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Attorneys for Plaintiff
Applied Optoelectronics, Inc.

UNITED STATES DISTRICT COURT

NORTHERN DISTRICT OF CALIFORNIA

APPLIED OPTOELECTRONICS, INC., Plaintiff, vs. EOPTOLINK TECHNOLOGY USA INC., Defendant.	Case No.: **COMPLAINT FOR PATENT INFRINGEMENT** **DEMAND FOR JURY TRIAL**

For its complaint against Defendant Eoptolink Technology USA Inc., (“Eoptolink” or “Defendant”), Plaintiff Applied Optoelectronics, Inc. (“AOI” or “Plaintiff”) alleges on personal knowledge as to its own activities and on information and belief as to the activities of others as follows:

THE PARTIES

1. Plaintiff AOI is a Delaware Corporation with its principal place of business located at 13139 Jess Pirtle Blvd., Sugar Land, Texas 77478.

2. On information and belief, Defendant Eoptolink Technology USA Inc. is a California Corporation with its principal place of business located at 3191 Laurelview Court, Fremont, CA 94538.

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3. On information and belief, Eoptolink is registered to do business in the State of California, has designated an agent for service of process in the State of California, and has a physical office located in the State of California and specifically in this district.

NATURE OF ACTION

4. This is an action alleging patent infringement by Defendant Eoptolink of U.S. Patent No. 9,448,367 (the "'367 Patent"), entitled "Multi-Channel Optical Transceiver Module Including Dual Fiber Type Direct Link Adapter for Optically Coupling Optical Subassemblies in the Transceiver Module," and issued on September 20, 2016; U.S. Patent No. 9,509,433 (the "'433 Patent"), entitled "Aligning and Directly Optically Coupling Photodetectors to Optical Demultiplexer Outputs in a Multichannel Receiver Optical Subassembly," and issued on November 29, 2016; U.S. Patent No. 10,230,470 (the "'470 Patent"), entitled "Multilayered Flexible Printed Circuit with Both Radio Frequency (RF) and DC Transmission Lines Electrically Isolated from Each Other and an Optical Transceiver Using Same," and issued on March 12, 2019; U.S. Patent No. 10,578,818 (the "'818 Patent"), entitled "Optical Transceiver," and issued on March 3, 2020; U.S. Patent No. 10,714,890 (the "'890 Patent"), entitled "Transmitter Optical Subassembly Arrangement with Vertically-Mounted Monitor Photodiodes," and issued on July 14, 2020; and U.S. Patent No. 11,177,887 (the "'887 Patent"), entitled "Substrate with Stepped Profile for Mounting Transmitter Optical Subassemblies and an Optical Transmitter or Transceiver Implementing Same," and issued on November 16, 2021 (all collectively, the "Asserted Patents"). A true and correct copy of each of the Asserted Patents is attached hereto as **Exhibits A–F**.

5. Plaintiff AOI is the assignee and owner of record of the '367 Patent, and all rights, title, and interest in and to the '367 Patent.

6. Plaintiff AOI is the assignee and owner of record of the '433 Patent, and all rights, title, and interest in and to the '433 Patent.

7. Plaintiff AOI is the assignee and owner of record of the '470 Patent, and all rights, title, and interest in and to the '470 Patent.

8. Plaintiff AOI is the assignee and owner of record of the '818 Patent, and all rights, title, and interest in and to the '818 Patent.

9. Plaintiff AOI is the assignee and owner of record of the ’890 Patent, and all rights, title, and interest in and to the ’890 Patent.

10. Plaintiff AOI is the assignee and owner of record of the ’887 Patent, and all rights, title, and interest in and to the ’887 Patent.

JURISDICATION AND VENUE

11. This is an action for patent infringement arising under the patent laws of the United States, Title 35 of the United States Code, including without limitation 35 U.S.C. §§ 271 *et seq.* This Court has subject matter jurisdiction over this case pursuant to 28 U.S.C. §§ 1331 and 1338(a), because this action arises under the patent laws of the United States, Title 35 of the United States Code, including but not limited to, 35 U.S.C. §§ 271, 281, 284 and 285.

12. This Court has personal jurisdiction over Eoptolink. On information and belief, Eoptolink designs products in this state and district and sells and offers for sale goods to customers in this state and district via its sales people and through its distributers, including without limitation at its physical office located at 3191 Laurelview Court, Fremont, CA 94538. On information and belief, Eoptolink is registered to do business in the State of California and has designated Jeffrey Chih Lo, located at 116 Scenic Crest, Irvine, CA 92618 as an agent for service of process in the State of California. On information and belief, Eoptolink has at least one physical office located in the State of California and specifically in this district at 3191 Laurelview Court, Fremont, CA 94538.

13. Further, Eoptolink’s website at https://www.eoptolink.com lists its US address as 3191 Laurelview Court, Fremont, CA 94538.

14. Venue is proper in the United States District Court for the Northern District of California under 28 U.S.C. §§ 1391(b)-(d) and/or 1400(b) because, on information and belief, Eoptolink has committed acts of infringement in this district and has a regular and established place of business in this district. On information and belief, Eoptolink designs products in this state and district, including without limitation at its physical office located in this district at 3191 Laurelview Court, Fremont, CA 94538, and sells and offers for sale infringing goods to customers

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in this state and district via its sales people and/or through its distributers. On information and belief, Eoptolink also imports infringing products into this district.

INTRADISTRICT ASSIGNMENT

15. This case is a patent infringement dispute that is appropriate for district-wide assignment.

AOI'S BUSINESS

16. AOI is a leading provider of fiber-optic networking products. It serves four growing end-markets: internet data centers (Data Center), Cable Television Broadband (CATV), fiber-to-the-home (FTTH), and telecommunications. AOI designs and manufactures a range of optical communications products employing our vertical integration strategy from laser chips, components, subassemblies and modules to complete turn-key equipment. AOI designs, manufactures, and integrates its own analog and digital lasers using a proprietary Molecular Beam Epitaxy (MBE) fabrication process, which it believes is unique in its industry. The lasers are proven to be reliable over time and highly tolerant of changes in temperature and humidity (delivering millions of hours service), making them well-suited to the CATV and FTTH markets where networking equipment is often installed outdoors.

17. AOI has a state-of–the-art semiconductor component fab at its USA Headquarters near Houston, Texas.

DEFENDANT'S INFRINGING ACTIVITIES

18. On information and belief, Eoptolink, either directly or through other entities under its control, imports, uses, offers for sale, and/or sells infringing products, including without limitation the Eoptolink 400G QSFP-DD LR4, Eoptolink 400G QSFP-DD FR4, Eoptolink 400G QSFP-DD DR4, Eoptolink 100G QSFP LR4 (QJ3D490147), Eoptolink 100G QSFP-DD LR4 (QL97099330), Eoptolink 100G QSFP DR1+, Eoptolink 100G CWDM4 (QP85060003), and Eoptolink 100G CWDM4 (QMBK440002) (the "Accused Products"). *See, e.g.*, **Exhibits G through AA**.

19. On information and belief, Eoptolink infringes the Asserted Patents by engaging in acts constituting infringement under 35 U.S.C. § 271, including without limitation by making,

using, selling and/or offering for sale in and/or importing into the United States without authority one or more Accused Products that infringe one or more claims of the Asserted Patents.

20. On information and belief, Eoptolink promotes, sells and/or offers to sell its products throughout the United States, including without limitation by offering the Accused Products through its sales people.

FIRST CAUSE OF ACTION

(Infringement of the ’367 Patent)

21. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1-20 of this Complaint.

22. On information and belief, Eoptolink infringes, literally and/or under the doctrine of equivalents, one or more claims of the ’367 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the ’367 Patent.

23. Defendant has directly infringed at least, for example, claim 1 of the ’367 Patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

24. The claim chart attached hereto as **Exhibits G-I** identifies on a limitation-by-limitation basis where each limitation of claim 1 of the ’367 Patent is found within the exemplary Accused Product. Each limitation of claim 1 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as claim 1 of the ’367 Patent.

25. Eoptolink does not have a license to any of Plaintiff’s patents or technology, including without limitation the Asserted Patents.

26. Eoptolink has knowledge and notice of the Asserted Patent and its infringement since at least, and through, the filing of this Complaint.

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27. As a direct and proximate result of Eoptolink's infringement, AOI has suffered, and will continue to suffer, damage in an amount to be proved at trial.

28. As a result of the harm suffered as alleged herein, AOI is entitled to relief under the Patent Act, including damages adequate to compensate it for such infringement, but in no event less than a reasonable royalty.

29. On information and belief, unless enjoined by this Court, Eoptolink will continue to do the acts complained herein, and unless restrained and enjoined will continue to do so, all to AOI's irreparable damage. It would be difficult to ascertain the amount of compensation which would afford AOI adequate relief for such future and continuing acts. AOI does not have an adequate remedy at law to compensate it for injuries threatened. Thus, AOI is entitled to an injunction against further infringement by Eoptolink.

SECOND CAUSE OF ACTION

(Infringement of the '433 Patent)

30. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1–29 of this Complaint.

31. On information and belief, Eoptolink infringes, literally and/or under the doctrine of equivalents, one or more claims of the '433 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the '433 Patent.

32. Defendant has directly infringed at least, for example, claim 1 of the '433 Patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

33. The claim chart attached hereto as **Exhibits J-K** identifies on a limitation-by-limitation basis where each limitation of claims 1 and 13 of the '433 Patent is found within the exemplary Accused Product. Each limitation of claims 1 and 13 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because

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the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as claims 1 and 13 of the ’433 Patent.

34. Eoptolink does not have a license to any of Plaintiff’s patents or technology, including without limitation the Asserted Patents.

35. Eoptolink has knowledge and notice of the Asserted Patents and their infringement since at least, and through, the filing of this Complaint.

36. As a direct and proximate result of Eoptolink’s infringement, AOI has suffered, and will continue to suffer, damage in an amount to be proved at trial.

37. As a result of the harm suffered as alleged herein, AOI is entitled to relief under the Patent Act, including damages adequate to compensate it for such infringement, but in no event less than a reasonable royalty.

38. On information and belief, unless enjoined by this Court, Eoptolink will continue to do the acts complained herein, and unless restrained and enjoined will continue to do so, all to AOI’s irreparable damage. It would be difficult to ascertain the amount of compensation which would afford AOI adequate relief for such future and continuing acts. AOI does not have an adequate remedy at law to compensate it for injuries threatened. Thus, AOI is entitled to an injunction against further infringement by Eoptolink.

THIRD CAUSE OF ACTION

(Infringement of the ’470 Patent)

39. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1–38 of this Complaint.

40. On information and belief, Eoptolink infringes, literally and/or under the doctrine of equivalents, one or more claims of the ’470 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the ’470 Patent.

41. Defendant has directly infringed at least, for example, claims 1, 10, 17 of the ’470 Patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

42. The claim chart attached hereto as **Exhibits L-M** identifies on a limitation-by-limitation basis where each limitation of claims 1, 10, and 17 of the ’470 Patent is found within the exemplary Accused Product. Each limitation of claims 1, 10, and 17 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as claims 1, 10, and 17 of the ’470 Patent.

43. Eoptolink does not have a license to any of Plaintiff’s patents or technology, including without limitation the Asserted Patents.

44. Eoptolink has knowledge and notice of the Asserted Patents and their infringement since at least, and through, the filing of this Complaint.

45. As a direct and proximate result of Eoptolink’s infringement, AOI has suffered, and will continue to suffer, damage in an amount to be proved at trial.

46. As a result of the harm suffered as alleged herein, AOI is entitled to relief under the Patent Act, including damages adequate to compensate it for such infringement, but in no event less than a reasonable royalty.

47. On information and belief, unless enjoined by this Court, Eoptolink will continue to do the acts complained herein, and unless restrained and enjoined will continue to do so, all to AOI’s irreparable damage. It would be difficult to ascertain the amount of compensation which would afford AOI adequate relief for such future and continuing acts. AOI does not have an adequate remedy at law to compensate it for injuries threatened. Thus, AOI is entitled to an injunction against further infringement by Eoptolink.

FOURTH CAUSE OF ACTION

(Infringement of the ’818 Patent)

48. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1–47 of this Complaint.

49. On information and belief, Eoptolink infringes, literally and/or under the doctrine of equivalents, one or more claims of the ’818 Patent, by making, using, selling, offering for sale,

and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the ’818 Patent.

50. Defendant has directly infringed at least, for example, claims 1 and 10 of the ’818 Patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

51. The claim charts attached hereto as **Exhibit N-U** identifies on a limitation-by-limitation basis where each limitation of claims 1 and 10 of the ’818 Patent is found within the exemplary Accused Product. Each limitation of claims 1 and 10 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as claims 1 and 10 of the ’818 Patent.

52. Eoptolink does not have a license to any of Plaintiff’s patents or technology, including without limitation the Asserted Patents.

53. As a direct and proximate result of Eoptolink’s infringement, AOI has suffered, and will continue to suffer, damage in an amount to be proved at trial.

54. As a result of the harm suffered as alleged herein, AOI is entitled to relief under the Patent Act, including damages adequate to compensate it for such infringement, but in no event less than a reasonable royalty.

55. On information and belief, unless enjoined by this Court, Eoptolink will continue to do the acts complained herein, and unless restrained and enjoined will continue to do so, all to AOI’s irreparable damage. It would be difficult to ascertain the amount of compensation which would afford AOI adequate relief for such future and continuing acts. AOI does not have an adequate remedy at law to compensate it for injuries threatened. Thus, AOI is entitled to an injunction against further infringement by Eoptolink.

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FIFTH CAUSE OF ACTION

(Infringement of the ’890 Patent)

56. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1–55 of this Complaint.

57. On information and belief, Eoptolink infringes, literally and/or under the doctrine of equivalents, one or more claims of the ’890 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the ’890 Patent.

58. Defendant has directly infringed at least, for example, claim 1 of the ’890 Patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

59. The claim chart attached hereto as **Exhibit V-W** identifies on a limitation-by-limitation basis where each limitation of claim 1 of the ’890 Patent is found within the exemplary Accused Product. Each limitation of claim 1 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as claim 1 of the ’890 Patent.

60. Eoptolink does not have a license to any of Plaintiff’s patents or technology, including without limitation the Asserted Patents.

61. As a direct and proximate result of Eoptolink’s infringement, AOI has suffered, and will continue to suffer, damage in an amount to be proved at trial.

62. As a result of the harm suffered as alleged herein, AOI is entitled to relief under the Patent Act, including damages adequate to compensate it for such infringement, but in no event less than a reasonable royalty.

63. On information and belief, unless enjoined by this Court, Eoptolink will continue to do the acts complained herein, and unless restrained and enjoined will continue to do so, all to AOI’s irreparable damage. It would be difficult to ascertain the amount of compensation which

would afford AOI adequate relief for such future and continuing acts. AOI does not have an adequate remedy at law to compensate it for injuries threatened. Thus, AOI is entitled to an injunction against further infringement by Eoptolink.

SIXTH CAUSE OF ACTION

(Infringement of the ’887 Patent)

64. AOI incorporates by reference as if fully set forth herein the allegations in Paragraphs 1–63 of this Complaint.

65. On information and belief, Eoptolink infringes, literally and/or under the doctrine of equivalents, one or more claims of the ’887 Patent, by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products, that infringe one or more claims of the ’887 Patent.

66. Defendant has directly infringed at least, for example, claims 1 and 10 of the ’887 Patent by making, using, selling, offering for sale, and/or importing into the United States without authority products, including without limitation the Accused Products.

67. The claim chart attached hereto as **Exhibit X-AA** identifies on a limitation-by-limitation basis where each limitation of claims 1 and 10 of the ’887 Patent is found within the exemplary Accused Product. Each limitation of claims 1 and 10 is literally present in the exemplary Accused Product. To the extent any limitation is found to be not present literally, such limitation is present in the exemplary Accused Product under the doctrine of equivalents because the exemplary Accused Product performs substantially the same function, in substantially the same way, to achieve substantially the same result as claims 1 and 10 of the ’887 Patent.

68. Eoptolink does not have a license to any of Plaintiff’s patents or technology, including without limitation the Asserted Patents.

69. As a direct and proximate result of Eoptolink’s infringement, AOI has suffered, and will continue to suffer, damage in an amount to be proved at trial.

70. As a result of the harm suffered as alleged herein, AOI is entitled to relief under the Patent Act, including damages adequate to compensate it for such infringement, but in no event less than a reasonable royalty.

71. On information and belief, unless enjoined by this Court, Eoptolink will continue to do the acts complained herein, and unless restrained and enjoined will continue to do so, all to AOI's irreparable damage. It would be difficult to ascertain the amount of compensation which would afford AOI adequate relief for such future and continuing acts. AOI does not have an adequate remedy at law to compensate it for injuries threatened. Thus, AOI is entitled to an injunction against further infringement by Eoptolink.

PRAYER FOR RELIEF

WHEREFORE, Plaintiff respectfully prays that the Court grant the following relief:

A. For judgment that Eoptolink has infringed and continues to infringe the '367 Patent;

B. For judgment that the '367 Patent is valid and enforceable;

C. For a preliminary and permanent injunction prohibiting Eoptolink, and all persons or entities acting in concert with Eoptolink, from infringing the '367 Patent;

D. For judgment that Eoptolink has infringed and continues to infringe the '433 Patent;

E. For judgment that the '433 Patent is valid and enforceable;

F. For a preliminary and permanent injunction prohibiting Eoptolink, and all persons or entities acting in concert with Eoptolink, from infringing the '433 Patent;

G. For judgment that Eoptolink has infringed and continues to infringe the '470 Patent;

H. For judgment that the '470 Patent is valid and enforceable;

I. For a preliminary and permanent injunction prohibiting Eoptolink, and all persons or entities acting in concert with Eoptolink, from infringing the '470 Patent;

J. For judgment that Eoptolink has infringed and continues to infringe the '818 Patent;

K. For judgment that the '818 Patent is valid and enforceable;

L. For a preliminary and permanent injunction prohibiting Eoptolink, and all persons or entities acting in concert with Eoptolink, from infringing the '818 Patent;

M. For judgment that Eoptolink has infringed and continues to infringe the ’890 Patent;

N. For judgment that the ’890 Patent is valid and enforceable;

O. For a preliminary and permanent injunction prohibiting Eoptolink, and all persons or entities acting in concert with Eoptolink, from infringing the ’890 Patent;

P. For judgment that Eoptolink has infringed and continues to infringe the ’887 Patent;

Q. For judgment that the ’887 Patent is valid and enforceable;

R. For a preliminary and permanent injunction prohibiting Eoptolink, and all persons or entities acting in concert with Eoptolink, from infringing the ’887 Patent;

S. An award of damages adequate to compensate Plaintiff for the infringement, as well as prejudgment and post-judgment interest from the date the infringement began, but in no event less than a reasonable royalty as permitted by 35 U.S.C. § 284;

T. A finding that this case is exceptional and an award of interest, costs, expenses, and attorneys’ fees incurred by Plaintiff in prosecuting this action as provided by 35 U.S.C. § 285;

U. For any other orders necessary to accomplish complete justice between the parties; and

V. For such other and further relief as this Court or a jury may deem just and proper.

JURY DEMAND

Pursuant to Rule 38 of the Federal Rules of Civil Procedure, Plaintiff demands a trial by jury on all cause of actions and issues so triable.

