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CLERK U.S. DISTRICT COURT
CENTRAL DIST. OF CALIF.
SANTA ANA
BY ________

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[Additional Counsel Listed on Signature Page]

UNITED STATES DISTRICT COURT
CENTRAL DISTRICT OF CALIFORNIA

LABYRINTH OPTICAL TECHNOLOGIES LLC

Plaintiff,

vs.

FUJITSU NETWORK COMMUNICATIONS, INC.

Defendant.

CASE NUMBER:

8:13-cv-00030-AG-MLG

FIRST AMENDED COMPLAINT FOR PATENT INFRINGEMENT; DEMAND FOR JURY TRIAL

DATE: June 6, 2013

Plaintiff Labyrinth Optical Technologies LLC ("Labyrinth") files this action for infringement of United States Patent No. 8,103,173 ("the '173 patent") against Defendant Fujitsu Network Communications, Inc. ("Fujitsu"), seeking damages and injunctive relief. Labyrinth alleges as follows:

JURISDICTION AND VENUE

1. This is an action for patent infringement arising under the Patent Laws of the United States, 35 U.S.C. § 1 et seq., alleging infringement of United States

Patent No. 8,103,173 ("the '173 patent"). A copy of the patent is attached hereto as **Exhibit A** and is incorporated herein by reference in its entirety.

2. This Court has exclusive subject matter jurisdiction over this action under 28 U.S.C. §§ 1331 and 1338(a).

3. This Court has personal jurisdiction over Fujitsu because it has conducted business in this district and has infringed, contributed to the infringement, and/or actively induced others to infringe Labyrinth's patent in this district as alleged in this Complaint (at a minimum by offering for sale and/or selling products which fall within the scope of the claims of the '173 patent).

4. Moreover, upon information and belief, Fujitsu continues to conduct business in this district and infringes, contributes to the infringement of, and/or actively induces others to infringe the '173 patent in this district.

5. Venue is proper in this Court pursuant to 28 U.S.C. §§1391(b), 1391(c) and/or 1400(b), in that a substantial part of the events giving rise to Labyrinth's claims occurred in the Central District of California and Fujitsu is subject to personal jurisdiction in the Central District of California (and thus for purposes of venue Defendant resides in the Central District of California).

THE PARTIES

6. Plaintiff Labyrinth is a limited liability company organized and existing under the laws of California, and having a principal place of business at 500 Newport Center Drive, 7th Floor, Newport Beach, California 92660.

7. Upon information and belief and after a reasonable opportunity for further discovery, Fujitsu Network Communications, Inc. is a corporation organized and existing under the laws of the state of California, having a principal place of business at 1250 E Arques Ave. M/S 124, Sunnyvale, CA 94085.

Fujitsu's registered agent for service of process in the State of California is C T Corporation System, 818 W. Seventh St., Los Angeles, CA, 90017.

THE PATENT IN SUIT

8. In optical data communications, systems were upgraded from a 10 Gb/s data transmission rates to a 40 Gb/s transmission rates. Data transmission rates at the much faster 40 Gb/s (or higher) presented extensive design challenges because the effects of polarization mode dispersion (PMD), chromatic dispersion and fiber non-linear effects such as cross-phase modulation become more dominant at the higher transmission rates.

9. The inventors of the patent-at-issue were driven to find a cost-effective method and system that compensates for PMD, optimizes signal to noise ratio performance and minimizes phase noise and nonlinearities (e.g., chromatic dispersion) associated with transmission over fiber at high data transmission rates.

10. The '173 patent entitled "Method and System For A Polarization Mode Dispersion Tolerant Optical Homodyne Detection System With Optimized Transmission Modulation" was duly and legally issued on January 24, 2012.

11. The assignee of the exclusive patent rights for the '173 patent is Labyrinth.

12. The '173 patent is valid and enforceable and has been at all times relevant to the instant action.

13. The '173 patent claims a system and method for coherent optical detection for an optimized transmission modulation.

14. For example, claim 1 of the '173 patent provides:

> (1) A method of compensating a quadrature modulated optical data signal for effects of chromatic dispersion occurring during transmission over optical fiber, the method comprising the steps of:

> (a) separating in-phase and quadrature components of the optical data signal;
>
> (b) optoelectrically converting the in-phase and quadrature components of the optical data signal into in-phase and quadrature data signals;
>
> (c) applying a corrective function to the in-phase and quadrature data signals, the corrective function modifying the in-phase and quadrature data signals in a manner that precisely counteracts effects of chromatic dispersion on the in-phase and quadrature components of the optical data signal.

’173 patent, Col. 12, ln. 42-56.

THE INFRINGING PRODUCT

15. Fujitsu manufactures, uses, offers for sale, or sells within the United States at least the FLASHWAVE 7500, FLASHWAVE 9500, and the 100 GE CFP transceivers that fall within the claims of the ’173 patent.

16. For purposes of example only, the FLASHWAVE 7500, FLASHWAVE 9500, and the 100 GE CFP transceivers fall within the scope of at least claim 1 of the ’173 patent as they meet each limitation recited therein. The FLASHWAVE 7500, FLASHWAVE 9500, and the 100 GE CFP transceivers have receivers that separate the in-phase and the quadrature components of the optical data signal upon reception, optoelectrically convert the in-phase and quadrature components of the optical data signal into in-phase and quadrature data signals, and apply a corrective function to the in-phase and quadrature data signals, which modifies the in-phase and quadrature data signals that precisely counteracts effects of chromatic dispersion on the optical data signal.

17. Fujitsu does not have a license or other authorization to practice the claims set forth in the '173 patent.

COUNT I

Fujitsu's Patent Infringement Under 35 U.S.C. § 271 of the '173 Patent

18. Labyrinth incorporates by reference the allegations of paragraphs 1-17.

19. Fujitsu has directly infringed the '173 patent at a minimum by making, using, selling and offering for sale products that falls within the scope of the '173 patent and have no substantial non-infringing uses, including, but not limited to, the FLASHWAVE 7500, FLASHWAVE 9500, and the 100 GE CFP transceivers.

20. Fujitsu has also contributorily infringed the '173 patent and induced infringement of the '173 patent after the filing of the initial complaint.

21. Fujitsu was aware of the '173 patent *at minimum* after the filing of the initial complaint.

22. Fujitsu has caused and will continue to cause Labyrinth substantial damage and irreparable injury by virtue of its continuing infringement.

23. Despite knowledge of the patent and its infringement, Fujitsu continues to make the FLASHWAVE 7500, FLASHWAVE 9500, and the 100 GE CFP transceivers available to its customers.

24. In addition, Fujitsu encourages its customers to use the FLASHWAVE 7500, FLASHWAVE 9500, and the 100 GE CFP transceivers in an infringing manner, even after it learned of the patent in suit.

25. When a Fujitsu customer utilizes the FLASHWAVE 7500, FLASHWAVE 9500, and the 100 GE CFP transceivers as designed and intended,

that customer infringes the '173 patent by meeting each claim element of at least claim 1.

26. Upon information and belief, Fujitsu includes instructions which instruct its customers how to utilize the infringing products; when carried out, such actions constitute direct infringement on the part of the customers, and the customer cannot use the products in any substantially non-infringing way.

27. As shown in Fujitsu's datasheets and made available at its website, Fujitsu still advertises that its FLASHWAVE 7500 utilizes dual polarization quadrature phase shift keying (referred to as DP-QSPK) modulation and coherent optical receiver to improve the performance of high polarization mode dispersion fibers in a manner that infringes the '173 patent. **Exhibit B.** When used by a customer, the FLASHWAVE 7500 infringes the '173 patent.

28. As shown in the Fujitsu's datasheets and made available at its website, the FLASHWAVE 9500 operates in a similar infringing manner with similar infringing technology such that the transponders and muxponders from either the 7500 or 9500 platforms can be mixed and matched over a common network. **Exhibit B.** When used by a customer, the FLASHWAVE 9500 infringes the '173 patent.

29. As shown in Fujitsu's press release and made available at its website, Fujitsu's 100 GE CFP transceivers use 100G DP-QPSK LN modulators and integrated receivers in a manner that infringes the '173 patent. **Exhibit C.** When used by a customer, Fujitsu's 100GE CFP transceivers infringe the '173 patent.

30. Upon information and belief, since these products compensate for chromatic dispersion as taught by the '173 patent, when used as intended and as instructed, there are no substantial non-infringing uses.

31. Fujitsu has caused and will continue to cause Labyrinth substantial damage and irreparable injury by virtue of its continuing infringement.

32. Labyrinth is entitled to recover from Fujitsu the damages sustained by Labyrinth as a result of their wrongful acts in an amount subject to proof at trial and an injunction preventing Fujitsu from continuing its wrongful acts.

WHEREFORE, Labyrinth respectfully requests that the Court enter a judgment as follows:

A. That Fujitsu has infringed the '173 patent under 35 U.S.C. § 271;

B. Permanently enjoining and restraining Fujitsu, its officers, directors, agents, servants, employees, licensees, successors, assigns, those in concert and participation with them, and all persons acting on its behalf or within its control under 35 U.S.C. § 283 from further acts that infringe the '173 patent, including but not limited to, making, using, selling, offering to sell, importing, exporting, advertising, or otherwise using, contributing to the use of, or inducing the use of all infringing products produced by Fujitsu;

C. Requiring Fujitsu to:

1. Send a copy of any decision in this case in favor of Labyrinth to each person or entity to whom Fujitsu has sold or otherwise distributed any products found to infringe the '173 patent, or induced to infringe the '173 patent, and informing such persons or entities of the judgment and that the sale or solicited commercial transaction was wrongful;

2. Recall and collect from all persons and entities that have purchased wholesale or are a distributor of any and all products found to infringe the '173 patent that were made, offered for sale, sold, or otherwise distributed by Fujitsu, or anyone acting on its behalf;

3. Destroy or deliver to Labyrinth all infringing products produced by Fujitsu; and

4. File with the Court and serve upon Labyrinth, within thirty (30) days after entry of final judgment in this case, a report in writing and subscribed under oath setting forth in detail the form and manner in which Fujitsu has complied with the Court's orders as prayed for.

D. Awarding Labyrinth patent infringement damages and pre-judgment interest pursuant to 35 U.S.C. § 284 including, but not limited to, lost profits and/or a reasonable royalty;

E. Declaring the case exceptional and awarding Labyrinth reasonable costs and attorney fees pursuant to 35 U.S.C. § 285;

F. Granting Labyrinth such other and further relief as justice and equity may require.

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JURY DEMAND

Labyrinth requests a jury trial.

Respectfully submitted,
Labyrinth Optical Technologies LLC

By its attorneys,
SIMMONS BROWDER GIANARIS
ANGELIDES & BARNERD LLC

Dated: June 6, 2013

By:

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CERTIFICATE OF SERVICE

Labyrinth Optical Technologies LLC v. Fujitsu Network Communications, Inc.; Case No. 8:13-cv-00030-AG-MLG

I am over eighteen years of age and not a party to the within action; my business address is 100 N. Sepulveda Boulevard, Suite 1350, El Segundo, California, 90245. I am employed in Los Angeles County, California.

On June 6, 2013, I served the following documents:

FIRST AMENDED COMPLAINT FOR PATENT INFRINGEMENT; DEMAND FOR JURY TRIAL

______ BY PERSONAL SERVICE as follows: I caused such envelope(s) to be delivered by hand to the addressee(s) at the address set forth below.

XX___ BY MAIL as follows: by placing the document(s) listed above in a sealed envelope with postage thereon fully prepaid, in the United States mail at Los Angeles, California addressed as set forth below.

_XX_____BY EMAIL as follows: by transmitting via the document(s) listed above the email address(es) set for the below on this date before 5:00 p.m.

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Attorneys for Defendant Fujitsu Network Communications, Inc.

I am readily familiar with the firm's practice of collection and processing correspondence for mailing. Under that practice it would be deposited with the U.S. Postal Service on that same day with postage thereon fully prepaid at El Segundo, California in the ordinary course of business. I am aware that on motion of the party served, service is presumed invalid if postal cancellation date or postage meter date is more than one day after the date of deposit for mailing in this affidavit.

I declare under penalty of perjury under the laws of the State of California that the foregoing is true and correct.

Federal: I declare that I am employed in the office of a member of the bar of this court at whose direction service was made.

Executed on June 6, 2013, at El Segundo, California.

Tiffany Kelly

EXHIBIT A

US008103173B2

(12) **United States Patent**
Schemmann et al.

(10) **Patent No.: US 8,103,173 B2**
(45) **Date of Patent: *Jan. 24, 2012**

(54) **METHOD AND SYSTEM FOR A POLARIZATION MODE DISPERSION TOLERANT OPTICAL HOMODYNE DETECTION SYSTEM WITH OPTIMIZED TRANSMISSION MODULATION**

(75) Inventors: **Marcel F. C. Schemmann**, Maria-Hoop (NL); **Zoran Maricevic**, Manlius, NY (US); **Antonije R. Djordjevic**, Belgrade (YU); **Darby Racey**, Cicero, NY (US)

(73) Assignee: **Teradvance Communications, LLC**, Manlius, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/554,241**

(22) Filed: **Sep. 4, 2009**

(65) **Prior Publication Data**

US 2010/0046957 A1 Feb. 25, 2010

Related U.S. Application Data

(62) Division of application No. 09/871,216, filed on May 31, 2001, now Pat. No. 7,599,627.

(51) **Int. Cl.**
H04B 10/04 (2006.01)

(52) **U.S. Cl.** **398/183**; 398/188; 398/202; 398/147; 398/184; 398/81; 398/208; 398/209; 398/203; 385/24; 385/27; 385/39; 375/271; 375/302; 375/322

(58) **Field of Classification Search** 398/182, 398/183, 184, 185, 186, 187, 188, 189, 190, 398/192, 194, 191, 202, 203, 204, 205, 206, 398/207, 208, 209, 140, 152, 158, 159, 147, 398/81; 385/24, 27, 39; 375/271, 302, 322
See application file for complete search history.

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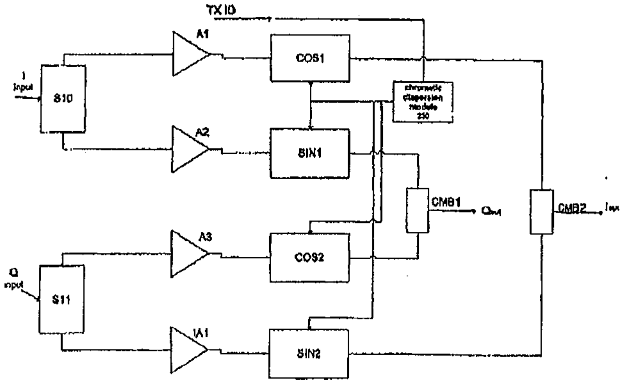
Primary Examiner — Hanh Phan
(74) *Attorney, Agent, or Firm* — Kenyon & Kenyon LLP

(57) **ABSTRACT**

An optical homodyne communication system and method in which a side carrier is transmitted along with data bands in an optical data signal, and upon reception, the side carrier is boosted, shifted to the center of the data bands, and its polarization state is matched to the polarization state of the respective data bands to compensate for polarization mode dispersion during transmission. By shifting a boosted side carrier to the center of the data bands, and by simultaneously compensating for the effects of polarization mode dispersion, the provided system and method simulate the advantages of homodyne reception using a local oscillator. The deleterious effects of chromatic dispersion on the data signals within the data bands are also compensated for by applying a corrective function to the data signals which precisely counteracts the effects of chromatic dispersion.

