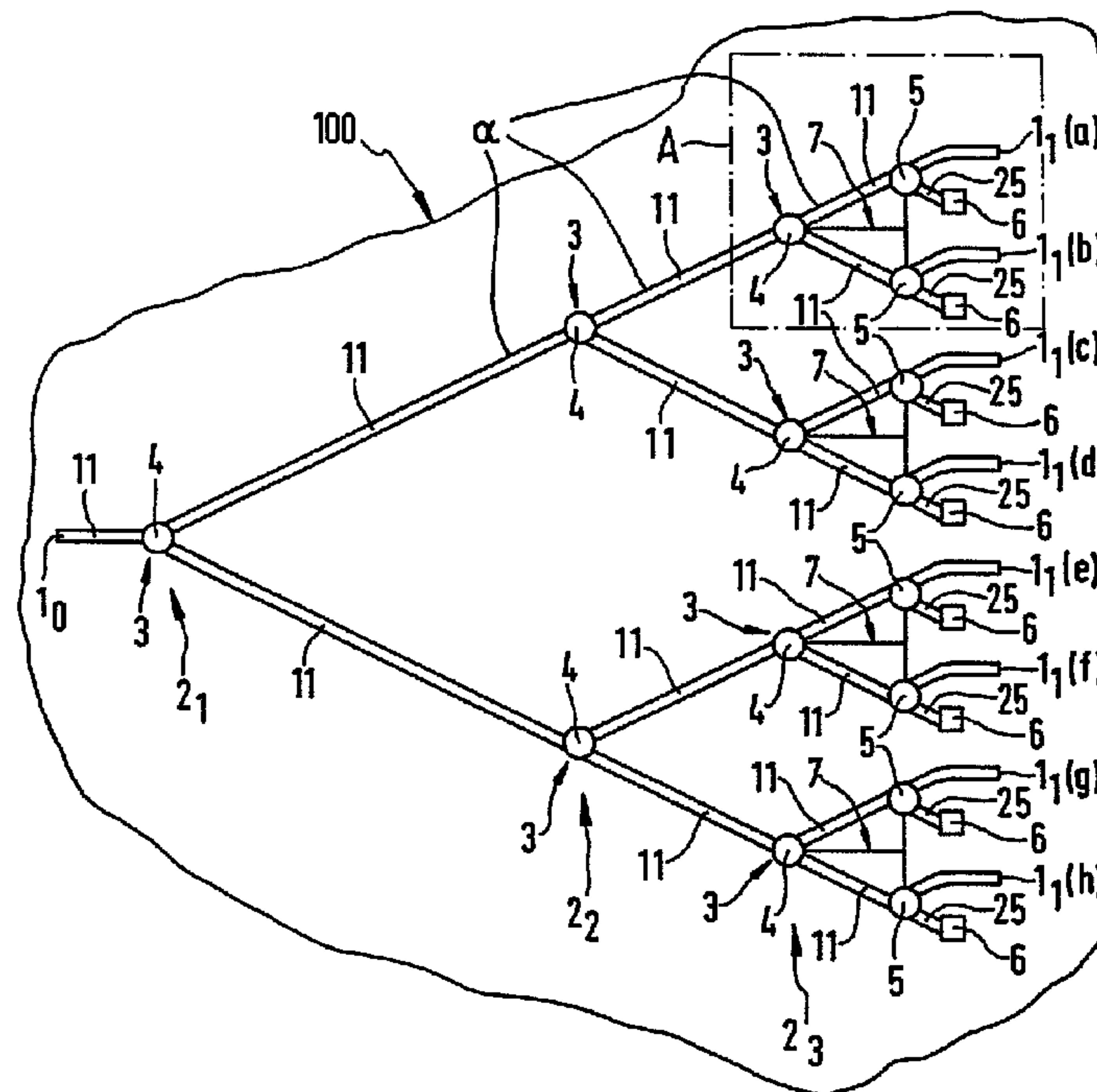




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(54) Titre : MATRICE DE COMMUTATION OPTIQUE 1XN ET NXN ARBORESCENTE
(54) Title: OPTICAL 1XN AND NXN SWITCHING MATRIX HAVING A TREE STRUCTURE



(57) Abrégé/Abstract:

Optical 1×N and N×N switching matrix having a tree structure. In the case of 1×N switching matrices having a tree structure, in which an optical input (1₀) is connected to N outputs (1₁) by means of an optical waveguide structure (1) which branches like a tree, and in which an optical changeover switch (4) is arranged in each junction point (3) of the waveguide structure, it is intended to improve the crosstalk suppression. To this end, in each case one gate switch (5) is assigned to each output (1₁) for optional release and blocking of this output (1₁) as a function of a switching state of the changeover switch (4) of a junction point (3) from which a branching waveguide (11) is connected to this output (1₁). An N×N switching matrix, which is also described, having greatly improved crosstalk suppression can be obtained with such 1×N switching matrices. For use in optical communications networks, for example telecommunications networks.



Abstract

1. Optical $1 \times N$ and $N \times N$ switching matrix having a tree structure.

2.1 In the case of $1 \times N$ switching matrices having a tree structure, in which an optical input (1_0) is connected to N outputs (1_1) by means of an optical waveguide structure (1) which branches like a tree, and in which an optical changeover switch (4) is arranged in each junction point (3) of the waveguide structure, it is intended to improve the crosstalk suppression.

2.2 To this end, in each case one gate switch (5) is assigned to each output (1_1) for optional release and blocking of this output (1_1) as a function of a switching state of the changeover switch (4) of a junction point (3) from which a branching waveguide (11) is connected to this output (1_1). An $N \times N$ switching matrix, which is also described, having greatly improved crosstalk suppression can be obtained with such $1 \times N$ switching matrices.

2.3 For use in optical communications networks, for example telecommunications networks.

3. Figure 1

20365-3663

-1-

Description

Optical 1xN and NxN switching matrix having a tree structure

The invention relates to an optical 1xN and NxN switching matrix having a tree structure, as claimed in the precharacterizing clause of patent claim 1 or 14, respectively.

Such switching matrices are generally known.

Optical switching matrices are key components of future optical communications networks. They enable the optical data stream to be directed in a flexible manner between different optical glass fibers or other optical waveguides without any limitation of the data rate.

Solid-state switching matrices which are integrated on a substrate are particularly compact and promise cost advantages over currently available electromechanical components (available, for example, from JDS FITELE, ASTARTE, OptiVideo, BT&D). Such solid-state switching matrices have been implemented on substrates composed, for example, of LiNbO₃ (see P. J. Duthie, M. J. Wale "16x16 single chip optical switch array in Lithium Niobate", Electron. Lett., Vol. 27, pages 1265-1266, 1991), silicon (see R. Nagase, A. Himeno, K. Kato, O. Okuno "Silica-based 8x8 optical-matrix-switch module with hybrid integrated driving circuits", ECOC '93, Montreux, Paper MoP1.2, pages 17-20) or III-V semiconductors (see K. Komatsu, K. Hamamoto, M. Sugimoto, A. Ajisawy, Y. Kohga, A. Suzuki "4x4GaAs/AlGaAs optical matrix switches with uniform device characteristics using alternating $\Delta\beta$ electrooptic wave directional couplers", J.Lightwave Technol., Vol. LT-9, pages 871-878, 1991 and L. Stoll, G. Müller, M. Honsberg, M. Schienle, S. Eichinger, U. Wolff "4x4 optical switch matrix on InP with low switching current", AEÜ, Vol. 46, pages 116-118).

20365-3663

-2-

The invention is based on the object of providing switching matrices of the said type having crosstalk suppression which is greater than that of the known switching matrices of this type.

5 This object is achieved by the features specified in the characterizing part of patent claims 1 and 14.

Preferred and advantageous refinements of the switching matrices according to the invention emerge from subclaims 2 to 13 and 15 to 27.

10 Because of their high level of crosstalk suppression, the optical NxN switching matrices according to the invention can be used particularly advantageously in optical networks, in particular public optical networks, for example telecommunications networks, in which a high level
15 of crosstalk suppression is essential for operation.

In accordance with this invention, there is provided an optical 1xN switching matrix having a tree structure with an optical input/output and a number N of optical outputs/inputs comprising: an optical waveguide
20 structure which connects the input/output to each output/input and which is composed of optical waveguides which branch in a tree configuration from the input/output in a direction of the outputs/inputs at junction points; a plurality of optical changeover switches, an optical
25 changeover switch per junction point, respectively, for optionally switching over between waveguides which branch off from the junction point; an optical gate switch assigned to at least one respective output/input of the optical outputs/inputs for optional optical release and blocking of
30 the respective output/input as a function of a switching state of a changeover switch of a junction point from which

20365-3663

-2a-

one branching waveguide is connected to the respective output/input.

In accordance with this invention, there is further provided an optical $N \times N$ switching matrix having a tree structure with a number N of optical inputs and a number N of optical outputs, comprising: two matrix rows, each having N optical $1 \times N$ switching matrices, each $1 \times N$ switching matrix having one optical input/output and N optical outputs/inputs; an optical switching network having two connection rows each row having $N \times N$ optical connections, each of which is used as an optical input and/or output, each connection in one connection row being optically connectable to each connection in the other connection row; a total of $N \times N$ optical outputs/inputs of the N optical $1 \times N$ switching matrices in each matrix row being connected in parallel to the $N \times N$ optical connections of in each case one connection row; and a total of N optical inputs/outputs of the N optical $1 \times N$ switching matrices of each matrix row forming the N inputs and/or N outputs of the $N \times N$ switching matrix; at least one optical $1 \times N$ switching matrix being a $1 \times N$ switching matrix having a tree structure with an optical input/output and a number N of optical outputs/inputs; the optical $1 \times N$ switching matrix having an optical waveguide structure which connects the input/output to each output/input and which is composed of optical waveguides which branch in a tree configuration from the input/output in a direction of the outputs/inputs at junction points; the optical $1 \times N$ switching matrix having a plurality of optical changeover switches, an optical changeover switch per junction point, respectively, for optionally switching over between waveguides which branch off from the junction point; the optical $1 \times N$ switching matrix having an optical gate switch assigned to at least one respective output/input of

20365-3663

-2b-

the optical outputs/inputs for optional optical release and blocking of the respective output/input as a function of a switching state of a changeover switch of a junction point from which one branching waveguide is connected to the
5 respective output/input.

