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(54) MODE COUPLING RECEIVER FOR QUANTUM COMMUNICATIONS AND QUANTUM COMMUNICATION SYSTEM COMPRISING SAID RECEIVER

(71) Applicant: **BRITISH TELECOMMUNICATIONS PUBLIC LIMITED COMPANY**, London (GB)

(72) Inventor: **Andrew LORD**, LONDON (GB)

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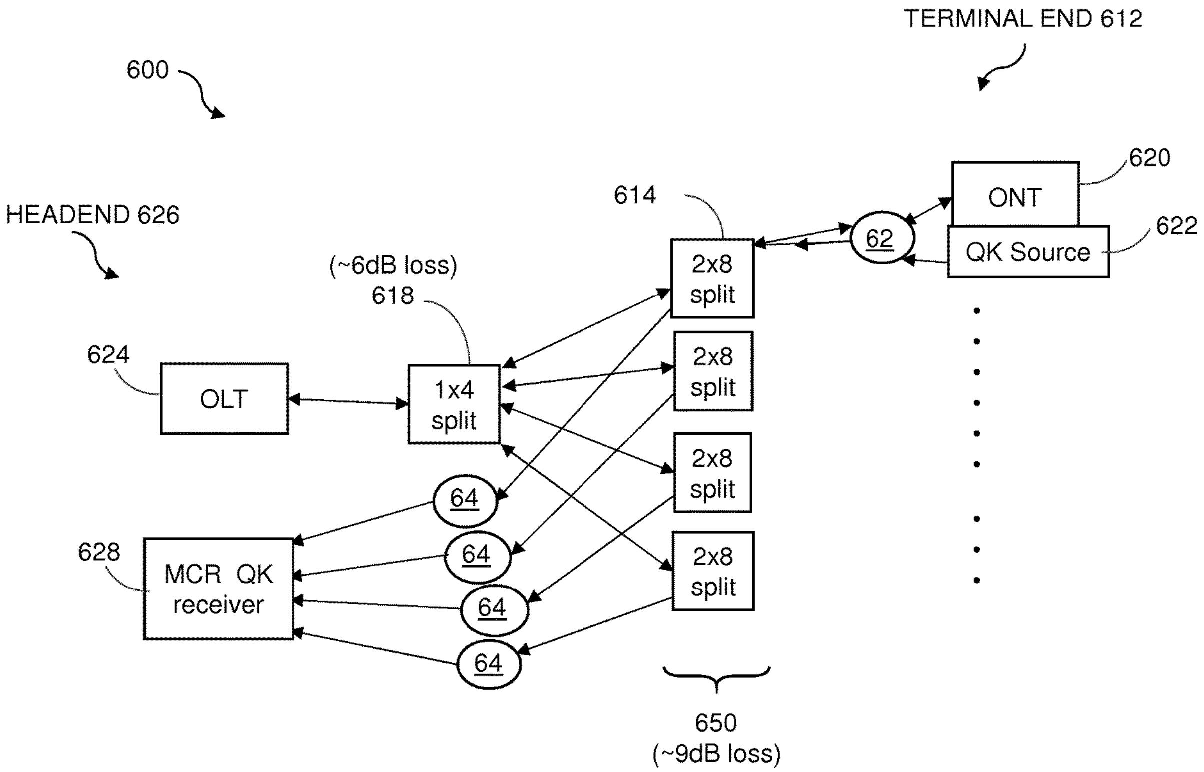
(57) ABSTRACT

An optical receiver including a mode-coupling receiver; in which the mode-coupling receiver includes a plurality of inputs; in which the mode-coupling receiver is configured to detect receipt of a single-photon signal comprising a stream of single photons on each of the plurality of inputs.



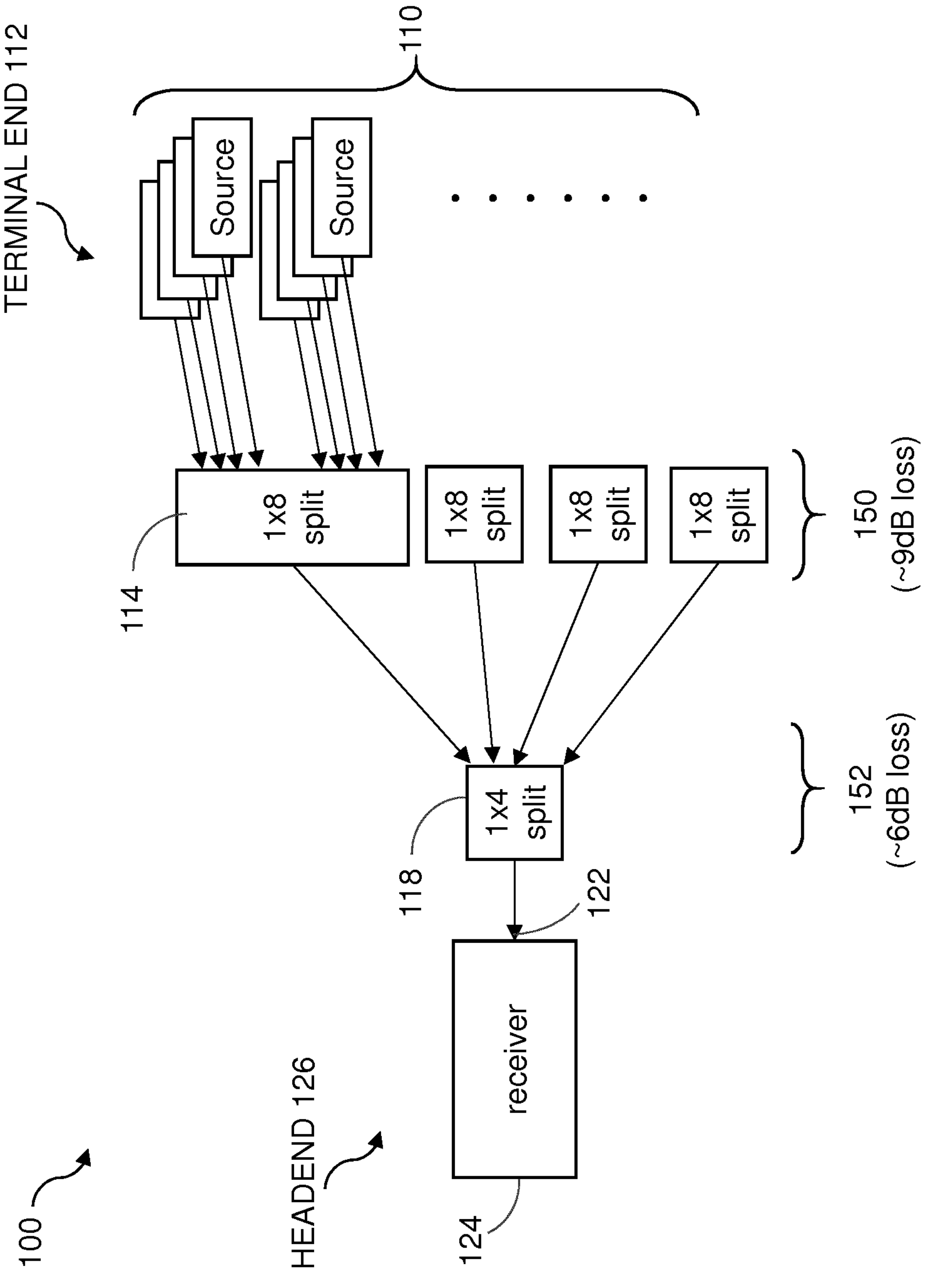


Figure 1. (PRIOR ART)