16 Claims, 10 Drawing Sheets



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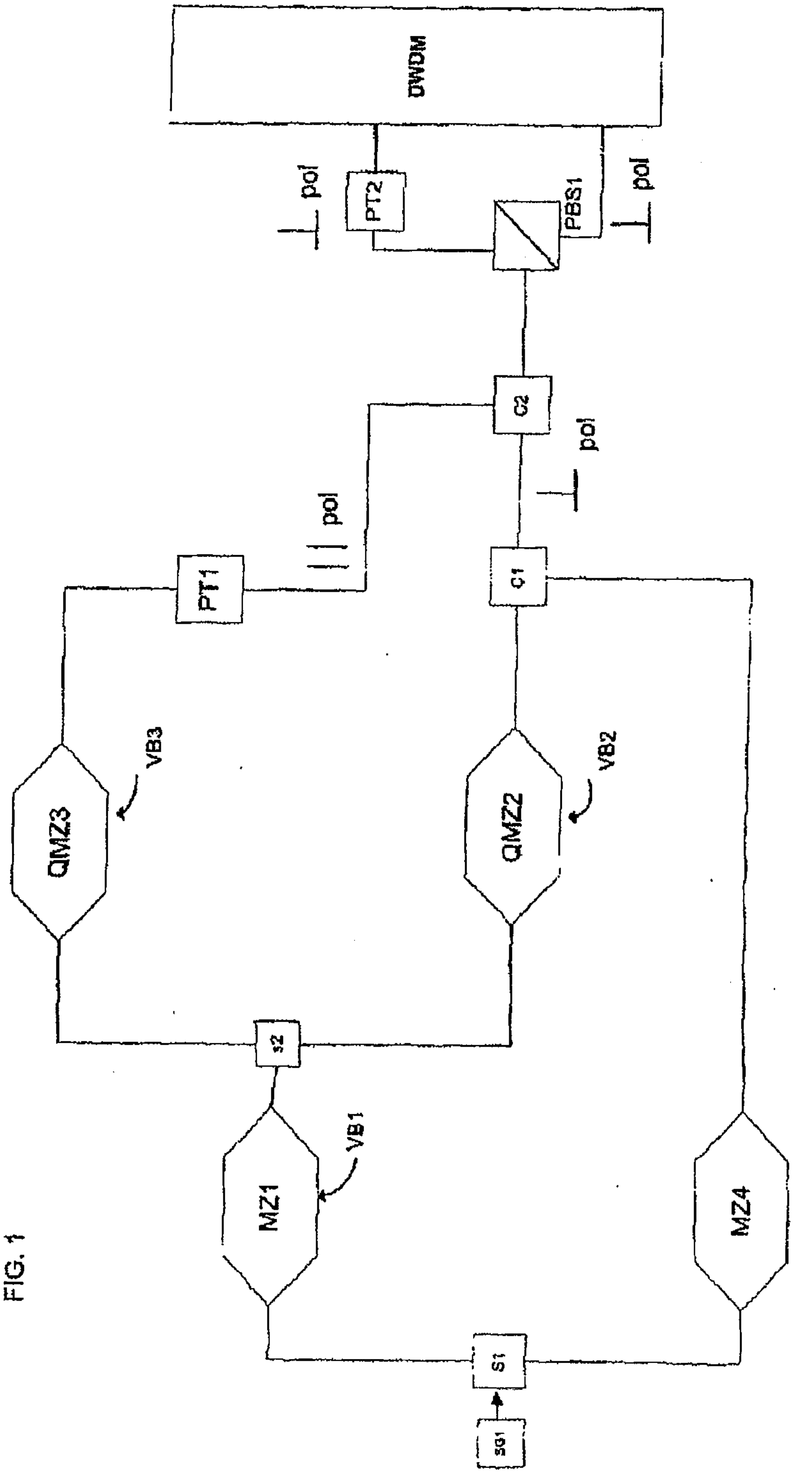

DWDM
PT2
pol
PBS1
pol
C2
pol
pol
PT1
C1
VB3
QMZ3
VB2
QMZ2
s2
VB1
MZ1
MZ4
S1
SG1

FIG. 1

FIG. 2a

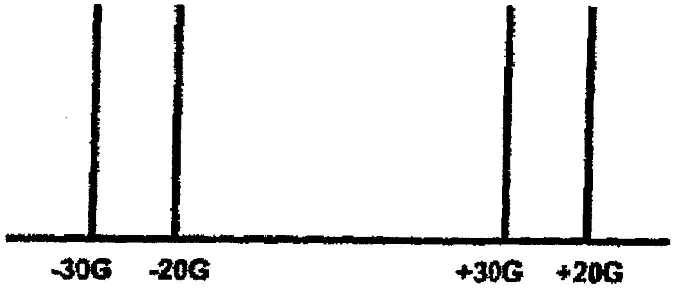


FIG. 2b

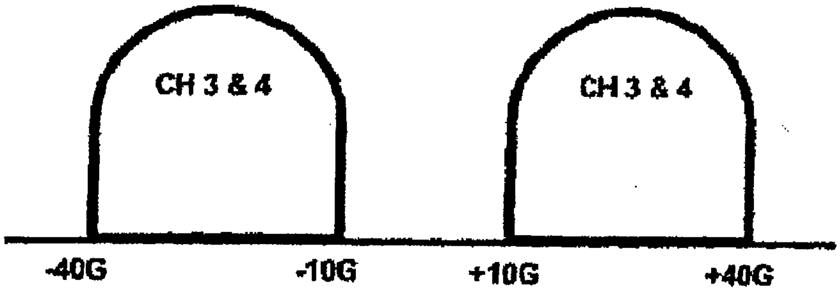


FIG. 2c

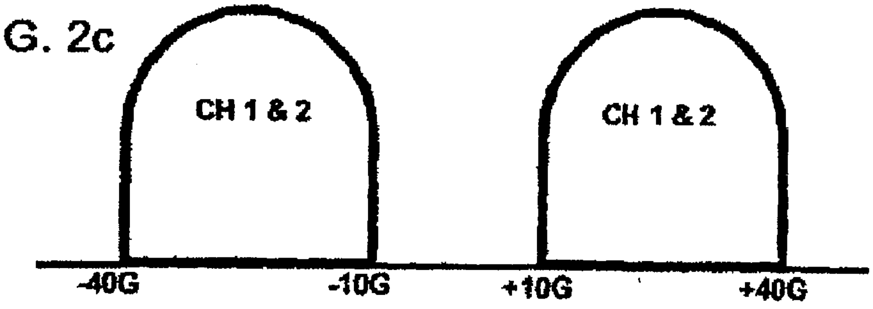


FIG. 3

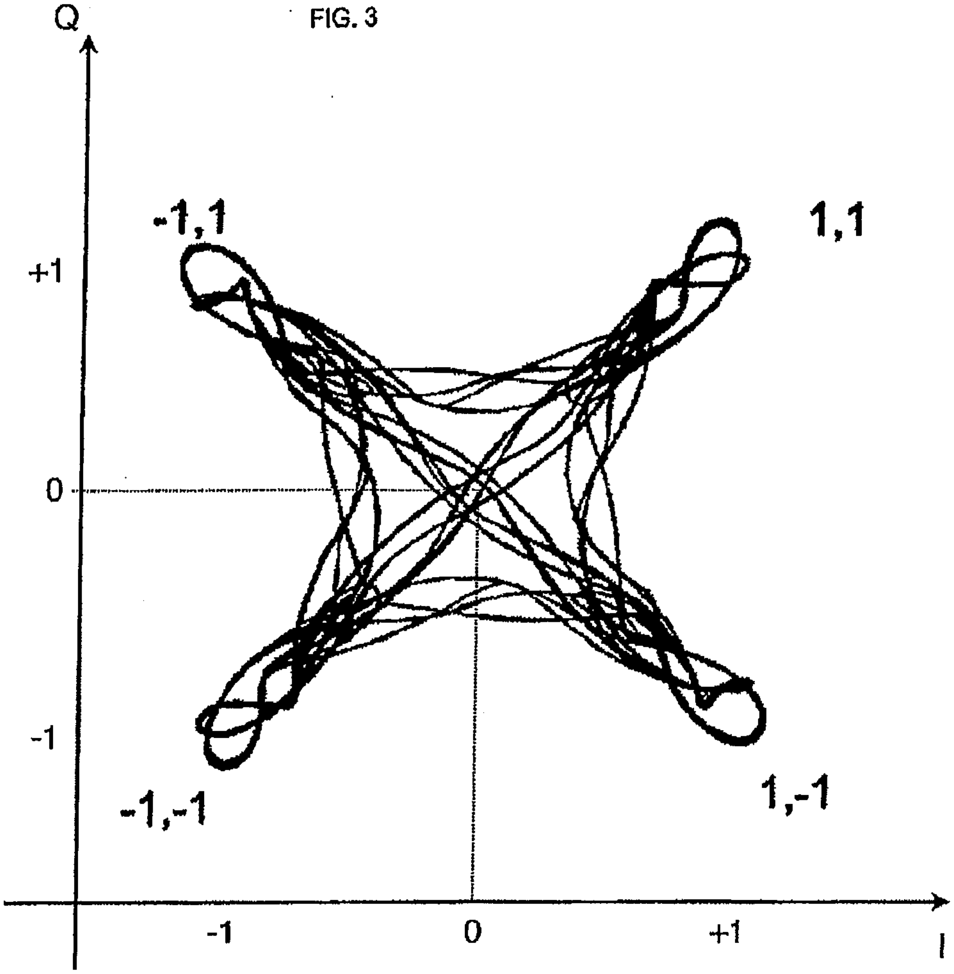


FIG. 4a

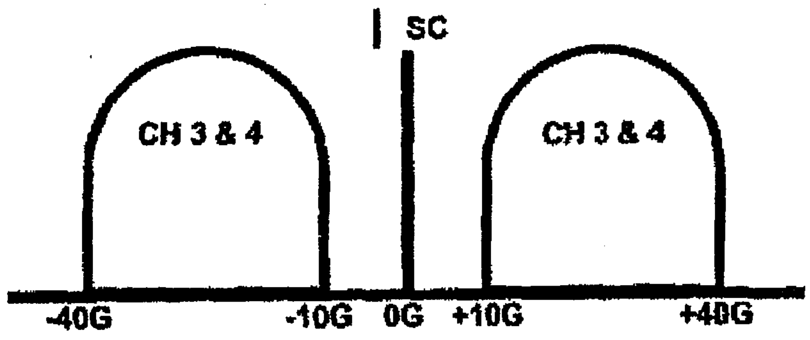


FIG. 4b

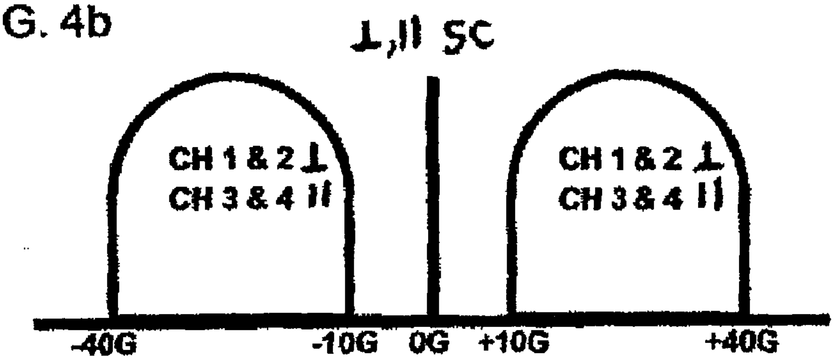
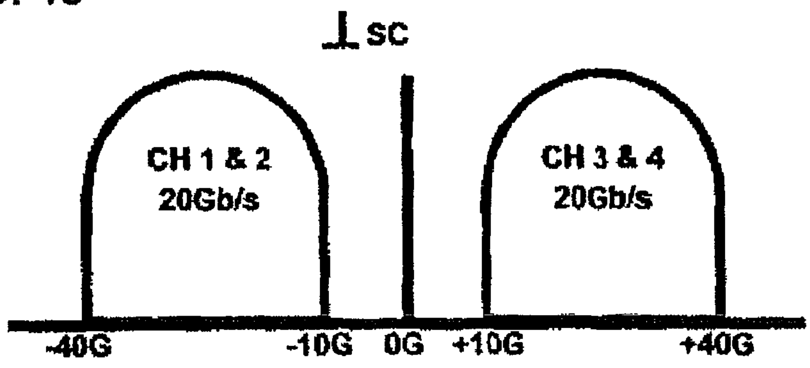


FIG. 4c



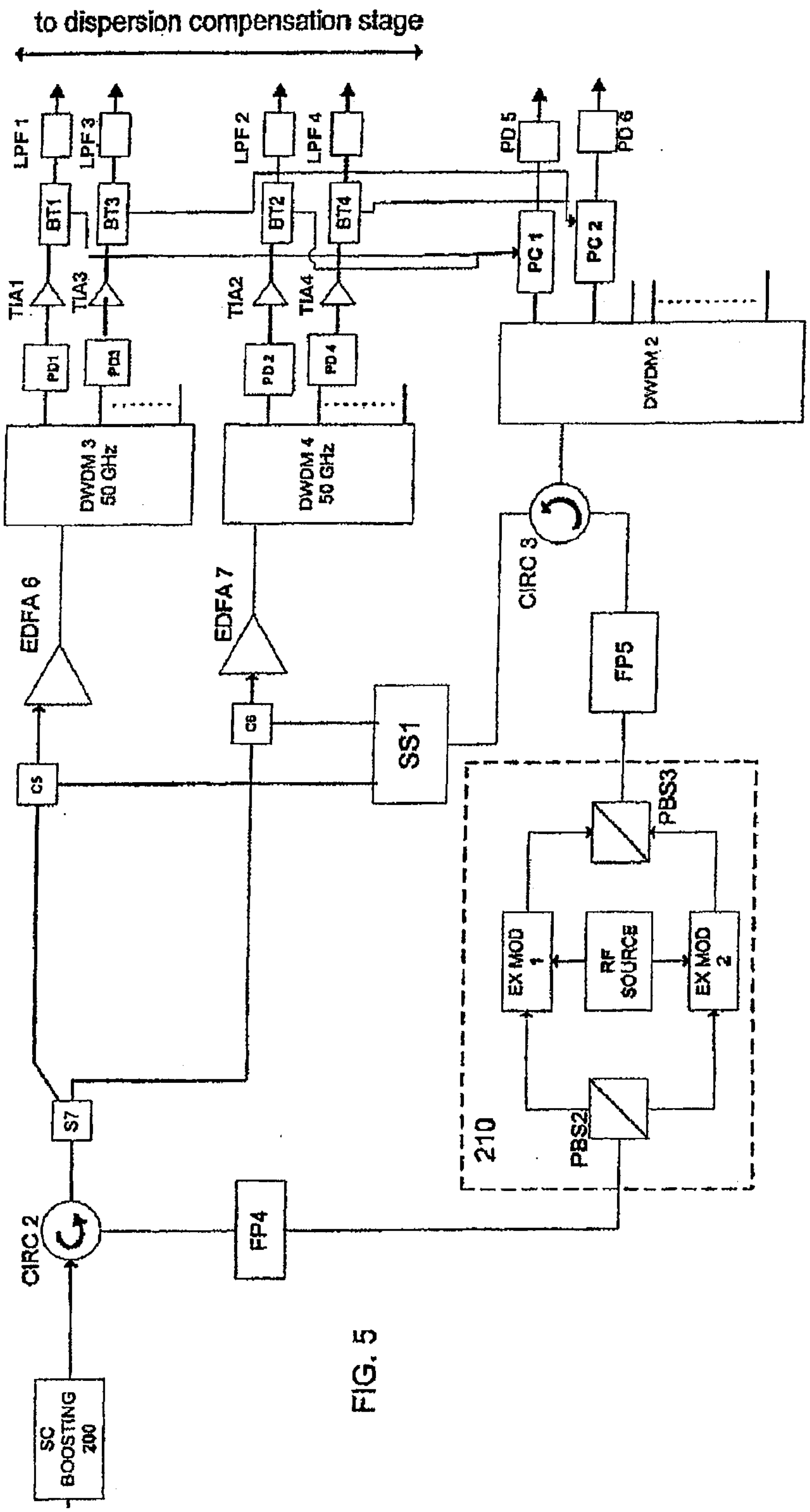

to dispersion compensation stage
LPF 1
LPF 3
LPF 2
LPF 4
PD 5
PD 6
BT1
BT3
BT2
BT4
PC 1
PC 2
TIA1
TIA3
TIA2
TIA4
PD1
PD3
PD 2
PD 4
DWDM 2
DWDM 3 50 GHz
DWDM 4 50 GHz
CIRC 3
EDFA 6
EDFA 7
FP5
C6
C5
SS1
PBS3
EX MOD 1
RF SOURCE
EX MOD 2
210
PBS2
S7
CIRC 2
FP4
SC BOOSTING 200