The invention will be explained in more detail in the following description using the figures by way of example, in which:

Figure 1 shows, as a schematic illustration, a
10 plan view of a 1xN switching matrix according to the invention,

Figures 2a to 2f show, as a schematic illustration, plan views of different implementations of the changeover and gate switch which is contained in the detail
15 A in Figure 1 as a detailed illustration,

Figure 3 shows, as a schematic illustration, a plan view of an NxN switching matrix according to the invention which is implemented using 1xN switching matrices according to the invention, and

20 Figure 4 shows, as a schematic illustration, a plan view of a conventional 1xN switching matrix which is the basis of the switching matrix according to the invention in Figure 1.

The figures are not to scale.

The optical $1 \times N$ switching matrix according to the invention has an input 1_0 and $N = 2^n$, $n = 1, 2, 3 \dots$ outputs 1_1 as well as a waveguide structure which is generally designated 1, comprises a number of $2^0 + 2^1 + \dots + 2^n$ optical waveguides 11 which branch at $N - 1$ junction points 3 like a tree, and which waveguide structure connects the input 1_0 to each of the outputs 1_1 .

The number n which, as indicated, is any desired integer ≥ 1 indicates the number of junction stages 2_j , where $j = 1$ to n , which follow one another from the input 1_0 in the direction 9 to the outputs 1_1 . Specifically, in the illustrated exemplary embodiment, n is chosen to be 3, that is to say $N = 2^3 = 8$, so that the number of junction points 3 is equal to 7 and the number of waveguides 11 which branch like a tree is equal to 15.

According to Figure 1, a waveguide 10 leads from the input 1_0 to a junction point 3 which forms the first junction stage 2_1 . Two waveguides 11 branch off from this junction point 3 and lead to in each case one of the two junction points 3 in the second junction stage 2_2 .

In each case two, that is to say a total of four, waveguides 11 branch off from each of the two junction points 3 in the second junction stage 2_2 and lead to in each case one of the total of four junction points 3 in the third and, in this example last, junction stage 2_3 .

In each case two, that is to say a total of eight, waveguides 11 branch off from each of the four junction points 3 in the third junction stage 2_3 and lead to in each case one of the total of eight outputs 1_1 in this example.

One optical switch 4 is provided in each case per junction point 3 for optionally switching over between the waveguides 11 which branch off from this junction point 3.

5 Switching over between the waveguides 11 which branch off from a junction point 3 means that the changeover switch 4 at this junction point 3 in one switching state releases the optical path to one of these branching waveguides 11 and blocks the optical path to
10 the other waveguide 11 and, in another switching state, releases the optical path to the other branching waveguide 11 and blocks the optical path to the one branching waveguide 11.

 For example, in one switching state of the
15 changeover switch 4 at the junction point 3 of the first junction stage 2_1 , a light signal which is supplied to this junction point 3 from the input 1_0 through the waveguide 10 passes only into one waveguide 11, for example the upper of the two waveguides 11 which branch
20 off from this junction point 3, but not into the lower branching waveguide 11. In the upper waveguide 11, the light signal is passed on to the upper junction point 3, which is connected to this waveguide 11, in the second junction stage 2_2 , but not into the lower waveguide 11.

25 When the changeover switch 4 at this junction point 3 is in the other switching state, the light signal passes only into the lower branching waveguide 11, in which it is passed on to the lower junction point 3 in the second junction stage 2_2 , but not into the upper
30 branching waveguide 11.

 The statement made with regard to the junction point 3 in the first junction stage 2_1 likewise applies to each junction point 3 in all the other junction stages 2_2 , 2_3 etc.

35 In practice, the changeover switches 4 are not sufficiently ideal that no element of the light signal which is supplied to the junction point 3 of this changeover switch 4

passes into the blocked branching waveguide 11, but a small proportion of this light signal, which causes crosstalk, also passes into this blocked branching waveguide 11.

5 In order to suppress the crosstalk effect with respect to an output 1_1 of the switching matrix to the optical path which is currently not carrying light, an optical gate switch 5 is assigned, according to the invention, to this output 1_1 for optional optical release
10 and blocking of this output 1_1 as a function of a switching state of the changeover switch 4 of a junction point 3 from which a branching waveguide 11 leads to this output 1_1 .

 Since each output 1_1 of the switching matrix may
15 be an output leading to the optical path which is currently not carrying light, it is expedient to assign in each case one such gate switch 5 to each output 1_1 of the switching matrix, by means of which gate switch 5 the crosstalk can be suppressed if required.

20 The switching matrix according to Figure 1 is an example of this case. In this switching matrix, two waveguides 11, each of which leads to in each case one of the outputs 1_1 , in each case branches off from each junction point 3 in the last junction stage 2_3 .

25 A gate switch 5 is in each case arranged in each of these waveguides 11 which branch off from the junction points 3 in the last junction stage 2_3 and, in one switching state, releases or blocks this waveguide 11, that is to say allows or does not allow a light signal,
30 which is carried in this branching waveguide 11, to pass to the output 1_1 to which this gate switch 5 is assigned.

 A changeover switch 4 at a junction point 3 in the last junction stage 2_3 from which a branching waveguide 11 leads to an output 1_1 to which a gate
35 switch 5 is assigned, and this gate switch 5 itself, advantageously comprise

an electrically controllable optoelectronic switch having a control electrode arrangement 54 to which [sic] electrical control signals for switching this switch 5 between at least two switching states, the gate switch 5, in one switching state, releasing the output 1_1 to which it is assigned, and the changeover switch 4 releasing the branching waveguide 11 which leads to this output 1_1 and, in the other switching state, the changeover switch 4 blocking the branching waveguide 11 which leads to this output 1_1 , and the gate switch 5 blocking this output 1_1 .

In the example according to Figure 1 this means, for example, for the topmost junction point 3 in the third junction stage 2₃ and the two outputs 1_1 which are located one above the other and to which the two waveguides 11 branch off from this topmost junction point 3 that

- the changeover switch 4 of this topmost junction point 3, in one switching state, is connected to the upper waveguide 11 which leads to the upper output 1_1 , and releases this waveguide 11 and blocks the lower waveguide 11 which leads to the lower output 1_1 , while, at the same time, the gate switch 5 which is assigned to the upper output 1_1 and is arranged in the upper branching waveguide 11, releases this upper output 1_1 , and the gate switch 5, which is assigned to the lower output 1_1 and is arranged in the lower branching waveguide 11, blocks this lower output 1_1 , and that

- in the other switching state the changeover switch 4 is connected to the lower waveguide 11 which leads to the lower output 1_1 and releases this lower waveguide 11 and blocks the upper waveguide 11 which leads to the upper output 1_1 , while, at the same time, the gate switch 5 which is assigned to the lower output 1_1 and is arranged in the lower waveguide 11 releases this lower output 1_1 and the gate switch 5, which is assigned to the upper output 1_1 and is arranged in the upper branching waveguide 11, blocks this upper output 1_1 .

This means, in particular, that a gate switch 5 always releases the output 1_1 assigned to it when the changeover switch 4 at the relevant junction point 3 is switched to the branching waveguide 11 which leads to this output 1_1 , and a gate switch 5 always blocks the output 1_1 assigned to it when the changeover switch 4 at the relevant junction point 3 blocks the branching waveguide 11 which leads to this output 1_1 .

Since the switching states of the gate switch 5 which is assigned to an output 1_1 are predetermined by the switching states of the changeover switch 4 of the relevant junction point 3 of the last junction stage 2_3 , additional control lines to the waveguide structure 1 are unnecessary, but a control electrode arrangement 54 of a gate switch 5 and a control electrode arrangement 54 of a changeover switch 4 can be electrically conductively connected to one another by means of an electrical lead arrangement 7, as a result of which the electrical control complexity of a switching matrix according to the invention is not greater than that of a conventional switching matrix. In addition, the electrical lead arrangement 7 can advantageously be integrated, together with the waveguide structure 1, on a substrate 100.

The changeover switch 4 and gate switch 5 may consist of different types of optical switch. Figures 2a to 2f show various examples with reference to the topmost junction point 3 of the last junction stage 2_3 in Figure 1, these figures showing an enlarged illustration of the detail A in Figure 1.

These examples can also be used in the same manner for every other junction point 3 in the last junction stage 2_3 and, in particular, for every junction point in the last junction stage of every other $1 \times N$ switching matrix according to the invention.

In the example according to Figure 2a, the changeover switch 4 which is arranged at the junction point 3 comprises a switch having more than two switching states, which

- 5 - in one switching state, is connected to the upper branching waveguide 11 which branches off from the junction point 3 and leads to the upper output 1_1 , and blocks the lower waveguide 11 which branches off from this junction point 3 and leads to the lower output 1_1 , in another switching state in contrast, is connected to the lower branching waveguide 11 and blocks the upper branching waveguide 11, and
- 10 - in a further switching state, is connected in such a manner that both the upper and the lower branching waveguides 11 are blocked at the same time.

The gate switch 5 which is assigned to the upper output 1_1 is arranged in the upper branching waveguide 11 which leads to this output 1_1 , and the gate switch 5 which is assigned to the lower output 1_1 is arranged in the lower branching waveguide 11 which leads to this output 1_1 , and each consists of an on and off switch which optionally releases or blocks the relevant waveguide 11.

The changeover switch 4 may consist, for example, of a known TIC switch (see B. Acklin, M. Schienle, B. Weiss, L. Stoll, G. Müller "Novel optical switches based on carrier injection in three and five waveguide couplers: TIC and SIC" Electron. Lett., 1994, Vol. 30, No. 3, page 217). According to this, the changeover switch 4 is in principle designed such that an end section 110 of the waveguide 11 which branches off from the upper junction point 3 of the second junction stage 2₂ and leads to the topmost junction point 3 of the third junction stage 2₃, and opposite end sections 111 of the waveguides 11 which branch off from the topmost junction point 3 are arranged on both sides of the end section 110 of the waveguide 11 which leads to the topmost junction point 3, at such a short distance from this waveguide 11 that an

optical signal which passes in this waveguide 11 to its end section 110 is coupled over from this end section 110 into one or the other branching waveguide 11, depending on how the electrodes 541 and 542 of the control electrode arrangement 54 of this changeover switch 4, which are located above the end sections 111 of these branching waveguides 11, are electrically connected.

The gate switch 5, which is designed as an on and off switch, of each of the two waveguides 11 which branch off from the topmost junction point 3 has a control electrode arrangement 54 in the form of an individual control electrode 540 which extends over a section 112 of this branching waveguide 11 and influences the material, which is located underneath, of the branching waveguide 11, depending on the switching state, in such a manner that an optical signal which is supplied from the end section 111 of this branching waveguide 11 is either passed through or is absorbed. At the same time, the signal which is passed through can also be optically intensified. The absorption which causes blocking of the relevant branching waveguide 11 can also be replaced by the signal which is being carried being radiated out laterally from this waveguide 11, in the longitudinal section 112.