Dated: November 19, 2024

WEINTRAUB TOBIN CHEDIAK COLEMAN GRODIN

By: */s/ Jo Dale Carothers*
Jo Dale Carothers

Attorneys for Plaintiff Applied Optoelectronics, Inc.

Exhibit A

US009448367B2

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

(10) **Patent No.: US 9,448,367 B2**
(45) **Date of Patent: Sep. 20, 2016**

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(54) **MULTI-CHANNEL OPTICAL TRANSCEIVER MODULE INCLUDING DUAL FIBER TYPE DIRECT LINK ADAPTER FOR OPTICALLY COUPLING OPTICAL SUBASSEMBLIES IN THE TRANSCEIVER MODULE**

(71) Applicant: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(72) Inventors: **I-Lung Ho**, Sugar Land, TX (US); **Stefan J. Murry**, Houston, TX (US); **Che-Shou (Richard) Yeh**, New Taipei (TW)

(73) Assignee: **Applied Optoelectronics, Inc.**, Sugar Land, TX (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.

(21) Appl. No.: **14/883,970**

(22) Filed: **Oct. 15, 2015**

(65) **Prior Publication Data**

US 2016/0041343 A1 Feb. 11, 2016

Related U.S. Application Data

(62) Division of application No. 13/709,195, filed on Dec. 10, 2012, now Pat. No. 9,170,383.

(51) **Int. Cl.**

G02B 6/36	(2006.01)
G02B 6/38	(2006.01)
G02B 6/42	(2006.01)

(52) **U.S. Cl.**

CPC ***G02B 6/3825*** (2013.01); ***G02B 6/3879*** (2013.01); ***G02B 6/421*** (2013.01); ***G02B 6/4246*** (2013.01); ***G02B 6/4292*** (2013.01); ***G02B 6/4293*** (2013.01); *G02B 6/38* (2013.01); *G02B 6/3807* (2013.01); *G02B 6/3869* (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC G02B 6/3825; G02B 6/3879; G02B 6/42; G02B 6/4201; G02B 6/4246; G02B 6/4292; G02B 6/38; G02B 6/3807; G02B 6/3877

USPC 385/53–78

See application file for complete search history.

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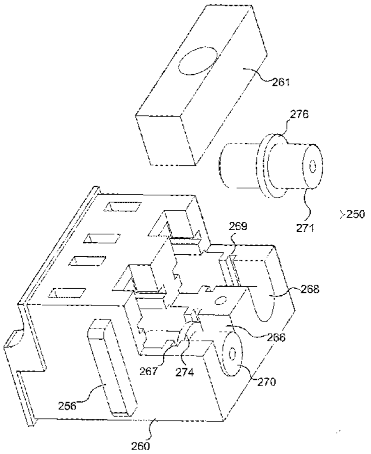
(Continued)

Primary Examiner — Ryan Lepisto
Assistant Examiner — Guy Anderson
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC; Norman S. Kinsella

(57) **ABSTRACT**

A multi-channel optical transceiver includes a multi-channel transmitter optical subassembly (TOSA), a multi-channel receiver optical subassembly (ROSA), and a dual fiber type direct link adapter directly linked to the multi-channel TOSA and the multi-channel ROSA with optical fibers. The dual fiber type direct link adapter is also configured to receive pluggable optical connectors, such as LC connectors, mounted at the end of fiber-optic cables including optical fibers for carrying optical signals to and from the transceiver. The dual fiber type direct link adapter thus provides the optical input and output to the transceiver for the optical signals received by the ROSA and transmitted by the TOSA. The multi-channel optical transceiver may be used in a wavelength division multiplexed (WDM) optical system, for example, in an optical line terminal (OLT) in a WDM passive optical network (PON).

9 Claims, 6 Drawing Sheets



(52) **U.S. Cl.**
CPC *G02B 6/3874* (2013.01); *G02B 6/3877* (2013.01); *G02B 6/42* (2013.01); *G02B 6/4201* (2013.01)

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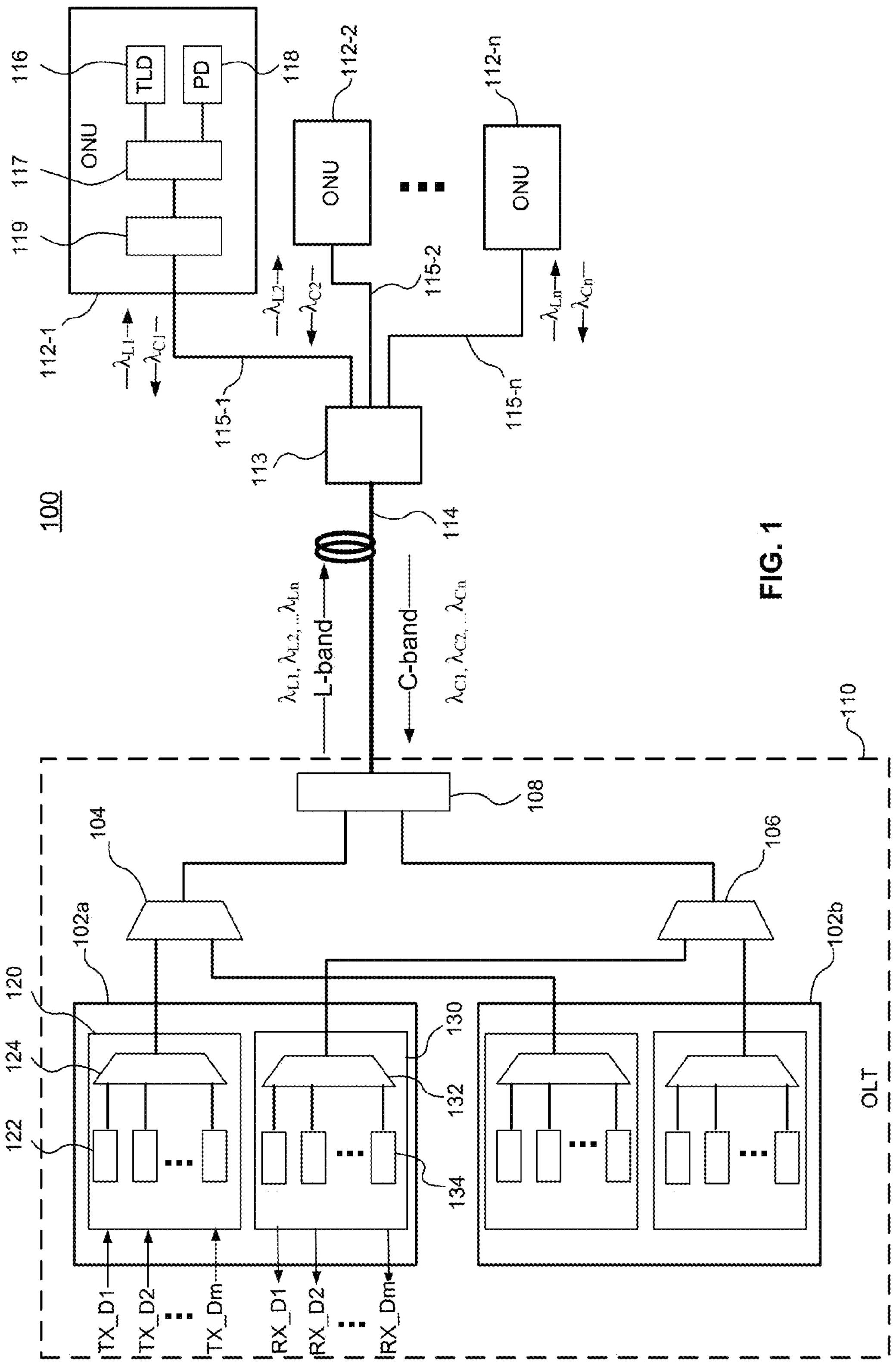
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L-band
C-band
$\lambda_{C1}, \lambda_{C2}, \ldots \lambda_{Cn}$
110
108
104
106
102a
102b
120
124
122
130
132
134
OLT
TX_D1
TX_D2
TX_Dm
RX_D1
RX_D2
RX_Dm

FIG. 1

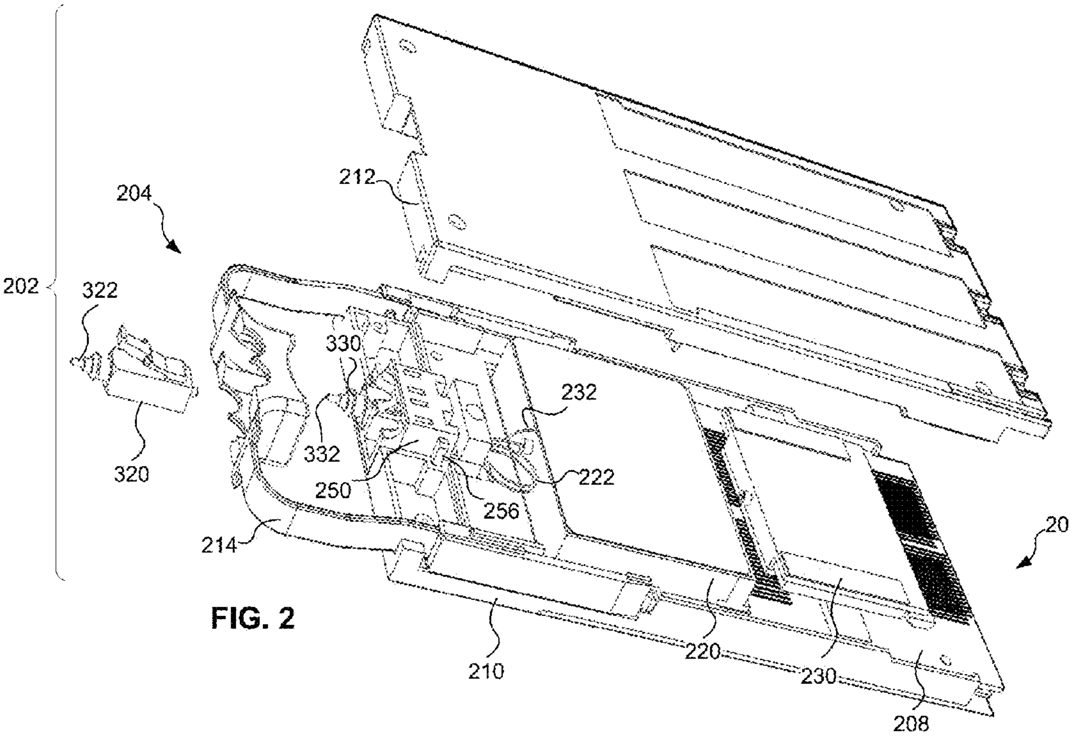
202
204
212
322
330
232
332
222
320
250
256
206
214
210
220
230
208

FIG. 2

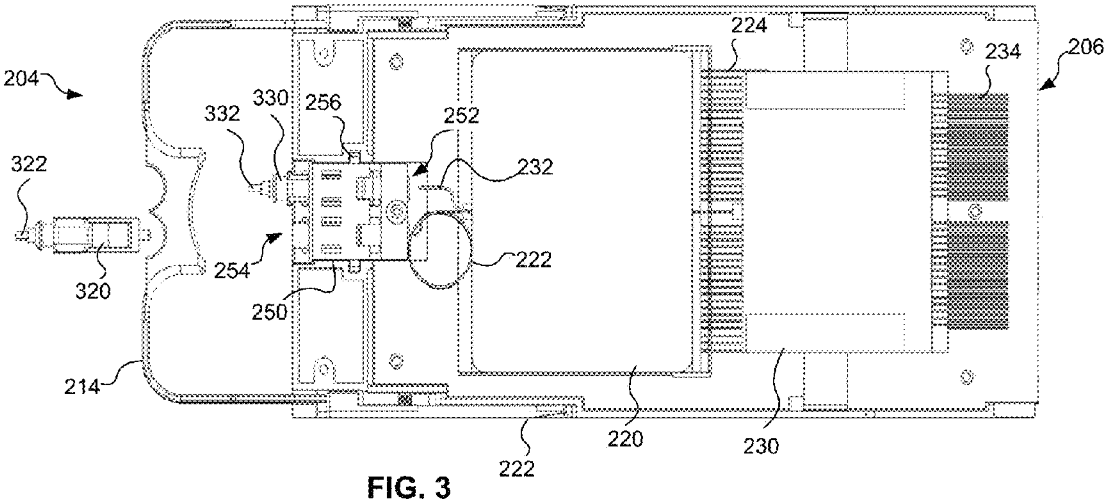
224
234
206
204
330
256
332
252
232
322
222
254
320
250
214
222
220
230

