



(86) Date de dépôt PCT/PCT Filing Date: 2000/10/20
(87) Date publication PCT/PCT Publication Date: 2001/04/26
(85) Entrée phase nationale/National Entry: 2002/03/22
(86) N° demande PCT/PCT Application No.: EP 2000/010428
(87) N° publication PCT/PCT Publication No.: 2001/029596
(30) Priorités/Priorities: 1999/10/21 (99203458.7) EP;
1999/10/26 (60/161,373) US

(51) Cl.Int.⁷/Int.Cl.⁷ G02B 6/28, G02B 6/34, H04J 14/02

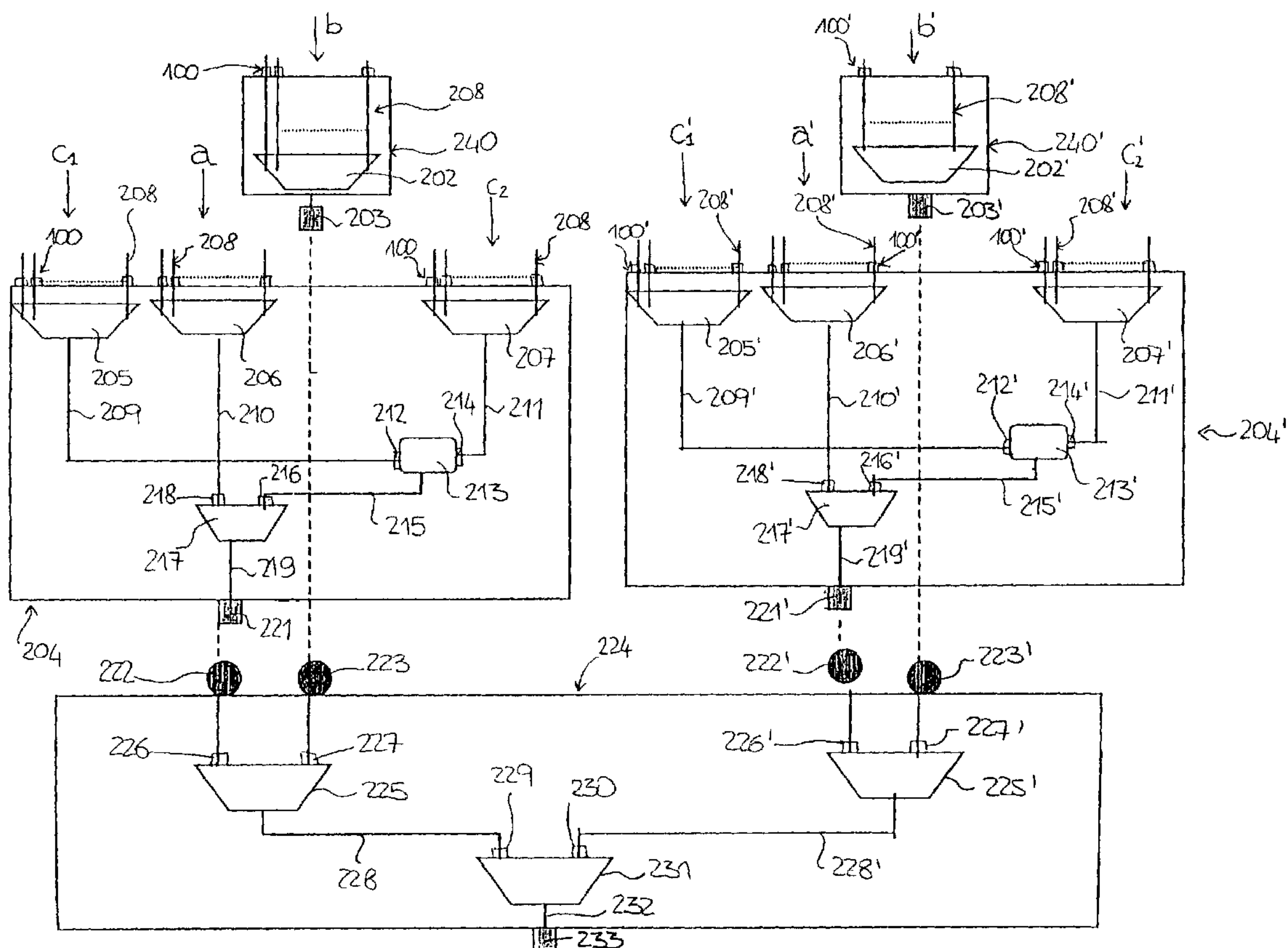
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(54) Titre : DISPOSITIF DE MULTIPLEXAGE OPTIQUE EN LONGUEURS D'ONDES ET SYSTEME DE
TELECOMMUNICATION OPTIQUE MLO

(54) Title: OPTICAL WAVELENGTH MULTIPLEXING DEVICE AND WDM OPTICAL TELECOMMUNICATION SYSTEM



(57) **Abrégé/Abstract:**

An optical multiplexing device (44; 45), for wavelength multiplexing a plurality M of optical channels (16) - with $M \geq 8$, said multiplexing device (44; 45) having N input ports (208, 208') - with $N \geq M$ - and one output port (233; 254) and comprising at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) having predetermined



(57) Abrégé(suite)/Abstract(continued):

intrinsic losses and coupled together according to a tree topology, said tree topology having N inputs and one output corresponding to said N input ports (208, 208') and one output port (233; 254) characterized in that a) the intrinsic loss of each of said at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) is preselected; and b) said at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) are arranged in said tree topology so that, passing through said multiplexing device (44; 45), at least two of said plurality M of optical channels (16) are attenuated differently from each other. When included in a WDM transmission system, e.g. a system using in-line fibre amplifiers, the different channel attenuations of the transmission line can be equalised.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



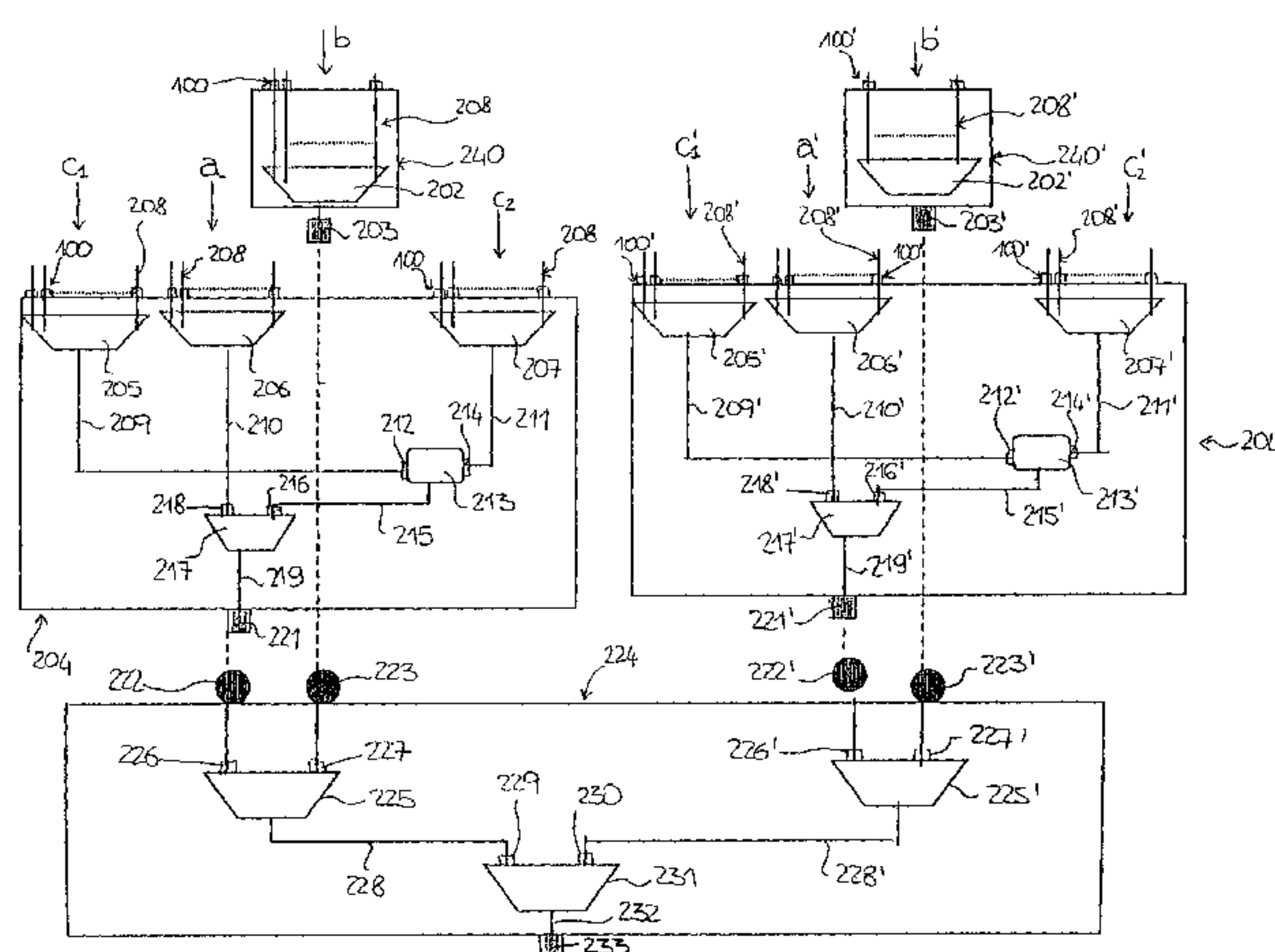
(43) International Publication Date
26 April 2001 (26.04.2001)

PCT

(10) International Publication Number
WO 01/29596 A1

- (51) International Patent Classification⁷: **G02B 6/28**, 6/34, H04J 14/02
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- (21) International Application Number: PCT/EP00/10428
- (22) International Filing Date: 20 October 2000 (20.10.2000)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
99203458.7 21 October 1999 (21.10.1999) EP
60/161,373 26 October 1999 (26.10.1999) US
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- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
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- Published:**
— With international search report.
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: OPTICAL WAVELENGTH MULTIPLEXING DEVICE AND WDM OPTICAL TELECOMMUNICATION SYSTEM



(57) Abstract: An optical multiplexing device (44; 45), for wavelength multiplexing a plurality M of optical channels (16) - with $M \geq 8$, said multiplexing device (44; 45) having N input ports (208, 208') - with $N \geq M$ - and one output port (233; 254) and comprising at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) having predetermined intrinsic losses and coupled together according to a tree topology, said tree topology having N inputs and one output corresponding to said N input ports (208, 208') and one output port (233; 254) characterized in that a) the intrinsic loss of each of said at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) is preselected; and b) said at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) are arranged in said tree topology so that, passing through said multiplexing device (44; 45), at least two of said plurality M of optical channels (16) are attenuated differently from each other. When included in a WDM transmission system, e.g. a system using in-line fibre amplifiers, the different channel attenuations of the transmission line can be equalised.

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**Optical wavelength multiplexing device and WDM optical
telecommunication system**

DESCRIPTION

5 The present invention relates to an optical device for wavelength multiplexing a plurality of optical signals and a WDM (Wavelength Division Multiplexing) optical telecommunication system comprising it.

In the present description and claims the expression

- 10 - "intrinsic loss of a coupler" is indicative of the attenuation that an optical coupler introduces on the optical channels passing through it;
- "balanced optical coupler" indicates an optical coupler that introduces substantially the same attenuation on the optical channels passing through it. That is, it
- 15 indicates an optical coupler that has the same intrinsic loss for all the channels passing through it;
- "unbalanced optical coupler" indicates an optical coupler which attenuates the optical channels passing through it differently from each other, depending on the input port
- 20 through which they enter the coupler. That is, it indicates an optical coupler that has different intrinsic losses for the channels passing through it;
- "Nx1 optical coupler" indicates a coupler having N input
- 25 ports (with $N \geq 2$) and one output port (or M output ports just one of which is used, with $M \geq 2$).

In WDM optical telecommunication systems, a plurality of optical signal having predetermined wavelengths different from each other (channels) are sent over a same optical

30 line by means of wavelength multiplexing devices. The transmitted channels may be either digital or analog.

Presently, the wavelength multiplexing device most commonly used for wavelength multiplexing N channels in optical telecommunication systems is a Nx1 passive balanced optical

coupler (e.g. a conventional planar optical coupler or a fused optical fiber coupler).

5 This optical coupler distributes the optical power of the optical channels entering the N input ports so that at the output port (or at each output port) there is a Nth fraction of power of each input channel (that is, it is a non wavelength selective optical coupler). This is true also when the number of the input channels entering the optical coupler is less than the number of the input ports
10 thereof.

Accordingly, at the output of a multiplexing device made by said Nx1 passive balanced optical coupler the power of each channel is attenuated by a factor N.

15 In present WDM telecommunication systems where the number of the transmitted channels is increasing more and more (e.g. up to 128 channels), this multiplexing device suffers the drawback of highly attenuating the transmitting power of each channel and, thus, of degrading the optical signal to noise ratio (SNR) at a receiving terminal.

20 Furthermore, said optical SNR degradation becomes more and more important as the bit rates of the transmitted channels raise. In fact, the required optical SNR level at the receiving terminal increases with the bit rate.

25 In order to decrease the power losses suffered by the optical channels, an optical wavelength multiplexing device other than the above mentioned passive optical coupler has been studied as, for example, a passive Arrayed Waveguide Grating (AWG) or a Mach Zehnder device as described in US 5 867 291.

<SEE PAGE 2a>

30 Furthermore, EP 0 887 963 discloses optical multiplexing devices comprising multiple WDMs which are optically coupled to a common trunk line carrying multi-channel wavelength multiplexed light. The multiple WDMs are cascaded in parallel or in series, or a combination of

<Moreover, US 5 809 190 discloses an apparatus and method of making a dense wavelength-division multiplexer (DWDM) using a fused-biconical taper technique. The DWDM disclosed comprises a plurality of multi-window wavelength-division multiplexers (MWDMS) which cascade together in several stages, each stage has several MWDMS having an identical window spacing. As shown in figures 3c-3e of this document, the spectral insertion loss of each MWDMS varies with the wavelengths of the channels. Therefore, the MWDMS disclosed by this document are all wavelength selective devices. Furthermore, as shown in figures 8a and 8b, the insertion loss of the DWDM apparatus is the same for each channel wavelength (for example, λ_1 , λ_2 , ... λ_8) for which the apparatus has been designed. Therefore, passing through the DWDM apparatus, the channels having wavelengths (e.g. λ_1 , λ_2 , ... λ_8) for which the apparatus has been designed are attenuated by the same amount.>

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both, from the trunk line and multiplex different channels or wavelength sub-ranges. The WDMs disclosed in this document are wavelength selective couplers and comprise an optical block carrying Fabry-Perot interference filters and
5 other reflective elements to define a multi-bounce, zigzag expanded beam light path through the optical block.

However, even if the above mentioned devices have typically low loss compared with the Nx1 passive balanced optical coupler, they are very complex to produce and extremely
10 expensive compared with said optical coupler.

Additionally, Applicant has remarked that in WDM telecommunication systems, besides channels multiplexing, also the equalization of optical power or SNR among different optical channels at the receiving terminal is an
15 important issue.

In fact, as they propagate along an optical fiber telecommunication link, the different optical channels accumulate imbalance in both the optical power and SNR owing to the fact that several optical components (optical
20 fiber included) have nonuniform wavelength-dependent loss.

Furthermore, in optically amplified WDM telecommunication systems, the imbalance among different channels in both the received power and optical SNR is also due to optical amplifiers. In fact, optical amplifiers, such as erbium-
25 doped fiber amplifiers, have nonuniform wavelength-dependent gain whereby each channel experiences a different optical gain.

The accumulated power and optical SNR imbalance can seriously limit system performance in three different ways.
30 First, the received power imbalance can eventually exceed that allowed by receiver dynamic range. Second, accumulated SNR imbalance can result in the Bit Error Rate (BER), at certain wavelengths, falling below required levels. Third, the minimum received signal power can fall below what is

required by receiver sensitivity (for a given bit rate) [Ozan K. Tonguz et al., "Gain Equalization of EDFA Cascades", Journal of Lightwave Technology, vol. 15, No. 10, October 1997, pages 1832-1841].

5 In order to solve the problem of nonuniform wavelength-dependent gain a pre-emphasis technique has been proposed (US 5 790 289, EP 0 918 405, US 5 225 922). This technique typically consists in adjusting the reciprocal power of the channels at the transmitting terminal so as to equalize the
10 nonuniform gain spectrum of optical amplifiers or the optical power or SNR of the optical channels at the receiving terminal.

<SEE PAGE 4a>

Furthermore, N. S. Bergano et al. ("100 Gb/s WDM Transmission of twenty 5 Gb/s NRZ data channels over
15 transoceanic distances using a gain flattened amplifier chain", ECOC '95, vol. 3, pages 967-970) discloses an experiment performed using a twenty wavelength transmitter and a 1260 Km gain flattened amplifier chain in a circulating loop. In such experiment, the odd and even
20 wavelengths were multiplexed separately in a series of 4x1, 6x1 and 2x1 directional couplers. Furthermore, a 7dB of optical pre-emphasis was needed at the transmitter to equalize the received optical signal-to-noise ratios.

