



US006665500B2

(12) **United States Patent**
Snawerdt

(10) **Patent No.:** **US 6,665,500 B2**
(45) **Date of Patent:** **Dec. 16, 2003**

(54) **DUAL-MODE FIBER OPTIC TELECOMMUNICATIONS SYSTEM AND METHOD**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 344 days.

(21) Appl. No.: **09/772,018**

(22) Filed: **Jan. 29, 2001**

(65) **Prior Publication Data**

US 2002/0101640 A1 Aug. 1, 2002

(51) **Int. Cl.**⁷ **H04B 10/04**

(52) **U.S. Cl.** **398/185; 398/186; 398/188**

(58) **Field of Search** 559/180, 181, 559/182, 183, 184, 185, 186, 187, 188, 110; 398/185, 186, 188, 202, 203, 204

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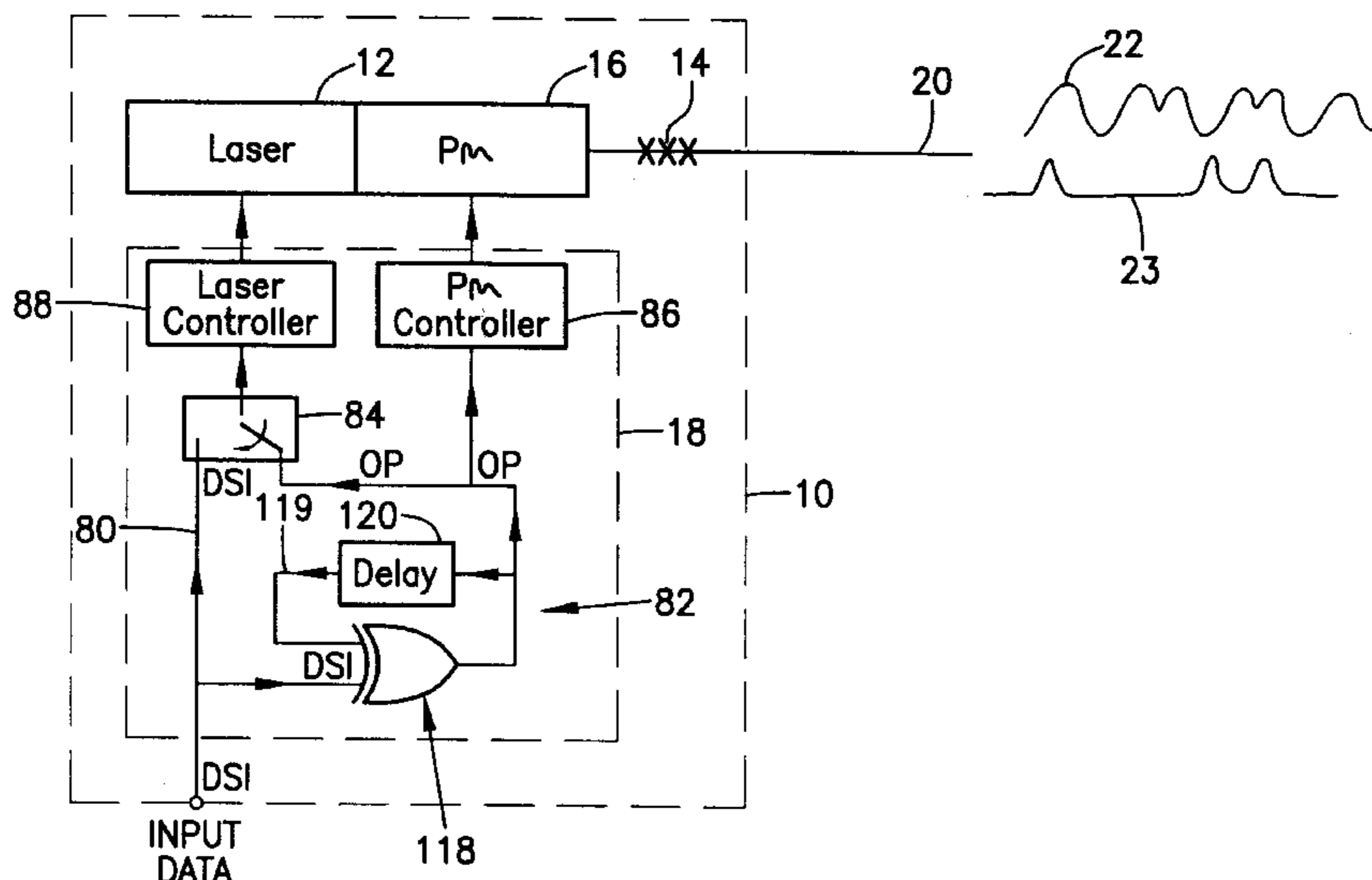
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(57) **ABSTRACT**

An optical data transmitter includes at least one light source, a phase modulator for phase modulating light from the light source, and a controller having an input for receiving an electronic data stream, the controller in a first mode controlling the phase modulator so as to create phase-modulated optical signals in the light as a function of the electronic data stream and the controller in a second alternate mode amplitude-modulating the light as a function of the electronic data stream. A dual-mode receiver, an optical data transmission system and a dual-mode optical signal are also disclosed.