FIG. 3

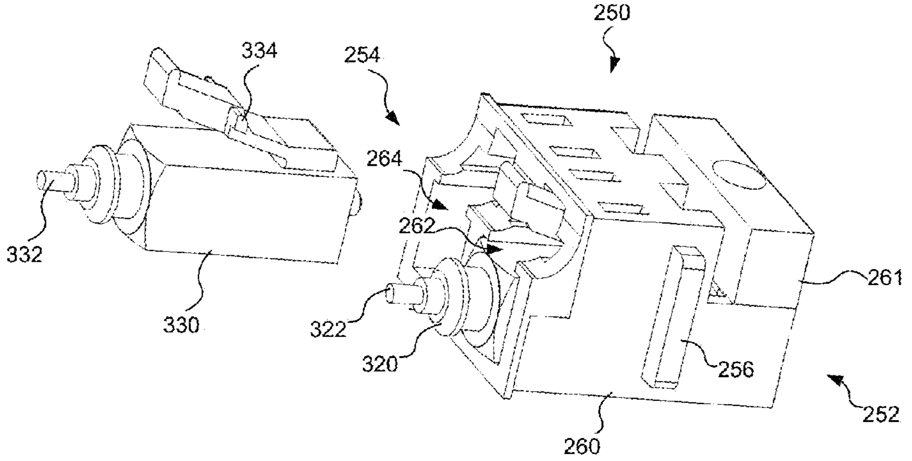

FIG. 4

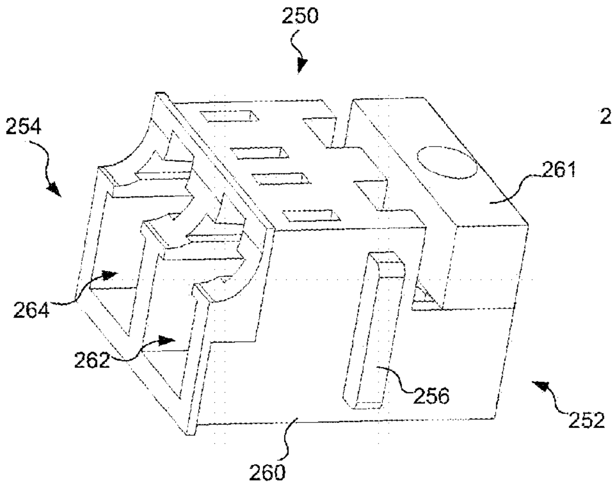

FIG. 5

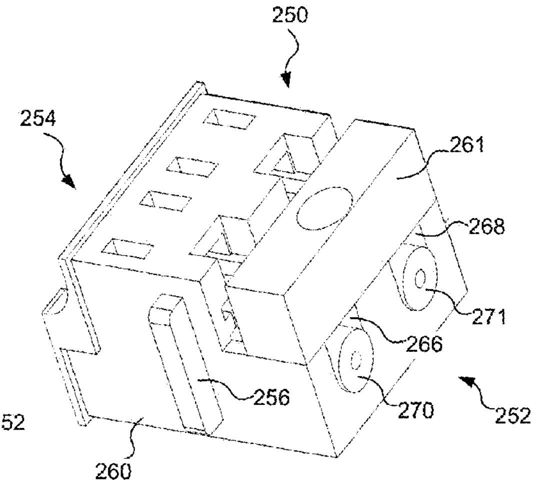

FIG. 6

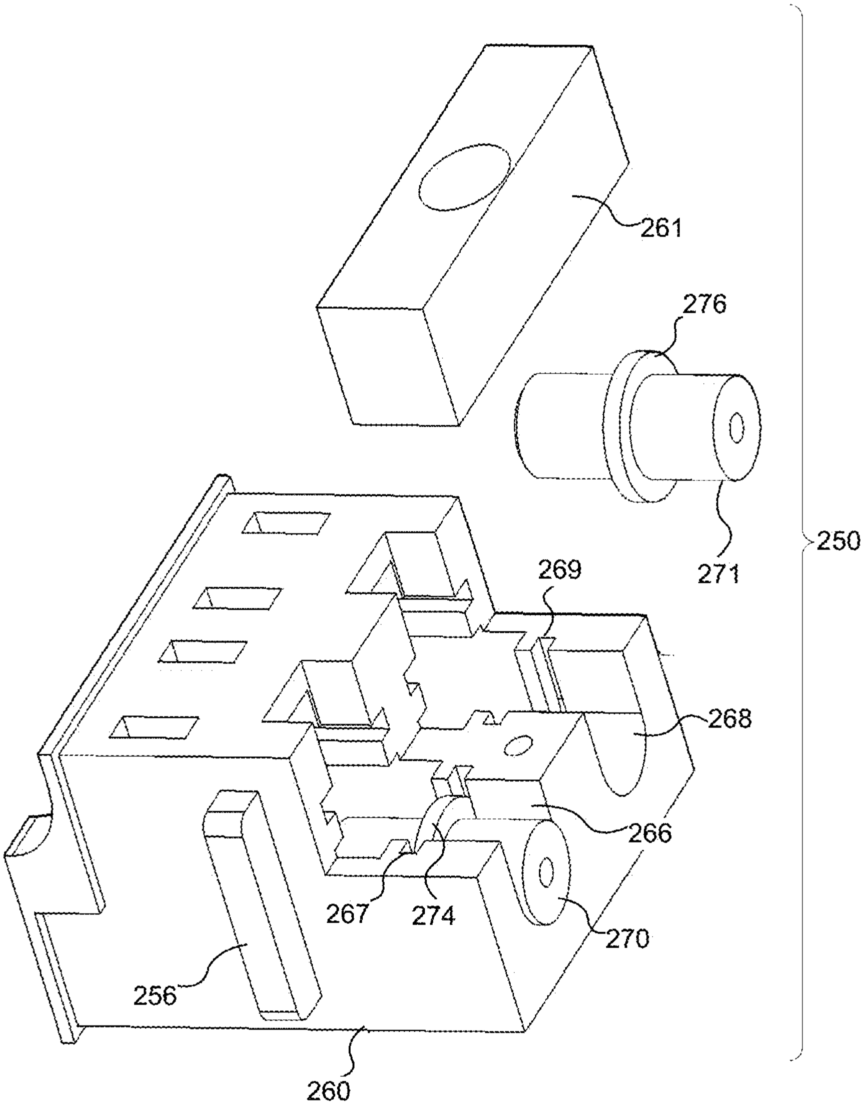

FIG. 7

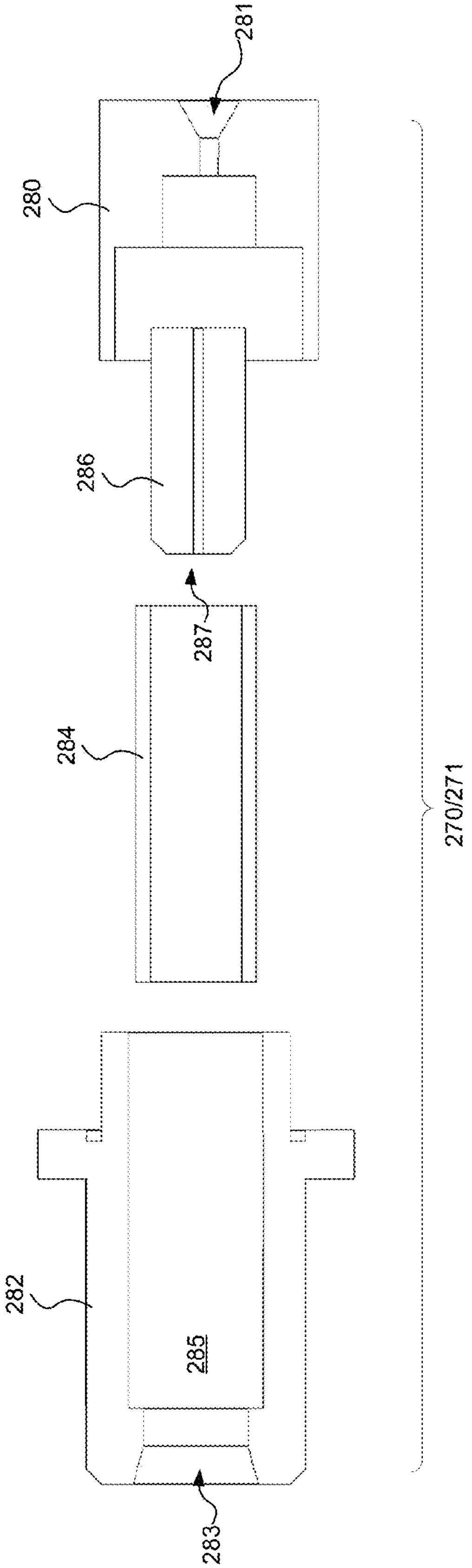

FIG. 8

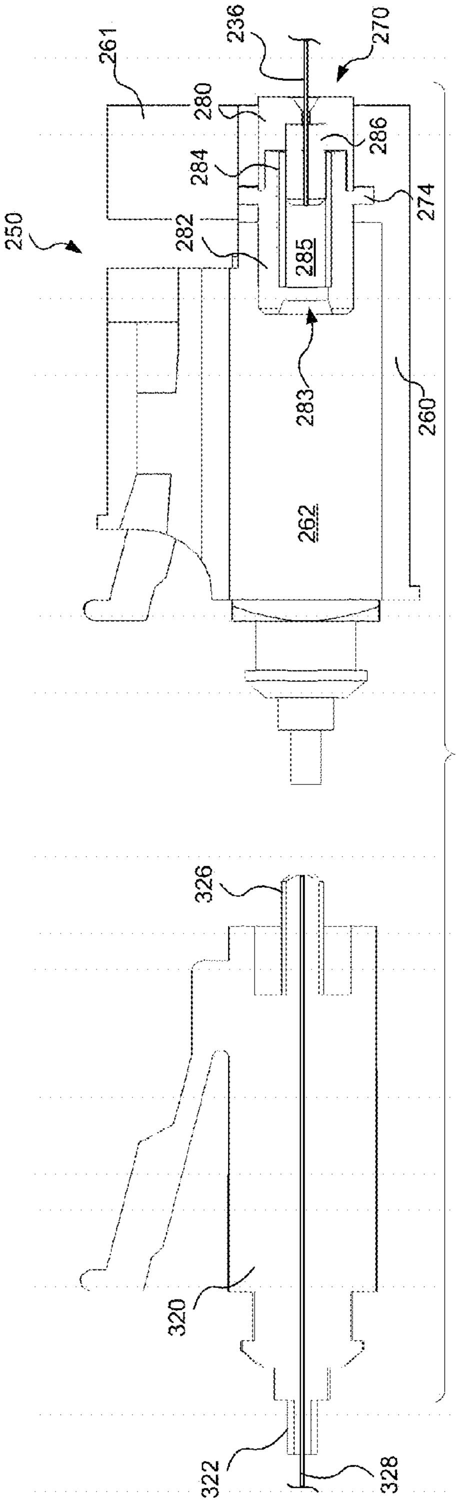
250
261
236
270
280
286
284
274
282
285
283
260
262
326
320
322
328

FIG. 9

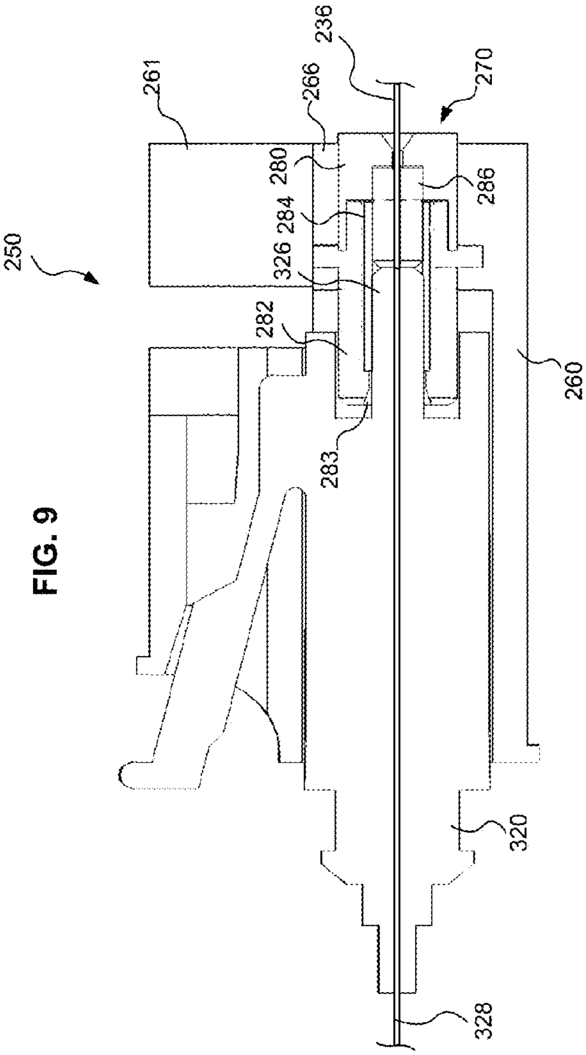
250
261
266
236
270
280
286
284
326
282
283
260
320
328

FIG. 10

MULTI-CHANNEL OPTICAL TRANSCEIVER MODULE INCLUDING DUAL FIBER TYPE DIRECT LINK ADAPTER FOR OPTICALLY COUPLING OPTICAL SUBASSEMBLIES IN THE TRANSCEIVER MODULE

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a divisional of U.S. patent application Ser. No. 13/709,195 filed Dec. 10, 2012, which is fully incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to multi-channel optical transceiver modules and more particularly, to a multi-channel transceiver module including a dual fiber type direct link adapter for optically coupling optical subassemblies in the transceiver module.

BACKGROUND INFORMATION

Optical communications networks, at one time, were generally “point to point” type networks including a transmitter and a receiver connected by an optical fiber. Such networks are relatively easy to construct but deploy many fibers to connect multiple users. As the number of subscribers connected to the network increases and the fiber count increases rapidly, deploying and managing many fibers becomes complex and expensive.

A passive optical network (PON) addresses this problem by using a single “trunk” fiber from a transmitting end of the network, such as an optical line terminal (OLT), to a remote branching point, which may be up to 20 km or more. One challenge in developing such a PON is utilizing the capacity in the trunk fiber efficiently in order to transmit the maximum possible amount of information on the trunk fiber. Fiber optic communications networks may increase the amount of information carried on a single optical fiber by multiplexing different optical signals on different wavelengths using wavelength division multiplexing (WDM). In a WDM-PON, for example, the single trunk fiber carries optical signals at multiple channel wavelengths to and from the optical branching point and the branching point provides a simple routing function by directing signals of different wavelengths to and from individual subscribers. In this case, each subscriber may be assigned one or more of the channel wavelengths on which to send and/or receive data.

To transmit and receive optical signals over multiple channel wavelengths, the OLT in a WDM-PON may include a multi-channel transmitter optical subassembly (TOSA) and a multi-channel receiver optical subassembly (ROSA). The multi-channel TOSA and the multi-channel ROSA may be connected to external optical fibers that carry the transmitted and received optical signals. Optical connectors, such as LC connectors, may be provided at the ends of the optical fibers for connecting the optical fibers to the respective multi-channel TOSA and multi-channel ROSA. OLT transceiver modules often are designed to fit a relatively small form factor. One challenge with such OLT transceiver modules is accommodating the multi-channel TOSA and ROSA in the relatively small space available in an OLT module. In particular, certain components that may be used to provide optical connections to the TOSA and ROSA, such as conventional LC adapters, may not fit within the limited space.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages will be better understood by reading the following detailed description, taken together with the drawings wherein:

FIG. **1** is a functional block diagram of a wavelength division multiplexed (WDM) passive optical network (PON) including at least one multi-channel optical transceiver, consistent with embodiments of the present disclosure.

FIG. **2** is an exploded view of a multi-channel optical transceiver including a dual fiber type direct link adapter for optically coupling directly to a TOSA and a ROSA, consistent with an embodiment of the present disclosure.

FIG. **3** is a top view inside the multi-channel optical transceiver shown in FIG. **2**.

FIG. **4** is a perspective view of one embodiment of the dual fiber type direct link adapter for coupling to first and second LC connectors.

FIGS. **5** and **6** are perspective views of the dual fiber type direct link adapter shown in FIG. **4** without the first and second LC connectors.

FIG. **7** is an exploded view of the dual fiber type direct link adapter shown in FIG. **4** illustrating the LC optical connecting portion.

FIG. **8** is a cross-sectional exploded view of the LC optical connecting portion of the dual fiber type direct link adapter shown in FIG. **4**.

FIGS. **9** and **10** are cross-sectional views of the dual fiber type direct link adapter shown in FIG. **4** with the LC connector disconnected and connected.

DETAILED DESCRIPTION

A multi-channel optical transceiver, consistent with embodiments described herein, generally includes a multi-channel transmitter optical subassembly (TOSA), a multi-channel receiver optical subassembly (ROSA), and a dual fiber type direct link adapter directly linked to the multi-channel TOSA and the multi-channel ROSA with optical fibers. The dual fiber type direct link adapter is also configured to receive pluggable optical connectors, such as LC connectors, mounted at the end of fiber-optic cables including optical fibers for carrying optical signals to and from the transceiver. The dual fiber type direct link adapter thus provides the optical input and output to the transceiver for the optical signals received by the ROSA and transmitted by the TOSA. The multi-channel optical transceiver may be used in a wavelength division multiplexed (WDM) optical system, for example, in an optical line terminal (OLT) in a WDM passive optical network (PON).

As used herein, “channel wavelengths” refer to the wavelengths associated with optical channels and may include a specified wavelength band around a center wavelength. In one example, the channel wavelengths may be defined by an International Telecommunication (ITU) standard such as the ITU-T dense wavelength division multiplexing (DWDM) grid. The term “coupled” as used herein refers to any connection, coupling, link or the like by which signals carried by one system element are imparted to the “coupled” element and “optically coupled” refers to coupling such that light from one element is imparted to another element. Such “coupled” devices are not necessarily directly connected to one another and may be separated by intermediate components or devices that may manipulate or modify such signals.

As used herein, "direct link" refers to optically coupling with a single optical fiber mechanically coupled between two components without using pluggable connectors at the ends of the fiber link.

Referring to FIG. **1**, a WDM-PON **100** including one or more multi-channel optical transceivers **102***a*, **102***b*, consistent with embodiments of the present disclosure, is shown and described. The WDM-PON **100** provides a point-to-multipoint optical network architecture using a WDM system. According to one embodiment of the WDM-PON **100**, at least one optical line terminal (OLT) **110** may be coupled to a plurality of optical networking terminals (ONTs) or optical networking units (ONUs) **112-1** to **112**-*n* via optical fibers, waveguides, and/or paths **114**, **115-1** to **115**-*n*. Although the OLT **110** includes two multi-channel optical transceivers **102***a*, **102***b* in the illustrated embodiment, the OLT **110** may include one or more multi-channel optical transceivers.

The OLT **110** may be located at a central office of the WDM-PON **100**, and the ONUs **112-1** to **112**-*n* may be located in homes, businesses or other types of subscriber location or premises. A branching point **113** (e.g., a remote node) couples a trunk optical path **114** to the separate optical paths **115-1** to **115**-*n* to the ONUs **112-1** to **112**-*n* at the respective subscriber locations. The branching point **113** may include one or more passive coupling devices such as a splitter or optical multiplexer/demultiplexer. In one example, the ONUs **112-1** to **112**-*n* may be located about 20 km or less from the OLT **110**.

The WDM-PON **100** may also include additional nodes or network devices, such as Ethernet PON (EPON) or Gigabit PON (GPON) nodes or devices, coupled between the branching point **113** and ONUs **112-1** to **112**-*n* at different locations or premises. One application of the WDM-PON **100** is to provide fiber-to-the-home (FTTH) or fiber-to-the-premises (FTTP) capable of delivering voice, data, and/or video services across a common platform. In this application, the central office may be coupled to one or more sources or networks providing the voice, data and/or video.

In the WDM-PON **100**, different ONUs **112-1** to **112**-*n* may be assigned different channel wavelengths for transmitting and receiving optical signals. In one embodiment, the WDM-PON **100** may use different wavelength bands for transmission of downstream and upstream optical signals relative to the OLT **110** to avoid interference between the received signal and back reflected transmission signal on the same fiber. For example, the L-band (e.g., about 1565 to 1625 nm) may be used for downstream transmissions from the OLT **110** and the C-band (e.g., about 1530 to 1565 nm) may be used for upstream transmissions to the OLT **110**. The upstream and/or downstream channel wavelengths may generally correspond to the ITU grid. In one example, the upstream wavelengths may be aligned with the 100 GHz ITU grid and the downstream wavelengths may be slightly offset from the 100 GHz ITU grid.

The ONUs **112-1** to **112**-*n* may thus be assigned different channel wavelengths within the L-band and within the C-band. Transceivers or receivers located within the ONUs **112-1** to **112**-*n* may be configured to receive an optical signal on at least one channel wavelength in the L-band (e.g., λ_{L1}, λ_{L2}, . . . λ_{Ln}). Transceivers or transmitters located within the ONUs **112-1** to **112**-*n* may be configured to transmit an optical signal on at least one channel wavelength in the C-band (e.g., λ_{C1}, λ_{C2}, . . . λ_{Cm}). Other wavelengths and wavelength bands are also within the scope of the system and method described herein.

The branching point **113** may demultiplex a downstream WDM optical signal (e.g., λ_{L1}, λ_{L2}, . . . λ_{Ln}) from the OLT **110** for transmission of the separate channel wavelengths to the respective ONUs **112-1** to **112**-*n*. Alternatively, the branching point **113** may provide the downstream WDM optical signal to each of the ONUs **112-1** to **112**-*n* and each of the ONUs **112-1** to **112**-*n* separates and processes the assigned optical channel wavelength. The individual optical signals may be encrypted to prevent eavesdropping on optical channels not assigned to a particular ONU. The branching point **113** also combines or multiplexes the upstream optical signals from the respective ONUs **112-1** to **112**-*n* for transmission as an upstream WDM optical signal (e.g., λ_{C1}, λ_{C2}, . . . λ_{Cn}) over the trunk optical path **114** to the OLT **110**.

One embodiment of the ONU **112-1** includes a laser **116**, such as a laser diode, for transmitting an optical signal at the assigned upstream channel wavelength (λ_{C1}) and a photodetector **118**, such as a photodiode, for receiving an optical signal at the assigned downstream channel wavelength (λ_{L1}). The laser **116** may include a tunable laser configured to be tuned to the assigned channel wavelength. This embodiment of the ONU **112-1** may also include a diplexer **117** coupled to the laser **116** and the photodetector **118** and a C+L band filter **119** coupled to the diplexer **117**, which allow the L-band channel wavelength (λ_{L1}) to be received by the ONU **112-1** and the C-band channel wavelength (λ_{C1}) to be transmitted by the ONU **112-1**.

The OLT **110** may be configured to generate multiple optical signals at different channel wavelengths (e.g., λ_{L1}, λ_{L2}, . . . λ_{Ln}) and to combine the optical signals into the downstream WDM optical signal carried on the trunk optical fiber or path **114**. Each of the OLT multi-channel optical transceivers **102***a*, **102***b* may include a multi-channel transmitter optical sub-assembly (TOSA) **120** for generating and combining the optical signals at the multiple channel wavelengths. The OLT **110** may also be configured to separate optical signals at different channel wavelengths (e.g. $\lambda_{C1}\lambda_{C2}$, . . . λ_{Cn}) from an upstream WDM optical signal carried on the trunk path **114** and to receive the separated optical signals. Each of the OLT multi-channel optical transceivers **102***a*, **102***b* may thus include a multi-channel receiver optical sub-assembly (ROSA) **130** for separating and receiving the optical signals at multiple channel wavelengths.

One embodiment of the multi-channel TOSA **120** includes an array of lasers **122**, such as laser diodes, which may be modulated by respective RF data signals (TX_D**1** to TX_Dm) to generate the respective optical signals. The lasers **122** may be modulated using various modulation techniques including external modulation and direct modulation. An optical multiplexer **124**, such as an arrayed waveguide grating (AWG), combines the optical signals at the different respective downstream channel wavelengths (e.g., λ_{L1}, λ_{L2}, . . . λ_{Lm}). In some embodiments, the lasers **122** may be tunable lasers that generate the optical signals at the respective channel wavelengths. In other embodiments, the lasers **122** may generate optical signals over a band of channel wavelengths and filtering and/or multiplexing techniques may be used to produce the assigned channel wavelengths. In the illustrated embodiment, the OLT **110** further includes a multiplexer **104** for multiplexing the multiplexed optical signal from the multi-channel TOSA **120** in the multi-channel transceiver **102***a* with a multiplexed optical signal from a multi-channel TOSA in the other multi-channel transceiver **102***b* to produce the downstream aggregate WDM optical signal.

One embodiment of the multi-channel ROSA **130** includes a demultiplexer **132** for separating the respective upstream channel wavelengths (e.g., λ_{C1}, λ_{C2}, . . . λ_{Cn}). An array of photodetectors **134**, such as photodiodes, detects the optical signals at the respective separated upstream channel wavelengths and provides the received data signals (Rλ_D1 to Rλ_Dm). In the illustrated embodiment, the OLT **110** further includes a demultiplexer **106** for demultiplexing the upstream WDM optical signal into first and second WDM optical signals provided to the respective multi-channel ROSA in each of the transceivers **102***a*, **102***b*. The OLT also includes a diplexer **108** between the trunk path **114** and the multiplexer **104** and the demultiplexer **106** such that the trunk path **114** carries both the upstream and the downstream channel wavelengths. The transceivers **102***a*, **102***b* may also include other components such as laser drivers, transimpedance amplifiers (TIAs), and control interfaces used for transmitting and receiving optical signals.

In one example, each of the multi-channel optical transceivers **102***a*, **102***b* may be configured to transmit and receive 16 channels such that the WDM-PON **100** supports **32** downstream L-band channel wavelengths and 32 upstream C-band channel wavelengths. In one example, the downstream L-band link between the OLT transceivers **102***a*, **102***b* and the ONUs **112-1** to **112-***n* may support a power budget of at least about 26 dB and the upstream C-band link between the ONUs **112-1** to **112-***n* and the OLT transceivers **102***a*, **102***b* may support a power budget of at least about 23 dB. One example of the WDM-PON **100** may operate at 1.25 Gbaud using 8B/10B encoded on-off keying as the modulation scheme. Other data rates and modulation schemes may also be used.