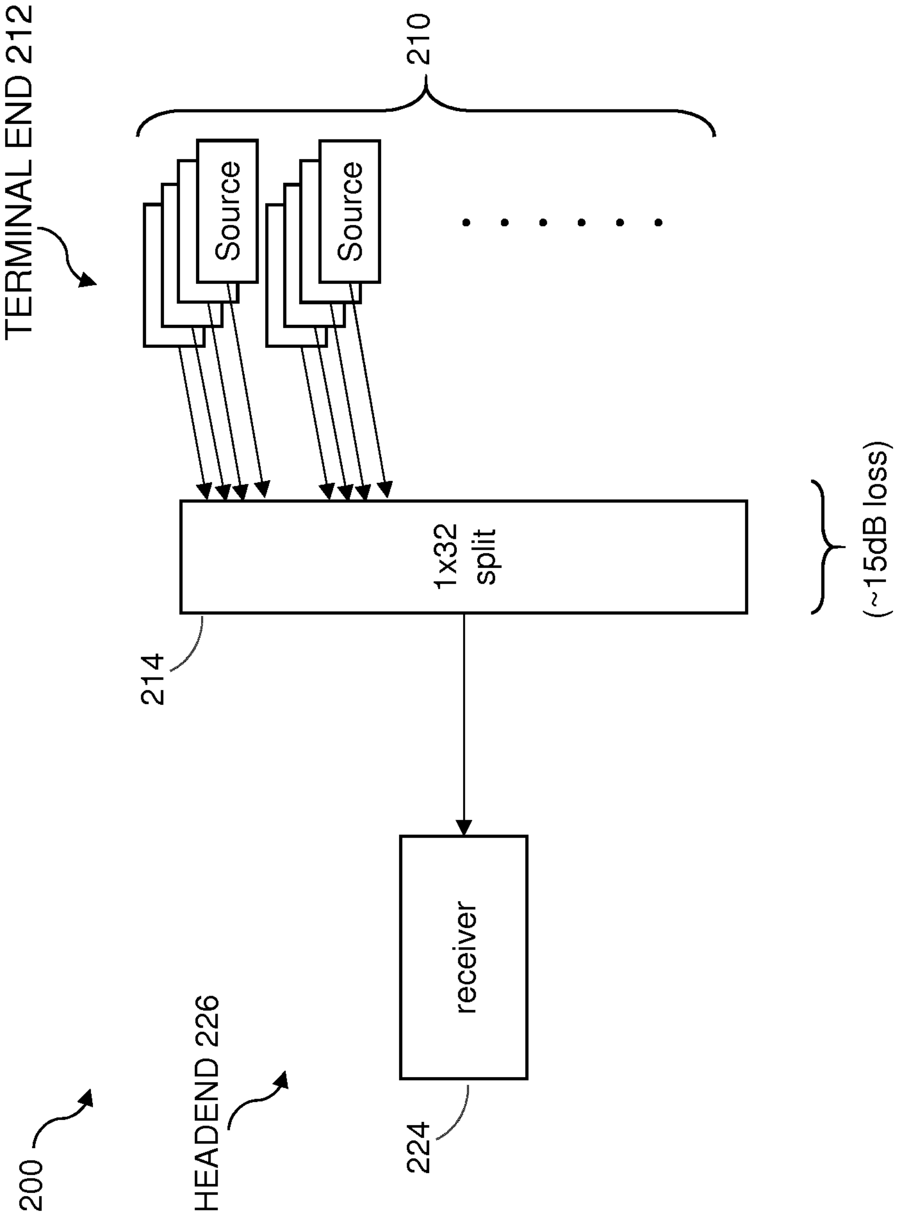


Figure 2. (PRIOR ART)

