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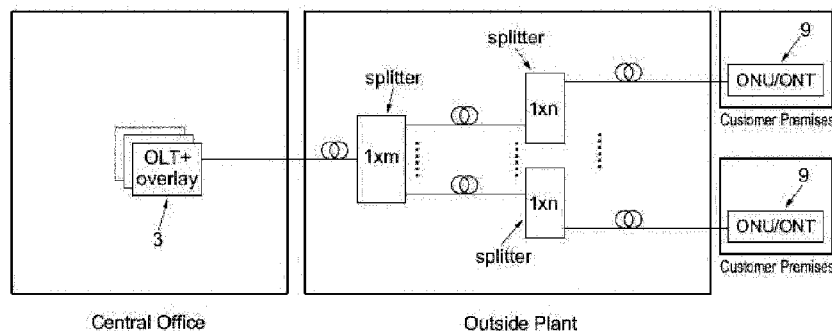
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(54) **Title:** A METHOD AND A SYSTEM FOR PHYSICAL LAYER MONITORING IN POINT TO MULTIPOINT PASSIVE OPTICAL NETWORKS BASED ON REFLECTOMETRY SYSTEMS

**FIG. 1**

(57) **Abstract:** The system comprises: a light source injecting a monitoring light signal together with at least one data light signal by means of a global light signal at an input of a PON; a power splitter splitting said global light signal into a plurality of sub-global signals; and a plurality of filters each of them connected between an output of said power splitter and a respective branch of said PON, and each of them allowing the pass of said at least one data light signal and of a single wavelength or set of wavelengths of said monitoring light signal giving as result a filtered sub-global light signal. The method is adapted to use the system for physical layer monitoring in PONs.

A method and a system for physical layer monitoring in point to multipoint passive optical networks based on reflectometry systems

Field of the art

The present invention generally relates, in a first aspect, to a method for physical layer monitoring in point to multipoint Passive Optical Networks (PONs) based on reflectometry systems, comprising emitting light to the interior of a PON and analysing the light reflected at different points of the PON, and more particularly to a method which allows discerning the branch of the PON where the light reflected comes from based on a filtering process of said emitted light performed in said points of the PON.

A second aspect of the invention relates to a system arranged for implementing the method of the first aspect.

Prior State of the Art

In today's Passive Optical Networks (PONs) the physical infrastructure is usually not entirely visible to the Network Management System (NMS). As a direct consequence, a physical failure (dirty or damaged contacts between connectors, macrobending, environmental constraints ...) and fibre breaks are very difficult to or cannot be detected before creating service outage in upper layers which in turn may lead to tremendous loss in business for the operators. These arguments have been gaining importance as the warranty on the quality of the infrastructure becomes a deciding factor in the strongly competitive marketplace. As a result, the telecom operators have come across the challenge of having reliable monitoring systems for the practical implementation of new outside plant (OSP) with PON architectures in point-to-multipoint topologies in order to achieve a low operational cost of the network, a reduced risk of service disruption and a rapid recovery time in case of failure at the optical physical layer.

Current deployment of Fibre-to-the-x (FTTx, x = H for home, B for building, C for curb and N for node) technology will require efficient physical layer supervision systems in order to reduce the cost of operation and maintenance (OPEX) of the optical access network. The vast majority of the current FTTx Passive Optical Network (PON) deployments are based on power splitters (PS), and so is expected for the massive deployments in the long term.

For a fibre network operator, it is essential to monitor the outside fibre plant in such a way that the identification and repair of physical layer faults are as quick as possible.

In order to quickly detect and solve a physical layer problem in a tree FTTx PON outside plant based on power splitters, it is very important to identify the specific branch where a fault may occur and the exact point where it may have taken place, with the best accuracy as possible.

The optimal situation to reduce the cost of a supervision system is to perform the measurements from the central office (CO), where all the feeder fibres of the FTTx PONs start. The feeder fibres 5 connect the CO with the outside plant and to all the customer premises, so the central office is a strategic point from where any problem in the fibre access network could be detected, identified or located.

In the typical situation of a PON supervision system based on OTDR, as it will be shown in Figure 2, an OTDR (1) is shared among several OLT PON ports (3) (including overlay signals) through a Fibre Optic Cross-connect System (2) (FOCS), which switches the OTDR port to the corresponding input port of the passive stage with WDM filters (4). The OTDR signal is delivered to the Outside Plant through the feeder fibre (5), where typically the point to multi-point optical fibre structure is formed by using first level (6) and second level (8) splitters, with splitting ratios of $1 \times m$ and $1 \times n$, respectively. The distribution section of the typical PON is built using the distribution fibres (7) connecting the two splitting levels, and finally the drop section of the PON is connected to the customer premises ONTs (9) through $m \times n$ drop fibres (9).

This tree-based topology of the FTTx PONs based on power splitters arises some important challenges and difficulties for optimal operation and maintenance tasks.

In this situation, the superposition in time of the reflections of the OTDR (1) supervision signal coming from the different distribution and drop fibres makes it mandatory to install individual optical elements in the outside plant (OSP) infrastructure in order to individually identify a fault in a single drop-fibre.

For FTTx-PONs, several physical layer monitoring solutions based on Optical Time Domain Reflectometry (OTDR) have been proposed in the literature [1].

OTDRs are equipment designed to test the complete length of a single optical fibre, capable of locating in distance both attenuation and reflection events. By transmitting a train of periodical high power optical pulses into a fibre cable and analyzing in time the Fresnel and Rayleigh reflected signals, OTDRs can obtain a trace along of the optical fibre.

Nevertheless, OTDRs are designed for point-to-point fibre links, so they cannot distinguish the events coming from different output fibres after an optical power splitter in a branched FTTx PON, because the reflections from the different distribution fibres are overlapped in time.

The obtained OTDR trace beyond the first power splitter becomes ambiguous, as a reflective or attenuation event cannot be individually assigned to a specific branch of the power splitter, except if a disambiguation mechanism is performed. These approaches have tried to overcome the limited performance of the conventional OTDR measurements, yet they have essential restrictions which are described next.

The most relevant physical layer supervision techniques for FTTx point-to-multipoint PONs, and the problems associated with these techniques, can be listed as:

- Techniques using an OTDR and FBGs [2] [3]. These techniques are aligned with the approach of Standard ITU-T L.66 [4], where the combined use of traditional OTDR at the CO and the installation of reflective filters in front of the ONTs are recommended. The main restrictions of this solution are the superposition between reflections and the ambiguity between reflection peaks coming from the filters installed in front of ONTs in a massive deployment scenario.

- Techniques using controlled reference reflections in the branch ends [5]. This work enhances the OTDR analysis of optical losses in point-to-multipoint PONs, and solves the ambiguity of end reflections from branches of equal lengths. The main restriction of this approach is that it requires an active switchable reflective element which must be synchronized with the OTDR, adding high cost and complexity to the supervision system.

- Techniques based on embedded low-cost OTDR inside ONTs [6]. This approach can be effective for physical layer problems that do not completely break the communication between the ONT and OLT. Otherwise, a backup communication network is required to send the OTDR measurement to the supervision system.

- Optical Code Division Multiplexing (OCDM) [7]. In this technique, Direct-Sequence OCDMA passive encoders in reflective operation installed in front of the ONTs are used to individually identify the corresponding reflections. Nevertheless, the manufacture of these encoders requires a large number of optical components for each one, and the complexity of managing the complete inventory can be very high. Besides, this technique only solves the ambiguity of reflections from ONT at very close distances from the Central Office, not providing any other physical layer information from the length of the drop fibres.

- Use of drop-fibres with individually-assigned Brillouin frequency shifts [8]. The need for specific Brillouin frequency shift single-mode fibre fabrication, and the complexity and cost of this kind of deployment is a very inconvenient drawback of this approach. It also requires Brillouin OTDRs which are not commercially available in the market and the effect of the environmental parameters should be taken into account or compensated to ensure the quality of the measurements.

- The invention [9] provides a method and apparatus for determining a failure of an Optical Network Unit (ONU) before a PON system failure occurs, by collecting and analyzing the monitoring information from both the Optical Line Terminal (OLT) and the ONU. Nevertheless, this invention is not capable of directly obtaining physical-layer information of the PON nor identifying the exact fault location.

- The invention [10], polarization dependent components are installed before and after the drop fibres in the PON. OTDR pulses with controlled polarization states, associated with each polarization marker, are used as the basis for distinguishing the branches from one another. The complexity of the signal analysis and processing for this technique, as well as the complexity of fabricating and managing a large number of polarization marked components in the outside plant at low cost, are the main drawbacks of this technique. No successful demonstration of this approach has been published in the past ten years.

- In the invention [11] a low cost system is described using a sweeping tunable laser and optical reflectors with different wavelengths at the start and end points of the optical fibres forming the PON. The reflections obtained from the different points are analyzed to obtain the attenuation of each single fibre section. This enhances the physical layer supervision of PON existing solutions while keeping low cost using inexpensive equipment and simple modifications of the Outside Plant; nevertheless, this solution requires the installation of filters at the customer end side of the drop fibres and the test method is not able to locate the exact point of a fibre defect.

- The proposal [12] describes a method for individual and full-length supervision of PON fibres using tunable OTDRs. It is based on a complete deployment of a WDM-PON structure installing optical multiplexer/demultiplexers in parallel to the power splitters of the legacy PON, requiring cyclic performance of the first level optical mux/demuxes (option 2). Even though the supervision of the PON can be achieved with high sensitivity, the number and cost of the elements and modifications required in the outside plant are higher and more complex than in the present invention, which only uses in-series filters at each output port of the previously existing components in the outside plant. Additionally, the wavelength plan and maximum number of drop fibres of

this previous patent strongly depends on the current technology of the cyclic filters and its evolution, while this new invention can use out-of-the shelf optical components with low cost and no limitation in the wavelength plan, just using one or more available subbands not being used for PON data transmission.

