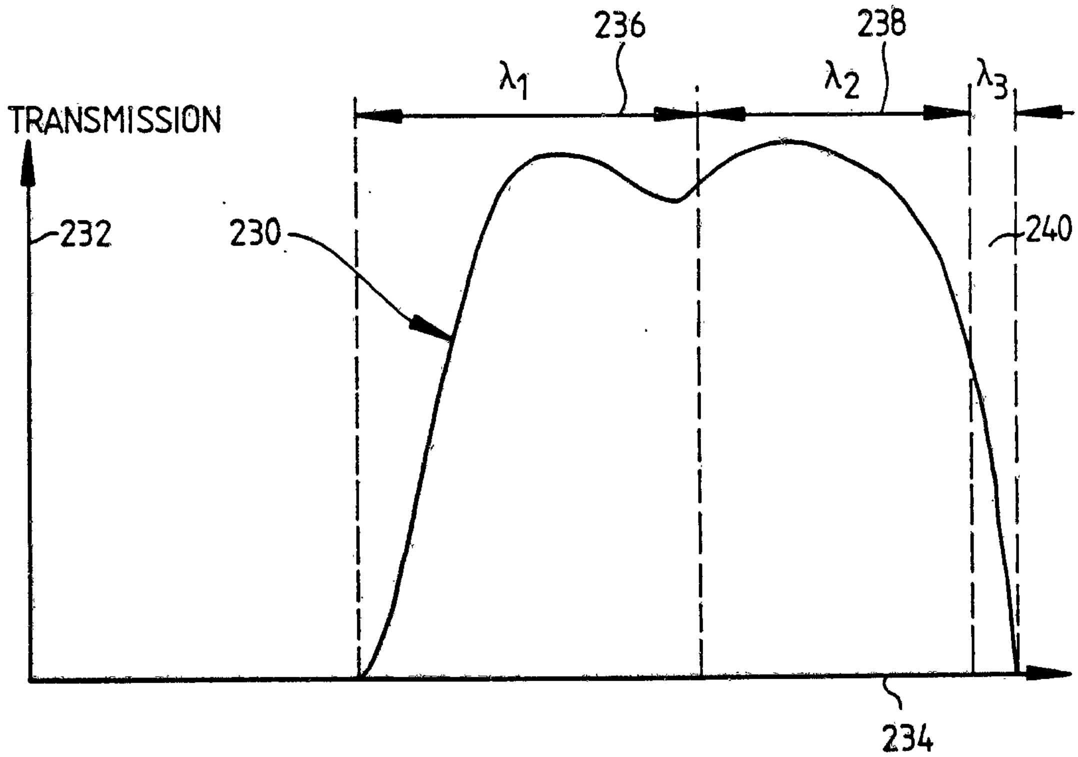

236
238
λ1
λ2
λ3
TRANSMISSION
232
230
240
234

FIG 12

