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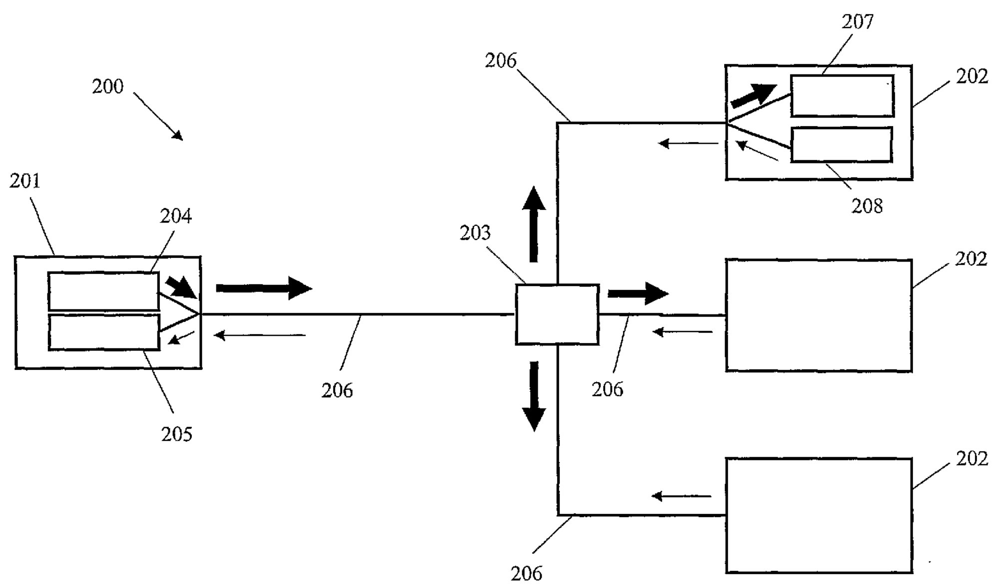
(54) **Title:** PASSIVE OPTICAL NETWORK COMPRISING MULTI-LONGITUDINAL MODE EMITTING DEVICES



(57) Abstract: Mode partition noise is reduced in a short haul optical system (e.g. a passive optical network) including multi-longitudinal mode (MLM) emitting devices (e.g. Fabry-Perot lasers) by providing an equalizing element, typically an equalizing filter, being capable of obtaining an acceptable and substantially invariant penalty in a received signal originated from a MLM emitting device disposed at any distance within a given range (e.g., up to 20 km). An equalizing element designed for obtaining a performance in accordance with the above can also be capable of obtaining a penalty within acceptable reception limits even in case of use of MLM emitting devices having relatively high average RMS widths (e.g. 2.5-3.0 nm).

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PASSIVE OPTICAL NETWORK COMPRISING MULTI-LONGITUDINAL MODE EMITTING DEVICES

[Technical field of the invention]

The present invention generally relates to optical communications. More particularly, the present invention relates to a passive optical network comprising transmitting stations including multi-longitudinal mode emitting devices (*e.g.* Fabry-Perot lasers).

[Background of the invention]

Passive Optical Networks (PONs) are expected to be deployed in order to provide end users with voice, video, and/or data services using optical technology in the coming years. Typically, PONs can serve up to 32 or 64 subscribers from a single fiber at a Central Office/Head-End (CO/HE) using one or more splitters to reach multiple subscribers. Typical fiber lengths between the CO and a generic subscriber can reach up to about 20 km. Voice, data, and IP video can be transmitted from an Optical Line Terminal (OLT) to the subscribers in a first wavelength band (*e.g.* around 1490 nm). Voice, data and IP video are transmitted from the subscriber's Optical Network Terminal (ONT), or Optical Network Unit (ONU) to the OLT at a second wavelength band (*e.g.* around 1310 nm). In some cases, a broadcast video overlay carried at a third wavelength band (*e.g.* around 1550 nm) is added to the PON using the same radio-frequency technology employed in cable TV networks. This 1550-nm RF signal can carry analog channels, digital channels, or both.

As shown in Figure 1, a basic architecture for communications in the PON is a point-to-multipoint network, where the OLT at the CO serves as the control point for the entire PON, and the ONU serves as the subscriber point or controlled point.

The splitter (SD) is a very simple device and is passive, with no electronics and/or power supply. It allows the downstream and upstream traffics (with respect to the OLT) to be split and combined from and onto the shared portion of the fiber. Different wavelengths are used for the two directions to avoid collisions and interactions between the downstream and upstream traffic flows.

To transmit downstream (thick arrows in Figure 1), the OLT broadcasts all the traffic to every ONU on the PON through the action of the splitters. The traffic can be framed as TDM (for T1 or other circuit-oriented traffic), or it can be encapsulated with ATM (Asynchronous Transfer Mode), Ethernet or other packet oriented protocols. In the reverse, or upstream, direction (thin arrows in Figure 1), multiple ONUs could potentially transmit simultaneously, causing collisions and interactions among the upstream traffic flows. PONs avoid this through an arbitration protocol that controls when each ONU is allowed to transmit. Typical methods include a TDM timeslot arrangement, or a prescheduled packet-allocation or bandwidth-allocation scheme.

While for long haul systems single longitudinal mode lasers (SLMs) having narrow spectral widths are typically used, in order to limit system penalties due to chromatic dispersion (in the following the term “dispersion” will be simply used, as being associated to chromatic dispersion), the use of SLMs in short haul systems, such as passive optical networks, seems to be not economic. Multi-longitudinal mode lasers (MLMs), instead, appear to be economically attractive in passive optical networks. Such lasers generally emit in the wavelength range between 1260 and 1360 nm and thus transmission fiber (*e.g.* standard single mode fiber) having zero dispersion near 1310 nm is usually employed with such lasers. Since local area networks currently have fiber lengths between sender and receiver of typically 20 km or less, the lower attenuation on the 1500 nm operating range is not essential, and the use of fiber having a zero dispersion wavelength at approximately the operating wavelength is employed beneficially, since also nonlinear effects are limited by the short fiber length.

Nevertheless, the use of MLMs introduces an error source not present when SLMs are used. In particular, a noise generating effect known as mode partition noise (MPN) becomes significant. For a discussion on MPN, reference can be made to Agrawal *et al.*, “Dispersion Penalty for 1.3 μm Lightwave Systems with Multimode Semiconductor Lasers”, Journal of Lightwave Technology, Vol.6, No.5, Pag.620-625 (May 1988). The mode partition noise results from the interaction of the fiber dispersion with the constantly changing power distribution among laser modes having a spectrum of wavelengths.

US patent application no. 2005/0163510 tackles the problem of significantly reducing MPN without the substantial increased cost of single mode lasers or the additional cost associated with expedients suitable for narrowing the spectrum actually injected into the fiber. According to the above patent application, in short haul networks such as passive optical networks it is possible to significantly reduce MPN by employing in the same optical path between a transmitter and a receiver both a transmission fiber having a dispersion zero in the 1312 nm operating region, *e.g.*, in the range 1260 to 1360 nm, and a length of additional fiber having specific characteristics. In particular, the additional fiber should have in the spectral region of transmission a dispersion to wavelength dependency with a slope of opposite sign to that of the transmission fiber. Still according to the above patent application, reliable calculation of the length of additional fiber suitable to make a manageable system penalty is possible using

$$L_{AF} = (S_{o,TF} / - S_{o,AF}) L_{TF}$$

where L_{AF} is the length of additional fiber, L_{TF} is the length of the transmission fiber, $S_{o,AF}$ is the first derivative of the dispersion with respect to wavelength at the central operating wavelength for the additional fiber, and $S_{o,TF}$ is the corresponding property for the transmission fiber.

Summary of the invention

The Applicant observes that the solution proposed in US 2005/0163510 may still result in excessive additional cost, due to the use of the additional fiber having a slope of opposite sign to that of the transmission fiber in the spectral region of transmission. In particular, the Applicant observes that an additional fiber having a slope of opposite sign to that of a standard single mode transmission fiber in a wavelength region around 1310 nm could be difficult to manufacture (then expensive), could reduce the dynamic range (maximum allowed attenuation of the transmission line) by adding attenuation of the optical field, and could introduce additional noise sources, such as nonlinear effects.

The inventors have perceived that in order to actually reduce costs related to the implementation of a short haul optical system, such as a passive optical network, comprising MLM emitting devices, a satisfying implementation should provide a solution to the problem introduced by mode partition noise independently of the distance between the MLM emitting device and the receiver. Such implementation would, in fact, provide the possibility of installing substantially in any practical case the same optical system, and, particularly, without the need of tuning each subscriber transmitting/receiving station according to its distance from the CO transmitting/receiving station.

The inventors have understood that an important step in order to devise a satisfying implementation according to the above is equalizing, as far as possible, the penalties of the received signals originated by the various MLM emitting devices, independently of their distance from the receiver. While the actual value of the penalty of the received signal is important in order to evaluate if the effect of the mode partition noise has been reduced, the variation of the penalty values is critical in order to understand if the distance between MLM emitting device and related receiver may still represent a problem.

More particularly, the inventors have understood that a satisfying solution for any short haul system including MLM emitting devices should obtain not only an acceptable penalty within acceptable reception limits (typically 2 dB, preferably 1 dB), but an equalized acceptable penalty for any possible distance between MLM emitting device and receiver.

The inventors have found that it is possible to provide an equalizing element, typically an equalizing filter, being capable of obtaining an acceptable and substantially invariant penalty (up to a maximum variation of 1 dB, or even 0.5 dB) in a received signal originated from a MLM emitting device disposed at any distance within a given range (*e.g.*, up to 20 km). It has also been found that an equalizing element designed for obtaining a performance in accordance with the above can also be capable of obtaining a penalty within acceptable reception limits even in case of use of MLM emitting devices having relatively high average RMS widths (*e.g.* 2.5-3.0 nm).

In a first aspect, the invention relates to an optical system comprising:

- a main transmitting/receiving station being adapted for transmitting downstream optical signals to a plurality of end transmitting/receiving stations, and for receiving upstream optical signals originated from said plurality of end transmitting/receiving stations;

- an optical link connecting said main station and said end transmitting/receiving stations, the optical link comprising at least one combining device being at least adapted to combine upstream signal portions originated from different end transmitting/receiving stations of said plurality in a common upstream signal;

wherein:

- at least one of the end transmitting/receiving stations of said plurality comprises a transmission device adapted for transmission of said upstream signals, the transmission device comprising an emitting device generating a plurality of emission modes at different wavelengths;
- at least one among:

  a) said main transmitting/receiving station, and

  b) said at least one end transmitting/receiving station comprising said emitting device,

  comprises an equalizing element having a transfer function, the transfer function being such that a penalty variation of the common upstream signal received at said main transmitting/receiving station is within 1 dB around a predetermined maximum penalty value, for any distance between said main transmitting/receiving station and said end transmitting/receiving stations up to a predetermined distance.

According to a second aspect, the invention relates to an optical transmitting/receiving station comprising:

- an input/output port being adapted to receive input optical signals in a first wavelength band and to send output optical signals in a second wavelength band;
- a routing device associated with said input/output port, the routing device being adapted to route the input optical signals towards a receiver device and the output optical signals towards said input/output port;
- a transmitter device comprising an emitting device generating a plurality of emission modes at different wavelengths, the emitting device being integrated with said routing device, the transmitter device being adapted to generate said output optical signals;

wherein the transmitter device further comprises a pre-distortion filter having a transfer function with a peak located at a frequency higher than zero, cooperating with the emitting device for the generation of the output optical signals.

According to a third aspect, the invention relates to an optical transmitting/receiving station adapted for use in an optical system comprising end transmitting/receiving stations including emitting devices generating a plurality of emission modes at different wavelengths and an optical link coupled to said end transmitting/receiving stations and combining upstream signal portions originated from said end transmitting/receiving stations in a common upstream signal in a first wavelength band, the optical transmitting/receiving station comprising:

- an input/output port being adapted to receive the common upstream signal and to send a downstream signal in a second wavelength band towards said optical link;
- a routing device associated with said input/output port, the routing device being adapted to route the common upstream signal towards a receiver device and the downstream signal towards said input/output port;
- a transmitter device being adapted to generate said downstream signal;

wherein the optical transmitting/receiving station comprises an equalizing filter associated with the receiver device, the equalizing filter having a transfer function such that a penalty variation associated with the common upstream signal is within 1 dB around a predetermined maximum penalty value, for any distance between the transmitting/receiving station and said end transmitting/receiving stations up to a predetermined distance.

Further features and advantages of the present invention will be made apparent by the following detailed description of preferred embodiments thereof, provided merely by way of non-limitative example, description that will be conducted with reference to the attached drawings.

