(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
11 November 2004 (11.11.2004)

PCT

(10) International Publication Number
WO 2004/098103 A1

(51) International Patent Classification[7]: H04B 10/18

(21) International Application Number: PCT/SG2003/000098

(22) International Filing Date: 29 April 2003 (29.04.2003)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant *(for all designated States except US)*: **AGENCY FOR SCIENCE, TECHNOLOGY AND RESEARCH** [SG/SG]; 10 Science Park Road, #01-01/03, The Alpha, Singapore Science Park II, Singapore 903031 (SG).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **LU, Chao** [CN/SG]; 8 Dover Rise #17-11, Heritage View, Singapore 138679 (SG). **LI, Zhihong** [CN/SG]; Block 926, #08-125, Jurong West Street 92, Singapore 640926 (SG). **CHEN, Jian** [CN/SG]; 83 Commonwealth Close, #16-181, Singapore 140083 (SG).

(74) Agent: **ELLA CHEONG MIRANDAH & SPRUSONS PTE LTD**; 111 North Bridge Road, #22-01 Peninsula Plaza, Singapore 179098 (SG).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

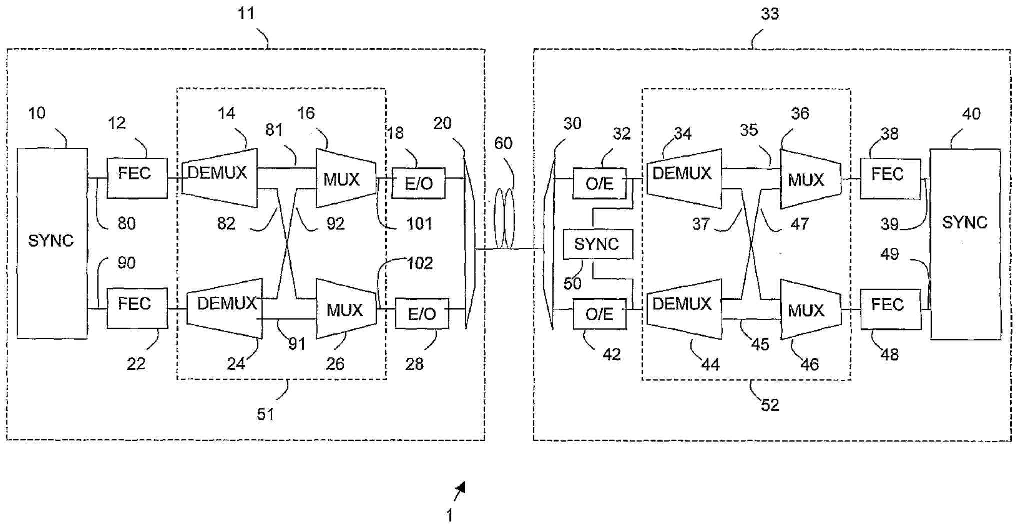
(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ,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

Declaration under Rule 4.17:
— *of inventorship (Rule 4.17(iv)) for US only*

Published:
— *with international search report*

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

(54) Title: A SYSTEM AND METHOD FOR MITIGATION OF POLARIZATION MODE DISPERSION IN OPTICAL SIGNALS



(57) Abstract: An embodiment is related to a system (1) using forward error correction (FEC) for mitigation or reduction of polarisation mode dispersion (PMD) effect of optical signals in an optical transmissive medium (60) by providing sufficient interleaving with wavelength diversity. An embodiment of the system having a tansmitter (11) and a receiver (33), each with a coder (12, 22, 38, 48) and interleaving sections (51, 52) for FEC coding/decoding and interleaving/de-interleaving, accordingly, to mitigate the effects of PMD.

WO 2004/098103 A1

A SYSTEM AND METHOD FOR MITIGATION OF POLARIZATION MODE DISPERSION IN OPTICAL SIGNALS

FIELD OF INVENTION

The invention generally relates to reduction or mitigation of a polarization mode dispersion (PMD) effect in optical signals, and more particularly, to utilizing wavelength diversity or interleaving for PMD effect mitigation in optical signals that are transmitted through, for example, optical fibre, optical isolators, optical couplers, and the like.

BACKGROUND

Polarization mode dispersion (PMD) is a statistical phenomenon caused by non-perfect circular geometry of the transmission fibre that causes a differential group delay (DGD) and random mode coupling between the two polarization modes inside a transmission optical fibre. PMD is one of the most important factors limiting the performance of a conventional high-speed optical communication system.