42948/93

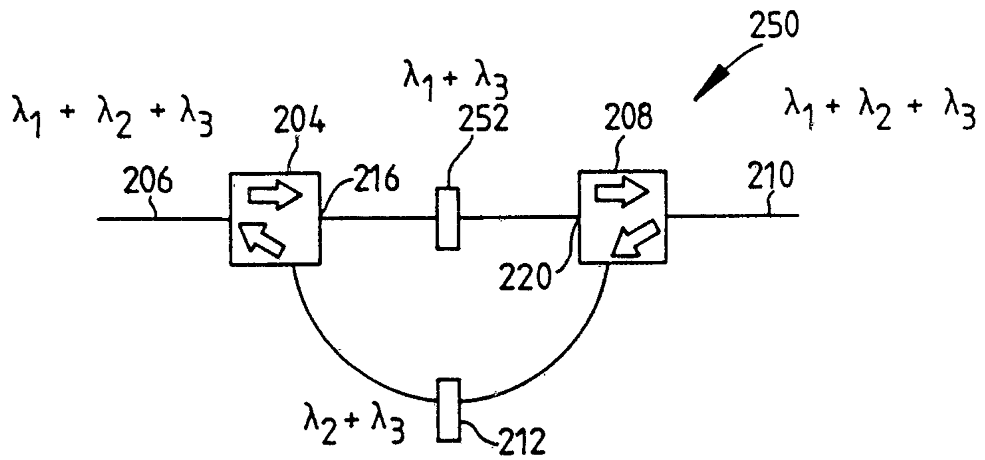
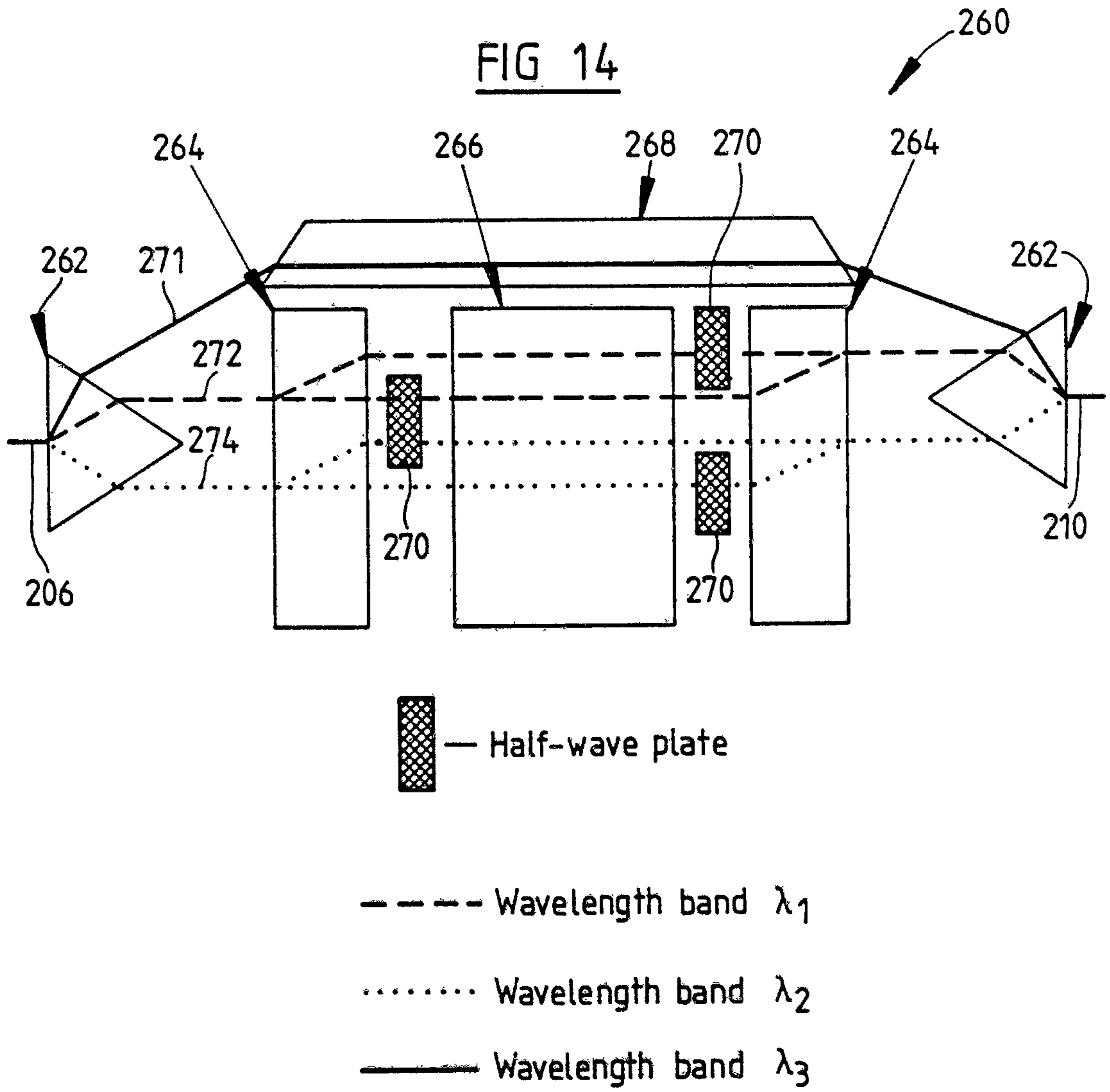