Description of the Invention

It is necessary to offer an alternative to the state of the art which covers the gaps found therein, particularly related to the lack of proposals which really allows locating exactly the point of a fibre defect, such as an attenuation or break, from the central office of the PON.

To that end, the present invention provides, in a first aspect, a method for physical layer monitoring in point to multipoint passive optical networks based on reflectometry systems, comprising:

- injecting a monitoring light signal at an input of a Passive Optical Network, or PON, to circulate there through;
- reflecting back, optical means provided at different points of said PON, at least part of said monitoring light signal, in the form of respective reflected light signals; and
- analysing said received reflected light signal to perform a physical layer monitoring of the PON;

On contrary to the known proposals, in the method of the invention, in a characteristic manner it further comprises, in order to perform said supervision simultaneously to the normal operation of the PON based on the injection of at least one data light signal:

- injecting said at least one data light signal and said monitoring signal together by means of a global light signal at said input of said PON;
- at least splitting said global light signal into a plurality of sub-global light signals;
- filtering each of said sub-global light signals by a corresponding one of a plurality of filters to output a filtered sub-global signal containing a single wavelength or set of wavelengths of said monitoring light signal and the whole band of said at least one data light signal; and
- sending to each branch of said PON at least part of said filtered sub-global signal.

Other embodiments of the method of the first aspect of the invention are described according to appended claims 2 to 5, and in a subsequent section related to the detailed description of several embodiments.

A second aspect of the present invention concerns to a system for physical layer monitoring in point to multipoint passive optical networks based on reflectometry systems, comprising:

- a light source arranged to inject a monitoring light signal at an input of a PON to circulate there through;
- a plurality of optical filters provided at different points of said PON to receive said monitoring light signal and filtering at least part thereof, in the form of respective filtered light signals;
- at least one power splitter which equally splits said monitoring light signal into splitted signals, each to be sent to one of different branches of said PON;
- light detecting means arranged to receive said respective reflections from the filtered light signals from said optical filters ; and
- analysis means connected to said light detecting means to analyse said received reflected light signals to perform a physical layer monitoring of the PON.

In the system of the second aspect of the invention, on contrary to the known systems mentioned in the prior state of the art section, and in a characteristic manner:

- said light source injecting said monitoring light signal together with at least one data light signal by means of a global light signal at said input of said PON;
- said power splitter splitting said global light signal into a plurality of sub-global signals; and
- a plurality of filters each of them connected between an output of said power splitter and a respective branch of said PON, and each of them allowing the pass of said at least one data light signal and of a single wavelength or set of wavelengths of said monitoring light signal giving as result a filtered sub-global light signal.

The system of the second aspect of the invention is adapted to implement the method of the first aspect.

Other embodiments of the system of the second aspect of the invention are described according to appended claims 7 to 19, and in a subsequent section related to the detailed description of several embodiments.

Brief Description of the Drawings

The previous and other advantages and features will be more fully understood from the following detailed description of embodiments, with reference to the attached drawings, which must be considered in an illustrative and non-limiting manner, in which:

Figure 1 shows the current generic point to multipoint PON architecture based on power splitters.

Figure 2 shows a current schematic of an OTDR supervision system for PONs and the different sections of a general PON architecture.

Figure 3 shows the current wavelength plan for PON and XG-PON systems.

Figure 4 shows the proposed physical layer supervision system.

Figure 5 shows the structure of the modified first level splitters using optical multi-passband filters in series with distribution and drop fibres, according to an embodiment of the present invention.

Figure 6 shows the structure of the modified second level splitters using optical multi-passband filters in series with distribution and drop fibres, according to an embodiment of the present invention.

Figure 7 shows the individual supervision of feeder and distribution fibres using the modified first level splitters, according to an embodiment of the present invention.

Figure 8 shows the wavelength plan for the proposed monitoring system.

Figure 9 shows the monitoring subband assignment for first level splitters for the proposed invention.

Figure 10 shows the individual supervision of drop fibres using the modified second level splitters, according to an embodiment of the present invention.

Figure 11 shows the monitoring wavelength assignment for drop fibres for the proposed invention.

Figure 12 shows a first level splitter with multi-passband optical filter implementation using circulators and WDM reflectors, according to an embodiment of the present invention.

Figure 13 shows a second level splitter with multi-passband optical filter implementation using circulators and WDM reflectors, according to an embodiment of the present invention.

Figure 14 shows a first level splitter with multi band-suppression optical filter implementation using in-series reflectors, according to an embodiment of the present invention.

Figure 15 shows a second level splitter with multi band-suppression optical filter implementation using in-series reflectors, according to an embodiment of the present invention.

Detailed Description of Several Embodiments

The present invention consists of a centralized OTDR measurement system to remotely obtain the individual characterization of each fibre in a FTTx point-to-multipoint PON all along its length. Therefore, the defined system is aimed at locating exactly the point of a fibre defect, such as an attenuation or break, from the central office of the PON.

This invention is relevant in the field of optical access networks with point-to-multipoint physical topology built of power splitters in the outside plant, such as GPON, EPON, 10G-GPON, 10G-EPON, and any future NG-PON system that uses part of or the complete fibre infrastructure of the former PONs.

The conceived system consists of an OTDR with tunable operating wavelength, and optical multi-passband filters in the remote/s node/s of the PON system. It does not require the installation of any component at the ONT side of each drop fibre.

OTDR operating wavelength must be tunable within an optical band reserved for monitoring purposes and available in the PON system under supervision. In Figure 3 it was shown the generic wavelength plan for PON and 10G-PON systems with optional video overlay services and maintenance band as defined by ITU-T L.66. Even though the water peak region has been usually avoided for data transmission due to the water peak attenuation of single mode fibre, this band can be useful for physical layer monitoring purposes. WDM techniques are only used for the OTDR measurements, maintaining the power splitting nature of the PON for data transmission.

In order to share the monitoring equipment in the central office for multiple PONs operating at an operator's point of presence (POP), fibre-optic cross-connect systems (FOCS) can be used in order to consecutively switch the OTDR signal to the different PON feeder fibres.

The invention relies on the use of in-series multi-passband and multi-band-suppression filters at the output ports of the PON power splitters which let the PON and/or NG-PON data transmission signals travel as well as a single optical subband or wavelength for each distribution and drop fibres of a PON for monitoring purposes, thus assigning a specific optical subband and wavelength for individually OTDR monitoring of optical fibres.

The system is designed in such a way that a single monitoring pulse does not travel through more than one fibre in parallel, thus avoiding the superposition of the

backscattering of the OTDR monitoring signals coming from the rest of the fibres that exist in the PON.

In Figure 4 it was shown the generic schematic architecture of the proposed supervision system with two levels of splitting. The current invention is based on two key characteristics:

- The specific passbands of the optical filters included in the first-level (60) and second level (81..8m) modified power splitters. These components behave as power splitters for the PON data transmission signals but use different passband ranges for the monitoring signals.

- The tunability capacity of the OTDR (10) located in the Central Office within the reserved monitoring optical band/s. Thanks to this capacity the OTDR is able to send a monitoring pulse using a wide range of wavelengths, typically one per PON customer.

The system is designed so that, for a fixed operating wavelength of the pulses launched by the Tunable OTDR (T-OTDR) (10), these pulses travel through the feeder fibre (5), a single fibre (71..7m) – being m the number of fibre outputs of the first-level modified splitter (60) – of the distribution section, and a single fibre (911..9mn) – being n the number of fibre outputs of the second-level modified splitters (81..8m) – of the drop section, thus supervising a single fibre link from the OLT to a specific ONT and avoiding the superposition of reflections from different branches at the OTDR receptor. This is realized because every output fibre branch of the modified splitters let pass a different optical monitoring signal, which depends on the operating wavelength of the T-OTDR (10).

The proposed modification of the splitters is performed by using special filters in-line with each output fibre:

In Figure 5 it was represented a modified first-level splitter (60) connected to a feeder fibre (5) with m outputs (71..7m), composed by a generic power splitter (6) with m outputs, where each output is connected in series with different special filters (21..2m) in charge of blocking all monitoring wavelengths except the wavelengths assigned to the subband of the specific distribution fibres (71..7m) used. In the specific case of using a monitoring pulse using λ_{11} wavelength assigned to the subband 1, it is divided by the power splitter (6) and suppressed in all special filters (22..2m), allowing passing this wavelength only through the special filter (21).

In Figure 6 it was represented a modified second-level splitter (8j) connected to a distribution fibre (71..7m) with n outputs (9j1..9jn), composed by a generic power splitter (8j) with n outputs, where each output is connected in series with different special filters (4j1...4jn) in charge of blocking all monitoring wavelengths except the wavelength

assigned to the specific drop fibre (9j1..9jn) used. In the specific case of using a monitoring pulse using λ_{j1} wavelength, it is divided by the power splitter (8j) and suppressed in all special filters (4j2..4jn), allowing passing this wavelength only through the special filter (4j1).

The power splitting nature is kept because the special filters are installed in series with the output fibres of the splitters.