A number of solutions have been proposed for PMD mitigation. These include PMD compensation as discussed in the article Ono, et al., "Polarization Control Method for Suppressing Polarization Mode Dispersion Influence In Optical Transmission Systems", Journal of Lightwave Technology, Vol. 12, No. 5, pp. 891-898, May 1994; electronic equalization as discussed in the article Bülow et al., "Electronic PMD Mitigation-from Linear Equalization to Maximum-Likelihood Detection", Proc. OFC 2001, WAA1, 2001; and forward error correction (FEC) as discussed in the article Ho et al., "Performance Analysis of Optical Transmission System with Polarization-Mode Dispersion and

Forward Error Correction", IEEE Photonics Technology Letters, Vol. 9, No.9, September, 1997. pp. 1288-1290.

Existing PMD compensation techniques for example the techniques discussed by Ono et al., although effective in most of situations for first order PMD, are still too complicated to be used in practical systems. In addition, to date no effective compensation technique exists for higher order PMD. At the same time, electronic equalizer for example as discussed by Bülow et al., is still difficult to be implemented for high-speed optical communication systems.

Forward Error Correction (FEC) code, such as Reed-Solomon (255, 239), has been used in high-speed optical transmission systems. The FEC code improves the transmission quality by digital signal processing regardless of the physical origin of transmission degradations. However, as clearly indicated in Ho et al., due to the very long burst error caused by PMD, FEC has traditionally not been very effective for PMD mitigation since no sufficient practical electronic interleaving has been possible.

In addition to PMD compensation techniques and electronic equalization, FEC has been proposed for PMD mitigation. In such a scheme, standard Reed-Solomon code (256, 239) with 7% data rate expansion and 8-byte error correction capability is typically used for data transmission. FEC has proven to be effective for high-speed optical transmission system affected by noise and nonlinearity, however, FEC has shown limited effectiveness for PMD mitigation.

Polarization scrambling and wavelength division multiplexing (WDM) redundancy with FEC have been proposed to enhance PMD mitigation as discussed in the respective articles Wedding et al., "Enhanced PMD Mitigation by Polarization

Scrambling and Forward Error Correction", Proc OFC 2001, WAA3, 2001, and Penninckx et al., "WDM Redundancy to Counteract PMD Effects in Optical Systems", Proc ECOC 2001, pp. 444-445, 2001.

Although a number of PMD compensators have been demonstrated, they are complicated and expensive to be used in practical systems. In addition, the difficulty in controlling different elements of a PMD compensator means that it may often be trapped in a local optimum thus limits its effectiveness for high order PMD compensation. Electronic equalization has been proven to have limited effect when DGD value is large as discussed by Bülow et al. Electronic equalization also has been difficult to be implemented for high-speed optical communication system where the effect of PMD is most severe. Although FEC has been proposed for PMD mitigation, effectiveness has been limited, which is mainly due to the slow time rate of change of PMD.

PMD fluctuation takes place in a timescale of minutes or hours, and the fastest rate of PMD fluctuation has been measured to be greater than 1ms as cited by another article by Bülow, et al., "Measurement of the Maximum Speed of PMD Fluctuation in Installed Field Fiber", Optical Fibre Communications Conference, OFC 1999, Technical Digest WE4 pp. 83-85. For example, for a 40Gbps transmission system, according to this result of Bülow, et al., at least 4×10^{10} bits will be affected if a large DGD value appears.

This will result in a long burst error in the transmission system. Effectively, all the bits in a FEC frame will experience the same amount of DGD. No electronic interleaving with the commonly used Reed-Solomon code (256, 239) is possible to correct such a long burst error. Polarization scrambling may reduce the burstness of the error and thus enable the operation of the FEC. However, very high speed polarization scramblers are needed. For the scheme using WDM redundancy, extra channels are required for PMD mitigation thus reducing the transmission efficiency.

There is thus a need for the use of a wavelength diversity scheme to achieve interleaving over multiple wavelengths, and an effective way for using FEC to reduce the effect of PMD in high-speed optical transmission system.

SUMMARY

An aspect of the invention provides a system for reducing polarization mode dispersion effect in optical signals in optical transmissive medium, the system comprising a transmitter means for transmitting an optical signal through the optical transmissive medium; and a receiver means for receiving the optical signal from the optical transmissive medium, wherein the transmitter means and receiver means comprise a coder means and an interleaving means, wherein the signal is encoded by coder means in the transmitter means, and the signal is decoded by coder means in the receiver means, of frames on at least two channels, each channel having at least two portions of the frames, and a portion of frames of one channel is interleaved by interleaving means with a portion of frames of another channel to reduce the effect of polarization mode dispersion effect on the optical signal.