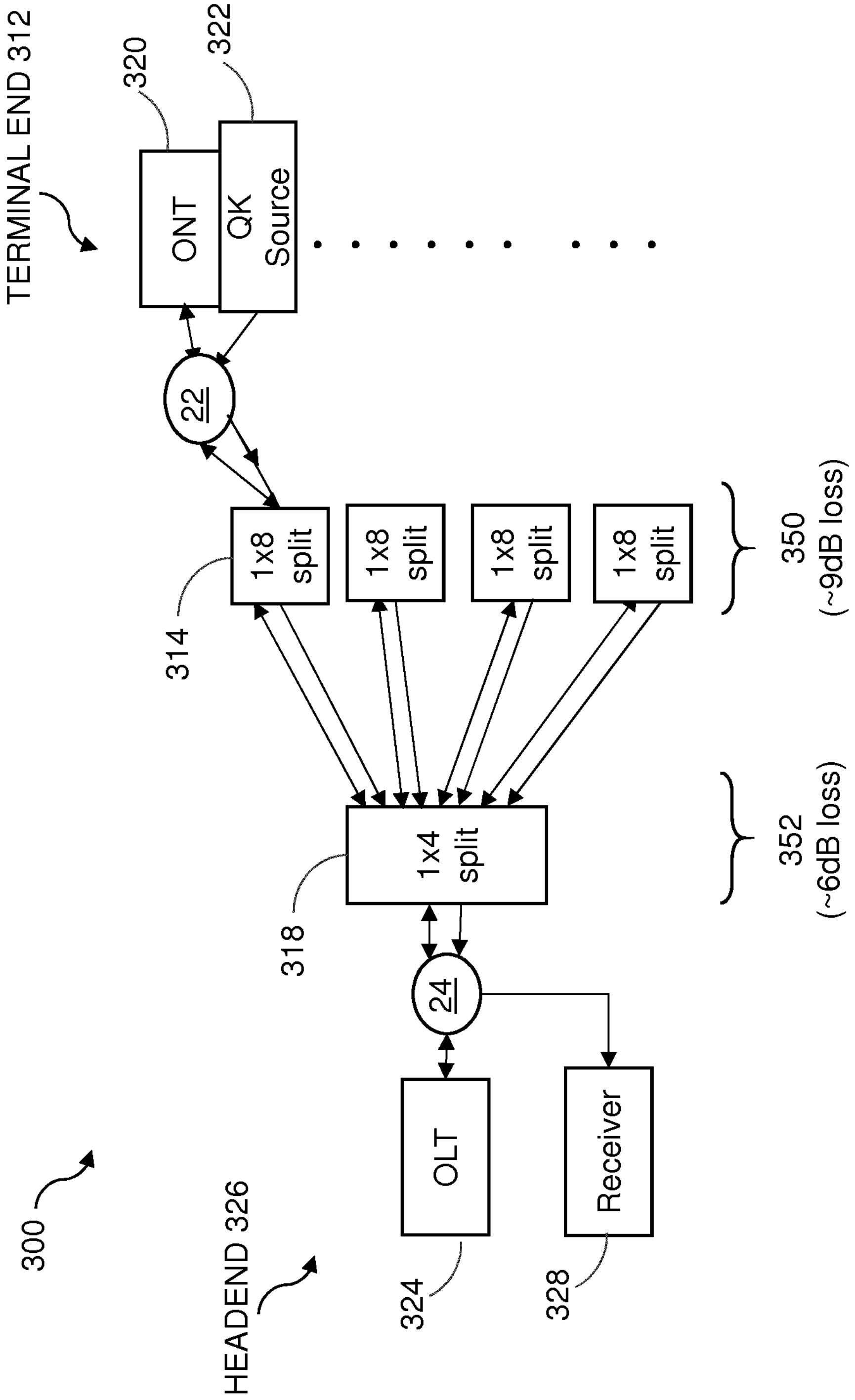


Figure 3. (PRIOR ART)

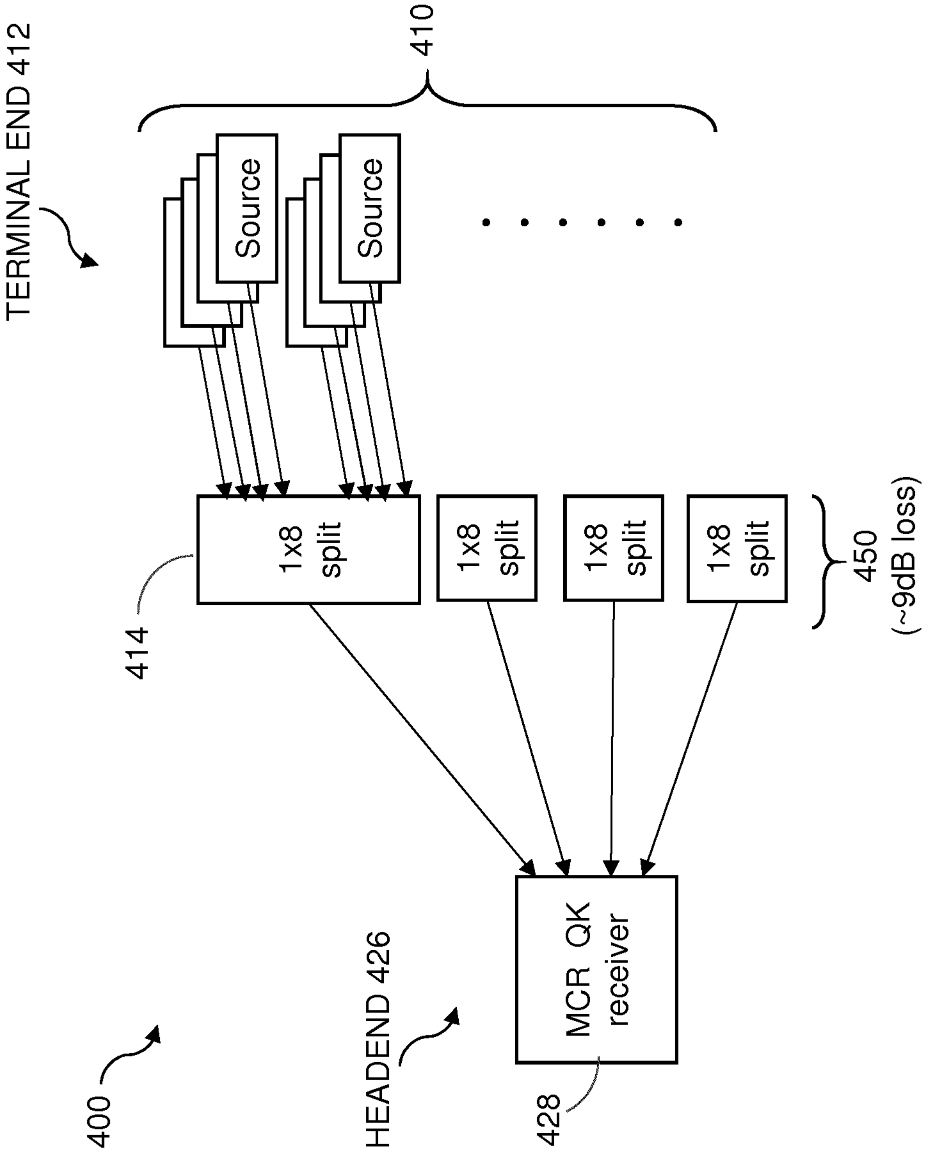

TERMINAL END 412
410
Source
Source
1x8 split
1x8 split
1x8 split
1x8 split
414
450 (~9dB loss)
MCR QK receiver
428
HEADEND 426
400

