

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
3 January 2008 (03.01.2008)

PCT

(10) International Publication Number
WO 2008/002913 A1

(51) International Patent Classification:
H04B 10/12 (2006.01) **H04B 10/18** (2006.01)

(21) International Application Number:
PCT/US2007/072118

(22) International Filing Date: 26 June 2007 (26.06.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11/426,794 27 June 2006 (27.06.2006) US

(71) Applicant (for all designated States except US): **SCIEN-
TIFIC-ATLANTA, INC.** [US/US]; 5030 Sugarloaf Park-
way, Lawrenceville, Georgia 30044 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **CHEN, Yihong**
[CN/US]; 2724 Wait Road, Naperville, Illinois 60564
(US). **VILLARRUEL, Fernando X.** [US/US]; 906 Ma-
son Street, Joliet, Illinois 60435 (US). **OTT, Daniel M.**
[US/US]; 1235 Anderson Drive, Batavia, Illinois 60510
(US).

(74) Agents: **LAFFERTY, Wm. Brook** et al.; Scientific-At-
lanta, Inc., Intellectual Property Dept., 5030 Sugarloaf
Parkway, Lawrenceville, Georgia 30044 (US).

(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH,
CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG,
ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL,
IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK,
LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW,
MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL,
PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY,
TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA,
ZM, ZW.

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM,
ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),
European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI,
FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL,
PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM,
GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

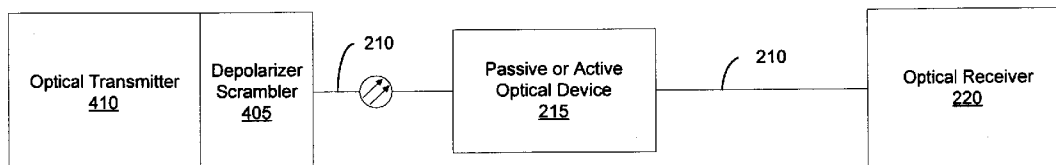
Published:

- with international search report
- before the expiration of the time limit for amending the
claims and to be republished in the event of receipt of
amendments

For two-letter codes and other abbreviations, refer to the "Guid-
ance Notes on Codes and Abbreviations" appearing at the begin-
ning of each regular issue of the PCT Gazette.

(54) Title: NOISE MITIGATION IN ANALOG OPTICAL TRANSMISSION SYSTEMS USING POLARIZATION SCRAM-
BLER

400



(57) Abstract: The present invention is directed towards systems and methods that include an optical polarization scrambler or depolarizer after the optical transmitter. In this manner, the optical signal is depolarized. Accordingly, the noise peaks that were translated from Guided Acoustic-Wave Brillouin Scattering (GAWBS) by the devices with polarization dependent loss or gain is mitigated in order to have little effect on the quality of the RF signal carried by lightwave.

WO 2008/002913 A1

NOISE MITIGATION IN ANALOG OPTICAL TRANSMISSION SYSTEMS USING POLARIZATION SCRAMBLER

INVENTORS: Yihong Chen
Fernando Villarruel
Dan Ott

FIELD OF THE INVENTION

This invention relates generally to fiber optic communications systems, such as cable television networks, and more specifically to an optical communications system having an analog and QAM transport.

BACKGROUND OF THE INVENTION

A broadband communications system, such as a two-way hybrid fiber/coaxial (HFC) system is used for transmitting video/audio, voice, and data signals. The communications system includes headend equipment for generating RF frequency signal and for imprinting the RF signal into optical carriers that are transmitted in the forward, or downstream, direction along optical fiber. The frequency band for the downstream signals is generally in a range from 45 MHz (Mega Hertz) to 1 GHz (Giga Hertz), and the frequency range for upstream signals is in a range from 15 MHz to about 40 MHz. Typically, the optical portion of the communications system utilizes passive and active devices along the transport routes to provide signals to a final distribution portion of the system. Subsequently, the RF (radio frequency) signals are extracted from optical carriers for final transmission to the subscribers through coaxial cable.