An embodiment provides the interleaving means further comprising at least two demultiplexers and at least two multiplexers for interleaving a portion of the frames of the signal from one channel with a portion of the frames of the signal from another channel. The transmitter means and the receiver means

may further comprise a synchroniser to synchronise the timing of the signal on each channel. The forward error correction code may be Reed-Solomon code (255,239). Additionally, the channels may have a channel spacing of at least $6\Delta\nu_{PMD}$ where $\Delta\nu_{PMD}$ is polarization mode dispersion frequency bandwidth. The each portion of frames on each channel may be substantially the same size. The optical transmissive medium is optical fibre.

Another aspect of the invention provides a method for reducing polarization mode dispersion effect in optical signals in optical transmissive medium, the method comprising transmitting from a transmitter means an optical signal through the optical transmissive medium, and receiving at a receiver means the optical signal from the optical transmissive medium, wherein the transmitter means and receiver means comprise a coder means and an interleaving means, wherein the signal is encoded by coder means in the transmitter means, and the signal is decoded by coder means in the receiver means, of frames on at least two channels, each channel having at least two portions of the frames, and a portion of frames of one channel is interleaved by interleaving means with a portion of frames of another channel to reduce the effect of polarization mode dispersion effect on the optical signal.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, objects and advantages of embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, in conjunction with drawings, in which:

FIG.1 shows a schematic diagram of a forward error correction (FEC) system with interleaving in accordance with an embodiment of the invention;

FIG.2 shows a graph of the required receiver Q factor to achieve a bit error rate (BER) of 10^{-12} as a function of polarization mode dispersion (PMD) under from different activations in accordance with an embodiment of the invention;

FIG. 3 shows a schematic block diagram of wavelength interleaving in accordance with an embodiment of the invention; and

FIG. 4 shows a graph of output v input BER of FEC with optical interleaving in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

A system 1 in accordance with an embodiment with four wavelengths, that is two wavelengths for each channel is shown in FIG 1. Of course, it will be appreciated that the system may be for any number of n wavelengths, with n being an integer greater than 1. However, for simplicity and for sake of clarity, the embodiment of two wavelengths is discussed in detail. The system 1 of FIG. 1 shows a schematic block diagram of a FEC system with interleaving. For example the system comprises a transmitting section 11 and a receiving section 33 connected via an optical transmissive medium, such as optical fiber 60. It will be appreciated that other embodiments may be configured with other optical transmissive mediums such as optical isolators, optical couplers, and the like, where PMD effects may be found.

The transmitting means or section 11 may receive a signal to transmit that is divided into signal parts in channels 80,90. Synchronizer 10 such as synchronous digital hierarchy (SDH) synchronizes each signal part in each channel. Each signal part is FEC encoded by FEC encoders 12,22 prior to an interleaving section 51. Interleaving section 51 then interleaves each of the signal parts in each channel by λ_1 81,91 and λ_2 82,92 with, for example, demultiplexers 14,24 such as time division multiplexing: demultiplexing (DEMUX) 14,24 and multiplexers 16,26 such as time division multiplexing: multiplexing (TDM-MUX) 16,26 which interleaves the channels, by λ_1 81,91 and λ_2 82,92, such that λ_1 81 of channel 1 is interleaved with λ_2 92 of channel 2, and λ_2 82 of channel 1 is interleaved with λ_1 91 of channel 2, to form the interleaved signal of channel 1 (one) 101 and channel 2 (two) 102, also shown in greater detail in FIG. 3 and discussed in greater detail below. After interleaving the signals of channel 1 and 2 are converted from electrical to optical via converter (E/O) 18,28, and transmitted to optical fiber 60 from optical multiplexer 20.

The receiving means or section 52 receives the signal from fiber 60 at optical demultiplexer 30 and divides the received signal into signal parts to channels for each part to be converted by converter (O/E) 32,42 for conversion of optical to electrical signals that are synchronized by synchronizer 50 prior to interleaving section 52. Interleaving section 52 receives the signal parts in the two channels at demultiplexers (DEMUX) 34,44. Interleaving section 51 then interleaves each of the signal parts in each channel by λ_1 35,45 and λ_2 37,47 with, for example, demultiplexers 34,44 such as time division multiplexing: demultiplexing (DEMUX) 34,44 and multiplexers 36,46 such as time division multiplexing: multiplexing (MUX) 36,46 which interleaves the channels, by λ_1 35,45 and λ_2 37,47, such that λ_1 35 of channel 1 is interleaved with λ_2 47 of channel 2, and λ_2 37 of channel 1 is interleaved with λ_1 45 of channel 2, to form the interleaved signal of channel 1 (one) and channel 2 (two), in a similar manner as discussed above. After interleaving the signals of channel 1 and 2 are FEC de-encoded by encoders 38,48 to provide de-encoded signals 39,48 of the channels. The channel de-encoded signals are synchronized by synchronizer 40 to provide the received signal. It will be appreciated that various configurations are possible to transmit and receive with the same or different channel/wavelength configuration, for example it may be possible to transmit with two channels/four wavelengths configuration, and receive in grater than two channels (n-channels)/four wavelengths (n-wavelengths), and vice versa.