However, the pre-emphasis is, typically, achieved by
25 optical attenuators adjusted for suitably attenuating the power of the channels at the transmitting terminal:

Therefore, in WDM optical telecommunication system using such pre-emphasis technique, besides being attenuated by the multiplexing device, the optical transmitting power of
30 the channels is further attenuated because of said adjustment of their reciprocal power. These additional losses at the transmitting terminal contribute towards degrading the optical SNR at the receiving terminal.

Accordingly, the applicant aimed at providing an optical

<Moreover, WO 99/07096 discloses a WDM optical transmission system comprising a multiplexing section, a transmitter power amplifier, long distance optical transmission fibers, an optical line amplifier, a receiver pre-amplifier and a
5 demultiplexing section. The non uniform gain spectrum of the optical amplifier is compensated by an equalizing filter that has a spectrum inverted with respect to that of the gain so as to flatten the gain response for the channels.>

device capable of reducing the power losses at a transmitting terminal of a WDM optical telecommunication system having a high number of channels and a WDM optical telecommunication system having reduced losses at the transmitting terminal.

It is therefore ^{AN} ~~first~~ aspect of the present invention to provide an optical multiplexing device, ~~for wavelength~~ multiplexing a plurality M of optical channels (with $M \geq 8$), said multiplexing device having N input ports (with $N \geq M$) and one output port and comprising at least three optical couplers having predetermined intrinsic losses and coupled together according to a tree topology, said tree topology having N inputs and one output corresponding to said N input ports and one output port, characterized in that

15 a) the intrinsic loss of each of said at least three optical couplers is preselected; and

b) said at least three optical couplers are arranged in said tree topology

so that, passing through said multiplexing device, at least two of said plurality M of optical channels are attenuated differently from each other so as to achieve a predetermined pre-emphasis while said plurality M of optical channels ~~(16) is multiplexed~~ ACCORDING TO CLAIM 12.

The multiplexing device of the invention suitably exploits the intrinsic losses of optical couplers to attenuate differently from each other at least two of said plurality M of optical channels while it multiplexes them.

Thus, in a WDM optical telecommunication system it allows to achieve a predetermined reciprocal attenuation of the power of the channels (e.g. for equalizing the optical power or SNR of the channels at the receiving terminal) without introducing significant additional losses on the channels besides those due to channels multiplexing.

In fact, for example, the device of the invention reduces the need of using the aforementioned optical attenuators at

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the transmitting terminal of a WDM telecommunication system.

In the present description and claim, the expression

⇒ "channels attenuated differently from each other" is used

5 to indicate that the difference in attenuation among the channels is at least equal to 1dB. Preferably, the difference in attenuation between said at least two channels is at least equal to 2dB. More preferably, it is at least equal to 3dB. Even more preferably, it is at
10 least equal to 3,5dB. Even more preferably, it is at least equal to 4dB. Further more preferably, it is at least equal to 4,5dB; and

⇒ "optical couplers having intrinsic losses different from each other " is used to indicate that the difference in

15 intrinsic loss among the couplers is at least equal to 1dB. Preferably, the difference in intrinsic loss among the couplers is at least equal to 2dB. More preferably, it is at least equal to 3dB. Even more preferably, it is at least equal to 3,5dB. Even more preferably, it is at
20 least equal to 4dB. Further more preferably, it is at least equal to 4,5dB.

In an embodiment, said tree topology has one input level having at least two optical couplers with intrinsic losses different from each other of at least 3 dB. Advantageously,
25 the difference in intrinsic losses between said at least two optical couplers is at least equal to 3.5 dB.

In an embodiment, at least one of said at least three optical couplers is a non wavelength selective unbalanced optical coupler. In this embodiment, said tree topology
30 typically has one input level and one output level. Preferably, said non wavelength selective unbalanced optical coupler is located at said output level of said tree topology.

In an embodiment, at least one of said at least three
35 optical couplers is a non wavelength selective optical

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coupler and at least one of said at least three optical couplers is a wavelength selective optical coupler.

Advantageously, said tree topology has one input level and one output level.

- 5 Advantageously, at said input level there are at least two optical couplers. Typically, said at least two optical couplers are selected from the group comprising 2x1 and 4x1 optical couplers. Preferably, said at least two optical couplers have intrinsic losses different from each other.
- 10 Advantageously, said at least two couplers at the input of said tree topology are balanced. According to a variant, at least one of said at least two optical couplers is unbalanced.

- Typically, at said output level of said tree topology,
- 15 there is one optical coupler. Preferably, said one output optical coupler is a 2x1 optical coupler. Advantageously, it is an unbalanced optical coupler. According to a variant, it is a balanced optical coupler.

- Preferably, said at least three optical couplers are
- 20 selected from the group comprising conventional planar optical couplers and fused optical fiber couplers. This, makes the multiplexing device of the invention very simple to produce and at a low cost.

- When the difference in wavelength between at least two
- 25 channels (or at least two group of channels) is higher than 4nm, at least one of said at least three optical couplers is advantageously a wavelength selective optical coupler for coupling said at least two channels (or two groups of channels). Preferably, said difference in wavelength is at
- 30 least higher than 8nm. More preferably, it is at least higher than 10nm. For example, said wavelength selective optical coupler is a conventional interferential filter.

As a wavelength selective coupler typically has less losses than a conventional planar optical coupler or fused optical

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fiber coupler, it allows to reduce the losses of the multiplexing device.

Of course, the expressions "planar optical coupler" and "fused optical coupler" are intended to indicate a non
5 wavelength selective optical coupler where otherwise not indicated.

Advantageously, said multiplexing device further comprises at least one attenuator having preselected loss. Typically, said at least one attenuator is located at one of said at
10 least N input ports of said multiplexing device. Said attenuator can be, for example, an attenuating splice.

Preferably, N is at least equal to 16. More preferably, N is at least equal to 32. Even more preferably, N is at least equal to 48. Even more preferably, N is at least
15 equal to 64. Further more preferably, N is at least equal to 128.

Advantageously, N is a power of 2.

Typically, the multiplexing device of the invention has at least five optical couplers. More preferably, it has at
20 least seven optical couplers. Even more preferably, it has at least eleven optical couplers. Further more preferably, it has at least fifteen optical couplers. Further more preferably, it has at least nineteen couplers.

Advantageously, said tree topology has one input level, one
25 output level and at least one intermediate level.

Advantageously, at said input level there are at least three optical couplers. Preferably, two of said at least three optical couplers have intrinsic losses different from each other. More preferably, two of said at least three
30 optical couplers have an intrinsic loss different from the intrinsic loss of a third of said at least three optical couplers. Even more preferably, said two optical couplers have an intrinsic loss lower than the intrinsic loss of

said third optical coupler. Typically, said at least three optical couplers are selected from the group comprising 2x1, 4x1, 8x1 and 16x1 optical couplers. Advantageously, said at least three optical couplers are balanced.

- 5 Typically, at said at least one intermediate level there is at least one optical coupler. Typically, said at least one optical coupler is a 2x1 optical coupler. Preferably, said at least one optical coupler is unbalanced. When the difference in wavelength between at least two group of
- 10 channels is higher than 4nm, said at least one optical coupler is advantageously a wavelength selective optical coupler for coupling said at least two groups of channels. Preferably, said difference in wavelength is at least higher than 8nm. More preferably, it is at least higher
- 15 than 10nm. For example, said wavelength selective optical coupler is a conventional interferential filter.

Typically, at said output level of said tree topology, there is one optical coupler. Preferably, said one output optical coupler is a 2x1 optical coupler. Advantageously,

20 it is a balanced optical coupler.

Typically, at least two groups of said optical channels are attenuated differently from each other.

Advantageously, two groups of said optical channels are attenuated differently from the remaining optical channels.

- 25 According to a variant, said optical channels are all differently attenuated to each other.

FURTHER

It is a ~~second~~ aspect of the present invention to provide a WDM optical telecommunication system ~~comprising~~ ^{ACCORDING TO CLAIM 1.}

- ~~a transmitting terminal for supplying a plurality M of~~
- 30 ~~optical channels (with $M \geq 8$) comprising a multiplexing unit for multiplexing said plurality M of optical channels, said multiplexing unit comprising a multiplexing device having N input ports (with $N \geq M$) and one output port and comprising at least three optical~~

- couplers having predetermined intrinsic losses and coupled together according to a tree topology, said tree topology having N inputs and one output corresponding to said N input ports and one output port;
- 5 - an optical telecommunication line operatively coupled to said transmitting apparatus, for transmitting said plurality M of optical channels multiplexed by said multiplexing device;
- a receiving terminal operatively coupled to said optical
10 telecommunication line for receiving at least one part of the plurality M of optical channels;
- characterized in that
- a) the intrinsic loss of each of said at least three optical couplers is preselected; and
- 15 b) said at least three optical couplers are arranged in said tree topology
- so that, passing through said multiplexing device, at least two of said plurality M of optical channels are attenuated differently from each other, the difference in attenuation
20 between said at least two channels being selected so as to achieve, at said receiving terminal, a predetermined value of optical power for said at least one part of the plurality M of optical channels.

25 As to the structural and functional features of the multiplexing device we refer to what already said above as far as the multiplexing device of the invention is concerned.

Preferably, the difference in attenuation between said at least two channels is selected so as to equalize, at said
30 receiving terminal, the optical power of said at least one part of the plurality M of optical channels.

Advantageously, the difference in attenuation between said at least two channels is selected so as to achieve, at said receiving terminal, a predetermined value of optical SNR
35 for said at least one part of the plurality M of optical channels. Preferably, it is selected so as to equalize, at

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said receiving terminal, the optical SNR of said at least one part of the plurality M of optical channels.

Typically, said optical telecommunication line comprises at least one optical amplifying unit having a predetermined
5 nonuniform wavelength dependent gain spectrum in a predetermined wavelength band.

In this case, the difference in attenuation between said at least two channels is typically selected depending on said gain spectrum. According to an embodiment, the difference
10 in attenuation between said at least two channels is selected so as to equalize the nonuniform gain spectrum of said at least one optical amplifying unit.

Advantageously, said plurality M of optical channels have wavelengths selected within said predetermined wavelength
15 band of the gain spectrum.

In an embodiment, the nonuniform gain spectrum of said at least one optical amplifying unit has a central substantially flat region and two opposite side inclined regions.

20 In this case, said three topology of the multiplexing device as an input level at which two groups of said plurality M of optical channels, having wavelengths within said two opposite side inclined regions, are preferably coupled by two corresponding optical couplers and a third
25 group of said optical channels, having wavelengths within said central substantially flat region, is preferably coupled by at least one optical coupler. More preferably, said two optical couplers have an intrinsic loss lower than the intrinsic loss of said at least one optical coupler.

30 Typically, the number of the channels in the two opposite side inclined regions is lower than the number of the channels in the central substantially flat region.

Preferably, said tree topology of the multiplexing device

has an intermediate level comprising a wavelength selective optical coupler for coupling said two groups of optical channels having wavelengths within said two opposite side inclined regions of said gain spectrum.

- 5 Advantageously, said amplifying unit comprises at least one erbium doped fiber amplifier.

According to an embodiment, said predetermined wavelength band wherein the amplifying unit has said predetermined nonuniform wavelength dependent gain spectrum comprises two
10 sub-bands.

Typically, said nonuniform gain spectrum has a central substantially flat region and two opposite side inclined regions in each sub-band.

- Advantageously, a first group of said plurality M of
15 optical channels has wavelengths selected within a first of said two sub-bands and a second group of said plurality M of optical channels has wavelengths selected within the second of said two sub-bands.

- Preferably, the multiplexing unit further comprises a
20 second multiplexing device, the first and the second multiplexing devices multiplexing the first and the second group of optical channels, respectively.

- As to the structural and functional features of said second multiplexing device reference is made to what already said
25 about the first multiplexing device of the multiplexing unit.

Advantageously, said amplifying unit has at least two erbium doped fiber amplifiers connected in parallel.

<SEE PAGE 12 a>

- The accompanying drawings, which are incorporated in and
30 constitute a part of this specification, illustrate embodiments of the invention, and together with the description, explain the advantages and principles of the

<It is a further aspect of the present invention to provide a WDM optical telecommunication system according to claim 11.

5 It is still a further aspect of the present invention to provide an use of an optical multiplexing device according to claim 22.>

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invention.

Fig. 1 is a schematic diagram of a WDM optical telecommunication system according to an embodiment of the present invention;

- 5 Fig. 2 is a schematic diagram of a first terminal site of the system of Fig. 1;

Fig. 3 is a schematic diagram of a transmitter power amplifier section of the first terminal site of Fig. 2;

- 10 Fig. 4 is a schematic diagram of an optical line site of the system of Fig. 1;

Fig. 5 is a schematic diagram of a second terminal site of the system of Fig. 1;

Fig. 6 is a schematic diagram of a demultiplexing section of the second terminal site of Fig. 5;

- 15 Fig. 7 is a schematic diagram of a nonuniform gain spectrum, at the output of a receiver pre-amplifier section in the second terminal site of Fig. 5, of a chain of optical amplifiers cascaded in the optical telecommunication system 1 of Fig. 1;

- 20 Fig. 8 is a schematic diagram of an embodiment of a first multiplexing device, according to the invention, of the first terminal site of Fig. 2;

- Fig. 9 is a schematic diagram of a step preemphasis curve (Fig. 9a) and a smoothened preemphasis curve (Fig. 9b)
25 obtained in the system of Fig. 1;

Fig. 10 is a schematic diagram of a first embodiment of a second multiplexing device, according to the invention, of the first terminal site of Fig. 2;

- Fig. 11 is a schematic diagram of a second embodiment of a
30 second multiplexing device, according to the invention, of

the first terminal site of Fig. 2.

For simplicity, the optical telecommunication system 1 hereinafter described with reference to Fig. 1 is unidirectional, that is signals travel from a terminal site to the other (in the present case from a first terminal site to a second terminal site), but any consideration that follow is to be considered valid also for bi-directional systems, in which signals travel in both directions.

Further, although the optical telecommunication system 1 is adapted to transmit up to one-hundred-twenty-eight (128) channels, from the hereinafter description it will be obvious that the number of channels is not a limiting feature for the scope ~~and the spirit~~ of the invention, and more than one-hundred-twenty-eight (128) channels can be used depending on the needs and requirements of the particular optical telecommunication system.

The first terminal site 10, that will be later described with reference to Fig. 2, is a transmitting terminal and preferably includes a multiplexing section (MUX) 11, a transmitter power amplifier section (TPA) 12 and a plurality of input channels 16. The second terminal site 20 is a receiving terminal and preferably includes a receiver pre-amplifier (RPA) section 14, a demultiplexing section (DMUX) 15 and a plurality of output channels 17.

Each input channel 16 is received by multiplexing section 11. Multiplexing section 11, that will be later described, multiplexes (or groups) input channels 16 preferably into three sub-bands, referred to as blue-band BB, first red-band RB1 and second red-band RB2, although multiplexing section 11 could alternatively group input channels 16 into a number of sub-bands greater or less than three.

The three sub-bands BB, RB1 and RB2 are then received in succession by the TPA section 12, at least one line site 40 and the second terminal site 20. Sections of optical fiber

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line 30 adjoin the at least one line site 40 with TPA section 12, RPA section 14, and possibly with others line sites 40 (not shown). TPA section 12, that will be later described with reference to Fig. 3, receives the separate
5 sub-bands BB, RB1 and RB2 from multiplexing section 11, amplifies and optimizes them, and then combines them into a single wide-band SWB for transmission on a first section of optical fiber line 30. Line site 40, that will be later described with reference to Fig. 4, receives the single
10 wide-band SWB, re-divides the single wide-band SWB into the three sub-bands BB, RB1 and RB2, eventually adds and drops signals in each sub-band BB, RB1 and RB2, amplifies and optimizes the three sub-bands BB, RB1 and RB2 and then recombines them into the single wide-band SWB. For the
15 adding and dropping operations, line site 40 may be provided with Optical Add/Drop Multiplexers (OADM) of a known type.

A second section of optical fiber line 30 couples the output of the line site 40 to either another line site 40
20 (not shown) or to RPA section 14 of second terminal site 20. RPA section 14, that will be later described with reference to Fig. 5, also amplifies and optimizes the single wide-band SWB and splits the single wide-band SWB into the three sub-bands BB, RB1 and RB2 before outputting
25 them.

Demultiplexing section 15, that will be later described with reference to Fig. 6, receives the three sub-bands BB, RB1 and RB2 from RPA section 14 and splits the three sub-bands BB, RB1 and RB2 into the individual wavelengths of
30 output channels 17. The number of input channels 16 and output channels 17 may be unequal, owing to the fact that some channels can be dropped and/or added in line site (or line sites) 40.

The following provides a more detailed description of the
35 various modules of the optical telecommunication system of the present invention depicted in Fig. 1.

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Fig. 2 shows a more detailed diagram of the first terminal site 10 which includes, in addition to the multiplexing section 11 and the TPA section 12 an optical line terminal equipment (OLTE) 41 and a wavelength converter section 5 (WCS) 42.

OLTE 41, which may correspond to a standard line terminal equipment for use in a conventional SONET, ATM, IP or SDH system, includes transmitting/receiving (TX/RX) units (not shown) in a quantity that equals the number of channels in 10 the first terminal site 10. As readily understood to one of ordinary skill in the art, OLTE 41 may also comprise a collection of smaller separate OLTEs, such as three.

In a preferred embodiment, OLTE 41 has one-hundred-twenty-eight (128) TX/RX units for supplying 128 signals. 15 Typically, said signals are at a generic wavelength.