FIG. 5

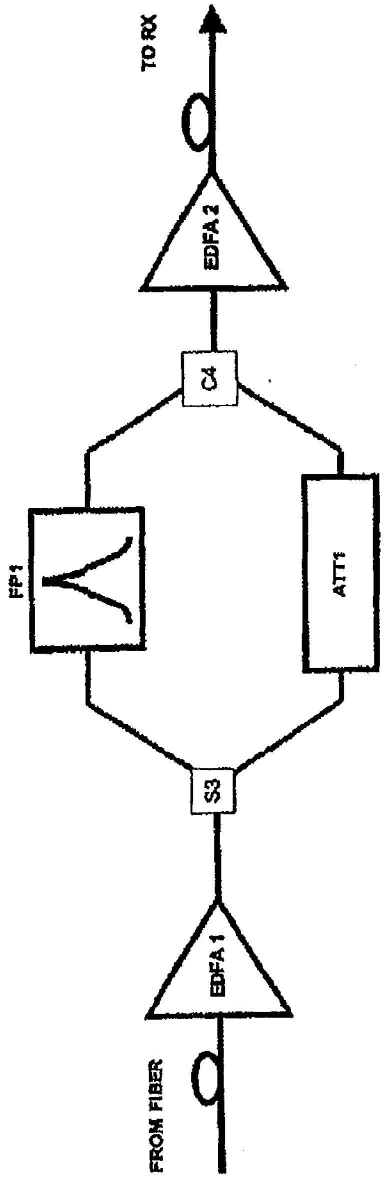


FIG. 6

FIG. 7

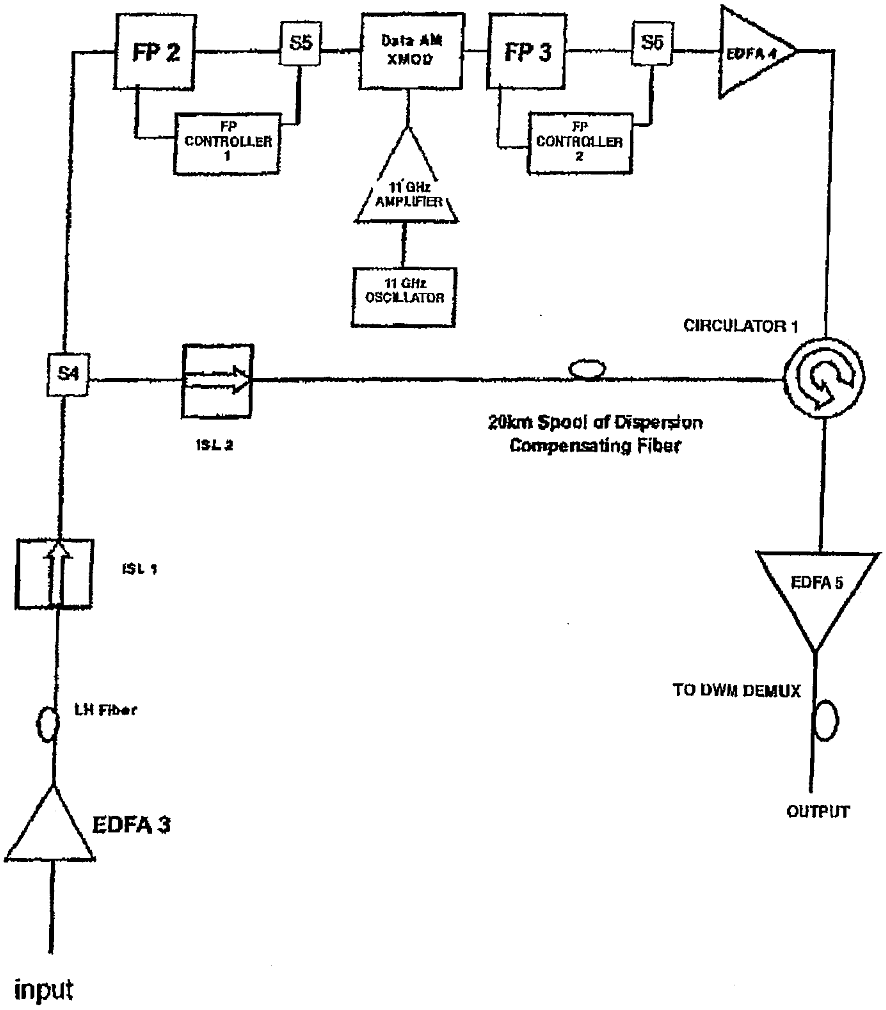

FP 2
S5
Data AM XMOD
FP 3
S6
EDFA 4
FP CONTROLLER 1
FP CONTROLLER 2
11 GHz AMPLIFIER
11 GHz OSCILLATOR
CIRCULATOR 1
S4
ISL 2
20km Spool of Dispersion Compensating Fiber
ISL 1
EDFA 5
TO DWM DEMUX
LH Fiber
OUTPUT
EDFA 3
input

FIG. 8a

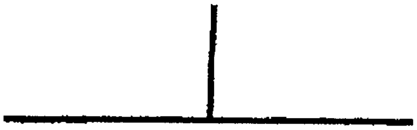


FIG. 8b

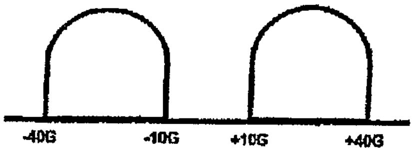


FIG. 8c

FIG. 8d

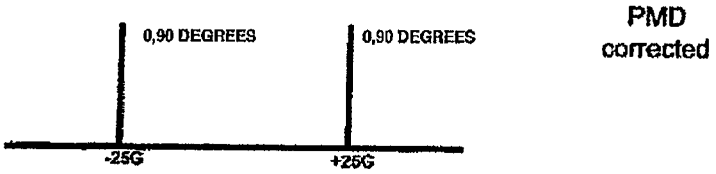
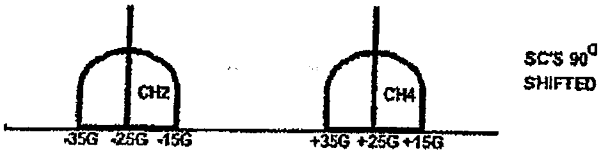


FIG. 8e

FIG. 8f



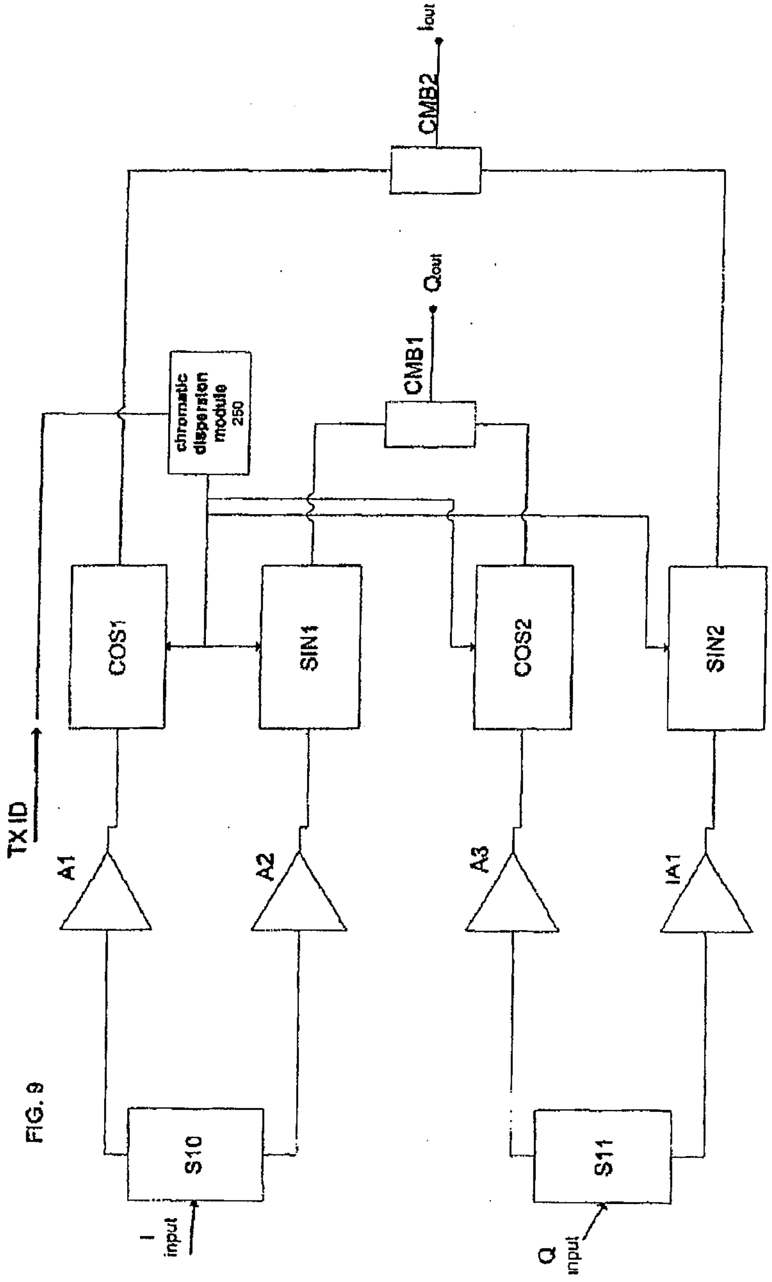

I_out
CMB2
Q_out
CMB1
chromatic dispersion module 250
COS1
SIN1
COS2
SIN2
TX ID
A1
A2
A3
IA1
S10
S11
I input
Q input

FIG. 9

FIG. 10a

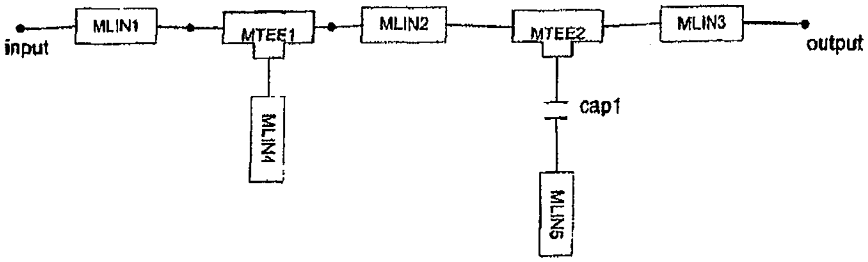
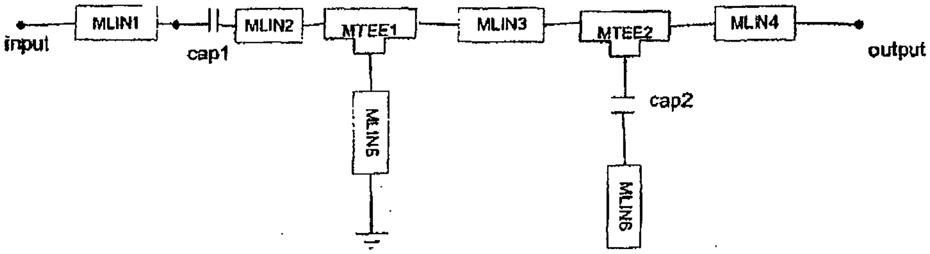


FIG. 10b



METHOD AND SYSTEM FOR A POLARIZATION MODE DISPERSION TOLERANT OPTICAL HOMODYNE DETECTION SYSTEM WITH OPTIMIZED TRANSMISSION MODULATION

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 09/871,216 filed on May 31, 2001, which is related to copending and commonly assigned U.S. patent application Ser. No. 09/748,750, filed in the United States Patent and Trademark office on Dec. 26, 2000, entitled "Method, System and Apparatus for Optically Transferring Information", which is expressly incorporated herein in its entirety by reference thereto.

FIELD OF THE INVENTION

The present invention relates to optical data communication, and in particular, relates to a method and optical data communication system that improves signal-to-noise ratio of optical data signals, counteracts polarization mode dispersion and improves robustness to fiber nonlinearities.

BACKGROUND INFORMATION

Currently, optical data communication systems are being upgraded from a 10 Gb/s data transmission rate up to a 40 Gb/s transmission rate. However, data transmission at 40 Gb/s (or higher) presents extensive design challenges because the effects of polarization mode dispersion (PMD), chromatic dispersion and fiber non-linear effects such as cross-phase modulation become more dominant at the higher transmission rates. In particular, the limit of tolerable polarization mode dispersion, usually defined as 14% of the data bit duration, is only 3.5 ps at a 40 Gb/s transmission rate. A 3.5 ps polarization mode dispersion translates to an attainable reach of several hundred kilometers over single mode fiber which has a typical fiber PMD of 0.1 ps/km$^{1/2}$.

Current optical communications systems, such as the PMD compensation arrangement described in U.S. Pat. No. 6,130,766 to Cao, generally attempt to compensate for PMD by splitting received optical signals into x and y mode components having orthogonal polarization, and then adjusting the delay on one of the orthogonal components to align the modes. This arrangement requires significant signal processing and differential delays to cover the range of frequencies carrying data.

Nonlinearities induced during optical transmission are also amplified at higher data rates. While it is necessary for accurate detection that optical data signals be at least 20 dB above background noise, if the data signals are transmitted with too much power, nonlinearities can play a greater role in distorting the signal. In addition, in coherent systems typical heterodyne optical reception systems suffer an inherent 3 dB penalty with respect to homodyne systems and introduce phase noise through use of a local oscillator, and thereby add a further level of complexity and constraints to optical system design.

What is therefore needed is a cost-effective method and system that compensates for PMD, optimizes SNR performance and minimizes phase noise and nonlinearities associated with transmission over fiber at high data transmission rates.

SUMMARY OF THE INVENTION

The present invention meets the above objectives by providing an optical homodyne communication system and method in which a reduced amplitude side carrier is transmitted along with data bands in an optical data signal, and upon reception, the side carrier is boosted, shifted to the center of the data bands, and its polarization state is matched to the polarization state of the respective data bands to compensate for polarization mode dispersion during transmission. This scheme achieves the signal-to-noise benefits of homodyne reception without incurring the conventional restrictions and complications of homodyne reception such as requiring the phase of a signal from a local oscillator to be locked to the phase of the optical signal.

According to one embodiment, the present invention provides a method of optical communication that begins with providing a quadrature modulated optical data including two data bands separated in frequency, each data band having in-phase and quadrature components. The power of the quadrature modulated optical data signal is limited in order to limit non-linear effects by reducing the power of the optical data signal during transitional states in which data symbols transmitted in the optical data signal change in value, and in particular by reducing the power to zero such that transmitted power decreases to zero at approximately the mid point of the transitional states. The optical data signal is combined with a side carrier at a single frequency between the two data bands of the optical data signal and then transmitted across optical fiber to a receiver.

At the receiver, the side carrier is separated from the two data bands of the combined optical data signal and increased in amplitude relative to the data. The side carriers are then shifted to the middle of each of the respective two data bands. Since the relationship between the polarization state of the side carriers and the polarization state of the data bands does not stay constant during transmission over optical fiber, the polarization state of the shifted side carriers is adjusted to match the polarization state of the data bands at which they are centered.

The present invention further provides a method of compensating for the effects of chromatic dispersion during transmission over optical fiber by separating the in-phase and quadrature components of the two data bands prior to optoelectric conversion, and, after optoelectric conversion, compensating for chromatic dispersion by applying a corrective function to each of the in-phase and quadrature components of the data bands, the corrective function precisely counteracting the effects of chromatic dispersion on the in-phase and quadrature components.

The present invention also provides a method of providing information concerning a transmission device by providing an optical data signal having data bands and a side carrier with the side carrier modulated to carry an identification code, the identification code including information concerning the transmitter. According to an embodiment of the present invention, the information concerning a transmitter embedded in the side carrier includes parameters used in the corrective function to precisely counteract the effects of chromatic dispersion.

An optical data signal transmitter is provided for generating the quadrature modulated optical data signal including at least one side carrier. The transmitter includes a Mach-Zender modulator which generates an optical carrier signal by modulating a pair of side carriers onto an input optical signal. The optical carrier signal is modulated by at least two phase modulators which modulate a pair of data signals, in quadrature, onto the optical carrier signal, outputting an optical data signal including at least two data bands. By spreading the data bands onto the pair of side carriers, the amplitude of the optical data signal is reduced to zero during transitions between data symbols. The transmitter also includes a second Mach-Zender modulator which imprints a low-frequency TX ID (transmitter identification code) side carrier onto the input optical signal. The TX ID signal side carrier then combined with the optical data signal for transmission. The transmitted identification code includes information concerning the transmitter, such as its location, from which the distance between the transmitter and a receiver may be deduced.