Brief description of the drawings

- Figure 1 schematically shows a typical architecture of a passive optical network;
- Figure 2 schematically shows an exemplary embodiment of a point-to-multipoint optical system or network according to the present invention;
- Figure 3 shows a plot of the penalty versus an average RMS width of a MLM

emitting device in an exemplary system configuration;

- Figure 4 shows an exemplary equalizing element usable in the framework of the present invention;
- Figure 5a-b show eye diagrams resulting from a simulation in which the effect of mode partition noise is not considered;
- Figure 6 shows a plot of power penalty versus distance in case of absence and of presence of two different examples of equalizing element, in a approximated model in which mode partition noise is not considered, and the emitted spectrum from an emitting device used in the model has a width equal to the average RMS spectral width of an actual MLM emitting device;
- Figure 7 shows two exemplary transfer functions of equalizing elements allowing to reduce the effect of mode partition noise, leading to the curves of Figure 6;
- Figure 8 shows a plot of eye closure penalty versus the spectral width of the emitting device used in the approximated model (RMS spectral width), in case of absence and of presence the two different examples of equalizing elements having the transfer functions disclosed in Figure 7;
- Figure 9 shows a plot of power penalty versus the average RMS spectral width of an actual MLM emitting device, in case of absence and of presence of the two different examples of equalizing elements having the transfer functions disclosed in Figure 7, derived from data taken from Figure 8;
- Figures 10a-b show eye diagrams resulting from simulations performed with an exemplary system configuration respectively in absence and in presence of an exemplary equalizing element among those the transfer function thereof is shown in Figure 7;
- Figure 11 shows an exemplary configuration of a main transmitting/receiving station including an equalizing element, to be used in a system according to Figure 2;
- Figure 12 shows an exemplary configuration of an end transmitting/receiving station including an equalizing element, to be used in a system according to Figure 2;
- Figures 13a-b show further exemplary transfer functions of equalizing elements allowing reduction of the mode partition noise.

Detailed description of preferred embodiments of the invention

Figure 2 schematically shows, in terms of functional blocks sufficient for the purposes of the present invention, an exemplary embodiment of an optical system 200 according to the present invention.

The system 200 comprises a main transmitting/receiving station 201 adapted for transmitting downstream optical signals (represented by thick arrows in Figure 2) to a plurality of end transmitting/receiving stations 202. For example, the optical system 200 can be a passive optical network following the G-PON (Gigabit Passive Optical Network) or B-PON (Broadband Passive Optical Network) standards (ITU-T G.983.3 and G.984.2, respectively). In a passive optical network following the above standards, the main transmitting/receiving station 201 can correspond to the Optical Line Terminal (OLT) and the end transmitting/receiving stations can correspond to the Optical Network Units (ONUs) or Optical Network Terminals (ONTs).

For the purpose of transmitting downstream optical signals, the main transmitting/receiving station 201 comprises at least one transmitter device 204. In typical implementations, the downstream optical signals may lie in a wavelength band around 1490 nm and/or around 1530 or 1550 nm. Known multiplexing techniques can be used for suitably modulating the optical carrier, in order to add information signals destined to the different end users associated with the end transmitting/receiving stations 202, *e.g.* TDM (Time Division Multiplexing) and/or WDM (Wavelength Division Multiplexing) techniques. Alternatively or additionally, broadcast techniques can also be used for adding information to the downstream optical signals destined to the end users, *e.g.* for downstream transmission of television signals (*e.g.* CATV signals, wherein the acronym CATV stays for Community Antenna TeleVision). An overall bandwidth for the downstream transmission (*i.e.*, the bandwidth of the whole of the information signals carried by the downstream optical signal for serving all the end transmitting/receiving stations 202) may typically be higher than about 100 Mbit/s. Values higher than 1 Gbit/s and up to some Gbit/s (*e.g.* 1.25 Gbit/s, 2.5 Gbit/s) or more are envisaged in current PON standards. The transmitter device 204 may comprise at least one narrow-band emitting device (*e.g.* a Distributed FeedBack, or DFB, laser). However, it has to be noticed that the detailed internal structure of the transmitter device 204 will not be explained in detail, being *per se* known to the skilled in the art, and being not related with the present invention.

The end transmitting/receiving stations of the plurality of end transmitting/receiving stations 202 typically comprise a receiver device 207, being adapted to receive the downstream optical signal sent by the main transmitting/receiving station 201. The reception of the optical signal typically comprises the extraction of the information signal carried by the optical signal and destined to the corresponding user. The extraction of the information signal may be performed by transforming the received downstream optical signal in a received electrical signal (*e.g.* by a photodiode), and then acting on the received electrical signal for demodulating the information signal. For the sake of simplicity, in Figure 2 the receiver device 207 has been included only for one of the end transmitting/receiving stations 202. However, it has to be understood that a respective receiver device is typically included in all the end transmitting/receiving stations 202. The receiver devices of different end transmitting/receiving stations should not necessarily be of the same type, the suitable receiver being related, for each end transmitting/receiving station 202, to the services subscribed by the associated end user, and/or to the particular position of the end transmitting/receiving station 202 within the network (*e.g.*, to the distance from the main transmitting/receiving station 201).

The main transmitting/receiving station 201 is also adapted for receiving upstream optical signals (represented by thin arrows in Figure 2) sent by the plurality of end transmitting/receiving stations 202.

For the purpose of receiving the upstream optical signals, the main transmitting/receiving station 201 comprises at least one receiver device 205. According to an embodiment of the present invention, the receiver device of the main transmitting/receiving station 201 may comprise an equalizing filter allowing reduction of detrimental effects caused on the upstream optical signals by mode partition noise, as it will be explained in detail in the remainder of the description.

The end transmitting/receiving stations of the plurality of end transmitting/receiving stations 202 further typically comprise a transmitter device 208, being adapted to send a respective portion of an upstream optical signal to the main transmitting/receiving station 201. For the sake of simplicity, in Figure 2 the transmitter device 208 has been included only for one of the end transmitting/receiving stations 202. However, it has to be understood that a respective transmitter device is typically included in all the end transmitting/receiving stations 202. The different portions of upstream optical signal generated by respective different end transmitting/receiving stations 202 can be combined together by exploiting known multiplexing techniques (typically TDM techniques). In typical implementations, the upstream optical signals may lie in a wavelength band around 1310 nm, *e.g.* in a band between 1260 nm and 1360 nm. An overall bandwidth for the upstream transmission (*i.e.*, the bandwidth of the whole of the information signals carried by the upstream optical signal and provided by all the end transmitting/receiving stations 202) may typically be higher than about 100 Mbit/s (*e.g.* about 155 Mbit/s, 622 Mbit/s). Values higher than 1 Gbit/s and up to some Gbit/s (*e.g.* 1.25 Gbit/s, 2.5 Gbit/s) or more are envisaged in current PON standards. According to an embodiment of the present invention, the transmitter device 208 of the main transmitting/receiving stations 202 may comprise an equalizing filter allowing reduction of detrimental effects caused on the upstream optical signals by mode partition noise, as it will be explained in detail in the remainder of the description.

It has to be observed that even if in Figure 2 the main transmitting station 201 and the end transmitting/receiving stations 202 appear to basically contain the same equipment, actually the main transmitting/receiving station 201 has a more complex structure with respect to the end transmitting/receiving stations 202. This is because the main transmitting/receiving station 201 should manage transmission and reception of a much higher volume of signals. Thus, control electronics of the main transmitting/receiving station 201 is typically more complex with respect to the control electronics of the end transmitting/receiving stations 202.

An optical link 206 connects the main transmitting/receiving station 201 and the end transmitting/receiving stations 202. The optical link 206 comprises a plurality of different optical paths adapted for reaching the plurality of end transmitting/receiving stations 202. One or more splitting/combining devices 203 can be disposed within the optical link 206 in order to split downstream signals generated by the main transmitting/receiving station 201 and propagating on a common optical path onto the different optical paths reaching the respective end transmitting/receiving station 202, and to combine upstream signal portions generated by the plurality of end transmitting/receiving stations 202 and propagating onto the different optical paths coupled to the same in a common upstream signal propagating in the common optical path reaching the main transmitting/receiving station 201. The splitting and combining functions can be performed by the same optical component/device or by different components/devices. Known wavelength- insensitive components (fiber, and/or waveguide, and/or microoptics, and/or star couplers) can be used in the splitting/combining device 203. Wavelength-sensitive components may be adopted in the splitting/combining device 203 for system configurations in which different groups of end transmitting/receiving stations are served by downstream signals having different wavelengths. The optical paths comprised in the optical link 206 are typically realized by optical fibers, typically single mode fibers. Advantageously, single mode fibers having a zero dispersion wavelength in the range between 1260 nm and 1360 nm are used in the optical link 206, *e.g.* standard single mode fibers having a zero dispersion wavelength around 1310 nm. The optical link 206 is a short haul optical link. For current PON applications, a maximum length of around 20 km for the optical link 206 is envisaged. The "maximum length of the optical link" can be defined as the maximum among the lengths of the optical paths connecting the main transmitting/receiving station 201 and the end transmitting/receiving stations 202. A maximum length of around 20 km (or any other value) can correspond to a range of some km around the actual value of 20 km (or of the any other value).

As it can be seen from Figure 2, downstream and upstream signals are inserted into and extracted from a common optical path at the main and the end transmitting/receiving stations 201, 202. Wavelength selective components can be used for correctly routing the downstream and upstream signals to/from the transmitter and receiver devices of the main and of the end transmitting/receiving stations 201, 202. For example, a passive diplexer or triplexer device can be disposed in the end transmitting/receiving stations 202. A routing device suitable for being used in the end transmitting/receiving stations 202 is for example disclosed in the PCT patent application no. WO05/124412, in the name of the same Applicant.

An important feature of the present invention is that at least some or all the transmitter devices respectively included in the end transmitting/receiving stations 202 comprise a multi-longitudinal mode (MLM) emitting device, *e.g.* a semiconductor laser of the Fabry-Perot type. In practical implementations, a high number of end transmitting/receiving stations 202 can be deployed in the optical system 200, in order to serve a corresponding high number of end users. The use of a MLM emitting device in the end transmitting/receiving station 202 is then particularly advantageous, since it allows keeping the cost of the overall system 200 low, a MLM emitting device being a low cost device. In fact, MLM emitting devices do not need complex driving circuits, and may be manufactured with a low cost process and in very high volumes. Furthermore, another advantage of MLM emitting devices is that they can be easily integrated with passive routing components/devices adapted for inserting the upstream signals from the transmitter device 208 onto the optical link portion 206 coupled to the end transmitting/receiving station 202 towards the main transmitting/receiving station 201, and for sending the downstream signals coming from the optical link portion 206 coupled to the end transmitting/receiving station 202 to the receiver device 207, *e.g.* passive diplexer or triplexer devices. In particular, low cost processes can be used for manufacturing both the routing device and the MLM emitting device, so that integration on a single chip (possibly using gluing and/or soldering for the integration of the MLM emitting device) can be made possible without complex micro-optics alignment and/or packaging. In this respect, it has to be noticed that MLM emitting devices do not need an isolator coupled to the output facet (such as, for example, DFB lasers), to control re-injection of possible reflected radiation into the laser cavity, so that integration on a single chip of the routing device and of the MLM emitting device is further facilitated. It is further observed that at least part of the receiver device 207 could be integrated on a single chip with the routing device and the MLM laser: for example, a photodiode could be integrated (*e.g.*, directly by growing/forming the same within a chip, or by gluing/soldering).

On the other hand, the use of MLM emitting devices may cause mode partition noise in the optical system 200, resulting from the interaction of the fiber dispersion with the changing power distribution among the various longitudinal modes emitted by the MLM emitting device. As it is known, in a MLM emitting device the power distribution among the emitted longitudinal modes (corresponding to different emitted wavelengths) continuously changes in a substantially unpredictable manner. Statistical methods are typically applied in order to find characterization parameters for MLM emitting devices. Typical characterization parameters include the central emission wavelength of the MLM emission spectrum (calculated as a weighted sum of the wavelength of the emitted modes, in which the weight assigned to each wavelength is its average power emission), the wavelength separation between the emitted modes, the average RMS (Root Mean Square) width of the MLM emission spectrum.

While the effect of the fiber dispersion is quite limited on short haul systems, the effect of mode partition noise could be detrimental for the correct reception of a transmitted signal, even on short distances. In particular, mode partition noise may cause unacceptable penalties in case of MLM average RMS width higher than 1.5-2.0 nm. For example, let's consider the case of transmission at 1.25 Gbit/s, on a length of 20 km of optical fiber having a dispersion of 3 ps/(nm km) at the transmission wavelength, with an expected BER of 10^{-11}. The following mathematical relations (taken from the above mentioned article by Agrawal) can be applied:

$$\alpha_{mpn} = 5\,log\left(\frac{1}{1-Q^2\sigma_{mpn}^2}\right) \qquad BER = \frac{1}{Q\sqrt{2\pi}}\exp\left(-\frac{Q^2}{2}\right)$$

$$\sigma_{mpn} = \frac{k}{\sqrt{2}}\left(1-\exp(-(\pi BDL\sigma_L)^2\right)$$

wherein:

- α_{mpn} is the system penalty due to pulse distortion fluctuation;
- σ_{mpn} is the variance of the eye opening fluctuation of the received signal due to fluctuation of the emitted modes;
- σ_L is the MLM average RMS width;
- k is the mode partition coefficient;
- B is the bit rate of the transmitted signal;
- D is the dispersion of the optical fiber;
- L is the length of the optical fiber.

Figure 3 is a plot of the system penalty α_{mpn} as a function of the MLM average RMS width σ_L for an optical transmission system having the above parameters, and k equal to one. As it can be seen, the penalty reaches an asymptote substantially in correspondence of a value σ_L equal to 2 nm, meaning that the effect of mode partition noise cannot be recovered in case of use of MLM emitting devices having an average RMS width higher than about 2 nm, whatever launch power is used. Since a significant number of commercial low cost Fabry-Perot lasers have an average RMS width higher than 2 nm (typical values may lie in a range 2.5-3.0 nm), it can be seen from Figure 3 that mode partition noise could cause many available MLM emitting devices to be unusable for high bit rate transmission even on short haul transmission systems.