19 Claims, 2 Drawing Sheets



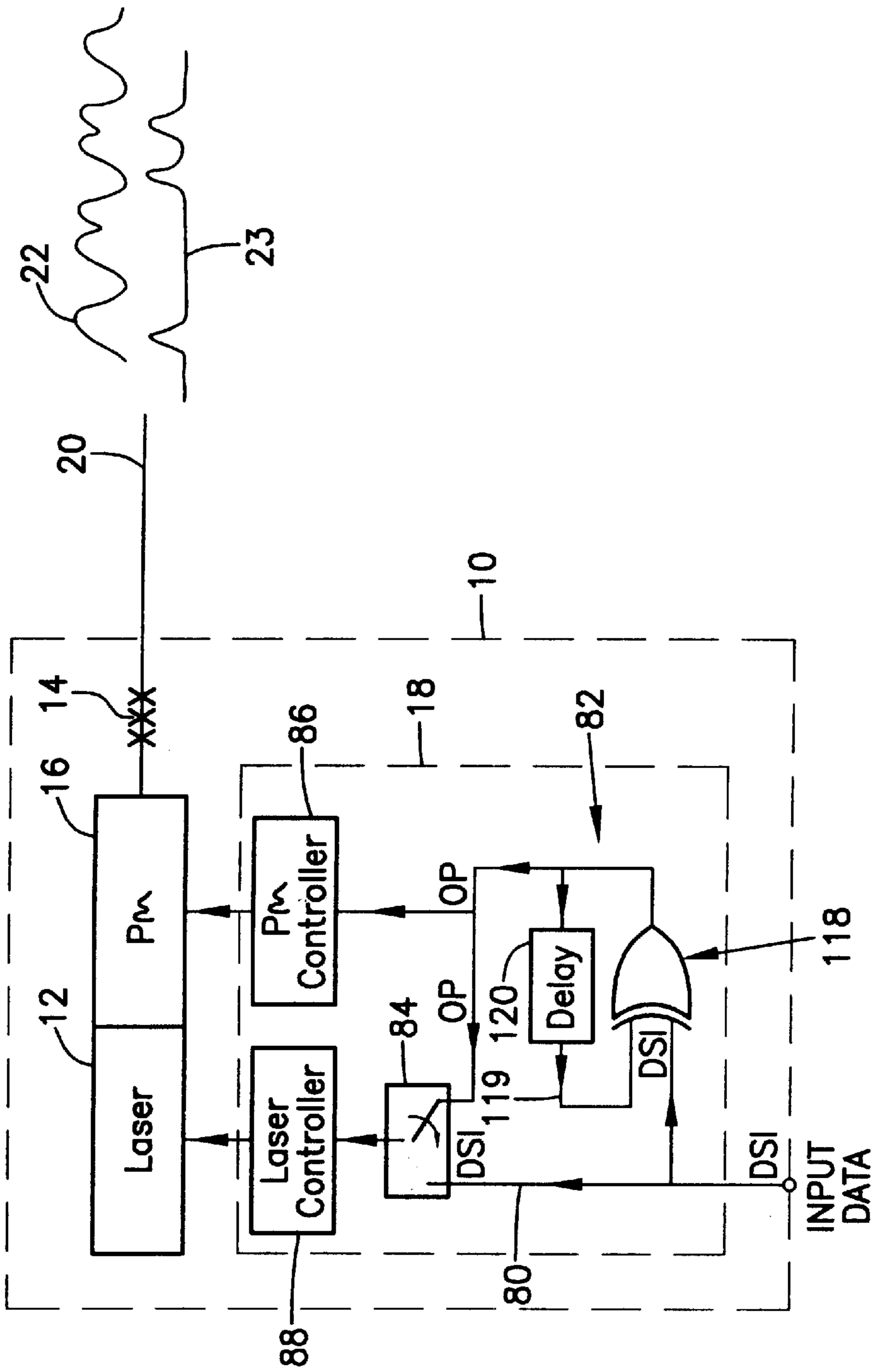


Fig. 1

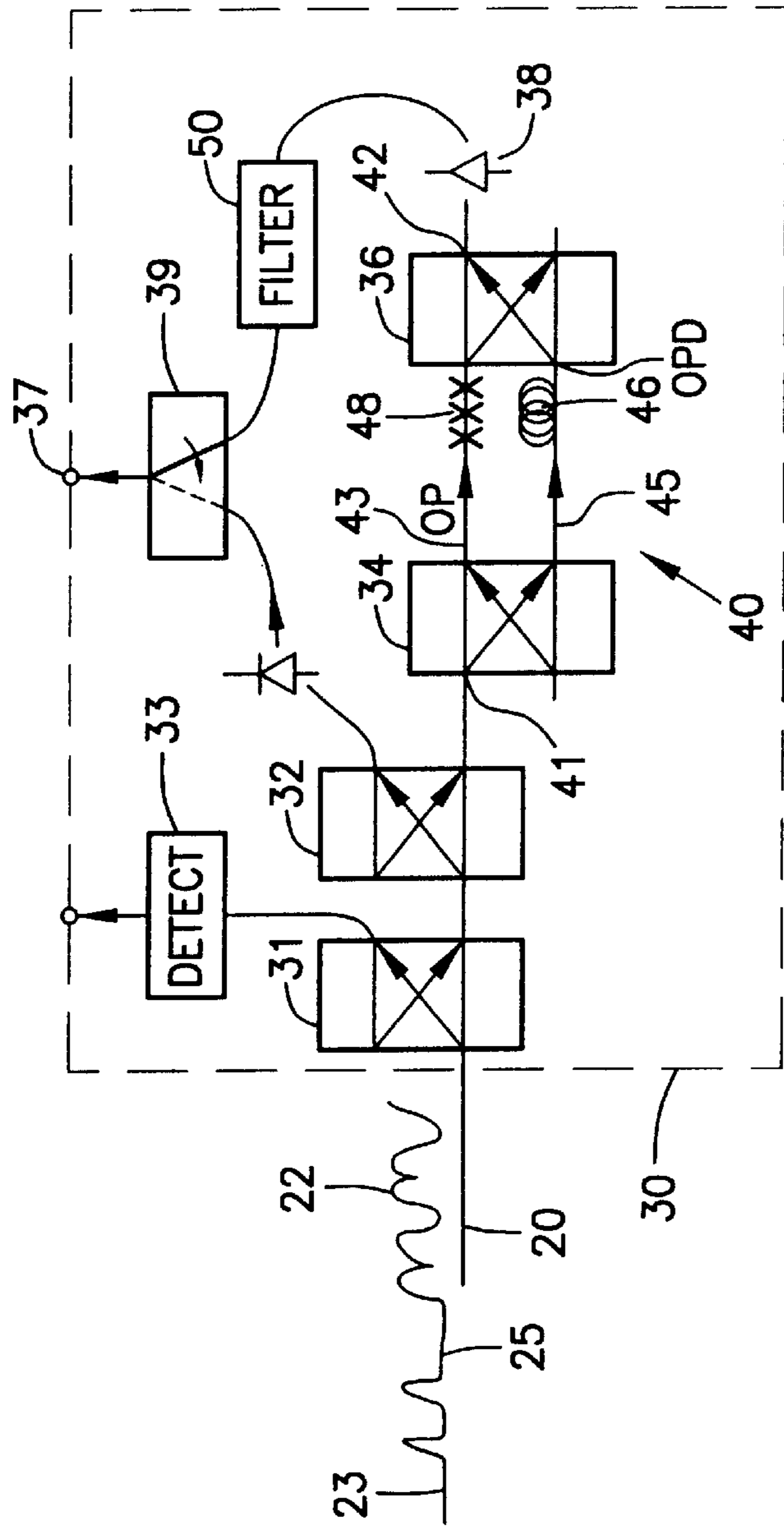


Fig. 2

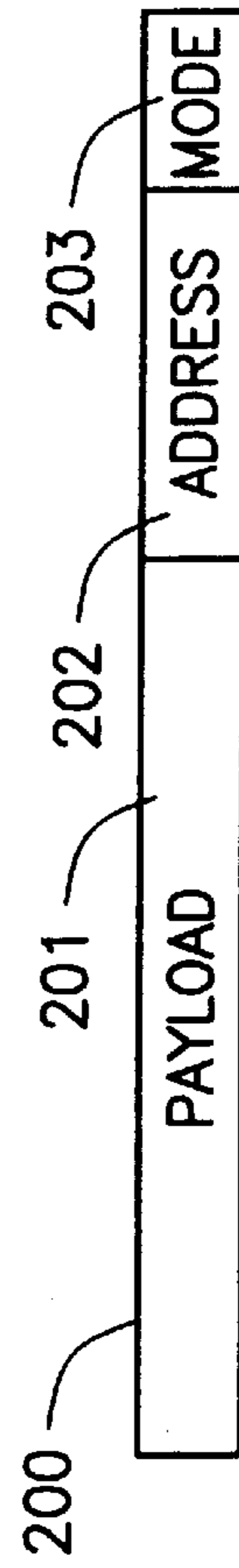


Fig. 3

DUAL-MODE FIBER OPTIC TELECOMMUNICATIONS SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to telecommunications and more particularly to transmitters and receivers for fiber optic networks.