Figure 4

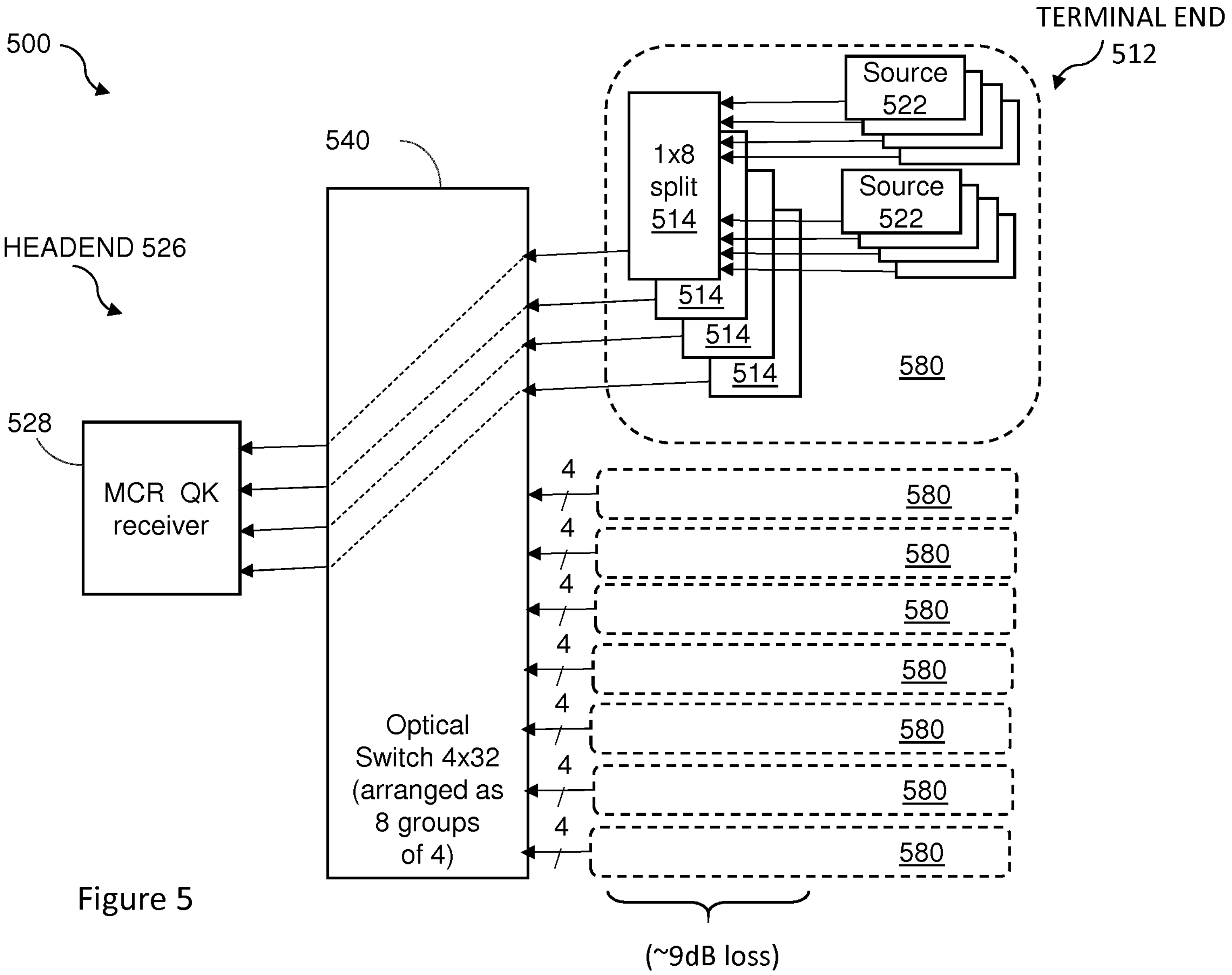

500
HEADEND 526
528
MCR QK receiver
540
Optical Switch 4x32 (arranged as 8 groups of 4)
TERMINAL END
512
Source 522
Source 522
1x8 split 514
514
514
514
580
4
4
4
4
4
4
4
580
580
580
580
580
580
580
(~9dB loss)

Figure 5

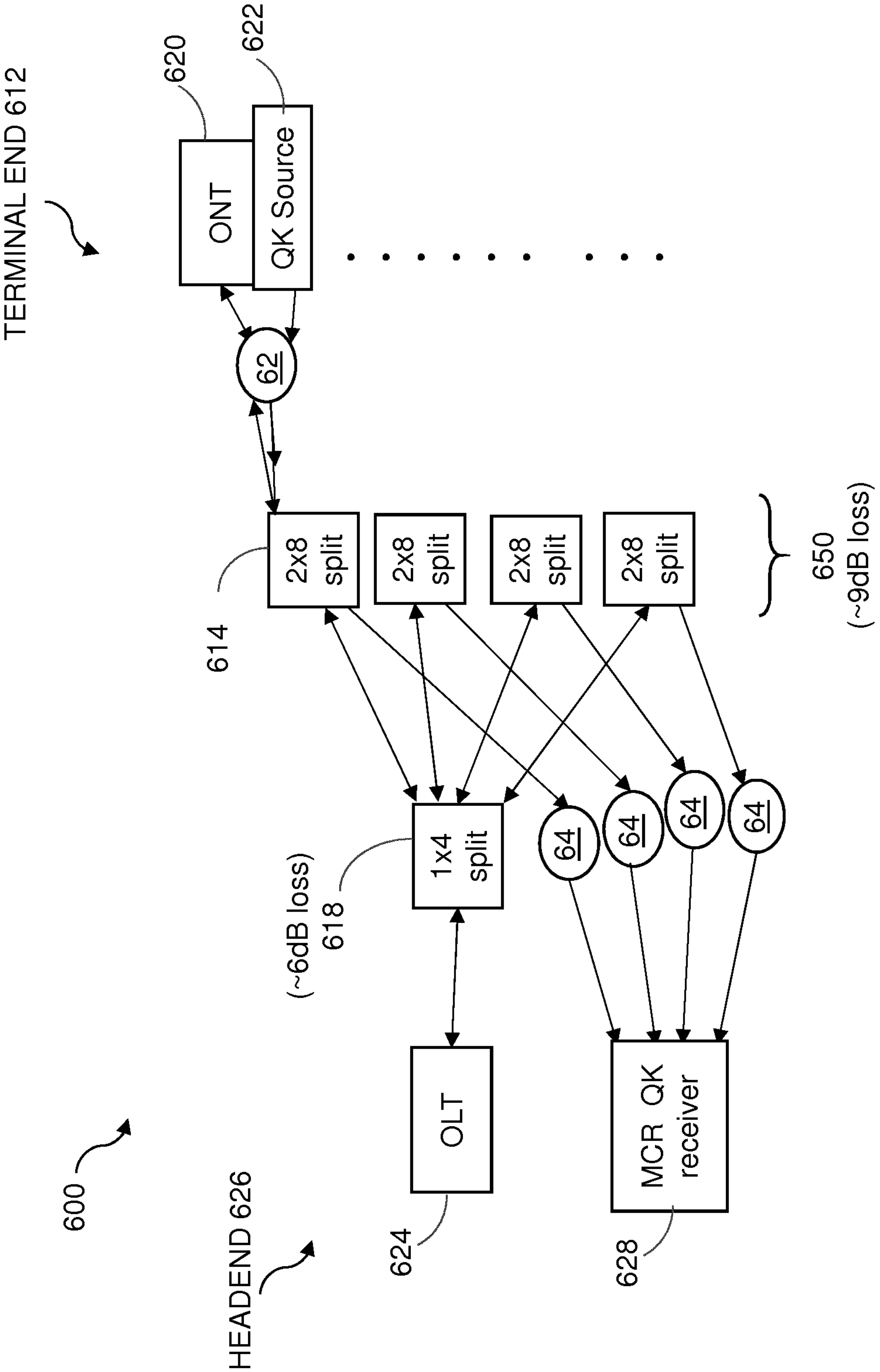

600
TERMINAL END 612
620
622
ONT
QK Source
62
2x8 split
2x8 split
2x8 split
2x8 split
614
650
(~9dB loss)
1x4 split
618
(~6dB loss)
64
64
64
64
HEADEND 626
OLT
624
MCR QK receiver
628