FIG 13

FIG 14



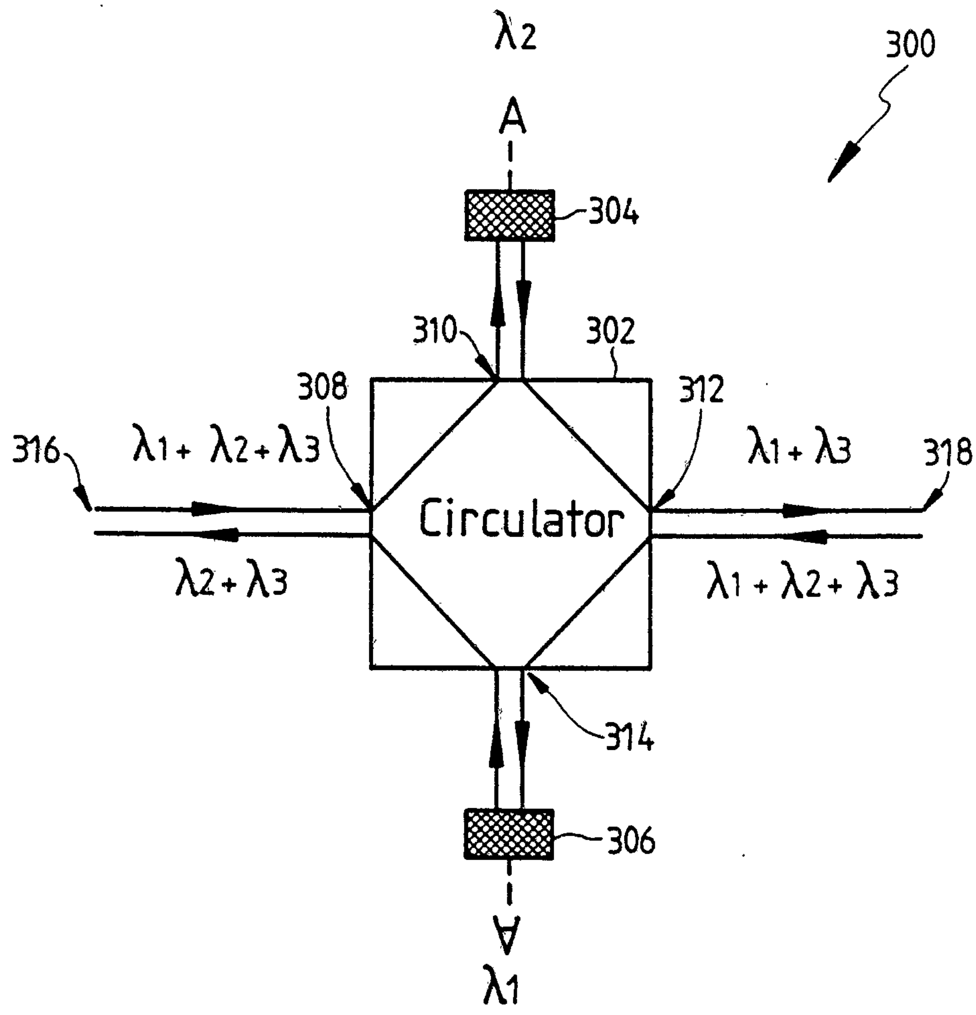

λ2
300
A
304
310
302
308
312
316
λ1 + λ2 + λ3
λ1 + λ3
318
Circulator
λ2 + λ3
λ1 + λ2 + λ3
314
306
A
λ1