In embodiments of the invention, forward error correction (FEC) can be used as an effective way for polarisation mode dispersion (PMD) mitigation if sufficient interleaving can be achieved. Here, wavelength diversity is used to achieve the interleaving. This is based on the fact that the PMD statistics is independent for two wavelength channels if their wavelength separation is larger than at least six times of the PMD bandwidth. It will be appreciated that the wavelength separation is not required to be larger than at least six times, and the wavelength separation may be less than at least six wavelengths. However, larger than at least six times will yield a more predictable performance. As a result, the probability that both wavelength channels have a large differential grouping display (DGD) value is much smaller than the probability that a single wavelength have a large DGD value. PMD bandwidth is given as described Jopson, et al., "Measurement of Second Order PMD Vectors in Optical Fibres", IEEE Photonics Technology Letters, Vol. 11, No. 9, September 1999, pp. 1153-1155, as:

$$\Delta \nu_{PMD} = \frac{1}{8\langle \Delta \tau \rangle}$$

Where $\Delta\nu$ is PMD frequency bandwidth and $<\Delta\tau>$ is the mean DGD value.

For example for a typical or average requirement of $<\Delta\tau> < 0.1T_{bit}$, for a 40Gbps system, then $<\Delta\tau> < 2.5$ps which corresponds to $\Delta\nu_{PMD} = 50$GHz. As a result, for wavelength channels $6\Delta\nu_{PMD} = 300$GHz apart, PMD statistics of the two wavelength channels can be considered independent.

For larger than average DGD value ($<\Delta\tau>$), the bandwidth will be even smaller. If part of the data is transmitted in a FEC frame in one wavelength channel and the other parts of the data are transmitted in other wavelength channels, the error burst length can be effectively reduced and the effectiveness of FEC can be improved.

For example, as shown in FIG. 3, there are two wavelength channels, channel 1 (one) 80,101 and channel 2 (two) 90,102. Each channel has λ_1 81,91 and λ_2 82,92 with channel spacing, and in this instance the channel spacing is greater than $6\Delta\nu_{PMD}$. In this embodiment, half of the coded FEC, in this example Reed-Solomon code(255,239), frame for channel 1 80 is transmitted on λ_1 and the other half of the frame is transmitted on λ_2, similarly transmit half of the data frame for channel 2 90 on λ_2 and half on λ_1, in this way, interleaving is achieved in wavelength space. Of course, the FEC coded signal may be divided in any arrangement, and the half-half arrangement is merely and example. Additionally, FEC codes other than Reed-Solomon include, for example, cyclic code, Bose Chadhuri Hocquenghem

(BCH) code, concatenated code, turbo code, and convolution code. The interleaving approach to reduce PMD effect in optical signals may be applied to all FEC codes, and in particular FEC codes that are able to correct burst errors.

In a preferred embodiment, the all wavelengths occupy 1/n frame, where n is the number of wavelengths. At a receiver, after optical detection, data on λ_1 and λ_2 for channel one 101 and channel two 102 is combined. It will be appreciated that this technique can easily be generalized to the case of multiple wavelengths with expected better performance.

In studying the performance a two wavelength system, the bit error rate (BER) for a system using wavelength interleaving and FEC is:

$$BER = \int_0^\infty \int_0^\infty p_{\langle\Delta\tau\rangle}(\Delta\tau_1) p_{\langle\Delta\tau\rangle}(\Delta\tau_2) p_{FEC}\left(\frac{p_e(Q,\Delta\tau_1) + p_e(Q,\Delta\tau_2)}{2}\right) d\Delta\tau_1 d\Delta\tau_2$$

Where $p_e(Q,\Delta\tau)$ is the BER for a system with signal to noise ratio Q and DGD value of $\Delta\tau$ and $p_{\langle\Delta\tau\rangle}(\Delta\tau_1)$ is the probability of DGD has a value of $\Delta\tau_1$ and mean value of $\langle\Delta\tau\rangle$. It follows a Maxwellian probability density function, and $p_{FEC}(p)$ is the output error probability though the use of FEC with a input error probability of p.

The BER for the system is shown in FIG. 2, compared with systems with no FEC applied 72, FEC applied without interleaving 74, FEC applied with interleaving technique 76, and with ideal interleaving 78. The BER output represented by representations of no-interleaving 72,74 and with ideal, non-practical interleaving 78 are discussed by Ho et al. With no FEC 72, FEC with no interleaving given as reference 74, clearly, improved performance is obtained when FEC is applied with interleaving 76.