As mentioned above, the upstream and downstream channel wavelengths may span a range of channel wavelengths on the 100 GHz ITU grid. Each of the transceivers **102***a*, **102***b*, for example, may cover 16 channel wavelengths in the L-band for the TOSA and 16 channel wavelengths in the C-band for the ROSA such that the transceivers **102***a*, **102***b* together cover 32 channels. Thus, the multiplexer **104** may combine 16 channels from one transceiver **102***a* with 16 channels from the other transceiver **102***b*, and the demultiplexer **106** may separate a 32 channel WDM optical signal into two 16 channel WDM optical signals. To facilitate use of the multiplexer **104** and the demultiplexer **106**, the range of channel wavelengths may skip channels (e.g., 2 channels) in the middle of the range.

Referring to FIGS. **2** and **3**, one embodiment of a multi-channel optical transceiver module **202** is shown and described in greater detail. As discussed above, multiple multi-channel transceiver modules may be used in an OLT of a WDM-PON to cover a desired channel range. The transceiver module **202** may thus be designed to have a relatively small form factor with minimal space within the transceiver module **202**. The multi-channel optical transceiver module **202** generally provides an optical input and output at one end **204** and electrical input and output at another end **206**. The transceiver module **202** includes a transceiver housing **210** containing a multi-channel TOSA **220**, a multi-channel ROSA **230**, and a dual fiber type direct link adapter **250** directly linked to the TOSA **220** and the ROSA **230** for providing the optical input and output.

The dual fiber type direct link adapter **250** is coupled to the TOSA **220** and to the ROSA **230** with respective optical fibers **222**, **232** to provide the direct link between the adapter **250** and both the TOSA **220** and the ROSA **230**. The dual fiber type direct link adapter **250** is also configured to receive pluggable optical connectors **320**, **330**, such as LC connectors, which terminate fiber optic cables **322**, **332**. When the optical connectors **320**, **330** are plugged into the dual fiber type direct link adapter **250**, the adapter **250** establishes an optical coupling between the TOSA **220** and the ROSA **230** and the respective optical fibers in the fiber-optic cables **322**, **332**, which carry the optical signals to and from the transceiver.

The dual fiber type direct link adapter **250** has a direct link end **252** mechanically coupled to the optical fibers **222**, **232** and a pluggable connector end **254** configured to receive the pluggable optical connectors **320**, **330**. The direct link end **252** of the dual fiber type direct link adapter **250** is located inside the transceiver housing **210** and the pluggable connector end **254** faces outside of the transceiver housing **210**. The illustrated embodiment of the dual fiber type direct link adapter **250** also includes one or more flanges **256** or other structures that engage the transceiver housing **210** and secure the adapter **250** within the housing **210**.

The transceiver module **202** may also include one or more printed circuit boards **208** coupled to the TOSA **220** and/or ROSA **230**. The printed circuit board(s) **208** may include electronic components such as laser drivers, transimpedance amplifiers (TIAs), and control interfaces. The TOSA **220** is coupled to conductive leads **224** for carrying the electronic signals including the data to be transmitted by the TOSA **220**. The ROSA **230** is coupled to the conductive leads **234** for carrying the electronic signals including the data received by the ROSA **230**.

A top housing portion **212** encloses the TOSA **220**, the ROSA **230**, the adapter **250**, the optical fibers **222**, **232**, and other components within the housing **210**. The transceiver housing **210** may have a width of less than about 55 mm, a length of less than about 130 mm, and a height of less than about 10 mm. To fit within this transceiver housing **210**, the dual fiber type direct link adapter **250** may have a length from the direct link end **252** to the pluggable connector end **254** of less than about 30 mm. More specifically, one example of a transceiver housing **210** may have a width of 54.6 mm, a length of 110 mm, and a height of about 9.8 mm, and the direct link adapter **250** has a length of about 28 mm. A pull tab **214** may be coupled to the transceiver housing **210** to facilitate handling of the transceiver **202**.

Referring to FIGS. **4-7**, the dual fiber type direct link adapter **250** is described in greater detail. In the illustrated embodiment, the dual fiber type direct link adapter **250** includes an adapter body portion **260** defining first and second connector receiving regions **262**, **264** at the pluggable connector end **254** and defining first and second slots **266**, **268** at the direct link end **252**. The first and second connector receiving regions **262**, **264** are configured to receive the respective pluggable optical connectors **320**, **330**, such as LC connectors. The first and second slots **266**, **268** are configured to receive respective direct link connector assemblies **270**, **272**, which are mechanically coupled to optical fibers (not shown) directly linking the TOSA and ROSA (not shown). An adapter cover portion **261** covers the slots **266**, **268** and retains the direct link connector assemblies **266**, **268**. The direct link connector assemblies **270**, **272** also include flange portions **274**, **276** (shown in FIG. **7**) that extend into receiving grooves **267**, **269** in the respective slots **266**, **268** to prevent axial movement and hold the direct link connector assemblies in the slots.

In one embodiment, the dual fiber type direct link adapter **250** is configured to mechanically and optically connect to an LC type optical connector. In other embodiments, the dual fiber type direct link adapter **250** may be configured to connect with other types of pluggable optical connectors.

The optical connectors **320**, **330** may be mechanically engaged with the dual fiber type direct link adapter **250** when plugged to maintain the optical coupling. The connector **330** includes, for example, a latch **334** that engages a corresponding portion within the adapter body portion **260**.

One end of each of the direct link connector assemblies **270**, **272** is mechanically coupled to the optical fibers to provide the direct link to the TOSA and ROSA, as described above. The other end of each of the direct link connector assemblies **270**, **272** defines a connector receptacle that extends into the respective connector receiving region **262**, **264** defined by the adapter body portion **260**, as described in greater detail below.

FIG. **8** shows the direct link connector assembly **270/271** in greater detail. In this illustrated embodiment, the direct link connector assembly **270** includes an outer housing formed by first and second outer housing portions **280**, **282** around a sleeve **284**, which receives a fiber ferrule **286**. A respective one of the optical fibers (not shown) may pass through an opening **281** in the first housing portion **280** and into the fiber ferrule **286**. The optical fiber may be secured to the fiber ferrule **286** such that an end face of the optical fiber is located at an optical coupling end **287** of the fiber ferrule **286**. The second housing portion **282** and the sleeve **284** define a connector receptacle **285** at the connector coupling end, which receives a fiber ferrule of a pluggable optical connector (not shown) through an opening **283**.

FIGS. **9** and **10** illustrate the connection of a pluggable optical connector **320** (e.g., an LC connector) to the dual fiber type direct link adapter **250**. As shown in FIG. **9** and described above, the direct link connector assembly **270** defines a connector receptacle **285** that extends into the connector receiving region **262**. The direct link optical fiber **236** extends into the connector assembly **270** and is secured to the fiber ferrule **286** with an end face of the optical fiber **236** exposed for optical coupling. The pluggable optical connector **320** includes a fiber ferrule **326** extending from one end. The optical fiber **328** in the fiber-optic cable **322** coupled to the optical connector **320** extends into the connector **320** and is secured to the fiber ferrule **286** with an end face of the optical fiber **328** exposed for optical coupling.

As shown in FIG. **10**, when the optical connector **320** is plugged into the dual fiber type direct link adapter **250**, the connector fiber ferrule **326** extends into the connector receptacle **285** and contacts the adapter fiber ferrule **286** such that optical coupling is established between the optical fibers **328**, **236**. In the illustrated embodiment, the pluggable optical connector **320** is an LC type optical connector and the connector assembly **270** (and connector receptacle **285**) is configured to mate with an LC type optical connector.

Accordingly, a dual fiber type direct link adapter, consistent with embodiments described herein, allows connection to a pluggable optical connector, such as an LC connector, while providing a direct optical link to both the TOSA and ROSA in a multi-channel optical transceiver. The direct link connection reduces the size of the adapter and allows a smaller transceiver module with a pluggable optical input and output.

Consistent with an embodiment, a multi-channel transceiver module includes a transceiver housing, a multi-channel transmitter optical subassembly (TOSA) located in the transceiver housing and configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths, and a multi-channel receiver optical subassembly (ROSA) located in the transceiver housing and configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths. A dual fiber type direct link adapter is located inside the transceiver housing and at one side of the transceiver housing. The dual fiber type direct link adapter has a direct link end located in the transceiver housing and a pluggable connector end facing outside of the transceiver housing. The direct link end of the dual fiber type direct link adapter is coupled to the TOSA with a first optical fiber and coupled to the ROSA with a second optical fiber to provide a direct link between the dual fiber type direct link adapter and the TOSA and the ROSA. The pluggable connector end is configured to receive first and second pluggable optical connectors for optically coupling the TOSA and the ROSA to external optical fibers.

Consistent with another embodiment, a dual fiber type direct link LC adapter includes an adapter body portion defining first and second LC connector receiving regions at an pluggable connector end and defining first and second slots at a direct link end. The dual fiber type direct link LC adapter includes also includes first and second direct link connector assemblies configured to be received in the first and second slots, respectively. Each of the direct link connector assemblies defines an LC connector receptacle at one end. The LC connector receptacle extends into a respective one of the LC connector receiving regions and is configured to receive a portion of an LC connector for optical coupling. Each of the direct link connector assemblies is configured to be mechanically coupled to an optical fiber at another end. The dual fiber type direct link LC adapter further includes an adapter cover portion configured to cover the first and second slots for retaining the direct link connector assemblies in the respective slots.

Consistent with a further embodiment, an optical line terminal comprises at least first and second multi-channel transceivers. Each of the multi-channel transceivers includes a transceiver housing, a multi-channel transmitter optical subassembly (TOSA) located in the transceiver housing and configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths, and a multi-channel receiver optical subassembly (ROSA) located in the transceiver housing and configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths. A dual fiber type direct link adapter is located inside the transceiver housing and at one side of the transceiver housing. The dual fiber type direct link adapter has a direct link end located in the transceiver housing and a pluggable connector end facing outside of the transceiver housing. The direct link end of the dual fiber type direct link adapter is coupled to the TOSA with a first optical fiber and coupled to the ROSA with a second optical fiber to provide a direct link between the dual fiber type direct link adapter and the TOSA and the ROSA. The pluggable connector end is configured to receive first and second pluggable optical connectors for optically coupling the TOSA and the ROSA to external optical fibers.

While the principles of the invention have been described herein, it is to be understood by those skilled in the art that this description is made only by way of example and not as a limitation as to the scope of the invention. Other embodiments are contemplated within the scope of the present invention in addition to the exemplary embodiments shown and described herein. Modifications and substitutions by one of ordinary skill in the art are considered to be within the scope of the present invention, which is not to be limited except by the following claims.

What is claimed is:

1. A dual fiber type direct link LC adapter comprising:

an adapter body portion defining first and second LC connector receiving regions at a pluggable connector end and defining first and second slots at a direct link end;

first and second direct link connector assemblies configured to be received in the first and second slots, respectively, each of the direct link connector assemblies defining an LC connector receptacle at one end, wherein the LC connector receptacle extends into a respective one of the LC connector receiving regions and is configured to receive a portion of an LC connector for optical coupling, and wherein each of the direct link connector assemblies is configured to be mechanically coupled to an optical fiber at another end; and

an adapter cover portion configured to cover the first and second slots for retaining the direct link connector assemblies in the respective slots.

2. The dual fiber type direct link LC adapter of claim **1**, wherein each of the direct link connector assemblies include a fiber ferrule for receiving the optical fiber and a sleeve around the fiber ferrule for defining at least a portion of the LC connector receptacle.

3. The dual fiber type direct link LC adapter of claim **1** wherein a length of the dual fiber type direct link adapter from the direct link end to the pluggable connector end is less than 30 mm.

4. The dual fiber type direct link LC adapter of claim **2** wherein each of the direct link connector assemblies further comprises an outer housing around the fiber ferrule and the sleeve, the outer housing defining at least a portion of the connector receptacle and including a flange portion for securing the direct link connector assembly.

5. The dual fiber type direct link LC adapter of claim **1** wherein the first and second slots are open on one side to receive the first and second direct link connector assemblies, respectively, in a direction orthogonal to longitudinal axes of the slots.

6. The dual fiber type direct link LC adapter of claim **5** wherein the first and second slots include grooves, respectively, for engaging the direct link connector assemblies to prevent axial movement.

7. The dual fiber type direct link LC adapter of claim **1** wherein the first and second slots include grooves, respectively, for engaging the direct link connector assemblies to prevent axial movement.

8. The dual fiber type direct link LC adapter of claim **7** wherein the first and second direct link connector assemblies further comprises flange portions configured to extend into the grooves of the first and second slots, respectively.

9. The dual fiber type direct link LC adapter of claim **6** wherein the first and second direct link connector assemblies further comprises flange portions configured to extend into the grooves of the first and second slots, respectively.

* * * * *

Exhibit B

US009509433B2

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

(10) **Patent No.: US 9,509,433 B2**
(45) **Date of Patent: Nov. 29, 2016**

(54) **ALIGNING AND DIRECTLY OPTICALLY COUPLING PHOTODETECTORS TO OPTICAL DEMULTIPLEXER OUTPUTS IN A MULTICHANNEL RECEIVER OPTICAL SUBASSEMBLY**

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(73) Assignee: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 50 days.

(21) Appl. No.: **14/088,883**

(22) Filed: **Nov. 25, 2013**

(65) **Prior Publication Data**

US 2014/0341578 A1 Nov. 20, 2014

Related U.S. Application Data

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(51) **Int. Cl.**

G02B 6/00	(2006.01)
H04J 14/02	(2006.01)
H04B 10/25	(2013.01)
H04B 10/60	(2013.01)
H04Q 11/00	(2006.01)

(52) **U.S. Cl.**
CPC ***H04J 14/025*** (2013.01); ***H04J 14/0246*** (2013.01)

(58) **Field of Classification Search**
CPC .. H04B 10/60; H04B 10/25; H04B 10/2504; H04J 14/0239; H04J 14/02; H04J 14/0246; H04J 14/025; H04J 14/0278; H04Q 11/0005; H04Q 2011/0032
USPC 398/68, 92, 70, 79; 385/14
See application file for complete search history.

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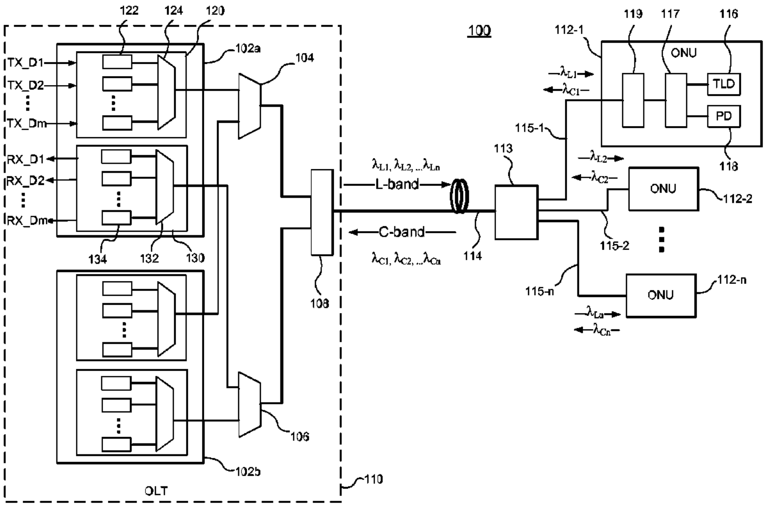
Primary Examiner — Akm Enayet Ullah
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC; Norman S. Kinsella

(57) **ABSTRACT**

A multi-channel receiver optical subassembly (ROSA) such as an arrayed waveguide grating (AWG), with outputs directly optically coupled to respective photodetectors such as photodiodes. In one embodiment, an AWG may be configured such that optical components of the AWG do not interfere with direct optical coupling, and the wire bonding points on the photodiodes may also be configured such that wire bonding does not interfere with direct optical coupling. The photodetectors may also be mounted on a photodetector mounting bar with a pitch sufficiently spaced to allow connection to floating grounds. A passive alignment technique may be used to determine the mounting locations on the photodetector mounting bar such that the photodetectors are aligned with the optical outputs.

20 Claims, 8 Drawing Sheets



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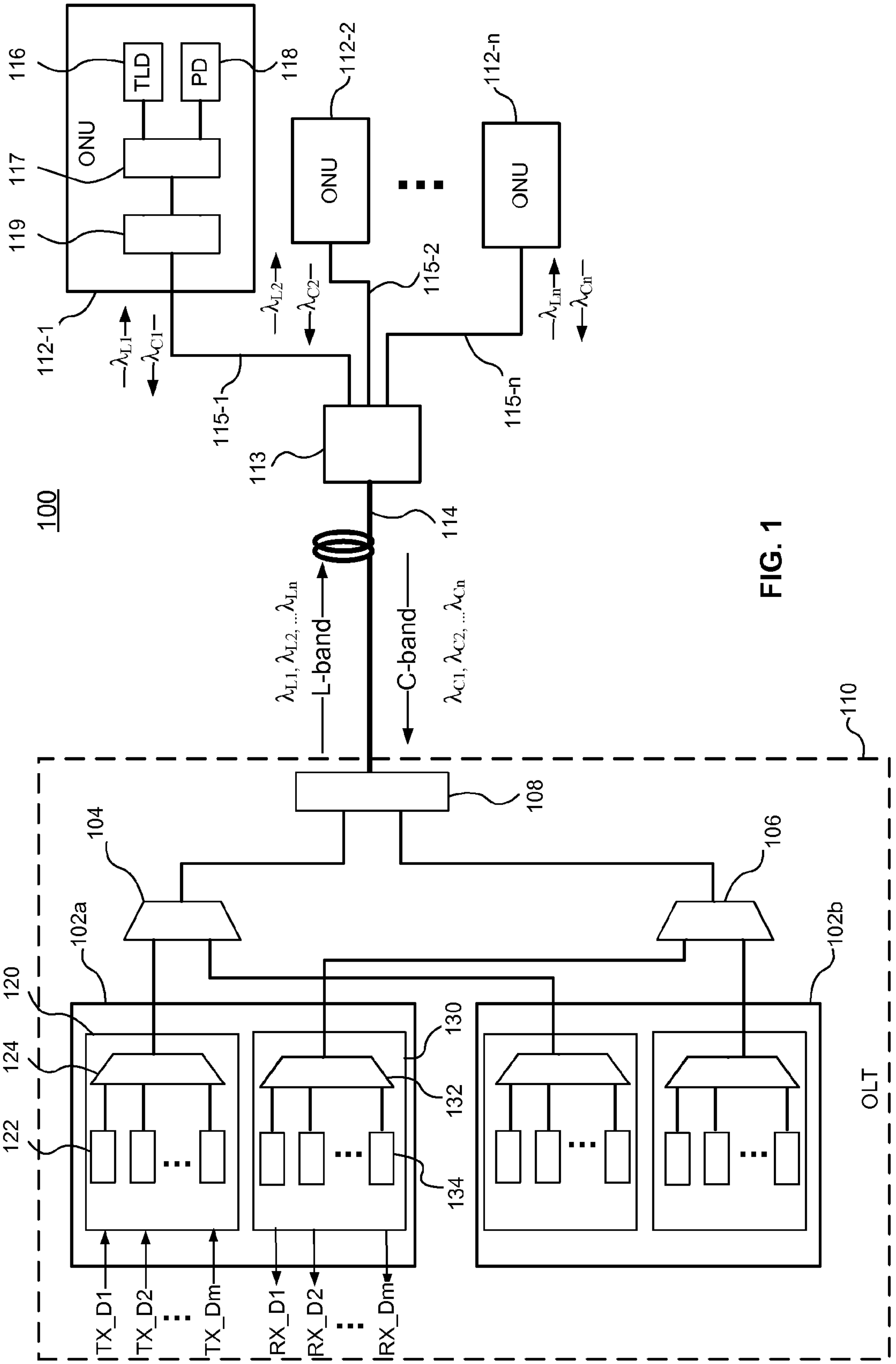
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ONU
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PD
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117
119
118
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112-n
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λ_{L2}
λ_{C2}
λ_{Ln}
λ_{Cn}
115-1
115-2
115-n
113
114
$\lambda_{L1}, \lambda_{L2}, \ldots \lambda_{Ln}$
L-band
C-band
$\lambda_{C1}, \lambda_{C2}, \ldots \lambda_{Cn}$
110
108
104
106
102a
102b
120
124
122
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132
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OLT
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TX_Dm
RX_D1
RX_D2
RX_Dm