In a point-to-multipoint system configuration such as that of Figure 2, a further complication is given by the fact that the effect of the mode partition noise is also related to the distance at which the transmitter including the MLM emitting device and the related receiver are disposed. Ideally, the end transmitting/receiving stations 202 could have any distance from the main transmitting/receiving station 201 between zero and a maximum distance related to the farer end transmitting/receiving station 202. For example, in practical PON installations, this could correspond to distances varying within an interval between 1 km and 20 km. For the purposes of the present invention, by "distance" between a main transmitting/receiving station and an end transmitting/receiving station should be considered as being equivalent to "fiber length". In particular, in case TDM signals coming from different distances are combined and received on a same receiver, the receiver will suffer from a non-constant noise, due to the different incidence of the mode partition noise on the different TDM signal portions, and adaptation to the fast changing noise level would be extremely difficult.

The inventors have perceived that in order to actually reduce costs related to the implementation of a point-to-multipoint optical system such as that of Figure 2 comprising MLM emitting devices, a satisfying implementation should provide a solution to the problem introduced by mode partition noise independently of the distance between the main transmitting/receiving station 201 and any of the end transmitting/receiving stations 202, or, in other words, for any distance between the main transmitting/receiving station 201 and the end transmitting/receiving stations 202. Such implementation would, in fact, provide the possibility of installing substantially in any practical case the same optical system, and particularly, without the need of tuning each end transmitting/receiving station 202 according to its distance from the main transmitting/receiving station.

The inventors have understood that an important step in order to devise a satisfying implementation according to the above is equalizing, as far as possible, the penalties of the received signals originated by the various MLM emitting devices, independently of their distance from the receiver. While the actual value of the penalty of the received signal is important in order to evaluate if the effect of the mode partition noise has been reduced, the variation of the penalty values is critical in order to understand if the distance between MLM emitting device and related receiver may still represent a problem.

More particularly, the inventors have understood that a satisfying solution for any short haul point-to-multipoint system including MLM emitting devices should obtain not only an acceptable penalty within acceptable reception limits (typically 2 dB, preferably 1 dB), but an equalized acceptable penalty for any possible distance between MLM emitting device and receiver.

The inventors have found that it is possible to provide an equalizing element, typically an equalizing filter, being capable of obtaining a substantially invariant penalty (up to a maximum variation of 1 dB, or even 0.5 dB) in a received signal originated from a MLM emitting device disposed at any distance within a given range (*e.g.*, up to 20 km). It has also been found that an equalizing element designed for obtaining a performance in accordance with the above can also be capable of obtaining a penalty within acceptable reception limits even in case of use of MLM emitting devices having relatively high average RMS widths (*e.g.* 2.5-3.0 nm).

In the following, a method for finding a transfer function for an equalizing element (*i.e.* for designing the equalizing element) allowing to reach the above result will be described.

Exemplarily, the method will be explained by making reference to an electronic equalizing filter disposed either in a position downstream a photodiode included in the receiver or upstream the MLM emitting device. In particular, the electronic equalizing filter exemplarily considered is a Forward Feed Equalizer (FFE) with a Finite Impulse Response (FIR) filter topology, comprising gain blocks and delay elements. Figure 4 shows the FIR filter topology considered for an exemplary FFE 400 to be placed, *e.g.*, downstream a photodiode. As shown in Figure 4, the FFE comprises a number of tap elements 401 being capable of splitting a respective portion of the input electrical signal, interlaced with delay elements 402. Each of the delay elements 402 introduces a predefined delay T on the remaining propagating electrical signal portion. The tapped signal portions, and the signal portion remaining after the last delay element 402, are fed to respective multiplier elements 403, each of which being capable of multiplying the respective input signal portion by a predefined coefficient (the coefficients are indicated in Figure 4 as $c_0 \ldots c_4$). The tapped multiplied signal portions are then fed to a summing element 404, in which the tapped multiplied signal portion are summed together, to form an output electrical signal to be forwarded for further electronic processing to other receiver elements. Figure 4 shows a FFE structure with five tap elements 401 and four delay elements 402: however, the number of tap elements 401 and delay elements 402 could be arranged depending on the specific needs. In the following, results obtained with three tap elements (and two delay elements) and five tap elements (and four delay elements) will be shown.

As a first approximation, the inventors have performed an evaluation of the power penalty versus distance for a typical transmission line of a short haul optical system, by considering a laser emission having a RMS spectral width equal to the average RMS width of a MLM emitting device, but without fluctuations due to mode partition noise.

For example, by considering a G-PON link with single mode transmission fiber having a dispersion at the operating wavelength of 3 ps/(nm km) and 20 km of maximum length, and a MLM emitting device having an average RMS width of 2.7 nm and a mode separation of 0.7 nm generating an optical signal modulated at 1.25 Gbit/s, it can be found that the transfer function between the electrical signal modulating the MLM emitting device and the electrical signal after the receiver photodiode of the system corresponds to a low pass filter having a 3 dB bandwidth lower than 1 GHz. The effect of such filter is to broaden a transmitted pulse, possibly generating inter-symbol interference (ISI). Figures 5a-5b respectively show the back-to-back eye diagram and the eye diagram after a propagation on 20 km. As it can be seen from Figure 5b, the penalty introduced by the propagation on the optical line is very low, showing that the deterministic ISI is not critical for the system. This is also confirmed by the curve 601 joining point represented by squares in Figure 6, which shows a plot of the evaluated power penalty versus the distance between MLM emitting device and receiver, which always stays below 1 dB.

Figure 6 shows two other curves 602, 603 representing the evaluated power penalty versus distance between MLM emitting device and receiver in case of addition of a FFE filter having the general structure shown in Figure 4. In particular, the curve 602 joining points represented as rhombuses refers to the power penalty obtained with a FFE filter with three tap elements and two delay elements, whereas the curve 603 joining points represented by triangles refers to the power penalty obtained with a FFE filter with five tap elements and four delay elements. The transfer function of the FFE filters has been chosen so as to obtain a sufficiently low and substantially flat penalty versus distance, still considering the approximation by which the laser emission has a RMS spectral width equal to the average RMS width of a MLM emitting device, without fluctuations due to mode partition noise. Figure 7 shows the transfer functions 701 and 702 of the FFE filters found by considering the above constraint (continuous line 701 for the three tap FFE, dashed line 702 for the five tap FFE) and leading to the behavior shown in the curves 602, 603 of Figure 6. The time delay T was set to 800 ps (corresponding to a delay time of the order of one bit for modulation at 1.25 Gbit/s), in both cases. The following table shows coefficient values (normalized to the central coefficient) adapted for obtaining transfer functions such as those shown in Figure 7.

	c_0	c_1	c_2	c_3	c_4
Three tap	-0.15 ÷ -0.1	1	-0.15 ÷ -0.1		
Five tap	0.00 ÷ 0.05	-0.15 ÷ -0.1	1	-0.15 ÷ -0.1	0.00 ÷ 0.05

The curves 602, 603 of Figure 6 correspond to penalty values higher than those of curve 601, the additional penalty being due to the presence of the FFE filter. However, the penalty variation versus distance is very low, being always well below 0.5 dB for any distance value between zero and 20 km, and the obtained power penalty values can be still considered as highly acceptable.

As said above, the transfer function of the filter has been determined as that function being able to substantially equalize the power penalty versus distance, in an approximation in which no mode partition noise is present and the emitted spectrum has a RMS spectral width equal to the average RMS width of the MLM emitting device. Surprisingly, it has been found that the transfer functions determined using this criterion also allow to obtain a substantially equalized (within a limit of maximum variation of 1 dB, or even 0.5 dB) power penalty of the received signal versus distance also in case fluctuation due to mode partition noise is considered, so that equalizing elements having such transfer functions can be advantageously employed for counteracting mode partition noise in point-to-multipoint optical systems in which MLM emitting devices are used (even MLM emitting devices having high average RMS width), particularly at the end transmitting/receiving stations, without the need of tuning or designing a dedicated equalizing element associated to each end transmitting/receiving station as a function of its distance from the main transmitting/receiving station.

According to a hypothesis formulated by the inventors for giving an explanation of the above, herein reported for the sake of completeness, without any limiting intent for the invention, the effect of laser mode power fluctuations (causing mode partition noise) can be considered as being equivalent to an increase of the average spectral width. For example, let's consider a MLM emitting device having an average RMS spectral width of 1.5 nm. With the line and transmission parameters previously reported (BER=10^{-11}, D=3 ps/(nm km), k=1, B=1.25 Gbit/s, L=20 km), according to the theory by Agrawal this MLM emitting device obtains a power penalty of about 1 dB (see Figure 3), and the eye closure penalty of the received signal after 20 km (hereinafter ECP) fluctuates around an average value ECP_{ave} according to a Gaussian distribution having a standard deviation σ_{mpn}=0.38 dB (see the above formula relating σ_{mpn} with σ_L, being σ_L equal to

1.5 nm). The value ($ECP_{ave}-\sigma_{mpn}$) can be associated to a very low value of ECP (ECP=0 if the Gaussian function is approximated with a rectangle), while the value ($ECP_{ave}+\sigma_{mpn}$) is associated to high ECP values. For the "equivalent" emitting devices not suffering of mode partition noise according to the approximation used above, this step of $2\sigma_{mpn}$ between these two ECP values may correspond to an increase of ECP due to a "change" from an emitting device having a very low average RMS width (equal to zero for ECP=0) to an emitting device having a higher value of average RMS width.

Figure 8 shows a plot of ECP values determined according to simulation in the approximation in which "equivalent" emitting devices not suffering mode partition noise are used, having an emitted spectrum with RMS spectral width equal to the average RMS width of a MLM emitting device, versus the same RMS spectral width, for an optical line having a length of 20 km, in case of use of no equalizing filter (curve 801), in case of use of the three taps equalizing filter having the transfer function 701 of Figure 7 (curve 802), and in case of use of the five taps equalizing filter having the transfer function 702 (curve 803). As it can be inferred from curve 801, an ECP increase equal to $2\sigma_{mpn}$ (0.76 dB) starting from ECP=0 can be related to a change from an "equivalent" emitting device emitting a spectrum having a null width to an "equivalent" emitting device emitting a spectrum having a RMS spectral width equal to about 2.5 nm. Thus, an "actual" MLM emitting device having an average RMS value of 1.5 nm corresponds to an "equivalent" emitting device having a RMS spectral width equal to 2.5 nm. By assuming constancy of the ratio between the RMS spectral width of the "equivalent" emitting device and the average RMS width of the "actual" MLM emitting device (this ratio can be obtained by dividing 2.5/1.5=1.66), for each value "σ_L" of average RMS width value of the "actual" RMS emitting device, σ_{mpn} can be approximated to ECP($1.66\sigma_L$)/2, wherein ECP($1.66\sigma_L$) corresponds to the ECP read from the plots in correspondence of an abscissa value equal to $1.66\sigma_L$.

According to one of the above formulas by Agrawal, the power penalty caused by mode partition noise can be calculated and is related to σ_{mpn}. In the above mentioned hypothesis, σ_{mpn} can be approximated by (ECP(1.66σ_L)-ECP(0))/2, with the ECP value read from the plots of Figure 8. Thus, a power penalty due to mode partition noise can be calculated also starting from the curves 802, 803 corresponding to the use of the equalizing filters having the transfer functions of Figure 7 using this model. A first observation related to the curves 802 and 803 of Figure 8 is that the ECP variation is much lower than the corresponding ECP variation obtained with the curve 801, practically in all the range of RMS spectral widths. This relative "flatness" of the curves obtained for the cases related to use of the equalizing filters found with the above procedure is parallel to the relative "flatness" of the curves 602, 603 of Figure 6. Thus, transfer functions suitable for realizing equalizing elements allowing to obtain substantial equalization of the power penalty of received signals emitted from MLM emitting devices disposed at various distances could also be obtained, in alternative or in combination to what disclosed above with reference to Figure 6, by imposing as constraint a relative flatness of the ECP figure versus the RMS spectral width of an equivalent emitting device not suffering of mode partition noise. Coming back to Figure 8, for a σ_L (average RMS width of an actual MLM emitting device) equal to 2.7 nm (typical maximum average RMS spectral width of a low cost MLM emitting device), the corresponding RMS spectral width is 4.5 nm (1.66σ_L): the ECP value read from curve 801 is about 2.5 dB, whereas the ECP values read from the curves 802, 803 are much lower. More significantly, the ECP variation in the range 0 ÷ 4.5 nm is very low (less than 1 dB) in curves 802, 803, whereas it is of 2.5 dB for the curve 801. This fact suggests that the use of the equalizing filters having the transfer functions according to the curves of Figure 7 allows to substantially reduce mode partition noise, even in case of use of actual MLM emitting devices having high average RMS spectral width (*e.g.* 2.7 nm).

The reduction of the detrimental effect of the mode partition noise performed by the equalizing filters is evident from Figure 9, which shows the power penalty α_{mpn} calculated according to the above formula by Agrawal versus the average RMS spectral width σ_L of an actual MLM emitting device, respectively in case of use of no equalizing filter (curve 901), of the three tap equalizing filter having the transfer function according to curve 701 in Figure 7 (curve 902), of the five tap equalizing filter having the transfer function according to curve 702 in Figure 7 (curve 903). In the Agrawal formula for the calculation of α_{mpn}, the value of σ_{mpn} has been found, for each value of σ_L, as (ECP(1.66σ_L)-ECP(0))/2, as explained above. As it can be seen, curve 901 of Figure 9 (corresponding to absence of equalizing elements) substantially reproduces the curve already reported in Figure 3 and found by the Agrawal theory, thus validating the used model. Curves 902, 903 show a very low value of power penalty up to σ_L values of about 2.7 nm, which confirms that detrimental effect of mode partition noise is substantially reduced by using the equalizing filters having the transfer functions reported in Figure 7. It is reminded that the results of Figure 9 correspond to a distance between a transmitter including a MLM emitting device and a receiver of 20 km, which can be considered as a worst case for possible current implementations of PONs.