Figure 6

MODE COUPLING RECEIVER FOR QUANTUM COMMUNICATIONS AND QUANTUM COMMUNICATION SYSTEM COMPRISING SAID RECEIVER

PRIORITY CLAIM

[0001] The present application is a National Phase entry of PCT Application No. PCT/EP2018/074887, filed Sep. 14, 2018, which claims priority from GB Patent Application No. 17191971.5, filed Sep. 19, 2017, each of which is hereby fully incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure invention relates to optical communications in general and, in particular, to the detection of single-photon signals.

BACKGROUND TO THE INVENTION

[0003] Quantum key distribution (QKD) is an application of single-photon optical communications for the sharing of secret keys between a quantum key (QK) source and a QK receiver (usually the secret key is shared between just one QK source and one QK receiver). In QKD, key information is shared using a single-photon signal that is an optical signal comprising a stream of single photons, in which each photon is detectable separately from every other photon in the stream. Once these single-photon signals are received by the receiver and measured, additional (unencrypted) messages are exchanged between QK source and QK receiver to decide which of the measured photons can be used in forming the secret key. QKD transmitters commonly produce a flow comprised of many coincident photons that is then filtered to reduce the flow down to a single photon at any one time.

[0004] Single-photon signal receivers, such as quantum key receivers, are complex and expensive. To reduce costs, the number of single-photon signal receivers required may be reduced by use of passive optical splitters (also known as passive optical couplers). Conventional splitters are passive optical components and may be operated bidirectionally (for example, as shown at **318** in FIG. **3**) so that, what acts as a 1×4 splitter in one direction will act as a 1×4 coupler if the direction of the light is reversed. It will be understood that what may be thought of as an input when a splitter is operated in one direction may be more appropriately thought of as an output when operating in the opposite direction. For simplicity, we use the term “output” to denote a fiber leaving a splitter or combiner, irrespective of whether an optical signal is flowing into or out of the splitter through that fiber.

[0005] Use of a passive optical splitter allows multiple single-photon QK sources to be connected to a single single-photon signal receiver via one or more stages of passive optical splitters. A splitter may be thought of as introducing a split in the optical path so that a signal on an input fiber is shared between multiple output fibers. A disadvantage with this approach is that each splitter incurs a loss and these losses increase the more the optical path is split between different fibers.

[0006] A limited power budget is available for operation between a single-photon QK source and a single-photon signal receiver. The power budget for an optical path is calculated from the launch power of the single-photon QK source, from which have to be subtracted the sensitivity of the single-photon signal receiver and the losses introduced by any splitters in the path. The length of optical fiber over which optical communication can reliably be achieved depends on the size of the resulting power budget, however, losses introduced by optical splitters into the optical path reduce the range.

[0007] FIG. **1** shows a conventional QKD PON **100**. PON technology relies on passive optical splitters, as no power is required for operation and, typically, fused-fiber optical splitters (also known as fused-fiber optic couplers) are commonly used. In the case of fused-fiber optical splitters, light is transferred between two fibers when they are brought together to meet and then diverge again. A standard design of optical splitter exchanges 50% of the light from each fiber to the other fiber. A standard 1×2 design of optical splitter has a single-output side with a single output fiber and a two-output side with two output fibers (that is, one of the fibers terminates after meeting the other fiber and one leg of the fiber is not connected to an output). Splitters with greater fan-outs can then be constructed from multiple 1×2 splitters. For example, a 1×4 splitter can be constructed by arranging three 1×2 splitters so that the single-output sides of the second and third optical splitter are connected to respective ones of the two-output side of the first optical splitter.

[0008] As noted, above, these splitters are bidirectional, so that, what acts as a 1×2 splitter in one direction will act as a 1×2 coupler if the direction of the light is reversed. Taking the example of a splitter with 50% transfer, while 50% of the input on the single-output will find its way to each of the two-outputs, 50% of the input on each of the two-outputs will find its way to the single-output (the other 50% goes to the unconnected fiber leg). In this way optical splitters introduce significant attenuation into the optical path in both directions (i.e. when splitting a single input signal between multiple outputs and when coupling multiple input signals onto a single output).

[0009] Returning to FIG. **1**, there are 32 QK sources **110** located at the terminal end **112** of QKD PON **100**, with the sources arranged as 4 groups of 8 sources (only one group of 8 shown). Each group of 8 is connected to the 8 fibers at one side of an 8-input, single output (1×8) splitter **114** in a first stage **150**, introducing about 9 dB loss. The single output from the other side of each 1×8 splitter **114** in the first stage **150** then feeds into one of the four fibers at one side of a 4-input, single output (1×4) splitter **118** in a second stage **152**, introducing about 6 dB loss—making a total of 15 dB loss for the combination of the first and second stages. Finally the single fiber output from the other side of the 1×4 splitter **118** in the second stage **152** feeds into an input **122** of an optical receiver **124** located at the headend **126** of QKD PON **100**. Each of the splitters **114**, **118** introduces a loss into the optical signal passing through it. The amount of loss depends on the degree of splitting, so that the 1×8 splitter will introduce twice the loss of the 1×4 splitter. The splitter-introduced losses accumulate over a path from QK source **110** to receiver **124** so that the power budget available to transmit over the path can be significantly reduced.

[0010] FIG. **2** shows an alternative conventional PON arrangement **200** for connecting 32 QK sources **210** located at the terminal end **212** of QKD PON **200** to a single receiver **224** located at the headend **226** of QKD PON **200**. Most elements of FIG. **2** have a direct equivalent in FIG. **1** and will not be described further here. Instead of two stages of splitter, in FIG. **2** each of the 32 QK sources is connected to one of 32 fibers at one side of a 1×32 splitter **214**, introducing about 15 dB loss. It will be noted that the total loss introduced by the two splitter stages in FIG. **1** is the same as the loss introduced by the single splitter stage in FIG. **2**.