The present invention further provides a receiver for implementing homodyne reception. The receiver includes a side carrier boosting module for increasing the amplitude of the side carrier relative to the data bands in the optical data signal. The receiver further includes a side carrier shifting module coupled to the side carrier boosting module which shifts the side carrier into two shifted carriers. Each of the shifted carriers is shifted to the center of one of the data bands. In addition, means for compensating polarization mode dispersion that are coupled to the side carrier shifting module match the polarization states of the shifted carriers to the data bands by adjusting either the polarization state of the shifted carriers or the polarization state of the data bands. After optoelectric conversion of the optical data signal, the receiver employs a chromatic dispersion correction stage that includes circuits that apply transfer functions to the in-phase and quadrature detected data channels

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a transmitter according to an embodiment of the present invention.

FIG. 2*a* shows the spectrum of an optical carrier signal at the output of MZ1 of FIG. 1 according to an embodiment of the present invention.

FIG. 2*b* shows the spectrum of an optical data signal at the output of QMZ3 of FIG. **1** after data modulation in quadrature according to an embodiment of the present invention.

FIG. 2*c* shows the spectrum of an optical data signal at the output of QMZ2 of FIG. 1 according to an embodiment of the present invention.

FIG. 3 shows a 10G symbol per second Quadrature Return to Zero (QRZ) constellation diagram of the output from QMZ2 and QMZ3.

FIG. 4*a* shows the spectrum of an optical data signal at the output of C1 of FIG. 1 according to an embodiment of the present invention.

FIG. 4*b* shows the spectrum of an optical data signal at the output of C2 of FIG. 1 according to an embodiment of the present invention.

FIG. 4*c* shows the spectrum of an optical data signal at the output of the DWDM of FIG. 1 according to an embodiment of the present invention.

FIG. 5 is a block diagram of a receiver according to an embodiment of the present invention.

FIG. 6 is a block diagram of a first embodiment of the side carrier boosting module according to the present invention.

FIG. 7 is a block diagram of a second embodiment of the side carrier boosting module according to the present invention which employs the Stimulated Brillouin Scattering (SBS) effect.

FIG. 8*a* shows the spectrum of an optical carrier signal at the output of the FP4 of FIG. 5 according to an embodiment of the present invention.

FIG. 8*b* shows the spectrum of an optical carrier signal at the output of the S7 of FIG. 5 according to an embodiment of the present invention.

FIG. 8*c* shows the spectrum of an optical carrier signal at the output of the PBS3 of FIG. 5 according to an embodiment of the present invention.

FIG. 8*d* shows the spectrum of an optical carrier signal at the output of the SS1 of FIG. 5 according to an embodiment of the present invention.

FIG. 8*e* shows the spectrum of an optical carrier signal at the output of the C5 of FIG. 5 according to an embodiment of the present invention.

FIG. 8*f* shows the spectrum of an optical carrier signal at the output of the C6 of FIG. 5 according to an embodiment of the present invention.

FIG. 9 is a block diagram of a chromatic dispersion compensation circuit according to an embodiment of the present invention.

FIG. 10*a* is a block diagram of a microstrip implementation of a circuit that applies a COS transfer function to an input signal according to an embodiment of the present invention.

FIG. 10*b* is a block diagram of a microstrip implementation of a circuit that applies a SIN transfer function to an input signal according to an embodiment of the present invention.

DETAILED DESCRIPTION

I. Transmission

In accordance with the present invention, at a transmitter, a pair of side carriers is modulated onto each side of a monochromatic optical carrier signal, which is then split into two channels. Each optical carrier signal channel is modulated with two 10 Gb/s data signals in an orthogonal phase relationship to one another. The data signals are spread onto the two side carriers in each channel, and in effect, are spread out by fifty percent in the frequency domain. This spreading is equivalent to multiplication by a sine wave at half the data rate, and results in each data symbol returning to zero between transitions, referred to as quadrature-return-to-zero (QRZ). Using QRZ, the power of the optical data signal is made independent of the data pattern. The polarization of one of the optical data signal channels is then shifted, and one of the channels is combined with a channel of the original monochromatic carrier that has been modulated with a transmission identification carrier of less than 100 kHz.

The two optical data signal bands, which each carry a 20 Gb/s data stream, are combined and either multiplexed with adjacent channels at similar frequency and orthogonal polarization or one of the two channels is shifted in polarization to match the other channel. In either case, the optical data signals are multiplexed according to a Dense Wave Division Mulitplexing (DWDM) scheme and transmitted along long haul fiber to a destination receiver.

FIG. 1 illustrates an embodiment of a transmitter according to the present invention, which may be implemented on a Lithium-Niobate chip, for example. An optical signal generator SG1, which may be a laser, generates a monochromatic, polarized optical carrier at a reference frequency which for purposes of the following discussion is designated as the origin (0 GHz) in terms of relative frequency. The optical signal is thereafter split into two channels, an upper channel going to Mach-Zender modulator MZ1 and a lower channel being transmitted to Mach-Zender modulator MZ4. The division of light intensity between the two channels can be uneven with the lower channel receiving, for example, just 10 percent of the light intensity generated by SG1. At narrow-band modulator MZ4, the lower channel of the optical signal is modulated with a "Transmitter Identification" (TX ID) tone in the frequency range of 10 KHz to 100 KHz above the reference frequency. At modulator MZ1, two sets of side carriers at +/−20 GHz and +/−30 GHz are modulated onto the optical signal. The spectrum for the modulated signal, denoted an optical carrier signal, is shown in FIG. 2*a*. As shown in the figure, the resulting spectrum output from MZ1 shows four peaks, two below the reference frequency at −30 GHz and −20 GHz relative to the reference frequency, and two above the reference frequency at +20 GHz and +30 GHz.

The output of modulator MZ1 is further split into an upper channel which is transmitted to quadrature data modulator QMZ3 and a lower channel which is transmitted to quadrature data modulator QMZ2. Data modulator QMZ2 imprints two individual 10 Gb/s data streams in quadrature (in orthogonal phase relationship) CH.1 and CH. 2 onto each of the pairs of side carriers above and below the reference frequency. Similarly, data modulator QMZ3 imprints individual 10 Gb/s data streams CH.3 and CH.4 onto each of the pairs of side carriers in the optical carrier signal. Respective bias control electrodes VB2 and VB3 assist in keeping the data streams in quadrature. Spectra of the outputs from QMZ3 and QMZ2 are shown in FIG. 2*b* and FIG. 2*c* respectively. As can be discerned in FIG. 2*b* and FIG. 2*c*, the output spectra from QMZ3 and QMZ2 show two data bands, one extending from −40 GHz to −10 GHz and another extending from +10 GHz to +40 GHz relative to the reference frequency.

By imprinting two 10 Gb/s data streams in quadrature, in effect, 20 Gb/s of data are modulated onto each pair of side carriers (−30, −20 GHz and +20, +30 GHz, respectively) and each 20 Gb/s data band covers 30 GHz in the frequency domain. By providing two side carriers, with one side carrier in the pair a clock rate away from the other (i.e., 30 GHz being a clock away from 20 GHz), the data bits in both I and Q format are multiplied in the time domain by a 5 GHz sinusoid which crosses zero every 100 ps. Thus, the total data signal always crosses through zero in between any pair of symbols (any pair of I,Q data), referred to as quadrature-return-to-zero (QRZ) modulation.

FIG. 3 illustrates the key property of the QRZ format, showing that the trajectory between two successive symbols always leads through the I-Q origin. Each corner of the figure represents a pair of I, Q data symbols (e.g., I=1,Q=−1 or I=−1, Q=1). As shown, to get from adjacent corner points I=1, Q=1 (upper right corner) to I=1, Q=−1 (lower right corner) the optical data signal must travel through the origin (0,0). During each trajectory through the origin, the power of the signal, which is proportion to the square of its amplitude, goes to zero.

Returning to FIG. 1, the output from modulator QMZ3 is input to a polarization transformer PT1, which shifts the polarization of the optical data signal output from QMZ3 90 degrees. The polarization of the signal output from PT1 is arbitrarily illustrated by parallel lines as parallel polarization as opposed to a perpendicular polarization of the original optical signal. Furthermore, the output optical data signal from modulator QMZ2 is combined at combiner C1 with the TX ID pilot signal from MZ4. The output from C1 is shown in FIG. 4*a*. As noted above, the intensity of the TX ID signal is reduced in comparison with the optical data signal from QMZ2. It is also noted that the polarization of the output signal from C1 is shown as perpendicular, since the polarization of the output from C1 remains unchanged from the original polarization. Thereafter, the output signal from PT1 is combined with the output signal from combiner C1 at C2. The spectrum of the output signal out of C2 is shown in FIG. 4*b*.

As can be discerned, the spectrum includes data channels **1**, **2**, **3** and **4** in both lower and upper data bands. Channels **1** and **2** are in perpendicular polarization and channels **3** and **4** are in parallel polarization. The reference carrier at approximately 0 GHz from MZ4 is in perpendicular polarization.

According to the illustrated embodiment, the output signal from C2 is input to a polarization beam splitter PBS1 which splits the signal into perpendicular and parallel polarized components, thereby separating the data channels **1** and **2** from channels **3** and **4**. The perpendicular component (containing data channels **1** and **2** as well as the central reference frequency) is transmitted along lower path **102** to a first channel of a dense wave division multiplexer DWDM, the parallel component (containing data channels **3** and **4**) is input to a polarization transformer PT2, which rotates the polarization of the parallel component back into a perpendicular state. The output from PT2 is then input to a second DWDM channel. Each DWDM channel acts as a band pass filter and passes only frequencies that fall within a 50 GHz band. Assuming for illustrative purposes that DWDM channel **1** passes frequencies from −50 GHz to 0 GHz relative to the reference frequency, and DWDM channel **2** passes frequencies from 0 to +50 GHz, data channels **1** and **2** are passed only in the data band from −40 GHz to −10 GHz and while data channels **3** and **4** are passed only in the data band from +10 GHz to +40 GHz. The DWDM multiplexes each of the passed bands onto a long haul fiber (not shown). The output spectrum from −50 GHz to +50 GHz output from the DWDM is shown in FIG. 4*c*. The adjacent DWDM channels each pass 20 Gb/s of data, combining for a total of 40 Gb/s.

In an alternative embodiment, a polarization multiplexing scheme may be used, making it unnecessary to separate data channels **1** and **2** from data channels **3** and **4**. As described in related and commonly owned application [Ser. No. 09/782,354] hereby incorporated for reference, the pairs of data channels can occupy the same data band if their polarization states remain orthogonal and thus do not interfere with each other. In this implementation, the polarization beam splitter PBS1 is not needed and the output from C2 can be sent directly to one of the DWDM input channels.

II. Reception

In accordance with the present invention, a homodyne reception system is employed to receive the optical data signal generated as described above. Upon reception, the transmitted side carrier at the reference frequency is boosted to increase the signal-to-noise ratio (SNR) of the optical data signal and to compensate for the attenuation of the side carrier in the transmitter. The boosting of the side carrier increases the SNR because of the implementation of homodyne reception in which overall detected signal power is increased in proportion to the power of the local oscillator, or in the present case (as will be discussed below), the transmitted side carrier.

Once the amplitude of the side carrier power is boosted relative to the transmitted data bands, the side carrier is shifted by +/−25 GHz into two side carriers that are each shifted to the center of one of the two data bands to further implement homodyne reception.

After the shifting of the side carriers, the two side carriers are separated and then modified by polarization controllers which match the time-varying polarization state of each the side carriers to the different time-varying polarization state of the respective data bands, thus overcoming the effects of polarization mode dispersion by controlling the polarization at only a single frequency.

According to an embodiment of the present invention, a chromatic dispersion compensation stage is used to counter the effects of dispersion during transmission over long haul fiber. Since the effects of dispersion can be modeled as a transfer function that is applied to the I and Q data signals, the chromatic dispersion compensation stage applies a compensating correction function that effectively counteracts the transfer function, rendering the I and Q data signals into their original non-dispersed state.

FIG. 5 illustrates an embodiment of a homodyne receiver according to the present invention. An optical data signal is received first by a side carrier boosting module **200** for which the present invention provides two exemplary embodiments. In a first embodiment of the side carrier boosting module, shown in FIG. 6, the optical data signal is first input to an optical amplifier EDFA1, which may be, for example, an erbium-doped fiber amplifier (EDFA). It is noted that all further optical amplifiers used in the implementations described below may be implemented as erbium-doped fiber amplifiers. The optical amplifier EDFA1 amplifies the entire spectrum of the received signal by, for example, approximately 15-18 dB. The amplified signal output from EDFA1 is split at S3 between an upper branch that is coupled to a Fabry-Perot resonator FP1 and a lower branch that is coupled to an attenuator ATT1.

The Fabry Perot resonator FP1 functions as a high-Q filter that nearly completely filters out all frequencies excepts for a series of frequencies that are separated by, for example, 100 Ghz which, according to the International Telecommunication Union (ITU) grid, is the amount of bandwidth allocated for each channel. The resonator FP1 is adjusted to pass the side carrier at the reference frequency and filter out the data bands of the optical data signal. It is noted in this regard that it is contemplated that the embodiments of the present invention be used in the context of the ITU grid, and that the reception approach described allows for simultaneous processing of side carriers for a plurality of ITU grid-spaced channels. The lower branch passed to ATT1, which contains both the data bands and the side carrier is attenuated. The signals output from FP1 and ATT1 are combined in combiner C4 and then passed to a further optical amplifier EDFA2 where the combined signal is again amplified by, for example, approximately 15-18 dB. Because the side carrier was isolated and boosted in FP1 and the data bands were attenuated in ATT1, the combined signal contains a side carrier boosted at least 10 dB in amplitude relative to the data bands.

A second embodiment of the side carrier boosting module, which advantageously makes use of the amplitude-enhancing effect of Stimulated Brillouin Scattering (SBS), is shown in FIG. 7. The SBS effect causes a first optical signal having narrow frequency band around frequency X to be amplified when collides with a signal of frequency X+≈11 GHz traveling in the opposite direction. Referring to FIG. 7, the received signal is input to optical amplifier EDFA3 which amplifies the entire spectrum of the input signal. The signal output from amplifier EDFA3 is transmitted to optical isolator ISL 1, which permits optical signal to travel only in one direction (the direction indicated by the arrow in the figure) and prevents optical signals being reflected or transmitted back toward the amplifier EDFA3. From the optical isolator ISL 1, the optical data signal is split into two branches at splitter S4.

A first upper branch from splitter S4 leads to Fabry Perot resonator FP2, which passes the side carrier (and other modes in the series of frequencies) in between the data bands. FP controller 1 automatically adjusts the resonator FP2 so that it correctly passes the side carrier using input from splitter S5 and filters out the data bands. The output from FP2 is delivered to external modulator XMOD 1, which also receives an 11 GHz signal from a 11 GHz oscillator through an 11 GHz amplifier. The external modulator XMOD 1 modulates the 11 GHz signal onto the side carrier. The spectrum of the output from the modulator XMOD 1 thereafter contains the reference frequency and two side frequencies located 11 GHz both above and below the reference frequency. This output signal is then transmitted to another resonator FP3, which is adjusted by FP controller 2 to center on (and pass) only the side frequency 11 GHz above the reference side carrier frequency. The resulting signal, carrying substantially a single frequency at the reference frequency +11 GHz, is amplified in optical amplifier EDFA4 and then input to circulator CIRC 1. The circulator passes signals in a counter-clockwise direction. More specifically, CIRC 1 passes the output from EDFA4 leftwards in a counter-clockwise rotation towards the output of optical isolator ISL 2. It is noted that the side carrier boosting scheme is also intended be used in conjunction with a dense wave division multiplexing scheme. Thus, the side carrier boosting module can simultaneously process and boost a plurality of side carriers spaced in frequency according to ITU channel spacing.

Simultaneously, the optical signal in the lower branch from splitter S4 is transmitted through isolator ISL 2 and then meets with the optical signal from the upper branch output from the circulator CIRC 1. This collision of the two optical signals traveling in opposite directions generates the SBS non-linear effect. According to one implementation, the fiber connecting isolator ISL 2 and circulator CIRC 1 can be dispersion compensating fiber which, due to its relatively smaller cross-section, promotes higher intensity and more pronounced non-linear effects such as SBS. When the optical data signal containing the reference side carrier collides with the 11 GHz side frequency signal from CIRC 1, a narrow band including the side carrier in the optical data signal is amplified relative to the data bands due to the SBS effect as explained above. This modified optical data signal then reaches the circulator CIRC 1 from which it passes in the counter-clockwise direction to optical amplifier EDFA5, which amplifies the entire spectrum of the modified optical data signal by 15-18 dB. The output from EDFA5 is the final output of the second embodiment of the side carrier boosting module **200**.