For further confirmation of the above results, Figures 10a-b show eye diagrams resulting from simulations performed with randomly varying mode power distribution. In particular, Figure 10a shows the eye diagram for a transmission line in absence of an equalizing filter, whereas the eye diagram of Figure 10b is related to a transmission line including the equalizing filter having the transfer function according to curve 702 in Figure 7. While the eye diagram of Figure 10a is quite closed, the eye diagram of Figure 10b is sufficiently open to obtain a BER of 10^{-12}.

Coming back to Figure 2, in case of use of MLM emitting devices at the end transmitting/receiving stations 202 the disposition of at least one equalizing element designed in accordance to what disclosed above allows to obtain substantially the same penalty for all the transmitting/receiving stations 202, independently of their respective distance from the main transmitting/receiving station 201, thus reducing mode partition noise.

In an advantageous configuration, the equalizing element could be located at the main transmitting/receiving station 201. In such case, only one additional element is disposed in the optical system 200, with a small additional cost. Figure 11 shows a possible configuration of a main transmitting/station 201, including a transmitter device 204 and a receiver device 205, in which the receiver device 205 comprises a photodiode 2051, a trans-impedance amplifier 2052, an equalizing element 2053 and a limiting amplifier 2054. The equalizing element 2053 could be for example a FFE with FIR filter topology, of the type disclosed in Figure 4. The configuration disclosed in Figure 11 is preferred since the trans-impedance amplifier 2052 typically has a linear behavior, whereas the limiting amplifier 2054 typically has a non-linear behavior, which can cause malfunction in the FFE 2053.

Alternatively or additionally, the equalizing element could be located at the end transmitting/receiving stations 202 including the MLM emitting devices. In such case, the additional cost can be mitigated by the fact that a dedicated equalizing element tuned according to the distance from the receiver is not needed. Figure 12 shows a possible configuration of an end transmitting/receiving station 202, including a receiver device 207 and a transmitter device 208, in which the transmitter device comprises a MLM emitting device (*e.g.* a Fabry-Perot laser) 2081, a driving circuit 2082 and an equalizing element 2083 associated with the driving circuit 2082. The equalizing element 2083 could be for example a FFE with FIR filter topology, of the type disclosed in Figure 4. In the configuration shown in Figure 12, the equalizing element 2083 is practically used as pre-distortion filter.

In preferred embodiments, the equalizing filter being capable of reducing the effect of mode partition noise as disclosed above is an electronic digital filter, particularly realized with FIR topology, such as that shown in Figure 4. The use of this filter is particularly advantageous in short haul point-to-multipoint optical systems such as that shown in Figure 2, since electronic filters can be realized with low cost manufacturing technology. In particular, FIR filters could be realized with CMOS technology (see, *e.g.* Maeng *et al.*, "A 0.18 μm CMOS Equalizer With Improved Multiplier for 4-PAM/20 Gbit/s Throughput Over 20 inch FR-4 Backplane Channel", 2004 IEEE MTT-S International Microwave Symposium Digest, Vol.1, p. 105-8 (2004). A further advantage of using an electronic equalizing filter in a system using MLM emitting devices, and particularly downstream a photodiode, is also related to the fact that the instability of the central wavelength emission does not represent an additional problem for the design of the equalizing filter. This is because the electrical signal in output from the receiver photodiode is substantially independent on such wavelength instability, due to the optical carrier frequency suppression.

A transfer function for an electronic filter, to be included in a main transmitting/receiving station and/or in an end transmitting/receiving station of a point-to multipoint short haul optical system in order to reduce the effect of the mode partition noise, should have a first peak located apart from a frequency f=0. The transfer function at the frequency corresponding to the first peak should preferably have a value between about 1.2 and 1.85 times the value at f=0. In order to perform reduction of the mode partition noise with fiber dispersion up to about 3 ps/(nm km) and maximum length of about 20 km, the first peak should be located at a frequency between 0.5 and 1.0 GHz. Figures 13a-13b show possible transfer function curves following the above requirements. The values on the ordinate axis represent the filter transmittivity (*i.e.*, the module of the transfer function), normalized to the value at f=0. As it can be seen from Figure 13b, other peaks may be also present near the first peak (not necessarily having a height lower than that of the first peak). Typically, the contribution given by such further peaks, if present, could be filtered by other control electronics, such as by a limiting amplifier. Transfer function of the kind shown in Figures 13a-b could be obtained with a FIR topology with at least three or five taps. Preferably, an odd number of taps may be used. Furthermore, preferably, a symmetric distribution of the coefficients may be adopted (*e.g.*, in a five tap FIR, $c_0=c_4$, $c_1=c_3$). Delay elements could be tuned to a time delay T comprised between t_{bit} and 2 t_{bit}, wherein t_{bit} represent the bit duration (*i.e.*, the inverse of the signal bandwidth).

Figure 14 shows an exemplary optical transmitting/receiving station 300 for use in a short haul optical system as disclosed above. The optical transmitting/receiving station 300 may be an optical network unit (ONU) of a PON.

The optical transmitting/receiving station 300 comprises an optical band splitter 300a for splitting/combining a first and a second optical wavelength band. Optical band splitter/combiner 300a comprises a first port 301, a second port 302 and a third port 303. Optical transmitting/receiving station 300 also comprises a first optical receiver 306 apt to receive a first optical wavelength λ1 within the first wavelength band (*e.g.* near 1490 nm), and optically connected to the third port 303 (through a waveguide 352), and may include a second optical receiver 307 apt to receive a second optical wavelength λ2 (*e.g.* near 1550 nm) within the second optical band and optically connected to the second port 302 (through a waveguide 353). The optical transmitting/receiving station 300 also comprises an additional optical band splitter/combiner 305 for splitting/combining a third optical wavelength band from the first and the second optical band, the device 305 being connected to the optical band splitter/combiner 300a, for example through an optical waveguide 311. Optical transmitting/receiving station 300 also comprises a MLM emitting device 304, apt to emit an optical radiation having a third wavelength λ3 within the third optical band (*e.g.* near 1310 nm), and optically connected to the optical band splitter/combiner 305, for example through optical waveguide 310. Optical band splitter/combiner 305 comprises a first port 305', a second port 305" and a third port 305'". Optical transmitting/receiving station 300 is apt to be connected to an optical transmission line through an input/output port 350. The MLM emitting device 304 is associated with a pre-distortion filter 351, for example a FIR filter as shown in Figure 4. The transfer function of the pre-distortion filter is selected so as to reduce mode partition noise caused by MLM emitting device independently of the distance between the transmitting/receiving station 300 and a PON CO transmitting/receiving station, as described above. In particular, the transfer function has a peak at a frequency higher than zero, as shown in Figures 13a-b.

In a preferred configuration, optical transmitting/receiving station 300 is based on PLC (Planar Lightwave Circuit) or IOC (Integrated Optical Circuit) technology, particularly silica-based technology, in all or part of its components. Advantageously, the MLM emitting device 304 is integrated on the same substrate (*e.g.* by gluing or soldering) carrying the remaining components, in particular carrying the waveguide 310, so that complex micro-optics alignment and/or packaging can be avoided, thus reducing manufacturing costs. Advantageously, the first and/or the second optical receiver 306, 307 can also be integrated (*e.g.*, directly by growing/forming the same within the substrate, or by gluing/soldering) on the same substrate carrying the remaining components, in particular the waveguides 352, 353. Preferably, the substrate and the optical components formed in the substrate may be made in high index contrast planar optics, for example having index contrast greater than about 1%, preferably greater than, or equal to, about 2%. Advantageously, the refractive index contrast is lower than, or equal to, about 4.5%, preferably lower than, or equal to, about 3%.

Although the present invention has been disclosed and described by way of some embodiments, it is apparent to those skilled in the art that several modifications to the described embodiments, as well as other embodiments of the present invention are possible without departing from the scope thereof as defined in the appended claims.

For example, the Applicant believes that the above disclosed design method related to the equalization of the power penalties could be applied in principle for any kind of filter, either optical or electrical, so that a transfer function for a filter suitable for reducing the mode partition noise could be found following the disclosed general rules.

Furthermore, the above calculations have been performed by considering a value k=1 for the mode partition coefficient of the MLM emitting device. The Applicant believes that such value can be considered as highly conservative. Commercial MLM emitting devices have lower k values, so that a strong tolerance is obtained by applying the above teachings. In particular, the same equalizing element designed (using k=1) for obtaining an acceptable system performance for lengths up to, *e.g.*, 20 km, may actually be used on longer system lengths (*e.g.* 30 km), still obtaining acceptable performances. This could be important in order to cope with more stringent requirements of possible future short haul system standards (*e.g.*, higher bit rates and/or system lengths).

CLAIMS

1. An optical system comprising:
   - a main transmitting/receiving station being adapted for transmitting downstream optical signals to a plurality of end transmitting/receiving stations, and for receiving upstream optical signals originated from said plurality of end transmitting/receiving stations;
   - an optical link connecting said main station and said end transmitting/receiving stations, the optical link comprising at least one combining device being at least adapted to combine upstream signal portions originated from different end transmitting/receiving stations of said plurality in a common upstream signal;

   wherein:
   - at least one of the end transmitting/receiving stations of said plurality comprises a transmission device adapted for transmission of said upstream signals, the transmission device comprising an emitting device generating a plurality of emission modes at different wavelengths;
   - at least one among:

     a) said main transmitting/receiving station, and

     b) said at least one end transmitting/receiving station comprising said emitting device,

     comprises an equalizing element having a transfer function, the transfer function being such that a penalty variation of the common upstream signal received at said main transmitting/receiving station is within 1 dB around a predetermined maximum penalty value, for any distance between said main transmitting/receiving station and said end transmitting/receiving stations up to a predetermined distance.

2. The optical system of claim 1, wherein an average RMS spectral width of said emitting device is at least 2.0 nm.

3. The optical system of claim 1 or 2, wherein said equalizing element is comprised exclusively in said main transmitting/receiving station.

4. The optical system of claim 1 or 2, wherein a respective equalizing element is

comprised exclusively in said at least one end transmitting/receiving station comprising said emitting device.

5. The optical system of any one of claims 1 to 4, wherein said equalizing element comprises an electronic filter.

6. The optical system of claim 5 as dependent on claim 3, wherein said electronic filter is included within a receiver device of said main transmitting/receiving station.

7. The optical system of claim 6, wherein said receiver device comprises a photodiode, and wherein said electronic filter is located downstream of said photodiode.

8. The optical system of claim 7, wherein said receiver device comprises a trans-impedance amplifier located downstream of said photodiode, wherein said trans-impedance amplifier is located between said photodiode and said electronic filter.

9. The optical system of claim 5 as dependent on claim 4, wherein said electronic filter is included within a respective transmitter device of said at least one end transmitting/receiving station comprising said emitting device.

10. The optical system of claim 9, wherein said transmitter device comprises a driving circuit associated to said emitting device, and wherein said electronic filter is associated to said driving circuit.

11. The optical system of any one of claims 5 to 10, wherein said electronic filter comprises a finite impulse response filter.

12. The optical system of claim 11, wherein said finite impulse response filter comprises tap elements and delay elements.

13. The optical system of any one of claims 5 to 12, wherein the transfer function of said electronic filter has a peak located at a frequency higher than zero.

14. The optical system of claim 13, wherein the transfer function has a first value at a frequency equal to zero, and wherein the value of the transfer function at said peak is comprised between 1.2 and 1.85 times the first value.

15. The optical system of claim 13 or 14, wherein said peak is located between 0.5 and 1.0 GHz.

16. The optical system of any one of the previous claims, wherein said transfer function is such that the penalty variation of the common upstream signal received at said main transmitting/receiving station is within 0.5 dB around said predetermined maximum penalty value, for any distance between said main transmitting/receiving station and said end transmitting/receiving stations up to a predetermined distance.

17. The optical system of any one of the previous claims, wherein said predetermined maximum penalty value is 2 dB.

18. The optical system of claim 17, wherein said predetermined maximum penalty value is 1 dB.

19. The optical system of any one of the previous claims, wherein said predetermined distance is a maximum length of the optical link.

20. The optical system of any one of the previous claims, wherein said predetermined distance is about 30 km.

21. The optical system of claim 20, wherein said predetermined distance is about 20 km.

22. The optical system of any one of the previous claims, wherein a bandwidth of the common upstream signal is at least 1 Gbit/s.

23. The optical system of any one of the previous claims, wherein said upstream signal portions originated from different end transmitting/receiving stations of

said plurality are combined in said common upstream signal according to a Time Division Multiplexing technique.

24. An optical transmitting/receiving station comprising:

- an input/output port being adapted to receive input optical signals in a first wavelength band and to send output optical signals in a second wavelength band;
- a routing device associated with said input/output port, the routing device being adapted to route the input optical signals towards a receiver device and the output optical signals towards said input/output port;
- a transmitter device comprising an emitting device generating a plurality of emission modes at different wavelengths, the emitting device being integrated with said routing device, the transmitter device being adapted to generate said output optical signals;

wherein the transmitter device further comprises a pre-distortion filter having a transfer function with a peak located at a frequency higher than zero, cooperating with the emitting device for the generation of the output optical signals.