As shown in Fig. 2, in a preferred embodiment OLTE 41 outputs a first group of sixteen (16) channels, a second group of forty-eight (48) channels and a third group of sixty-four (64) channels.

20 Accordingly, WCS 42 includes one-hundred-twenty-eight (128) wavelength converter modules WCM1-WCM128.

Units WCM1-WCM16 each receive a respective one of the first group of signals emitted from OLTE 41 to convert it from a generic wavelength into a selected wavelength comprised in 25 the blue band BB; units WCM17-WCM64 each receive one of the second group of signals emitted from OLTE 41 to convert it from a generic wavelength into a selected wavelength comprised in the first red band RB1; and units WCM65-WCM128 each receive one of the third group of signals emitted from 30 OLTE 41 to convert it from a generic wavelength into a selected wavelength comprised in the second red band RB2.

As described in US 5267073, each WCM1-128 preferably comprises a module having a photodiode (not shown) for receiving an optical signal from OLTE 41 and converting it

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to an electrical signal, a laser or optical source (not shown) for generating a selected carrier wavelength, and an electro-optic modulator such as a Mach-Zehnder modulator (not shown) for externally modulating the fixed carrier
5 wavelength with the electrical signal. Alternatively, each WCM1-128 may comprise a photodiode (not shown) together with a laser diode (not shown) that is directly modulated with the electrical signal to convert the received generic wavelength to the selected carrier wavelength of the laser
10 diode.

Although Fig. 2 shows that the signals are provided and generated by the combination of OLTE 41 and WCM1-WCM128, each signal can also be directly provided and generated by an optical source suitable for supplying a signal with the
15 selected wavelength.

The multiplexing section 11 includes three wavelength multiplexing devices (WM) 43, 44 and 45. For the preferred one-hundred-twenty-eight (128) channels system, each selected wavelength signal output from units WCM1-WCM16 is
20 received by WM 43, each selected wavelength signal output from WCM17-WCM64 is received by WM 44 and each selected wavelength signal output from WCM65-WCM128 is received by WM 45. WM 43, WM 44 and WM 45 combine the received signals of the three bands BB, RB1 and RB2 into three respective
25 wavelength division multiplexed signals. As shown in Fig. 2, WM 43 is a 16x1 wavelength multiplexing device, WM 44 is a 48x1 wavelength multiplexing device and WM 45 is a 64x1 wavelength multiplexing device. The WM 43, 44, 45 will be later described.

30 With reference to fig. 3, the BB, RB1 and RB2 multiplexed signals output from multiplexing section 11 are received by TPA section 12.

TPA section 12 includes three amplifier sections 51, 52, 53, each for a respective band BB, RB1 and RB2 and a
35 coupling filter 54. Amplifier sections 51, 52 and 53 are

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preferably erbium-doped two-stages fiber amplifiers (although other rare-earth-doped fiber amplifiers or semiconductor amplifiers may be used).

Each of the amplifiers 51, 52 and 53 is pumped by one or two laser diodes to provide optical gain to the signals it amplifies. The characteristics of each amplifier, including its length and pump wavelength, are selected to optimize the performance of that amplifier for the particular sub-band that it amplifies. For example, the first stage of amplifier sections 51 and 52 may be pumped with a laser diode (not shown) operating at 980 nm (or 1480 nm) to amplify the BB band and the RB1 band, respectively, in a linear or in a saturated regime. Appropriate laser diodes are available from the Applicant. The laser diodes may be coupled to the optical path of the pre-amplifiers using 980/1550 (or 1480/1550) wavelength selective couplers (not shown) commonly available on the market, for example model SWDM0915SPR from E-TEK DYNAMICS, INC., 1885 Lundy Ave., San Jose, CA (USA). The 980 nm pump provides a low noise figure for the amplifiers compared with other possible pump wavelengths. The first stage of amplifier section 53 is preferably erbium-doped and amplifies the RB2 band with a 1480 nm (or 980 nm) pump (not shown) coupled to the optical path of the RB2 band using a 1480/1550 (or 980/1550) wavelength selective coupler (not shown).

The second stage of each amplifier section 51-53 preferably operates in a saturated condition. The second stage of amplifier section 51 is preferably erbium-doped and amplifies the BB band with another 980 nm (or 1480 nm) pump (not shown) coupled to the optical path of the BB band using a 980/1550 (or 1480/1550) wavelength selective coupler (not shown) described above. The 980 nm pump provides better gain behavior and noise figure for signals in the low band region that covers 1529-35 nm. The second stage of amplifier section 52 is preferably erbium-doped and amplifies the RB1 band with a laser diode pump source

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operating at 1480 nm. Such a laser diode is available on the market, such as model FOL1402PAX-1 supplied by JDS FITELE, INC., 570 Heston Drive, Nepean, Ontario (CA). The 1480 nm pump provides better saturated conversion efficiency behavior, which is needed in the RB1 band for the greater number of channels in the region that covers 1542-1561 nm. Alternatively, a higher power 980 nm pump laser or multiplexed 980 nm pump sources may be used. The second stage of amplifier section 53 is preferably erbium-doped and amplifies the RB2 band with another 1480 nm pump (not shown) coupled to the optical path of the RB2 band using a WDM coupler (not shown).

After passing through the amplifiers of TPA 12, the amplified BB, RB1 and RB2 bands output from amplifier sections 51, 52 and 53, respectively, are received by filter 54. Filter 54 is a conventional band combining filter and may, for example, include two cascaded interferential filters with three port (not shown), the first coupling the BB band with the RB1 band and the second coupling the BB/RB1 bands provided by the first filter with the RB2 band.

The single wide-band SWB output from filter 54 of TPA section 12 passes through a length of transmission fiber (not shown) of optical fiber line 30 such as 100 kilometers, which attenuates the channels comprised within the single wide-band SWB. Consequently, line site 40 receives and amplifies the channels within the single wide-band SWB. As shown in Fig. 4, line site 40 includes several optical amplifiers (AMP) 64-69, three optical filters 70-72, an optical equalizing filter (EQ) 74 and three OADM devices 75-77.

Filter 70 receives the single wide-band SWB and separates the RB2 band from the BB and the RB1 bands. Amplifier 64 receives and amplifies the BB and the RB1 bands, whereas filter 71 receives the output from amplifier 64 and separates the BB band and the RB1 band. The gain spectrum

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in the BB band is first equalized in a conventional way by using a conventional equalizing filter 74, then the BB band is received by the first OADM 75 where predetermined signals are dropped and/or added, and further amplified by
5 amplifier 65. The RB1 band, is first amplified by amplifier 66, then received by the second OADM 76 where predetermined signals are dropped and/or added, and further amplified by amplifier 67. The RB2 band is first amplified by amplifiers 68, then received by the third OADM 77 where
10 predetermined signals are dropped and/or added, and further amplified by amplifier 69. The amplified BB, RB1 and RB2 bands are then recombined into the single wide-band SWB by filter 72.

Amplifier 64, which receives the BB and the RB1 bands,
15 preferably is an optical fiber amplifier that is operated in a linear regime. That is, amplifier 64 is operated in a condition where its output power is dependent on its input power. Depending on the actual implementation, amplifier 64 may alternatively be a single-stage or a multi-stage
20 amplifier. By operating it in a linear condition, amplifier 64 helps to ensure relative power independence between the BB and RB1 band channels. In other words, with amplifier 64 operating in a linear condition, the output power (and signal-to-noise ratio) of individual channels in
25 the one of the two sub-bands BB, RB1 does not vary significantly if channels in the other sub-band RB1, BB are added or removed. To obtain robustness with respect to the presence of some or all of the channels in a dense WDM system, first stage amplifier (such as amplifier 64) must
30 be operated, in a line site 40, in an unsaturated regime, before extracting a portion of the channels for separate equalization and amplification. In a preferred embodiment, amplifier 64 is an erbium-doped fiber amplifier, pumped in a co-propagating direction with a laser diode (not shown)
35 operating at 980 nm pump to obtain a noise figure preferably less than 5.5 dB for each band.

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Filter 71 may comprise, for example, a three-port device, preferably a conventional interferential filter, having a drop port that feeds the BB band into equalizing filter 74 and a reflection port that feeds the RB1 band into
5 amplifier 66.

Amplifier 66 is preferably an erbium-doped fiber amplifier that is operated in saturation, such that its output power is substantially independent from its input power. In this way, amplifier 66 serves to add a power booster to the
10 channels in the RB1 band compared with the channels in the BB band. Due to the greater number of channels in the RB1 band compared with the BB band in the preferred embodiment, i.e. forty-eight (48) channels as opposed to sixteen (16), the RB1 band channels typically will have had a lower gain
15 when passing through amplifier 64. As a result, amplifier 66 helps to balance the power for the channels in the RB1 band compared with the BB band. Of course, for other arrangements of channels between the BB and the RB1 bands, amplifier 66 may not be required or may alternatively be
20 required on the BB band side of line site 40.

With respect to the RB1 band of channels, amplifiers 64 and 66 may be viewed together as a two-stage amplifier with the first stage operated in a linear mode and the second stage operated in saturation. To help stabilize the output power
25 between channels in the RB1 band, amplifier 64 and 66 are preferably pumped with the same laser diode pump source. In this manner, as described in EP 695049, the residual pump power from amplifier 64 is provided to amplifier 66. More particularly, line site 40 includes a wavelength
30 selective coupler positioned between amplifier 64 and filter 71 that extracts 980 nm pump light that remains at the output of amplifier 64. This wavelength selective coupler may be, for example, model number SWDMCPR3PS110 supplied by E-TEK DYNAMICS, INC., 1885 Lundy Ave., San
35 Jose, CA (USA). The output from this wavelength selective coupler feeds into a second wavelength selective coupler

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(not shown) of the same type and positioned in the optical path after amplifier 66. The two couplers are joined by an optical fiber 78 that transmits the residual 980 nm pump signal with relatively low loss. The second wavelength selective coupler passes the residual 980 nm pump power into amplifier 66 in a counter-propagating direction.

From amplifier 66, RB1 band signals are conveyed to OADM 76, for example an OADM of a known type. From OADM 76, RB1 band signals are fed to amplifier 67. For the preferred erbium-doped fiber amplifier, amplifier 67 has a pump wavelength of, for example, 1480 nm from a laser diode source (not shown) having a pump power in excess of the laser (not shown) that drives amplifiers 64 and 66. The 1480 nm wavelength provides good conversion efficiency for high output power output compared with other pump wavelengths for erbium-doped fibers. Alternatively, a high power 980 nm pump source or a group of multiplexed pump sources, such as two pump sources at 980 nm, or one at 975 nm and another at 986 nm, could be used to drive amplifier 67. Amplifier 67 preferably operates in saturation to provide the power boost to the signals within the RB1 band, and if desired, may comprise a multi-stage amplifier.

After passing through amplifier 64 and filter 71, the BB band enters equalizing filter 74. The gain characteristic for the erbium-doped fiber spectral emission range has a peak or hump in the BB band region, but remains fairly flat in the RB1 band region. This is why, in order to provide a proper flattening of the gain characteristic for the channels, the spectrum of the channels is preferably splitted into a BB band and a RB1 band and these bands are processed separately.

In a preferred embodiment, the equalizing filter 74 comprises a two-port device based on a conventional long period chirped Bragg grating technology that gives selected attenuation at different wavelengths. For instance, equalizing filter 74 for the BB band may have a transfer

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function substantially equal to the inverse of the gain spectrum in the BB band region and an operating wavelength range of 1529 nm to 1536 nm, with a wavelength at the bottom of the valley at between 1530.3 nm and 1530.7 nm.

5 Equalizing filter 74 need not be used alone and may be combined in cascade with other filters (not shown) to provide an optimal filter shape, and thus, gain equalization for the particular amplifiers used in the WDM system 1. Equalizing filter 74 may be manufactured by one

10 skilled in the art, or may be obtained from numerous suppliers in the field. It is to be understood that the particular structure used for the equalizing filter 74 is within the realm of the skilled artisan and may include, for instance, a specialized Bragg grating like a long

15 period grating, an interferential filter, or Mach-Zehnder type optical filters.

From equalizing filter 74, BB band signals are conveyed to OADM 75, which is, for example, of the same type of OADM 76, and then to amplifier 65. With the preferred erbium-

20 doped fiber amplifier, amplifier 65 has a pump wavelength of 980 nm, provided by a laser diode source (not shown) and coupled via a wavelength selective coupler (not shown) to the optical path for pumping the amplifier 65 in a counter-propagating direction. Since the channels in the BB band

25 pass through both amplifier 64 and amplifier 65, equalizing filter 74 may compensate for the gain disparities caused by both amplifiers. Thus, the decibel drop for equalizing filter 74 should be determined according to the overall amplification and line power requirements for the BB band.

30 The amplifier 65 preferably operates in saturation to provide a power boost to the signals in the BB band, and may be a multi-stage amplifier if desired.

The RB2 band is received from fiber amplifier 68, which is, preferably, an erbium doped fiber amplifier pumped with a

35 980 nm or a 1480 nm pump light, depending on the system requirements. From amplifier 68, RB2 band channels are

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conveyed to OADM 77, which is, for example, of the same type of OADMs 75 and 76, and then fed to amplifier 69. Amplifier 69 is, as an example, an erbium doped amplifier adapted to amplify the RB2 band by means of a combination
5 of one or more 1480 pump lasers.

After passing through amplifiers 65, 67 and 69 respectively, the amplified BB, RB1 and RB2 bands are then recombined by filter 72 into the single wide-band SWB. Like filter 54 of fig. 3, filter 72 may, for example,
10 include two cascaded interferential three port filter (not shown), the first coupling the BB with the RB1 bands and the second coupling the BB and RB1 bands provided by the first filter with the RB2 band.

Besides amplifiers 64-69, filters 70-72 and 74, and OADMs
15 75-77, line site 40 may also include a dispersion compensating module (DCM) (not shown) for compensating for chromatic dispersion that may arise during transmission of the signals along the long-distance communication link. The DCM (not shown) is preferably comprised of sub-units
20 coupled upstream one or more of amplifiers 65, 67, 69 for compensating the dispersion of channels in the BB, RB1, RB2 bands, and may also have several forms. For example, the DCM may have an optical circulator with a first port connected to receive the channels in one or more than one
25 of the three bands BB, RB1 and RB2. A chirped Bragg grating may be attached to a second port of the circulator. The channels will exit the second port and be reflected in the chirped Bragg grating to compensate for chromatic dispersion. The dispersion compensated signals will then
30 exit a next port of the circulator for continued transmission in the WDM telecommunication system 1. Other devices besides the chirped Bragg grating, such as a length of dispersion compensating fiber, may be used for compensating the chromatic dispersion. The design and use
35 of the DCM section are not limiting the present invention and the DCM section may be employed or omitted in the WDM

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system 1 depending on overall requirements for system implementation.

After the line site 40, the combined single wide-band SWB signal passes through a length of long-distance optical transmission fiber of optical fiber line 30. If the distance between the first and the second terminal site 10, 20 is sufficiently long to cause attenuation of the optical signals, i.e. 100 kilometers or more, one or more additional line sites 40 providing amplification may be used. In a practical arrangement, five spans of long-distance transmission fiber are used (each having a power loss of 0,22 dB/km and a length such as to provide a total span loss of approximately 25 dB), separated by four amplifying line site 40.

Following the final span of transmission fiber, RPA section 14 receives the single wide-band SWB from last line site 40 and prepares the signals of the single wide-band SWB for reception and detection at the end of the communication link. As shown in Fig. 5, RPA section 14 may include amplifiers (AMP) 81-85, filters 86 and 87, an equalizing filter 88 and, if necessary, three router modules 91-93.

Filter 86 receives the single wide-band SWB and separates the RB2 band from the BB and RB1 bands. Amplifier 81 is preferably doped with erbium and amplifies the BB and RB1 bands to help improve the signal-to-noise ratio for the channels in the BB and RB1 bands. Amplifier 81 is pumped, for example, with a 980 nm pump or with a pump at some other wavelength to provide a low noise figure for the amplifier. The BB and RB1 bands are in turn separated by filter 87.

As with TPA section 12 and line site 40, amplifier 82 and 83 amplify the BB band and, respectively, the RB1 band, with a 980 nm pumping. To help stabilize the output power between channels in the RB1 band, amplifier 81 and 83 are preferably pumped with the same 980 nm laser diode pump

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source, by using a joining optical fiber 89 that transmits the residual 980 nm pump signal with relatively low loss. Specifically, amplifier 81 is associated with a wavelength selective coupler, positioned between amplifier 81 and
5 filter 87, that extracts the 980 nm pump light that remains at the output of amplifier 81. This wavelength selective coupler may be, for example, model number SWDMCPR3PS110 supplied by E-TEK DYNAMICS, INC., 1885 Lundy Ave., San Jose, CA (USA). The output from this wavelength selective
10 coupler feeds into a second wavelength selective coupler of the same type and positioned in the optical path after amplifier 83. The two couplers are joined by an optical fiber 89 that transmits the residual 980 nm pump signal with relatively low loss. The second wavelength selective
15 coupler passes the residual 980 nm pump power into amplifier 83 in a counter-propagating direction. Thus, amplifiers 81-83, filter 87 and equalizing filter 88 perform the same functions as amplifiers 64, 65 and 66, filter 71, and equalizing filter 74, respectively, of line
20 site 40 and may comprise the same or equivalent parts depending on overall system requirements.