Returning to FIG. 5, the optical data signal output from the side carrier boosting module **200** is input to circulator CIRC 2, which in turn transmits the signal in a counter-clockwise direction to Fabry-Perot resonator FP4, having a free spectral range (FSR) of 100 GHz and finesse on the order of 1000. The resonator FP4 is also tuned to select the side carrier at (approximately) the reference frequency (O GHz). FIG. 8*a* shows a spectrum of the signal output from FP4, indicating that the data bands have again been filtered out. The data bands that are filtered out at FP4 are resent back toward circulator CIRC 2, where they are redirected in a counter-clockwise direction towards splitter S7. The spectrum of the output from splitter S7, which includes the two filtered data bands at −40 GHz to −10 GHz and +10 GHz to +40 GHz, is shown in FIG. 8*b*.

It is noted that when the optical data signal is transmitted over long haul fiber between the transmitter and the receiver, the polarization state of the transmitted signal is scrambled, with the result that the received signal has an unknown time-varying polarization state. Since the time-varying polarization state varies with frequency, the side carrier is expected to have a different time-varying polarization state than either of the data bands because it is separated from the centers of data bands by 25 GHz. When the output from resonator FP4 is fed to the side carrier shifting module **210**, the side carrier's orthogonal polarization states are split in polarization beam splitter PBS2, and then each of the orthogonal signals are separately modulated by 25 GHz in XMOD 2 and XMOD 3, respectively, and then joined back in PBS3. The output from PBS3 is illustrated in FIG. **8**c, which shows two side carriers at −25 GHz and +25 GHz from the reference frequency, respectively. The output from PBS2 is passed on to Fabry-Perot filter FP5 (FSR=50 GHz, finesse >500) which passes both the 25 GHz left and right shifted side carriers, and transmits them to circulator CIRC 3. Circulator CIRC 3 delivers shifted SC's to reflective polarization controllers PC 1, PC 2, through respective adjacent 50 GHz-spaced channels of WDM demultiplexer DWDM 2. The polarization controllers PC 1, PC 2 are constructed to provide control of the phase of the signals reflected from the polarization controllers back to the demultiplexer DWDM 2. Such control may be used, for instance, in order to compensate for the effective fiber length between the polarization controllers PC 1, PC 2 and the demultiplexer DWDM 2. In one implementation, the polarization controllers PC 1, PC 2 include mirrors and piezoelectric actuators to adjust the distance the reflected signal travels, which in turn controls the phase of the reflected optical signal.

Each polarization controller PC 1, PC 2 is used to transform the time-varying polarization state of one of the two side carriers so that the polarization states of each side carrier matches the time varying polarization state of the respective data bands which are centered at the side carrier (−25 GHz and +25 GHz). To accomplish this, each polarization controller PC 1, PC2 obtains feedback from the photodiodes that receive the data bands. PC 1 receives the feedback via bias-T couplers BT 1 and BT 3, while PC 2 receives feedback via bias-T couplers BT 2 and BT 4. As will be described below, the demultiplexers at the top of FIG. 5, DWDM 3, DWDM 4, receive both the data bands and the side carriers, filter them into separate, adjacent frequency channels and then effectively multiply the side carrier and data bands together at photodiodes PD1, PD2, PD3 and PD4 (and other photodiodes of adjacent channels that are not shown) which respond to the intensity of the signal (i.e., the square of the amplitude). The product signal output from the photodiodes is delivered to the respective polarization controllers PC 1, PC 2 via bias-T couplers BT 1, BT 2, BT 3 and BT 4. The outputs from BT 1 and BT 3, which contain converted data signals 1 and 2, corresponding to data channels 1 and 2, are combined to provide feedback to polarization controller PC 1, and the outputs from BT 2 and BT 4, which contain data signals 3 and 4, corresponding to data channels 3 and 4, are combined to provide feedback polarization controller PC 2. It is noted that the data signals 1 and 2 are expected to have a similar polarization state since, during transmission, they occupy the same frequency range. Equally, data signals 3 and 4, corresponding to data channels 3 and 4, are expected to have a similar polarization state. At the polarization controllers PC 1, PC 2, the time-varying polarization of the combined product signals are compared to the polarization state of the individual side carrier signals.

By continually adjusting the polarization of the side carrier signal and then comparing the modified polarization state to the combined product signals, the polarization controllers PC 1, PC 2 can accurately match the time-varying polarization state of each of the side carriers with the time-varying polarization state of the corresponding data bands. This technique takes advantage of fact that it is easier to adjust the single polarization state of a single side carrier frequency than to adjust the multitude of polarization states of a band of frequencies, for example, a 20 GHz data band, via wide-band polarization compensation. However, polarization mode dispersion compensation can also be performed here by adjusting the average polarization of the data band, which is treated as having a single polarization, and then matching to the polarization of the side carrier.

Returning once again to FIG. 5, the polarization controllers PC 1, PC 2 output polarization compensated side carrier signals to circulator CIRC 3, from which they are forwarded to splitter SS1. The splitter SS1 also shifts the phase of one of the output branches by 90 degrees relative to other branch. The output spectrum from SS1 is shown in FIG. **8**d. These 0 degree and 90 degree phase shifted carriers are recombined in combiners C5 and C6, respectively, with the data bands output from splitter S7. In-phase (0 degree shifted) and quadrature (90 degree-shifted) signal spectrums out of outputs of respective combiners C5 and C6 are shown in FIG. **8**e and FIG. **8**f. As can be discerned, in each spectrum, a side carrier is positioned in the center of a data band. Each side of the spectra is equivalent to a spectrum generated by a conventional homodyne system in which the local oscillator frequency is matched to the center frequency of the data band. Furthermore, as in conventional homodyne reception, the power of the central carrier frequency is boosted relative to the data portion in order to the improve signal-to-noise ratio of the detected signal. The side carrier that has been shifted 0 degrees can be used to detect the in-phase (I) 10 Gb/s data channels from the transmitter (channels 1, 3) and the side carrier that has been shifted 90 degrees can be used to detect the quadrature (90 degree shifted) 10 Gb/s data channels (channels 2, 4).

The combined signal from C5 is sent through optical amplifier EDFA6 and the combined signal from C6 is sent through optical amplifier EDFA7 to final 50 GHz spaced demultiplexers DWDM 3 and DWDM 4. Each of the demultiplexers DWDM 3, DWDM 4 separate the data bands and side carriers in adjacent channels for electro-optic conversion at photodiodes PD 1, PD 2 and PD 3, PD 4 respectively. In this manner 10 GB/s data channels 1 and 3 are separated in DWDM 3 and 10 Gb/s channels 2 and 4 are separated in DWDM 4, resulting in the output of four separate 10 Gb/s data signals.

In an implementation of the receiver according to the present invention, low-bandwidth photodiodes can be placed at reflective ends of polarization controllers in each leg of WDM demultiplexer to provide monitor outputs proportional to fluctuations in each of carriers, for example caused by cross phase modulation (XPM). Since the respective 10 Gb/s data channels corresponding to the side carriers generally fluctuate in sympathy, the effect of carrier fluctuation can be removed if the monitor output fluctuations are subtracted from the outputs of the respective received 10 Gb/s output channels.

After the converted data signals are further processed through trans-impedance amplifiers TIA1, TIA2, TIA 3, TIA 4 and low pass filters LPF1, LPF2, LPF3, LPF4, they are input to a chromatic dispersion compensation stage shown schematically in FIG. 9. It is noted in this context that the dispersion compensation stage can equally be implemented at the quadrature data modulators on the transmitter side instead of, or in addition to, implementation at the receiver. The effects of fiber-induced chromatic dispersion on quadrature-modulated sinusoidal data signals can be described by the following matrix equation:

$$\begin{bmatrix} I\_out(D, L, f) \\ Q\_out(D, L, f) \end{bmatrix} = \begin{bmatrix} \cos\phi 1(D, L, f) & \sin\phi 1(D, L, f) \\ -\sin\phi 1(D, L, f) & \cos\phi 1(D, L, f) \end{bmatrix} \begin{bmatrix} I\_in(f) \\ Q\_in(f) \end{bmatrix} \tag{1}$$

where I_out(f) and Q_out(f) are frequency domain representations of output I and Q signals, which are modified from frequency domain representations of input I and Q signals, I_in(f) and Q_in(f), by the dispersion matrix, for which

$$\Phi1(D, L, f) = D\cdot L\cdot\frac{0.8}{4\cdot\pi}\cdot 10^{-26}\cdot(2\pi f)^2 \tag{2}$$

D denotes the fiber dispersion in units of ps/nm*km, L stands for fiber length in meters and f stands for frequency in Hz.

The dispersion matrix can be interpreted as a transfer function which applies a clockwise rotation angle that is proportional to the square of the frequency of the transmitted sinusoid. To counter the dispersion effect, it is feasible to apply an inverse transfer function, which can be interpreted as a counterclockwise rotation, also proportional to the square of the frequency. This counter-dispersion, or correction function may be described by the following matrix equation:

$$\text{disp\_corr}(D, L, f) = \begin{bmatrix} \cos(\phi1(D, L, f)) & -\sin(\phi1(D, L, f)) \\ \sin(\phi1(D, L, f)) & \cos(\phi1(D, L, f)) \end{bmatrix} \tag{3}$$

Therefore to correct the I and Q data signal for the effects of chromatic dispersion, the correction function is applied to the I and Q input signals (again, either at the transmitter or at the receiver, as is shown). Multiplying the correction function by the input signals yields:

$$I\_out=\cos\Phi1(D,L,f)\cdot I\_in-\sin\Phi1(D,L,f)\cdot Q\_in$$

$$Q\_out=\sin\Phi1(D,L,f)\cdot I\_in+\cos\Phi1(D,L,f)\cdot Q\_in \tag{4}$$

From equation (4), it is clear that dispersion compensation can be obtained by modifying the input I and Q data signals with an appropriate transfer function and then combining the modified signal. An embodiment of a dispersion correction circuit that performs these operations is shown in FIG. **9**. As shown, the I input signal is input to a splitter **S10**, from which an upper branch is delivered to amplifier A1 and a lower branch is delivered to an amplifier A2 in order to boost the signal. The upper branch is transmitted to a COS1 circuit which applies the cosine portion of the dispersion correction function cos Φ1(D,L,f) to the input data signal as will be described further below. The lower branch from the splitter **S10** is fed to a SIN1 circuit which applies the complementary sine portion of the dispersion correction function.

The Q data signal is concurrently input to splitter **S11** and broken up into an upper branch which is fed through amplifiers A3, and a lower branch which is delivered to inverting amplifier IA1 which, in addition to boosting the signal, also shifts the phase of the signal by 180 degrees. The upper and lower branches are thereafter input to respective COS2 and SIN2 circuits which perform the same functions as the COS1 and SIN1 circuits, respectively. As shown, the modified signal from the SIN1 circuit, which is the product I_in times sin Φ1(D,L,f), is combined with the output from COS2, the product, Q_in times cos Φ1(D,L,f), at combiner CMB1. Comparison with equation (4), shows that the output of combiner CMB1 matches the desired Q_out output for dispersion compensation. Similarly, the combination at CMB2, containing the products I_in times cos Φ1(D,L,f) and Q_in times −sin Φ1(D,L,f), matches the desired I_out output for dispersion compensation.

Furthermore, the TX ID pilot signal, which, as noted above, is modulated onto the reference frequency +/−10-100 kHz, is received at the polarization controllers PC **1**, PC **2** and converted to the RF domain at photodetectors PD3 and PD4. The TX pilots may be coded by frequency modulation or by another code modulation technique. The TX ID identifies the particular transmitter sending the signal, allowing information, such as the length of optical fiber between the transmitter and the receiver (which is the same as the parameter, L, used in the dispersion correction function), to be extracted from the coded signal. This information is transmitted to the chromatic dispersion compensation stage where it is received by a chromatic dispersion module **250**. The chromatic dispersion module, in turn, is coupled to the SIN and COS circuits and causes adjustments to be made to the respective transfer functions applied to the I and Q inputs in accordance with the information extracted from the TX ID.

According to an embodiment of the present invention, the SIN and COS circuits of FIG. **9** are implemented as microstrip circuits which use layers or regions of copper deposited on a circuitboard having various widths and lengths, to adjust electromagnetic effects that modify signals sent through the copper layers or regions. FIG. **10***a* and FIG. **10***b* illustrate implementations of the sin Φ1(D,L,f) and cos Φ1(D,L,f) transfer functions respectively. As is known in the art, various combinations of linear strips, (denoted as MLIN), t-junctions (denoted as MTEE), and capacitive elements (cap**1**, cap**2**), again having various adjustable lengths and widths are used to fine-tune the electromagnetic wave effects in the copper regions to simulate the desired transfer functions.

In the foregoing description, the method and system of the invention have been described with reference to a number of examples that are not to be considered limiting. Rather, it is to be understood and expected that variations in the principles of the method and apparatus herein disclosed may be made by one skilled in the art and it is intended that such modifications, changes, and/or substitutions are to be included within the scope of the present invention as set forth in the appended claims. For example, although only a 10 Gbp/s digital baseband is discussed, the inventive principles herein may be applied to higher or lower data rates as the case may be.

What is claimed is:

1. A method of compensating a quadrature modulated optical data signal for effects of chromatic dispersion occurring during transmission over optical fiber, the method comprising the steps of:

separating in-phase and quadrature components of the optical data signal;

optoelectrically converting the in-phase and quadrature components of the optical data signal into in-phase and quadrature data signals;

applying a corrective function to the in-phase and quadrature data signals, the corrective function modifying the in-phase and quadrature data signals in a manner that precisely counteracts effects of chromatic dispersion on the in-phase and quadrature components of the optical data signal.

2. The method of claim 1, wherein the corrective function is a function of a coefficient of fiber dispersion, a length of the optical fiber, and frequency of the optical data signal.

3. A receiver for receiving and processing an optical data signal, the optical data signal including at least two data bands and at least one side carrier, each of the at least two data bands including a pair of quadrature modulated data signals, the receiver comprising:

a side carrier boosting module, the side carrier boosting module for increasing an amplitude of the at least one side carrier relative to the at least two data bands;

a side carrier shifting module coupled to the side carrier boosting module, the side carrier shifting module for shifting the at least one side carrier into at least two shifted carriers, each of the at least two shifted carriers shifted to a center of one of the at least two data bands; and

means for compensating polarization mode dispersion coupled to the side carrier shifting module, the means for compensating adjusting a polarization state of one of:

a) each of the at least two shifted carriers to match a polarization state of one of the at least two data bands; and

b) the at least two data bands to match a polarization state of the at least two shifted carriers.

4. The receiver of claim **3**, wherein the side carrier boosting module includes:

a splitter for splitting the received optical data signal and transmitting the optical data signal into an upper branch and a lower branch;

a Fabry-Perot resonator coupled to the upper branch for filtering the at least one side carrier from the at least two data bands in the optical data signal fed to the upper branch;

an attenuator coupled to the lower branch for attenuating the optical data signal transmitted via the lower branch;

a combiner coupled to both the upper and lower branches, the combiner combining and outputting the optical data signals transmitted via each of the upper and lower branches; and

an optical amplifier coupled to the combiner for amplifying the output of the combiner;

wherein an amplitude of the at least one side carrier is increased relative to an amplitude of the at least two data bands.

5. The receiver of claim **3**, wherein the side carrier boosting module includes:

a splitter for splitting the received optical data signal and transmitting the optical data signal into an upper branch and a lower branch; and

a Fabry-Perot resonator coupled to the upper branch for filtering the at least one side carrier from the at least two data bands in the optical data signal fed to the upper branch;

a modulator coupled to the Fabry-Perot resonator for modulating an 11 GHz signal onto the at least one side carrier output from the Fabry-Perot resonator;

a further Fabry-Perot resonator coupled to an output of the modulator for selecting a frequency 11 GHz above the at least one side carrier; and

a circulator coupled to both an output of the further Fabry-Perot resonator and the lower branch, the circulator sending the output of the further Fabry-Perot resonator in along the lower branch in a direction opposite to a transmission direction of the optical data signal;

wherein the optical data signal collides with the output of the further Fabry-Perot resonator inducing a Stimulated Brillouin Scattering effect, the effect enhancing an amplitude of the at least one side carrier in the optical data signal relative to an amplitude of the at least two data bands in the optical data signal.