The electrical lead arrangement 7 connects an electrode 541 of the switch 4 through an electrical lead 71 to the electrode 540 of the gate switch 5 which is arranged in the upper branching waveguide 11, and connects the other electrode 541 of the changeover switch 4 through an electrical lead 72 to the electrode 540 of the gate switch 5 which is arranged in the lower branching waveguide 11.

In one switching state, a voltage U_1 is applied to one electrode 541 of the changeover switch 4 and that electrode 540 of a gate switch 5 which is connected to this electrode 541, and another voltage U_2 is applied to the other electrode 541 of the changeover switch 4 and to that

electrode 540 of the other gate switch 5 which is connected to this other electrode 541.

These two voltages U_1 and U_2 result, for example, in an optical signal which is supplied to the changeover switch 4 being coupled over into the upper branching waveguide 11 and being passed through from the gate switch 5, which is arranged in this waveguide 11, to the upper output 1_1 , while, in the lower branching waveguide 11, an undesirable small element of this signal is always coupled over into this lower branching waveguide 11 and is blocked by the gate switch 5 which is arranged in this lower branching waveguide 11, so that this element does not reach the lower output 1_1 .

If, conversely, the voltage U_1 is applied to the other electrode 541 of the changeover switch 4 and to the electrode 540, which is connected by the lead 72 to this other electrode 541, of the gate switch 5 which is arranged in the lower waveguide 11, and the voltage U_2 is applied to one electrode 541 of the changeover switch 4 and to the electrode 540, which is connected to this electrode 541, of the gate switch 5 which is arranged in the upper waveguide 11, the relationships are precisely reversed, that is to say the optical signal which is supplied is coupled over into the lower branching waveguide 11 and is passed through by the gate switch 5, which is arranged in this waveguide 11, to the lower output 1_1 , while an undesirable element of this signal is always coupled over into the upper branching waveguide 11 and is blocked by the gate switch 5 which is arranged in this upper waveguide 11, so that this element does not reach the upper output 1_1 .

The examples according to Figures 2b to 2f differ from the example according to Figure 2a essentially in that each gate switch 5 consists of a changeover switch for optionally switching over between the branching waveguide 11, in which this gate switch 5 is arranged, and of a

waveguide 25, which branches off from this waveguide 11 in an additional junction point 30 and leads to an optical sump 6.

5 In the example according to Figure 2b, the changeover switch 4 which is arranged in the junction point 3 is structurally identical to the changeover switch 4 according to Figure 2a, but each gate switch 5 is, in contrast, a changeover switch in the form of a controllable optical directional coupler, which is
10 generally known.

The directional coupler of the upper or lower branching waveguide 11 which leads from the junction point 3 to the upper or lower output 1_1 , respectively, is formed in such a manner that an end section 251 of the
15 waveguide 25, which branches off from this upper or lower branching waveguide 11, respectively, is arranged at such a short distance from the upper or lower branching waveguide 11, respectively, in the additional junction point 30 that optical power can be coupled over between
20 this end section 251 and the upper or lower branching waveguide 11, respectively, it being possible to control this coupling over in a known manner by means of a control electrode arrangement 54, in such a manner that an optical signal which is carried in the upper or lower
25 branching waveguide 11, respectively, is either passed on in this waveguide 11 to the upper or lower output 1_1 , respectively, and is not coupled over into the waveguide 25 which leads to the optical sump 6, or is coupled over into the waveguide 25 which leads to the optical sump 6
30 and is not passed on in the upper or lower branching waveguide 11, respectively, to the upper or lower output 1_1 , respectively. Any radiation which is coupled over into the waveguide 25 which leads to the optical sump 6 is rendered harmless in the optical sump 6.

35 The control electrode arrangement 54 may, for example, consist of an electrode 543 which branches off above the upper or lower branching waveguide 11, respectively, or the waveguide 25 which branches off from this waveguide 11 and leads to the optical sump 6, and is

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94 P 1658

- 11a -

arranged in the region of the

end section 251 of the waveguide 25.

5 In the example according to Figure 2b, such an electrode 543 is in each case provided above the end section 251 of the waveguide 25 which leads to the optical sump 6. An electrical lead arrangement 7 has an electrical lead 74 which connect the electrode 543, via the end section 251 of the waveguide 25 which branches off from the upper branching waveguide 11, to the electrode 542 which is arranged above the end section 111, which is located in the junction point 3, of the lower branching waveguide 11, while the electrode 543 is connected via the end section 251 of the waveguide 25, which branches off from the lower branching waveguide 11, to the electrode 541, which is arranged above the end section 111, which is located in the junction point 3, of the upper branching waveguide 11, by means of an electrical lead 73 in the lead arrangement.

15 As a result of this type of electrical connection of the electrodes 541, 542 and 543, it is possible, in a similar manner to that in the example according to Figure 2a

- by application of a voltage difference of one polarity between the lead 73 and the lead 74, to achieve the switching state in which the optical signal, which is carried in the supplying waveguide 11 to the junction point 3, is coupled over into the upper branching waveguide 11 and is supplied to the upper output 1₁, while, at the same time, an undesirable element of this supplied signal, which is coupled over into the lower branching waveguide 11, is coupled over into the waveguide 25 which branches off from this lower branching waveguide 11 and is rendered harmless in the sump 6 which is connected to this waveguide 25, and
- 35 - by application of a voltage difference of the opposite polarity between the lead 73 and the lead 74, to achieve the other switching state, in which the optical signal which is supplied to the junction point 3 is coupled over into the lower

branching waveguide 11 and is supplied to the lower output 1_1 , while, at the same time, an element of this supplied signal which is coupled over into the upper branching waveguide 11 is coupled over into the waveguide 25, which branches off from this upper branching waveguide 11, and is rendered harmless in the optical sump 6 which is connected to this waveguide 25.

The examples according to Figures 2a and 2b differ from the examples 2c to 2f described in the following text in that the changeover switch 4 which is arranged in the junction point 3 has a different structure than the two gate switches 5.

In contrast to this, in the examples according to Figures 2c to 2f, the changeover switch 4 which is arranged in the junction point 3 and the gate switches 5 which are likewise designed as changeover switches are advantageously and essentially of the same design.

In the example according to Figure 2c, the changeover switch 4 which is arranged in the junction point 3, like the examples according to Figures 2a and 2b, comprises a changeover switch having more than two switching states. Furthermore, each gate switch 5 is a changeover switch like the changeover switch 4, for example a TIC switch.

In the example according to Figure 2c, both the upper branching waveguide 11 which leads from the junction point 3 to the upper output 1_1 and the lower branching waveguide 11 which leads from the junction point 3 to the lower output 1_1 are split into in each case one first waveguide section 11_1 and in each case one second waveguide section 11_2 , which is separated from the first waveguide section.

The first waveguide section 11_1 of each branching waveguide 11 has, on the one hand, an end section 111 which is located in the junction point 3 and forms the end section 111

of the changeover switch 4 according to Figure 2a and, on the other hand, has an opposite end section 110, which corresponds to the end section 110 in the changeover switch 4 according to Figure 2a.

5 The second section 11₂ of each branching waveguide 11 has, on the one hand, an end section 111 which is arranged at a short distance from the end section 110 of the first waveguide section 11₁ of this branching waveguide 11 and corresponds to the end section
10 111 in the changeover switch 4 according to Figure 2a, and is, on the other hand, connected to the output 1₁ to which this branching waveguide 11 leads.

 An end section 111 of a waveguide 25 is arranged a short distance away on that side of the end section 110
15 of the first section 11₁ of this branching waveguide which faces away from the second waveguide section 11₂ of each branching waveguide 11, and this end section 111 corresponds to the end section 111 in the changeover switch 4 according to Figure 2a, forms the waveguide
20 which branches off from this branching waveguide 11 in the additional junction point 30, and leads to an optical sump 6.

 The end section 110 of the first waveguide section 11₁ of each branching waveguide 11, and the
25 adjacent end sections 111 of the second waveguide section 11₂ of this branching waveguide 11 and of the waveguide 25 which branches off from this waveguide 11, together with an electrode arrangement 54 which is arranged in the region of these end sections 110 and 111, define the gate
30 switch 5, which is arranged in this branching waveguide 11 and is in the form of a changeover switch.

 The electrode arrangement 54 of the gate switch 5, which is arranged in each branching waveguide 11 and is in the form of a changeover switch, comprises an
35 electrode 541, which is arranged above the end section 111 of the second waveguide section 11₂ of this branching waveguide 11, and an electrode 542,

which is arranged above the end section 111 of the waveguide 25 which branches off from this branching waveguide 11.

5 The end section 110 of the waveguide 11 which leads to the junction point 3, and those end sections 111 of the first waveguide section 11₁ of the upper and lower branching waveguides 11 which are arranged on both sides of this end section 110, together with an electrode arrangement 54 which is arranged in the region of these
10 end sections 110 and 111, define the changeover switch 4 which is arranged in this junction point 3.

The electrode arrangement 54 of the changeover switch 4 in the junction point 3 comprises an electrode 541, which is arranged above the end section 111 of the
15 first waveguide section 11₁ of the upper branching waveguide section 11, and an electrode 542, which is arranged above the end section 111 of the first waveguide section 11₁ of the lower branching waveguide 11.

An electrical lead arrangement 7 has an electrical lead 75 which connects the electrodes 541 of the end
20 sections 111 of the first and second waveguide sections 11₁ and 11₂ of the upper branching waveguide 11, and the electrode 542 of the end section 111 of the waveguide 25 which branches off from the lower branching waveguide 11, and has an electrical lead 76, which connects the elec-
25 trodes 541 of the end sections 111 of the first and second waveguide sections 11₁ and 11₂ of the lower branching waveguide 11, and the electrode 542 of the end section 111 of the waveguide 25 which branches off from
30 the upper branching waveguide 11.

As a result of this type of electrical connection of the electrodes 541, 542 and 543, it is possible, in a similar manner to that in the example according to Figure 2b

35 - by application of a voltage difference of one polarity between the lead 75 and the lead 76, to achieve the switching state in which the optical signal, in which the optical signal which is supplied to the end section 110

of the supplying waveguide 11 is coupled over into the first waveguide section 11₁ of the upper branching waveguide 11 which leads to the upper output 1₁, and is coupled over from this first waveguide section 11₁ into the second waveguide section 11₂ of this upper waveguide 11 and passes to the upper output 1₁, while an undesirable element of this signal which is coupled over into the first waveguide section 11₁ of the lower branching waveguide 11 which leads to the lower output 1₁ is coupled over into the waveguide 25 which branches off from this lower waveguide 11, and is supplied to the optical sump 6 which is connected to this waveguide 25, and

- by application of a voltage difference of the opposite polarity between the lead 75 and the lead 76, to achieve the switching state in which the optical signal which is supplied to the end section 110 of the supplying waveguide 11 is coupled over into the first waveguide 11₁ of the lower branching waveguide 11 which leads to the lower output 1₁, and is coupled over from this first waveguide section 11₁ into the second waveguide section 11₂ of this lower waveguide 11 and is supplied to the lower output 1₁, while an undesirable element of this signal which is coupled over into the first waveguide section 11₁ of the upper branching waveguide 11 is coupled over into the waveguide 25 which branches off from this upper branching waveguide 11, and is supplied to the optical sump 6 which is connected to this waveguide 25.