Inherent in the optical transmission fiber of the communications system, there is a forward Brillouin scattering with frequency shifting, which is known as Guided Acoustic-Wave Brillouin Scattering (GAWBS). In optical fiber, acoustic modes, such as intrinsic vibration and phonons, are guided by the cylindrical structure. The acoustic modes correspond to the radially and circumferentially propagating phonons that produce uniaxial strain or dilatation at the core. The resulting oscillatory strain and density fluctuations cause phase and polarization modulation of the confined optical field. The guided acoustic wave scatters the optical signals to the forward direction and causes a

frequency shift of the optical light. This frequency shift is mostly in the range from about 50 MHz to about 800 MHz and it overlaps with the RF frequency range from about 20 MHz to 1GHz. The scattered light with shifted frequency travels along with the unscattered light signal in optical fiber and it results in a degraded signal-to-noise ratio (SNR) or carrier-to-noise ratio (CNR). What is needed, therefore, is a method and system of mitigating the GAWBS noise that affects the transport of analog signals.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram illustrating an example of a conventional ring-type broadband communications system, such as a two-way hybrid/fiber coaxial (HFC) network.

FIG. 2 is a block diagram of a simplified optical transmission system that is suitable for use in the communications system of FIG. 1.

FIG. 3 illustrates a GAWBS spectrum in a typical optical link with SMF-8 optical fiber.

FIG. 4 is a block diagram of an optical transmission system including a depolarizer that is used in order to offset polarization dependent loss (PDL) in accordance with the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

The present invention will be described more fully hereinafter with reference to the accompanying drawings in which like numerals represent like elements throughout the several figures, and in which an exemplary embodiment of the invention is shown. This invention may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein; rather, the embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. All examples given herein, therefore, are intended to be non-limiting and are provided in order to help clarify the description of the invention.

The present invention is directed towards an optical communications system including a depolarizer or polarization scrambler. Placement of a depolarizer or a polarization scrambler in the optical system mitigates the negative effect of GAWBS noise peaks on the transmission of optical signals. Analog video and QAM transmission

are most susceptible to those noise peaks and as a result the signal quality is degraded. It will be appreciated that noise peaks generated by GAWBS in a digital transmission system are usually not picked up by the transmitted signal, and so they do not have a significant impact on the quality of the transmission. A general overview of a typical communications system is described herein below.

FIG. 1 is a block diagram illustrating an example of a conventional ring-type broadband communications system, such as a two-way hybrid/fiber coaxial (HFC) network. It will be appreciated that other networks exist, such as a star-type network. These networks may be used in a variety of systems, including, for example, cable television networks, voice delivery networks, and data delivery networks to name but a few. The broadband signals transmitted over the networks include multiple information signals, such as video, voice, audio, and data, each having different frequencies. Headend equipment included in a signal source, or a headend facility 105, receives incoming information signals from a variety of sources, such as off-air signal source, a microwave signal source, a local origination source, and a satellite signal source and/or produces original information signals at the facility 105. The headend 105 processes these signals from the sources and generates forward, or downstream, broadcast signals that are delivered to a plurality of subscriber equipment 110. The broadcast signals can be digital or analog signals and are initially transported via optical fiber 115 using any chosen transport method, such as SONET, gigabit (G) Ethernet, 10 G Ethernet, or other proprietary digital transport methods. The broadcast signals are typically provided in a forward bandwidth, which may range, for example, from 45 MHz to 1 GHz. The information signals may be divided into channels of a specified bandwidth, e.g., 6 MHz, that conveys the information. The information is in the form of carrier signals that transmit the conventional television signals including video, color, and audio components of the channel. Also transmitted in the forward bandwidth may be telephony, or voice, signals and data signals.

Optical transmitters (not shown), which are generally located in the headend facility 105, convert the electrical broadcast signals into optical broadcast signals. In most networks, the first communication medium 115 is a long haul segment that transports the signals typically having a wavelength in the 1550 nanometer (nm) range. The first communication medium 115 carries the broadcast optical signal to hubs 120. The hubs 120 may include routers or switches to facilitate routing the information signals

to the correct destination location (e.g., subscriber locations or network paths) using associated header information. The optical signals are subsequently transmitted over a second communication medium 125. In most networks, the second communication medium 125 is an optical fiber that is typically designed for shorter distances, and which transports the optical signals over a second optical wavelength, for example, in the 1310 nm range.