This invention is detailed using a generic PON topology based on two splitting levels; nevertheless, either a single splitting level or more than two levels are also possible, extending the monitoring wavelength plan design described between the first and second levels, to the next levels. For a splitting point in the PON, the general wavelength plan design criteria consists of letting pass just part of the monitoring signal through each output port of the splitter, being a different part of this signal from the other output ports.

When the OTDR pulses are within the wavelengths or optical subband ($\lambda_{11}...$ λ_{1n}) assigned to the branch (71) of the first modified splitter (60), as shown in Figure 7 (a), the T-OTDR receives only the reflections of this distribution fibre (71), and thus the individual characterization of the complete length of this distribution fibre is obtained, while the data transmission with video overlay or any other data services are delivered to all the distribution fibres (71..7m). By tuning the operation wavelength of the tunable OTDR (10) to a different value, the corresponding fibre characterization is achieved. The illustration of the monitoring of the distribution fibre (7m) was shown in Figure 7 (b). The WDM (4) passband must include all the OTDR operating wavelengths, so the feeder fibre (5) characterization is always obtained. The modified splitter (60) behaves like a typical power splitter for the rest of the signals other than OTDR monitoring pulses.

The T-OTDR (10) must be able to select a single operating wavelength at a time for monitoring the complete optical path from the CO to a specific ONT. Monitoring wavelengths are grouped into several subbands, as shown in Figure 8, where a subband is needed per each distribution fibre and a specific monitoring wavelength is needed per individual drop fibre (911..9nm) in the PON system. No specific numerical values are assigned to monitoring wavelengths in order to allow flexibility to the system. The only restriction is that no overlapping between monitoring and data and overlay signals takes place in the PON.

In Figure 9 it was shown how the monitoring subbands are related to the distribution fibres. For example, the first output of the modified splitter (60) corresponds to the distribution fibre (71) and this fibre is related to the subband 1, the second output corresponds to the distribution fibre (72) and this fibre is related to the subband 2 and so

on up to the last output which corresponds to the distribution fibre (7m) and this fibre is related to the subband m.

The monitoring principle of operation was shown in Figure 10 for a generic second-level modified splitter 8j ($j=1\dots m$). Any of the n different wavelengths ($\lambda_{j1}\dots \lambda_{jn}$) coming from the previous corresponding first-level modified splitter (60) reach the modified splitter (8j) through distribution fibre (7j), but each wavelength travels only through a specific output port of the modified splitter (8j), thus characterizing the full length of a single fibre of the drop section ($9j1\dots 9jn$).

For example, in Figure 10 (a) it was represented a specific tunable OTDR (10) pulse using λ_{j1} wavelength coming from distribution fibre (7j) that reaches to a generic second-level splitter (8j) that routes the monitoring pulse only to the output (9j1), providing the data and video signals in all outputs (9j1...9jn). In case that the monitoring pulse uses another wavelength, for example λ_{jn} wavelength as shown in Figure 10 (b), the second-level splitter (8j) routes the monitoring pulse only to the output (9jn), providing also the data and video signals in all outputs (9j1...9jn).

In Figure 11 it was shown the different wavelengths inside a generic monitoring subband j ($j=1\dots m$) composed of n different monitoring wavelength. Only a monitoring wavelength is assigned to a specific drop fibre (9j1...9jn) ($j=1\dots m$).

This document specifies two possible implementations for the special filters, the first implementation is based on multi-passband filters whereas the second alternative is based on multi band-suppression filters, but other possibilities could be considered. Both options are compatible in the same PON system, so it is not limited to use only one option for all splitters that exist in a PON port.

- Option 1: multi-passband filters implementation of modified splitters

The transmission characteristics of the multi-passband filters must include the corresponding monitoring subbands or wavelengths, as assigned in the designed monitoring system, in both directions of signals propagation, downstream and upstream. The transmission characteristics of the multi-passband filters in downstream direction must also include the wavelengths of the PON and/or NG-PON downstream data signals, and the wavelengths of the PON and/or NG-PON upstream data signals in the upstream direction.

Out-of-the-shelf passive components either in thin-film-filter (TFF) technology, optical multiplexer-demultiplexers, or Fibre Bragg Gratings and optical circulators can be used to build the passband filters with the desired transmission characteristics.

A possible implementation of the first level modified splitter (60) with multi-passband filters (21...2m) using WDM reflectors and optical circulators (630) was shown

in Figure 12. Optical circulators (630) operating both at the monitoring and data signals deliver all the signals coming from the splitter (6) to the line of WDM reflectors. For the distribution fibre (71), the reflectors (611) and (620) send back the OTDR monitoring subband with wavelengths $\lambda_{11} \dots \lambda_{1n}$ and the PON and/or NG-PON downstream signals (λ_{DS} , λ_{NG}) again to the optical circulator and this to the output fibre (71). Any other wavelength will be blocked and lost from the tunable OTDR point of view. In the upstream direction, this filter implementation (21) is transparent.

Similar performance should have filter (2m) designed for the monitoring of the distribution fibre (7m), the only difference consisting of the monitoring subband of reflector (61m), which includes wavelengths $\lambda_{m1} \dots \lambda_{mn}$.

The second level modified splitters (8j) implementation using WDM reflectors (620, 8j1...8jn) and circulators (630) was shown in Figure 13 using a similar implementation for individual monitoring of drop fibres (9j1...9jn), using individual wavelengths ($\lambda_{j1} \dots \lambda_{jn}$) ($j=1 \dots m$).

The WDM reflectors (611...61m), (8j1...8jn) ($j=1 \dots m$) and (620) can be implemented using Fibre Bragg Gratings (FBG) or Thin Film Filters (TFF).

- Option 2: multi-band suppression filters implementation of modified splitters

In the previous implementation (option 1), the optical filters (21...2m) functionality is achieved by reflecting the desired optical signals (PON data, overlay and assigned monitoring signal/s) into the PON, so that the scattering of the propagating monitoring signal which is selected is used to analyze the physical status of the specific fibre related to the monitoring wavelength or subband.

Another implementation is possible by using the reflections to avoid the propagation of the monitoring signals which do not correspond to the fibre under test, thus only letting the desired signal travel through the fibre under test.

From a logical perspective, it is the same to select a signal or to avoid the undesired signals, because both have the same effect: only the desired signal travels through the fibres under test.

The first level implementation of the modified power splitter (60) using multi band-suppression filters was shown in Figure 14, where Λ_i ($i=1 \dots m$) identify the subband i , comprising n wavelengths $\lambda_{i1} \dots \lambda_{in}$. The in-line filters (21...2m) are built with reflective or suppression filters, used to reject the undesired subbands, rather than to let them travel through the fibres under test, as in option 1.

In order to illustrate the performance of this implementation, filter (21) is considered a multi band-suppression filter, as shown in Figure 14. When any wavelength of the monitoring subband Λ_1 gets to the splitter input from fibre (5), the

signal is divided and delivered to all the filters (21..2m). In filter (21), as it does not include a reflection filter for subband Λ_1 , the signal will travel through fibre (71). In the rest of the filters, say 2j (j=2...m), the signal at the subband Λ_1 will be reflected or suppressed. The OTDR in the central office will detect the reflections of the undesired signals at the 2j filters (j $\neq$ 1 in this example), and most importantly, the OTDR will detect the scattering reflection as the signal at the subband Λ_1 will travel through fibre (71), thus characterizing its full fibre length in an individual manner.

The implementation of the second or additional levels follows the same idea, which is reflecting or suppressing the undesired signals over the monitoring subband and let to travel through the fibre under test only a specific monitoring sub-band or wavelength, which is analyzed in the OTDR at the central office to characterize the full length of the fibre under test.

In case of a generic second-level modified splitter (8j), as shown in Figure 15, with an assigned monitoring subband Λ_j including monitoring wavelengths $\lambda_{j1} \dots \lambda_{jn}$ (j=1...m), if the monitoring wavelength λ_{j1} reaches the modified splitter (8j) through fibre (7j), it will be divided in power and will be delivered to all the filters (4j1..4jn). At filter (4j1), the only wavelength which is not reflected back nor suppressed is λ_{j1} , then the monitoring wavelength will travel through fibre (9j1) and it will be characterized in the OTDR at the central office. At filter (4j2) and all the rest up to (4jn), the monitoring wavelength λ_{j1} will be reflected back or suppressed, and the OTDR will only detect a peak reflection at the splitter (if reflected) or nothing (if suppressed). Thus the only fibre that will be characterized all along its length will be (9j1). The same concept is applied if any other wavelength λ_{jk} is used as monitoring signal in the tunable OTDR for characterizing the full length of the specific fibre 9jk (k=1...n).

The proposed implementation of multi band-suppression filters can be achieved by building Fibre Bragg Gratings in series with high reflectivity or using Thin Film Filters.

With regards to option 1, option 2 offers the same functionality with less components and the advantage that the filters 21...2m and 4j1...4jn (j=1...m) do not depend neither on the PON data nor overlay wavelengths, so it is a future proof implementation which does not depend on the PON technology used at the installation time, but only on the monitoring subbands and wavelengths.

In both options, more splitting levels of modified splitters could also be implemented if there is enough optical spectrum available for monitoring purposes, and extending the design principle previously described between first and second-level splitters to the following levels.

Advantages of the invention

This invention applies to FTTx topologies for PON systems with power splitters in the outside plant, and enables the physical supervision of the network independently of active data equipment, reducing the operational expenditures (OPEX) of the network operator.

More specifically, the most advantageous functionalities of the proposed reflectometric system and method with regards other previous solutions are the following:

- This invention permits individual fibre supervision of a complete optical distribution network of a point to multipoint PON with one or more levels of splitting, all along a specific fibre length, even for fibres at the drop section of the PON.