25. The optical transmitting/receiving station of claim 24, wherein said receiver device is integrated with said routing device.

26. The optical transmitting/receiving station of claim 24 or 25, wherein the second wavelength band is around 1310 nm.

27. The optical transmitting/receiving station of any one of claims 24 to 26, wherein the transfer function has a first value at a frequency equal to zero, and wherein the value of the transfer function at said peak is comprised between 1.2 and 1.85 times the first value.

28. The optical transmitting/receiving station of any one of claims 24 to 27, wherein said peak is located between 0.5 and 1.0 GHz.

29. The optical transmitting/receiving station of any one of claims 24 to 28,

wherein said filter comprises a finite impulse response filter.

30. The optical transmitting/receiving station of claim 29, wherein said finite impulse response filter comprises tap elements and delay elements.

31. An optical transmitting/receiving station adapted for use in an optical system comprising end transmitting/receiving stations including emitting devices generating a plurality of emission modes at different wavelengths and an optical link coupled to said end transmitting/receiving stations and combining upstream signal portions originated from said end transmitting/receiving stations in a common upstream signal in a first wavelength band, the optical transmitting/receiving station comprising:

- an input/output port being adapted to receive the common upstream signal and to send a downstream signal in a second wavelength band towards said optical link;
- a routing device associated with said input/output port, the routing device being adapted to route the common upstream signal towards a receiver device and the downstream signal towards said input/output port;
- a transmitter device being adapted to generate said downstream signal;

wherein the optical transmitting/receiving station comprises an equalizing filter associated with the receiver device, the equalizing filter having a transfer function such that a penalty variation associated with the common upstream signal is within 1 dB around a predetermined maximum penalty value, for any distance between the transmitting/receiving station and said end transmitting/receiving stations up to a predetermined distance.

32. The optical transmitting/receiving station of claim 31, wherein said equalizing filter comprises a finite impulse response filter.

33. The optical transmitting/receiving station of claim 32, wherein said finite impulse response filter comprises tap elements and delay elements.

34. The optical transmitting/receiving station of any one of claims 31 to 33, wherein the transfer function of said equalizing filter has a peak located at

frequency higher than zero.

35. The optical transmitting/receiving station of claim 34, wherein the transfer function has a first value at a frequency equal to zero, and wherein the value of the transfer function at said peak is comprised between 1.2 and 1.85 times the first value.

36. The optical transmitting/receiving station of any one of claims 34 or 35, wherein said peak is located between 0.5 and 1.0 GHz.

37. The optical transmitting/receiving station of any one of claims 31 to 36, wherein the first wavelength band is around 1310 nm.