2. Background Information

In current fiber optic networks, an electronic data stream is fed to a laser amplitude modulator. The laser amplitude modulator typically pulses or alters the laser output to create an amplitude-modulated optical signal representative of the electronic data stream. The laser amplitude modulator and laser thus define a transmitter for transmitting the optical signal over an optical fiber, which is then received by a receiver. The receiver for the amplitude-modulated optical signals of the optical data typically includes a photodiode to convert the optical signals back into the electronic data stream.

The reading of the amplitude-modulated optical data signals using a photodiode is straightforward: the optical signals either produce an electric output at the photodiode or they do not. As a result, an output electronic data stream of zeros and ones is generated.

However, optical fiber may be tapped. The optical fibers can be spliced or even merely clamped so as to obtain optical signals from the fiber. It also may be possible to tap fibers without physically touching the optical fiber, for example by reading energy emanating or dissipating along the fiber. Amplitude-modulated optical signals, with their ease of detection from a photodiode, require that only a small amount of energy be tapped and passed through the photodiode in order to be converted into a tapped electronic data stream.

To confront non-secure optical and non-optical data lines, it has been known to use public key/private key encryption so that the data stream being transmitted is encoded in a format that makes it difficult to decode. Encryption however has several drawbacks, including the need for extra processing steps and time. Moreover, public key/private key encrypted data can be cracked, and the devices and algorithms for doing so are constantly improving.

U.S. Pat. No. 5,455,698 purports to disclose a secure fiber optic communications system based on the principles of a Sagnac interferometer. A data transmitter is a phase modulator for modulating counter-propagating light beams sent by a receiver round a loop. The receiver includes a light source, a beamsplitter for splitting light from the light source into counter-propagating light beams and for receiving the phase-modulated light beams, and an output detector. U.S. Pat. No. 5,223,967 describes a similar Sagnac-interferometer-based system operating over a single optical fiber.

The Sagnac-interferometer-based systems described in these patents have the disadvantage that they require the light to travel over a loop, whether back and forth in a single fiber or over a long length looped fiber. As a result, either the link budget for the single fiber must be doubled or else a looped fiber with significant and expensive extra length of at least twice that of a single fiber must be laid between the transmitter and the receiver. Moreover, the receiver contains the light source, as opposed to the current installed base where the transmitter has the light source.

The Sagnac-interferometer-based systems thus are expensive to build and operate, and do not work particularly well with existing systems.

U.S. Pat. No. 6,072,615 purports to describe a method for generating a return-to-zero optical pulses using a phase modulator and optical filter. The RZ-pulse optical signal transmitted over the fiber is easily readable by a detector.

U.S. Pat. No. 5,606,446 purports to describe an optical telecommunications system employing multiple phase-compensated optical signals. Multiple interferometric systems are combined for the purpose of multiplexing various payloads on the same optical transmission path. The patent attempts to describe a method for providing fiber usage diversity using optical coherence length properties and a complex transmit/receive system. Each transmitter has a splitter, a plurality of fibers and a plurality of phase modulators to create the multiplexed signal, which is then demultiplexed at the receiver. This system is complex and expensive.

The phase-modulated based systems described above moreover are not compatible with existing receivers, a major disadvantage.

SUMMARY OF THE PRESENT INVENTION

An object of the present invention is to provide a transmitter for transmitting either phase-modulated or amplitude-modulated optical signals. An alternate or additional object of the present invention is to provide a receiver for receiving either phase-modulated or amplitude-modulated optical signals.

The present invention provides a transmitter having at least one light source, a phase modulator for phase modulating light from the light source, and a controller having an input for receiving an electronic data stream, the controller in a first mode controlling the phase modulator so as to create phase-modulated optical signals in the light as a function of the electronic data stream and the controller in a second alternate mode amplitude-modulating the light as a function of the electronic data stream.

The present invention thus permits a phase-modulated transmission mode or an amplitude-modulated transmission mode, or both a phase and amplitude modulated transmission mode, which can permit the transmitter to work with different types of receivers. An optical fiber typically connects the transmitter of the present invention to the receiver.

The controller in the first mode preferably phase-modulates the light as a function of an output of a delayed-feedback exclusive-or gate having the electronic data stream as an input. The first mode is thus a highly secure data transmission mode, as described in co-owned and co-pending U.S. patent application Ser. No. 09/765,153, entitled "Secure Fiber Optics Telecommunications System and Method" and filed on Jan. 17, 2001, the entire disclosure of which is hereby incorporated by reference herein.

In the second mode, the light may be amplitude modulated either by altering the energy provided to the light source or by altering the light emitted by the light source. The light source preferably is a laser, for example a semiconductor laser operating at a 1550 nm, or other, wavelength.