In addition, a further switching state is possible in which supplied signals are not coupled over and passed on either in the changeover switch 4 or in the gate switches 5.

35 The arrangement according to Figure 2d differs from the arrangement according to Figure 2c in that, instead of the TIC switches, known DOS switches, which likewise have more than two switching states, are used as changeover switches, in which

in each case one waveguide fork 40 having an electrode arrangement 54 is arranged in the junction point 3 and the additional junction points 30.

5 The waveguide 11 which leads to the junction point 3 is split in said point 3 in the region of the fork 40 into the upper and lower branching waveguides 11, which waveguides 11 lead, respectively, to the upper and lower output 1₁. From the upper and lower branching waveguide 11, respectively, the waveguide 25 which
10 branches off from this waveguides 11 branches in the relevant additional junction point 30, in the region of the fork 40 which is arranged there, and leads to an optical sump 6.

The electrode arrangement 54 has two electrodes
15 544 and 545 in the region of each fork 40. In the case of the fork 40 in the changeover switch 4, the electrode 544 is arranged above the fork branch from which the upper branching waveguide 11 branches off, and the electrode 545 is arranged above the fork branch from which the
20 lower branching waveguide 11 branches off. In the case of the fork 40 in the gate switch 5 of each branching waveguide 11, the electrode 544 is arranged above the fork branch which is arranged in this branching waveguide 11 and forms a section of this waveguide 11, and the
25 electrode 545 is arranged above the fork branch from which that waveguide 25 which branches off from this waveguide 11 branches.

In comparison with the examples according to Figures 2c and 2d, the electrode 544 corresponds to the
30 electrode 541, and the electrode 545 corresponds to the electrode 542, both in the changeover switch 4 and in each gate switch 5.

In the example according to Figure 2d, precisely the same switching behaviour as in the case of the
35 example according to Figure 2c can be achieved by the same lead arrangement 7 of leads 75 and 76 which electrically connect the electrodes 544 and 545 in the same manner as the electrodes 541 and 542, respectively, in the example according to Figure 2c.

In the example according to Figure 2e, the changeover switch 4 and the gate switches 5 each comprise a changeover switch in the form of a known controllable optical directional coupler, as is used, for example, in the example according to Figure 2b for the gate switches 5.

In the case of the example according to Figure 2e, the example is set up, for example, such that the waveguide 11 which leads to the junction point 3 merges in this junction point 3, without any interruption, into the branching waveguide 11 which leads to an output 1_1 , for example the lower branching waveguide 11 which leads to the lower output 1_1 . The branching waveguide 11 which leads to the other output 1_1 , in the example the upper output 1_1 , is split in a similar way to that in the case of the example according to Figure 2b into a first waveguide section 11_1 and a second waveguide section 11_2 , which is separated from it.

The first waveguide section 11_1 has an end section 112 which is arranged at a short distance from the waveguide 11, which leads to this junction point 3, in the region of the changeover switch 4 in said junction point 3, and, together with this waveguide 11 and an electrode arrangement 54, defines the directional coupler of the changeover switch 4.

The first waveguide section 11_1 of the upper branching waveguide 11 in the example merges in the additional junction point 30, without any interruption, into the waveguide 25 which branches off from this upper branching waveguide 11 and leads to an optical sump 6.

The second waveguide section 11_2 of the upper branching waveguide 11 leads to the upper output 1_1 and has an end section 113 in the additional junction point 30 of this upper waveguide 11, in the region of the gate switch 5 which is arranged in this upper waveguide 11, which end section 113, together with the first waveguide section 11_1 and an electrode

arrangement 54, defined to the directional coupler of this gate switch 5.

5 A waveguide 25 branches off from the lower branching waveguide 11 in an additional waveguide 11 in an additional junction point 30, leads to an optical sump and, in the region of the gate switch 5 which is arranged in this lower branching waveguide 11, has an end section 114 which is arranged at a short distance from the lower branching waveguide 11 and, together with this waveguide 10 11 and an electrode arrangement 54, defines the directional coupler of this gate switch 5.

The electrode arrangement 54 of the changeover switch 4 and of each gate switch 5 in this example according to Figure 2e is formed by in each case one 15 electrode 543, which arranged above the end section 112, the end section 113 and the end section 114, which electrodes are electrically conductively connected to one another by, for example, a lead arrangement 7 in the form of a lead 75. The directional couplers of the changeover 20 switch 4 and of the gate switches 5 can be controlled in the correct manner by the electrodes 543 which are electrically connected to one another in such a manner, such that an optical signal which is supplied in the waveguide 11 which leads to the junction point 3 passes 25 either only to the upper output 1_1 or only to the lower output 1_1 , and undesired elements of this signal pass into the upper or lower sump 6, respectively, and not to an output 1_1 .

The example according to Figure 2f differs from 30 the example according to Figure 2e only in that the optical directional couplers in the example according to Figure 2e are replaced in the example according to Figure 2f by known integrated optical Mach-Zehnder interferometers.

35 Each of the interferometers has, in a known manner, an optical coupler 61 which splits an optical signal, which is supplied in a supplying waveguide 11, between two inteferometer arms 62 and 63 which are composed of optical waveguides,

and has an optical coupler 64 which causes the signal elements which are supplied in the interferometer arms to interfere with one another and then switches to one or the other of two continuing waveguides 11 or 11 and 25 as a function of an electrical control signal which is applied to one electrode arrangement 54.

The electrode arrangement 54 of each interferometer comprises, for example, an electrode 546 which is arranged above one interferometer arm 63 and functionally corresponds to the electrode 543 in the example according to Figure 2e. A lead arrangement 7 which comprises an electrical lead 75 and connects the three electrodes 546 to one another ensures that the example according to Figure 2f has the same switching behavior as the example according to Figure 2e.

The $1 \times N$ switching matrix according to the invention can in principle and, in particular, be operated bidirectionally in the illustrated exemplary embodiments, that is to say each output 1_1 can be an input for an optical signal which can be carried in the waveguide structure 1 to the single input 1_0 , so that the previous input 1_0 can also be an output. This is taken account of in the claims in that 1_0 is designated the "input/output" and 1_1 is designated the "output/input". This advantageous characteristic of the $1 \times N$ switching matrix according to the invention is important for the $N \times N$ switching matrix according to the invention.

An $N \times N$ switching matrix according to the invention is illustrated by way of example and schematically for $N = 8$ in Figure 3. This switching matrix has a central optical switching network 15 with a connection row 15₁ composed of in each case $8 \times 8 = 64$ optical connections on the left-hand side and a connection row 15₂ composed of in each case $8 \times 8 = 64$ optical connections on the right-hand side of this network, each connection being used as an optical input and/or output of the switching network 15, and the switching network 15 being designed internally in such a manner

that each connection in the connection row 15_1 on the left-hand side can be connected optically to each connection in the connection row 15_1 on the right-hand side, and vice versa. The switching network 15 may be,
5 for example, a generally known perfect shuffle.

Arranged on the left-hand side of the switching network 15 is a matrix row 200 comprising in each case eight optical 1×8 switching matrices according to the invention, each 1×8 switching matrix having in each case
10 one optical input/output 1_0 and in each case eight optical outputs/inputs 1_1 , of which in each case only one is provided with this reference signal 1_1 in each 1×8 switching matrix.

Likewise located on the right-hand side of the
15 optical switching network 15 is a matrix row 200 comprising in each case eight optical 1×8 switching matrices according to the invention, each 1×8 switching matrix having in each case one optical input/output 1_0 and in each case eight optical outputs/inputs 1_1 , of which in
20 each case only one is provided with this reference symbol 1_1 , once again, in each 1×8 switching matrix.

The total of $8 \times 8 = 64$ optical outputs/inputs 1_1 in the eight optical 1×8 switching matrices in the matrix row 200 on the left-hand side of the switching network 15
25 are connected in parallel to the $8 \times 8 = 64$ optical connections in the connection row 15_1 on this left-hand side and the total of $8 \times 8 = 64$ optical outputs 1_1 of the eight optical 1×8 switching matrices in the matrix row 200 on the right-hand side of the switching network 15 are
30 connected in parallel to the $8 \times 8 = 64$ optical connections in the connection row 15_1 on this right-hand side.

The total of eight optical inputs/outputs 1_0 of the eight optical 1×8 switching matrices in the matrix row 200 on the left-hand side of the switching network 15
35 form the inputs or outputs of the 8×8 switching matrix, and the total of eight

optical inputs/outputs 1_0 of the eight 1×8 switching matrices in the matrix row 200 on the right-hand side of the switching network 15 form the eight outputs and inputs of the 8×8 switching matrix which can be operated
5 bidirectionally not only when $N = 8$.

Each 1×8 switching matrix in Figure 3 may comprise the exemplary 1×8 switching matrix according to Figure 1.

Figure 4 shows a conventional $1 \times N$ switching
10 matrix without a gate switch 5, for comparison with the $1 \times N$ switching matrix according to the invention in Figure 1, parts which otherwise correspond being provided with the same reference symbols.

The $1 \times N$ switching matrices and $N \times N$ switching
15 matrices according to the invention have the advantage that the crosstalk suppression is greatly improved, no additional control complexity is required, the insertion loss is increased only to a minimal extent, and no additional production costs are necessary.

20 In the case of the $1 \times N$ switching matrix according to the invention, the crosstalk suppression is increased by that of the gate switch 5 for each optical path from the input/output 1_0 to an output/input 1_1 .

In the following text, data for the 1×8 switching
25 matrix according to the invention in Figure 1 are compared with the conventional 1×8 switching matrix according to Figure 4, it being assumed that both the changeover switch 4 and the gate switches 5 are TIC switches having more than two switching states. In order
30 to distinguish more clearly between the outputs/inputs 1_1 , these inputs/outputs are additionally provided with the letters a to h in brackets in Figures 1 and 4.

If, for example, the changeover switch 4 in the
topmost junction point 3 in the last junction stage 2, is
35 switched such that the signal light is passed via the upper of the two

waveguides 11 which branch off from this topmost junction point 3, to the output a, the crosstalk light from the lower of the two waveguides 11 which branch off from this topmost junction point 3 and lead to the output b is at the same time passed through the waveguide 25, which branches off from this lower branching waveguide 11, into the sump 6 which is connected to this waveguide.