FIG 15

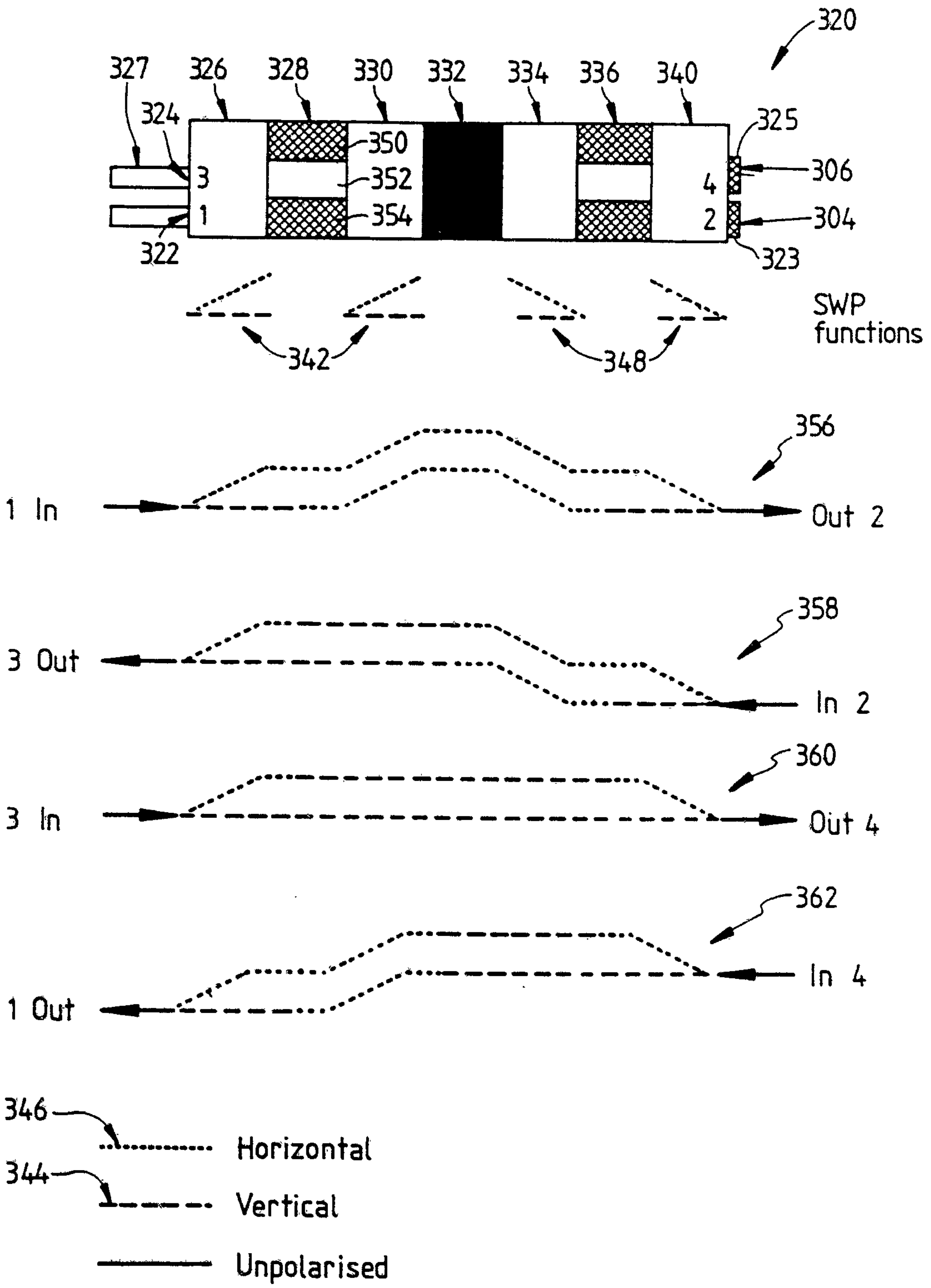

320
327
326
328
330
332
334
336
340
324
325
3
350
352
354
1
4
2
306
304
322
323
SWP functions
342
348
356
1 In
Out 2
358
3 Out
In 2
360
3 In
Out 4
362
1 Out
In 4
346
Horizontal
344
Vertical
Unpolarised