RPA section 14 may also include a dispersion compensating module (DCM) (not shown) for compensating for chromatic dispersion that may arise during transmission of the
25 signals along the long-distance communication link. The DCM (not shown) is preferably comprised of sub-units coupled upstream one or more of amplifiers 82, 83, 85 for compensating the dispersion of channels in the BB, RB1, RB2 bands, and may have the forms described with reference to
30 TPA section 12.

Amplifier 84 is coupled to filter 86 to receive and amplify the RB2 band. Amplifier 84 is, for example, an erbium-doped amplifier identical to the amplifier 68 of fig. 4. RB2 band channels are then received by amplifier 85 that
35 is, for example, an erbium-doped amplifier of a known type.

RPA section 14 further comprises a routing stage 90, which

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permits to adapt the channel spacing within the BB, RB1 and RB2 bands to the channel separation capability of demultiplexing section 15. In particular, if the channel separation capability of demultiplexing section 15 is for a relatively wide channel spacing (e.g. 100 GHz grid) while channels in WDM system 1 are densely spaced (e.g. 50 GHz), then RPA section 14 could include the routing stage 90 shown in Fig. 5. Other structures may be added to RPA section 14 depending on the channel separation capability of demultiplexing section 15.

Routing stage 90 includes three router modules 91-93. Each router module 91-93 separates the respective band into two sub-bands, each sub-band including half of the channels of the corresponding band. For example, if the BB band includes sixteen (16) channels λ_1 - λ_{16} , each separated by 50 GHz, then router module 91 would split the BB band into a first sub-band BB' having channels $\lambda_1, \lambda_3, \dots, \lambda_{15}$ separated by 100 GHz and a second sub-band BB'' having channels $\lambda_2, \lambda_4, \dots, \lambda_{16}$ separated by 100 GHz and interleaved with the channels in the sub-band BB'. In a similar fashion, router modules 92 and 93 would split the RB1 band and the RB2 band, respectively, into first sub-bands RB1' and RB2' and second sub-bands RB1'' and RB2''.

Each router module 91-93 may, for example, include an optical coupler (not shown) that has a first series of Bragg gratings attached to a first port and a second series of gratings attached to a second port. The Bragg gratings attached to the first port would have reflection wavelengths that correspond to every other channel (i.e. the even channels), while the Bragg gratings attached to the second port would have reflection wavelengths that correspond to the remaining channels (i.e. the odd channels). This arrangement of gratings will also serve to split the single input path into two output paths with twice the channel-to-channel spacing.

Alternatively, each router module 91-93 separates the

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respective band into two or more serial sub-bands. For example, if the BB band includes sixteen (16) channels λ_1 - λ_{16} , each separated by 50 GHz, then router module 91 would split the BB band into a first sub-band BB' having channels
 5 $\lambda_1, \lambda_2, \dots, \lambda_8$ and into a second sub-band BB'' having channels $\lambda_9, \lambda_{10}, \dots, \lambda_{16}$. In order to separate the respective band in two or more serial sub-bands, routers 91-93 may comprise interferential filters.

After passing through RPA section 14, the BB', BB'', RB1',
 10 RB1'', RB2' and RB2'' sub-bands are received by demultiplexing section 15. In the embodiment shown in Fig. 6, demultiplexing section 15 includes six conventional wavelength demultiplexers (WDs) 95', 95'', 96', 96'', 97', 97'' which receive the respective sub-bands BB', BB'',
 15 RB1', RB1'', RB2' and RB2'' and provide the output channels 17. Demultiplexing section 15 further includes receiving units Rx1-Rx128 for receiving the output channels 17.

The wavelength demultiplexers preferably comprise arrayed waveguide grating (AWG) devices, but alternative structures
 20 for achieving the same or similar wavelength separation are contemplated. For instance, one may use interferential filters, Fabry-Perot filters, Mach Zehnder devices or in-fiber Bragg gratings in a conventional manner to demultiplex the channels within the sub-bands BB', BB'',
 25 RB1', RB1'', RB2', RB2''.

In a preferred configuration, demultiplexer section 15 combines interferential filter and AWG filter technology. Alternatively, one may use Fabry-Perot filters or in-fiber Bragg gratings. WDs 95', 95'', which are preferably eight
 30 channel demultiplexers with interferential filters, receive and demultiplex first sub-band BB' and second sub-band BB'', respectively. Specifically, WD 95' demultiplexes channels $\lambda_1, \lambda_3, \dots, \lambda_{15}$, and WD 95'' demultiplexes channels $\lambda_2, \lambda_4, \dots, \lambda_{16}$. Both WD 95' and WD 95'', however, may be
 35 1x8 type AWG 100 GHz demultiplexers. Similarly, WDs 96' and 96'' receive and demultiplex first sub-band RB1' and

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second sub-band RB1'', respectively, to produce channels $\lambda_{17}-\lambda_{64}$ and WDs 97' and 97'' receive and demultiplex first sub-band RB2' and second sub-band RB2'', respectively, to produce channels $\lambda_{65}-\lambda_{128}$. Both WD 96' and WD 96'' may be 1x 32 type AWG 100 GHz demultiplexers that are underequipped to use only twenty-four of the available demultiplexer ports and both WD 97' and WD 97'' may be 1x 32 type AWG 100 GHz demultiplexers that uses all the available demultiplexer ports. Output channels 17 are composed of the individual channels demultiplexed by WDs 95', 95'', 96', 96'', 97', 97'', and each channel of output channels 17 is received by one of receiving units Rx1-Rx128.

Fig. 7 is a qualitative graph of the nonuniform gain spectrum at the end of the chain of optical amplifiers cascaded along the optical telecommunication system 1 (e.g. at the output of the RPA section 14) having five spans of long-distance transmission fiber (each having a length such as to provide a total span loss of approximately 25 dB) separated by four amplifying line site 40. This graph does not show the tilt due to the known saturation phenomenon in the chain of optical amplifiers and approximately corresponds to the different gain for channels travelling through the telecommunication system and the different allocation of the three sub-bands BB, RB1 and RB2.

In particular, the first sub-band BB preferably covers the range between 1529 nm and 1535 nm, corresponding to a first amplification wavelength range of erbium-doped fiber amplifiers, and allocates up to sixteen (16) channels; the second sub-band RB1 falls between 1541 nm and 1561 nm, corresponding to a second amplification wavelength range of erbium-doped fiber amplifiers, and allocates up to forty-eight (48) channels; and the third sub-band RB2 covers the range between 1575 nm and 1602 nm, corresponding to an amplification wavelength range of erbium-doped fiber amplifiers, and allocates up to sixty-four (64) channels. The gain spectral graph of the erbium-doped fiber

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amplifiers is such that, although the 1575-1602 nm range offers the best performances in terms of amplification, channels can be advantageously allocated down to 1565 nm and up to 1620 nm.

- 5 The following provides a more detailed description of the wavelength multiplexing devices WM 44 and WM 45, according to the present invention, of the multiplexing section 11.

Fig. 8 shows an embodiment of the 64x1 multiplexing device WM 45 operating in the RB2 band apted, according to the
10 present invention, to be used in the optical telecommunication system 1.

The WM 45 comprises fifteen optical couplers arranged in a tree topology having 64 input ports and one output port.

Said tree topology has one input level, one output level
15 and three intermediate levels.

The input level comprises eight balanced optical couplers: two couplers 16x1 202, 202', two couplers 8x1 206, 206' and four 4x1 couplers 205, 205', 207, 207'.

The first intermediate level comprises two 2x1 wavelength
20 selective optical couplers 213, 213'.

The second intermediate level level comprises two 2x1 unbalanced couplers 217, 217'.

The third intermediate level comprises two 2x1 balanced couplers 225, 225'.

25 The output level comprises one 2x1 balanced coupler 231.

Of course, the expressions "balanced coupler" and "unbalanced coupler" are intended to indicate a non wavelength selective optical coupler where otherwise not indicated.

30 In its turn, said 16x1 optical couplers 202, 202' are

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located in corresponding multiplexing units 240, 240', said couplers 205, 206, 207, 213, 217 and 205', 206', 207', 213', 217' are located in multiplexing units 204 and 204', respectively; and couplers 225, 225' and 231 are located in
5 a multiplexing unit 224.

The two 16x1 optical couplers 202, 202' have 16 input fibers 208 and 208', respectively, and are each able to combine 16 entering optical channels along a single corresponding output port 203 and 203'.

10 The optical coupler 205, 205', 206, 206', 207, 207' have input optical fibers 208, 208' and optical output fibers 209, 209', 210, 210', 211, 211', respectively.

As the left side of the tree topology is specular to the right side, same numerical references followed by the
15 superscript " ' " are used to indicate same components. Furthermore, the description of the right side of the tree topology also applies to the left side thereof.

The output fiber 209 of the optical coupler 205 is connected to a first input 212 of the wavelength selective
20 optical coupler 213 and the output fiber 211 of the optical coupler 207 is connected to a second input 214 of said coupler 213.

An output fiber 215 of the coupler 213 is connected to an input port 216 of the unbalanced optical coupler 217.

25 The wavelength selective optical coupler 213 is able to combine channels entering port 212 and 214 along a single port 215.

The output fiber 210 of the optical coupler 206 is connected to an input port 218 of the unbalanced optical
30 coupler 217.

The unbalanced optical coupler 217 is able to combine the optical channels entering at input ports 218 and 216 along

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the output fiber 219.

In the embodiment of the invention shown in Fig. 8, the unbalanced optical coupler 217 is of the type 40:60: i.e., 40% of the optical power at the input port 218 is sent at the output fiber 219 and 60% of the optical power at the input port 216 is sent at the output fiber 219.

The optical fibers 219 and 219' are respectively connected to the output ports 221 and 221' of the multiplexing units 204 and 204'.

10 The output port 221 of the multiplexing unit 204 and the output port 203 of the multiplexing unit 240 are respectively optically connected to input ports 222 and 223 of the multiplexing unit 224.

Moreover, the output port 221' of the multiplexing unit 204' and the output port 203' of the multiplexing unit 240' are respectively optically connected to input ports 222' and 223' of the multiplexing unit 224.

The two optical couplers 225 and 225' of the multiplexing unit 224 have respectively input ports 226, 227 and 226' and 227' optically connected respectively to the input ports 222, 223 and 222', 223'.

The optical couplers 225 and 225' are able to combine optical channels entering the input fibers along the output fibers 228 and 228'.

25 The output fibers 228 and 228' are connected to ports 229, and 230 of the 2x1 optical coupler 231 that is able to combine the entering optical channels along one output fiber 232. This output fiber 232 is connected to an output port 233 of the WM 45.

30 Accordingly, the multiplexing device WM 45 combines 64 channels entering from fibers 208 and 208' in a single output port 233.

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Typically, the optical couplers in the WM 45 are conventional planar optical couplers or fused fiber optical couplers. This makes the wavelength multiplexing device WM 45 very simple to produce and at low cost.

- 5 Furthermore, if necessary, such conventional couplers can be advantageously made of the type polarization maintaining at low cost and by means of a conventional, easy to implement, technology.

10 E-TEK makes fiber fused and planar optical coupler suitable for using in the WM 45 above described, e.g., the 2x2 optical coupler 217 can be an E-TEK coupler, Model SWBC2PS0PRL19 and the 16x1 optical coupler 202 can be an E-TEK coupler, Model SWTCYE30RPRL10 having operating band of 1574-1603 nm.

- 15 In the embodiment shown, optical couplers 213 and 213' are wavelength selective optical coupler. More particularly, they are conventional band combining interferential filters. However, they can also be planar optical couplers or fused fiber optical couplers.

- 20 Interferential filters are preferred because they have less intrinsic losses than the planar or fused fiber optical couplers. Band combining interferential filters suitable for using in the WM 45 of the invention are made by E-TEK.

25 Preferably, each input fiber 208, 208' is provided of attenuating splices 100, 100' selected so as to have a predetermined value of loss, as it will be later described. Typically, these attenuating splices 100, 100' are of the conventional type for which a pre-established attenuation is obtained by a suitable misalignment of the optical axes
30 of the fibers that are connected therein.

In the WM 45 there are eight different optical paths for eight different groups of channels.

As shown in Fig. 8, these eight optical paths are the

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following:

- the path a (a') comprising the optical couplers 206, 217, 225 and 231 (206', 217', 225', 231);
- the path b (b') comprising the optical couplers 202, 225
5 and 231 (202', 225', 231);
- the path c_1 (c_1') comprising the optical couplers 205, 213, 217, 225, 231 (optical coupler 205', 213', 217', 225', 231);
- the path c_2 (c_2') comprising the optical coupler 207, 213
10 217, 225, 231 (optical coupler 207', 213', 217', 225', 231).

Each optical path has a loss that depends on the intrinsic losses of the optical couplers comprised therein.

In fact, a conventional Nx1 optical coupler comprises N
15 optical waveguides, as planar waveguides or optical fibers, optically coupled and the coupling occurring between adjacent waveguides introduces a loss. As already described above, this loss is related to the number of optical waveguides optically coupled, independently on the number
20 of the effectively used input ports.

For example, an ideal Nx1 balanced optical coupler having N = 2^n input ports introduces on the channels passing through it an ideal intrinsic loss equal to $n \cdot 3\text{dB}$. Furthermore, an additional loss, "excess loss", due to production process
25 has also to be considered. Typically, the excess loss rises as the number of input ports of the coupler increases.

Thus, the real intrinsic loss of a coupler is generally the sum of the ideal intrinsic loss and the excess loss.

The optical couplers of the described embodiment of the
30 invention have substantially the following real intrinsic losses, IL:

- optical coupler 206, (206'): IL = 10.2 dB;
- optical coupler 202, (202'): IL = 14.3 dB;
- optical couplers 205 (205'), 207 (207'): IL = 7 dB;

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- unbalanced optical couplers 217, (217'): IL = 4.4 dB for channels entering port 218 (218') and outgoing from port 219 (219'); IL = 2.5 dB for channels entering port 216 (216') and outgoing from port 219 (219')
- 5 - optical couplers 225, (225'), 231: IL = 3.4 dB
- wavelength selective optical couplers 213 and 213': IL = 1 dB.

The real intrinsic losses of the optical coupler indicated in the present description are given to exemplify and are
10 not restrictive.

Reference is now made to the operation of the wavelength multiplexing device WM 45 of the invention.

The 64 channels belonging to the RB2 band have wavelengths $\lambda_1, \lambda'_1, \lambda_2, \lambda'_2, \lambda_3, \lambda'_3, \dots, \lambda_{32}, \lambda'_{32}$.

- 15 A first sub-band RB2' comprises thirty-two channels (32) having wavelengths $\lambda_1 - \lambda_{32}$ and a second sub-band RB2" comprises 32 channels having wavelengths $\lambda'_1 - \lambda'_{32}$.

In each sub-band the channels have a spacing of 100 GHz while the distance between a channel λ_n of the first sub-band and a channel λ'_n of the second sub-band is of 50 GHz.
20

With reference to Fig. 7, the four (4) wavelengths $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ and the four (4) wavelengths $\lambda'_1, \lambda'_2, \lambda'_3, \lambda'_4$ lie in a inclined side region C_1 of the gain spectrum in the RB2 band.

- 25 The four (4) wavelengths $\lambda_{29}, \lambda_{30}, \lambda_{31}, \lambda_{32}$ and the four (4) wavelengths $\lambda'_{29}, \lambda'_{30}, \lambda'_{31}, \lambda'_{32}$ lie in the inclined side region C_2 of the gain spectrum in the RB2 band.

The twenty-four (24) wavelengths $\lambda_5, \lambda_6, \dots, \lambda_{27}, \lambda_{28}$ and the wavelengths $\lambda'_5, \lambda'_6, \dots, \lambda'_{27}, \lambda'_{28}$ lie in a substantially flat
30 central region of the gain spectrum in the RB2 band.

In more detail, the eight wavelengths $\lambda_5, \dots, \lambda_{12}$ ($\lambda'_5, \dots, \lambda'_{12}$) correspond to a region A and the sixteen wavelengths $\lambda_{13}, \dots,$

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λ_{28} ($\lambda'_{13}, \dots, \lambda'_{28}$) correspond to a region B of the gain spectrum in the RB2 band.

Because of the shape of the gain spectrum, the channels having wavelengths $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda'_1, \lambda'_2, \lambda'_3, \lambda'_4$ (region C_1) and the channels having wavelengths $\lambda_{29}, \lambda_{30}, \lambda_{31}, \lambda_{32}, \lambda'_{29}, \lambda'_{30}, \lambda'_{31}, \lambda'_{32}$ (region C_2) are less amplified than the channels having wavelengths $\lambda_5, \lambda_6, \dots, \lambda_{27}, \lambda_{28}, \lambda'_5, \lambda'_6, \dots, \lambda'_{27}, \lambda'_{28}$ (regions A, B). More particularly, the maximum gain difference Δ between the side regions C_1, C_2 and the central regions A, B is equal to 4 dB.

In the embodiment shown, the real intrinsic losses of the couplers of the multiplexing device WD 45 and their arrangement in the tree topology are selected so as to attenuate the channels having wavelengths in regions A and B more than the channels having wavelengths in regions C_1 and C_2 of a quantity equal to about Δ (4dB). In this way, at the receiving line site 20 of the optical telecommunication system 1 having five spans of long-distance transmission fiber (each providing a total span loss of approximately 25 dB and separated by four amplifying line sites 40) a suitable optical SNR for the optical channels 17 in the RB2 band can be achieved.