It is assumed for driving the 1x8 switching matrix that only those changeover switches 4 and gate switches 5 are electrically driven through which the intended optical path passes. In accordance with the design of the 1x8 switching matrix according to the invention, only two gate switches 5 are driven in this case.

If, for example, the optical path α leading from the input 1_0 to the output a is selected, then the changeover switch 4 of the junction point 3 in the first junction stage 1_1 is switched to the upper waveguide 11 which branches off from this junction point 3 and leads to the upper junction point 3 in the second junction stage 2_2 . The changeover switch 4 which is located in this junction point 3 is switched to the upper waveguide 11 which branches off from this junction point 3 and leads to the topmost junction point 3 in the third junction stage 2_3 . The changeover switch which is located in this topmost junction point 3 is switched to the upper branching waveguide 11 which leads from this topmost junction point 3 to the output a. The gate switch 5 which is located in this waveguide 11 is switched such that the signal light passes to this output a. In contrast, the gate switch 5, which is located in the lower branching waveguide 11 which leads from the topmost junction point 3 to the output b, is switched such that the crosstalk light which is carried in this waveguide 11 is not passed to the output b, but to the sump 6 which is connected to this gate switch 5 by the waveguide 25 which branches off from this lower branching waveguide 11. All the other changeover switches 4 and

gate switches 5 are in the third switching state, in which no signal light passes through the changeover switches 4 and the gate switches 5.

It is assumed for each changeover switch 4 and each gate switch 5 that the transmission when the optical path is released is -1 dB, is -11 dB when the optical path is blocked, and is -6 dB in the third switching state, in which both optical paths are intended to be blocked.

The following table shows the crosstalk powers of the 1x8 switching matrix in Figure 1 for this case, in comparison with the 1x8 switching matrix in Figure 4 for the case when the topmost output a of both matrices is driven via the optical path α .

Output	Light power Figure 4 [dB]	Light power Figure 1 [dB]	Crosstalk Figure 4 [dB]	Crosstalk Figure 1 [dB]	Improvement [dB]
a	-3	-4	-	-	-1
b	-13	-24	-10	-20	10
c	-18	-24	-15	-20	5
d	-18	-24	-15	-20	5
e	-23	-29	-20	-25	5
f	-23	-29	-20	-25	5
g	-23	-29	-20	-25	5
h	-23	-29	-20	-25	5

These transmission values show that the 1x8 switching matrix according to the invention produces a considerable improvement of 10 dB in the crosstalk suppression, in particular on the main crosstalk path leading to the output b. The price of this is only a minor increase of 1 dB in the insertion loss. Overall, the usable window (= power difference between the highest power crosstalk channel and the wanted channel) of the 1x8 switching matrix according to the invention is increased by 10 dB in comparison with the conventional 1x8 switching matrix.

A corresponding increase in the window of 20 dB can be expected for an 8x8 switching matrix constructed using these 1x8 switching matrices according to the invention, which is extraordinarily advantageous from the systems engineering point of view.

In general, for an NxN switching matrix according to the invention, the worst case crosstalk suppression CT turns out to be

$$CT = 2 CT_1 + 2 CT_2 - 10 \log (\log_2(N)),$$

where CT_1 is the crosstalk suppression of a gate switch and CT_2 is the crosstalk suppression of a changeover switch, the attenuation values are quoted in dB and the approximation stated in R.A. Spanke "Architectures for large nonblocking optical space switches", IEEE J. Quantum Electronics, Vol. QE-22, No. 6, page 964, 1987 is used.

In the case of conventional NxN switching matrices without any gate switches according to the invention, and in the case of which CT_1 is omitted, the crosstalk suppression may be poorer than 20 dB.

20365-3663

-26-

CLAIMS:

1. An optical 1xN switching matrix having a tree structure with an optical input/output and a number N of optical outputs/inputs comprising:

- 5 an optical waveguide structure which connects the input/output to each output/input and which is composed of optical waveguides which branch in a tree configuration from the input/output in a direction of the outputs/inputs at junction points;
- 10 a plurality of optical changeover switches, an optical changeover switch per junction point, respectively, for optionally switching over between waveguides which branch off from the junction point;

an optical gate switch assigned to at least one respective
15 output/input of the optical outputs/inputs for optional optical release and blocking of the respective output/input as a function of a switching state of a changeover switch of a junction point from which one branching waveguide is connected to the respective output/input.

- 20 2. The switching matrix as claimed in claim 1, wherein one respective gate switch is respectively assigned to each output/input for optional release and blocking of the respective output/input as a function of a switching state of a changeover switch of a junction point from which
25 a branching waveguide is connected to the respective output/input.

3. The switching matrix as claimed in claim 1, wherein at least the waveguide structure, the changeover switch and the gate switch of a 1xN switching matrix are
30 integrated on a common substrate.

20365-3663

-27-

4. The switching matrix as claimed in claim 1, wherein a respective changeover switch of a respective junction point from which a respective branching waveguide is connected to an output/input to which a respective gate switch is assigned, and the respective gate switch itself, each being an electrically controllable optoelectronic switch having an electrode arrangement that receive electrical control signals for switching the respective changeover switch between at least two switching states, the respective gate switch, in one of the switching states, releasing the output/input to which the respective gate switch is assigned, and the respective changeover switch being switched to the branching waveguide which is connected to the respective output/input and releasing the waveguide, and, in the other switching state, the respective changeover switch blocking the branching waveguide, and the gate switch blocking the respective output/input.

5. The switching matrix as claimed in claim 4, wherein the electrode arrangement of a gate switch and the electrode arrangement of a changeover switch are conductively connected to one another by an electrical lead arrangement.

6. The switching matrix as claimed in claim 1, wherein a gate switch, which is assigned to a respective output/input, has an on and off switch which is arranged in the branching optical waveguide which connects a junction point to the respective output/input.

7. The switching matrix as claimed in claim 1, wherein a gate switch, which is assigned to a respective output/input, has a changeover switch which is arranged in the branching waveguide which connects a junction point to the respective output/input and which is used for optionally

20365-3663

-28-

switching over between the branching waveguide and a further waveguide which branches off from the branching waveguide at an additional junction point and which leads to an optical receiver.

5 8. The switching matrix as claimed in claim 1, wherein each of the changeover switches is a waveguide switch which has an optical directional coupler.

9. The switching matrix as claimed in claim 1, wherein each of the changeover switches is a waveguide
10 switch which has a Mach-Zehnder interferometer.

10. The switching matrix as claimed in claim 1, wherein each of the changeover switches is a waveguide switch which has a waveguide fork.

11. The switching matrix as claimed in claim 1,
15 wherein each of the changeover switches is a switch which has more than two switching states, which is switched in one switching state to one waveguide which branches off from a respective junction point of a respective changeover switch, is switched in another switching state to another waveguide
20 which branches off from the respective junction point and which is switched in a further switching state such that the one branching waveguide and the other branching waveguide are simultaneously blocked.

12. The switching matrix as claimed in claim 11,
25 wherein the changeover switch which has more than two switching states is a waveguide switch.

13. The switching matrix as claimed in claim 11, wherein the changeover switch which has more than two switching states is a DOS switch.

20365-3663

-29-

14. An optical NxN switching matrix having a tree structure with a number N of optical inputs and a number N of optical outputs, comprising:

two matrix rows, each having N optical 1xN switching

5 matrices, each 1xN switching matrix having one optical input/output and N optical outputs/inputs;

an optical switching network having two connection rows each row having NxN optical connections, each of which is used as an optical input and/or output, each connection in one

10 connection row being optically connectable to each connection in the other connection row;

a total of NxN optical outputs/inputs of the N optical 1xN switching matrices in each matrix row being connected in parallel to the NxN optical connections of in each case one

15 connection row; and

a total of N optical inputs/outputs of the N optical 1xN switching matrices of each matrix row forming the N inputs and/or N outputs of the NxN switching matrix;

at least one optical 1xN switching matrix being a 1xN

20 switching matrix having a tree structure with an optical input/output and a number N of optical outputs/inputs;

the optical 1xN switching matrix having an optical waveguide structure which connects the input/output to each

output/input and which is composed of optical waveguides

25 which branch in a tree configuration from the input/output in a direction of the outputs/inputs at junction points;

the optical 1xN switching matrix having a plurality of optical changeover switches, an optical changeover switch per junction point, respectively, for optionally switching

20365-3663

-30-

over between waveguides which branch off from the junction point;

the optical 1xN switching matrix having an optical gate switch assigned to at least one respective output/input of the optical outputs/inputs for optional optical release and blocking of the respective output/input as a function of a switching state of a changeover switch of a junction point from which one branching waveguide is connected to the respective output/input.

10 15. The switching matrix as claimed in claim 14, wherein each optical 1xN switching matrix is a 1xN switching matrix.

16. The switching matrix as claimed in claim 14, wherein one respective gate switch is respectively assigned to each output/input for optional release and blocking of the respective output/input as a function of a switching state of a changeover switch of a junction point from which a branching waveguide is connected to the respective output/input.

20 17. The switching matrix as claimed in claim 14, wherein at least the waveguide structure, the changeover switch and the gate switch of a 1xN switching matrix are integrated on a common substrate.

18. The switching matrix as claimed in claim 14, wherein a respective changeover switch of a respective junction point from which a respective branching waveguide is connected to an output/input to which a respective gate switch is assigned, and the respective gate switch itself, each being an electrically controllable optoelectronic switch having an electrode arrangement that receive electrical control signals for switching the respective

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20365-3663

-31-

changeover switch between at least two switching states, the respective gate switch, in one of the switching states, releasing the output/input to which the respective gate switch is assigned, and the respective changeover switch
5 being switched to the branching waveguide which is connected to the respective output/input and releasing the waveguide, and, in the other switching state, the respective changeover switch blocking the branching waveguide, and the gate switch blocking the respective output/input.

10 19. The switching matrix as claimed in claim 18, wherein the electrode arrangement of a gate switch and the electrode arrangement of a changeover switch are conductively connected to one another by an electrical lead arrangement.

15 20. The switching matrix as claimed in claim 14, wherein a gate switch, which is assigned to a respective output/input, has an on and off switch which is arranged in the branching optical waveguide which connects a junction point to the respective output/input.

20 21. The switching matrix as claimed in claim 14, wherein a gate switch, which is assigned to a respective output/input, has a changeover switch which is arranged in the branching waveguide which connects a junction point to the respective output/input and which is used for optionally
25 switching over between the branching waveguide and a further waveguide which branches off from the branching waveguide at an additional junction point and which leads to an optical receiver.