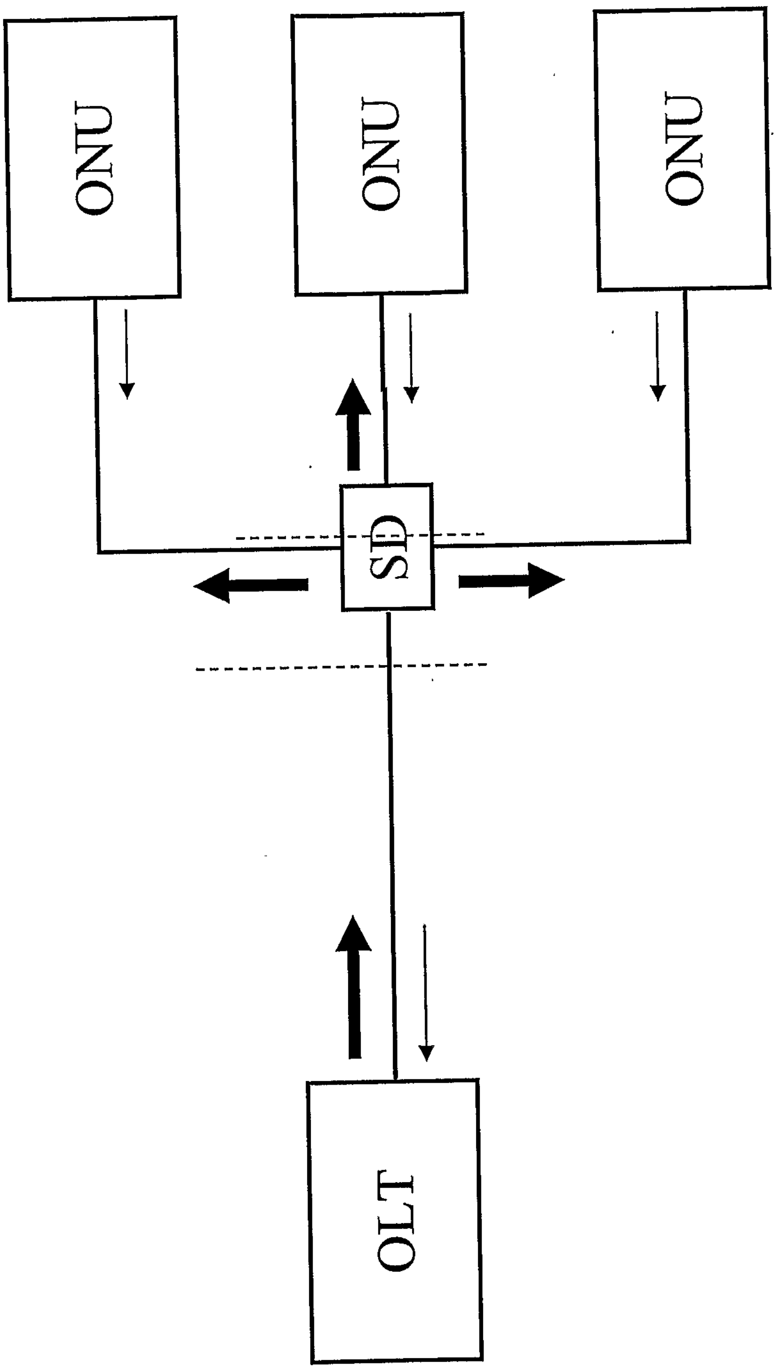

Figure 1

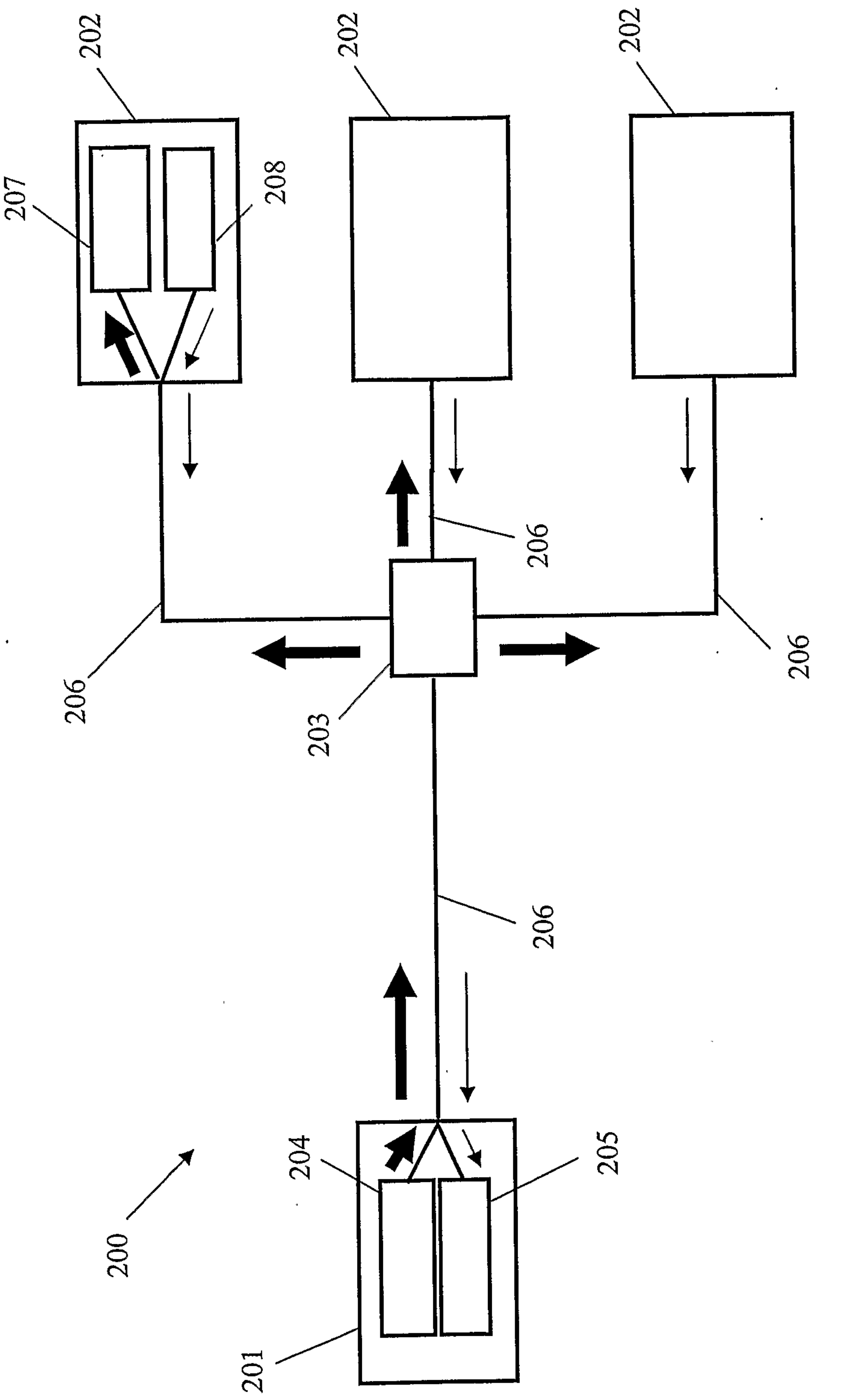

Figure 2

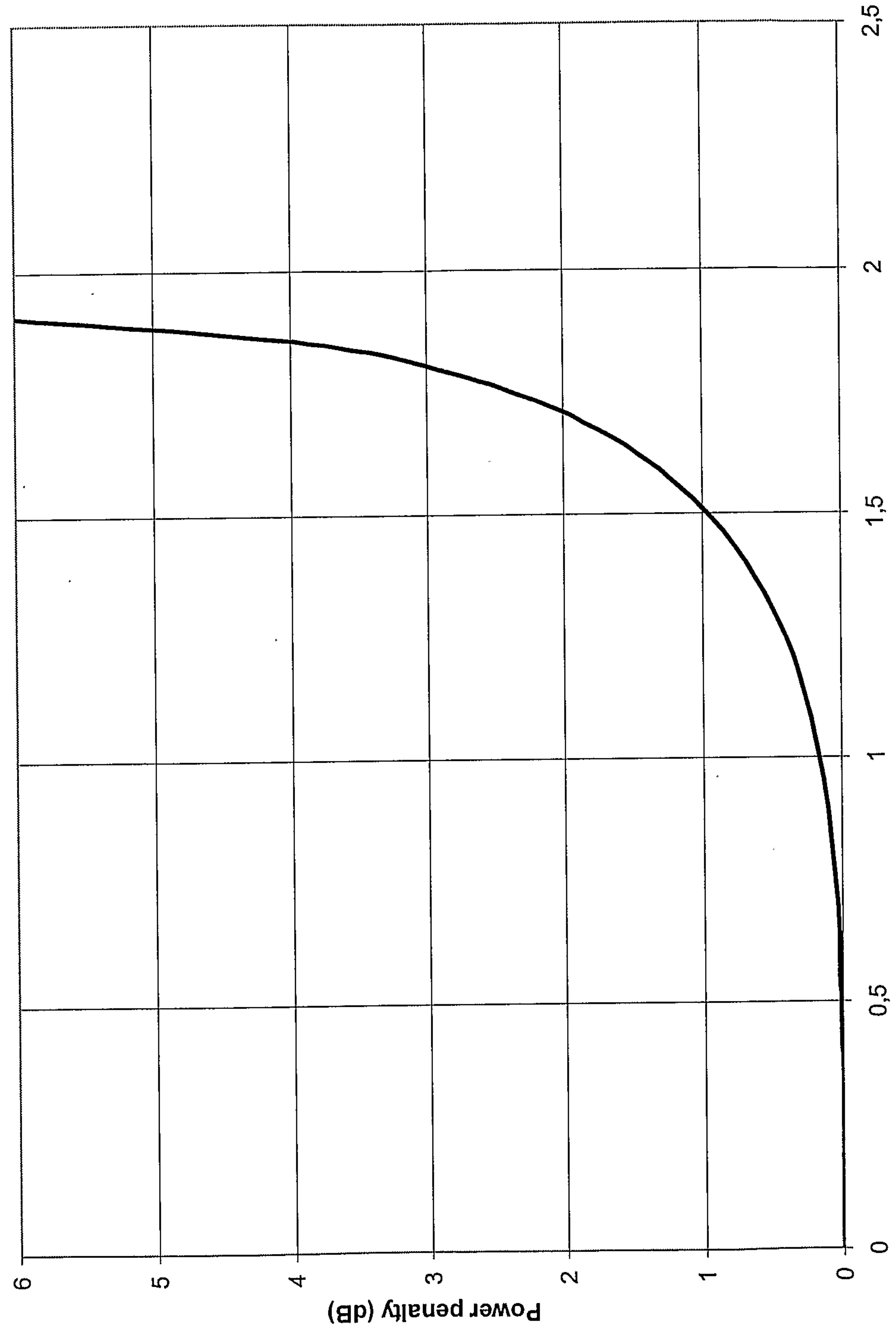

Figure 3

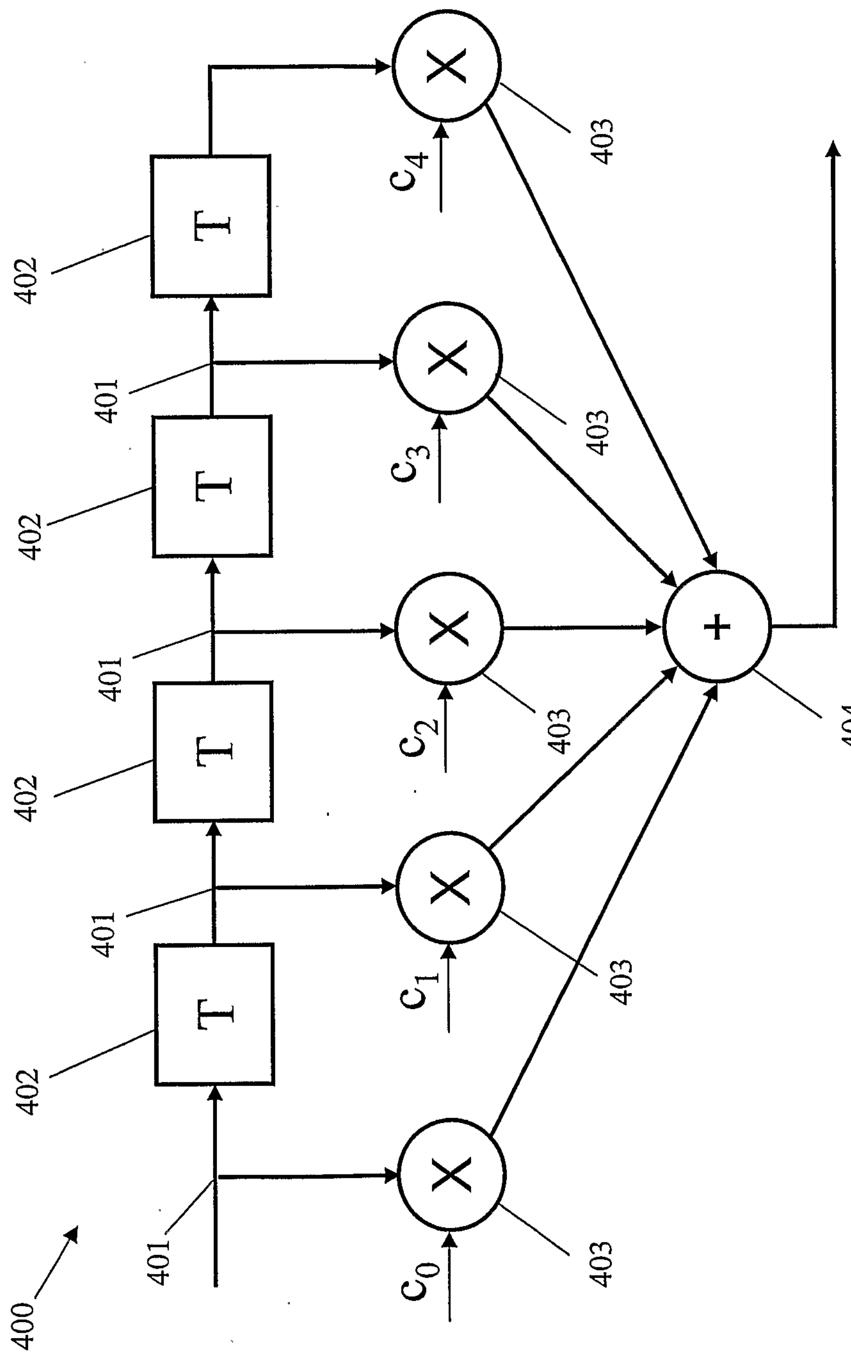

Figure 4

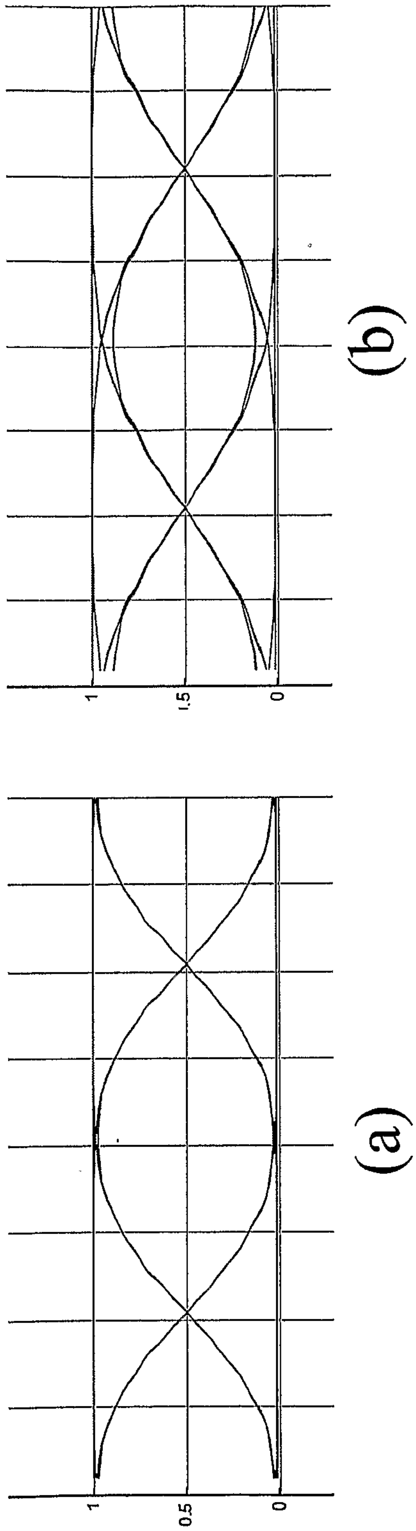

Figure 5

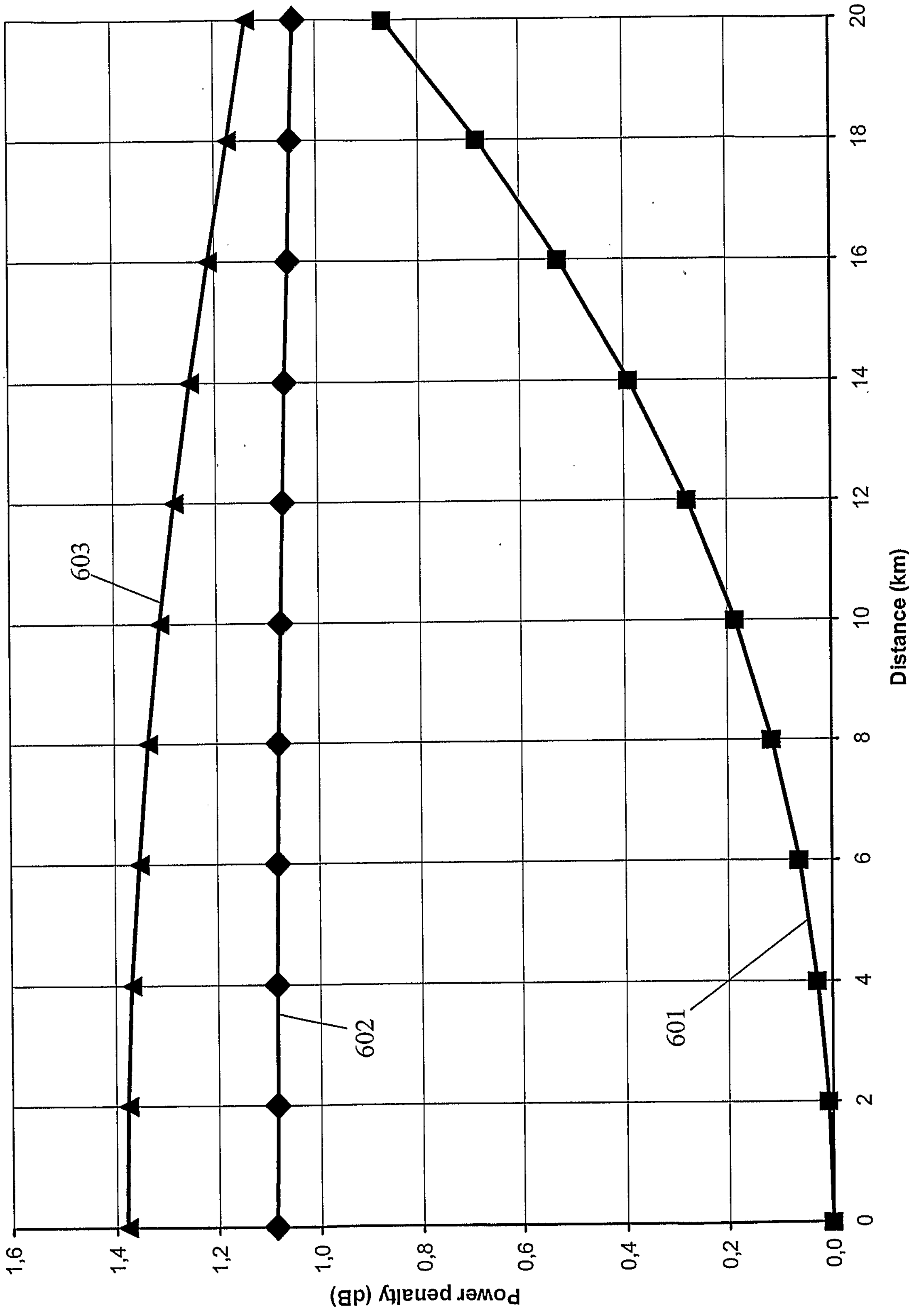
Power penalty (dB)
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
Distance (km)
0
2
4
6
8
10
12
14
16
18
20
601
602
603

Figure 6

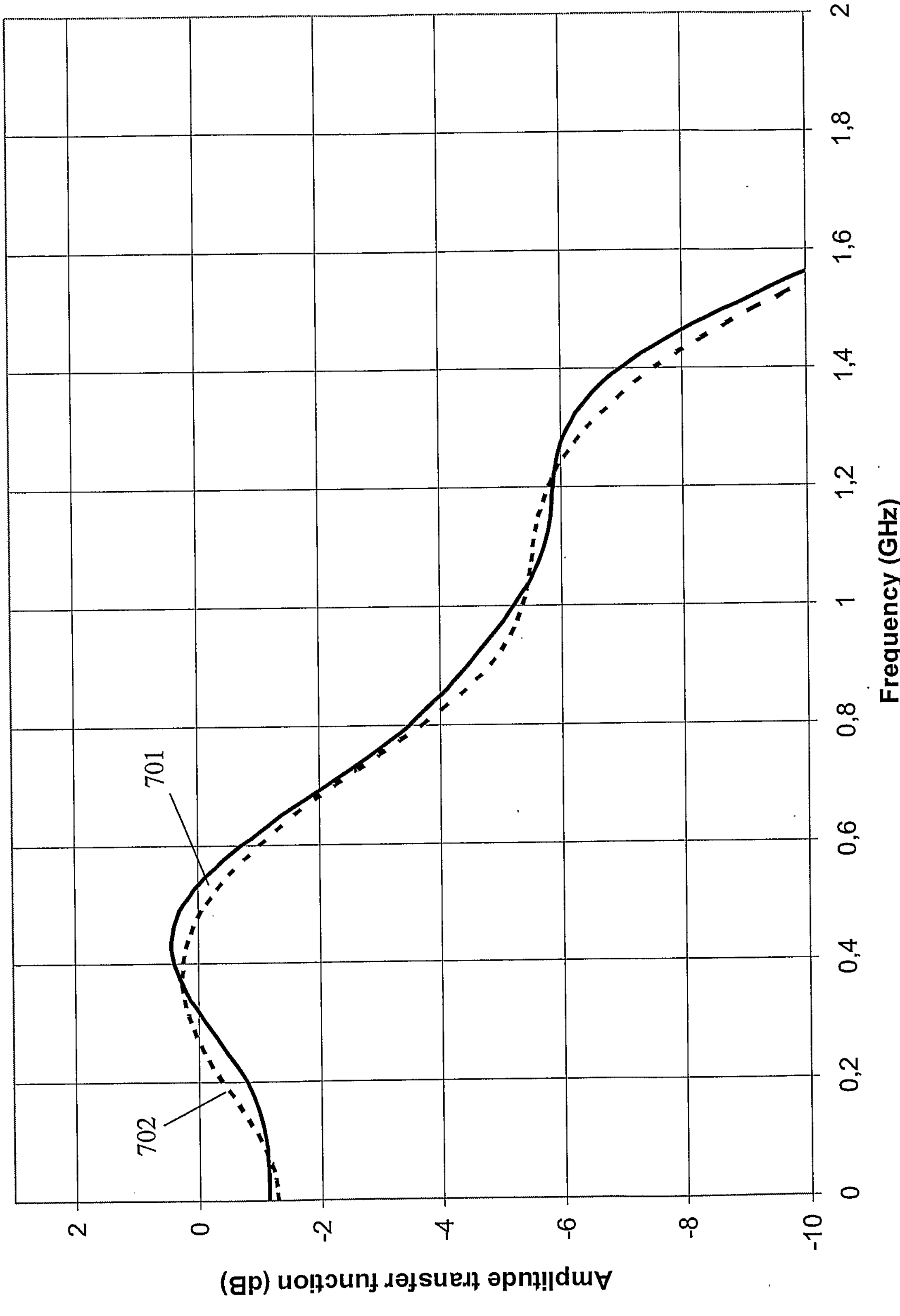
Amplitude transfer function (dB)
2
0
-2
-4
-6
-8
-10
Frequency (GHz)
0
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6
1,8
2
701
702