From the hub 120, the signals are transmitted to an optical node 130 including an optical receiver and a reverse optical transmitter (not shown). The optical receiver converts the optical signals to electrical, or radio frequency (RF), signals for transmission through a distribution network. The RF signals are then transmitted along a third communication medium 135, such as coaxial cable, and are amplified and split, as necessary, by one or more distribution amplifiers 140 positioned along the communication medium 135. Taps (not shown) further split the forward RF signals in order to provide the broadcast RF signals to subscriber equipment 110, such as set-top terminals, computers, telephone handsets, modems, televisions, etc. It will be appreciated that only one subscriber location 110 is shown for simplicity, however, each distribution branch may have as few as 500 or as many as 1000 subscriber locations. Additionally, those skilled in the art will appreciate that most networks include several different branches connecting the headend facility 105 with several additional hubs, optical nodes, amplifiers, and subscriber equipment. Moreover, a fiber-to-the-home (FTTH) network 145 may be included in the system. In this case, optical fiber is pulled to the curb or directly to the subscriber location and the optical signals are not transmitted through a conventional RF distribution network.

In a two-way network, the subscriber equipment 110 generates reverse RF signals, which may be generated for a variety of purposes, including video signals, e-mail, web surfing, pay-per-view, video-on-demand, telephony, and administrative signals. These reverse RF signals are typically in the form of modulated RF carriers that are transmitted upstream in a typical United States range from 5 MHz to 40 MHz through the reverse path to the headend facility 105. The reverse RF signals from various subscriber locations are combined via the taps and passive electrical combiners (not shown) with other reverse signals from other subscriber equipment 110. The combined reverse electrical signals are amplified by one or more of the distribution amplifiers 140 and generally converted to optical signals by the reverse optical transmitter included in the optical node 130 before

being transported through the hub ring and provided to the headend facility 105.

FIG. 2 is a block diagram of a simplified optical transmission system 200 that is suitable for use in the communications system of FIG. 1. A polarized optical source, transmitter 205, converts the electrical signals into optical signals before transmission through the communications system 200. The optical signals are then transmitted along an optical fiber 210. Passive or active optical devices 215 amplify or pass the signals along as necessary. An optical receiver 220 receives the optical signals for conversion to electrical signals for further transmission.

The optical fiber 210 and the passive and/or active devices 215 inherently all produce, or generate, polarization dependent loss (PDL) or polarization dependent gain (PDG), more or less. As a result, the optical devices 205, 210, 215 generate a local oscillator that interacts with the depolarized scattered light at the receiver and produces a heterodyne signal, thereby imprinting a GAWBS signature onto the RF signals in the RF domain.

FIG. 3 illustrates a GAWBS spectrum 300 in a typical optical link with SMF-8 optical fiber. As can be seen in the spectrum 300, the GAWBS noise peaks are mainly in the frequency range from 20 MHz to 1 GHz. The higher the PDL or the PDG is in the devices, the more efficient the heterodyne detection and, therefore, the higher the GAWBS noise peaks. Additionally, in a communications system with multiple fiber sections, many optical amplifiers and other passive and/or active components, GAWBS noise accumulates along the transmission link. One solution to reducing the GAWBS noise peaks is to decrease the PDL or PDG of the optical devices used in the optical links. However, there is a limit as to how much of this can be done in practice due to limited or no availability of zero-PDL devices.

FIG. 4 is a block diagram of an optical transmission system 400 including a polarization scrambler or a depolarizer 405 that is used to change the optical signal from a polarized state to an unpolarized state. It will be appreciated that PDL of an optical device does not have any effect on unpolarized light. Accordingly, the GAWBS noise peaks are mitigated in the RF domain. As shown in FIG. 4, a depolarizer 405 is placed immediately after the optical transmitter 410. Alternatively, the depolarizer 405 may be built into the optical transmitter 410. The depolarizer 405 may also be placed anywhere in the optical link to reduce GAWBS noise, but ideally, the depolarizer 405 should be placed as close to the optical transmitter 410 as possible.