FIG. 1

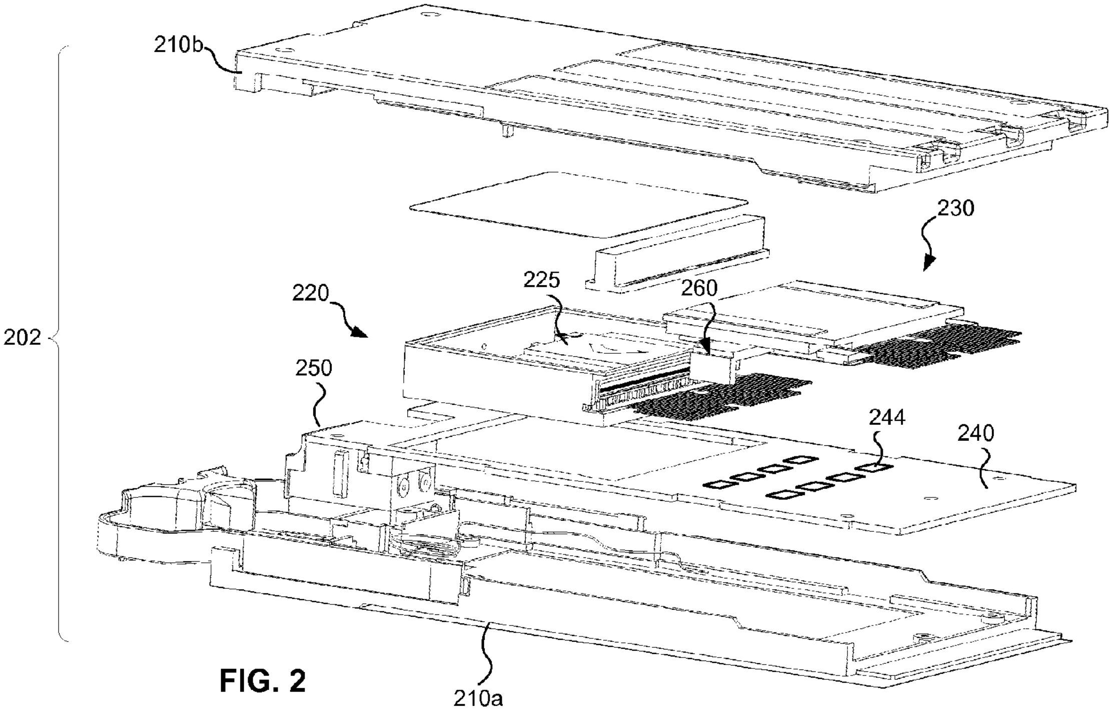
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FIG. 2

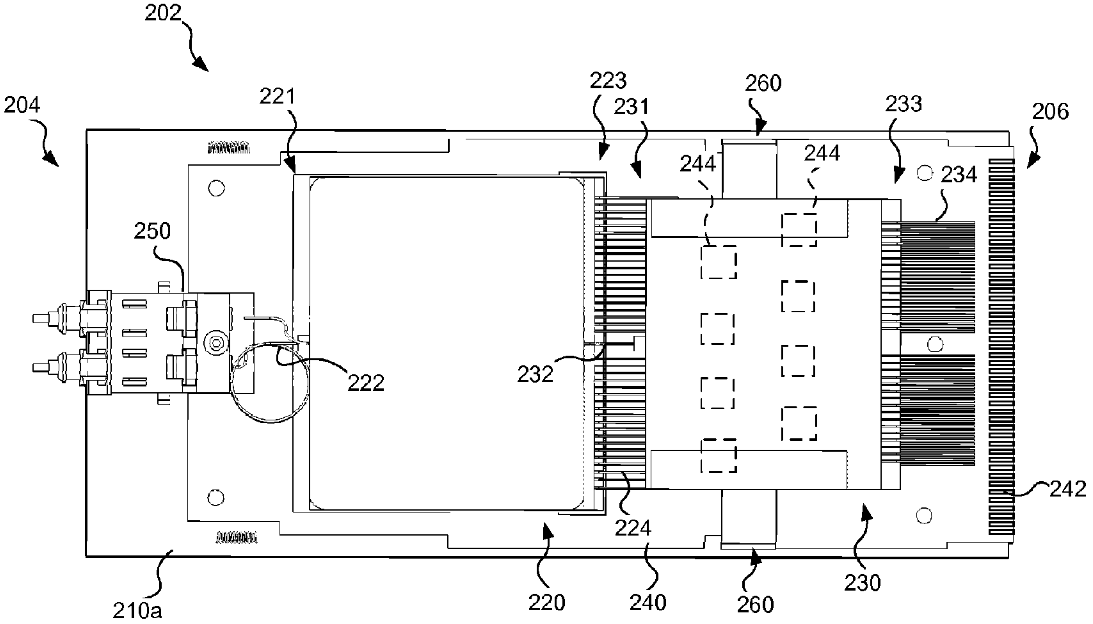
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FIG. 3

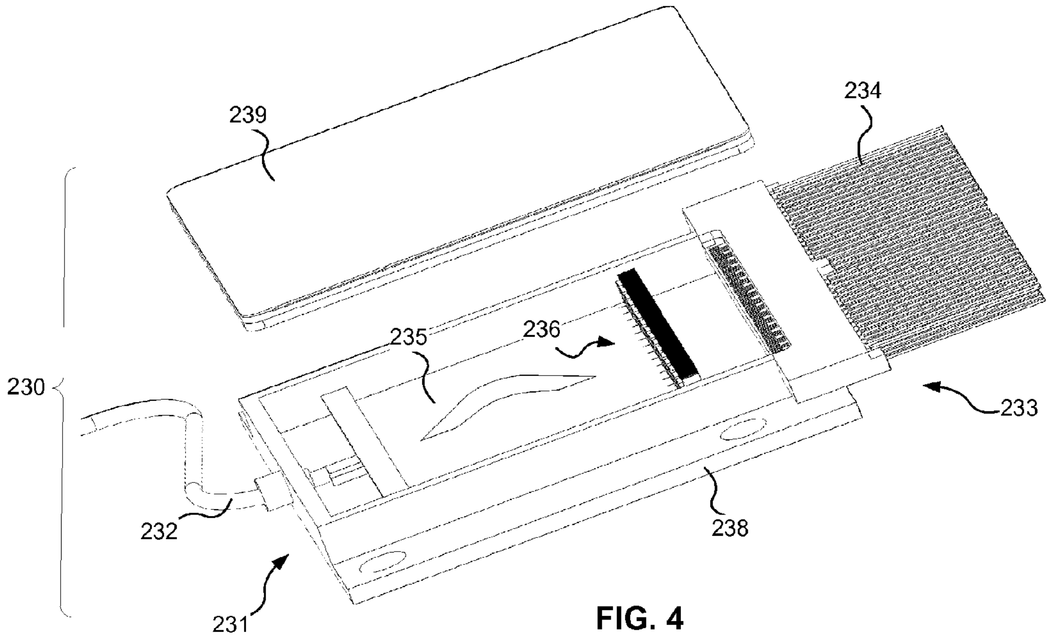

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FIG. 4

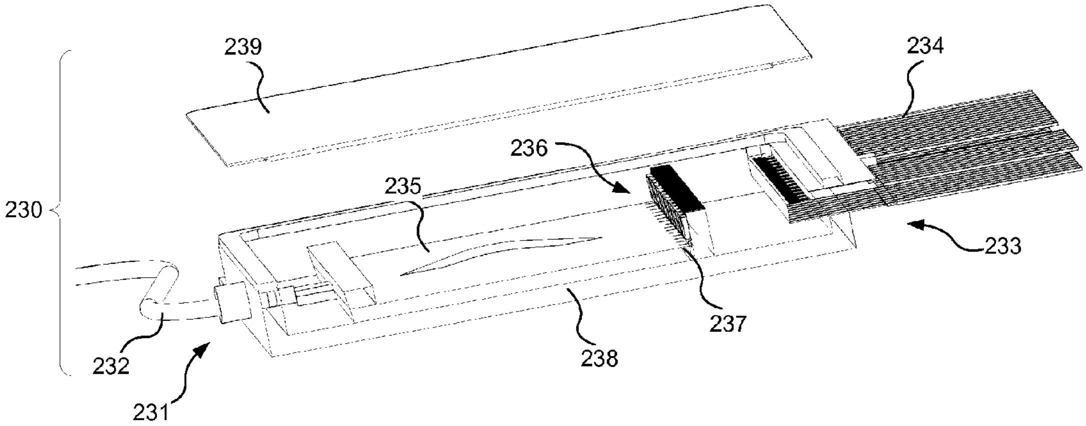

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FIG. 5

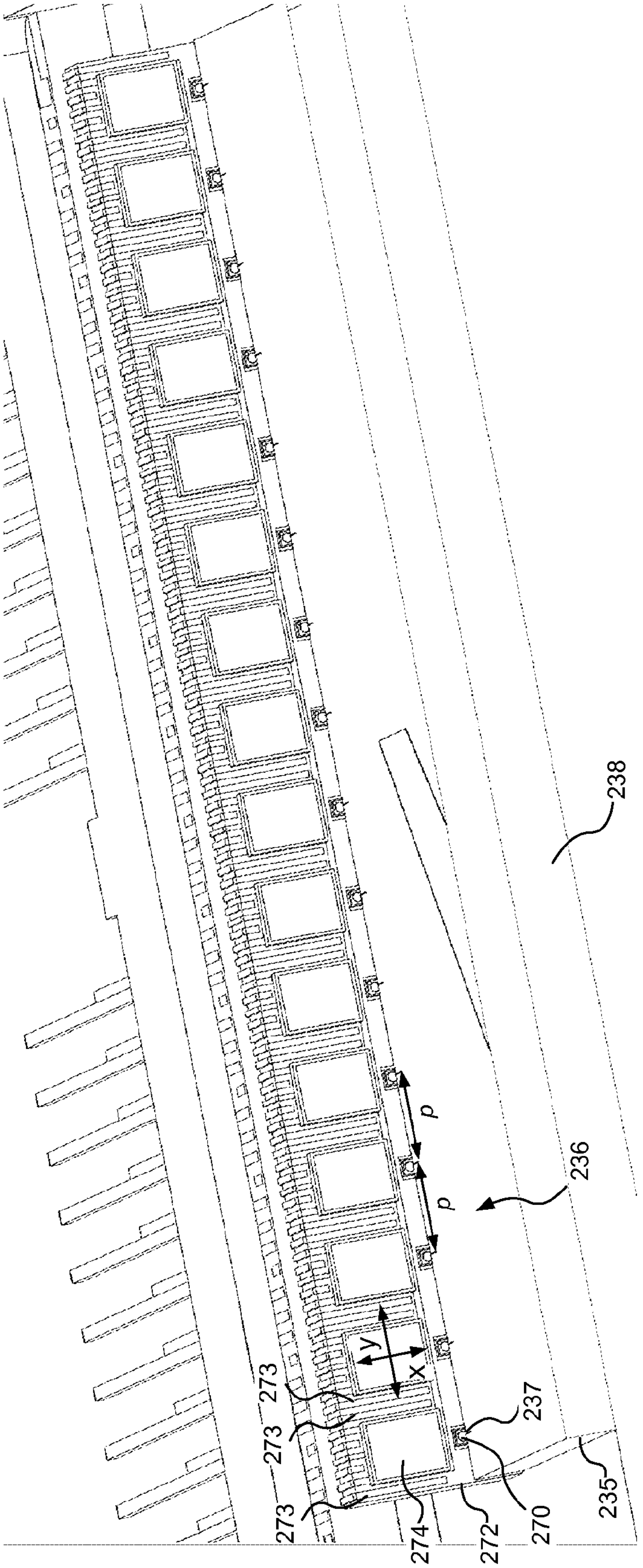
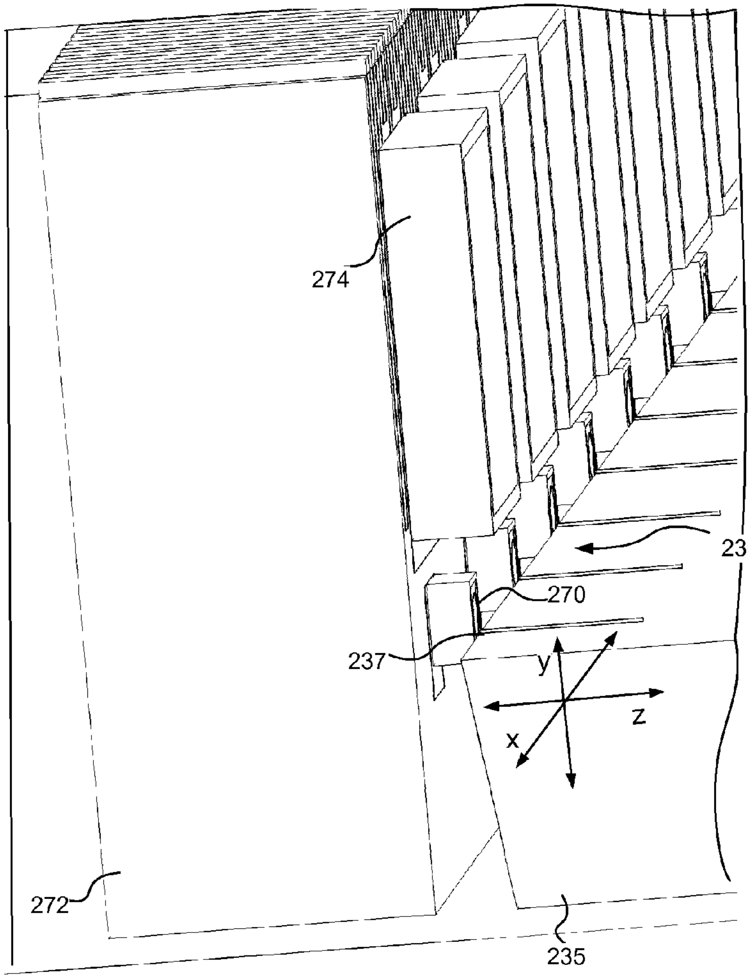


FIG. 6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x
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235

FIG. 7

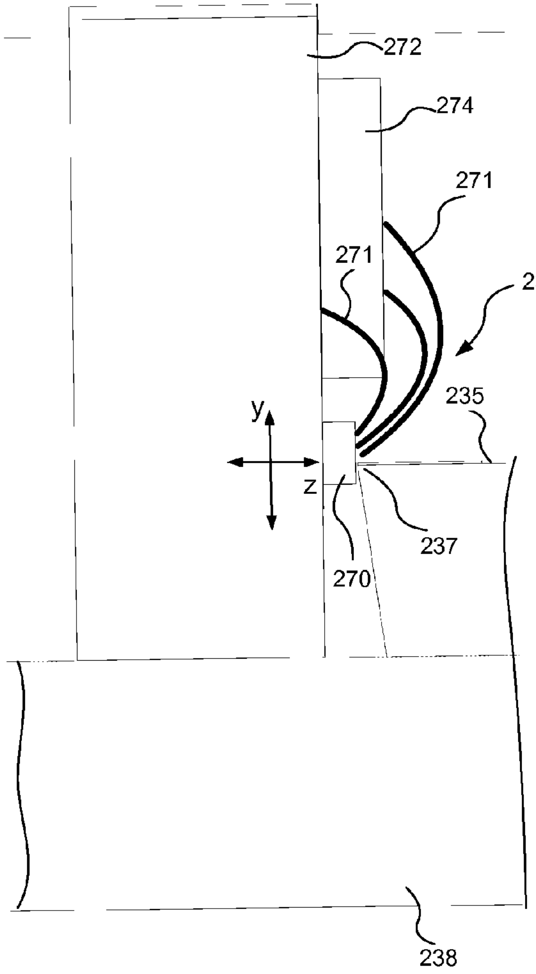
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FIG. 8