From time to time, the difference in attenuation among the channels having wavelengths in regions A and B and those having wavelengths in regions C_1 and C_2 can be selected so as to meet predetermined system requirements as, for example, the equalization of the optical power or SNR of the optical channels 17 at the second terminal site 20.

The channels having wavelengths $\lambda_5, \dots, \lambda_{12}$ (corresponding to the region A of the amplifier gain spectrum) pass through the above defined optical path a and undergo substantially the following losses:

- IL=10.2 dB caused by the optical coupler 206;
- IL=4.4 dB caused by optical coupler 217;
- $Il_c=1$ dB caused by the optical connection between output

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- port 221 and input port 222;
- IL = 3.4 dB caused by the optical coupler 225;
 - IL = 3.4 dB caused by optical coupler 231.

Thus, for channels $\lambda_5, \dots, \lambda_{12}$ passing through the path a the
 5 total loss IL_{aT} is equal to about 22.4 dB, wherein the
 index "T" indicates the Total loss.

By considering also the loss due to connection at port 233
 the total loss IL_{aT} is equal to about 23 dB.

The channels having wavelength $\lambda'_5, \dots, \lambda'_{12}$ pass through the
 10 above mentioned path a', equal to the path a, and undergo a
 total loss $IL_{a',T} = IL_{aT}$ that is equal to about 22.4 dB (or to
 about 23 dB by considering the connections at port 233
 too).

The channels having wavelengths $\lambda_{13}, \dots, \lambda_{28}$ ($\lambda'_{13}, \dots, \lambda'_{28}$),
 15 corresponding to the region B of the amplifier gain
 spectrum, propagate along path b (b') and undergo
 substantially the following losses:

- IL = 14.3 dB caused by the optical coupler 202 (202');
 - $IL_c = 1$ dB caused by the optical connection between output
 20 port 203 and input port 223;
- IL = 3.4 dB caused by the optical coupler 225 (225');
- IL = 3.4 dB caused by optical coupler 231.

The total loss $IL_{bT} = IL_{b',T}$ is equal to about 22.1 dB. By
 considering the connection at port 233 the total loss $IL_{bT} =$
 25 $IL_{b',T}$ is equal to about 22.6 dB.

The channels having wavelengths $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ ($\lambda'_1, \lambda'_2, \lambda'_3, \lambda'_4$)
 and $\lambda_{29}, \lambda_{30}, \lambda_{31}, \lambda_{32}$ ($\lambda'_{29}, \lambda'_{30}, \lambda'_{31}, \lambda'_{32}$), corresponding to
 the regions C_1 and C_2 of the amplifier gain spectrum,
 propagate respectively along paths c_1 (c'_1) and c_1 (c'_2) and
 30 undergo substantially the following losses:

- IL = 7 dB caused by the optical coupler 205 or 207 (205'
 or 207');
- IL = 1 dB caused by coupler 213 (213');
- IL = 2.5 dB caused by the unbalanced optical coupler 217

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(217'),

- $IL_c = 1$ dB caused by the optical connection between output port 221 and input port 222;
- $IL = 3.4$ dB caused by the optical coupler 225 (225');
- 5 - $IL = 3.4$ dB caused by optical coupler 231.

The total loss $IL_{c\ 1,2\ T} = IL_{c'\ 1,2\ T}$ is equal to about 18.3 dB. By considering the connection at port 233 the total loss $IL_{c\ 1,2\ T} = IL_{c'\ 1,2\ T}$ is equal to about 18.8 dB.

Therefore, the channels having wavelengths corresponding to the regions A, B of the gain spectrum undergo a total loss greater of about 4 dB than the total loss suffered by the channels having wavelengths corresponding to the regions C_1, C_2 .

Fig. 9a, RB2 band, shows a schematic graph of the preemphasis "step" undergone by the channels passing through the optical paths described above.

By suitably adjusting the losses introduced by the attenuating splices 100, a smoothening of the curve of Fig. 9a can be achieved, as schematically shown in Fig. 9b.

Compared to a conventional optical WDM telecommunication system, the system 1 of the invention carries out the preemphasis and multiplexing operations at the transmitting terminal site 10 with reduced losses.

In fact, as described above, in the system 1 of the invention these operations are both performed by the multiplexing device 45 of the invention that has a maximum total loss of about 22.6 dB.

On the contrary, in a conventional system the preemphasis and multiplexing operations are performed by optical attenuators (adjusted so as to have a preemphasis value of 4dB) and a conventional 64x1 optical passive balanced coupler, respectively. Therefore, at the transmitting terminal of a conventional system the maximum total loss is

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equal to about 27 dB (4dB of preemphasis, 18 dB of ideal intrinsic loss of the conventional 64x1 optical coupler, about 4 dB of excess loss and 1 dB for the connection at the output port of the coupler).

- 5 With the embodiment shown of the system 1 of the invention, a total loss improvement of about 4.4 dB is, thus, achieved.

Additionally, it is worth noting that, at the transmitting terminal site of a WDM telecommunication system having a
10 high number of channels (e.g. 128 channels), the connections among a corresponding high number of transmitting units - each comprising, for example, one OLTE and one wavelength conversion modules WCM - and the input ports of the multiplexing device are very complicated and
15 take up a lot of room.

Additionally, the arrangement of the devices comprised in terminal or line sites of an optical telecommunication system is regulated by standardizing rules as the ones fixed by the American National Standard Institute (ANSI) or
20 the European Standard Telecommunication Institute (ETSI).

With reference to transmitting units, the ANSI standard establishes that a sub-rack may houses eight or multiple of eight transmitting units in suitable slots.

In its turn, the ETSI standard establishes that a single
25 sub-rack may houses six or multiple of six transmitting units.

Typically, eight or sixteen transmitting units in each sub-rack, for ANSI standard, and six or twelve transmitting units in each sub-rack, for ETSI standard, are employed.

- 30 Furthermore, according to these rules, one multiplexing device can be connected at most to two sub-rack.

The multiplexing device of the invention, thanks to the

flexibility of its structure, simplifies the connections to external devices (e.g. transmitting units) and can be easily designed from time to time so as to meet a required standard (e.g. ANSI or ETSI) simply by grouping its optical
5 couplers in predetermined multiplexing units.

For example, the multiplexing device WM 45 shown in Fig. 8, comprising four multiplexing units 240, 240', 204 and 204' with 16 inputs, can advantageously be used to multiplex 64 channels outcoming from four sub-racks, each comprising 16
10 transmitting units according to the ANSI standard.

Furthermore, each multiplexing unit 240, 240', 204, 204' of WM 45 can be housed in separated sub-racks and can be placed near the sub-rack containing the corresponding 16 transmitting units so as to facilitate the connections
15 among transmitting units and the multiplexing device.

Accordingly, since the multiplexing device WM 45 of the invention has the same modularity of the sub-rack designed according to the ANSI standard, it can extremely simplify the connections among OLTE 41 and WCM 42 units and
20 multiplexing unit 11.

According to the invention, multiplexing devices that are particularly suitable for the ETSI standard can be easily designed by a person skilled in the art on the basis of the present description ~~and without departing from the spirit~~
25 ~~of the invention.~~

If only 32 channels are employed in the RB2 band, the WM 45 described before and depicted in Fig. 8 can be modified by eliminating the optical paths a', b', c'. In this case, the wavelength multiplexing device comprises the optical
30 unit 240, the multiplexing unit 204, the optical coupler 225 and the output fiber 228 of the optical coupler 225 can be used as its output port. Furthermore, since it has not the optical coupler 231 and the number of the optical connections is reduced, the total losses of paths a, b and

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c are decreased to about $IL_{aT} = 19.5$ dB; $IL_{bT} = 19.1$ dB and $IL_{cT} = 15.2$ dB, respectively.

Fig. 10 shows an embodiment of the 48x1 multiplexing device WM 44 operating in the RB1 band apted, according to the present invention, to be used in the optical telecommunication system 1.

The WM 44 comprises eleven optical couplers arranged in a tree topology having 48 input ports and one output port.

Said tree topology has one input level, one output level and two intermediate levels.

The input level comprises six balanced optical couplers: two couplers 16x1 202, 202' and four 4x1 couplers 205, 205', 207, 207'.

The first intermediate level comprises two 2x1 wavelength selective optical couplers 213, 213'.

The second intermediate level level comprises two 2x1 unbalanced couplers 217, 217'.

The output level comprises one 2x1 balanced coupler 231.

In its turn, said couplers 202, 205, 207, 213, 217 and 202', 205', 207', 213', 217' are located in multiplexing units 250 and 250', respectively; and coupler 231 is located in a multiplexing unit 270.

The two multiplexing units 250, 250' have input fibers 208 and 208' and have output ports 251 and 251'. Both ports 251 and 251' are optically connected to the input ports 253 and 253' of the multiplexing unit 270.

The multiplexing unit 270 has an output port 254.

The output ports of the optical couplers 205 and 207 (205' and 207') are optically connected to the input ports of the optical coupler 213 (213').

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The output ports of the optical couplers 202 (202') and the optical coupler 213 (213') are connected to the input ports of the unbalanced optical coupler 217 (217').

The output fiber 219 (219') of the unbalanced optical
5 coupler 217 (217') is connected to the output port 251 (251') of multiplexing unit 250 (250').

Each input fiber 208, 208' is provided of attenuating splices 100, 100' able to be adjusted at a suitable value of loss.

10 The devices employed in the WM 44 are of the same type of the ones described with reference to WM 45 and thus are indicated with the same reference numbers.

In particular, all the balanced optical couplers, the unbalanced optical couplers and the wavelength selective
15 optical couplers have the same real intrinsic losses of the corresponding ones depicted in Fig. 8 and before listed.

Suitable devices employed in the WM 44 for the RB1 band are made by E-TEK.

The operation of the WM 44 will be now described.

20 The 48 channels belonging to the RB1 band have wavelengths $\lambda_1, \lambda'_1, \lambda_2, \lambda'_2, \lambda_3, \lambda'_3, \dots, \lambda_{24}, \lambda'_{24}$. A first group of channels comprises thirty-two (24) channels having respectively wavelengths $\lambda_1 - \lambda_{24}$ a second group of channels comprises channels having wavelength $\lambda'_1 - \lambda'_{24}$.

25 With reference to Fig. 7, the wavelengths $\lambda_1, \lambda_2, \lambda_3, \lambda_4$, and the wavelengths $\lambda'_1, \lambda'_2, \lambda'_3, \lambda'_4$ lie in a side inclined region E_1 of the gain spectrum in the RB1 band.

The wavelengths $\lambda_{21}, \lambda_{22}, \lambda_{23}, \lambda_{24}$ and the wavelengths $\lambda'_{21}, \lambda'_{22}, \lambda'_{23}, \lambda'_{24}$ lie in a side inclined region E_2 of the gain
30 spectrum in the RB1 band.

In their turn, the wavelengths $\lambda_5, \lambda_6, \dots, \lambda_{19}, \lambda_{20}$ and the

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wavelengths $\lambda'_5, \lambda'_6, \dots, \lambda'_{19}, \lambda'_{20}$ lie in a central substantially flat region D of the gain spectrum in the RB1 band.

In the embodiment shown, the maximum gain difference Δ between the side regions E_1, E_2 and the central D is of about 4 dB.

Analogously to the WM 45, in the embodiment shown, the real intrinsic losses of the couplers of the multiplexing device WD 44 and their arrangement in the tree topology are selected so as to attenuate the channels having wavelengths in the central region D more than the channels having wavelengths in regions E_1 and E_2 of a quantity equal to Δ (4dB). In this way, at the receiving line site 20 of the optical telecommunication system 1 having five spans of long-distance transmission fiber (each providing a total span loss of approximately 25 dB and separated by four amplifying line sites 40) a suitable optical SNR for the optical channels 17 in the RB1 band can be achieved.

The channels having wavelengths $\lambda_5, \lambda_6, \dots, \lambda_{19}, \lambda_{20}$ ($\lambda'_5, \lambda'_6, \dots, \lambda'_{19}, \lambda'_{20}$), corresponding to the region D of the gain spectrum, propagate along an optical path d (d') comprising the optical coupler 202 (202'), the unbalanced optical coupler 217 (217') and the optical coupler 231.

The channels having wavelengths $\lambda_1, \lambda_2, \lambda_3, \lambda_4$, and wavelengths ($\lambda'_1, \lambda'_2, \lambda'_3, \lambda'_4$), corresponding to the side region E_1 of the amplifiers gain spectrum, propagate along an optical path e_1 (e'_1) comprising the optical coupler 207 (207'), the wavelength selective coupler 213 (213'), the unbalanced optical coupler 217 (217') and the optical coupler 231.

The channels having wavelengths $\lambda_{21}, \lambda_{22}, \lambda_{23}, \lambda_{24}$, and wavelengths ($\lambda'_{21}, \lambda'_{22}, \lambda'_{23}, \lambda'_{24}$), corresponding to the side region E_2 of the amplifiers gain spectrum, propagate along an optical path e_2 (e'_2) comprising the optical coupler 205

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(205'), the wavelength selective coupler 213 (213'), the unbalanced optical coupler 217 (217') and the optical coupler 231.

Therefore, the channels passing through the path d and d' undergo substantially the following losses:

- IL = 14.3 dB caused by the optical coupler 202 (202');
- IL = 2.5 caused in the unbalanced optical coupler 217 ;
- $IL_c = 1$ dB caused by the connection between the port 251 and the port 253;
- IL = 3.4 dB caused by the optical coupler 231.

The total loss $IL_{dT} = IL_{d',T}$ is equal to about 21.2 dB (by considering the connection at port 254 the total loss $IL_{dT} = IL_{d',T}$ is equal to about 22.2 dB).

The channels following the path e_1 , e_2 and e'_1 , e'_2 undergo substantially the following losses:

- IL = 7 dB caused by the optical coupler 205 or 207 (205' or 207');
- IL = 1 dB caused by wavelength selective coupler 213 (213');
- IL = 4.4 dB caused by the unbalanced optical coupler 217 (217');
- $IL_c = 1$ dB caused by the optical connection between the port 251 (251') and 253 (253');
- IL = 3.4 dB caused by optical coupler 231.

The total loss $IL_{eT} = IL_{e',T}$ is equal to about 16.8 dB (by considering the connection at port 254 the total loss $IL_{eT} = IL_{e',T}$ is equal to about 17.8 dB).

Accordingly, the channels having wavelengths corresponding to the regions D of the optical amplifier gain undergo a total loss greater of about 4 dB than the total loss suffered by the channels having wavelengths corresponding to the regions E_1 , E_2 .

Fig. 9a, RB1 band, is a graph of the preemphasis step undergone by the channels passing through the above

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mentioned optical paths of the WM 44.

Similarly to the WM 45, a suitable adjustment of the attenuating splices 100, 100' for any channels allows a smoothening of the curve of Fig. 9a as shown in Fig. 9b.

- 5 In order to multiplex only 24 channels the multiplexing unit 250' and the optical coupler 231 can be eliminated and the port 251 of multiplexing unit 250 can be used as output port of the multiplexing device.

10 As the WM 45, also the WM 44 has the advantage of reducing the losses at the transmitting terminal site 10 of the telecommunication system 1 and of improving the connections to the transmitting units.

For example, the WM 44 of Fig. 10 have a modularity suitable for the connection to three sub-racks each
15 comprising 16 transmitting units, according to the ANSI standard. In fact, the sixteen input ports of the optical coupler 202 and the ones of optical coupler 202' can be connected to corresponding transmitting units of a first and second sub-rack while the eight input ports of the
20 optical couplers 205, 207 and the ones of optical couplers 205', 207' can be connected to a first and a second group of eight transmitting units of the third sub-rack, respectively.

A second embodiment of the 48 channels WM 44 operating in
25 the RB1 band made in accordance with the invention is shown in Fig. 11.

Compared with the first embodiment shown in Fig. 10, the optical couplers of this second embodiment of WM 44 are grouped differently, in order to satisfy a different
30 modularity requirement.

In fact, this embodiment, having modularity 8 and 16, is suitable for the connection to 6 sub-racks each comprising 8 transmitting units or to 2 sub-racks, each comprising 8

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transmitting units, and 2 sub-racks, each comprising 16 transmitting units.

In the WM 44 of Fig. 11, the two 16x1 optical couplers 202 and 202' are arranged in two multiplexing units 280, 280';
5 the four couplers 205, 207, 205', 207' are arranged in multiplexing units 260, 260' and the three couplers 217, 217', 231 are arranged in multiplexing unit 270.

The output ports 203 and 203' of the multiplexing units 280, 280' are connected to input ports 263 and 263',
10 respectively, of the multiplexing unit 270.

Moreover, the output ports 261 and 261' of the two multiplexing units 260 and 260' are connected to input ports 262, 262', respectively, of the multiplexing unit 270.

15 All the components utilized in the device of Fig. 11 are of the same type of the ones employed for the WM 44 of Fig. 10 and, thus, have the same numerical references.

In particular, the balanced optical couplers, the unbalanced optical couplers and the wavelength selective
20 optical couplers provide the same losses before listed.

In figure are shown the optical paths e_1 , e_2 , d and e'_1 , e'_2 , d that have the same total losses as indicated before.

Since the operating of the device of Fig. 11 is analogous to that one of Fig. 10, reference is made to what already
25 said above.

In the embodiment described of the telecommunication system 1 of the invention, the gain equalization in the BB band is performed by means of the above mentioned equalization filters 74 and 88 and the wavelength multiplexing device WM
30 43 is a conventional passive optical balanced coupler. For example, it is a planar or fused fibers coupler.