In greater detail, curve 72 shows the tolerance of PMD when no FEC technique is applied. PMD tolerance is approximately $0.2T_{bit}$, if $<\tau> > 0.2T_{bit}$, regardless of the value of Q, performance is limited. For example to realize BER $< 10^{-12}$, the minimum Q value required is about 17, which is difficult to achieve in common optical transmission systems.

Curve 74 shows the situation after FEC without interleaving technique is applied. Although there is little improvement of tolerance of PMD, the minimum Q value required to achieve BER $< 10^{-12}$ is sharply decreased to approximately 8.

Curve 78 shows an ideal case where FEC with full or infinite interleaving is applied. There is great improvement to the PMD tolerance, however, this technique is not practical to implement.

Shown in FIG. 2, curve 76 is the results shown for an embodiment of the invention, corresponding to the two-wavelength diversity technique with FEC. It is shown that the PMD tolerance is increased by $0.25T_{bit}$, which may improve if the number of wavelengths is increased in wavelength diversity. It should be noted that PMD will not automatically increase with an increase of wavelengths used, rather the value of PMD may change randomly for different wavelength channels.

In FIG. 4, region 112 is the region that transmitted signal is not acceptable when FEC is not used, because the BER is higher than an acceptable level, for example when BER is approximately 10^{-9}. The transmission is acceptable when FEC modules are used, because BER will typically be lower than 10^{-9}. Region 110 is the region where the transmitted signal may be acceptable if FEC is used with optical interleaving. Thus, when FEC is used in the system, interleaving improves the region of acceptable transmission signals.

The embodiments offer PMD mitigation through the use of wavelength interleaving, that is compatible with existing high speed optical communication systems while the data rate is maintained. The interleaved wavelengths can be transmitted and add/drop together as a wavelength bundle. For example, for a 32 wavelength system with 4 wavelength interleaving, 8 wavelength bundles can be formed. This compares favourably with the wavelength redundancy scheme where all the 32 wavelengths have to be transmitted and add/drop together.

Another embodiment may comprise 32 wavelengths with 2 wavelength interleaving. In such an arrangement, 16 wavelength bundles are formed, and 2 wavelengths may be added are dropped together at anytime. The add/drop feature of any wavelength may be added or dropped together in a wavelength bundle. The wavelength bundle refers to a group of wavelengths are transmitted and received together. For example for a 32 wavelength system with 4 wavelength interleaving, using wavelengths 1,9,17,25, these four wavelengths form a bundle. The bundle of four wavelengths then may be transmitted, received and add or drop together. It will be appreciated that interleaving that is done in the electrical domain may form part of the feature of standard FEC to reduce the effect of dispersion and noise. However, interleaving in the electric domain does not and cannot provide a practical solution to solve PMD problem since at any wavelength the effect of PMD to every bits in a FEC frame is the same. An embodiment of the invention solves this problem using wavelength interleaving in optical domain since the PMD statistics for different wavelengths are different.

In the foregoing manner, a system and method for reducing polarization mode dispersion (PMD) effect in optical signals is disclosed. Only several embodiments are described. However, it will be apparent to one skilled in the art in view of this disclosure that numerous changes and/or modifications may be made without departing from the scope of the invention.

CLAIMS:

1. A system for reducing polarization mode dispersion effect in optical signals in optical transmissive medium, the system comprising:
a transmitter means for transmitting an optical signal through the optical transmissive medium; and
a receiver means for receiving the optical signal from the optical transmissive medium, wherein the transmitter means and receiver means comprise a coder means and an interleaving means, wherein the signal is encoded by coder means in the transmitter means, and the signal is decoded by coder means in the receiver means, of frames on at least two channels, each channel having at least two portions of the frames, and a portion of frames of one channel is interleaved by interleaving means with a portion of frames of another channel to reduce the effect of polarization mode dispersion effect on the optical signal.

2. A system of claim 1 wherein the interleaving means further comprising at least two demultiplexers and at least two multiplexers for interleaving a portion of the frames of the signal from one channel with a portion of the frames of the signal from another channel.

3. A system of claim 1 or 2 wherein the transmitter means and the receiver means further comprising a synchroniser to synchronise the timing of the signal on each channel.

4. A system of any preceding claim wherein the forward error correction code is Reed-Solomon code (255,239).

5. A system of any preceding claim wherein the channels have a channel spacing of at least $6\Delta\nu_{PMD}$ where $\Delta\nu_{PMD}$ is polarization mode dispersion frequency bandwidth.