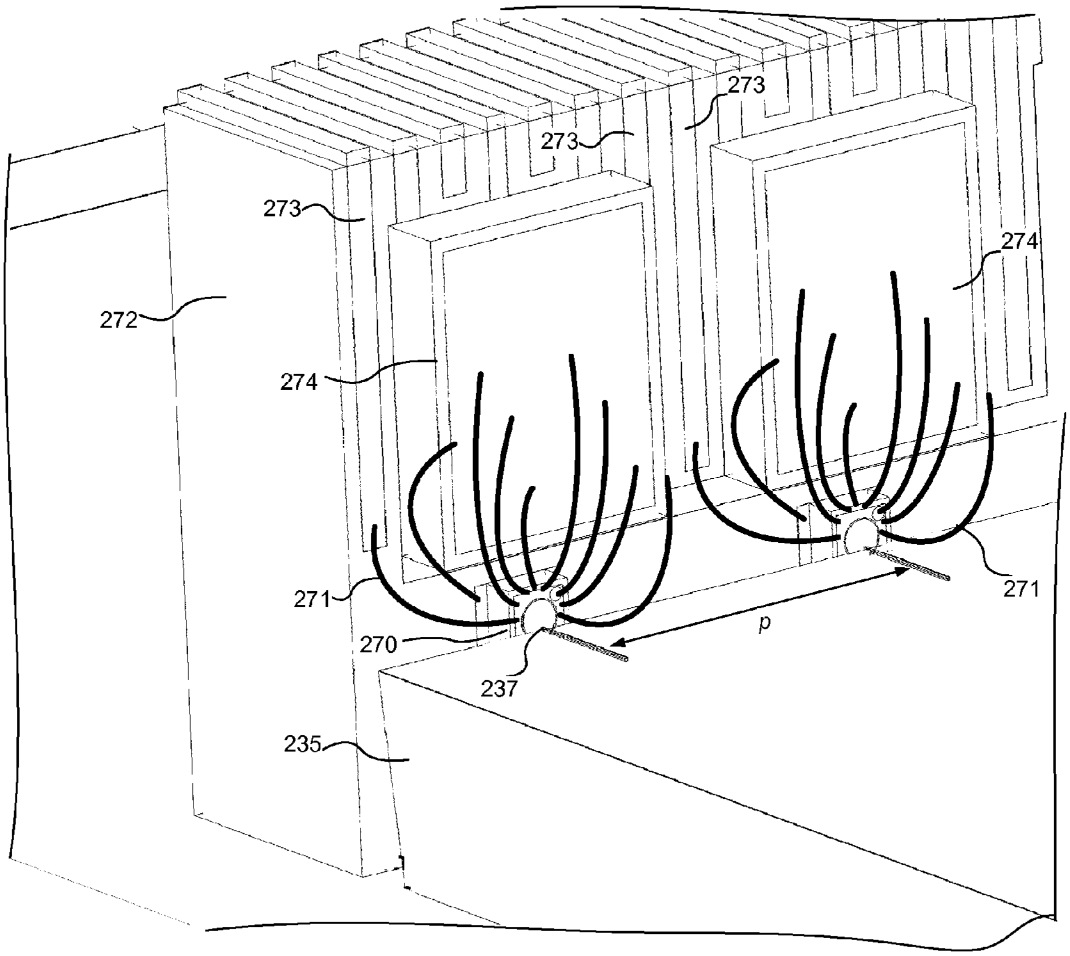

FIG. 9

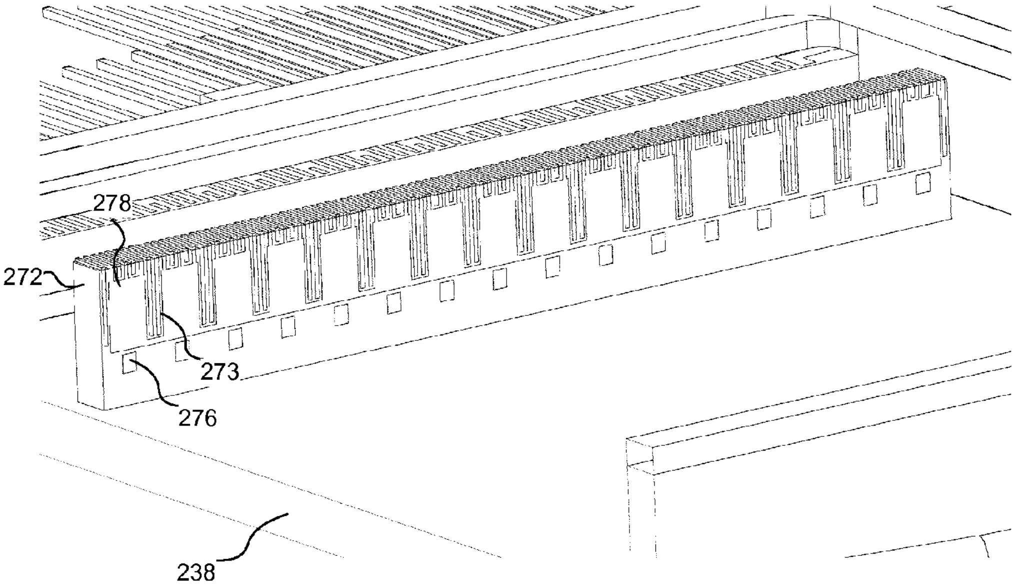

FIG. 10A

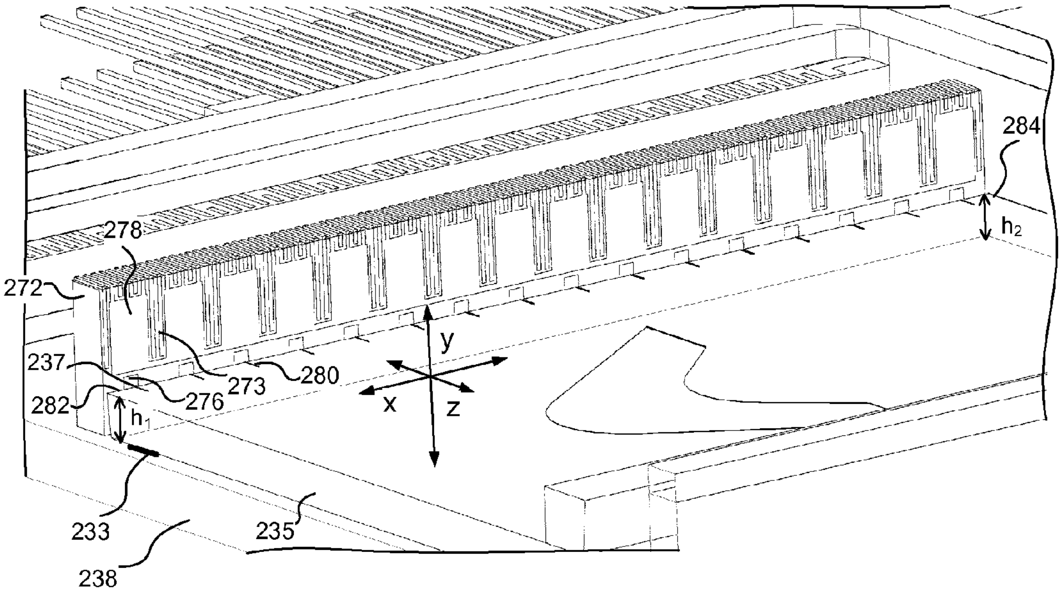

FIG. 10B

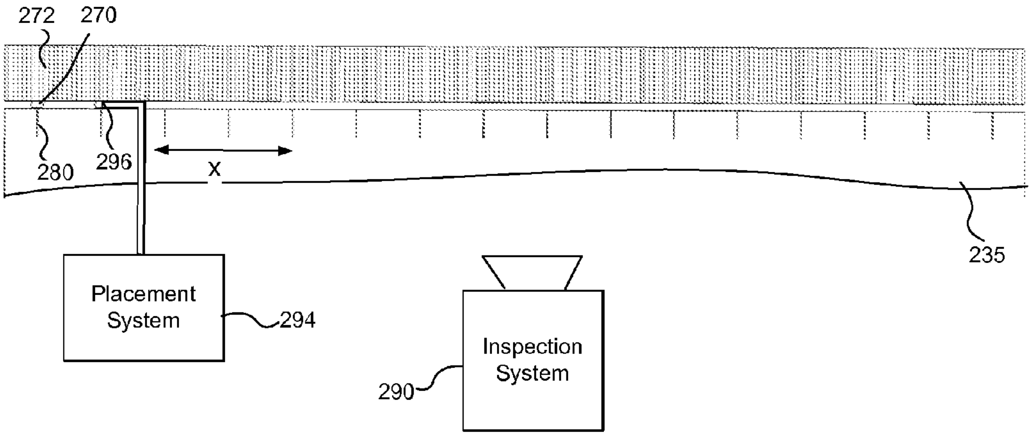

FIG. 10C

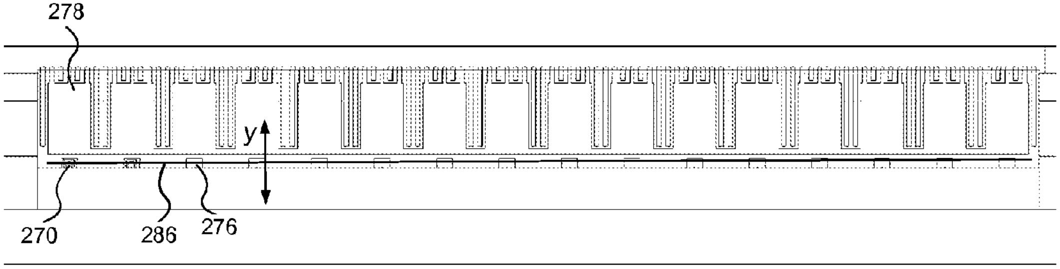

FIG. 10D

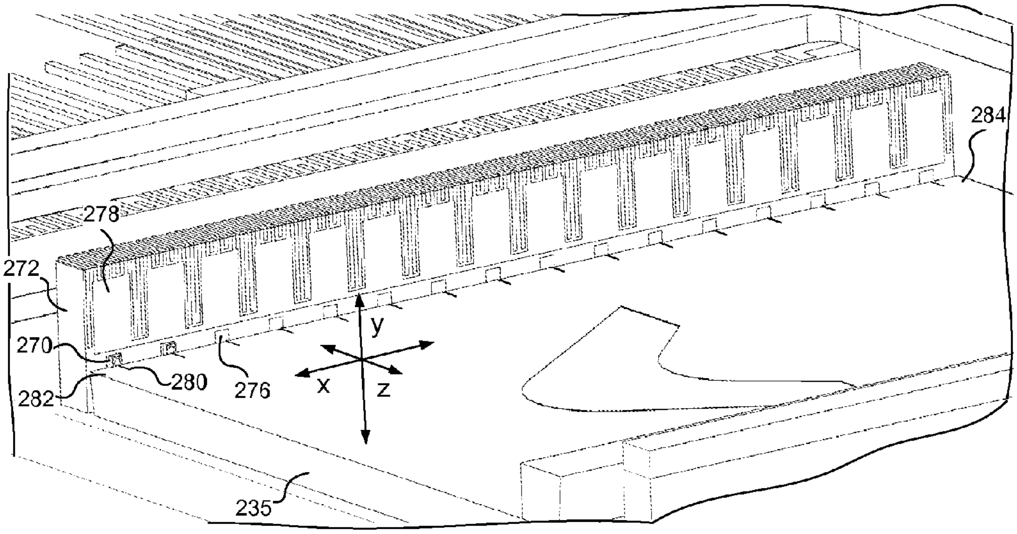

FIG. 10E

ALIGNING AND DIRECTLY OPTICALLY COUPLING PHOTODETECTORS TO OPTICAL DEMULTIPLEXER OUTPUTS IN A MULTICHANNEL RECEIVER OPTICAL SUBASSEMBLY

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation-in-part of U.S. patent application Ser. No. 13/893,802 filed May 14, 2013, which is fully incorporated herein by reference.

TECHNICAL FIELD

The present disclosure relates to optical transceivers and more particularly, to aligning and directly optically coupling photodetectors to optical demultiplexer outputs in a multichannel receiver optical subassembly (ROSA).

BACKGROUND INFORMATION

Optical communications networks, at one time, were generally “point to point” type networks including a transmitter and a receiver connected by an optical fiber. Such networks are relatively easy to construct but deploy many fibers to connect multiple users. As the number of subscribers connected to the network increases and the fiber count increases rapidly, deploying and managing many fibers becomes complex and expensive.

A passive optical network (PON) addresses this problem by using a single “trunk” fiber from a transmitting end of the network, such as an optical line terminal (OLT), to a remote branching point, which may be up to 20 km or more. One challenge in developing such a PON is utilizing the capacity in the trunk fiber efficiently in order to transmit the maximum possible amount of information on the trunk fiber. Fiber optic communications networks may increase the amount of information carried on a single optical fiber by multiplexing different optical signals on different wavelengths using wavelength division multiplexing (WDM). In a WDM-PON, for example, the single trunk fiber carries optical signals at multiple channel wavelengths to and from the optical branching point and the branching point provides a simple routing function by directing signals of different wavelengths to and from individual subscribers. In this case, each subscriber may be assigned one or more of the channel wavelengths on which to send and/or receive data.

To transmit and receive optical signals over multiple channel wavelengths, the OLT in a WDM-PON may include a multi-channel transmitter optical subassembly (TOSA), a multi-channel receiver optical subassembly (ROSA), and associated circuitry. One challenge with such OLT transceiver modules is accommodating the multi-channel TOSA, ROSA and circuitry in the relatively small space available in an OLT module. Designing a subassembly, such as the ROSA, with a smaller size presents potential problems with optical coupling between optical components in the subassembly. Limitations on the power budget of multiple channel optical transceivers present an additional challenge because higher receiver sensitivity may be required but difficult to achieve given the limited space for optical and opto-electronic components.

In the ROSA, multiple photodiodes are optically coupled to multiple outputs from an optical demultiplexer, such as an arrayed waveguide grating (AWG), for receiving multiple optical signals over multiple channels. To provide the coupling efficiency needed for a desired receiver sensitivity, these optical couplings are often made using a fiber array and/or lenses. The limited space within a smaller sized ROSA housing, however, may not be sufficient to accommodate fiber arrays and lenses used for such optical couplings. Aligning the photodiodes with the optical demultiplexer outputs may also be difficult without using expensive active alignment techniques and equipment.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages will be better understood by reading the following detailed description, taken together with the drawings wherein:

FIG. **1** is a functional block diagram of a wavelength division multiplexed (WDM) passive optical network (PON) including at least one compact multi-channel optical transceiver, consistent with embodiments of the present disclosure.

FIG. **2** is an exploded view of a compact multi-channel optical transceiver including a multi-channel TOSA, ROSA and circuit board, consistent with an embodiment of the present disclosure.

FIG. **3** is a top view inside the compact multi-channel optical transceiver shown in FIG. **2**.

FIG. **4** is an exploded perspective view of a multi-channel ROSA for use in a compact multi-channel optical transceiver, consistent with an embodiment of the present disclosure.

FIG. **5** is a cross-sectional view of the multi-channel ROSA shown in FIG. **4**.

FIG. **6** is a cross-sectional front perspective view of the array of photodetectors directly optically coupled to the respective optical outputs of the optical demultiplexer in the ROSA shown in FIG. **4**.

FIG. **7** is an enlarged, side perspective view of the array of photodetectors directly optically coupled to the respective optical outputs of the optical demultiplexer in the ROSA shown in FIG. **4**.

FIG. **8** is an enlarged side view of a photodetector directly optically coupled to an optical output of an optical demultiplexer and wire bonded to an associated transimpedance amplifier (TIA).

FIG. **9** is an enlarged perspective view of photodetectors directly optically coupled to optical outputs of an optical demultiplexer and wire bonded to associated TIAs.

FIGS. **10A-10E** illustrate a method of passively aligning and directly optically coupling an array of photodetectors with respective optical outputs of an optical demultiplexer.

DETAILED DESCRIPTION

A multi-channel receiver optical subassembly (ROSA), consistent with embodiments described herein, includes an optical demultiplexer, such as an arrayed waveguide grating (AWG), with outputs directly optically coupled to respective photodetectors such as photodiodes. In one embodiment, an AWG may be configured such that optical components of the AWG do not interfere with direct optical coupling, and the wire bond points on the photodiodes may also be configured such that wire bonding does not interfere with direct optical coupling. The photodiodes may also be mounted on a photodetector mounting bar with a pitch sufficiently spaced to allow connection to floating grounds. A passive alignment technique may be used to determine the mounting locations on the photodetector mounting bar such that the photodetectors are aligned with the optical outputs. A compact multi-channel optical transceiver may include the multi-channel ROSA, and the optical transceiver may be used in a wavelength division multiplexed (WDM) optical system, for example, in an optical line terminal (OLT) in a WDM passive optical network (PON).

As used herein, "channel wavelengths" refer to the wavelengths associated with optical channels and may include a specified wavelength band around a center wavelength. In one example, the channel wavelengths may be defined by an International Telecommunication (ITU) standard such as the ITU-T dense wavelength division multiplexing (DWDM) grid. The term "coupled" as used herein refers to any connection, coupling, link or the like and "optically coupled" refers to coupling such that light from one element is imparted to another element. The term "directly optically coupled" refers to an optical coupling without any intermediate optical components such as lenses or fiber arrays.

Referring to FIG. **1**, a WDM-PON **100** including one or more multi-channel optical transceivers **102***a*, **102***b*, consistent with embodiments of the present disclosure, is shown and described. The WDM-PON **100** provides a point-to-multipoint optical network architecture using a WDM system. According to one embodiment of the WDM-PON **100**, at least one optical line terminal (OLT) **110** may be coupled to a plurality of optical networking terminals (ONTs) or optical networking units (ONUs) **112-1** to **112-***n* via optical fibers, waveguides, and/or paths **114**, **115-1** to **115-***n*. Although the OLT **110** includes two multi-channel optical transceivers **102***a*, **102***b* in the illustrated embodiment, the OLT **110** may include one or more multi-channel optical transceivers.

The OLT **110** may be located at a central office of the WDM-PON **100**, and the ONUs **112-1** to **112-***n* may be located in homes, businesses or other types of subscriber location or premises. A branching point **113** (e.g., a remote node) couples a trunk optical path **114** to the separate optical paths **115-1** to **115-***n* to the ONUs **112-1** to **112-***n* at the respective subscriber locations. The branching point **113** may include one or more passive coupling devices such as a splitter or optical multiplexer/demultiplexer. In one example, the ONUs **112-1** to **112-***n* may be located about 20 km or less from the OLT **110**.

The WDM-PON **100** may also include additional nodes or network devices, such as Ethernet PON (EPON) or Gigabit PON (GPON) nodes or devices, coupled between the branching point **113** and ONUs **112-1** to **112-***n* at different locations or premises. One application of the WDM-PON **100** is to provide fiber-to-the-home (FTTH) or fiber-to-the-premises (FTTP) capable of delivering voice, data, and/or video services across a common platform. In this application, the central office may be coupled to one or more sources or networks providing the voice, data and/or video.

In the WDM-PON **100**, different ONUs **112-1** to **112-***n* may be assigned different channel wavelengths for transmitting and receiving optical signals. In one embodiment, the WDM-PON **100** may use different wavelength bands for transmission of downstream and upstream optical signals relative to the OLT **110** to avoid interference between the received signal and back reflected transmission signal on the same fiber. For example, the L-band (e.g., about 1565 to 1625 nm) may be used for downstream transmissions from the OLT **110** and the C-band (e.g., about 1530 to 1565 nm) may be used for upstream transmissions to the OLT **110**. The upstream and/or downstream channel wavelengths may generally correspond to the ITU grid. In one example, the upstream wavelengths may be aligned with the 100 GHz ITU grid and the downstream wavelengths may be slightly offset from the 100 GHz ITU grid.

The ONUs **112-1** to **112-***n* may thus be assigned different channel wavelengths within the L-band and within the C-band. Transceivers or receivers located within the ONUs **112-1** to **112-***n* may be configured to receive an optical signal on at least one channel wavelength in the L-band (e.g., λ_{L1}, λ_{L2}, . . . λ_{Ln}). Transceivers or transmitters located within the ONUs **112-1** to **112-***n* may be configured to transmit an optical signal on at least one channel wavelength in the C-band (e.g., λ_{C1}, λ_{C2}, . . . λ_{Cn}). Other wavelengths and wavelength bands are also within the scope of the system and method described herein.

The branching point **113** may demultiplex a downstream WDM optical signal (e.g., λ_{L1}, λ_{L2}, . . . λ_{Ln}) from the OLT **110** for transmission of the separate channel wavelengths to the respective ONUs **112-1** to **112-***n*. Alternatively, the branching point **113** may provide the downstream WDM optical signal to each of the ONUs **112-1** to **112-***n* and each of the ONUs **112-1** to **112-***n* separates and processes the assigned optical channel wavelength. The individual optical signals may be encrypted to prevent eavesdropping on optical channels not assigned to a particular ONU. The branching point **113** also combines or multiplexes the upstream optical signals from the respective ONUs **112-1** to **112-***n* for transmission as an upstream WDM optical signal (e.g., λ_{C1}, λ_{C2}, . . . λ_{Cn}) over the trunk optical path **114** to the OLT **110**.