Fig. 7 schematically shows the curve corresponding to the

gain spectrum in the BB band at the end of the chain of optical amplifiers cascaded in the telecommunication system 1 (unbroken line) and the corresponding equalized gain curve (dashed line).

- 5 However, the gain equalization in the BB band can also be carried out by means of a multiplexing device of the invention suitably designed according to principles that will be clear to the skilled in the art on the basis of the present description ~~and without departing from the spirit~~
10 ~~of the invention.~~

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CLAIMS

1. A WDM optical telecommunication system (1) comprising
 - a transmitting terminal (10) for supplying a plurality M of optical channels (16) - with $M \geq 8$ - comprising a multiplexing unit (11) for multiplexing said plurality M of optical channels (16), said multiplexing unit (11) comprising a multiplexing device (44; 45) having N input ports (208, 208') - with $N \geq M$ - and one output port (233; 254) and comprising at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) having preselected intrinsic losses and coupled together according to a tree topology, said tree topology having N inputs and one output corresponding to said N input ports (208, 208') and one output port (233; 254);
 - an optical telecommunication line (30, 40) operatively coupled to said transmitting terminal (10), for transmitting said plurality M of optical channels (16) multiplexed by said multiplexing device (44; 45), the plurality M of optical channels (16) accumulating optical power and optical SNR imbalance along the optical telecommunication line (30, 40);
 - a receiving terminal (20) operatively coupled to said optical telecommunication line (30, 40) for receiving at least one part (17) of said plurality M of optical channels (16), said at least one part of channels (17) comprising at least two channels;
- wherein both
- a) the preselected intrinsic loss of each of said at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231); and
 - b) the arrangement of said at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) in said tree topology
- are such that, passing through said multiplexing device, at least two of said at least one part of channels (17) are attenuated differently from each other, characterized in

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that the difference in attenuation between said at least two channels is selected so as to achieve, at said transmitting terminal (10), a pre-emphasis predetermined depending on at least one of said optical power imbalance and optical SNR imbalance accumulated along the optical telecommunication line (30, 40).

2. A WDM optical telecommunication system (1) according to claim 1, wherein the difference in attenuation between said at least two channels is selected so as to equalize, at said receiving terminal (20), the power of said at least one part (17) of the plurality M of optical channels (16).

3. A WDM optical telecommunication system (1) according to claim 1, wherein the difference in attenuation between said at least two channels is selected so as to achieve, at said receiving terminal (20), a predetermined value of optical SNR for said at least one part (17) of the plurality M of optical channels (16).

4. A WDM optical telecommunication system (1) according to claim 3, wherein the difference in attenuation between said at least two channels is selected so as to equalize, at said receiving terminal (20), the optical SNR of said at least one part (17) of the plurality M of optical channels (16).

5. A WDM optical telecommunication system (1) according to any of claims 1 to 4, wherein said optical telecommunication line (30, 40) comprises at least one optical amplifying unit (40) having a predetermined nonuniform wavelength dependent gain spectrum in a predetermined wavelength band.

6. A WDM optical telecommunication system (1) according to claim 5, wherein the difference in attenuation between said at least two channels is selected depending on said gain spectrum.

7. A WDM optical telecommunication system (1) according to

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claim 5 or 6, wherein the nonuniform gain spectrum of said at least one optical amplifying unit (40) has a central substantially flat region (A, B, D) and two opposite side inclined regions (E₁, E₂, C₁, C₂).

5 8. A WDM optical telecommunication system (1) according to claim 7, wherein said tree topology of the multiplexing device (44; 45) has an input level at which two groups of said plurality M of optical channels, having wavelengths within said two opposite side inclined regions (E₁, E₂, C₁,
10 C₂), are coupled by two corresponding optical couplers (205, 205', 206, 206', 207, 207') and a third group of said optical channels, having wavelengths within said central substantially flat region (A, B, D), is coupled by at least one optical coupler (202, 202').

15 9. A WDM optical telecommunication system (1) according to claim 8, wherein said two optical couplers (205, 205', 206, 206', 207, 207') have an intrinsic loss lower than the intrinsic loss of said at least one optical coupler (202, 202').

20 10. A WDM optical telecommunication system (1) according to claim 8 or 9, wherein said tree topology of the multiplexing device (44; 45) has an intermediate level comprising a wavelength selective optical coupler (213, 213') for coupling said two groups of optical channels,
25 having wavelengths within said two opposite side inclined regions (E₁, E₂, C₁, C₂), coming from said two optical couplers (205, 205', 206, 206', 207, 207').

11. A WDM optical telecommunication system (1) comprising
- a multiplexing device (44; 45) for multiplexing a
30 plurality M of optical channels (16) - with $M \geq 8$ - said multiplexing device (44; 45) having N input ports (208, 208') - with $N \geq M$ - and one output port (233; 254) and comprising at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217',
35 225, 225', 231) having preselected intrinsic losses and

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coupled together according to a tree topology, said tree topology having N inputs and one output corresponding to said N input ports (208, 208') and one output port (233; 254);

- 5 - an optical telecommunication line (30, 40) operatively coupled to said multiplexing device (44; 45), for transmitting said plurality M of optical channels (16) multiplexed by said multiplexing device (44; 45), the plurality M of optical channels (16) accumulating optical
10 power and optical SNR imbalance along the optical telecommunication line (30, 40);

wherein both

- a) the preselected intrinsic loss of each of said at least three optical couplers (202, 202', 205, 205', 207, 207',
15 206, 206', 213, 213', 217, 217', 225, 225', 231); and
b) the arrangement of said at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) in said tree topology are such that, passing through said multiplexing device, at
20 least two of said plurality M of optical channels (16) are attenuated differently from each other, characterized in that the difference in attenuation between said at least two channels is selected so as to provide said plurality M of optical channels (16) with a pre-emphasis predetermined
25 depending on at least one of said optical power imbalance and optical SNR imbalance accumulated along the optical telecommunication line (30, 40).

12. An optical multiplexing device (44; 45), for wavelength multiplexing a plurality M of optical channels (16) having
30 predetermined wavelengths different from each other - with $M \geq 8$ - said multiplexing device (44; 45) having N input ports (208, 208') - with $N \geq M$ - and one output port (233; 254) and comprising at least five optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217,
35 217', 225, 225', 231) having preselected intrinsic losses and coupled together according to a tree topology, said tree topology having N inputs and one output corresponding

to said N input ports (208, 208') and one output port (233; 254), wherein both

a) the preselected intrinsic loss of each of said at least five optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231); and

b) the arrangement of said at least five optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) in said tree topology are such that, passing through said multiplexing device (44; 45), at least two of said plurality M of optical channels (16) are attenuated differently from each other, characterized in that the difference in attenuation between said at least two channels is selected so as to achieve a predetermined pre-emphasis while said plurality M of optical channels (16) is multiplexed and in that at least one of said at least five optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) is a non wavelength selective optical coupler at said predetermined wavelengths.

13. An optical multiplexing device (44; 45) according to claim 12, wherein said tree topology has one input level having at least two optical couplers (202, 202', 205, 205', 207, 207', 206, 206') with intrinsic losses different from each other of at least 3 dB.

14. An optical multiplexing device (44; 45) according to claim 13, wherein the difference in intrinsic losses between said at least two optical couplers (202, 202', 205, 205', 207, 207', 206, 206') is at least equal to 3.5 dB.

15. An optical multiplexing device (44; 45) according to claim 12, wherein at least one of said at least five optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) is an unbalanced optical coupler (217, 217') non wavelength selective at said predetermined wavelengths.

16. An optical multiplexing device (44; 45) according to

claim 15, wherein said tree topology has one input level, one output level and at least one intermediate level.

17. An optical multiplexing device (44; 45) according to claim 16, wherein said non wavelength selective unbalanced optical coupler (217, 217') is located at said intermediate level of said tree topology.

18. An optical multiplexing device (44; 45) according to any of claims 12 to 17, wherein the difference in attenuation between said at least two channels is at least equal to 1 dB.

19. An optical multiplexing device (44; 45) according to claim 18, wherein the difference in attenuation between said at least two channels is at least equal to 2 dB.

20. An optical multiplexing device (44; 45) according to any of claims 12 to 19, wherein at least one of said at least five optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) is a wavelength selective optical coupler.

21. An optical multiplexing device (44; 45) according to any of claims 12 to 20, having at least seven optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231).

22. Use of a optical multiplexing device (44; 45) for providing a plurality M - with $M \geq 8$ - of optical channels (16) having predetermined wavelengths different from each other with a predetermined pre-emphasis while multiplexing them, said multiplexing device (44; 45) having N input ports (208, 208') - with $N \geq M$ - and one output port (233; 254) and comprising at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) having preselected intrinsic losses and coupled together according to a tree topology, said tree topology having N inputs and one output corresponding

to said N input ports (208, 208') and one output port (233; 254), wherein both

a) the preselected intrinsic loss of each of said at least three optical couplers (202, 202', 205, 205', 207, 207',

5 206, 206', 213, 213', 217, 217', 225, 225', 231); and

b) the arrangement of said at least three optical couplers (202, 202', 205, 205', 207, 207', 206, 206', 213, 213', 217, 217', 225, 225', 231) in said tree topology

are such that, passing through said multiplexing device
10 (44; 45), at least two of said plurality M of optical channels (16) are attenuated differently from each other so as to achieve said predetermined pre-emphasis while said plurality M of optical channels (16) is multiplexed.