[0011] FIG. **3** shows a conventional QKD PON **300** similar to the arrangement of FIG. **1** but now with data signals (bidirectional arrows) transmitted over common paths together with the QKD signals (unidirectional arrows). Each single path from filter **22** to switch **314**, e.g. an optical fiber, is represented by the unidirectional arrow to denote the QKD signal and a bidirectional arrow to denote the data signal. FIG. **3** shows a data source (ONT) **320** in addition to a QK source **322** located at terminal end **312** of QKD PON **300**. FIG. **3** also shows a data receiver (OLT) **324** in addition to a QK receiver **328** located at headend **326** of QKD PON **300**. Most elements of FIG. **3** have a direct equivalent in FIG. **1** and will not be described further here. FIG. **3** also shows optical filters **22** and **24**. Each optical filter **22** has two inputs and one output and is used to combine onto an optical path to one of the splitters **314**, the data signal from one of 32 ONTs **320** (only one shown) and the QKD signal from a corresponding one of 32 QK sources **322** (only one shown). That is, each filter **22** acts to combine signals in the part of the optical spectrum used to carry the QKD signal with signals in the part of the optical spectrum used to carry data. In total, 32 optical filters **22** are provided, one optical filter for each pair of ONT **320** and QK source **322** and each combining signals onto a different optical path to one of the splitters **314**.

[0012] Optical filter **24** has two inputs and two outputs and is used to separate the QKD signals originating at the thirty-two QK sources **322** and received via the splitters **314**, **318** from the data signals originating at the thirty-two ONTs **320** and also received via the splitters **314**, **318**. That is, filter **24** acts to pass to a first output connecting to the QK receiver **328**, signals in the part of the optical spectrum used to carry the QKD signal while blocking signals in the part of the optical spectrum used to carry data from passing to the QK receiver. Filter **24** also acts to pass to a second filter output connecting to the OLT **324**, signals in the part of the optical spectrum used to carry data, while blocking signals in the part of the optical spectrum used to carry the QKD signal from passing to the OLT.

SUMMARY OF THE INVENTION

[0013] According to a first aspect of the disclosure, there is provided an optical receiver comprising a mode-coupling receiver; in which the mode-coupling receiver comprises a plurality of inputs; in which the mode-coupling receiver is configured to detect receipt of a single-photon signal comprising a stream of single photons on each of the plurality of inputs.

[0014] According to a second aspect of the disclosure, there is provided a method of detecting a plurality of single-photon signals, in which the method comprises: operating a single-photon signal receiver comprising a multiple-input, mode-coupling receiver; in which the multiple-input, mode-coupling receiver is configured to detect receipt of a single-photon signal comprising a stream of single photons on each of the plurality of inputs.

[0015] In this way, single-photon signal (e.g. QKD) access systems may be provided in which a plurality of single-photon signal optical transmitters (or single-photon signal sources) connect to the same single-photon signal receiver. By increasing the number of single-photon signals that are connected directly into the same single-photon signal receiver in the access systems, it is possible to create access systems in which losses are reduced, when compared to conventional designs. As a result, significant performance improvements and cost savings are possible.

[0016] According to an embodiment, the single-photon signals comprise photons encoded in different quantum states. According to an embodiment, each photon represents quantum key information.

[0017] According to an embodiment, there is provided a communications system, in which the communications system comprises the multiple-input, mode-coupling receiver; in which the communications system also comprises an access network connecting a plurality of single-photon signal sources with the optical receiver, in which each of the plurality of inputs of the mode-coupling receiver is connected via the access network for receipt of a single-photon signal from a different one of the plurality of single-photon signal sources.

[0018] According to an embodiment the communications system also comprises an optical switch configured to select, for connection to a switch output, a switch input selected from a plurality of switch inputs; in which each of the plurality of switch inputs is connected to different one of the plurality of single-photon signal sources; in which the switch output is connected for sending to one of the plurality of inputs of the mode-coupling receiver, a single-photon signal from the one of the plurality of single-photon signal sources connected to the selected switch input.

[0019] In this way, many more single-photon signal sources may be efficiently connected to the same single-photon signal receiver.

[0020] According to an embodiment the optical switch comprises a plurality of outputs, in which the switch is configured to select, for connection to each of the plurality of switch outputs, a different one of the plurality of switch inputs; in which each of the plurality of switch outputs is connected to a different one of the plurality of inputs of the mode-coupling receiver.

[0021] According to an embodiment the quantity of switch outputs equals the quantity of mode-coupling receiver inputs.

BRIEF DESCRIPTION OF THE FIGURES

[0022] In order that the present disclosure may be better understood, embodiments thereof will now be described, by way of example only, with reference to the accompanying drawings in which:

[0023] FIGS. **1**, **2** and **3** show schematics of conventional single-photon signal PONs.

[0024] FIGS. **4**, **5** and **6** show schematics of single-photon signal PONs according to embodiments of the disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

[0025] According to embodiments, QKD keys are sent on single-photon signals to a receiver from multiple QK source nodes. Each of the QK source nodes is directly coupled to the same photodetector of a single receiver node. According to an embodiment, at least some of the QK source nodes are coupled through an optical switch to the same photodetector of a single receiver node. In this way, a single receiver can agree QKD secret keys with multiple QK sources at improved range and reliability by reducing the number of splits in the QKD path and in this way reducing the losses introduced into the QKD path. Embodiments result in reduced costs by reducing the number of receivers required and by reducing the need for associated cryogenic cooling.

[0026] According to an embodiment, a control system ensures the QK sources transmit their photons so that they arrive at the receiver in an interleaved fashion.

[0027] FIG. **4** shows a QKD PON **400** according to a first embodiment of the disclosure, which provides an MCR-based QKD receiver (QK MCR) **428**: that is a mode-coupled receiver (MCR) configured to operate in single-photon detection mode. The MCR is so named because multiple modes are coupled into the same photo-detector, with each mode connecting light from a different fiber into the same photo-detector. The large-area photo detector of the MCR allows direct coupling of multiple fibers to the receiver and provides an almost loss-less optical power combiner at the receiver. To configure the QK MCR to detect single-photons it is operated with an increased bias voltage to bring about single-photon avalanche detection. The detector substrate is biased to react to the arrival of a single-photon with an avalanche current by exploiting impact ionization. Single-photon avalanche detection may be achieved with bias voltages greater than 3×10^7 volts per meter, although this value may change with developments in MCR technology.