Figure 7

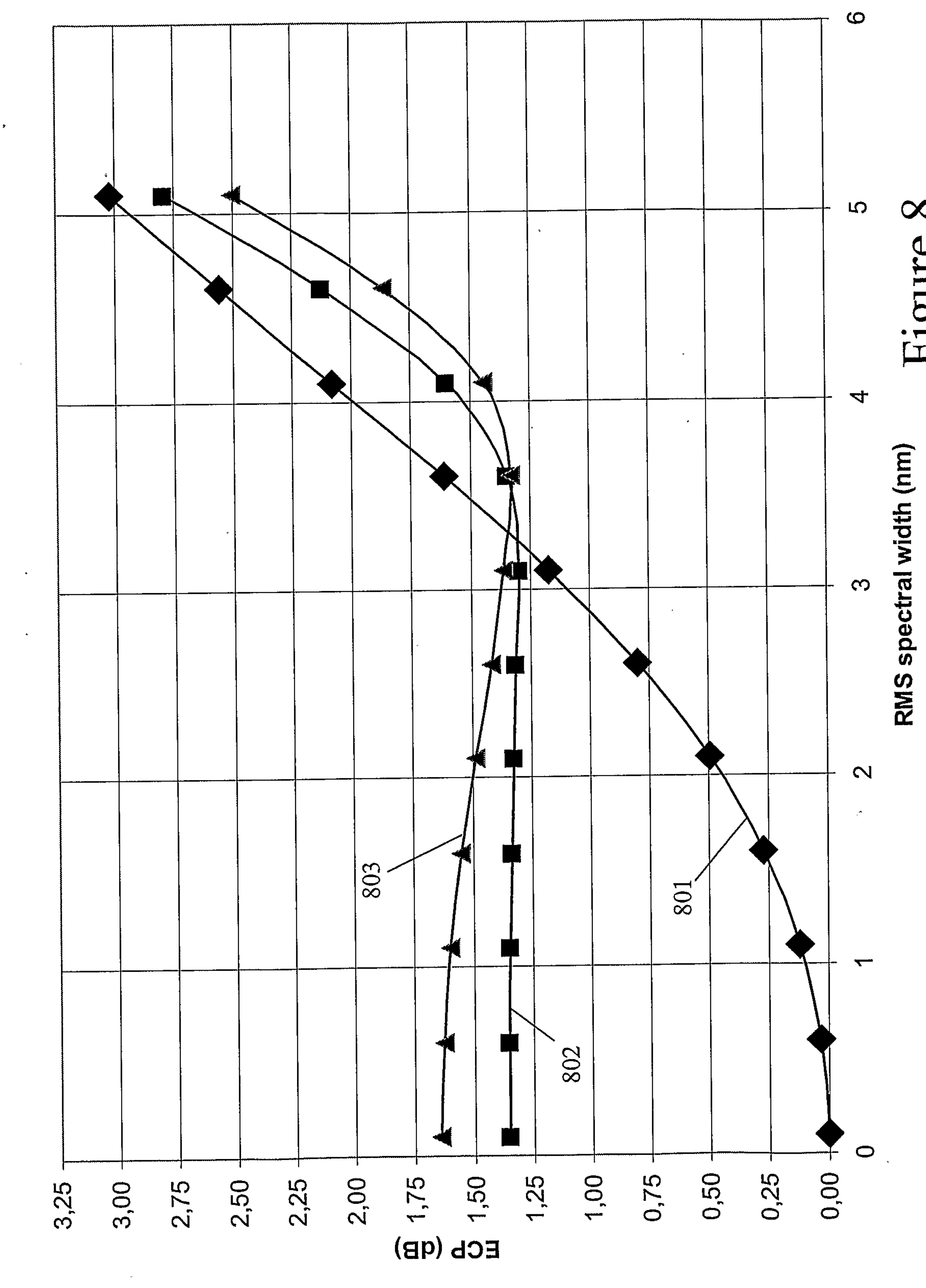
ECP (dB)
3,25
3,00
2,75
2,50
2,25
2,00
1,75
1,50
1,25
1,00
0,75
0,50
0,25
0,00
RMS spectral width (nm)
0
1
2
3
4
5
6
801
802
803

Figure 8

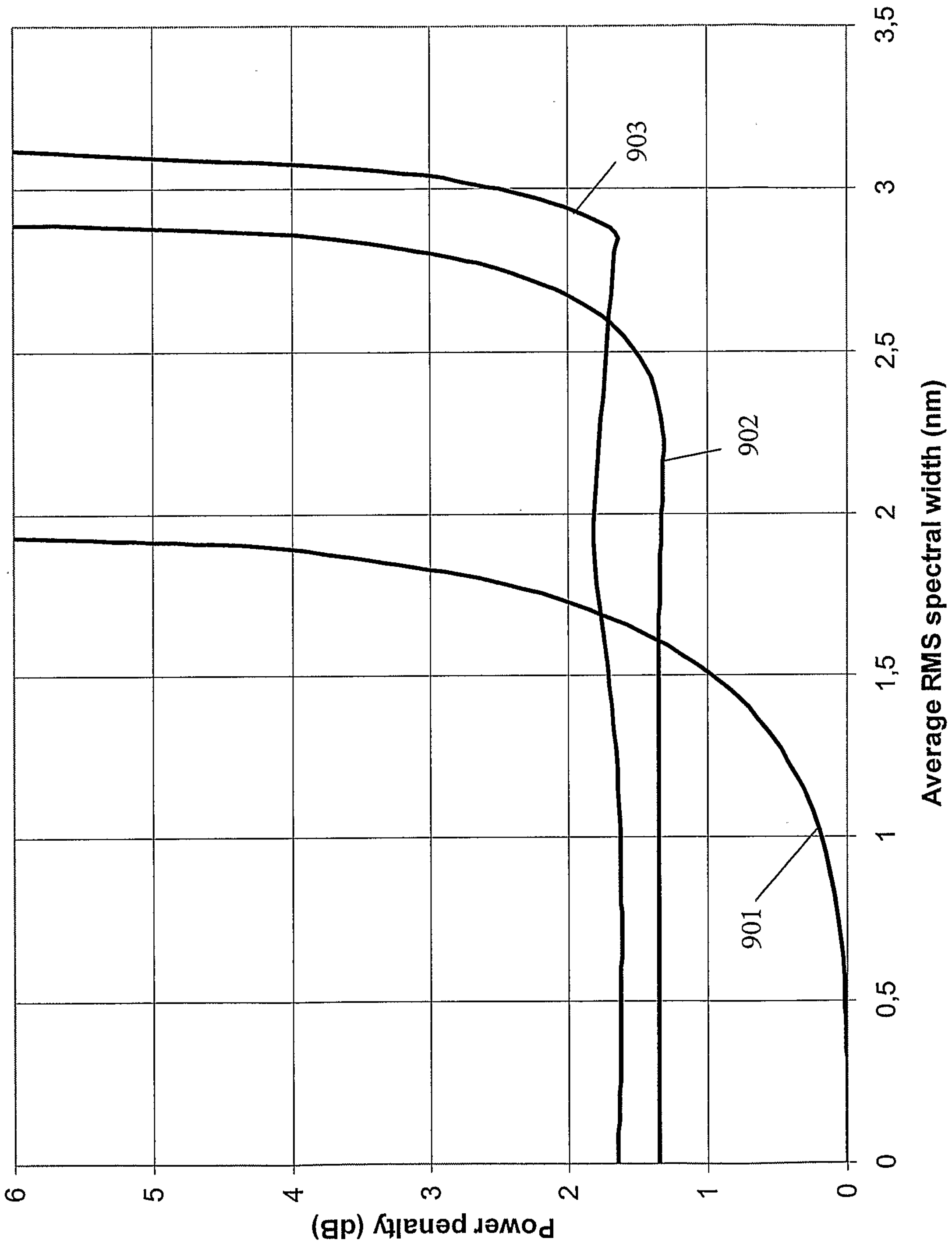
Power penalty (dB)
0
1
2
3
4
5
6
Average RMS spectral width (nm)
0
0,5
1
1,5
2
2,5
3
3,5
901
902
903