Since PDL takes advantage of organized or polarized light, it is able to transfer the noise into the RF domain that is shown as the GAWBS noise peaks. In accordance with the present invention, the polarization scrambler or depolarizer 405 scrambles the light from the optical transmitter 410. The depolarized light is then transmitted downstream to the receiver 220. Advantageously and in accordance with the present invention, the unpolarized light does not cause any effect at the device with polarization dependent loss; therefore, the GAWBS does not transfer noise into the RF domain.

The Detailed Description of a Preferred Embodiment set forth above is to be regarded as exemplary and not restrictive, and the breadth of the invention disclosed herein is to be determined from the following claims as interpreted with the full breadth permitted by the patent laws.

Claims

1. An optical transmitter for providing an analog optical signal, the optical transmitter comprising:
a depolarizer for depolarizing the optical light, wherein the depolarizer mitigates
5 the effect of a noise signal on the analog optical signal.
2. The optical transmitter of claim 1, wherein the optical transmitter provides at least one of an analog video and a quadrature amplitude modulation (QAM) radio frequency (RF) signal in a frequency range from 50 MHz to 1 GHz.
- 10 3. The optical transmitter of claim 1, wherein the noise signal is produced by one of polarization dependent loss and polarization dependent gain of at least one of an optical amplifier, an optical receiver, and an optical fiber span and other optical components.
- 15 4. A method for providing an optical signal, the method comprising the steps of:
providing an analog modulated optical signal; and
depolarizing the analog modulated optical signal to provide a depolarized analog modulated optical signal, wherein the depolarizing step mitigates a noise signal.
- 20 5. The method of claim 4, wherein the noise signal is produced by one of polarization dependent loss and polarization dependent gain of at least one of an optical amplifier, an optical receiver, and an optical fiber span and other optical components.
6. The method of claim 4, wherein the depolarized analog modulated optical signal is
25 transmitted in a frequency range from 50 MHz to 1 GHz.
7. An optical link for providing an optical signal, the optical link comprising:
an optical transmitter for providing optical light, wherein the optical light
comprises an analog and QAM radio frequency (RF) signal; and
30 a depolarizer for depolarizing the optical light, wherein the depolarizer mitigates the effect of a noise signal inserted by optical equipment located in the optical link.

8. The optical link of claim 7, wherein the optical transmitter provides analog video and quadrature amplitude modulation (QAM) radio frequency (RF) signals in a frequency range from 50 MHz to 1 GHz.

9. The optical link of claim 7, wherein the optical equipment comprises:
at least one section of optical transmission fiber;
at least one optical amplifier; and
at least one optical receiver.

10. The optical link of claim 9, wherein the depolarizer is located anywhere throughout the at least one section of optical transmission fiber for the purpose of suppressing the noise signal.

11. The optical link of claim 7, wherein the optical transmitter and the depolarizer are comprised in a single integrated device.

12. A communications system for transmitting video, voice, and data signals, the communications system including devices that display unwanted noise signals in a radio frequency (RF) domain, the communications system comprising:

at least one section of optical transmission fiber;
an optical transmitter for providing optical light;
at least one optical amplifier for amplifying the optical light;
at least one optical receiver for receiving the optical light,
wherein the at least one section of optical transmission fiber, the at least one optical amplifier, and the at least one optical receiver generates a noise signal due to at least one of polarization dependent loss and polarization dependent gain; and
a depolarizer for depolarizing the optical light to provide a depolarized optical light, wherein depolarizing the optical light mitigates the generated noise signal.

13. The communications system of claim 12, wherein the optical transmitter and the depolarizer are comprised in a single integrated device.

14. The communications system of claim 12, wherein the depolarizer is located in each of the at least one section of optical transmission fiber.

15. The communications system of claim 12, wherein the optical transmitter provides at least one of an analog video and a QAM RF signal in a frequency range from 50 MHz to 1GHz.

16. The communications system of claim 12, wherein the noise signal is produced by one of polarization dependent loss and polarization dependent gain of at least one of the optical amplifier, the at least one optical receiver, and the at least one section of optical communications fiber.