In the second mode, the light may be amplitude modulated either in direct relation to an input data stream (known as the direct second or amplitude-modulated mode), or as a function of an output of a delayed-feedback exclusive-or gate having the electronic data stream as an input (known as

the delayed second or amplitude-modulated mode). In the delayed second mode, the optical signal may or may not also be phase modulated. In the direct second mode, the amplitude-modulated optical signals sent by the transmitter can be read common receivers, or by the receiver of the present invention. In the delayed second mode, the amplitude-modulated optical signals can be read by the receiver of the present invention as well as by the receiver of incorporated-by-reference U.S. patent application Ser. No. 09/765,153, entitled "Secure Fiber Optics Telecommunications System and Method" and filed on Jan. 17, 2001.

The controller preferably has two circuits, a first circuit for controlling the phase modulation and a second circuit controlling the amplitude modulation. Preferably, a switch, which may be composed of hardware or software, is provided to activate the first mode, the delayed second mode, or the direct second mode. An operator may set the switch of a first transmitter to the first mode, the delayed second mode, or the direct second mode, so that the transmitter generally always operates in that mode.

Alternately, the switch can be controlled by bit data in a packet of a packet-based data input stream. The bit data may be set for example to zero or one or two or three, so that the data contained in the packet is sent either via the first mode or via the direct second mode or the delayed second mode with no phase modulation or the delayed second mode with phase modulation as a function of the bit data. The transmitter thus produces an alternating amplitude-modulated and phase-modulated data stream, which can be read by a receiver of the present invention. The packets preferably contain data regarding the transmission mode for the next packet so as to permit the receiver to have time to switch between alternate receive modes.

Both the operator-set and packet-switched systems have the advantage that telecommunications providers can provide customers differentiated services, for example a secure mode and a non-secure mode, although the bit-based method provides carriers more options for devising service levels.

The at least one light source may include two lasers, a first laser for the amplitude-modulated signals, and a second laser for the phase-modulated signals. A coupler couples the light from the two lasers together. Preferably, however, a single laser directly next to the phase-modulator is provided. This prevents delay between the laser and the phase-modulator when modes are switched.

The present invention also provides a receiver for receiving optical signals, the optical signals including both phase-modulated optical signals and direct amplitude-modulated optical signals. The receiver includes an interferometer for reading the phase-modulated signals and a detector to read the direct amplitude-modulated optical signals.

The receiver also may read delayed amplitude-modulated optical signals through the interferometer.

Preferably, an energy level detector is also provided at the receiver for measuring light energy in a fiber.

Preferably, the second light path has a delay with respect to the first light path, the delay being matched to a delay at the transmitter during the phase-modulated transmission mode and the delayed second amplitude-modulated mode.

The receiver can read a mixed optical signal of both phase-modulated and direct and delayed amplitude-modulated signals, with the direct amplitude-modulated signals being read off the third path.

The receiver can be set by an operator to receive in one of the three modes, or can be switched to the various receive

modes by a bit set in a packet. For example, the current packet being received sets the receiver to the proper receive mode for the next packet.

The present invention also provides a dual-mode optical transmission system comprising a transmitter for transmitting amplitude-modulated signals in a first mode and phase-modulated signals in a second mode, an optical fiber connected to the transmitter, and a receiver having an interferometer being connected to the optical fiber. The first and second mode signals can be read by the receiver, and can be switched based on either an operator input or packet-based data.

The present invention also provides a method for transmitting optical data in two modes comprising the steps of:

phase modulating light from at least one light source during a first transmission mode so as to transmit phase-modulated optical data; and

amplitude modulating light from the at least one light source during a second alternate transmission mode so as to transmit amplitude-modulated optical data.

Preferably, the at least one light source is a single laser.

The amplitude modulating step may include amplitude modulating the light as a direct function of an input electronic data stream, or as a function of an output of a delayed-feedback exclusive-or gate.

The method may further include switching between the phase modulating and the amplitude modulating steps as a function of a packet bit set.

Also provided by the present invention is an optical signal comprising amplitude-modulated signals representative of an input data stream during a first time period and phase-modulated signals representative of the input data stream during a second time period subsequent or prior to the first time period.

It should be understood however that, while phase-modulated signals are preferred in the secure transmission mode, under certain circumstances a mixture of phase and amplitude modulation could be possible. For example, amplitude modulated signals not related to the input optical data stream could be transmitted during the secure phase-modulation mode without necessarily affecting security.

BRIEF DESCRIPTION OF THE DRAWINGS

Two preferred embodiments of the present invention are described below by reference to the following drawings, in which:

FIG. 1 shows a preferred embodiment of a transmitter of the present invention;

FIG. 2 shows a preferred embodiment of a receiver of the present invention; and

FIG. 3 shows details a packet for possible use with the transmitter of the present invention

DETAILED DESCRIPTION

FIG. 1 shows a preferred embodiment of a dual-mode transmitter **10** according to the present invention for transmitting signals to an optical fiber **20**. Transmitter **10** includes a single laser **12**, for example a semiconductor laser emitting a narrow band of light at approximately 1550 nm, or at other wavelengths. Light emitted from laser **12** passes through a phase modulator **16**, for example a Mach-Zender phase modulator, directly next to or part of the same package as laser **12**. The light may be depolarized by a depolarizer **14**. An electronic controller **18**, for example a PLC, controls phase modulator **16** and the amplitude of the light output of laser **12**, for example through pulsing the laser.