FIG 16

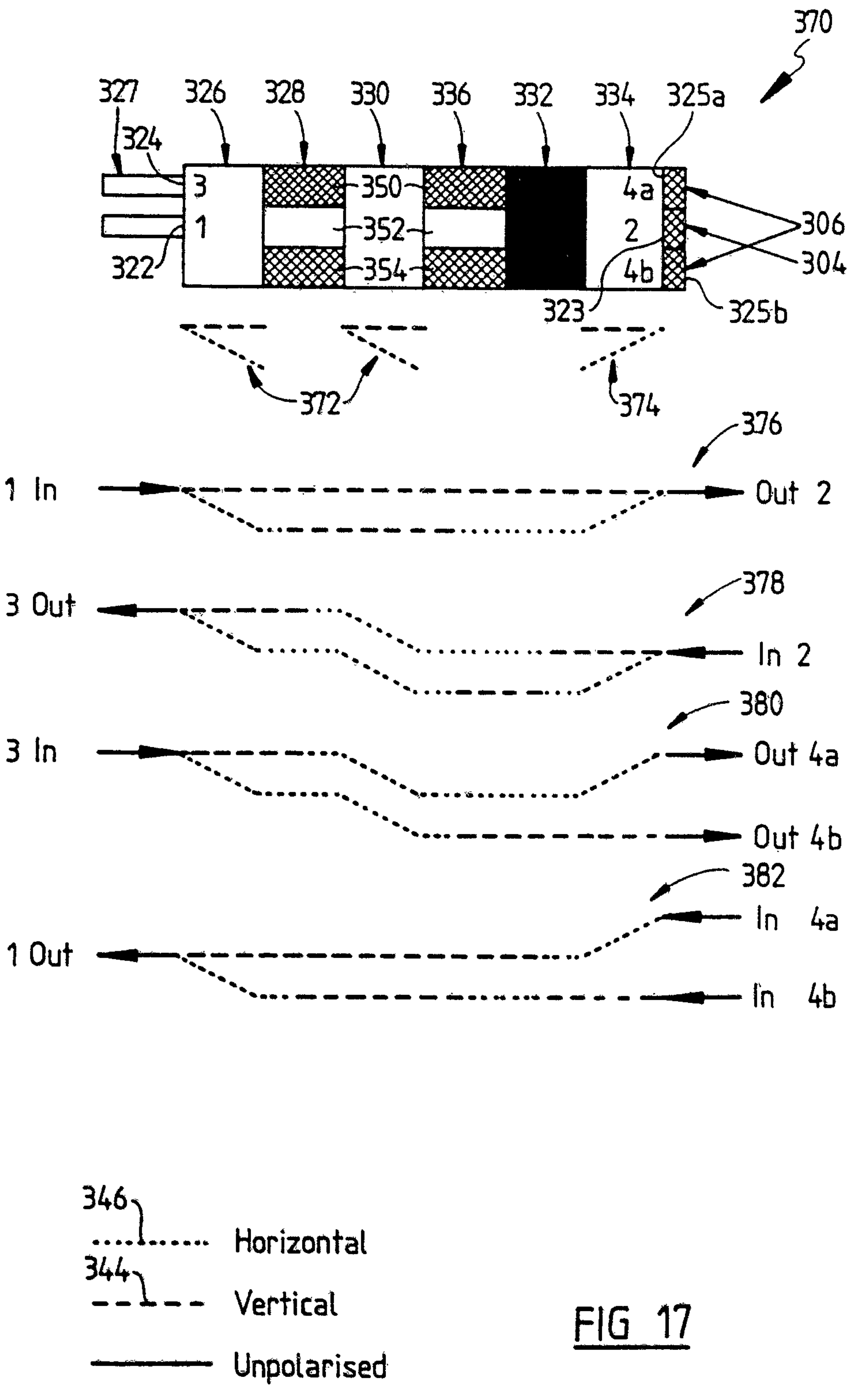

370
327
326
328
330
336
332
334
325a
324
3
1
350
352
354
4a
2
4b
306
304
322
323
325b
372
374
376
1 In
Out 2
378
3 Out
In 2
380
3 In
Out 4a
Out 4b
382
In 4a
1 Out
In 4b
346
Horizontal
344
Vertical
Unpolarised