6. The receiver of claim **5**, wherein the side carrier boosting module includes:

an amplifier for amplifying the output from the further Fabry-Perot resonator;

an isolator in the lower branch downstream of the splitter, the isolator blocking the progress of the output from the further Fabry-Perot resonator along the lower branch; and

dispersion compensating fiber coupling the circulator with the isolator along the lower branch, the dispersion compensating fiber enhancing Stimulated Brillouin Scattering events occurring within the fiber.

7. The receiver of claim **3**, further comprising:

a chromatic dispersion compensation stage, the chromatic dispersion stage receiving as input in-phase and quadrature-phase signals of the quadrature modulated data signals, the chromatic dispersion correction stage including:

a first splitter for splitting the input in-phase signal into a first branch and a second branch;

a first COS circuit coupled to the first splitter for applying a COS transfer function to the in-phase signal in the first branch;

a first SIN circuit coupled to the first splitter for applying a first SIN transfer function to the in-phase signal in the second branch;

a second splitter for splitting the input quadrature-phase signal into a first quadrature branch and a second quadrature branch;

an inverter coupled to the second quadrature branch for changing the phase of the quadrature signal in the second branch 180 degrees;

a second COS circuit coupled to the first splitter for applying a COS transfer function to the quadrature signal in the first branch;

a second SIN circuit coupled to the first splitter for applying a SIN transfer function to the quadrature signal in the second branch;

a first combiner for combining output from the first SIN circuit with output from the second COS circuit into a corrected quadrature output signal; and

a second combiner for combining output from the first COS circuit with output from the second SIN circuit into a corrected in-phase output signal.

8. The receiver of claim **7**, wherein the received optical data signal includes a transmitter identification code embedded in one of the at least one side carrier and the chromatic dispersion compensation stage further includes:

a chromatic dispersion module coupled to an input for receiving the transmitter identification and also coupled to the first and second COS circuits and the first and second SIN circuits;

wherein the chromatic dispersion module is operative to transmit signals to the first and second COS circuits and the first and second SIN circuits, the signal effectuating adjustments to the respective transfer functions applied by the first and second COS circuits and the first and second SIN circuits in accordance with information extracted from the transmitter identification.

9. The receiver of claim **8**, wherein the extracted information includes information describing the location of a transmitter from which the received optical data signal originates.

10. The receiver of claim **8**, wherein the first and second COS circuits and the first and second SIN circuits include microstrip elements, the microstrip elements having variable lengths and widths and modifying input signals according to the variable lengths and widths.

11. The receiver of claim **3**, wherein means for compensating polarization mode dispersion include:

a frequency filter coupled to an output of the side carrier shifting module; and at least two polarization controllers, the at least two polarization controllers coupled to the frequency filter and to a photodetector output, each polarization controller receiving one of the two shifted side carriers and altering a polarization state of the received shifted side carrier to match a polarization state of the data band at which the shifted side carrier is centered, the polarization state of the data band being received via feedback from the photodetector output.

12. The receiver of claim 11, further comprising:

a phase shifter coupled to and receiving output side carriers from the at least two polarization controllers, the phase shifter splitting the received shifted side carrier signals into a first branch and a second branch, the second branch signal being shifted 90 degrees with respect to the first branch signal;

a first combiner for combining the first branch with the data bands of the optical data signal;

a second combiner for combining the second branch with the data bands of the optical data signal; and

a first demultiplexer coupled to the first combiner and filtering output from the first combiner into first and second in-phase channels according to frequency, the first and second in-phase channels each including a data band and a shifted side carrier;

a second demultiplexer coupled to the second combiner and filtering output from the second combiner into third and fourth quadrature-phase channels according to frequency, the third and fourth quadrature-phase channels each including a data band and a shifted side carrier; and

at first set of photodetectors coupled to the first demultiplexer for optoelectrically converting the first and second in-phase channels; and

a second set of photodetectors coupled to the second demultiplexer for optoelectrically converting the third and fourth quadrature-phase channels;

wherein output from the first and second set of photodetectors is provided to the at least two polarization controllers, the polarization controllers match polarization states of the first, second, third and fourth channels with the respective side carrier within each of the channels.

13. The receiver of claim 12, wherein the first and second demultiplexers are dense wave division demultiplexers.

14. A method of correcting a quadrature modulated optical data signal for effects of chromatic dispersion comprising the steps of:

deriving in-phase and quadrature data signals via a homodyne reception system; and

applying a corrective function to the in-phase and quadrature data signals, the corrective function modifying the in-phase and quadrature data signals in a manner that precisely counteracts effects of chromatic dispersion on the in-phase and quadrature components of the optical data signal.

15. A method of correcting in-phase and quadrature data signals for effect of chromatic dispersion prior to modulation onto an optical data signal, comprising the steps of:

providing an in-phase data signal on a first input and providing a quadrature data signal on a second input; and

applying a corrective function to the in-phase and quadrature data signals, the corrective function modifying the in-phase and quadrature data signals in a manner that precisely counteracts effects of chromatic dispersion occurring when the in-phase and quadrature data signals are modulated onto the optical data signal and transmitted across optical fiber.

16. A receiver for receiving and processing an optical data signal, the optical data signal including at least two data bands and at least one side carrier, each of the at least two data bands including a pair of quadrature modulated data signals, the receiver comprising:

a side carrier boosting module, the side carrier boosting module for increasing an amplitude of the at least one side carrier relative to the at least two data bands;

a side carrier shifting module coupled to the side carrier boosting module, the side carrier shifting module for shifting the at least one side carrier into at least two shifted carriers, each of the at least two shifted carriers shifted to a center of one of the at least two data bands; and

a chromatic dispersion compensation stage, the chromatic dispersion stage receiving as input in-phase and quadrature-phase signals of the quadrature modulated data signals, the chromatic dispersion correction stage including:

a first splitter for splitting the input in-phase signal into a first branch and a second branch;

a first COS circuit coupled to the first splitter for applying a COS transfer function to the in-phase signal in the first branch;

a first SIN circuit coupled to the first splitter for applying a first SIN transfer function to the in-phase signal in the second branch;

a second splitter for splitting the input quadrature-phase signal into a first quadrature branch and a second quadrature branch;

an inverter coupled to the second quadrature branch for changing the phase of the quadrature signal in the second branch 180 degrees;

a second COS circuit coupled to the first splitter for applying a COS transfer function to the quadrature signal in the first branch;

a second SIN circuit coupled to the first splitter for applying a SIN transfer function to the quadrature signal in the second branch;

a first combiner for combining output from the first SIN circuit with output from the second COS circuit into a corrected quadrature output signal; and

a second combiner for combining output from the first COS circuit with output from the second SIN circuit into a corrected in-phase output signal.

* * * * *

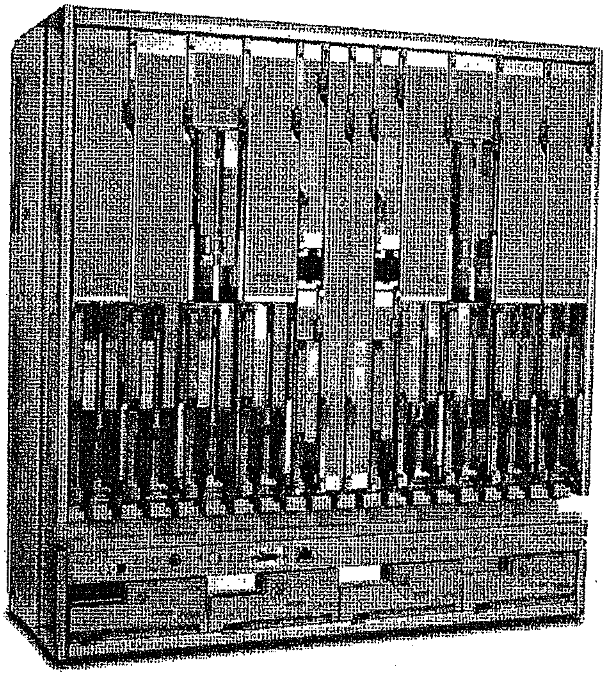
EXHIBIT B

FUJITSU

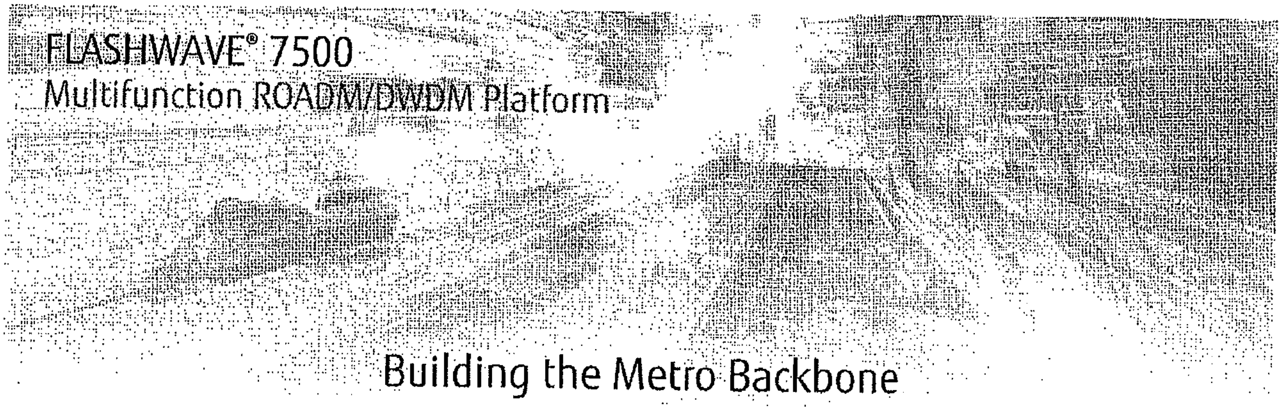
shaping tomorrow with you

FLASHWAVE® 7500

Multifunction ROADM/DWDM Platform



The FLASHWAVE 7500 platform offers advanced DWDM, optical hubbing, ROADM, and network capabilities to deliver and manage growing metro and regional networks. The system supports both ANSI and ETSI-certified solutions, with flexible configurations to optimize metro and regional networks.



FLASHWAVE® 7500

Multifunction ROADM/DWDM Platform

Building the Metro Backbone

Metro and regional optical networks are entering a period of dramatic expansion, driven by demand for high-speed data services, legacy TDM services, and high-bandwidth video services. Competing successfully requires a network architecture that consolidates and manages all high-bandwidth services over a single core optical transport network. The FLASHWAVE 7500 system provides a high-capacity ROADM platform for metro and regional networks, improving operational efficiency, reducing operations expenses, and lowering overall network costs.

Flexible Architecture, Deployed Worldwide

Chosen by major service providers worldwide, the FLASHWAVE 7500 platform is deployed in North America, Europe and Asia. American National Standards Institute (ANSI) and European Telecom Standards Institute (ETSI)-certified versions allow operation in any global environment. The platform aggregates TDM, SONET, Ethernet, and video services onto a single core optical transport infrastructure, improving efficiency, flexibility, and cost-effectiveness.

Field-Proven Technology

As the industry-leading metro ROADM platform, thousands of FLASHWAVE 7500 nodes are in operation with dozens of carriers worldwide, providing proven real-world performance. In addition, the systems go through rigorous internal system testing and verification prior to each software release. The FLASHWAVE 7500 platform has also been extensively tested by numerous outside facilities. These include customer test labs, NEBS, UL, Telcordia OSMINE, in addition to federal government testing and certification by the U.S. Defense Information Systems Agency (DISA)-sanctioned Joint Interoperability Test Command (JITC).

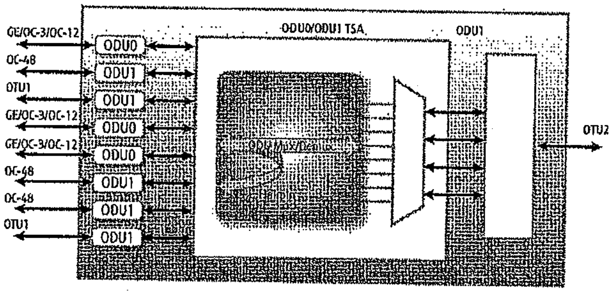
Recent Product Enhancements

New FLASHWAVE 7500 features and enhancements improve network performance, enable new applications, and offer DWDM network and operational efficiencies. These new capabilities deliver significant capital and operational cost benefits.

OTN Muxponder

Optical Transport Network (OTN) technology has been used for years in DWDM equipment, implemented as G.709 digital wrapper for wavelengths. OTN provides a common frame structure, optical layer Operations, Administration and Maintenance (OAM), General Communications Channel (GCC0), and Forward Error Correction (FEC) for improved performance.

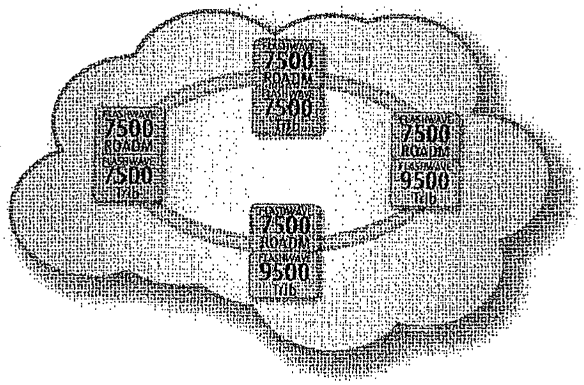
Carriers are adopting OTN for sub-wavelength multiplexing and aggregation applications, in addition to its role as a digital wrapper for wavelengths. OTN multiplexing offers several benefits over other techniques, including universal containers supporting any signal type, transparent aggregation of signals, an industry-standard multiplexing scheme, and robust OAM.

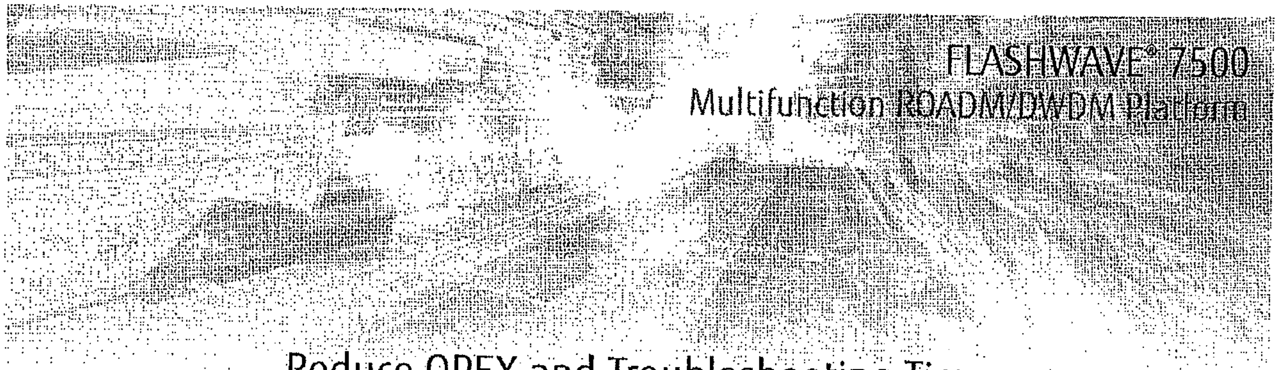


With the introduction of the OTN muxponder unit on the FLASHWAVE 7500 platform, carriers can enable OTN multiplexing and services on existing ROADM networks. Supporting eight client ports of OC-3, OC-12, OC-48, GbE, and OTU1 services, the OTN muxponder maps all services into standard OTN containers and a 10G OTU2 network interface. In addition to the OTN muxponder unit, Fujitsu is adding 40G OTU3 support to the existing 40G transponder cards. OTN is transforming optical transport networks–with Fujitsu leading the way.

FLASHWAVE 7500 and 9500 Integration

Carriers can now have the best of both worlds, with the ability to mix and match transponders and muxponders from either the FLASHWAVE 7500 or 9500 platforms, over a common FLASHWAVE 7500 ROADM network.





FLASHWAVE® 7500
Multifunction ROADM/DWDM Platform

Reduce OPEX and Troubleshooting Time

With thousands of FLASHWAVE 7500 nodes deployed, existing carriers and networks can upgrade to the latest technologies and advancements, such as the Fujitsu 100G transponder and 100G muxponders, all running over their existing ROADM infrastructure. FLASHWAVE 7500 and 9500 integration enables carriers to expand and enhance their network without the need for costly overbuilds.