6. A system of any preceding claim wherein the each portion of frames on each channel substantially the same size.

7. A system of any preceding claim wherein the optical transmissive medium is optical fibre.

8. A method for reducing polarization mode dispersion effect in optical signals in optical transmissive medium, the method comprising:
transmitting from a transmitter means an optical signal through the optical transmissive medium; and
receiving at a receiver means the optical signal from the optical transmissive medium, wherein the transmitter means and receiver means comprise a coder means and an interleaving means, wherein the signal is encoded by coder means in the transmitter means, and the signal is decoded by coder means in the receiver means, of frames on at least two channels, each channel having at least two portions of the frames, and a portion of frames of one channel is interleaved by interleaving means with a portion of frames of another channel to reduce the effect of polarization mode dispersion effect on the optical signal.

9. A method of claim 8 wherein the interleaving means further comprising at least two demultiplexers and at least two multiplexers for interleaving a portion of the frames of the signal from one channel with a portion of the frames of the signal from another channel.

10. A method of claim 8 or 9 wherein the transmitter means and the receiver means further comprising a synchroniser to synchronise the timing of the signal on each channel.

11. A method of any of claims 8-10 wherein the forward error correction code is Reed-Solomon code (255,239).

12. A method of any of claims 8-11 wherein the channels have a channel spacing of at least $6\Delta\nu_{PMD}$ where $\Delta\nu_{PMD}$ is polarization mode dispersion frequency bandwidth.