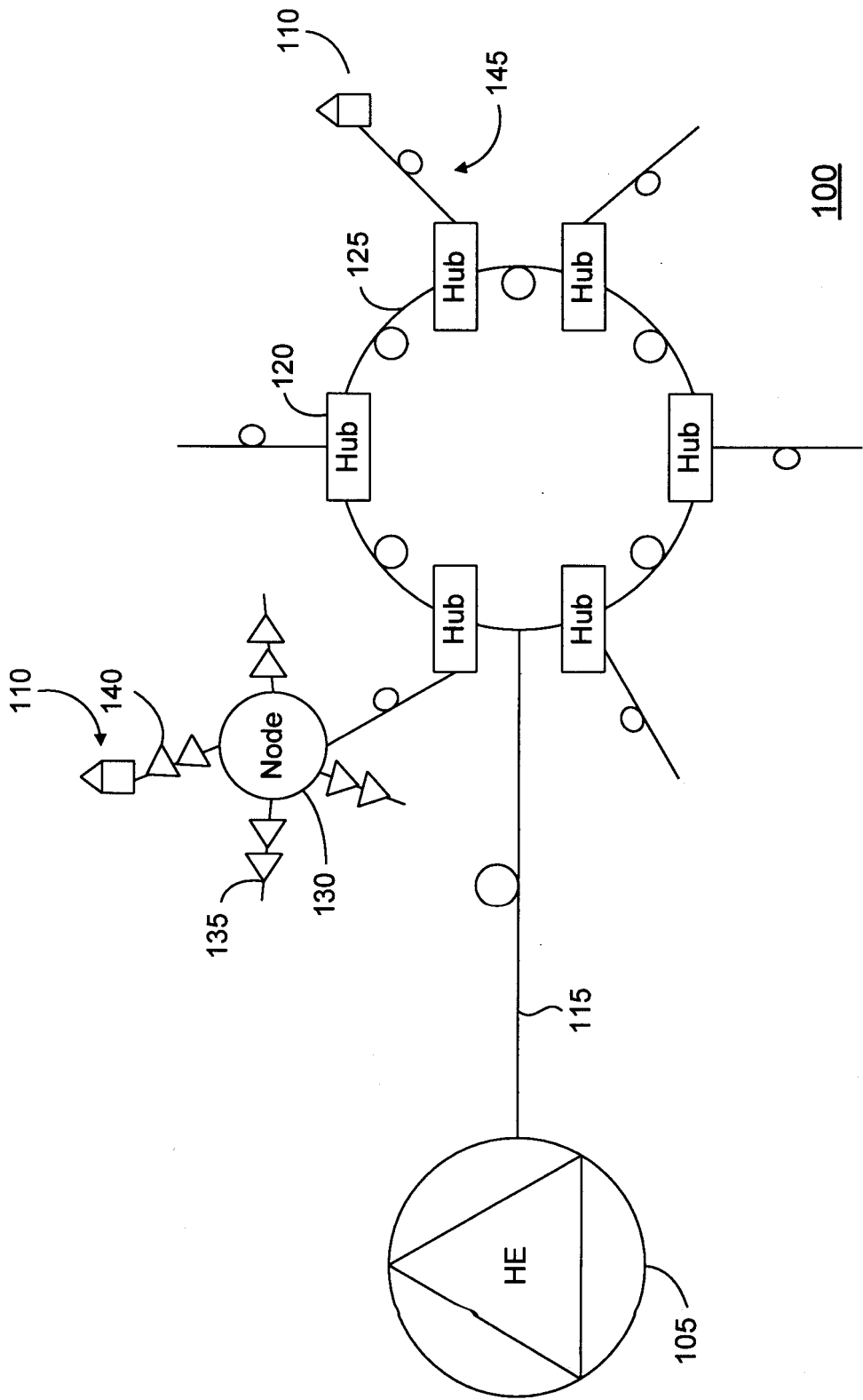


FIG. 1
Prior Art

200

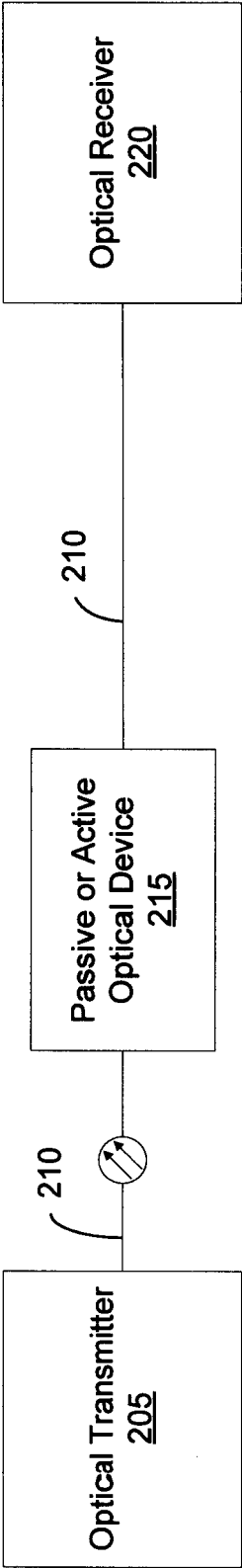


FIG. 2
Prior Art

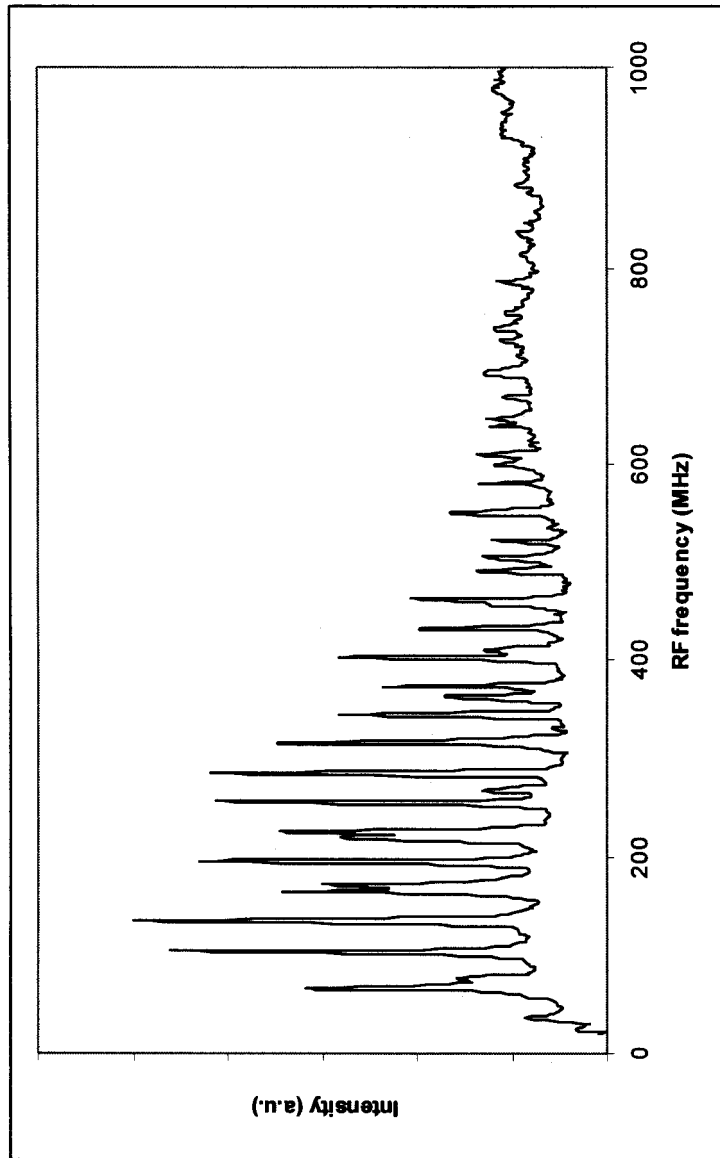
300

FIG. 3
Prior Art

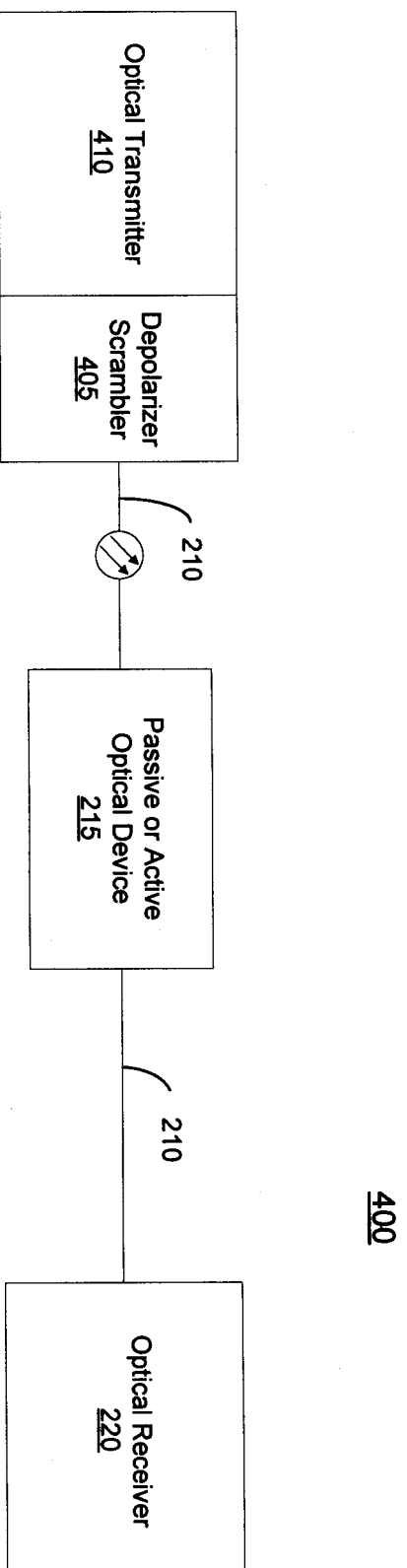


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2007/072118

A. CLASSIFICATION OF SUBJECT MATTER
 INV. H04B10/12 H04B10/18

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

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

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

EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 781 001 A (PIRELLI CAVI SPA [IT] CISCO SYSTEMS INTERNAT B V [NL]) 25 June 1997 (1997-06-25) column 1, line 21 - line 30 column 5, line 40 - line 46 column 6, line 6 - line 15 column 6, line 53 - line 58 figure 1 column 9, line 18 - line 36 -----	1-16
X	EP 0 792 069 A (GEN INSTRUMENT CORP [US]) 27 August 1997 (1997-08-27) column 5, line 43 - line 57; figure 2 ----- -/--	1-16