FIG 17

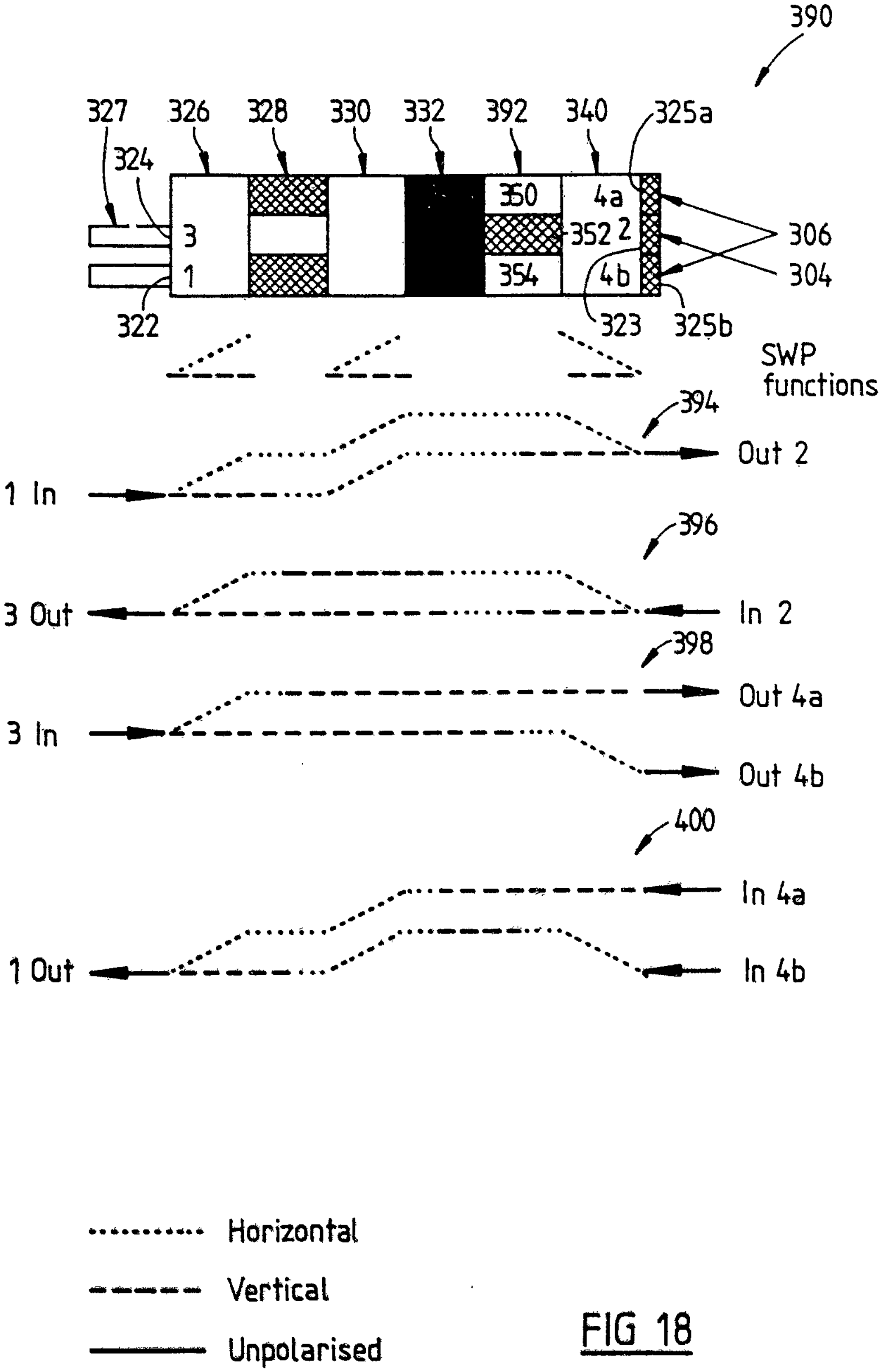

390
327
326
328
330
332
392
340
325a
324
3
1
350
4a
352
2
354
4b
306
304
322
323
325b
SWP functions
394
1 In
Out 2
396
3 Out
In 2
398
3 In
Out 4a
Out 4b
400
In 4a
1 Out
In 4b
Horizontal
Vertical
Unpolarised