Controller **18** directs the input data DSI to a direct amplitude modulation circuit **80** and to a circuit **82** having a delayed-feedback exclusive-or gate **118**. Input data DSI forms one input of exclusive-or gate **118**. The other input of the delayed-feedback exclusive-or gate **118** is a feedback loop **119**, which feeds back the output of exclusive-or gate **118**, and has an electronic delay circuit **120**, which causes a delay, for example, a certain number of bits later. Delayed-feedback exclusive-or gate **118** outputs the output electronic data stream OP. The data OP exiting circuit **82** is directed both to a switch **84** and a phase modulator controller **86**. Direct circuit **80** also supplies an input with data DSI to switch **84**.

The output of switch **84** is directed to an amplitude controller **88** for laser **12**, which during an amplitude modulation mode is modulated according to the output from switch **84**. Amplitude controller **88**, during an amplitude-modulation mode, thus amplitude modulates the laser **12** so that an amplitude-modulated signal **23**, representative of either the data DSI or OP, passes to fiber **20**.

During an amplitude modulation mode, phase modulator controller **86** either does not phase modulate the light, or phase modulates based upon the output of the delayed feedback exclusive-or circuit **82**.

When switch **84** receives data from circuit **82**, the laser amplitude is a function of the output OP of the delayed-feedback exclusive-or gate **118**. The transmitter **10** thus transmits in a delayed-feedback exclusive-or amplitude-modulated mode, defined herein as the delayed amplitude-modulated mode. When switch **84** receives data DSI from direct circuit **80**, the laser amplitude is a direct function of the input electronic data DSI. The transmitter **10** thus transmits in the direct amplitude-modulated mode.

During the alternate phase-modulation mode, the amplitude controller **88** directs the laser to emit constant wavelength, non-pulsed light. Depending on the output OP of circuit **82**, phase modulator **16** then either imparts a known initial phase shift to the light which could be 0 degrees or else imparts another known offset phase shift preferably equal to the known initial phase shift+180 degrees on the light passing through phase modulator **16**. An optical signal **22**, which represents a stream of binary bits, is thus created. Optical signal **22** is transmitted over fiber **20**. This signal provides a secure data transmission mode. The phase-modulated signal must be read with an interferometer having a proper delay path, and any tap to obtain enough light to read the phase-modulated signal is easily detectable.

In the direct amplitude modulated mode, a standard receiver can read the signals **23**.

In the delayed amplitude modulated mode, signals OP are sent in a pulsed fashion. These signals can be read by the receiver disclosed in incorporated-by-reference U.S. patent application Ser. No. 09/765,153, entitled "Secure Fiber Optics Telecommunications System and Method" and filed on Jan. 17, 2001. A standard receiver with a photodiode also could read the delayed amplitude modulated signals. The photodiode output could then be split into two legs, with one leg having a delay, which must be similar to the delay **120** in the delayed-feedback exclusive-or gate **118**. The two legs are then passed through an exclusive-or gate to obtain the proper signal DSI.

In the phase-modulated mode, the phase-modulated signals **22** can read by the receiver disclosed in incorporated-by-reference U.S. patent application Ser. No. 09/765,153, entitled "Secure Fiber Optics Telecommunications System and Method" and filed on Jan. 17, 2001. The signals **22** pass

through a splitter, with one path having an optical delay similar to the delay **120**. The light recombines in a coupler so that input stream DSI can be reconstituted.

Receiver **10** shown in FIG. 2 is a preferred embodiment permitting three modes. However, the present invention also encompasses a transmitter with the phase-modulated mode and only one of the direct and delayed amplitude-modulated modes. A transmitter with the phase-modulated mode and the direct amplitude-modulated mode only, for example, is backwards-compatible with existing receivers in the amplitude-modulated mode and yet can provide a secure and non-secure mode with receivers having an interferometer as disclosed herein. A transmitter with the phase-modulated mode and the delayed amplitude-modulated mode only provides secure and non-secure modes and is compatible for both modes with the receiver disclosed in U.S. patent application Ser. No. 09/765,153, entitled "Secure Fiber Optics Telecommunications System and Method" and filed on Jan. 17, 2001.

The present invention also provides a receiver compatible with existing transmitters, with the transmitter disclosed in U.S. patent application Ser. No. 09/765,153, entitled "Secure Fiber Optics Telecommunications System and Method" and filed on Jan. 17, 2001, and with the transmitter of the present invention.