One embodiment of the ONU **112-1** includes a laser **116**, such as a laser diode, for transmitting an optical signal at the assigned upstream channel wavelength (λ_{C1}) and a photodetector **118**, such as a photodiode, for receiving an optical signal at the assigned downstream channel wavelength (λ_{L1}). The laser **116** may include a tunable laser configured to be tuned to the assigned channel wavelength. This embodiment of the ONU **112-1** may also include a diplexer **117** coupled to the laser **116** and the photodetector **118** and a C+L band filter **119** coupled to the diplexer **117**, which allow the L-band channel wavelength (λ_{L1}) to be received by the ONU **112-1** and the C-band channel wavelength (λ_{C1}) to be transmitted by the ONU **112-1**.

The OLT **110** may be configured to generate multiple optical signals at different channel wavelengths (e.g., λ_{L1}, λ_{L2}, . . . λ_{Ln}) and to combine the optical signals into the downstream WDM optical signal carried on the trunk optical fiber or path **114**. Each of the OLT multi-channel optical transceivers **102***a*, **102***b* may include a multi-channel transmitter optical subassembly (TOSA) **120** for generating and combining the optical signals at the multiple channel wavelengths. The OLT **110** may also be configured to separate optical signals at different channel wavelengths (e.g., λ_{C1}, λ_{C2}, . . . λ_{Cn}) from an upstream WDM optical signal carried on the trunk path **114** and to receive the separated optical signals. Each of the OLT multi-channel optical transceivers **102***a*, **102***b* may thus include a multi-channel receiver optical subassembly (ROSA) **130** for separating and receiving the optical signals at multiple channel wavelengths. As will be described in greater detail below, the multi-channel TOSA **120** and ROSA **130** are configured and arranged to fit within a relatively small transceiver housing and to facilitate heat transfer within the transceiver housing.

One embodiment of the multi-channel TOSA **120** includes an array of lasers **122**, such as laser diodes, which may be modulated by respective RF data signals (TX_D**1** to TX_Dm) to generate the respective optical signals. The lasers **122** may be modulated using various modulation techniques including external modulation and direct modulation. An optical multiplexer **124**, such as an arrayed waveguide grating (AWG), combines the optical signals at the different respective downstream channel wavelengths (e.g., λ_{L1}, λ_{L2}, . . . λ_{Lm}). The TOSA **120** may also include a temperature control system for controlling temperature of the lasers **122** and the multiplexer **124** to maintain a desired wavelength precision or accuracy.

In some embodiments, the lasers **122** may be tunable lasers that generate the optical signals at the respective channel wavelengths. In other embodiments, the lasers **122** may generate optical signals over a band of channel wavelengths and filtering and/or multiplexing techniques may be used to produce the assigned channel wavelengths. Examples of optical transmitters including a laser array and AWG are disclosed in greater detail in U.S. patent application Ser. No. 13/543,310 (U.S. Patent Application Pub. No. 20130016971), U.S., patent application Ser. No. 13/357,130 (U.S. Patent Application Pub. No. 20130016977), and U.S. patent application Ser. No. 13/595,505 (U.S. Patent Application Pub. No. 20130223844), all of which are fully incorporated herein by reference. In the illustrated embodiment, the OLT **110** further includes a multiplexer **104** for multiplexing the multiplexed optical signal from the multi-channel TOSA **120** in the multi-channel transceiver **102***a* with a multiplexed optical signal from a multi-channel TOSA in the other multi-channel transceiver **102***b* to produce the downstream aggregate WDM optical signal.

One embodiment of the multi-channel ROSA **130** includes a demultiplexer **132** for separating the respective upstream channel wavelengths (e.g., λ_{C1}, λ_{C2}, . . . λ_{Cn}). An array of photodetectors **134**, such as photodiodes, detects the optical signals at the respective separated upstream channel wavelengths and provides the received data signals (RX_D1 to RX_Dm). As described in greater detail below, the outputs of the demultiplexer **132** may be aligned with and directly optically coupled to the photodetectors **134** to provide a relatively high coupling efficiency. In the illustrated embodiment, the OLT **110** further includes a demultiplexer **106** for demultiplexing the upstream WDM optical signal into first and second WDM optical signals provided to the respective multi-channel ROSA in each of the transceivers **102***a*, **102***b*. The OLT **110** also includes a diplexer **108** between the trunk path **114** and the multiplexer **104** and the demultiplexer **106** such that the trunk path **114** carries both the upstream and the downstream channel wavelengths. The transceivers **102***a*, **102***b* may also include other components, such as laser drivers, transimpedance amplifiers (TIAs), and control interfaces, used for transmitting and receiving optical signals.

In one example, each of the multi-channel optical transceivers **102***a*, **102***b* may be configured to transmit and receive 16 channels such that the WDM-PON **100** supports 32 downstream L-band channel wavelengths and 32 upstream C-band channel wavelengths. In one example, the downstream L-band link between the OLT transceivers **102***a*, **102***b* and the ONUs **112-1** to **112-***n* may support a power budget of at least about 26 dB and the upstream C-band link between the ONUs **112-1** to **112-***n* and the OLT transceivers **102***a*, **102***b* may support a power budget of at least about 23 dB. One example of the WDM-PON **100** may operate at 1.25 Gbaud using 8B/10B encoded on-off keying as the modulation scheme. Other data rates and modulation schemes may also be used.

As mentioned above, the upstream and downstream channel wavelengths may span a range of channel wavelengths on the 100 GHz ITU grid. Each of the transceivers **102***a*, **102***b*, for example, may cover 16 channel wavelengths in the L-band for the TOSA and 16 channel wavelengths in the C-band for the ROSA such that the transceivers **102***a*, **102***b* together cover 32 channels. Thus, the multiplexer **104** may combine 16 channels from one transceiver **102***a* with 16 channels from the other transceiver **102***b*, and the demultiplexer **106** may separate a 32 channel WDM optical signal into two 16 channel WDM optical signals. To facilitate use of the multiplexer **104** and the demultiplexer **106**, the range of channel wavelengths may skip channels (e.g., 2 channels) in the middle of the range. According to one example of a multi-channel optical transceiver used in the WDM-PON **100**, the desired wavelength precision or accuracy is ±0.05 nm, the desired operating temperature is between −5 and 70° C., and the desired power dissipation is about 16.0 W.

Referring to FIGS. **2** and **3**, one embodiment of a compact multi-channel optical transceiver module **202** is shown and described in greater detail. As discussed above, multiple multi-channel transceiver modules may be used in an OLT of a WDM-PON to cover a desired channel range. The transceiver module **202** may thus be designed to have a relatively small form factor with minimal space. The compact optical transceiver module **202** generally provides an optical input and output at an optical connection end **204** and electrical input and output at an electrical connection end **206**. The transceiver module **202** includes a transceiver housing **210***a*, **210***b* enclosing a multi-channel TOSA **220**, a multi-channel ROSA **230**, a circuit board **240**, and a dual fiber adapter **250** directly linked to the TOSA **220** and the ROSA **230** for providing the optical input and output. The transceiver housing **210***a*, **210***b* may have a width of less than about 55 mm, a length of less than about 130 mm, and a height of less than about 10 mm. More specifically, one example of a transceiver housing **210** may have a width of 54.6 mm, a length of 110 mm, and a height of about 9.8 mm.

In the example embodiment, the TOSA **220** is located in the transceiver housing **210***a*, **210***b* proximate the optical connection end **204** and the ROSA **230** is located in the transceiver housing **210***a*, **210***b* proximate the electrical connection end **206**. The circuit board **240** is located proximate the transceiver housing bottom portion **210***a* and extends to the electrical connection end **206**. The ROSA **230** is located between the circuit board **240** and the transceiver housing top portion **210***b*. As will be described in greater detail below, the ROSA **230** may be spaced from the circuit board **240** to provide space for circuit board components and may be inverted and positioned proximate the transceiver housing top portion **210***b* to facilitate heat transfer from the ROSA **230** to the housing top portion **210***b*.

The TOSA **220** and the ROSA **230** each have an optical connection end **221**, **231** directed toward the transceiver optical connection end **204** and an electrical connection end **223**, **233** directed toward the transceiver electrical connection end **206**. The optical connection ends **221**, **231** of the TOSA **220** and the ROSA **230** are optically coupled to the dual fiber adapter **250** with respective optical fibers **222**, **232**, respectively, to provide a direct link between the adapter **250** and both the TOSA **220** and the ROSA **230**. The electrical connection ends **223**, **233** of the TOSA **220** and the ROSA **230** are electrically connected to the circuit board **240** using TOSA pins **224** and ROSA pins **234**, respectively, soldered to conductive pads on the circuit board **240**. The circuit board **240** includes input/output conductive pads **242** proximate the transceiver electrical connection end **206**. Input conductive pads **242** may be provided on one side of the circuit board **240** for providing RF input to the TOSA

220 and output conductive pads **242** may be provided on the other side of the circuit board **240** for providing output from the ROSA **230**.

The dual fiber adapter **250** is also configured to receive pluggable optical connectors, such as LC connectors (not shown), to connect the TOSA **220** and ROSA **230**, respectively, to fiber optic cables (not shown). When the pluggable optical connectors are plugged into the dual fiber adapter **250**, the adapter **250** establishes an optical coupling between the TOSA **220** and the ROSA **230** and the respective optical fibers in the fiber-optic cables, which carry the optical signals to and from the transceiver.

The multi-channel TOSA **220** includes an array of lasers (not shown in FIGS. **2** and **3**) coupled to a multiplexer **225** such as an AWG. A temperature control system may be used to control the temperature of the individual lasers to provide a desired wavelength with a desired wavelength precision or accuracy. In one example, the temperature of each laser is maintained within ±0.5° C. in the operating range between −5 and 70° C. to maintain a wavelength precision or accuracy of about ±0.05 nm. The temperature control system may include a thermoelectric cooler (TEC), and the multiplexer **225** and/or the lasers may be mounted on the TEC in a bottom region of the TOSA **220**. Examples of the TOSA are described in greater detail in U.S. patent application Ser. No. 13/708,064 (U.S. Patent Application Pub. No. 20140161455) and U.S. patent application Ser. No. 13/708,569 (U.S. Patent Application Pub. No. 20140161457), which are fully incorporated herein by reference.

Although the illustrated embodiment shows the TOSA **220** with the bottom region facing the transceiver housing bottom portion **210***a*, the TOSA **220** may also be inverted and the bottom of the TOSA **220** may be thermally coupled to (e.g., touching) the transceiver housing top portion **210***b*. The transceiver module **202** may be mounted in a cage assembly with the transceiver housing top portion **210***b* being located proximate a heat sink at the top of the cage. Because the TOSA **220** generates most of the heat from the bottom portion (e.g., from the TEC), the upside down or inverted configuration may provide better thermal dissipation and improve the overall working temperature range of the transceiver module **202**.

The multi-channel ROSA **230** includes a demultiplexer, such as an AWG, coupled to an array of photodetectors, such as photodiodes, as will be described in greater detail below. The printed circuit board **240** may include circuitry and electronic components such as laser diode drivers, transimpedance amplifiers (TIAs), control interfaces, and temperature control circuitry. In the example embodiment, the circuit board **240** includes integrated circuit (IC) components **244** electrically connected to the TOSA **220** and the ROSA **230**, for example, using conductive traces on or in the circuit board **240**. The IC components **244** are mounted on at least one side of the circuit board **240** between the circuit board **240** and the ROSA **230** and may also be mounted on the opposite side of the circuit board **240**. The IC components **244** may be arranged on the circuit board **240** in one or more rows of IC components **244**.

In one embodiment, the IC components are combination IC components including a laser diode driver and a photodiode limiting amplifier. Each laser diode driver is electrically connected to a respective laser diode on the TOSA **220** and each photodiode limiting amplifier is electrically connected to a respective photodiode on the ROSA **230**. In the example embodiment of a sixteen (16) channel transceiver, for example, the circuit board **240** may include 16 combination IC components **244**. The 16 combination IC components may be arranged in two rows of four IC components **244** on each side of the circuit board **240**.

In the example embodiment, ROSA supports **260** hold and support the ROSA **230** on each side of the ROSA **230**. The ROSA supports **260** are mounted to the transceiver housing bottom portion **210***a* such that the ROSA **230** is spaced from the circuit board **240**. The illustrated embodiment of the ROSA supports **260** have an L-shaped portion such that the ROSA supports **260** extend from sides of the transceiver housing bottom portion **210***a* and support the ROSA **230** without interfering with the circuit board **240** or any components thereon.

Referring to FIGS. **4** and **5**, an embodiment of the multi-channel ROSA **230** is described in greater detail. The ROSA **230** includes a demultiplexer **235**, such as an AWG, mounted on a ROSA base portion **238**. Optical outputs **237** of the demultiplexer **235** are optically coupled to an array of photodetectors **236**, such as photodiodes. An input of the demultiplexer **235** is optically coupled to the input optical fiber **232** at the optical connection end **231** and the output of the photodetectors **236** are electrically connected to the ROSA pins **234** at the electrical connection end **233**. A ROSA cover **239** covers the ROSA base portion **238** and encloses the demultiplexer **235** and array of photodetectors **236**.

As shown in FIGS. **4** and **5**, optical outputs **237** of the demultiplexer **235** are directly optically coupled to the respective photodetectors **236** without any intermediate optical components such as lenses or fibers. Where the demultiplexer **235** is an AWG, for example, the light exits the waveguides of the AWG and enters the photodetectors **236** without passing through any medium other than air. As such, the AWG may be designed and configured without components (e.g., a glass rail) used to couple the AWG to a fiber array, which allows the direct optical coupling. The waveguides in the AWG may be modified to account for any optical changes resulting from the removal of any such components, such as changes in the index of refraction or other changes in the light path.

Referring to FIGS. **6**-**9**, direct optical coupling of the array of photodetectors **236** to the respective optical outputs **237** of the optical demultiplexer **235** is shown and described in greater detail. In the illustrated embodiment, the array of photodetectors **236** include PIN type photodiodes **270** mounted on a photodetector mounting bar **272** together with associated transimpedance amplifiers (TIAs) **274**. The photodiodes **270** are aligned with and spaced from the optical outputs **237** of the demultiplexer **235** with a spacing that is close enough to achieve a coupling efficiency of 95% or greater with an alignment tolerance (i.e., in the X, Y axes) high enough to allow passive alignment (e.g., an alignment tolerance of at least about 20 microns). In one example, the photodiodes **270** may be spaced from the optical outputs **237** (i.e., in the Z axis) in a range of 10-40 microns, which allows a coupling efficiency greater than 95% and an alignment tolerance of about 20 microns. In the illustrated embodiment of a 16 channel ROSA, for example, 16 photodiodes **270** are aligned with 16 optical outputs **237** and electrically connected to 16 associated TIAs **274**, respectively.

As shown in FIGS. **8** and **9**, each of the photodiodes **270** is electrically connected to each of the TIAs **274** using wire bonding. Wires **271** extend from wire bonding points on the photodiodes **270** to wire bonding points on the associated TIAs **274**. Wires **271** also extend between the photodiodes **270** and/or TIAs **274** and conductive paths or pads on the mounting bar **272**, for example, to ground paths **273**. Although one embodiment includes nine (9) wires **271** between each photodiode/TIA pair, as shown in FIG. **9**, other numbers of wires may also be used. The photodiodes **270** are designed and configured with wire bonding points arranged in a pattern (e.g., using a cross over design) such that the wires **271** do not interfere with the optical demultiplexer **235**, thereby allowing the direct optical coupling with sufficient proximity to achieve the desired coupling efficiency (e.g., 95% or greater) and with a tolerance alignment high enough to allow passive alignment (e.g., at least 20 microns). In other words, the wire bonding points are arranged on the region of each of the photodiodes **270** that does not oppose the demultiplexer **235** when directly optically coupled. Where the optical multiplexer **235** is about 0.7 mm thick, for example, the wire bond points may be located on a region of the mounted photodiode **270** that extends above 0.8 mm measured from the ROSA housing bottom portion **238**. Designing and configuring an AWG without a glass rail for connecting to a fiber array, as discussed above, also prevents interference with the wire bonding and allows the close proximity of the photodiodes **270** to the respective optical outputs **237**.

The photodiodes **270** may also be spaced sufficiently on the mounting bar **272** (i.e., in the X axis) to allow each of the photodiodes **270** to be connected to a floating ground. Connecting the photodiodes **270** to a floating ground instead of a common ground may prevent loss of receiver sensitivity. The floating grounds may include the ground paths **273** on the mounting bar **272** between the TIAs **274**. Thus, the TIAs **274** are spaced on the mounting bar **272** sufficiently to allow space for the ground paths **273** between the TIAs **274**, and the photodiodes **270** associated with each of the TIAs **274** are mounted with a pitch p corresponding to the pitch p of the TIAs **274**. In one example, where the TIAs **274** are each about 1 mm wide, the TIAs **274** and the photodiodes **270** have a pitch p on the mounting bar **272** greater than 1 mm and more specifically about 1.375 mm. In one embodiment, the optical demultiplexer **235** may be an AWG designed with the optical outputs **237** having a pitch p matching that of the photodiodes **270** when mounted on the mounting bar **272**.

Referring to FIGS. **10**A-**10**E, a passive alignment method is described in greater detail. Passive alignment generally refers to alignment without actively directing light into a photodiode and monitoring the photodiode output. This passive alignment method may be used to align each of the photodiodes **270** (e.g., in the X and Y axis) with each of the respective optical outputs **237** of the optical demultiplexer **235** to provide the desired coupling efficiency. Although a passive alignment method is described herein, active alignment methods may also be used to provide alignment of the photodetectors in the ROSA described above.

The photodetector mounting bar **272** is mounted to the ROSA bottom portion **238** without the photodiodes and TIAs, as shown in FIG. **10**A. The mounting bar **272** may be mounted using an adhesive, such as epoxy, or other suitable techniques. The mounting bar **272** includes photodiode conductive pads **276** and TIA conductive pads **278** with a pitch p corresponding to the desired pitch of the mounted photodiodes and TIAs. The ground paths **273** are located on the mounting bar **272** between the TIA conductive pads **278**.

The optical demultiplexer **235** (e.g., the AWG) is also mounted to the ROSA bottom portion **238**, as shown in FIG. **10**B. Although the illustrated embodiment shows the mounting bar **272** being mounted before the optical demultiplexer **235**, the demultiplexer **235** may also be mounted before the mounting bar **272**. In either case, the mounting bar **272** (i.e., without the photodiodes and TIAs) and the demultiplexer **235** are mounted with a spacing (e.g., along the Z axis) that is sufficient to accommodate the photodiodes with the desired close proximity spacing (e.g., 10-40 microns) for direct optical coupling with the desired coupling efficiency. The demultiplexer **235** includes alignment markings **280** that mark the locations of the optical outputs **237** of the optical demultiplexer **235** along the X axis. The mounting bar **272** and the optical demultiplexer **235** are mounted to the ROSA housing base portion **238** such that the alignment markings **280** align with respective photodiode conductive pads **276** on the mounting bar **272**.

The optical demultiplexer **235** is mounted to the ROSA housing base portion **235** using an adhesive **233**, such as an epoxy. Because the adhesive **233** may have different thicknesses at different sides **282**, **284** of the optical demultiplexer **235**, the position of the optical outputs **237** in the Y axis may vary relative to the ROSA housing base portion **238**. To account for this variation, distances h_1, h_2 are measured at each side **282**, **284** of the optical demultiplexer **235** from the ROSA housing base portion **238** to a location on the optical demultiplexer **235** (e.g., the top of an AWG chip). These distances may then be used to provide passive alignment of the photodiodes **270** with the optical outputs **237** in the Y axis as disclosed in greater detail below.