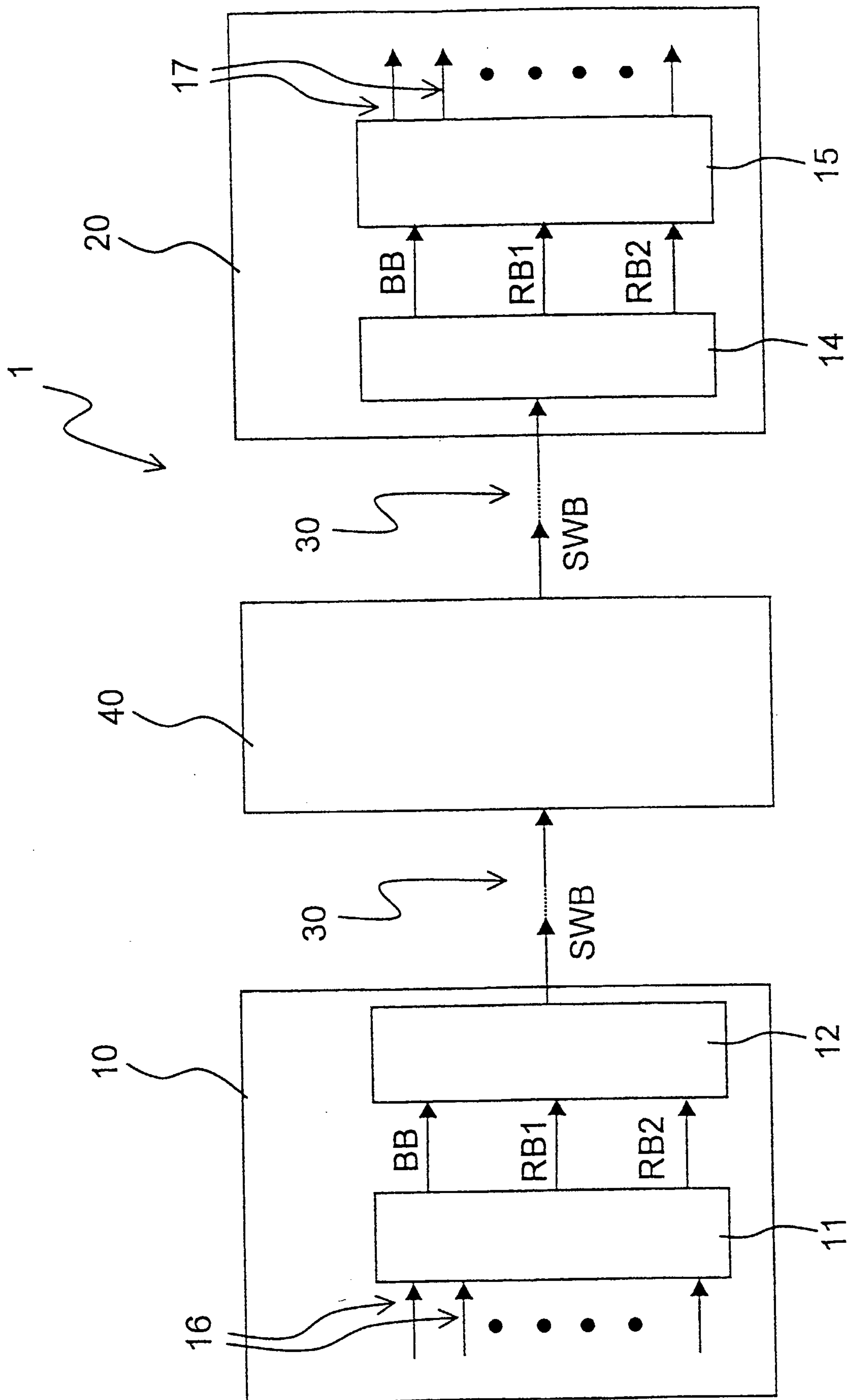


Fig. 1

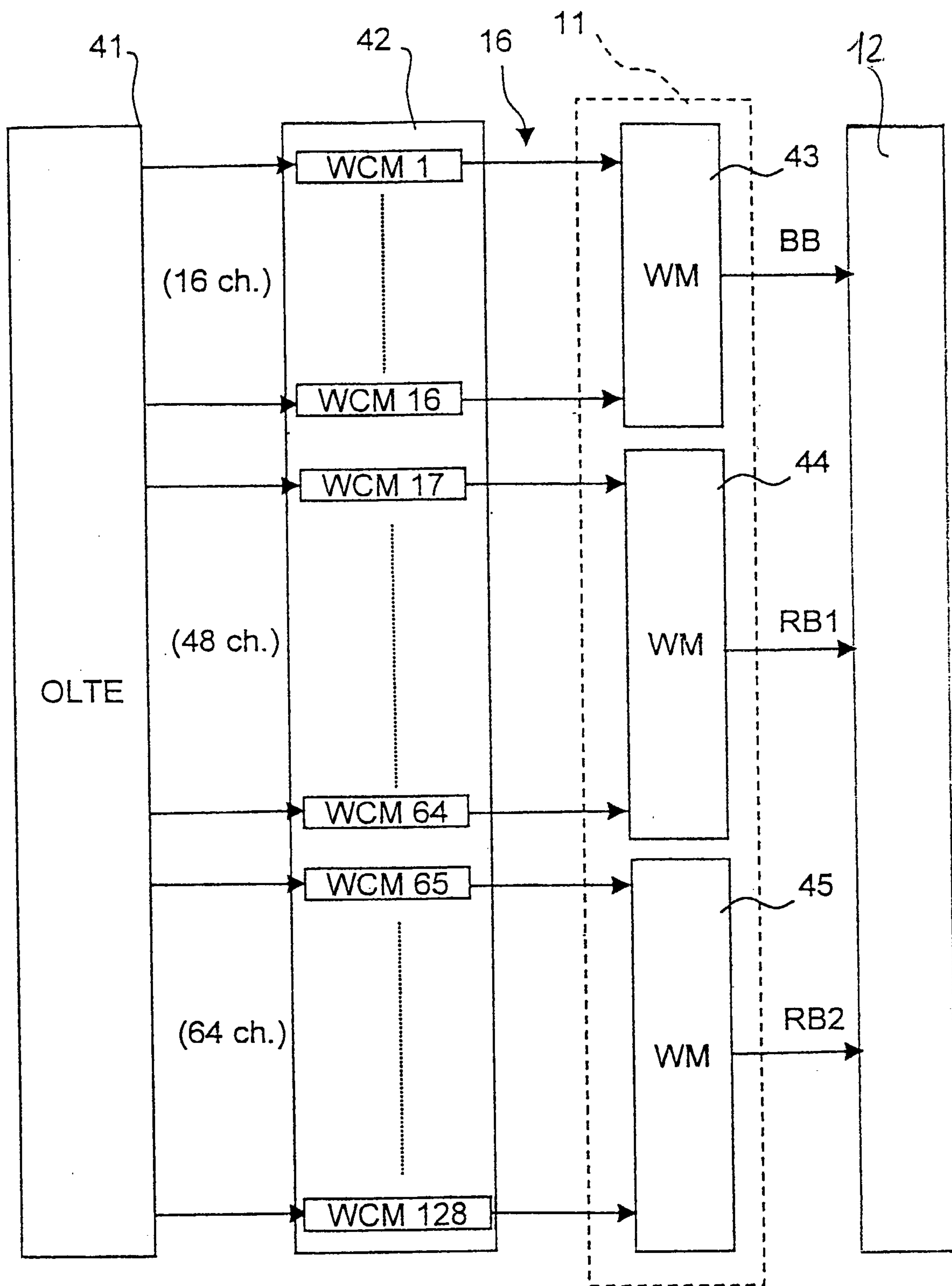


Fig. 2

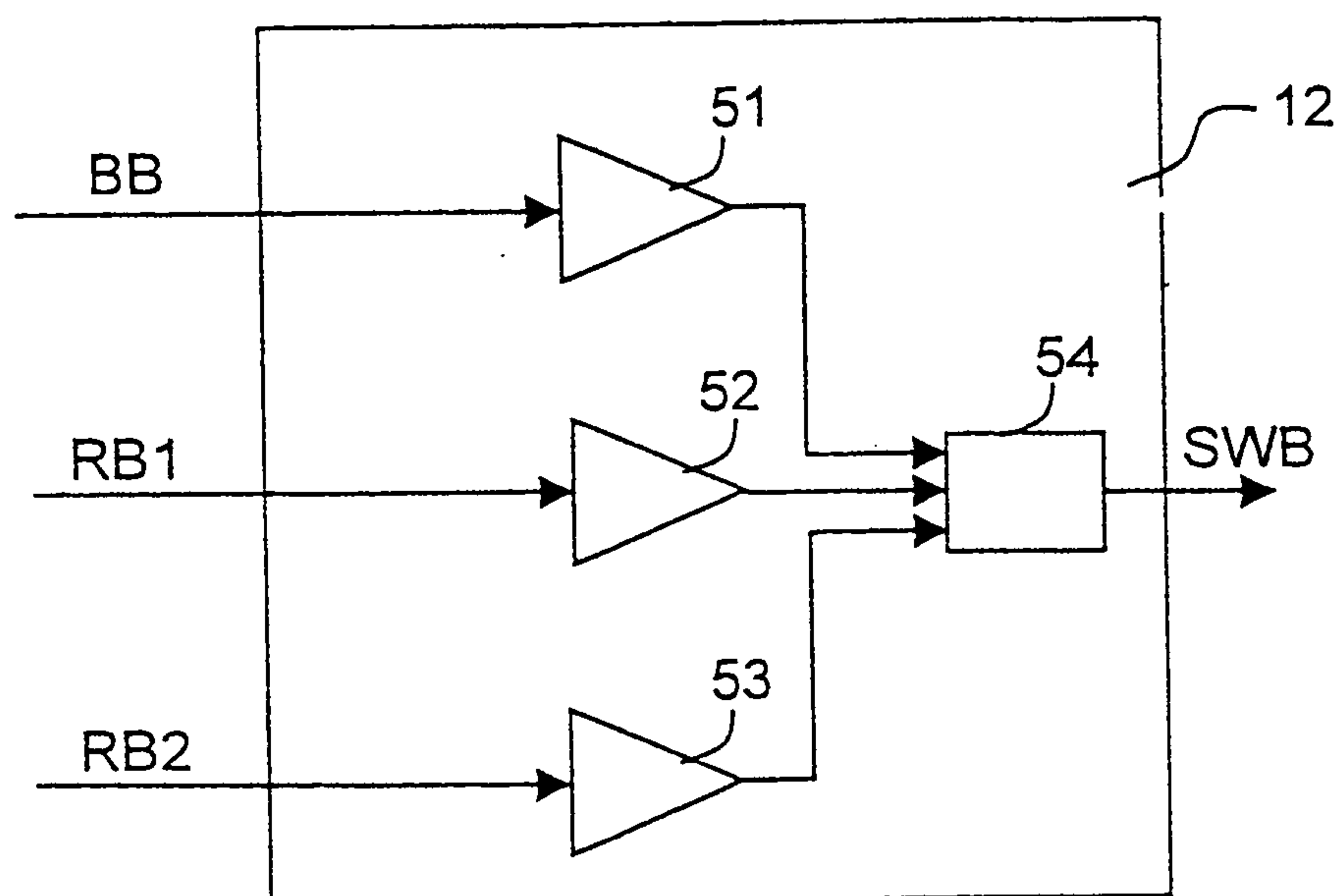


Fig. 3

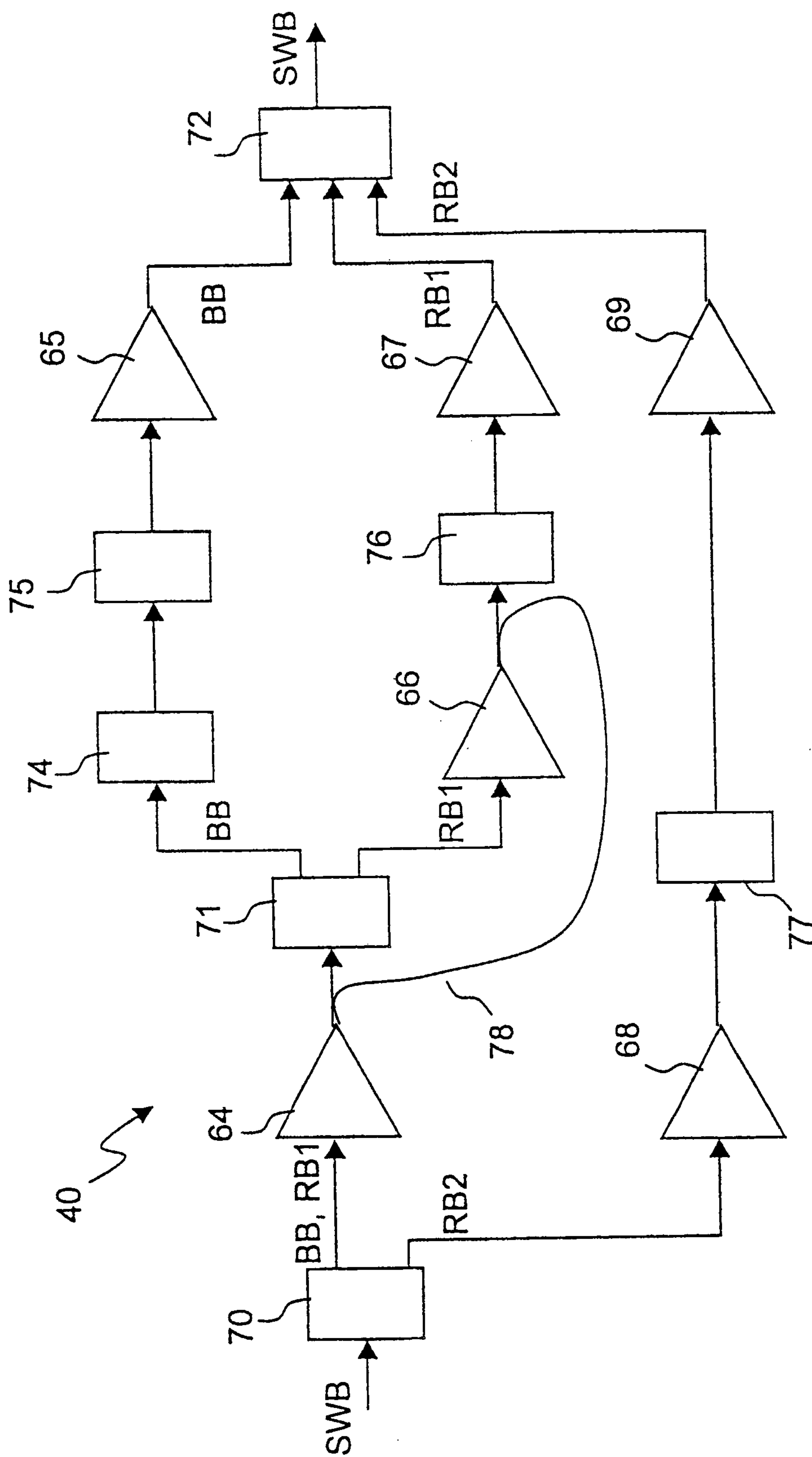


Fig. 4

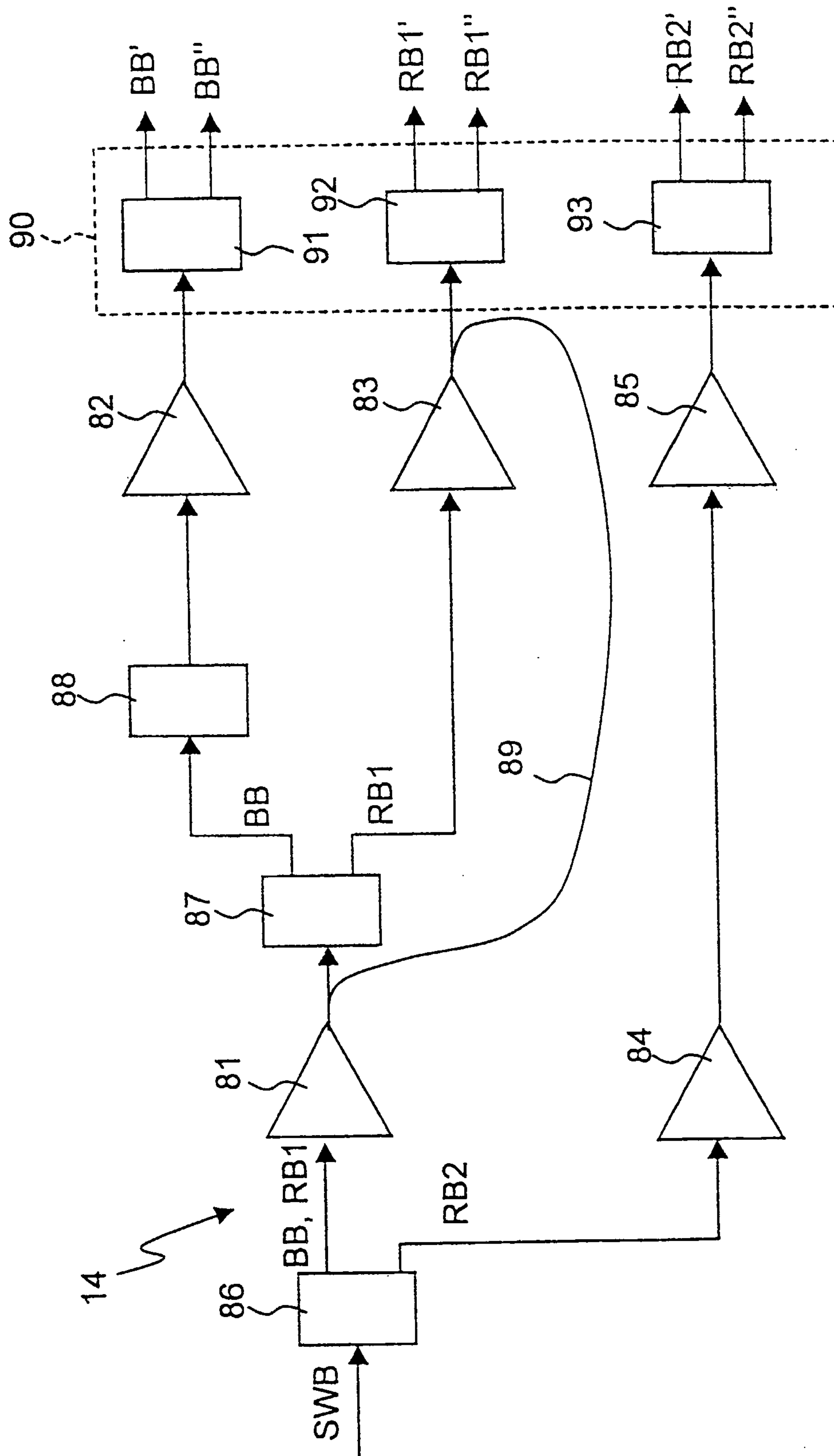


Fig. 5

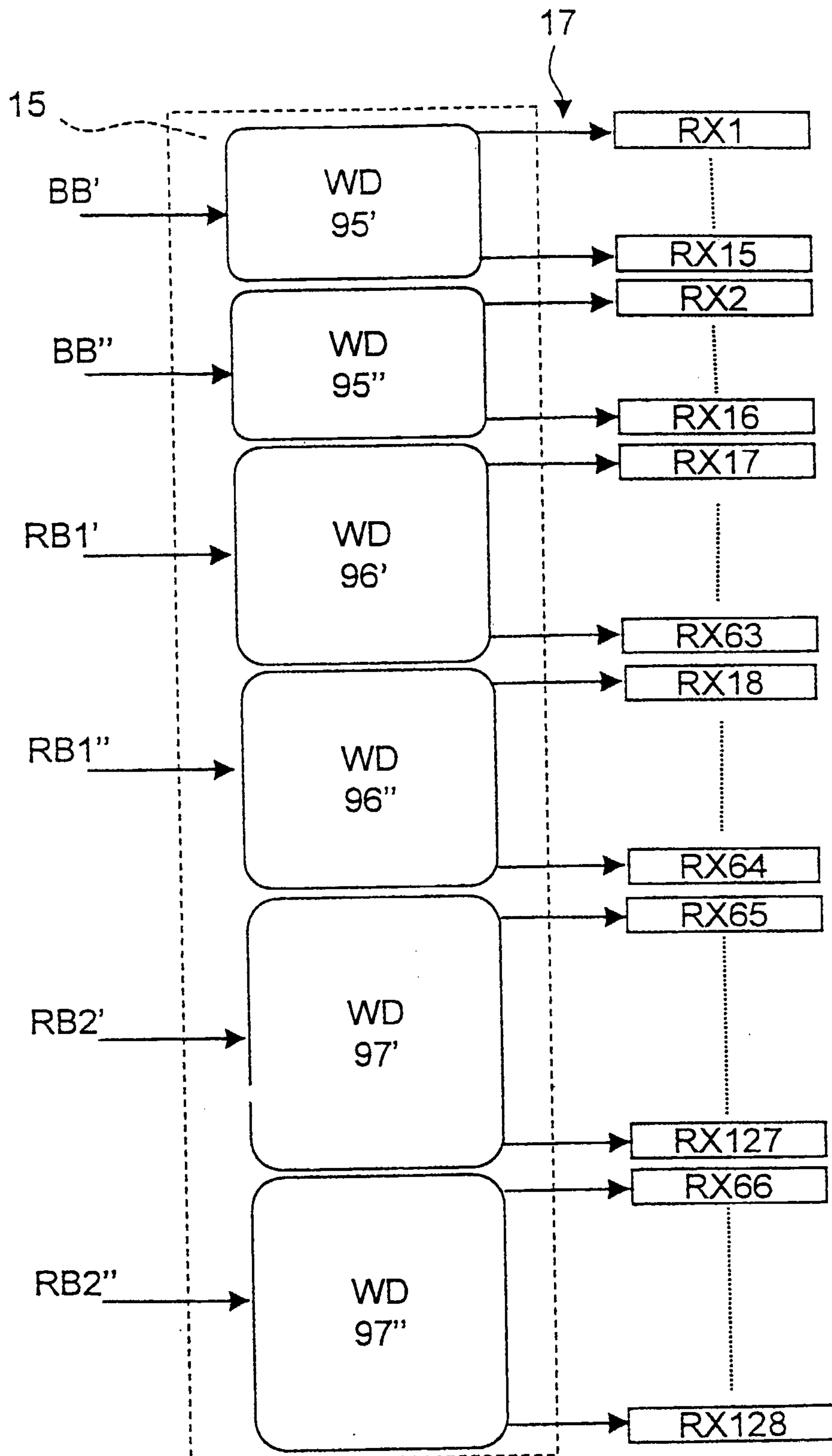


Fig. 6