- This invention avoids the restrictions of reflections superposition in previous reflectometric solutions for power splitter PONs.

- This invention allows the exact location of a fibre fault in a power splitter based PON.

- This invention does not need for reflective filters at the ONT side, thus avoiding installation of additional elements at the customer premises or at demarcation points.

- This invention uses a reduced number of out-of-the shelf low cost mature optical components with flexible installation and wavelength assignment in the operator's fibre outside plant.

A person skilled in the art could introduce changes and modifications in the embodiments described without departing from the scope of the invention as it is defined in the attached claims.

ACRONYMS

10G-EPON	10 Gigabit EPON
10G-GPON	10 Gigabit GPON
CO	Central Office
EPON	Ethernet PON
FBG	Fibre Bragg Grating
FOCS	Fibre Optic Cross-connect System
FTTH	Fibre to the Home
FTTx	Fibre to the Building/Home/Node/Curb
GPON	Gigabit PON
ITU-T	International Telecommunication Union -Telecommunication
NG-PON	Next Generation PON
OCDM	Optical Code Division Multiplexing
ODN	Optical Distribution Network
OEPM	Oficina Española de Patentes y Marcas
OLT	Optical Line Termination
ONT/ONU	Optical Network Terminal/Optical Network Unit
OPEX	Operational Expenditure
OSP	OutSide Plant
OTDR	Optical Time Domain Reflectrometer
PON	Passive Optical Network
POP	Point of Presence
P2MP	Point to Multi-Point
P2P	Point to Point
PS	Power Splitter
SMF	Single-Mode Fibre
TDM	Time Division Multiplexing
TFF	Thin Film Filter
T-OTDR	Tunable - Optical Time Domain Reflectrometer
WDM	Wavelength Division Multiplexing

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Claims

1.- A method for physical layer monitoring in point to multipoint passive optical networks based on reflectometry systems, comprising:

- injecting a monitoring light signal at an input of a Passive Optical Network, or PON, to circulate there through;
- reflecting back, optical means provided at different points of said PON, at least part of said monitoring light signal, in the form of respective reflected light signals; and
- analysing said received reflected light signals to perform a physical layer monitoring of the PON;

wherein the method is **characterised in that** it further comprises, in order to perform said supervision simultaneously to the normal operation of the PON based on the injection of at least one data light signal:

- injecting said at least one data light signal and said monitoring signal together by means of a global light signal at said input of said PON;
- at least splitting said global light signal into a plurality of sub-global light signals;
- filtering each of said sub-global light signals by a corresponding one of a plurality of filters to output a filtered sub-global signal containing a single wavelength or set of wavelengths of said monitoring light signal and the whole band of said at least one data light signal; and
- sending to each branch of said PON at least part of said filtered sub-global signal.

2.- A method as per claim 1, comprising allocating said monitoring light signal in a supervision frequency band different from the operation frequency band used by said at least one data light signal.

3.- A method as per claim 1 or 2, wherein each of said filters outputs a different wavelength or set of wavelengths of said monitoring light signal.

4.- A method as per any of the previous claims, comprising performing a further splitting and filtering of said filtered sub-global signal and sending the obtained signal to a corresponding sub-branch of said branch.

5.- A method as per any of the previous claims, comprising selecting said PON from a plurality of PONs previous to said injection.

6.- A system for physical layer monitoring in point to multipoint passive optical networks based on reflectometry systems, comprising:

- a light source arranged to inject a monitoring light signal at an input of a PON to circulate there through;

- a plurality of optical filters provided at different points of said PON to receive said monitoring light signal and filtering at least part thereof, in the form of respective reflected light signals;

- at least one power splitter (6) which equally splits said monitoring light signal into splitted signals, each to be sent to one of different branches of said PON (71..7m);

- light detecting means arranged to receive said respective reflected light signals from said optical filters ; and

- analysis means (10) connected to said light detecting means to analyse said received reflected light signals to perform a physical layer monitoring of the PON;

wherein the system is **characterised in that** it further comprises:

- said light source injecting said monitoring light signal together with at least one data light signal by means of a global light signal at said input of said PON;

- said power splitter (6) splitting said global light signal into a plurality of sub-global signals; and

- a plurality of filters (21..2m) each of them connected between an output of said power splitter (6) and a respective branch of said PON (71..7m), and each of them allowing the pass of said at least one data light signal and of a single wavelength or set of wavelengths of said monitoring light signal giving as result a filtered sub-global light signal.

7.- A system as per claim 6, wherein said power splitter (6) and said filters (21..2m) form a first stage (60), the system comprising a plurality of second stages (81..8m) equal or analogous to said first stage (60) with second power splitters (8j) and second filters (411..4mn), each interconnected between each of said PON branches (71..7m) and a plurality of corresponding PON sub-branches (911..9mn).

8.- A system as per claim 7, wherein each of said second stages (81..8m) is arranged to split and filter according to a specific wavelength said filtered sub-global signal and to deliver each obtained signal to said corresponding PON sub-branch.

9.- A system as per claim 6, 7 or 8, wherein each of said plurality of filters (21..2m) or second filters (411..4mn) is a multi-passband filter.

10.- A system as per claim 9, wherein said multi-passband filter comprises an optical circulator (630) connected to said power splitter (6;8), to said PON branch (71..7m) or corresponding sub-branch (911..9mn) and to a line of optical reflectors.

11.- A system as per claim 10, wherein said optical circulator (630) delivers said global or sub-global light signal to said optical reflectors, said optical reflectors reflecting a single wavelength or set of wavelengths of said monitoring light signal to said light detecting means and sending back said at least one data light signal to said optical

circulator, when said global or sub-global light signal travels in the direction from said light source to a customer premises through the distribution or drop fiber in which said circulator (630) is connected.

12.- A system as per claim 10 or 11, wherein said optical reflectors are Wavelength Division Multiplexing, or WDM, reflectors.

13.- A system as per claim 12, wherein said WDM reflectors are implemented using Fibre Bragg Gratings or Thin Film Filters.

14.- A system as per any of the previous claims 10 to 13, wherein said multi-passband filter is transparent for a light signal travelling in the direction from a customer premises to said light source.

15.- A system as per claim 6, 7 or 8, wherein each of said plurality of filters (21..2m) or second filters (411..4mn) is a multi band-suppression filter.

16.- A system as per claim 15, wherein said multi-band suppression filter comprises an optical filter (641..64m; 111..1mn) that reflects or suppresses said monitoring light signal except a single wavelength or set of wavelengths and allows the pass of said at least one data light signal/s.

17.- A system as per claim 16, wherein said optical filter is implemented using Fibre Bragg Gratings or Thin Film Filters.

18.- A system as per any of previous claims 6 to 17, wherein said analysis means (10) comprises an Optical Time Domain Reflectometer, or OTDR, with tunable operating wavelength.

19.- A system as per claim 18, wherein a fibre optic cross-connect system with one input (2) is periodically switched to a plurality of outputs to connect said OTDR to a plurality of PONs.

20.- A system as per claim 8 to 19 when depending on claim 7, comprising constituting a plurality of stages equal or analogous to said first stage, each of said stages interconnected between a PON branch or sub-branch and a plurality of PON sub-branches.