[0028] In the arrangement of FIG. **4**, a plurality of QK sources **410** is connected through a single stage **450** of splitters **414** into the four-input QK MCR **428**. The multiple-input QK MCR **428** allows multiple fibers to be coupled to the same photodetector.

[0029] When compared with FIG. **1**, it will be apparent that the arrangement of FIG. **4** provides connection for the same number of QK sources (i.e. **32**) to a QK receiver but a whole stage of splitters (i.e. second stage **120**) has been removed and the associated losses avoided. Where in FIG. **1**, two stages of splitters **116**, **120** are required, only one stage of splitters **450** is used in FIG. **4**. The reduction in the number of splitter stages that the arrangement of FIG. **4** significantly improves the power budget and, as a result, enables communication over greater fiber transmission distances. For example, with a QKD power output of 20 dB, a single stage of splitters with 9 dB loss leaves an 11 dB power budget, which is equivalent to up to 44 km of fiber (assuming a fiber loss of 0.25 dB/km). Similarly, when compared with FIG. **2**, it will be apparent that the arrangement of FIG. **4** provides connection for the same number of QK sources (i.e. 32) to a QK receiver but a using one ×8 splitter **414** in each path instead of the ×32 splitter **214** of FIG. **2**, with a corresponding reduction in splitter losses. The reduction in the number of splits per path that the arrangement of FIG. **4** provides, when compared to FIGS. **1** and **2**, significantly improves the power budget (as illustrated above) and, as a result, enables communication over greater fiber transmission distances.

[0030] FIG. **5** shows a QKD PON **500** according to a second embodiment of the disclosure with an optical switch **540** in the paths of the QKD signals. Most elements of FIG. **5** have a direct equivalent in FIG. **4** and will not be described further here. When compared to FIG. **4**, FIG. **5** shows a similar arrangement but now provides connection for a greatly increased 256 QK sources **522** located at the terminal end **512** of QKD PON **500** to a single MCR-based QK receiver (QK MCR) **528** located at the head end **526** of QKD PON **500** while only requiring a single ×8 splitter **514** in each path. Due to the large number of QK sources represented in FIG. **5**, some details have been replaced with blocks for clarity. That is, each block **580** in FIG. **5** comprises four 1×8 splitters **514**, with each splitter connected on one side to eight QK sources **522** (only the first eight shown) and connected on the other side to an input of optical switch **540**. Optical switches operated in a 1×N (single-output) configuration are known. As shown in FIG. **5**, a modified optical switch **540** is provided with the same number of outputs as there are inputs to the QK MCR **528** (although, according to other embodiments, the optical switch may be provided with fewer outputs than there are inputs to the QK MCR **528**). In the present example, there are four inputs to the MCR, so that the N×M switch selected in the arrangement of FIG. **5**, is implemented with 4 outputs and 32 inputs (32×4), with the 32 inputs arranged as 8 groups of 4 and each switch output connected to a different input to the QK MCR **528**. Each switch input is connected to an optical splitter **514** that, in this example, combines QKD signals from a group of eight QK sources **522**, so that the multiple-input QK MCR **528** is connected to receive from 4×8×8=256 QK sources. The splitters **514** are configured as 1×8, with a single-output side connected to a switch input and an eight-output side where each fiber is connected to a different QK source. According to an embodiment, the 32 switch inputs are grouped into 8 groups (only one shown) with 4 inputs per group. The switch directs the four inputs from each group in turn, towards the four switch outputs that are connected to the four inputs of the QK MCR **528** so that the receiver can be connected to each QK source over a cycle through the eight groups. The loss introduced by the switch is typically about 1 dB, which is significantly less that the loss introduced by a typical splitter. As a result, the power budget for FIG. **5** will be significantly higher than that for FIG. **1**.

[0031] FIG. **6** shows a similar arrangement to FIG. **4** but now with data signals (bidirectional arrows) transmitted over common paths through the splitters together with the QKD signals (unidirectional arrows). Most elements of FIG. **6** have a direct equivalent in FIG. **3** or **4** and will not be described further here. FIG. **6** shows QKD PON **600** according to an embodiment, comprising at a terminal end **612**, thirty-two data sources (ONT) **620** in addition to thirty-two QK sources **622** (only one of each shown). QKD PON **600** also comprises at a headend **626**, a data receiver (OLT) **624** in addition to a QK MCR receiver **628**. In FIG. **6**, the splitters **614** in a first stage **650** are configured in a different way to the splitters in FIGS. **4** and **5**. In FIG. **6** the first stage **650** of splitters **614** is configured with a two-output side and an eight-output side (2×8) where the two-output side provides separate optical paths to the OLT **624** and to the QK MCR receiver **628**. The combined signal received at one of splitters **614** from the terminal end **612** will be divided between the two outputs so that both data and QKD photons will appear at each output. One output from each first stage splitter **614** is directed to a second stage splitter **618**. Splitter **618** is similar to second stage splitters shown in earlier Figures and has four inputs, each connected to a first output of one of the first-stage splitters **614** and a single output connected to OLT **624**. QK MCR receiver **628** has four inputs with each input connected to a second output of a different one of the first-stage splitters **614**. FIG. **6** also shows optical filters **62** and **64**. Each optical filter **62** has a first input connected to the output of one of ONTs **620** and a second input connected to an output of one of QK sources **622**. Each optical filter **62** has an output connected over an optical path to an input of a first-stage splitter **614**. Each Optical filter **62** combines onto the optical path to the first stage of splitters **650** the data signal from an ONT **620** and the QKD signals from a corresponding QK source **622**. That is, each filter **62** acts to combine signals in the part of the optical spectrum used to carry the QKD signal with signals in the part of the optical spectrum used to carry data. Each single path from filter **62** to switch **614**, e.g. an optical fiber, is represented in FIG. **6** by a unidirectional arrow to denote the QKD signal and a bidirectional arrow to denote the data signal.

[0032] Optical filters **64** are connected between each second output of the first-stage splitters **614** and an input to QK MCR receiver **628**. Optical filters **64** filter out the data signal received via the first stage splitter **614** from the ONTs **620**. That is, filters **64** act to pass signals in the part of the optical spectrum used to carry the QKD signal but block signals in the part of the optical spectrum used to carry data. The loss introduced by a filter may typically be around 0.5 dB, which is significantly less that the loss introduced by a typical splitter

[0033] Optical filters **64** prevent data signals from reaching the QK receiver. Filters (not shown) may also be provided on the path to the OLT **624**. According to an embodiment, no filters are provided on the path to the OLT **624**, as any QKD photons following this path will represent such a weak signal, when compared to the data signals, that the QKD photons will have negligible effect at the OLT. When compared with FIG. **3**, it will be apparent that a whole stage of splitters (i.e. **352** in FIG. **3**) and the associated losses (in this case, 6 dB) have been avoided in the path from QK source to QK receiver. In other terms, the reduction in the number of splits per path that the arrangement of FIG. **6** provides when compared to FIG. **3**, significantly improves the power budget and, as a result, enables communication of QK signals over greater fiber transmission distances. That is, a path from any one of the QK sources **622** to the QK MCR **628** in FIG. **6** has a total of 8 splits compared to the 32 splits (=4×8) in an equivalent path in FIG. **3**. The arrangement of FIG. **6** can be extended by introduction of an optical switch to increase the number of QK sources connecting to a single QK MCR receiver, as described previously with reference to FIG. **5**.