13. A method of any of claims 8-12 wherein the each portion of frames on each channel substantially the same size.

14. A system of any of claims 8-13 wherein the optical transmissive medium is optical fibre.

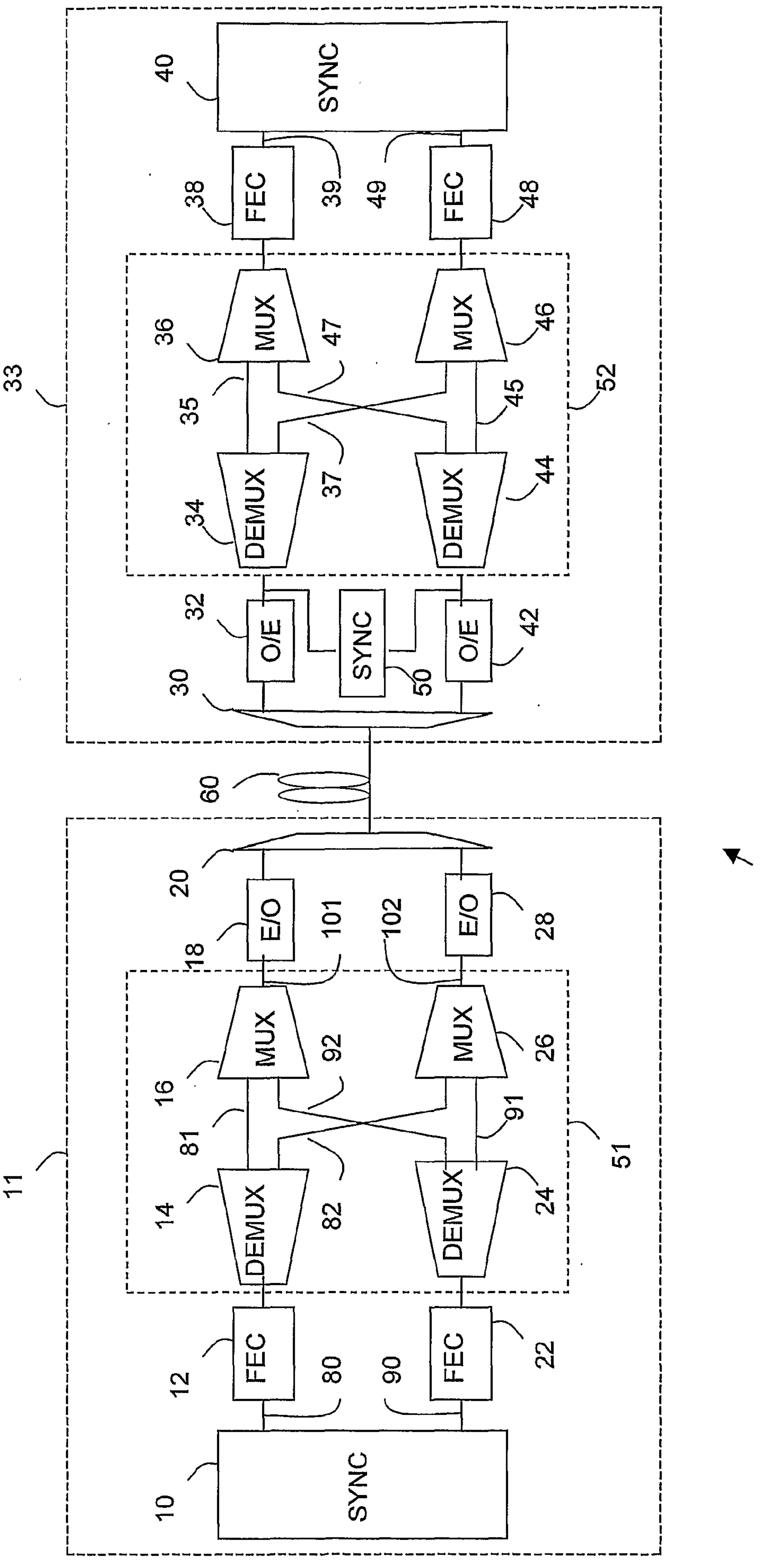

SYNC
FEC
FEC
MUX
MUX
DEMUX
DEMUX
O/E
O/E
SYNC
E/O
E/O
MUX
MUX
DEMUX
DEMUX
FEC
FEC
SYNC
1
10
11
12
14
16
18
20
22
24
26
28
30
32
33
34
35
36
37
38
39
40
42
44
45
46
47
48
49
50
51
52
60
80
81
82
90
91
92
101
102