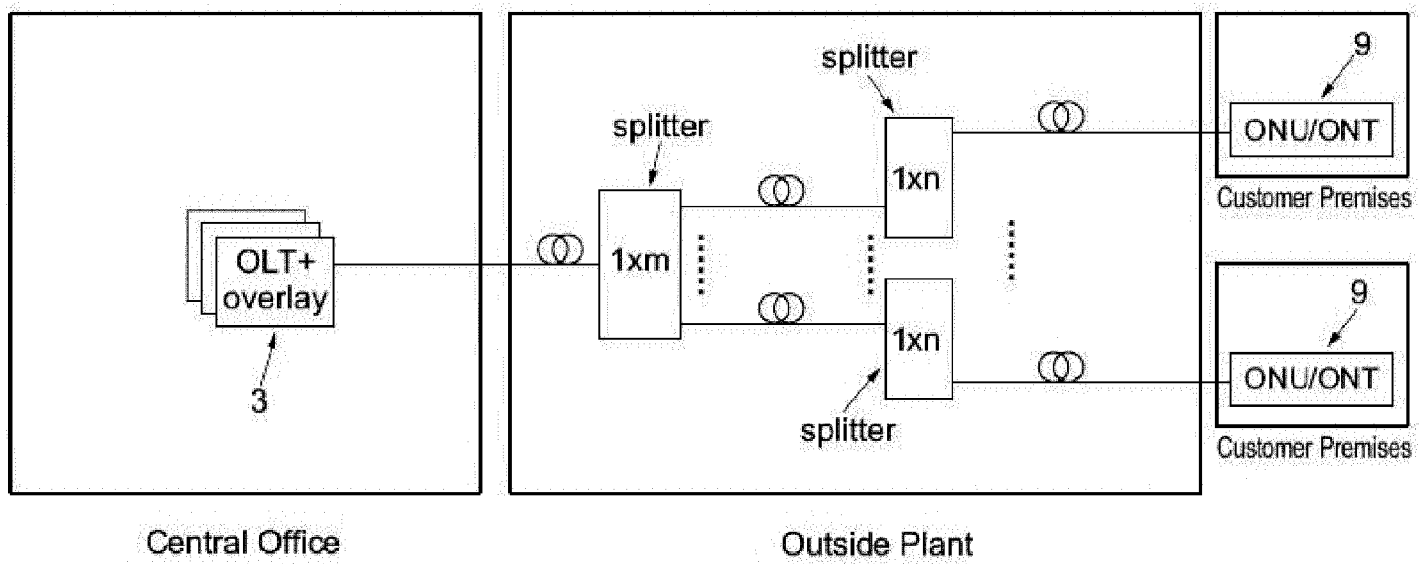
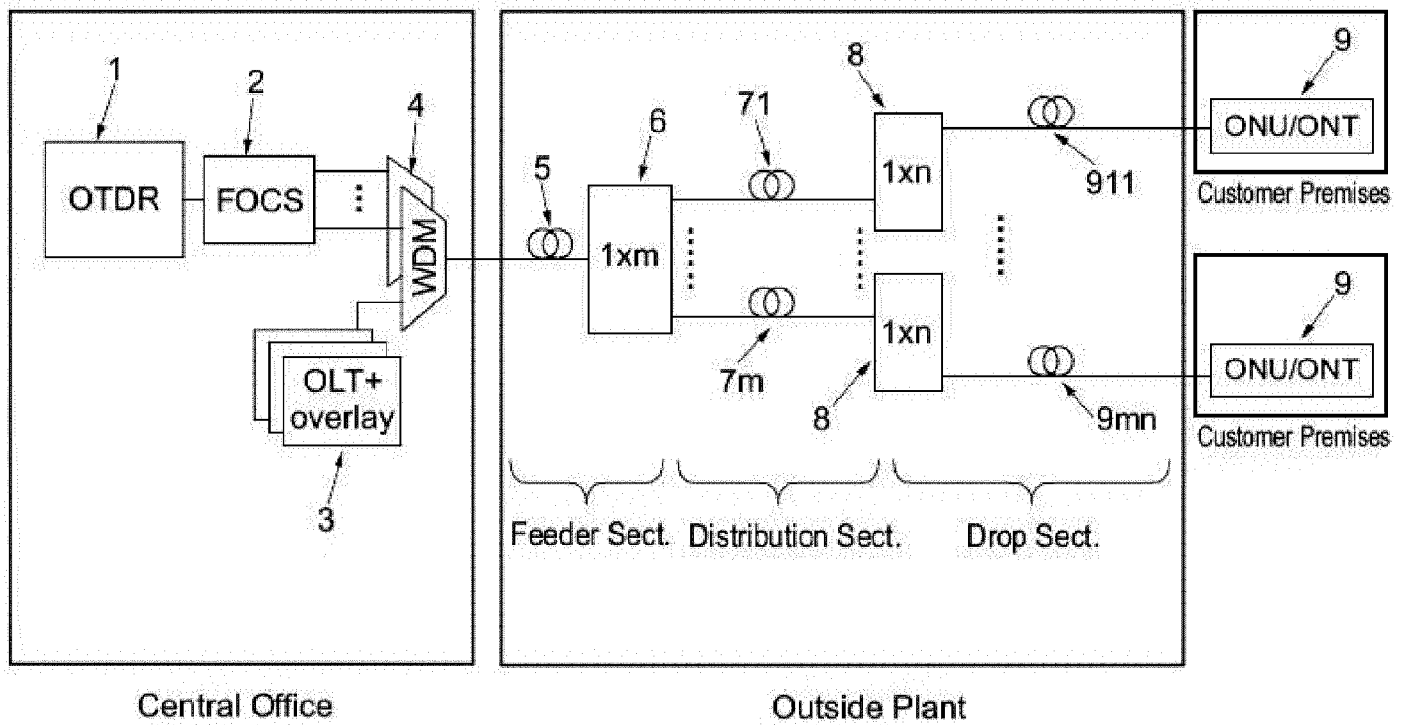