Figure 9

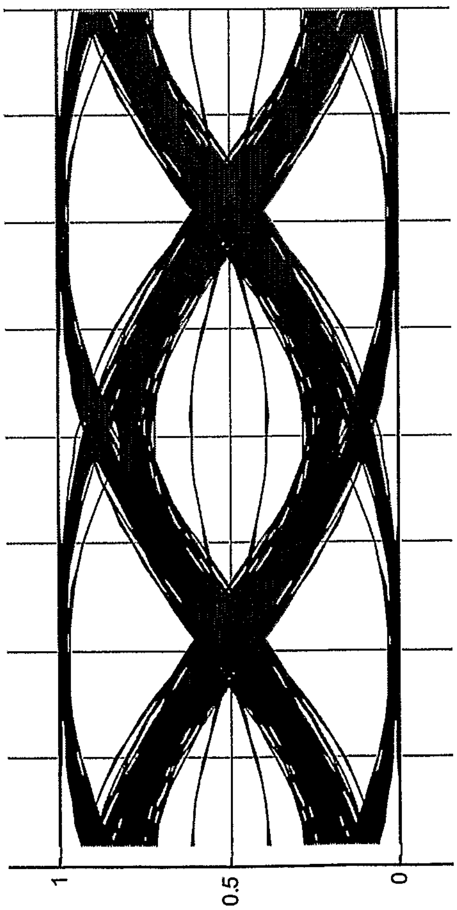

Figure 10a

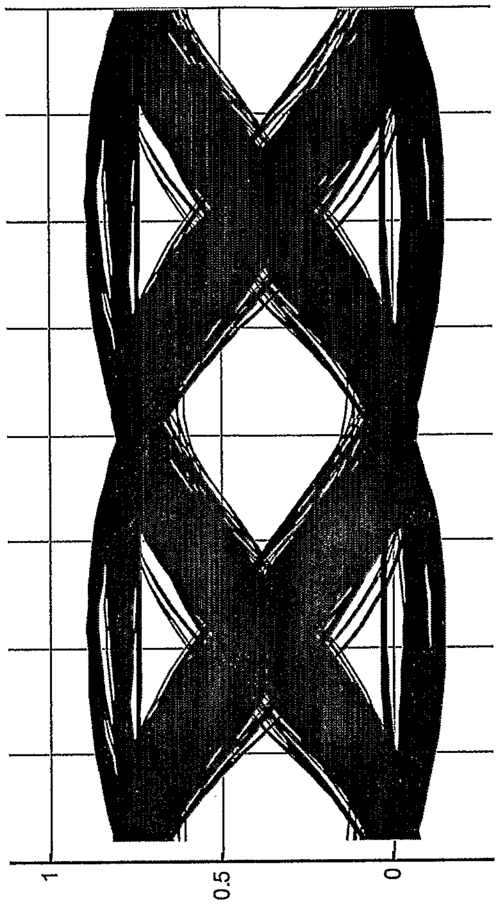

Figure 10b

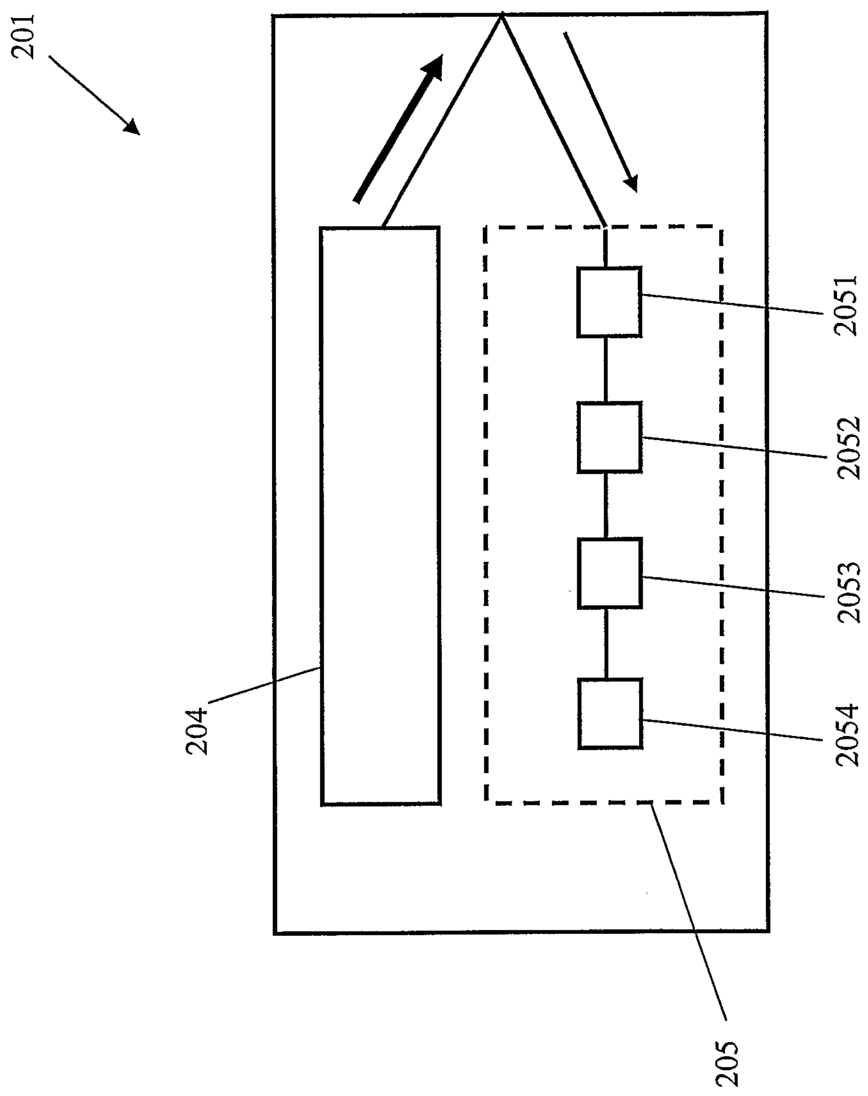

Figure 11

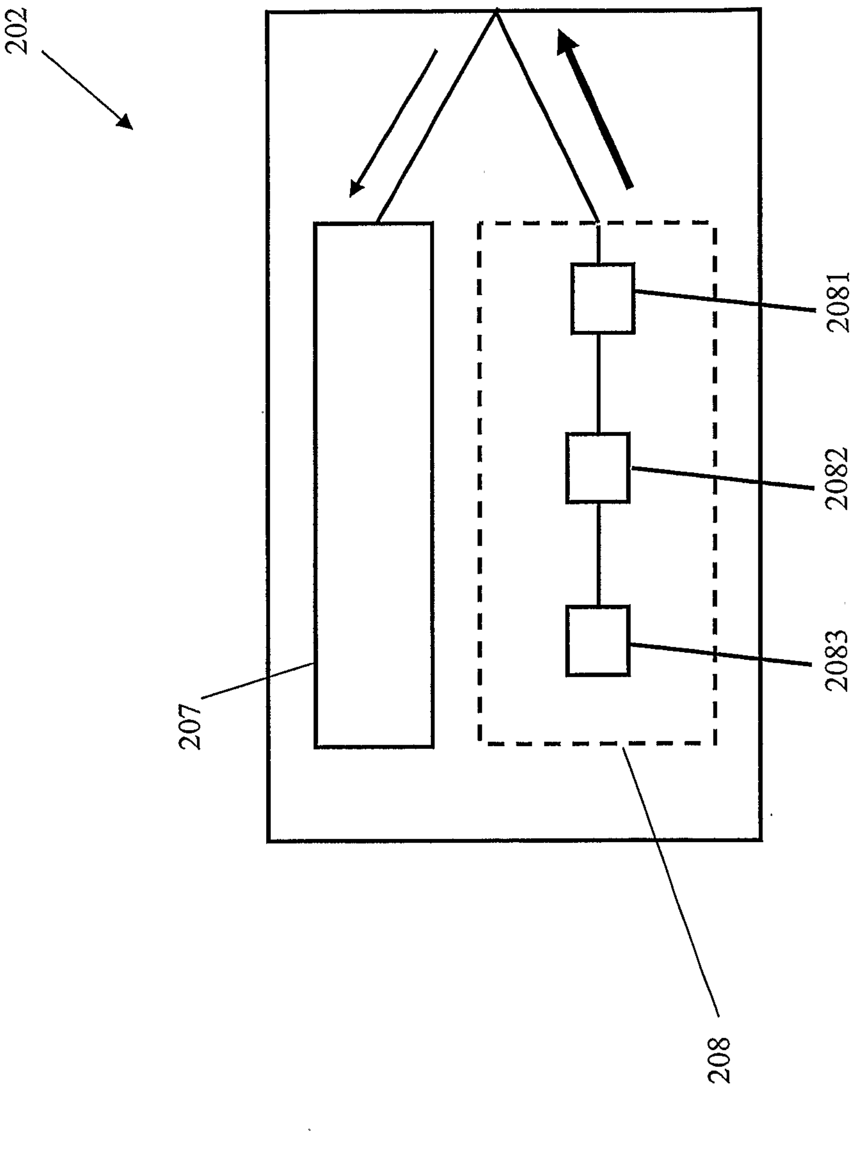

Figure 12

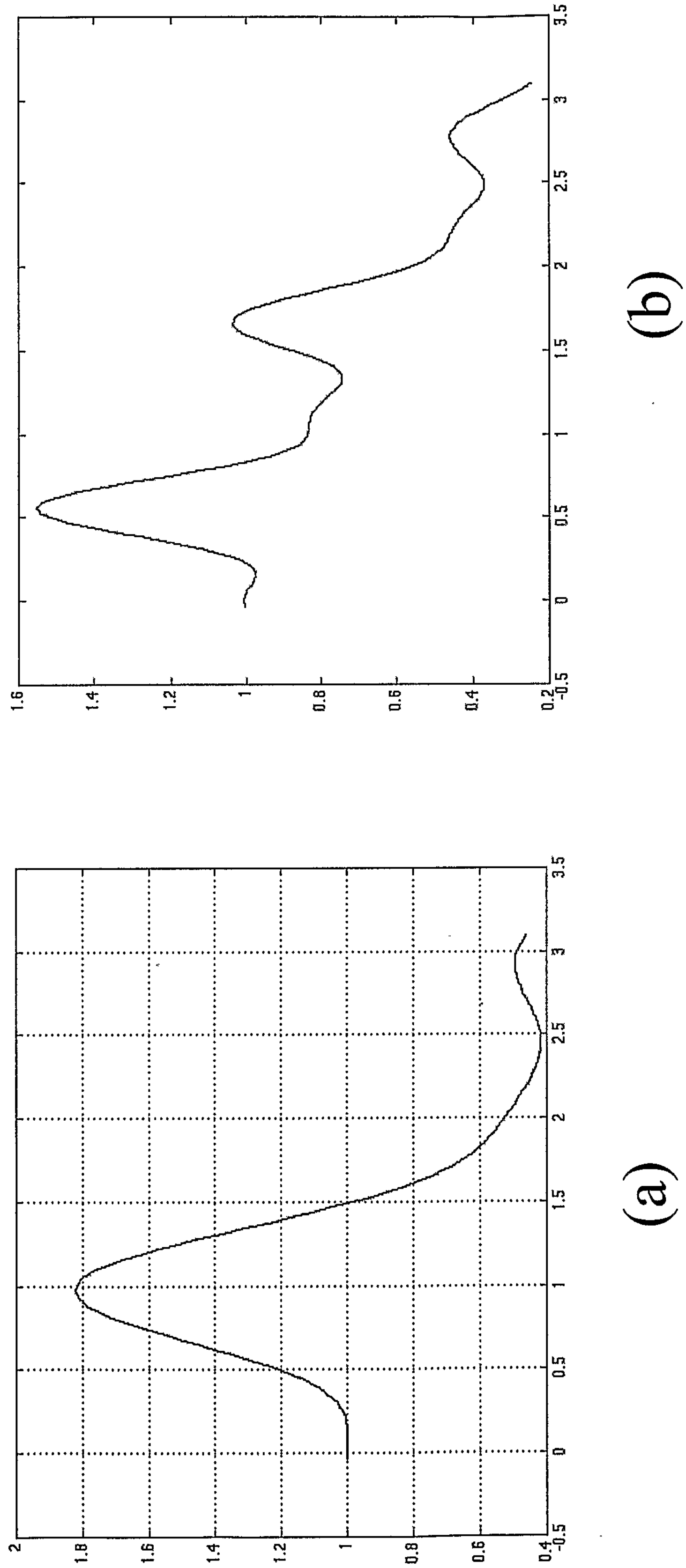

Figure 13

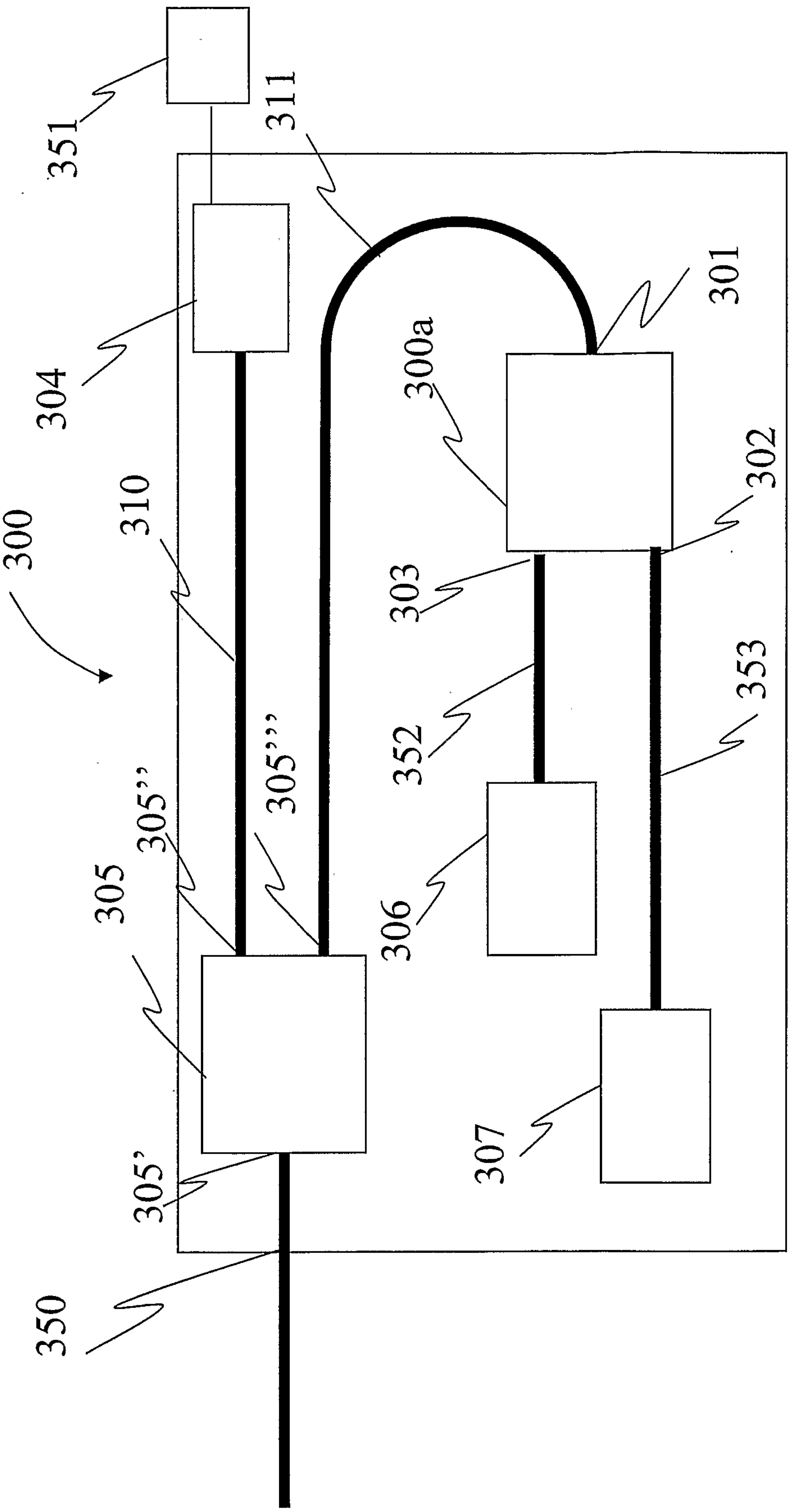
300
300a
301
302
303
304
305
305'
305''
305'''
306
307
310
311
350
351
352
353

Figure 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/IT2006/000057

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B10/207 H04B10/13

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04B H01S H04J

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

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 381 047 B1 (FRIGO NICHOLAS J [US] ET AL) 30 April 2002 (2002-04-30) column 5, line 1 - column 9, line 13 figures 5,9	1-37
A	US 2005/163510 A1 (MATTHEWS MANYALIBO J [US]) 28 July 2005 (2005-07-28) cited in the application paragraph [0005] - paragraph [0006] paragraph [0008] - paragraph [0009] paragraph [0019] - paragraph [0027]	1-37

-/--

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

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 October 2006	26/10/2006

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

INTERNATIONAL SEARCH REPORT

International application No
PCT/IT2006/000057

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2005/070177 A2 (CLARIPHY COMMUNICATIONS INC [US]; SWENSON NORMAN [US]; VOOIS PAUL [US]) 4 August 2005 (2005-08-04) page 4, line 15 - line 20 page 7, line 25 - line 30 page 10, line 29 - page 14, line 18 page 21, line 14 - page 22, line 21 -----	
A	BATES R J S: "EQUALIZATION AND MODE PARTITION NOISE IN ALL-PLASTIC OPTICAL FIBER DATA LINKS" IEEE PHOTONICS TECHNOLOGY LETTERS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 4, no. 10, 1 October 1992 (1992-10-01), pages 1154-1157, XP000316543 ISSN: 1041-1135 the whole document -----	1-37

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IT2006/000057

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6381047 B1	30-04-2002	NONE	
US 2005163510 A1	28-07-2005	NONE	
WO 2005070177 A2	04-08-2005	US 2005191059 A1	01-09-2005