As shown in FIG. 2, receiver **30** can receive either direct or delayed amplitude-modulated signals as well as phase-modulated signals. Receiver **30** includes a coupler/splitter **31**, functioning as a splitter. Splitter **31** splits off a portion of the light, directing part of the optical energy to an energy level or tap detector **33** and passes the remaining light to a second coupler/splitter **32**.

Splitter **32** splits light to a photodiode **35** for converting amplitude-modulated optical signals into electrical signals. The receiver also has an interferometer **40** receiving the rest of the light from splitter **32**. The interferometer **40** has a coupler/splitter **34**, functioning as a splitter, and a coupler/splitter **36**, functioning as a coupler.

Detector **33** monitors, during the phase-modulation transmission mode, the light energy in the fiber **20** via the light energy coupled to the detector by splitter **31**. If the amplitude drops during this mode, most likely from a tap, the detector alerts the receiver and can, for example, sound an alarm or alert network maintenance personnel. Additionally, since the receiver is generally part of a component box, which also includes a transmitter, the component box transmitter can send a signal back to the component box containing transmitter **10** so as to instruct transmitter **10** to stop sending data, or to send data over a standby fiber. During an amplitude-modulation transmission mode, the detector **33** can be set to a different trip level.

Optical signals **22**, **23** in fiber **20**, after passing splitter **31** and splitter **32**, enter interferometer **40** at an input **41** of splitter **34**. Splitter **34** splits the light entering input **41**, so that the signals **22**, **23** travel over both a first fiber **43** and a second fiber **45**. A depolarizer **48** may depolarize light passing through fiber **43**, preferably, or fiber **45** as an alternative. Second fiber **45** includes a delay fiber **46** which may include a fiber loop of a desired length. Delay fiber **46** then provides an input to coupler **36** which recombines the delayed signal with the non-delayed signal propagating through fiber **43** and depolarizer **48** at output **42**. The physical delay imposed by the interferometer **40** in the second light path through fiber **45**, with its delay loop **46**, with respect to light passing through the first light path through fiber **43** and depolarizer **48** is selected to match as

closely as possible an electronic delay time imposed by electronic delay circuit **120** of the controller **18**. If the first path in the interferometer **40** has a length **L1** and the second path a length **L2**, the length **L2** is selected, preferably by sizing loop **46**, as a function of **L1**, the speed of light v in fibers **43** and **45**, the light propagation delay through the depolarizer **48**, DPD, and the electronic delay time ED. The speed of light in the fibers may be estimated as a function of the wavelength and the type of fiber used. The length **L1** is known. When depolarizer **48** is in path **43**, **L2** is then chosen to approximate, and preferably equal, the amount $(ED + DPD) \cdot v + L1$.

The phase-modulated signals **22** recombining at output **42** thus recombine the signal OP with a delayed signal OPD, delayed by an amount of time equivalent to the electronic delay time ED. If the data in the OP and OPD signals each represents a zero, or each represents a one, at the inputs **44** and **47** to coupler **36**, the signals **22** will destructively interfere when recombined at output **42** of coupler **36**. Output detector **38** then detects no light and produces a zero signal. If one of the data bits in the OP and OPD signals represents a zero and the other one represents a one, at the inputs **44** and **47** to coupler **36**, the signals will constructively interfere when recombined at coupler output **42**. This is true for both phase-modulated and amplitude-modulated signals. Output detector **38** then detects light and produces an electronic signal representative of a one. When receiving phase-modulated signals or the delayed amplitude-modulated signals, detector **38** thus outputs the input data stream DSI. A filter **50** can be provided to filter out noise or other minor inaccuracies in the recombination of the signals. This stream is transmitted via a switch **39** to output **37**.

The interferometer **40** comprising coupler/splitter **34** and **36**, fibers **43** and **45**, delay fiber **46**, and depolarizer **48** functions as an optical exclusive-or gate with one input leg delayed for signals arriving at input **41** of coupler **34**. Interferometer **40** as a whole thus optically and physically "decodes" the signal OP produced by the delayed-feedback exclusive-or gate **118**.

When receiving direct amplitude modulated signals, the detector outputs a signal that is meaningless. Switch **39** is thus set to receive an input from photodiode **35**, which is representative of stream DSI, and thus stream DSI is sent to output **37**.

The receiver of the present invention thus can receive both direct amplitude-modulated signals and phase-modulated signals. The receiver **30** also could include a circuit after photodiode **35** so as to convert the delayed amplitude-modulated signals to the stream DSI. In this case, the output detector **38** would only be used to read the phase-modulated signals.

Controlling of the change between secure mode and the amplitude-modulated modes can function in a variety of ways, depending on the overall system configuration. With the transmitter **10** and the receiver **30**, an operator can configure the transmitter **10** and receiver **30** so that the system functions in any of the three modes.