[0034] A conventional QK receiver is unable to distinguish between the arrival of multiple coincident photons. However, the effect of such coincident arrivals is to increase the noise level and common QKD protocols have a small error tolerance that can cope with coincident arrival of multiple photons at a low rate.

[0035] To reduce the error rate resulting from the coincident arrival of multiple photons, synchronization may be provided between the single-photon signal receiver and a plurality of single-photon signal sources so that photon transmission is timed so as to avoid coincident photons arriving at the MCR. A control protocol (for example COW or BB84) receives a request from a single-photon signal source for an opportunity to send. The control protocol replies with a grant to send during a distinct time-slot. The control protocol can, in this way ensure that each single-photon signal source transmits in a distinct time-slot to the other single-photon signal sources, so that single-photon signals only arrive at the head end from one single-photon signal source at a time. The control protocol also knows the source of a single-photon signal arriving at the receiver at a particular time because the control protocol will have allocated the time slot in which the single-photon signal was sent. The control protocol may be executed at the QK receiver or at the OLT of an associated date network. Signaling for the control protocol may be carried in frame headers over an associated data network, such as the PON shown between OLT and ONTs in FIG. **6**.

[0036] The control protocol may be configured so that each QK source is controlled to take it in turns to provide a burst of photons at a rate R that the receiver can cope with (an "acceptable" rate) for long enough to establish a key. Otherwise, the control protocol may be configured so that the N QK sources are controlled to send photons in distinct time slots forming an interleaved pattern at 1/N times the acceptable rate.

[0037] It will be understood by those skilled in the art that, although the present disclosure has been described in relation to the above described example embodiments, the invention is not limited thereto and that there are many possible variations and modifications which fall within the scope of the invention. Although described, above, in relation to an application of single-photon signals to QKD, the invention has application to the communication and detection of any single-photon signal. The invention may use a MCR that has more than or fewer than four inputs. The invention may be used with more than one stage of splitters but will nevertheless reduce the overall number of splits required in each optical path between QK source and receiver in a particular PON. The invention is not limited to any particular number of stages of splitters but may be implemented with more than two stages, according to the circumstances.

1. An optical receiver comprising:

a mode-coupling receiver, wherein the mode-coupling receiver comprises a plurality of inputs, and wherein the mode-coupling receiver is configured to detect receipt of a single-photon signal comprising a stream of single photons on each of the plurality of inputs.

2. The optical receiver as claimed in claim **1**, wherein each input of the mode-coupling receiver is configured to receive a single-photon signal from a different one of a plurality of single-photon signal sources.

3. The optical receiver as claimed in claim **1**, wherein **2** the single-photon signal comprises photons encoded in different quantum states, wherein each photon represents quantum key information.

4. The optical receiver as claimed claim **1**, wherein the optical receiver also comprises a programmable device configured to execute a quantum key distribution protocol to derive a cryptographic key from the single-photon signal received at the optical receiver on at least one of the plurality of inputs.

5. A communications system comprising the optical receiver of claim **1**, wherein the communications system also comprises an access network connecting a plurality of single-photon signal sources with the optical receiver, and wherein each of the plurality of inputs of the mode-coupling receiver is connected via the access network for receipt of a single-photon signal from a different one of the plurality of single-photon signal sources.

6. The communications system as claimed in claim **5**, wherein the access network comprises at least one optical splitter in which at least one of the plurality of inputs of the mode-coupling receiver is connected via an optical splitter for receipt of a single-photon signal from multiple ones of the plurality of single-photon signal sources.

7. The communications system as claimed in claim **5**, wherein **5**, in which the communications system also comprises an optical switch configured to select, for connection to a switch output, a switch input selected from a plurality of switch inputs, wherein each of the plurality of switch inputs is connected to a different one of the plurality of single-photon signal sources, and wherein the switch output is connected for sending to one of the plurality of inputs of the mode-coupling receiver, a single-photon signal from the one of the plurality of single-photon signal sources connected to the selected switch input.

8. The communications system as claimed in claim **7**, wherein the optical switch comprises a plurality of outputs, wherein the switch is configured to select, for connection to each of the plurality of switch outputs, a different one of the plurality of switch inputs, and wherein each of the plurality of switch outputs is connected to a different one of the plurality of inputs of the mode-coupling receiver.

9. The communications system as claimed in claim **8**, wherein a quantity of switch outputs equals a quantity of mode-coupling receiver inputs.

10. The communications system as claimed in claim **5**, wherein, for an N-input mode-coupling receiver, each single-photon signal source is configured to send photons at a maximum rate of R/N photons per second, where R is the maximum single-photon bit-rate of the mode-coupling receiver.

11. A method of detecting a plurality of single-photon signals, in which the method comprises:

operating a single-photon signal receiver comprising a multiple-input, mode-coupling receiver;

wherein the multiple-input, mode-coupling receiver is configured to detect receipt of a single-photon signal comprising a stream of single photons on each of the plurality of inputs.

12. The method as claimed in claim **11**, comprising routing to each input of the mode-coupling receiver, a single-photon signal from a different one of a plurality of single-photon signal sources.

13. The method as claimed in claim **11**, comprising executing a quantum key distribution protocol to derive a cryptographic key from the single-photon signal received at the optical receiver on at least one of the plurality of inputs.

14. The method as claimed in claim **11**, comprising switching a single-photon signal from a selected one of a plurality of inputs of an optical switch to an output of the optical switch, wherein; each of the plurality of switch inputs is connected to a different one of a plurality of single-photon signal sources, and wherein the switch output is connected to one of the plurality of inputs of the mode-coupling receiver.

15. The method as claimed in claim **11**, comprising switching to a different output of an optical switch, a different single-photon signal from each of a selected number of inputs of the optical switch, wherein the number of switch outputs equals the number of mode-coupling receiver inputs, and wherein each of the switch outputs is connected to a different one of the plurality of inputs of the mode-coupling receiver.

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