40G Improves Network Utilization

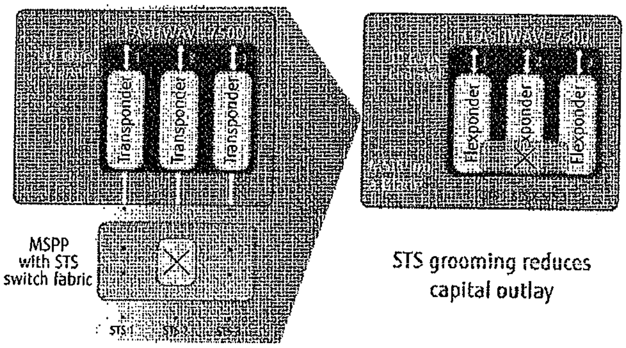
The FLASHWAVE 7500 system supports 10G, 40G, and 100G (via 9500 trib) wavelengths with a wide array of transponder and muxponder service units.

Recently, 40G units have become increasingly popular and widely deployed, providing carriers with a fourfold improvement in capacity. Fujitsu supports both coherent and non-coherent 40G units. The non-coherent 40G units are based on Adaptive Dual Phase Shift Keying (ADPSK) and provide a cost-effective method for expanding capacity in metro and regional DWDM networks. However, these 40G ADPSK units are not applicable on high Polarization Mode Dispersion (PMD) fiber spans.

PMD is an optical impairment with some older fibers that limits both transmission speeds and span distances. The 40G coherent transponders enable deployment and operation over high PMD routes, which were previously limited to 10G operation. Carriers reap substantial savings by eliminating the need to remove and replace problematic high-PMD routes.

Sub-Wavelength Aggregation Reduces Capex

The Flexponder unit is an 8-port multirate, multiservice unit that integrates SONET STS-1 aggregation and switching along with WDM on a single card. Commonly referred to as a "Multiservice Provisioning Platform (MSPP)-on-a-blade," these cards perform the functions previously performed by standalone SONET MSPPs, saving equipment costs, space, and power.



STS grooming reduces capital outlay

The flexponder can be used as a single unit, supporting eight multirate, multiservice ports along with an integrated 20G STS-1 switch fabric for traffic grooming, or with multiple units. When using multiple flexponders, the system provides sub-wavelength aggregation and grooming across all units installed in a shelf with a 160G STS-1 distributed switching matrix.

Stacked Muxponders Reduce Remote Costs

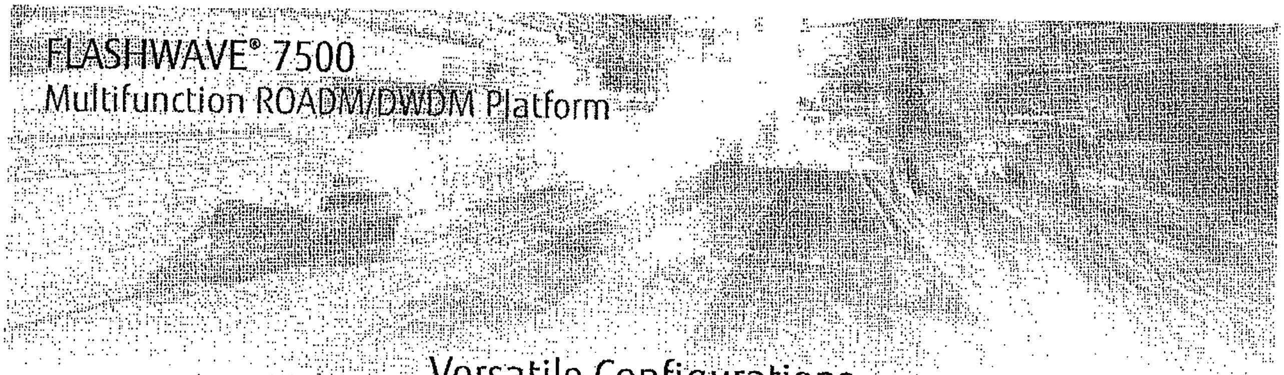
The FLASHWAVE 7500 Extension Shelf provides a low-cost method of extending services to customer premises or remote locations. Instead of a full ROADM node at the remote location, the Extension Shelf can be deployed with a single transponder or muxponder, utilizing the network-side optical interface as a single-channel transport system. The limitation of this approach is that many remote sites require more low-speed aggregation ports than available on a single 10G muxponder unit. By combining multiple 10G muxponder cards with a 40G muxponder card in a stacked configuration, carriers can efficiently aggregate remote services and transport them over a single 40G channel, without the cost of a full ROADM node.

A similar application is to provide capacity expansion and fiber relief on fully filled DWDM networks. By upgrading to 40G wavelengths, carriers can expand their network capacity by a factor of four, without costly network overbuilds. Existing 10G muxponders, providing low-rate client OC-3/12/48 or GbE services, can be combined with the 40G muxponder unit in a stacked configuration to enable 40G or even 100G DWDM transport.

Enhanced Software Operational Features

Several operational features and enhancements have been incorporated to improve performance and reduce operation time and costs.

[illegible]	[illegible]
Security Enhancements	Added protection for user passwords and network ports ensures the utmost security from network compromise for the most demanding, secure network environments
Enhanced alarm storage for WSS & amplifier modules	Additional storage of PM values aids in network troubleshooting and prevention
Client-side DWDM XFPs	Reduces costs by eliminating the need for back-to-back transponders when interconnecting WDM networks (FLASHWAVE 7210 or 9500)
Multiple IS-IS instances	Enables OSI management area to be subdivided specifically within optical hub nodes, as networks grow and expand in size. Improved network management and scalability



FLASHWAVE® 7500

Multifunction ROADM/DWDM Platform

Versatile Configurations

As a unified, scalable platform, the FLASHWAVE 7500 system offers flexible configurations to support a wide range of applications, including:

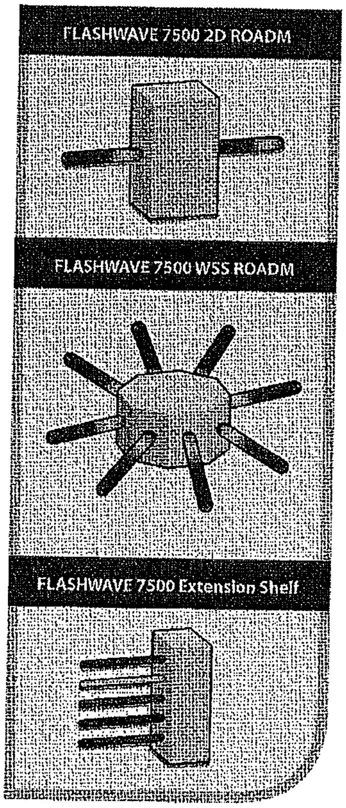
- FLASHWAVE 7500 WSS ROADM (1–12 degree optical hubbing)
- FLASHWAVE 7500 2-degree ROADM
- FLASHWAVE 7500 Extension Shelf for low-cost, remote nodes
- FLASHWAVE 7500 In-Line Amplifier (ILA)

The FLASHWAVE 7500 optical line cards and software are common to all configurations, reducing operational costs for engineering, training, installation and spare parts. Chassis options include a 23-inch North American version, a 19-inch version, and a 500 mm front-access ETSI version.

The FLASHWAVE 7500 system also supports managed service extensions with the FLASHWAVE CDS Micro Packet Optical Networking Platform (Packet ONP) and FLASHWAVE 7120 Access CWDM/DWDM platform. The FLASHWAVE CDS is a compact 2RU customer premises platform that provides advanced Ethernet services and legacy SONET services. The FLASHWAVE 7120 provides a small, cost-effective WDM solution for transporting multiple wavelengths in access applications.

The FLASHWAVE 7500 platform supports both mixed 10G and 40G wavelengths on the same network, enabling carriers to efficiently and cost-effectively upgrade their WDM capacity, without the need for expensive overbuild networks.

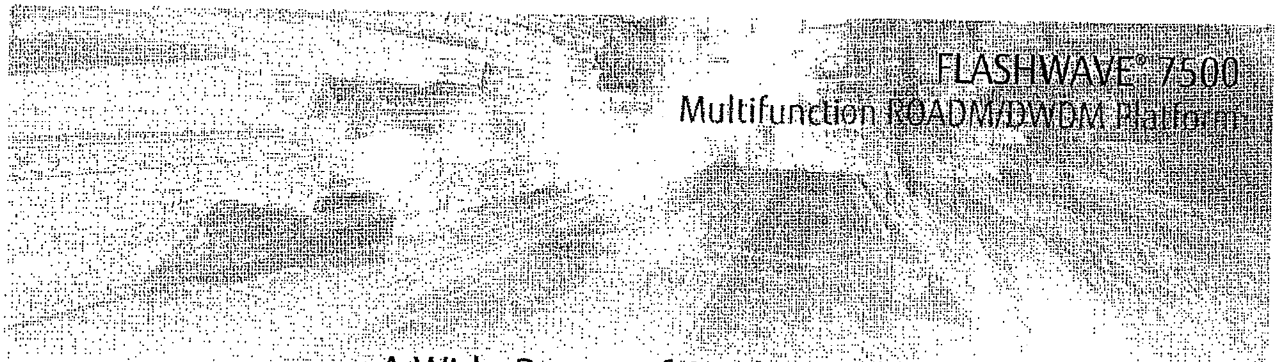
FLASHWAVE 7500 WSS ROADM
The FLASHWAVE 7500 wavelength selective switch (WSS) ROADM provides a powerful and cost-effective solution for metro and regional networks. Supporting up to 40 channels and capacity up to 1.6 Tb, the system provides an ideal solution for consolidated core optical networks, eliminating costly multiple overlay networks for each service type. Advanced features, such as automatic power balancing, optical hubbing, and A-Z wavelength provisioning, reduce operational expenses and improve service implementation times. Configurations range from simple 2-degree ROADMs to multidegree optical hub nodes supporting complex mesh network architectures.



FLASHWAVE 7500 2D ROADM
An economical choice for locations only requiring two degrees of connectivity, as opposed to multidegree hubbing, the FLASHWAVE 7500 2D ROADM can be deployed alone or in mixed applications along with FLASHWAVE 7500 WSS optical hub nodes. The 2D ROADM provides full 1–40 channel support, ring, linear, and terminal configurations, and utilizes all of the same optical line cards for client-side service interfaces. In addition, the 2D ROADM supports up to eight transponder slots on the same shelf as the ROADM switch/muxponder and amplifier cards, enabling single-shelf deployments for low channel-count sites. Additional tributary shelves can always be added when additional slot capacity is required.

FLASHWAVE 7500 Extension Shelf
The FLASHWAVE 7500 Extension Shelf is a non-ROADM standalone configuration designed to extend individual services to customer premises. Primarily intended for single-channel extensions, the system offers very low-cost service delivery without the need for DWDM layer amplifiers, optical switches, and multiplexer/demultiplexer units.

FLASHWAVE 7500 ILA
Large optical networks require amplification every 60–100 Km, depending on the fiber type, data rates, and service mix. At those midpoints where service or wavelength drops are not required, the FLASHWAVE 7500 ILA offers a very economical solution to re-amplify the WDM signal and extend the network reach. If service or wavelength drops are ever needed at an ILA location, the FLASHWAVE 7500 ILA can be upgraded in-service to a full ROADM node.



FLASHWAVE® 7500

Multifunction ROADM/DWDM Platform

A Wide Range of Applications

Core Transport Infrastructure

As a high-capacity optical transport platform, the FLASHWAVE 7500 ROADM is ideal for aggregating large, high-bandwidth services over a single optical core network. Previously, carriers typically deployed separate transport networks for each service type and network layer. The FLASHWAVE 7500 consolidates TDM, SONET, Ethernet, and video services into a single DWDM infrastructure, providing substantial savings and streamlining the network architecture, while providing additional capacity for future network growth.

Collapsed Network Functions

The FLASHWAVE 7500 system is more than just a pure optical transport platform, as it also supports sub-wavelength grooming and aggregation for legacy SONET services. In a typical network, SONET MSPPs provide STS-1 grooming and aggregation for OC- 3/12/48 interfaces, with an OC-192 interconnection to the DWDM layer. Most DWDM locations also have many subtending SONET MSPPs, providing STS-1 level aggregation, grooming, and switching.

The FLASHWAVE 7500 Flexponder unit eliminates the need for subtending SONET MSPPs, by integrating SONET physical interfaces, STS-1 switching, and SONET protection switching into a single unit along with DWDM. The FLASHWAVE 7500 Flexponder supports eight multirate, multiservice ports that can be individually provisioned for OC-3/12/48 or GbE services, with a high-speed, full-band tunable OTU2 (10G DWDM) network interface. The Flexponder can be used as a single unit providing eight multirate ports along with an integrated 20G STS-1 switch fabric. It can be deployed in pairs, functioning as a SONET MSPP on a blade with SONET 1+1 and UPSR protection switching, along with the integrated STS-1 fabric. Finally, multiple units can be deployed supporting up to 160G of STS-1 switching and aggregation across all ports in the shelf.

High-PMD Routes

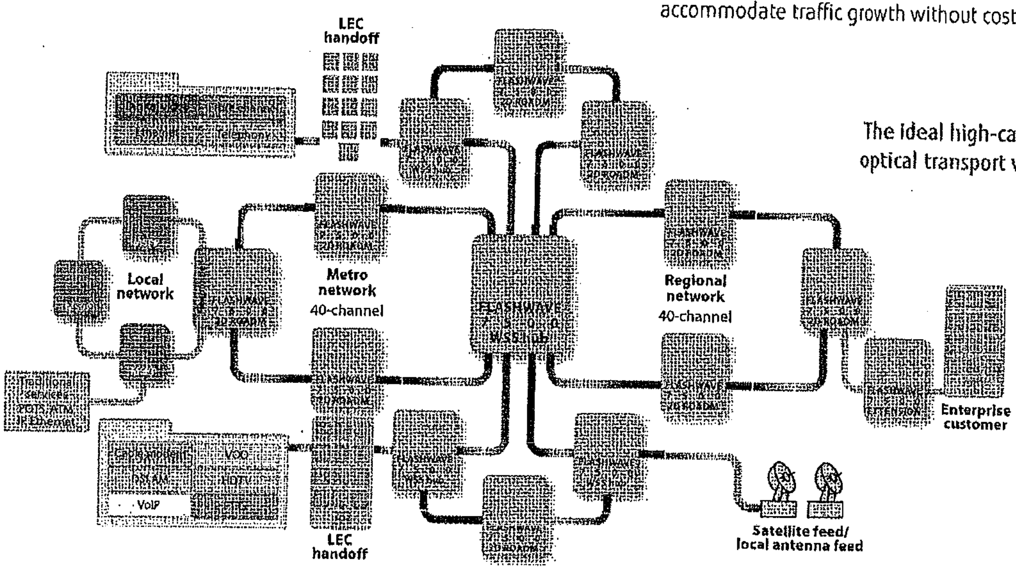
For optical routes with high polarization mode dispersion (PMD), the FLASHWAVE 7500 platform supports both 10G and 40G transponders superficially designed for problematic high-PMD fiber. The 40G coherent transponder and muxponder units utilize advanced DP-QSPK modulation and coherent optical receivers, which improves performance over high-PMD fiber.

Video Distribution

Perfectly suited for video applications in the cable and IPTV industry, the FLASHWAVE 7500 platform lets service providers distribute both broadcast and VoD video streams over large metro and regional networks from headend offices to video serving offices or distribution hubs.

Private Network Applications

As the backbone infrastructure for large private network applications, the FLASHWAVE 7500 system ensures that financial institutions, educational consortiums and federal government installations can accommodate traffic growth without costly network upgrades.



The ideal high-capacity optical transport vehicle

FLASHWAVE® 7500
Multifunction ROADM/DWDM Platform

Network Life Cycle Services

Fujitsu offers a broad selection of professional services to assist at every stage in a network's evolution and operation. From planning through deployment and ongoing maintenance to future enhancements, Fujitsu Network Life Cycle Services are available whenever needed. Our comprehensive range of services includes network and system design, training, customized deployment, craft interface software, migration planning and more. Your Fujitsu sales representative can guide you in selecting the right service options for your business.