22. The switching matrix as claimed in claim 14,
30 wherein each of the changeover switches is a waveguide switch which has an optical directional coupler.

20365-3663

-32-

23. The switching matrix as claimed in claim 14, wherein each of the changeover switches is a waveguide switch which has a Mach-Zehnder interferometer.

24. The switching matrix as claimed in claim 14,
5 wherein each of the changeover switches is a waveguide switch which has a waveguide fork.

25. The switching matrix as claimed in claim 14, wherein each of the changeover switches is a switch which has more than two switching states, which is switched in one
10 switching state to one waveguide which branches off from a respective junction point of a respective changeover switch, is switched in another switching state to another waveguide which branches off from the respective junction point and which is switched in a further switching state such that the
15 one branching waveguide and the other branching waveguide are simultaneously blocked.

26. The switching matrix as claimed in claim 25, wherein the changeover switch which has more than two switching states is a waveguide switch.

20 27. The switching matrix as claimed in claim 25, wherein the changeover switch which has more than two switching states is a DOS switch.

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PATENT AGENTS

FIG 1

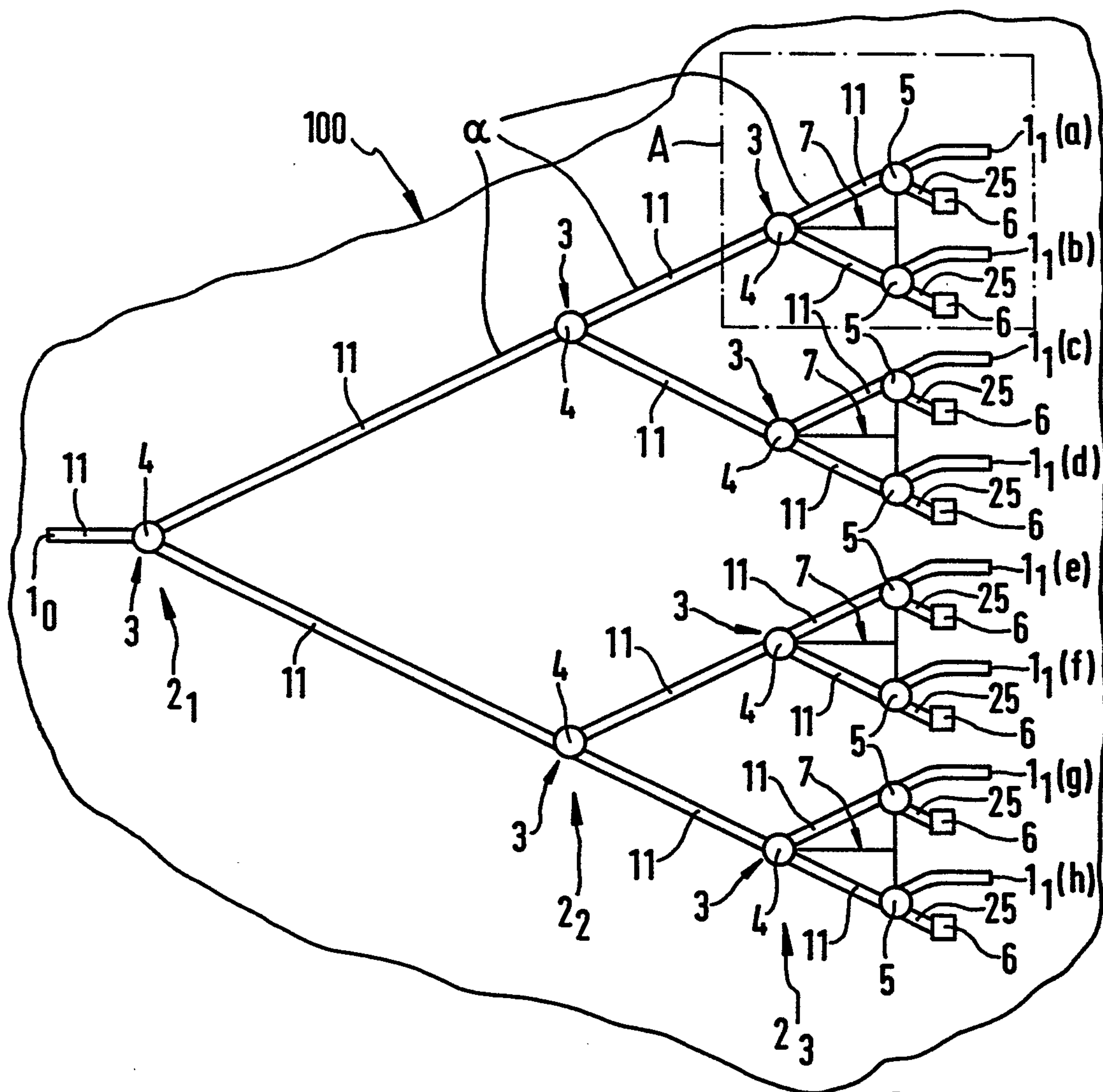


FIG 2a

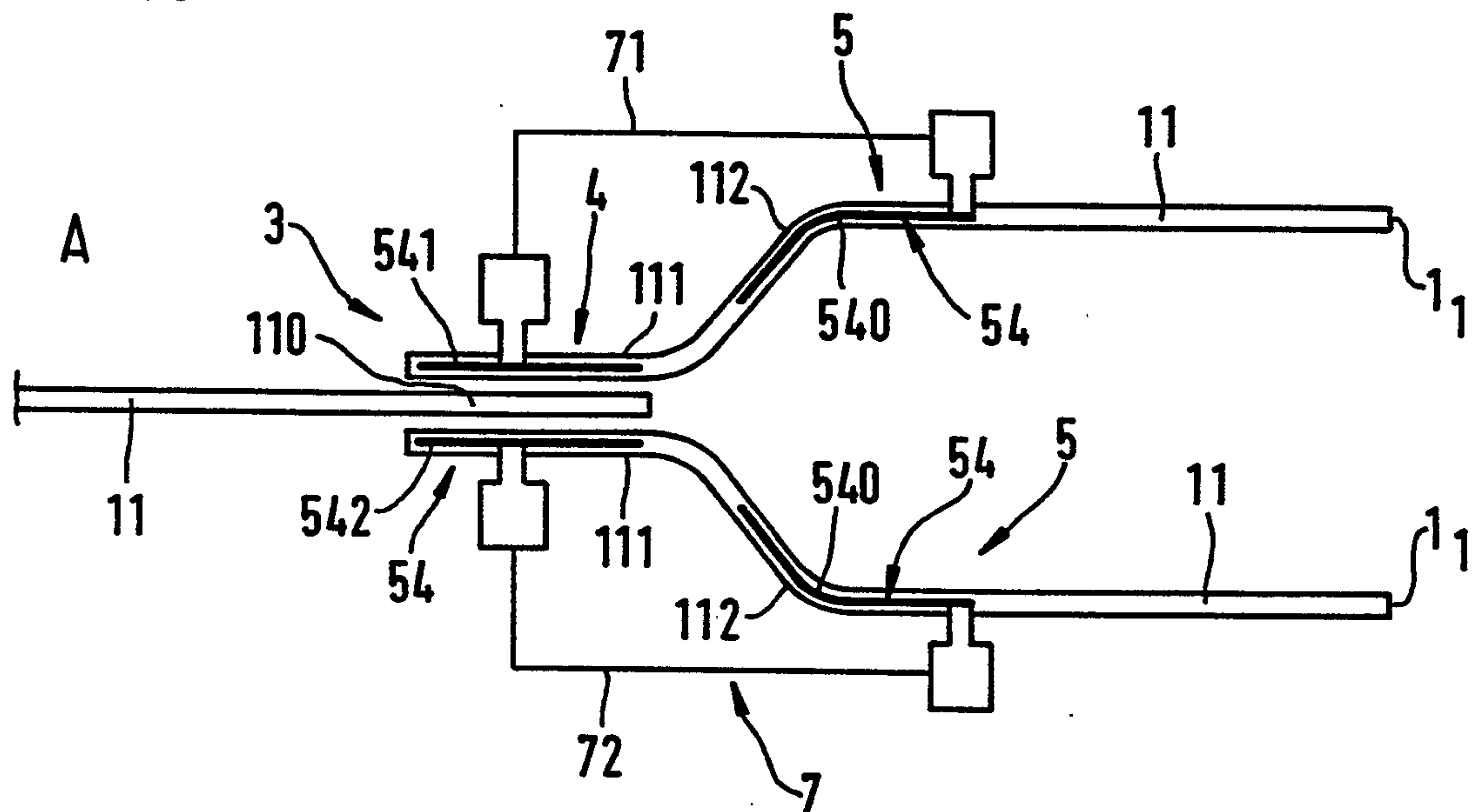


FIG 2b

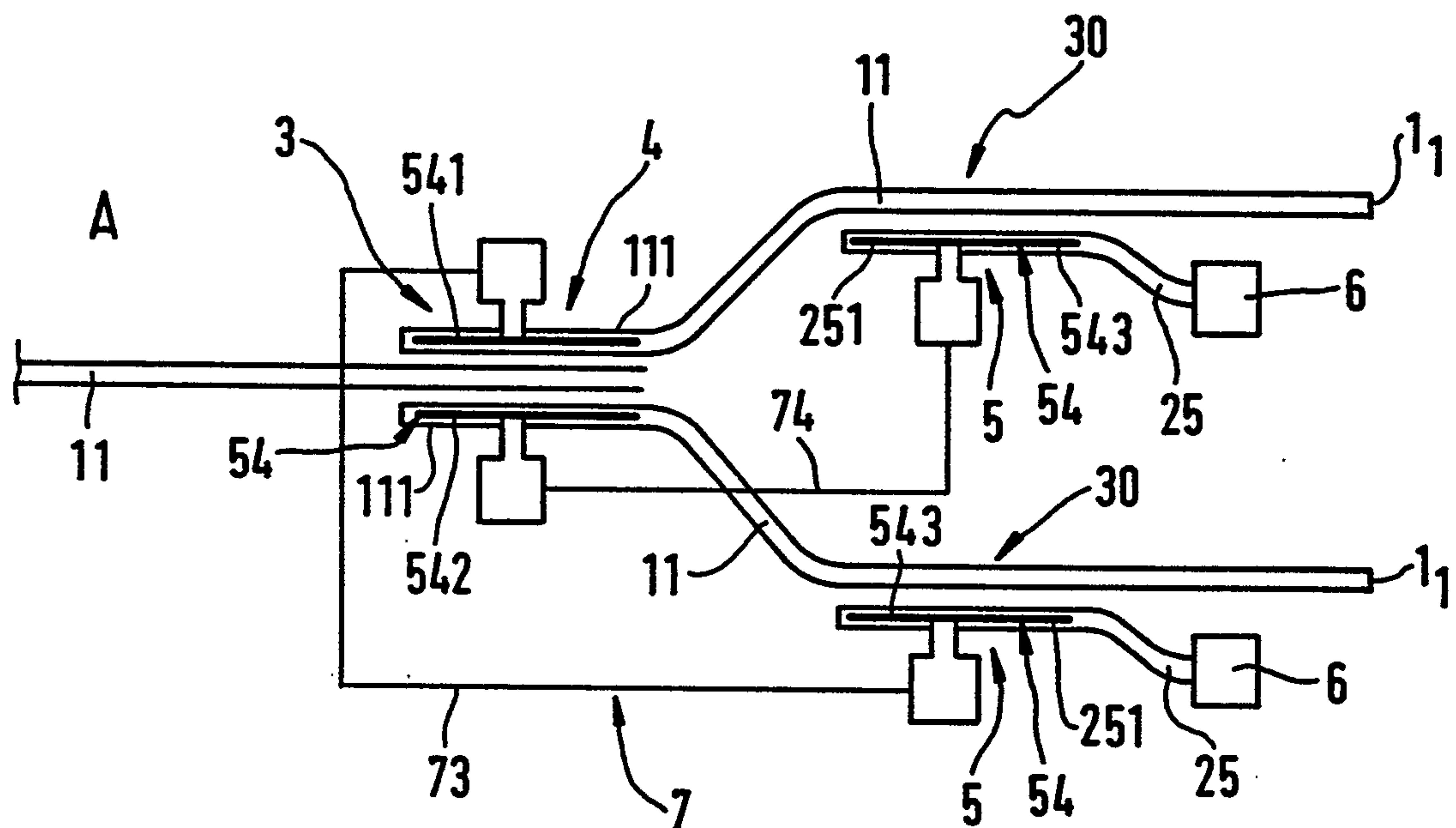


FIG 2c

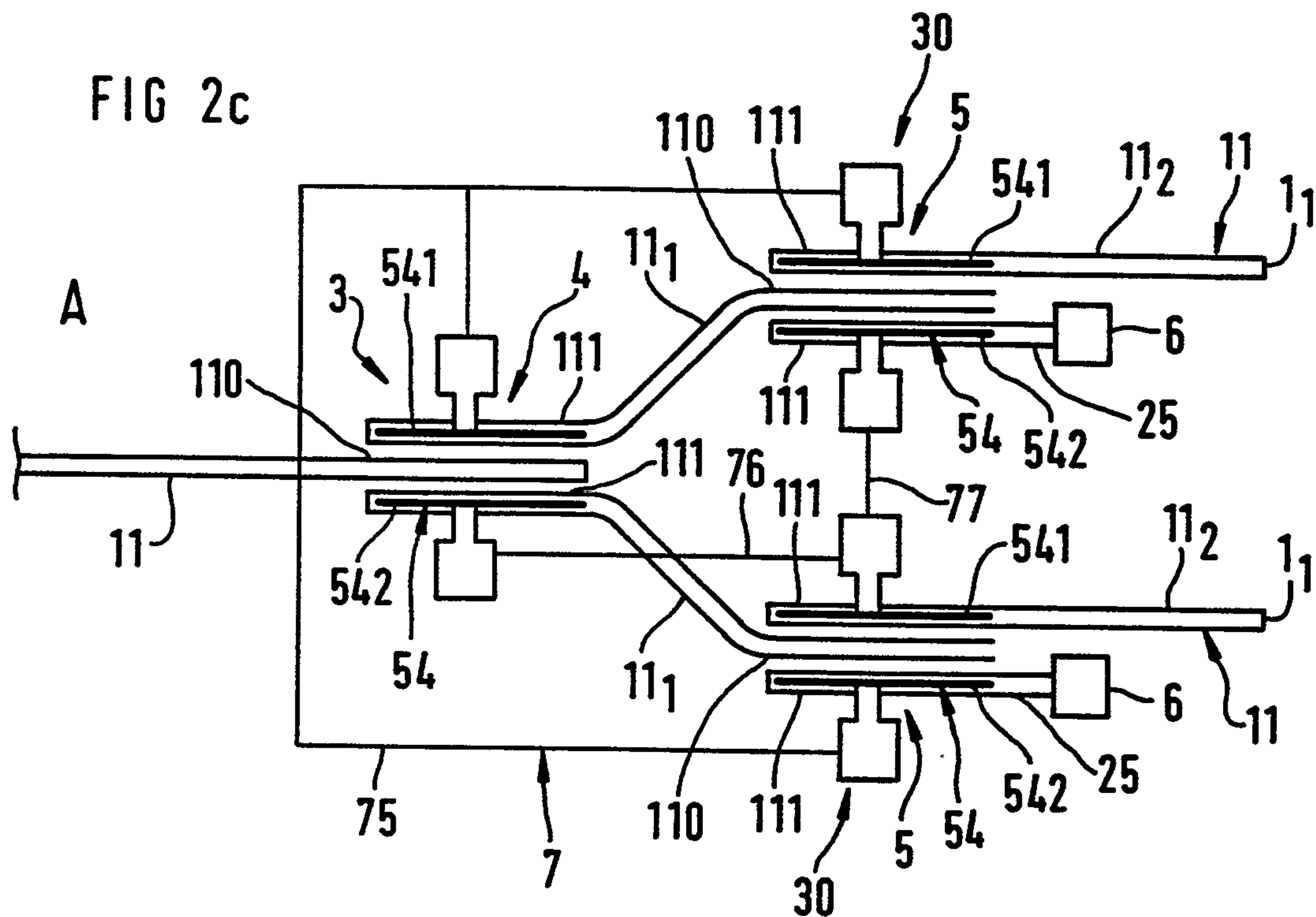


FIG 2d

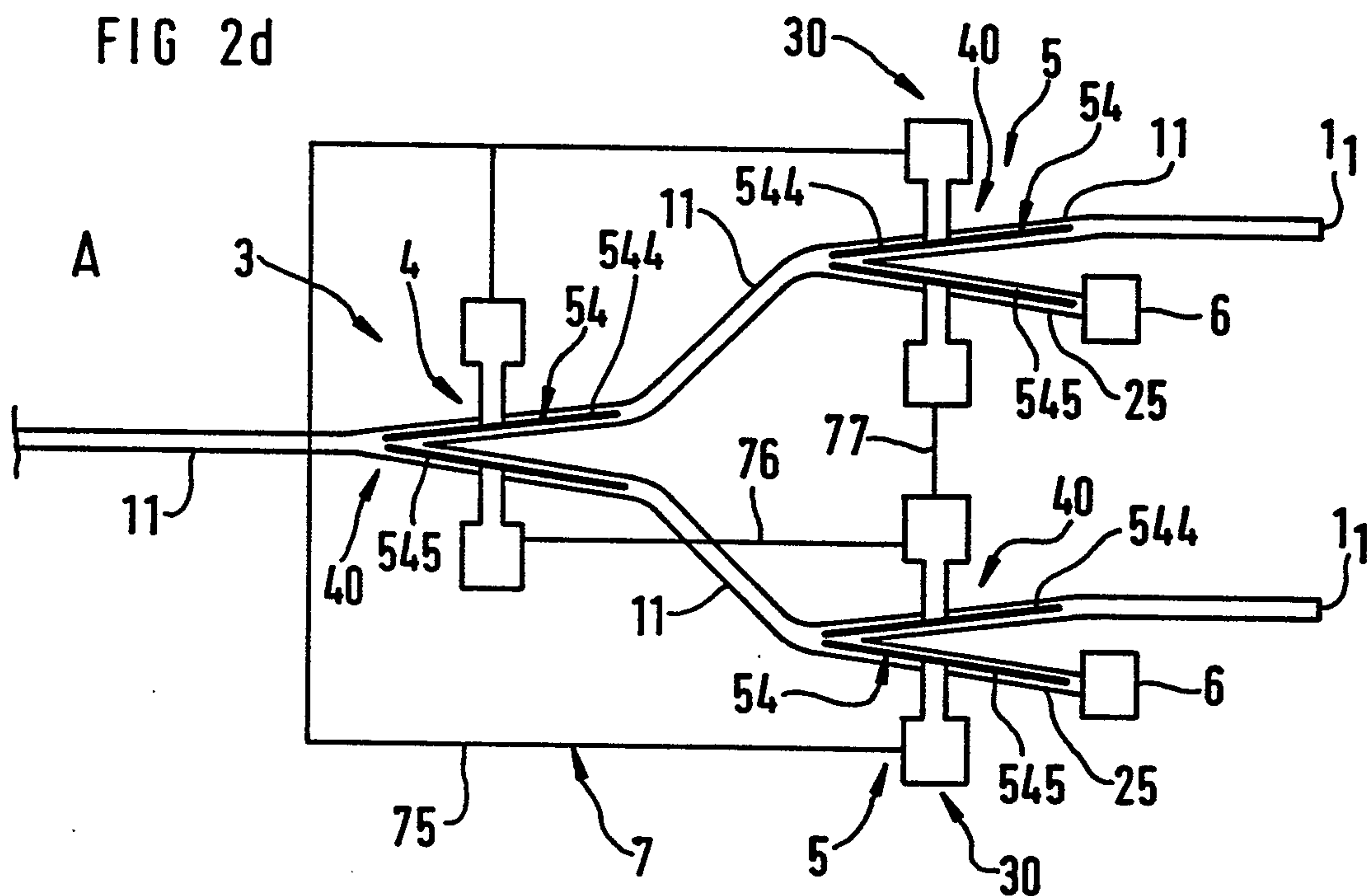


FIG 2e

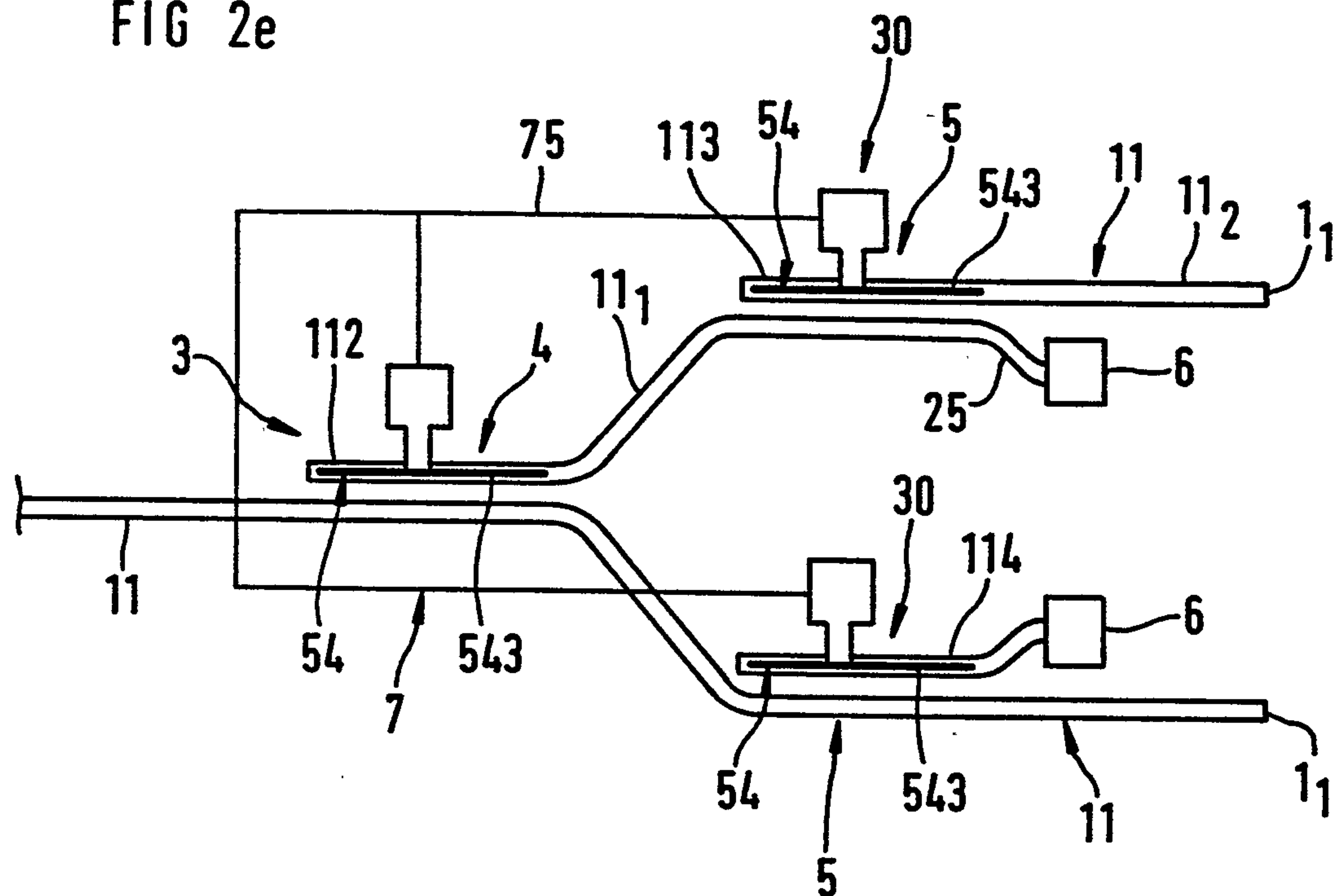


FIG 2f

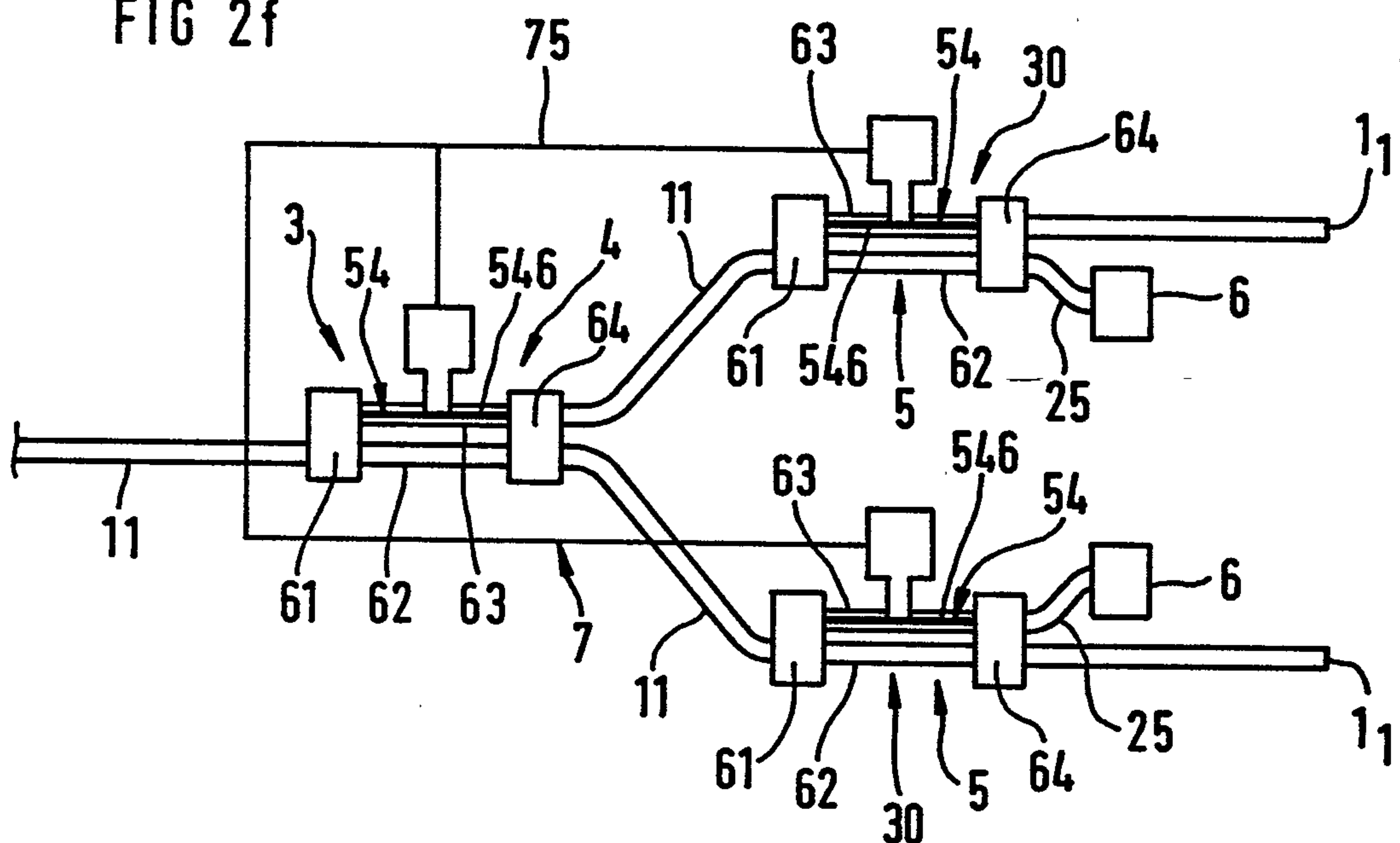


FIG 3

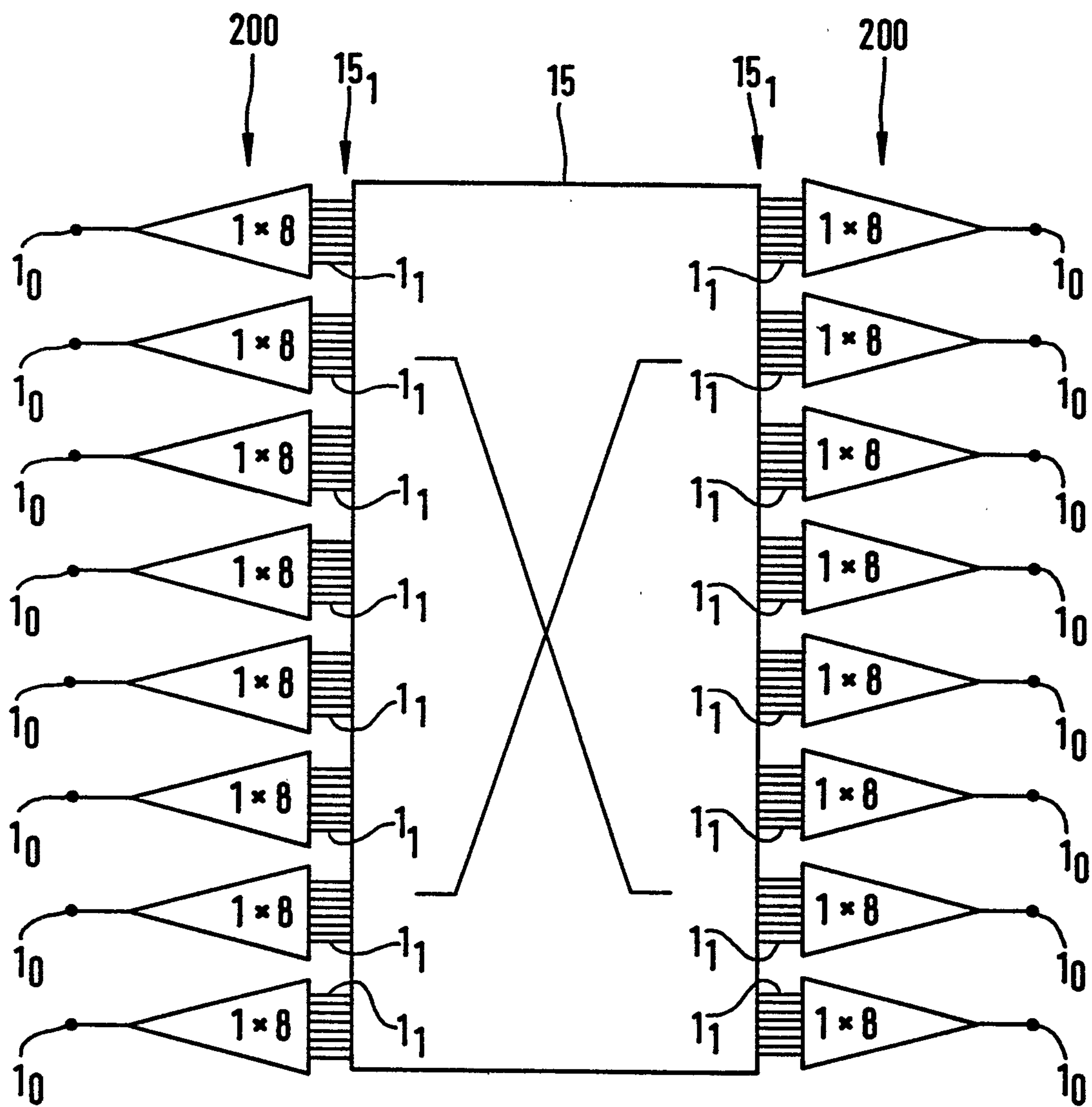


FIG 4