If the system includes a dual-mode transmitter (defined herein as a transmitter with a phase-modulation mode and one or more amplitude-modulation modes), an input packet data bit also could be used to set the mode.

Signal **25** in FIG. **2** is shown as a combination of amplitude-modulated signals **23** and phase-modulated signals **22**, which occurs for example when packets with different modes are sent one after another.

FIG. **3** shows an example of such a packet **200** having a data payload **201**, and address **202**, and mode data **203**.

Depending on the mode data, the transmitter transmits in a phase-modulated or amplitude-modulated mode. If the transmitter is similar to transmitter **30**, the mode data further includes whether to amplitude-modulate in direct or delayed mode. Preferably, the mode data **203** is set not for its own packet N, but for the following packet N+1, thus providing a buffer time for the receiver to change modes. Thus, when packet N+1 is received, the receiver is set to the proper receive mode. The mode data could also be set more than one packet ahead, for example N+2.

If both a dual mode transmitter and a dual mode receiver are used in a system, a telecommunications service provider thus could charge certain customers for an enhanced secure mode service for their packet-based data, while permitting other customers to send data in a non-secure mode in their packets.

An alternate embodiment of the transmitter of the present invention can include two lasers, with the first laser being controlled during the amplitude modulation modes. The second laser is a continuous wave laser modulated by a phase modulator in the alternate secure mode. A coupler couples the light from the first laser and second lasers together, so that the optical signal for either mode travels over a single fiber.

What is claimed is:

1. An optical data transmitter comprising:
 - a laser;
 - a phase modulator for phase modulating light from the light source; and
 - a controller having an input for receiving an electronic data stream, the controller in a first mode controlling the phase modulator so as to create phase-modulated optical signals in the light from the laser as a function of the electronic data stream and the controller in a second alternate mode amplitude-modulating the light from the laser as a function of the electronic data stream, the first mode and the second mode occurring at different times.
2. The transmitter as recited in claim 1 wherein the controller in the second mode amplitude modulates the light in direct relation to the input data stream.
3. The transmitter as recited in claim 1 wherein the controller in the second mode amplitude modulates the light as a function of an output of a delayed-feedback exclusive-or gate having the electronic data stream as an input.
4. The transmitter as recited in claim 1 wherein the controller has a switch for switching between the first and second modes.
5. The transmitter as recited in claim 4 wherein the switch is operator-activated.
6. The transmitter as recited in claim 1 wherein the switch is bit-data activated.
7. The transmitter as recited in claim 6 wherein bit data contained in a packet activates the switch.
8. The transmitter as recited in claim 1 wherein the laser is directly adjacent the phase-modulator.
9. The transmitter as recited in claim 1 wherein during the second mode the phase-modulator provides a constant or no phase-modulation change.
10. An optical data transmitter comprising:
 - a light source;
 - a phase modulator for phase modulating light from the light source; and
 - a controller having an input for receiving an electronic data stream, the controller in a

first mode controlling the phase modulator so as to create phase-modulated optical signals in the light from the light source as a function of the electronic data stream and the controller in a second alternate mode amplitude-modulating the light from the light source as a function of the electronic data stream; wherein the controller in the first mode preferably phase-modulates the light as a function of an output of a delayed-feedback exclusive-or gate having the electronic data stream as an input.

11. A receiver for receiving optical signals, the optical signals including both phase-modulated optical signals and direct amplitude-modulated optical signals, the receiver comprising:

- an interferometer for reading the phase-modulated signals; and
 - a detector to read the direct amplitude-modulated optical signals;
- wherein the interferometer receives delayed amplitude-modulated optical signals.

12. The receiver as recited in claim **11** further comprising a switch for switching between an output of the interferometer and another output of the detector.

13. The receiver as recited in claim **12** wherein the switch is operator-controlled.

14. The receiver as recited in claim **12** wherein the switch is bit-data controlled.

15. The receiver as recited in claim **11** further comprising an energy level detector for measuring light energy in a fiber.

16. A dual-mode optical transmission system comprising: a transmitter having a laser for transmitting amplitude-modulated signals in a first mode and phase-modulated signals in a second mode and a controller for switching an output of the laser between the first mode and the second mode, the second mode occurring at a different time than the first mode;

an optical fiber connected to the transmitter; and

a receiver having an interferometer being connected to the optical fiber.

17. A method for transmitting optical data in two modes comprising the steps of:

phase modulating light from a laser during a first transmission mode so as to transmit phase-modulated optical data; and

amplitude modulating light from the laser during a second alternate transmission mode so as to transmit amplitude-modulated optical data, the second alternate transmission mode occurring at a time separate from the first transmission mode.

18. The method as recited in claim **17** wherein during the first transmission mode the light is not amplitude-modulated.

19. The method as recited in claim **17** wherein during the second alternate transmission mode the light is both amplitude-modulated and phase-modulated.

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