Popular planning and deployment services for the FLASHWAVE 7500 multifunction ROADM/DWDM platform include:

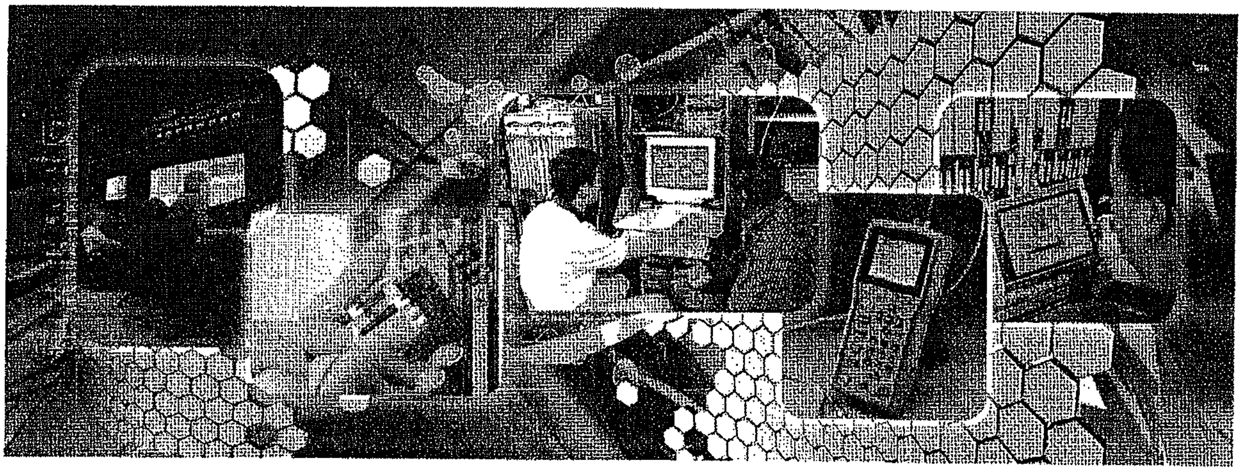
Fiber characterization – Fujitsu offers comprehensive analysis of installed fiber to improve current network performance, prepare for new growth and identify potential issues.

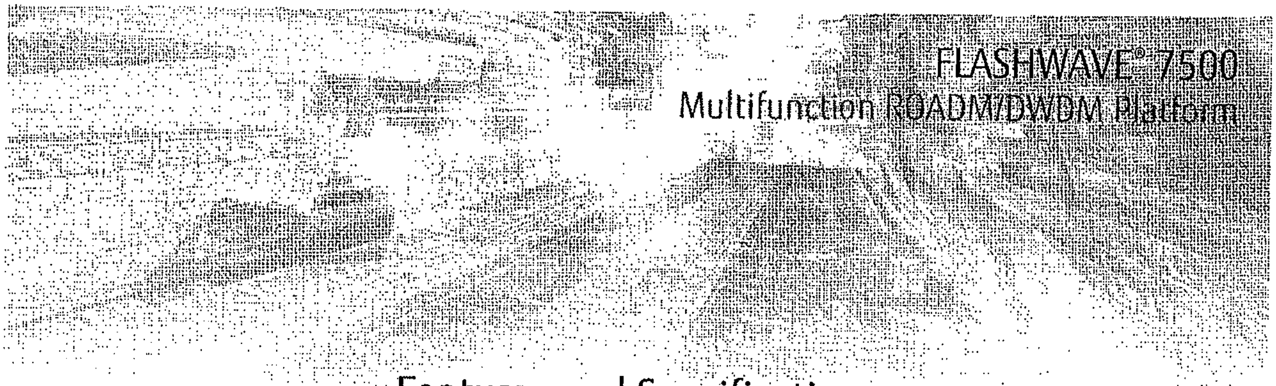
Onsite mentoring – Our experts provide full training and knowledge transfers.

Design services for DWDM networks – Our professional design staff works with you to prepare a complete, custom roadmap for success.

Fujitsu Maintenance and Support Program
For a complete professional maintenance solution, the Fujitsu Maintenance and Support Program has the right combination of flexibility and comprehensive assurance. Choose the level and types of service you need to supplement your own resources. The Maintenance and Support Program helps keep your network running smoothly, provides critical care and protects the longevity of your investment.

Network Operations Center
With a full range of vendor-independent network fault and performance monitoring features, the Fujitsu Network Operations Center (NOC) offers guaranteed, round-the-clock system protection. Our reliable NOC facility is available as a primary or supplemental operations resource. This service not only helps you control costs and maintain high levels of customer satisfaction, it also provides trustworthy and reliable after-hours and emergency coverage.





FLASHWAVE® 7500
Multifunction ROADM/DWDM Platform

Features and Specifications

Architectures	• Optical hubbing (up to 12 degrees) • Ring • Mesh • Linear add/drop • Point-to-point • In-Line Amplifier (ILA)
Network Capacity	• 1.6 Tbps (40 wavelengths at 40 Gbps each) • Up to 1200 Km reach without regeneration • WSS-based optical switch fabric (1 to 12 degrees) • 2D-only ROADM option • Optional Raman amplifiers for extended-reach spans • FLASHWAVE 7500 Extension Shelf for low-cost remote services
Optical Line Cards	• Transponders/regenerators for 10G and 40G services • Muxponders including 4x1 10G, 4x1 2.5G, and 8x1 10G • OTN muxponder 8-port for OC-3/12/48/GbE and OTU1 services • Flexponder 8x1 SONET MSPP-on-a-blade for OC-3/12/48 and GbE services • Full C-band tunable narrowband optics at 10G, 40G, and 100G • G.709-compliant digital wrappers with RS-FEC, Ultra FEC (U-FEC and enhanced FEC (E-FEC) • SFP/XFP pluggable client-side optics

Optical Line Cards

40G transponder	• OC-768/STM-256 • OTU3
40G muxponder (4 x 10G)	• OC-192/STM-64 • 10 GbE • OTU2
10G universal transponder	• OC-192/STM-64 • 10 GbE • OTU2
10G muxponder (4 x 2.5G)	• OC-48/STM-16
OTN mupxonder (8-port)	• OC-3/12/48 • STM1/STM4/STM16 • GbE • OTU1
10G Flexponder (8-port)	• OC-3/12/48 • STM1/STM4/STM16 • GbE
Gbe muxponder (8-port)	• GbE
Multirate 2.5G transponder (1-port)	• Multirate transponder 100 Mbps–2.7 Gbps for any service type

System Features	• Automatic per-channel power balancing • A-Z wavelength provisioning • Sub-wavelength grooming and aggregation (160G) per shelf • Optical hubbing for ring and mesh network interconnections • ILA upgrades to full ROADM node in-service	
Operations	• TL1 over TCP/IP • TL1 over OSI • SNMP (alarms) • Remote software updates • Remote memory backup/restore • NETSMART® 500 Element Manager • NETSMART 1500 Management System • NETSMART 2000 Network Design and Planning Tool	
Monitoring and Alarms	• Optical per-channel and WDM monitoring • Wavelength management • Optical layer (OTN) PM • SONET/SDH PM • Gigabit Ethernet PM	
Power Consumption/ Heat Dissipation	• Optical/hub shelf • Tributary shelf • ILA	<360W (1228 BTU/hr) <630W (2150 BTU/hr) <360W (1228 BTU/hr)

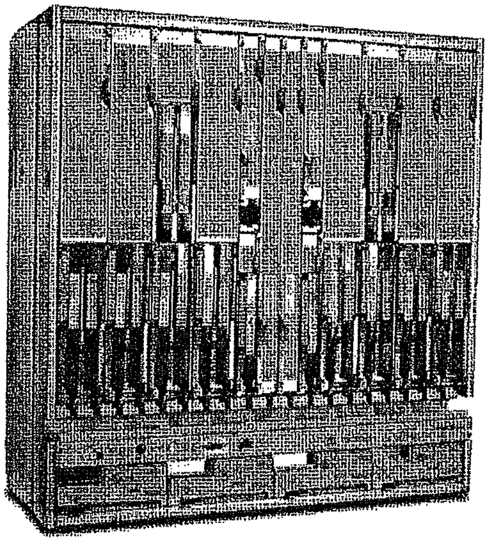
Operating Environment	• Temperature
	• Humidity
	• Power input
	• NEBS Level 3 compliant
	• FLASHWAVE 7500 ETSI system meets the following requirements for CE marking:
	  • EMC Directive 2004/108/EC
	  • UL/ IEC 60950
	  • IEC/EN 60825-1 and IEC/EN60950-1 requirements for a Class 1 laser product
	  • Restriction of Hazardous Substances Directive 2002/95/EC
	  • Waste of Electrical and Electronic Equipment (WEEE) Directive 2002/96/EC
		–5 to 50 °C (23 to 122 °F)
		5 to 95% (non-condensing)
		–48 V DC

Physical Characteristics	Dimensions (H x W x D)	23" Shelf: 22.5 x 21.5 x 11.5" (572 x 546 x 292 mm) 19" Shelf: 22.5 x 17.3 x 11.5" (572 x 439 x 292 mm) ETSI shelf: 30.2 x 19.3 x 11.5" (767 x 490 x 292 mm)
	Weight (fully loaded shelf)	<145 lb (66 kg)

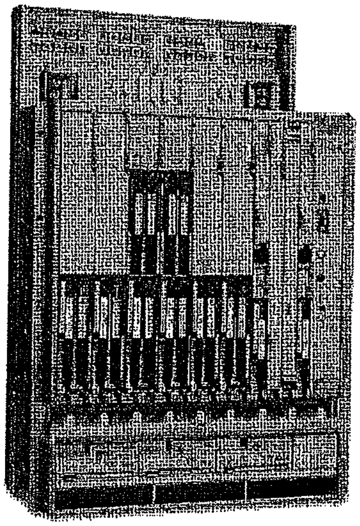
FLASHWAVE® 7500

Multifunction ROADM/DWDM Platform

Available in ANSI and ETSI Shelf Configurations



FLASHWAVE 7500 ANSI Shelf



FLASHWAVE 7500 ETSI Shelf

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Home > News > Fujitsu Introduces Cutting-edge 100G Optical Component and Module Solutions at OFC/NFOEC 2013

- Home
  - About
  - Business
  - Facilities
  - Products & Services
  - News

PRESS RELEASE

Fujitsu Optical Components Limited

Fujitsu Introduces Cutting-edge 100G Optical Component and Module Solutions at OFC/NFOEC 2013

Kawasaki, Japan, March 15, 2013 - Fujitsu Optical Components Limited (FOC) announced today that it will be displaying its cutting-edge 100G optical component and module solutions at the OFC/NFOEC (*1) 2013 show which will be held next week in Anaheim, California, USA. The product exhibition can be seen in FOC's booth #1310 at the Anaheim Convention Center, March 19-21, 2013.

Rapid increase in the volume of communications traffic has come from the spread of new services such as mobile broadband using smart devices, social networking, cloud computing and on-line streaming. This has created a great demand for 100G optical networks. The requirement for Core Networks to handle larger capacity and longer distance on their links has led to a spread of 100G optical networks using digital coherent transmission systems (*2). Similarly, the requirements on IP networks between data centers and metro core networks to achieve larger capacity, higher port density, and lower cost has led to the spread of 100 GbE optical networks.

FOC has been the industry leader in the development of ultra–high speed optical components and modules needed to meet this requirement. FOC released its 100G coherent transceiver (as defined in the OIF (*3) 100GLH-EM specifications) for 100G digital coherent transmission systems and its 100GbE CFP LR4/ER4 transceiver (compliant with the CFP MSA) for 100GbE networks in advance of other companies. FOC will now newly introduce a 100 GbE CFP2 transceiver intended for LR4 applications as well. Combined with its 100G DP-QPSK (*4) LN modulator (first in the world) and integrated receivers for use in coherent transceiver applications, FOC truly provides a total solution to a broad range of customer requirements at 100 Gbps.

At OFC/NFOEC 2013, FOC will introduce its latest product line-up and future product roadmap for 100G coherent and CFP/CFP2 transceivers, 100G DP-QPSK LN modulators, and 100G DP-QPSK integrated receivers. This exhibition will show that FOC can support the customer's total needs for 100G optical components and modules.

【100G Coherent Transceiver】
This product is defined in the OIF 100GLH-EM specification for 100G digital coherent transmission systems. Digital signal processing has been applied to compensate for waveform distortion which results in high tolerance to optical dispersion. High performance and reliability have been achieved by using FOC's in house 100G DP-QPSK LN modulator and 100G DP-QPSK integrated receiver.

【CFP2 Transceiver】
This product is compliant with the CFP2 MSA specifications for LR4 applications in 100G Ethernet networks (CFP2 transceiver for ER4 applications is now under development.). The CFP2 transceiver uses a 28 x 4Gbps lane electrical interface compliant with the CEI-28G-VSR specification. The introduction of this new interface enables compact size (about half width of the current CFP) and low power consumption (about 1/3 of the current CFP) transceiver.

【100G DP-QPSK LN Modulator】
This product is a Mach-Zehnder modulator made from Lithium Niobate (LiNbO3) designed to meet the OIF specifications for 128 Gbs (32 Gbaud) DP-QPSK applications. The modulator incorporates the DP-QPSK optical modulation circuit, polarization beam combiner and monitor photodiode all inside of a compact package. The FOC design allows for both wide bandwidth and low drive voltage operation.

【100G DP-QPSK Integrated Receiver】
This product is a 100G integrated receiver compliant with the OIF specifications for 100Gbps digital coherent receiving systems. The integration of 90° Hybrids (*5), Balanced Receivers (*6) and

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Polarizing Beam Splitters all into a single package by PLC (*7) and micro-assembly technologies allows to realize a compact, low-cost and high-performance 100G integrated receiver.

In addition, Fujitsu Laboratories Ltd will demonstrate 400GbE transmission technology using DMT (Discrete Multi-Tone) modulation format in the FOC booth as "DMT Modulation Format 400GbE Transmission Demonstration".

FOC will also participate in OIF Interoperability 2013 at OIF booth #2769.

OIF Interoperability 2013
More than ten OIF member companies will unite under the banner of the Optical Internetworking Forum to showcase multi-vendor participation in OIF Interoperability 2013 – Enabling the Next-Generation of 100G Optical Modules. The OIF's PLL demonstration will showcase the draft CEI-28G-VSR implementation agreement key to enabling the next generation of more efficient, smaller form factor 4x 25G Optical Modules.
A public demonstration of the event will be on display March 19-21, 2013 at OFC/NFOEC in Anaheim, CA, OIF Booth #2769. Additional information can be found at http://www.oiforum.com/public/OIF_Interoperability_2013.html

Additional Information

- http://jp.fujitsu.com/foc/en/

Glossary & Notes

(*1) Acronym for Optical Fiber Communication Conference and National Fiber Optic Engineers Conference

(*2) Converts the received optical signal to an electrical signal in the optical receiving section after combining the received optical signal with a local reference light, and then compensates the waveform distortion that occurs in the optical transmission path by digital signal processing. This technique allows for significant reduction in system cost through the elimination of optical dispersion compensators and optical amplifiers (for loss compensation).

(*3) Acronym for Optical Internetworking Forum. The OIF is an organization that promotes standardization for the equipment and components used in optical networks.

(*4) Acronym for Dual-Polarization Quadrature Phase Shift Keying. It is a method of phase modulation for digital signals, in which 2 bits of data are allocated to each of 4 modulated optical phases (0, 90, 180, 270°) for both P-polarized and S-polarized light.

(*5) Optical mixer component that is used for coherent signal demodulation purposes in heterodyne and intradyne detection systems. The hybrid mixes the incoming optical data signal with light from an input optical reference source and guides the combined signal to the balanced receivers.

(*6) A receiver consisting of two photodiodes which receives differential optical output from delay line interferometers and 90° Hybrids. Improved receiver characteristics are achieved by using the difference between the two photodiode currents.

(*7) Acronym for Planar Lightwave Circuit. Optical circuit chip on a silicon or quartz substrate containing optical waveguides with accuracies on the order of an optical wavelength

Customer Contacts

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Sales Promotion Dept.
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About Fujitsu Optical Components

Aiming to strengthen Fujitsu's optical module business, Fujitsu Optical Components was established on April 1st, 2009 as a wholly owned subsidiary of Fujitsu Limited. With the establishment of the new company, the sales, research and development, and manufacturing functions of Fujitsu's optical module business were integrated under a unified management structure. Headquartered in Kawasaki, Japan, Fujitsu Optical Components is a leading supplier of advanced, highly reliable, customer-focused optical components for datacom and telecommunication applications in the global market.

Its broad product line-up includes100G Coherent Transceiver, 100GE CFP/CFP2 Transceivers, 40G/100G LN Modulators, 100G Integrated Receivers, SR/IR/LR/DWDM (Fixed & Tunable) XFP Transceivers and SFP+ Transceivers. For additional information, visit http://jp.fujitsu.com/foc/en/

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Top of Page

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