FIG. 1

**FIG. 2**

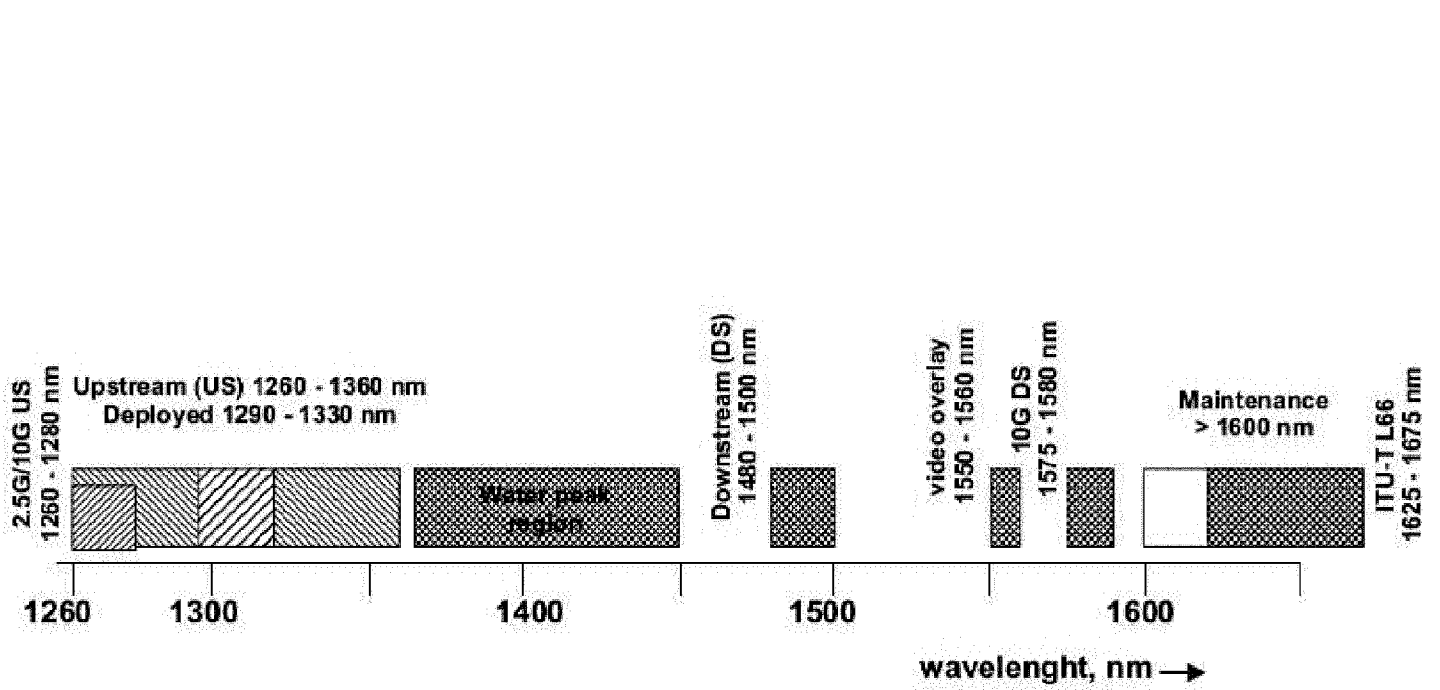
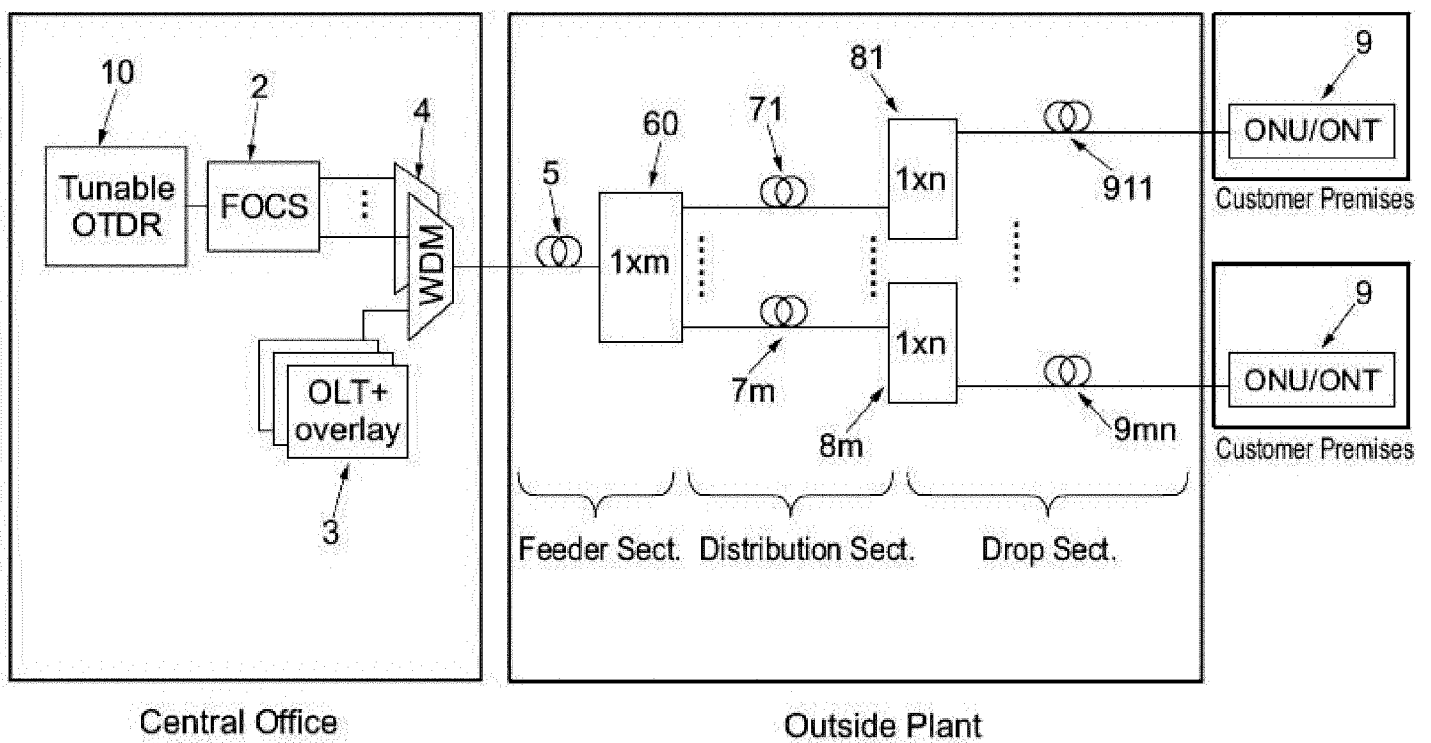
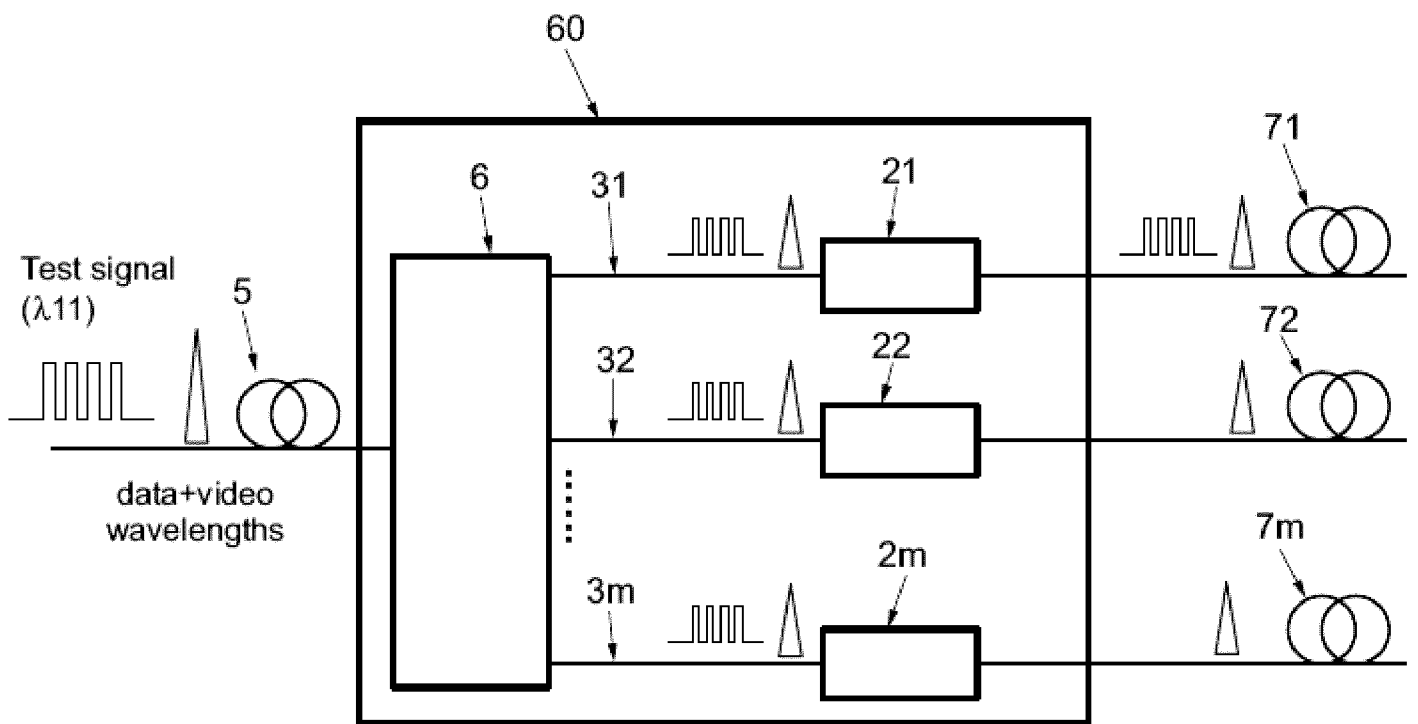
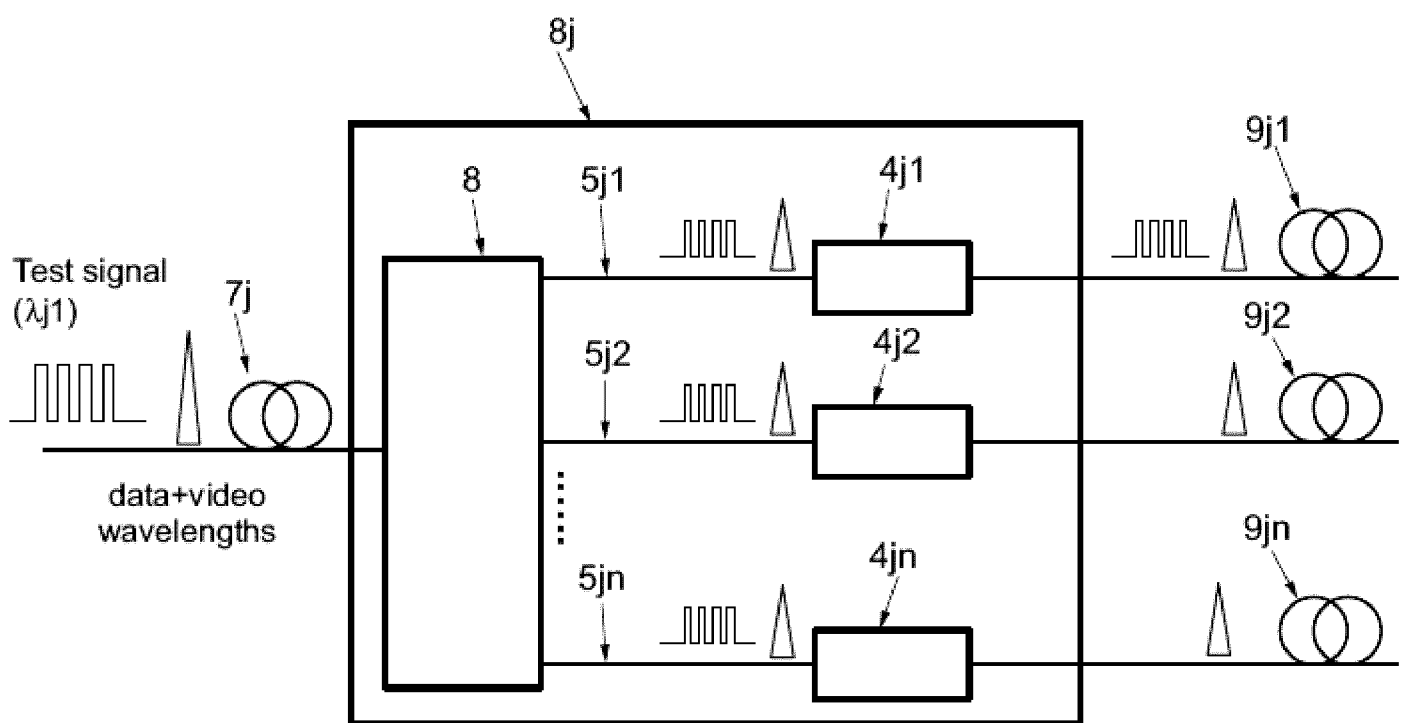
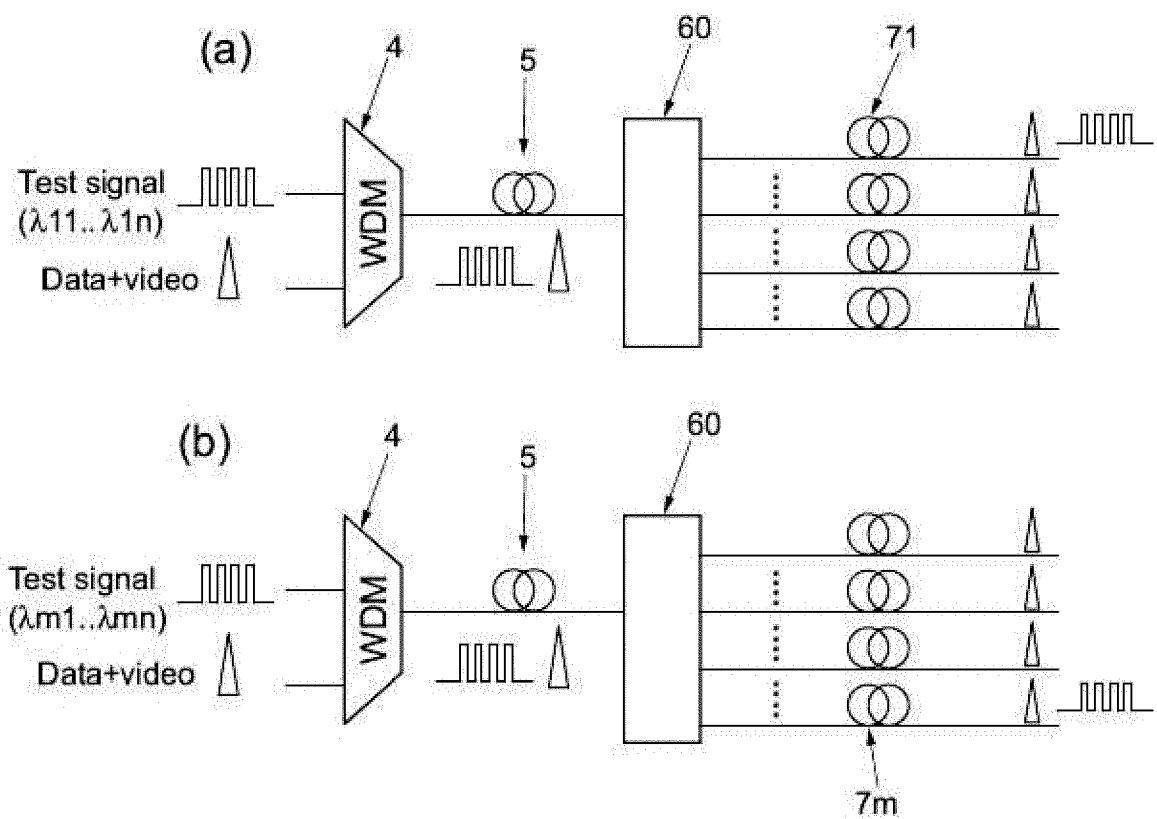