FIG 18

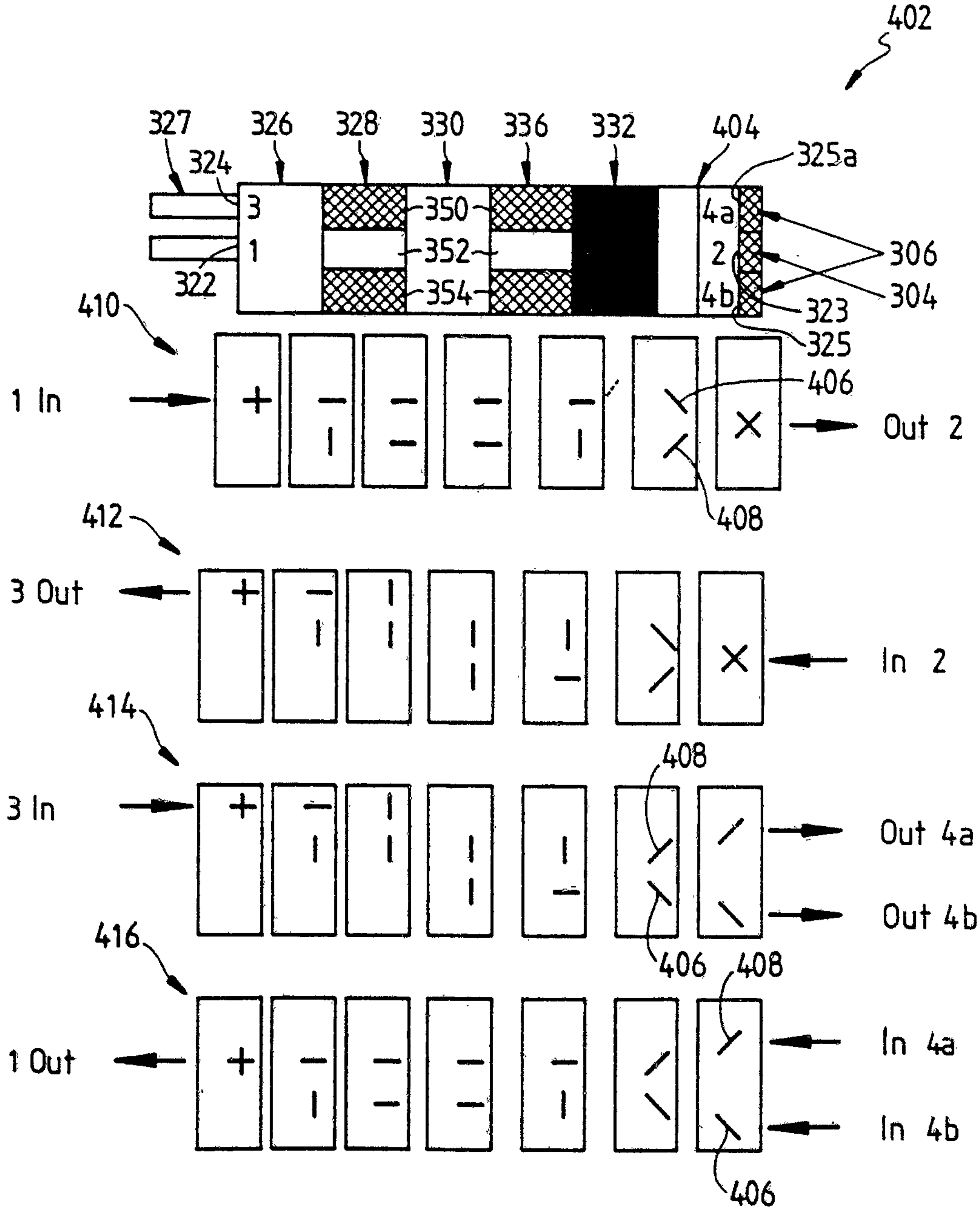


FIG 19

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU93/00258

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.[5] H04B 10/24, G02F 1/01, 1/09, 1/095, 1/21, 1/225

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 H04B 10/24, G02F 1/01, 1/09, 1/095, 1/21, 1/225

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU : IPC as above

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	AU,B, 60287/90 (627062) OKI ELECTRIC INDUSTRIES CO. LTD) 7 February 1991 (07.02.91)	
A	EP,A, 0412543 (NEC CORPORATION) 13 February 1991 (13.02.91)	
A	EP,A, 0421654 (AMERICAN TELEPHONE AND TELEGRAPH COMPANY) 10 April 1991 (10.04.91)	
A,P	EP,A, 0500157 (KONINKLIJKE PTT NEDERLAND N.V.) 26 August 1992 (26.08.92)	

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
14 July 1993 (14.07.93)	22 JULY 1993 (22.07.93)

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This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
AU	60287/90	CA US	2022690 5060301	EP	412717	JP	3067231
EP	0412543	JP	3069927	US	5031998		
EP	0421654	JP	3150524	US	5033830		
EP	0500157	CA	2061210	NL	9100292		
							END OF ANNEX