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

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

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

L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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

& document member of the same patent family

Date of the actual completion of the international search

14 November 2007

Date of mailing of the international search report

21/11/2007

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
 NL - 2280 HV Rijswijk
 Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
 Fax: (+31-70) 340-3016

Authorized officer

Cochet, Bertrand

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2007/072118

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 311 869 A (GEN INSTRUMENT CORP [US] GEN INSTRUMENT CORP [US]; GEN SEMICONDUCTOR I) 8 October 1997 (1997-10-08) page 5, line 3 - line 8 page 7, line 13 - line 26 page 8, line 4 - line 26 page 15, line 21 - line 29 page 25, line 21 - page 26, line 2 -----	1-16
X	HOWERTON M ET AL: "SBS Suppression Using a Depolarized Source for High Power Fiber Applications" JOURNAL OF LIGHTWAVE TECHNOLOGY, XX, XX, vol. 14, no. 3, March 1996 (1996-03), pages 417-422, XP011028442 ISSN: 0733-8724 page 417, left-hand column; figure 1 -----	1,3-16

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2007/072118

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 0781001	A	25-06-1997	AU 709120 B2	19-08-1999
			AU 7427096 A	26-06-1997
			BR 9604740 A	23-06-1998
			CA 2192635 A1	22-06-1997
			CN 1159688 A	17-09-1997
			DE 69631817 D1	15-04-2004
			DE 69631817 T2	17-03-2005
			IT MI952722 A1	23-06-1997
			JP 9200128 A	31-07-1997
			NZ 299898 A	19-12-1997
			US 5910852 A	08-06-1999
EP 0792069	A	27-08-1997	DE 69712943 D1	11-07-2002
			DE 69712943 T2	23-01-2003
			HK 1005284 A1	27-09-2002
			US 5699179 A	16-12-1997
GB 2311869	A	08-10-1997	HK 1029835 A1	31-08-2001
			HK 1005671 A1	16-03-2001
			US 5787211 A	28-07-1998