FIG. 1

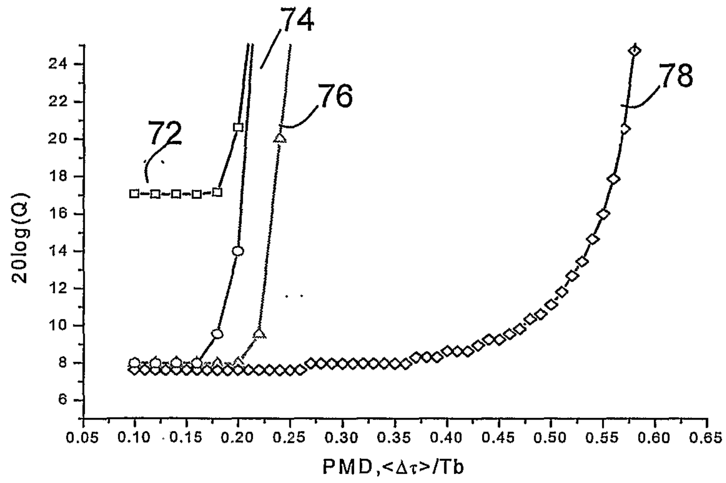


FIG. 2

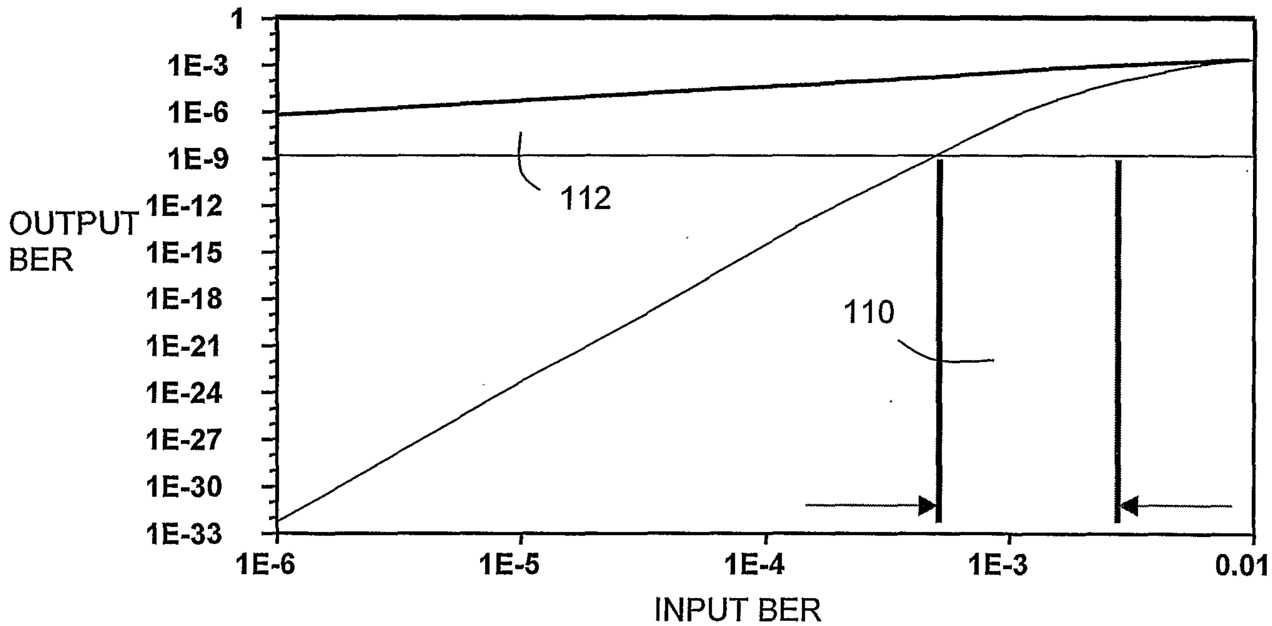
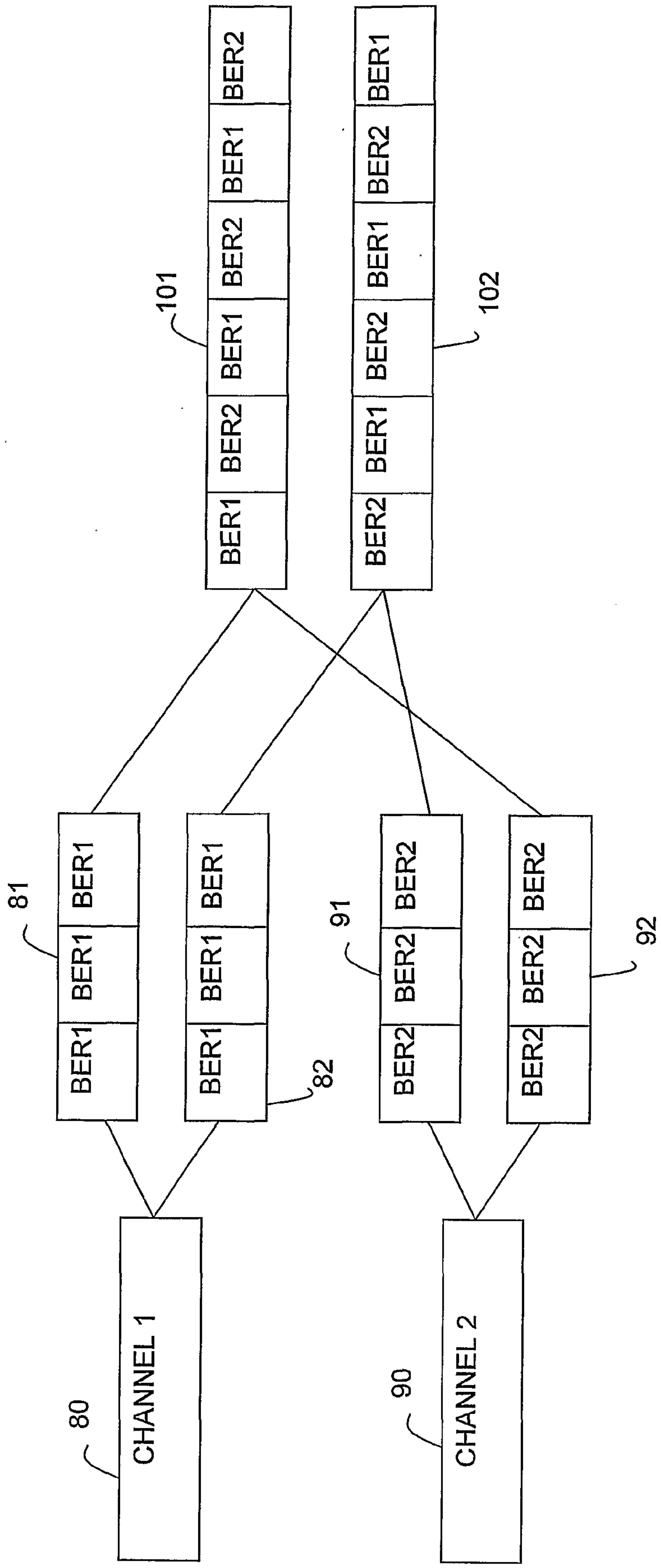


FIG. 4



BER2
BER1
BER2
BER1
BER2
BER1
BER1
BER2
BER1
BER2
BER1
BER2
101
102
BER1
BER1
BER1
BER1
BER1
BER1
BER2
BER2
BER2
BER2
BER2
BER2
81
82
91
92
CHANNEL 1
CHANNEL 2
80
90

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG03/00098

A.	**CLASSIFICATION OF SUBJECT MATTER**
Int. Cl. [7]:	H04B 10/18
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)	
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched	
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) WPAT (optical, frame, interleaving, polarization mode dispersion, code)	
C.	**DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6437892 B1 (Fang et al.) 20 August 2002 Column 5, line 38-column 6, line 26	1-14
A	US 6529307 B1 (Peng et al.) 4 March 2003 The whole document	

☐ 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 application or patent 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 6 June 2003	Date of mailing of the international search report 16 JUN 2003
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized officer **J. Law** Telephone No : (02) 6283 2179

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG03/00098

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member
US	6437892	NONE
US	6529307	NONE

END OF ANNEX