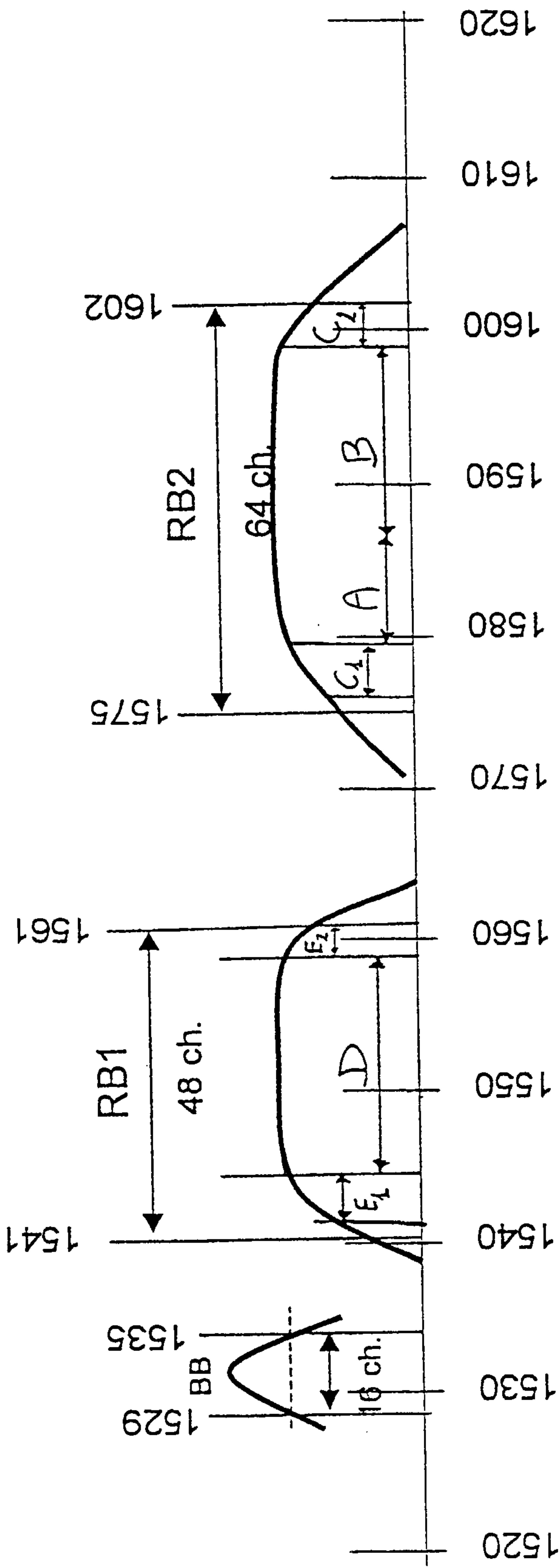


Fig. 7

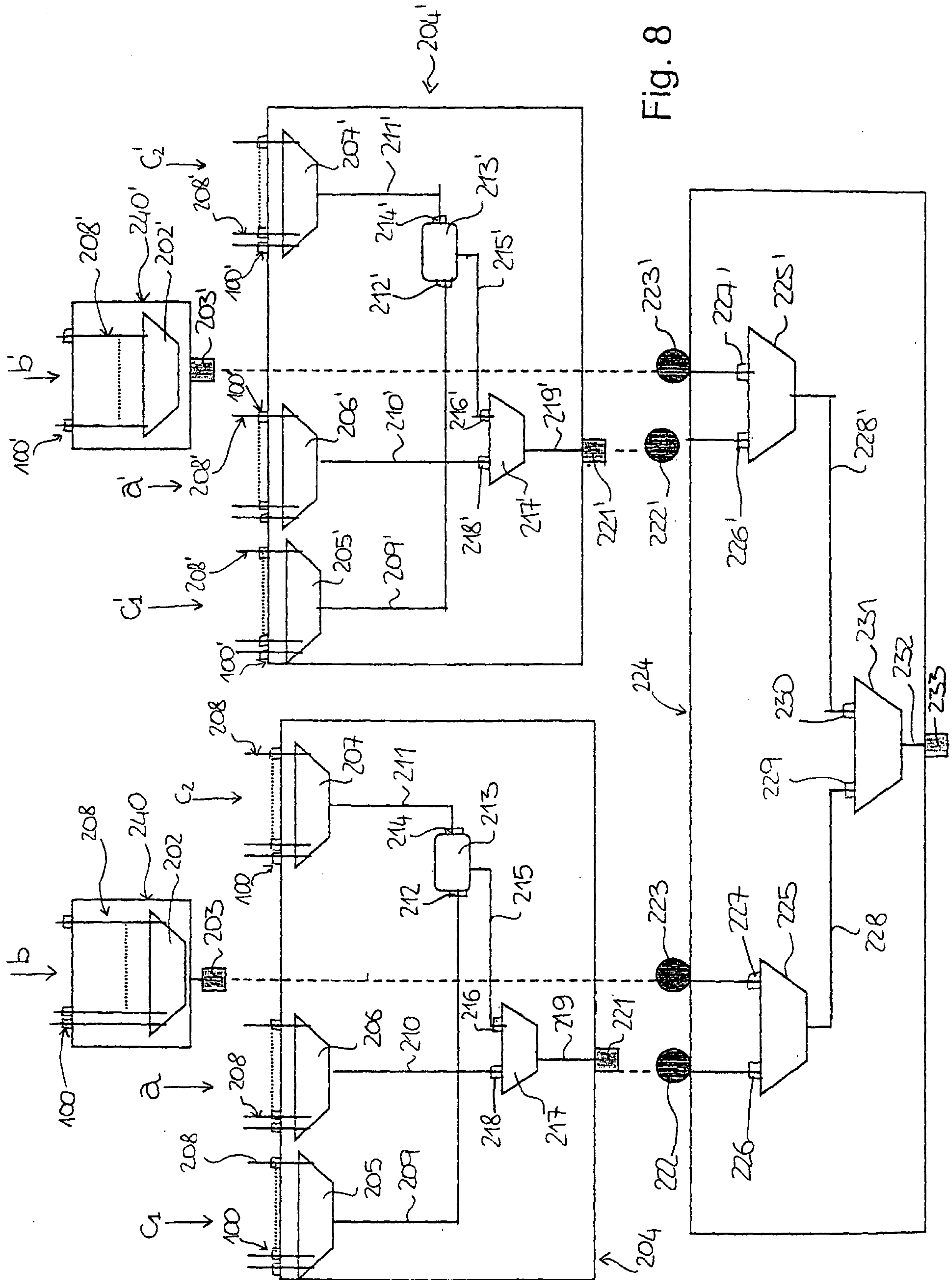


Fig. 8

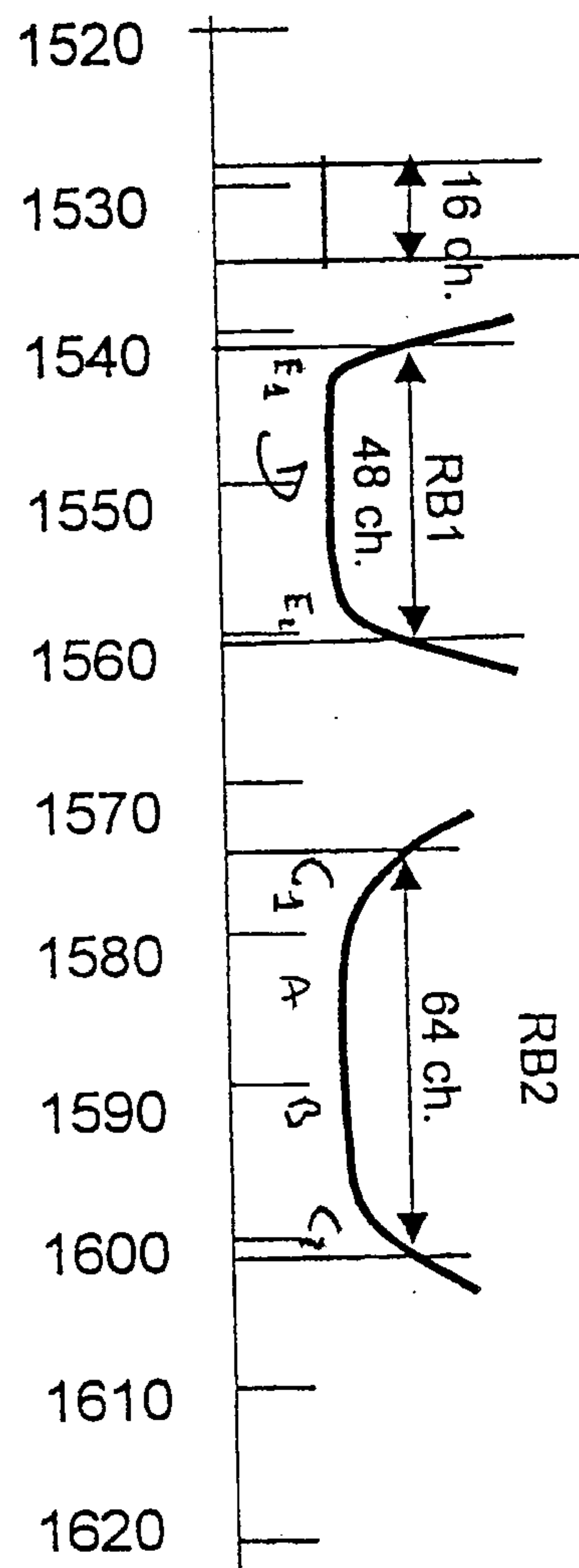


Fig. 9b

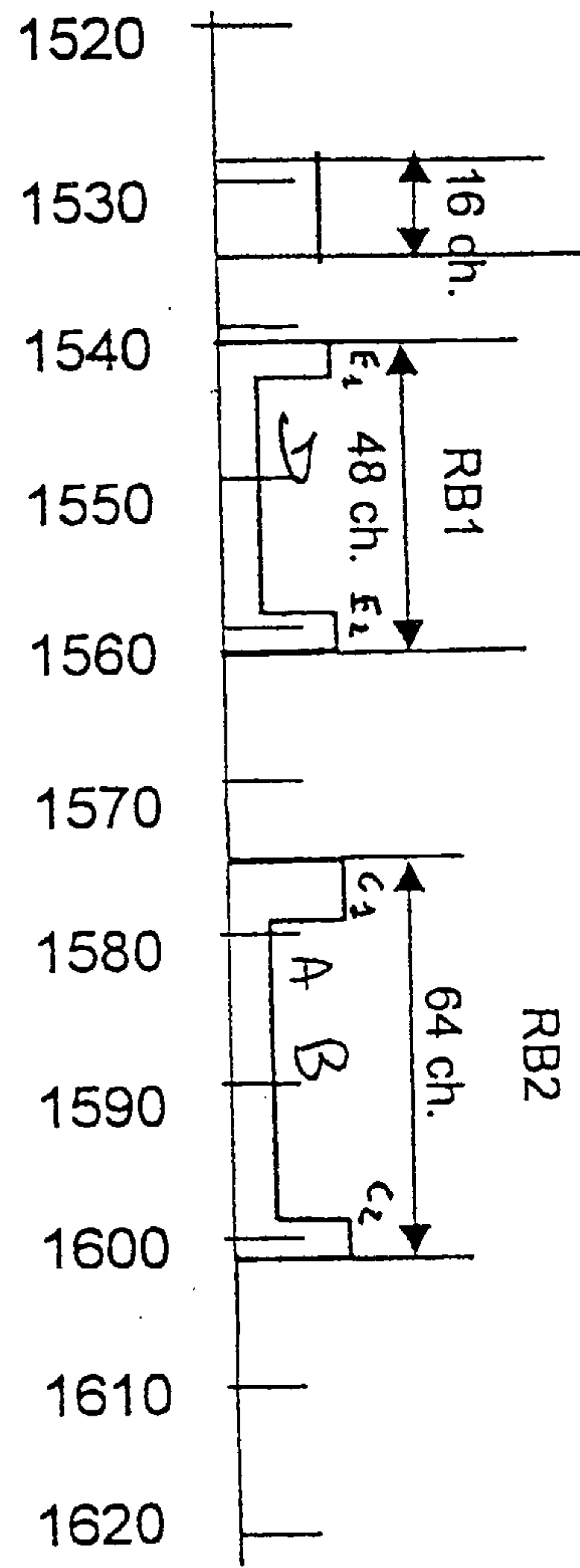


Fig. 9a

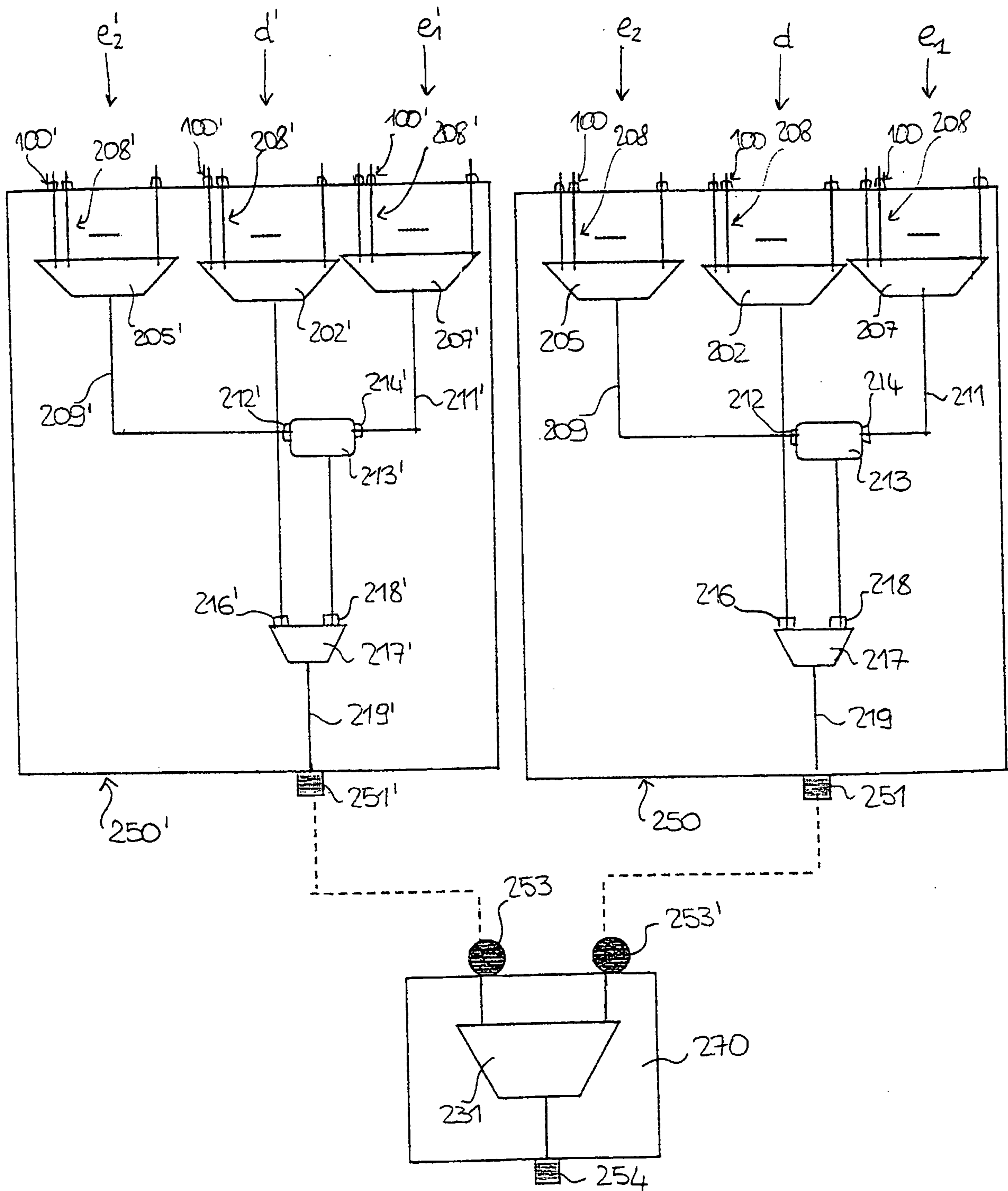


Fig. 10

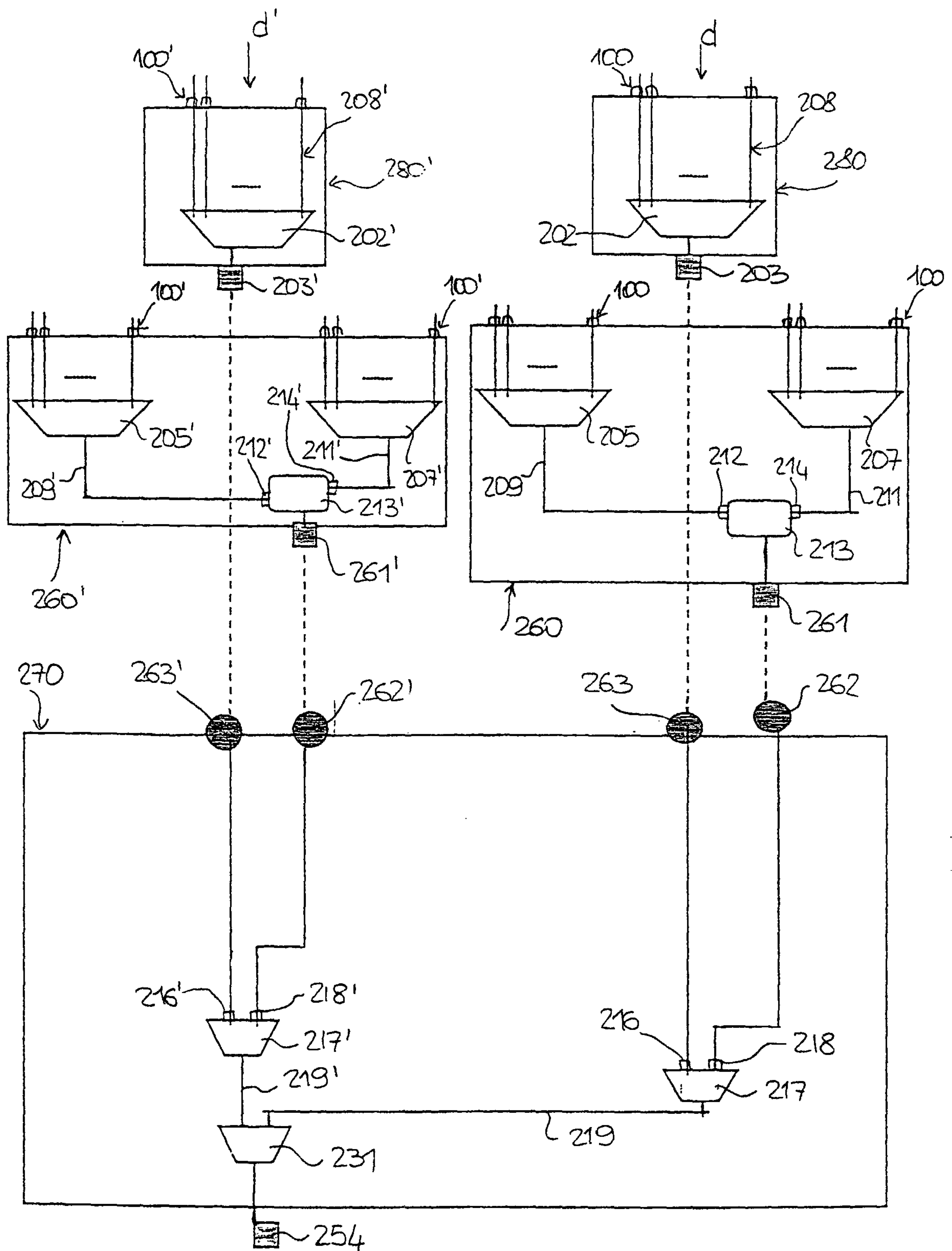


Fig. 11