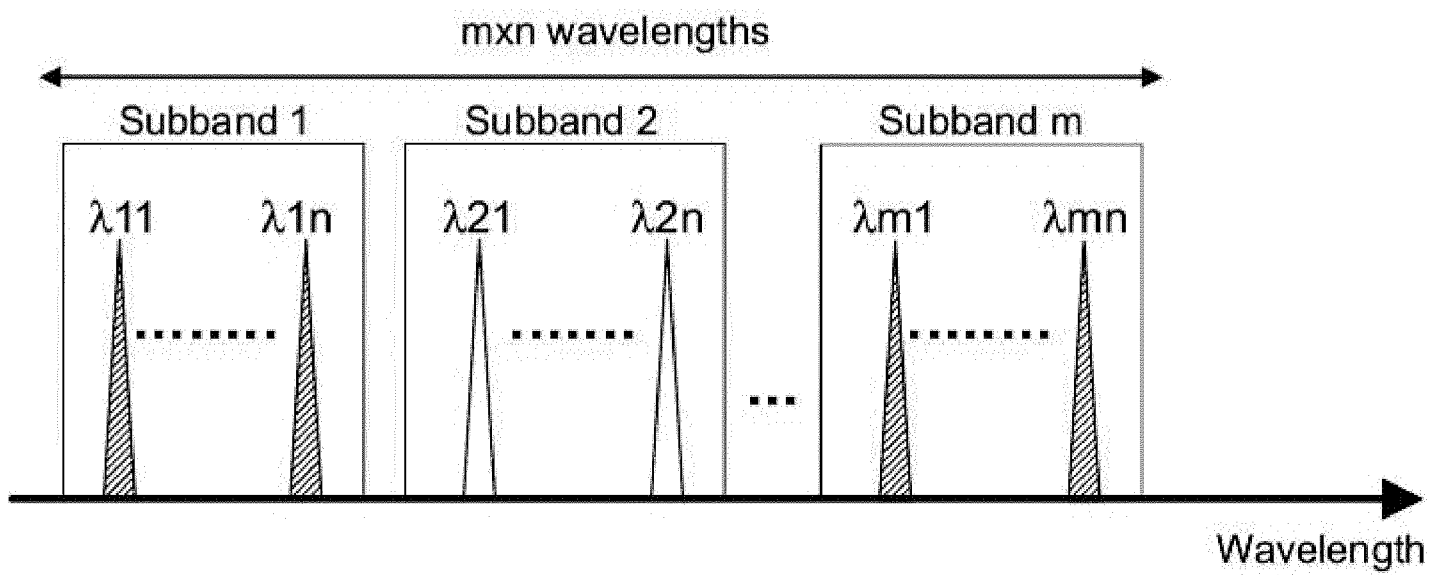
FIG. 3

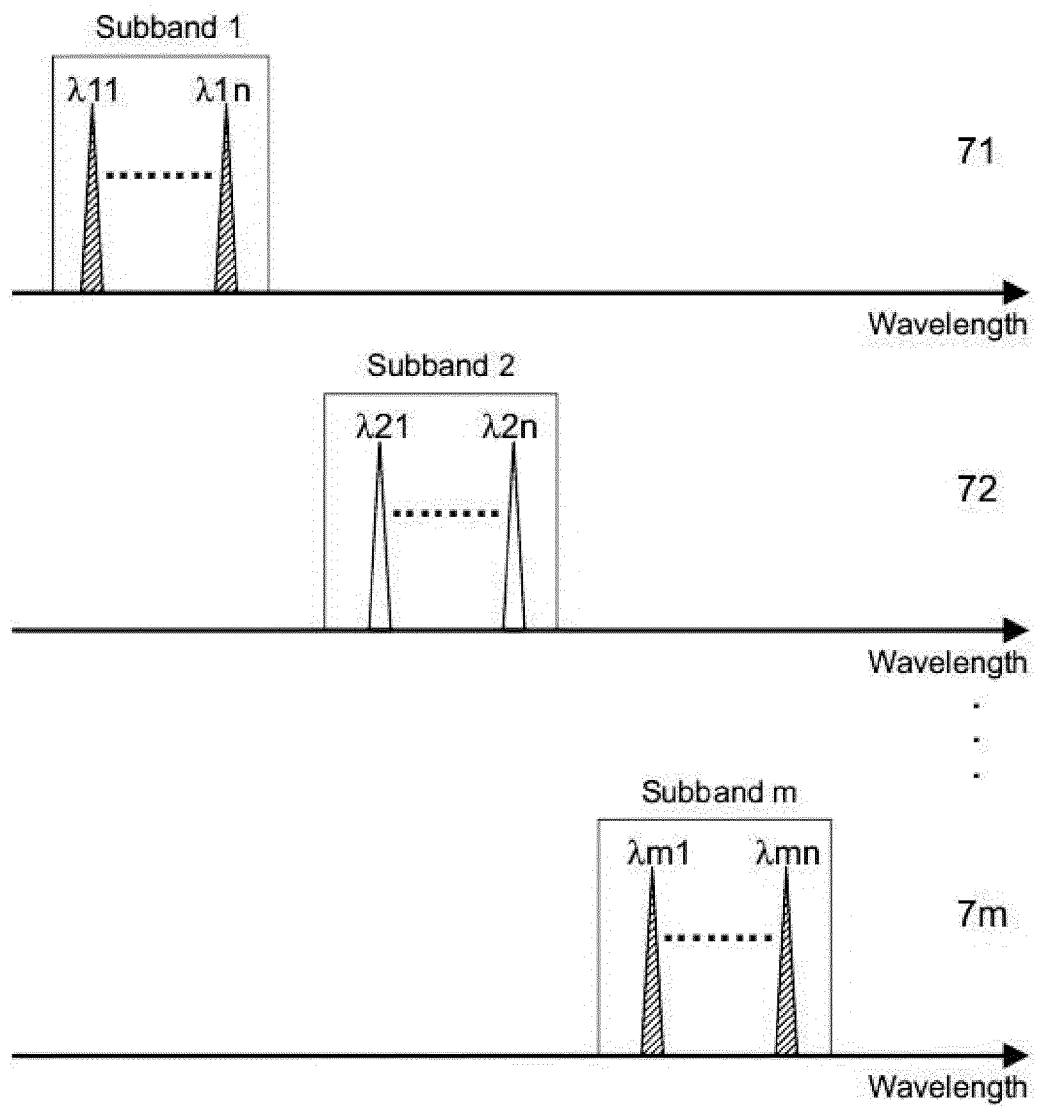
**FIG. 4**

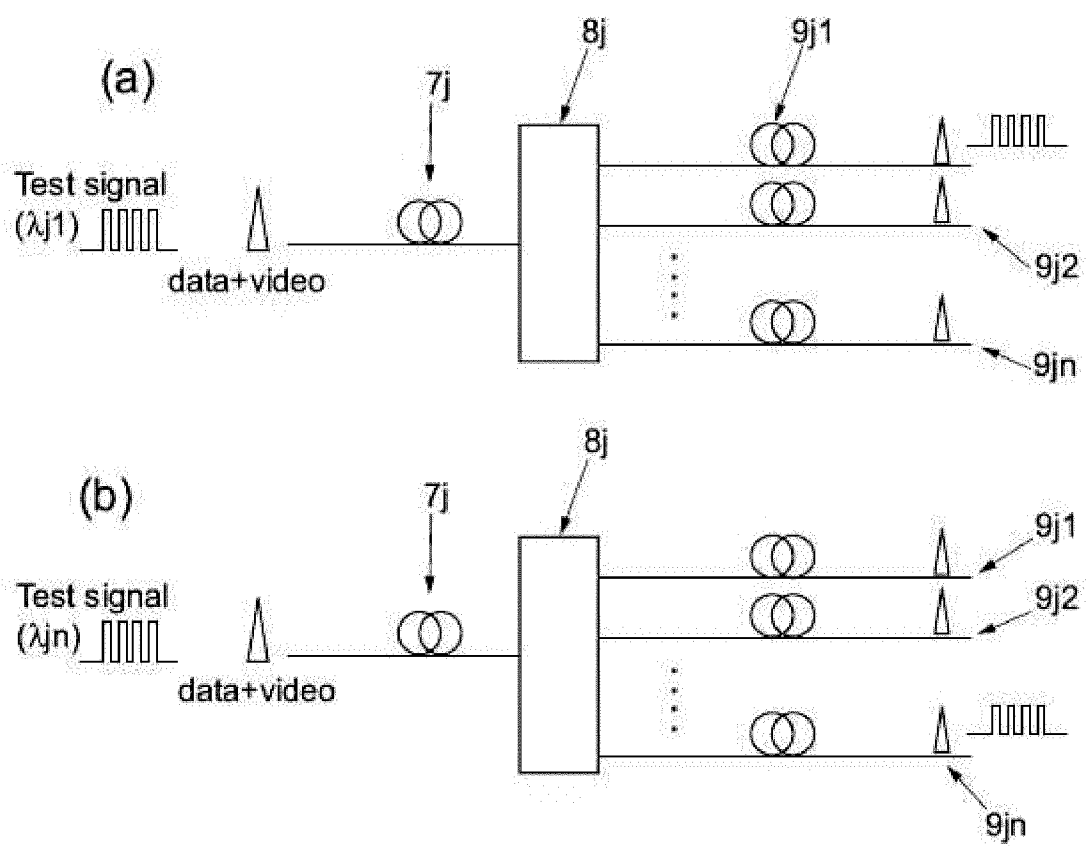
**FIG. 5**

**FIG. 6**

**FIG. 7**

**FIG. 8**

**FIG. 9**

**FIG. 10**

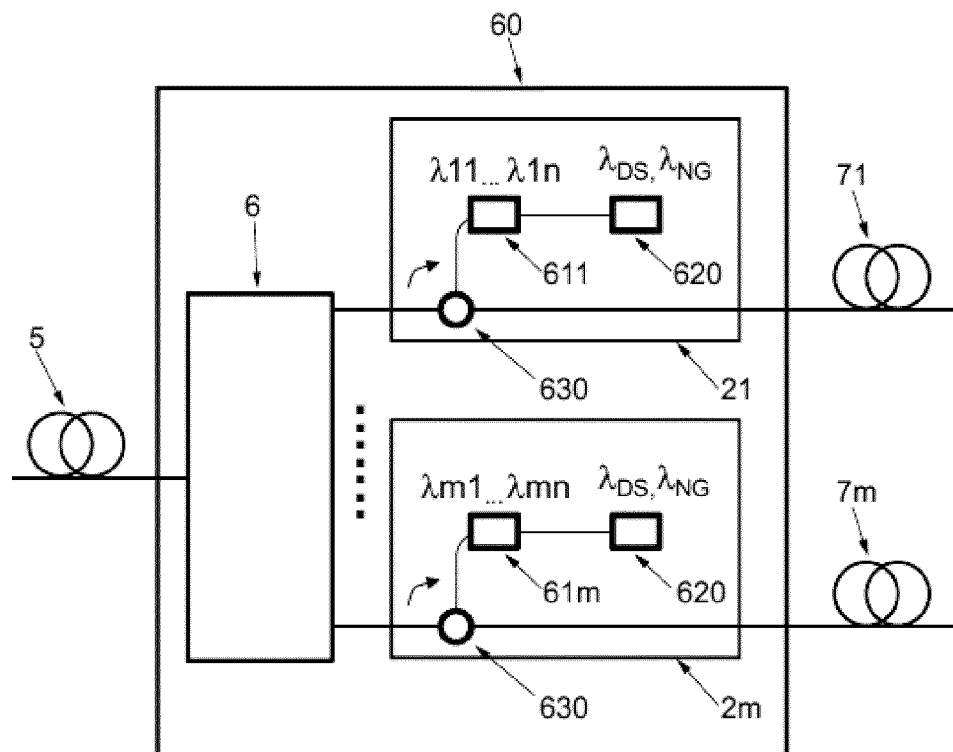


FIG. 12

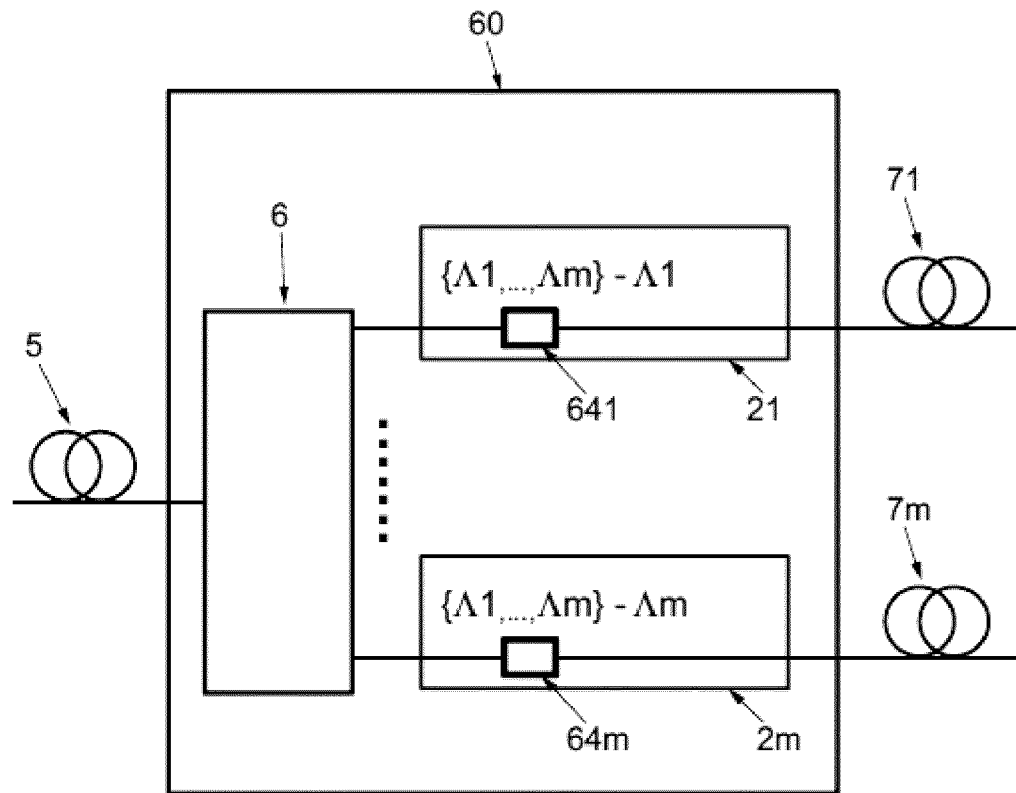
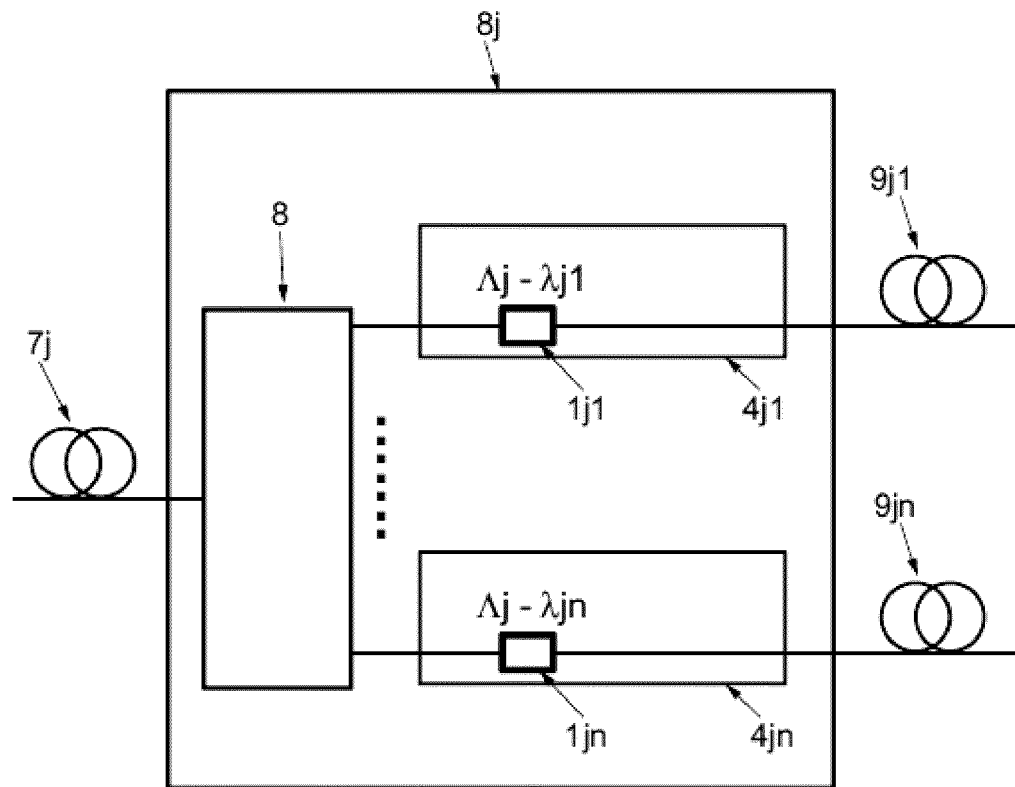


FIG. 14

**FIG. 15**

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/057906

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04B10/08 G01M11/00
ADD.

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 G01M

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 practicable, search terms used)

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/263123 A1 (ZHU TIAN [US] ET AL) 22 October 2009 (2009-10-22) figures 1,4 paragraphs [0034] - [0041] paragraphs [0044] - [0049] paragraph [0052] paragraph [0055] paragraphs [0075] - [0079] -----	1-20



Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search

11 July 2012

Date of mailing of the international search report

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Petitit, Nicolas

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2012/057906

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009263123 A1	22-10-2009	CA 2723462 A1	29-10-2009
		CN 102067483 A	18-05-2011
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