After the mounting bar **272** and the optical demultiplexer **235** have been mounted to the ROSA housing base portion **238**, each of the photodiodes **270** may be positioned between the mounting bar **272** and the optical demultiplexer **235** and aligned in the X and Y axes at each of the respective locations as shown in FIGS. **10**C-**10**E. Each aligned photodiode **270** may be mounted to the photodiode conductive pad **276**, for example, using a conductive epoxy applied to the conductive pad **276** and/or to the photodiode **270** prior to positioning and aligning the photodiode **270**. Conductive epoxy, such as silver epoxy, allows cathodes of the photodiodes to be electrically connected to the respective photodiode conductive pads **276**.

To provide the passive alignment in the illustrated embodiment, an inspection system **290** is positioned for imaging the photodetector mounting bar **272**. The inspection system **290** may include a microscope and inspection projector such as the type known for use in inspecting small areas for opto-electronic assembly. The inspection system **290** generates an alignment line **286** based on the measured distances h_1, h_2 at the respective sides **282**, **284** of the optical demultiplexer **235** and projects or displays the alignment line **286** on the mounting bar **272** for use in aligning the photodiodes in the Y axis (see FIG. **10**D). The alignment line **286** corresponds to the variation in position of the optical outputs **237** in the Y axis relative to the ROSA housing base portion **238**.

The alignment line **286** may be formed between two points determined from the measured distances h_1, h_2. For an AWG having a thickness of 0.7 mm, for example, if the measured distances h_1, h_2 are 0.78 mm and 0.795 mm, respectively, the alignment line **286** will have a variance of 15 microns between the ends (e.g., at the positions of the photodiode **1** and photodiode **16**). Because the optical outputs **237** are aligned linearly from the first side **282** to the second side **284** of the demultiplexer **235**, the alignment line **286** generated from the distances h_1, h_2 measured at each of the sides **282**, **284** may be used to align all of the photodiodes **270** in the Y axis without having to measure the distances at each of the locations of the optical outputs **237**.

While viewing the mounting bar **272** with the inspection system **290**, the individual photodiodes **270** may be positioned, aligned and mounted. Each of the photodiodes **270** may be aligned in the X axis using the alignment markings **280** and may be aligned in the Y axis using the alignment line **286**. According to one method, the photodiodes **270** may be manually positioned (e.g., using tweezers). According to another method, a placement system **294** may be used to automatically position each photodiode **270** to the aligned location. The placement system **294** may include automated machines known for use in holding and positioning small optical or opto-electronic components. One example of a placement system **294** includes a vacuum tip **296** capable of holding the photodiode **270**.

After all of the photodiodes **270** have been aligned and mounted, the TIAs (not shown in FIGS. **10**A-**10**E) may be mounted to the TIA conductive pads **278**, for example, using a silver epoxy or other conductive epoxy. The photodiodes, TIAs and conductive paths may then be wire bonded to provide the electrical connections.

Accordingly, the multi-channel optical transceiver module, consistent with embodiments described herein, provides a direct optical coupling between an array of photodetectors and a plurality of optical outputs of an optical demultiplexer in a relatively small space and with a relatively high coupling efficiency. A passive alignment method may also be used to align the photodetectors with the optical outputs of the optical demultiplexer with the relatively high coupling efficiency.

Consistent with an embodiment, a multi-channel receiver optical subassembly (ROSA) includes a ROSA housing and an optical demultiplexer located in the ROSA housing. The optical demultiplexer includes multiple optical outputs corresponding to multiple channels and is configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths, respectively. The multi-channel ROSA also includes an array of photodetectors located in the ROSA housing and aligned with and directly optically coupled to the multiple optical outputs, respectively, of the optical demultiplexer.

Consistent with another embodiment, a multi-channel optical transceiver module includes a transceiver housing having a transceiver optical connection end and a transceiver electrical connection end. The transceiver optical connection end of the transceiver housing is configured to provide an optical connection and the transceiver electrical connection end of the transceiver housing being configured to provide an electrical connection. The multi-channel optical transceiver module also includes a circuit board located in the transceiver housing proximate the transceiver housing bottom portion. The circuit board includes RF inputs located proximate the transceiver electrical connection end of the transceiver housing. The multi-channel optical transceiver module further includes a multi-channel transmitter optical subassembly (TOSA) located in the transceiver housing and electrically connected to the circuit board. The TOSA is configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths. The multi-channel optical transceiver module also includes a multi-channel receiver optical subassembly (ROSA) located in the transceiver housing and electrically connected to the circuit board. The ROSA is configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths. The ROSA includes an optical demultiplexer including multiple optical outputs corresponding to multiple channels. The optical demultiplexer is configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths, respectively. The ROSA also includes an array of photodetectors aligned with and directly optically coupled to the multiple optical outputs, respectively, of the optical demultiplexer.

Consistent with a further embodiment, a method is provided for aligning photodetectors to optical outputs of an optical demultiplexer in a multi-channel receiver optical subassembly (ROSA). The method includes: mounting an optical demultiplexer on a ROSA housing base portion, wherein the optical demultiplexer includes alignment markings indicating locations of optical outputs of the optical demultiplexer along a first axis, wherein the optical demultiplexer is spaced from a photodetector mounting bar; measuring at least first and second distances from the ROSA housing base portion to the optical demultiplexer at respective first and second sides of the optical demultiplexer; displaying an alignment line on the photodetector mounting bar for indicating a photodetector position along a second axis, the alignment line extending between first and second points on the photodetector mounting bar corresponding to the first and second distances measured at the first and second sides of the optical demultiplexer; and mounting photodetectors on the photodector mounting bar, wherein each of the photodectors is aligned along the first axis with the one of the alignment markings and aligned along the second axis with the alignment line such that the photodectors are passively aligned with respective ones of the optical outputs of the optical demultiplexer.

While the principles of the invention have been described herein, it is to be understood by those skilled in the art that this description is made only by way of example and not as a limitation as to the scope of the invention. Other embodiments are contemplated within the scope of the present invention in addition to the exemplary embodiments shown and described herein. Modifications and substitutions by one of ordinary skill in the art are considered to be within the scope of the present invention, which is not to be limited except by the following claims.

What is claimed is:

1. A multi-channel receiver optical subassembly (ROSA) comprising:

a ROSA housing;

an optical demultiplexer located in the ROSA housing, the optical demultiplexer including multiple optical outputs corresponding to multiple channels, the optical demultiplexer being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths, respectively; and

an array of photodetectors located in the ROSA housing and spaced from the optical demultiplexer, the array of photodetectors aligned with and directly optically coupled to the multiple optical outputs, respectively, of the optical demultiplexer.

2. The multi-channel ROSA of claim **1** wherein the optical demultiplexer includes an arrayed waveguide grating (AWG).

3. The multi-channel ROSA of claim **1** wherein the array of photodetectors are mounted on a photodetector mounting bar.

4. The multi-channel ROSA of claim **3** wherein the array of photodetectors includes a plurality of PIN photodiodes and a plurality of transimpedance amplifiers (TIAs) mounted on the photodetector mounting bar, the PIN photodiodes being electrically connected to respective ones of the TIAs.

5. The multi-channel ROSA of claim **4** wherein the PIN photodiodes are wire bonded to the respective ones of the TIAs, and wherein wire bonding points on the PIN photodiodes are arranged to avoid interfering with the AWG.

6. The multi-channel ROSA of claim **1** wherein the optical outputs are spaced from the photodetectors by a distance of 10-40 microns.

7. The multi-channel ROSA of claim **1** wherein the array of photodetectors has a pitch of at least 1 mm.

8. The multi-channel ROSA of claim **1** wherein each of the photodetectors are electrically connected to a floating ground.

9. The multi-channel ROSA of claim **1** wherein the optical demultiplexer includes sixteen (16) optical outputs corresponding to sixteen (16) channels.

10. The multi-channel ROSA of claim **1** wherein the photodetectors are directly optically coupled with the optical outputs with a coupling efficiency of 95% or higher.

11. The multi-channel ROSA of claim **10** wherein the photodetectors are spaced sufficiently close to the optical outputs to provide an alignment tolerance of at least 20 microns.

12. The multi-channel ROSA of claim **1** wherein the optical demultiplexer includes an arrayed waveguide grating (AWG), wherein the array of photodetectors includes a plurality of PIN photodiodes and a plurality of transimpedance amplifiers (TIAs) mounted on a photodetector mounting bar, the PIN photodiodes being electrically connected to respective ones of the TIAs, wherein the optical outputs of the AWG are spaced from the PIN photodiodes by a distance of 10-40 microns, and wherein the array of photodetectors has a pitch of at least 1 mm.

13. A multi-channel optical transceiver module comprising:

a transceiver housing having a transceiver optical connection end and a transceiver electrical connection end, the transceiver optical connection end of the transceiver housing being configured to provide an optical connection and the transceiver electrical connection end of the transceiver housing being configured to provide an electrical connection;

a circuit board located in the transceiver housing proximate the transceiver housing bottom portion, wherein the circuit board includes RF inputs located proximate the transceiver electrical connection end of the transceiver housing;

a multi-channel transmitter optical subassembly (TOSA) located in the transceiver housing and electrically connected to the circuit board, the TOSA being configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths; and

a multi-channel receiver optical subassembly (ROSA) located in the transceiver housing and electrically connected to the circuit board, the ROSA being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths, wherein the ROSA comprises:

an optical demultiplexer including multiple optical outputs corresponding to multiple channels, the optical demultiplexer being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths, respectively; and

an array of photodetectors aligned with and directly optically coupled to the multiple optical outputs, respectively, of the optical demultiplexer.

14. The multi-channel optical transceiver module of claim **13** wherein the optical demultiplexer includes an arrayed waveguide grating (AWG).

15. The multi-channel optical transceiver module of claim **13** wherein the array of photodetectors are mounted on a photodetector mounting bar.

16. The multi-channel optical transceiver module of claim **15** wherein the array of photodetectors includes a plurality of PIN photodiodes and a plurality of transimpedance amplifiers (TIAs) mounted on the photodetector mounting bar, the PIN photodiodes being electrically connected to respective ones of the TIAs.

17. The multi-channel optical transceiver module of claim **16** wherein the PIN photodiodes are wire bonded to the respective ones of the TIAs, and wherein wire bonding points on the PIN photodiodes are arranged to avoid interfering with the AWG.

18. The multi-channel optical transceiver module of claim **13** wherein the optical outputs are spaced from the photodetectors by a distance of 10-40 microns.

19. The multi-channel optical transceiver module of claim **13** wherein the photodetectors are directly optically coupled with the optical outputs with a coupling efficiency of 95% or higher, and wherein the photodetectors are spaced sufficiently close to the optical outputs to provide an alignment tolerance of at least 20 microns.

20. A multi-channel receiver optical subassembly (ROSA) comprising:

a ROSA housing;

an optical demultiplexer located in the ROSA housing, the optical demultiplexer including multiple optical outputs corresponding to multiple channels, the optical demultiplexer being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths, respectively;

an array of photodetectors located in the ROSA housing, the array of photodetectors aligned with and directly optically coupled to the multiple optical outputs, respectively, of the optical demultiplexer; and

wherein the optical demultiplexer includes an arrayed waveguide grating (AWG), wherein the array of photodetectors includes a plurality of PIN photodiodes and a plurality of transimpedance amplifiers (TIAs) mounted on a photodetector mounting bar, the PIN photodiodes being electrically connected to respective ones of the TIAs, wherein the optical outputs of the AWG are spaced from the PIN photodiodes by a distance of 10-40 microns, and wherein the array of photodetectors has a pitch of at least 1 mm.

* * * * *

Exhibit C

US010230470B2

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

(10) **Patent No.: US 10,230,470 B2**
(45) **Date of Patent: Mar. 12, 2019**

(54) MULTILAYERED FLEXIBLE PRINTED CIRCUIT WITH BOTH RADIO FREQUENCY (RF) AND DC TRANSMISSION LINES ELECTRICALLY ISOLATED FROM EACH OTHER AND AN OPTICAL TRANSCEIVER USING SAME

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(72) Inventors: **Kai-Sheng Lin**, Sugar Land, TX (US); **Yi Wang**, Katy, TX (US); **Kevin Liu**, Houston, TX (US)

(73) Assignee: **Applied Optoelectronics, Inc.**, Sugar Land, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 93 days.

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(51) **Int. Cl.**

G02B 6/42	(2006.01)
H04B 10/40	(2013.01)

(Continued)

(52) **U.S. Cl.**

CPC ***H04B 10/40*** (2013.01); ***G02B 6/12004*** (2013.01); ***G02B 6/12009*** (2013.01); ***G02B 6/421*** (2013.01); ***G02B 6/4246*** (2013.01); ***G02B 6/4256*** (2013.01); ***G02B 6/4262*** (2013.01); ***G02B 6/4281*** (2013.01); ***H05K 1/028*** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC H04B 10/40; G02B 6/4256; H05K 1/028; H05K 5/0026

See application file for complete search history.

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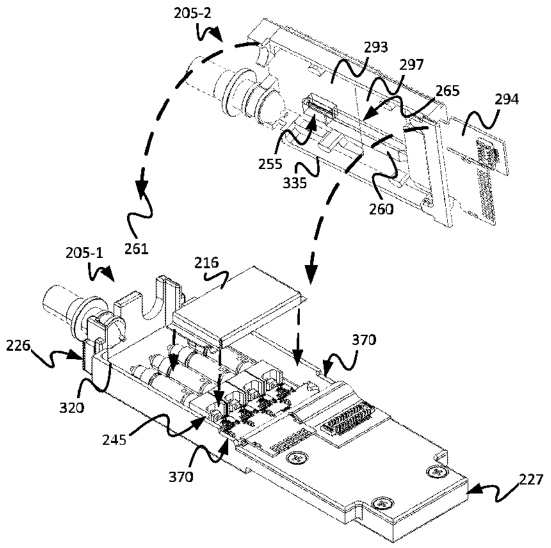
Primary Examiner — Akm E Ullah
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC

(57) ABSTRACT

In accordance with an embodiment, a multi-layered flexible printed circuit (FPC) is disclosed that includes two or more insulating layers to route conductive traces carrying radio frequency (RF) signals, e.g., data signals, and conductive traces carrying direct current (DC) signals, e.g., power signals and low-frequency control signals, while sufficiently isolating the RF signals from electrical interference by the DC transmission lines. This advantageously eliminates having two or more separate FPCs to electrically couple each optical subassembly, e.g., receiver optical subassemblies (ROSAs) and transmitter optical subassemblies (TOSAs), to associated circuitry in a transceiver housing, which saves space and reduces manufacturing complexity, for example.

20 Claims, 11 Drawing Sheets



(51) **Int. Cl.**

H05K 1/18	(2006.01)
H05K 1/02	(2006.01)
G02B 6/12	(2006.01)
H05K 1/11	(2006.01)

(52) **U.S. Cl.**

CPC ***H05K 1/0218*** (2013.01); *H05K 1/118* (2013.01); *H05K 1/189* (2013.01); *H05K 2201/052* (2013.01); *H05K 2201/09672* (2013.01); *H05K 2201/10189* (2013.01)

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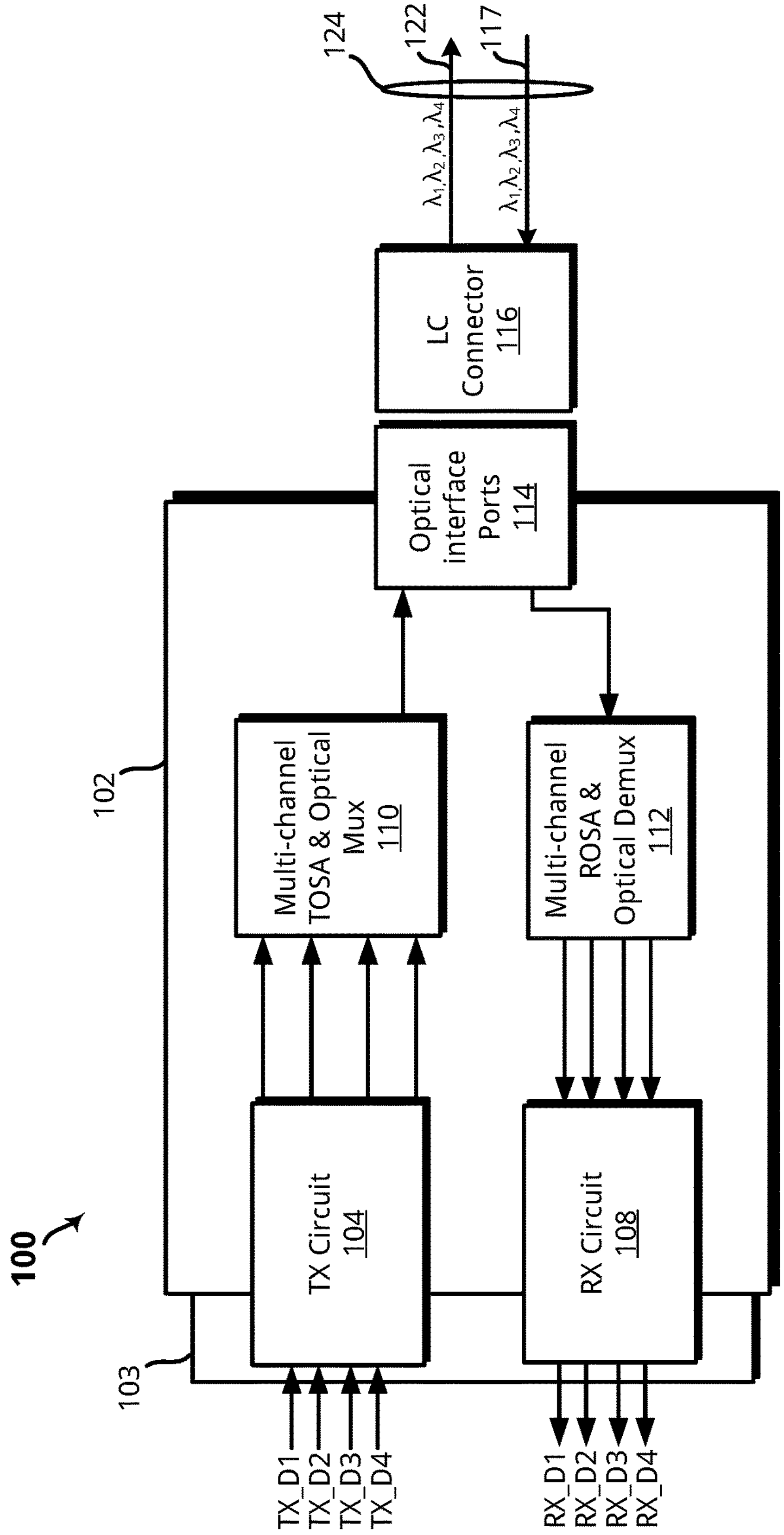
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102
103
TX_D1
TX_D2
TX_D3
TX_D4
TX Circuit
104
Multi-channel TOSA & Optical Mux
110
RX_D1
RX_D2
RX_D3
RX_D4
RX Circuit
108
Multi-channel ROSA & Optical Demux
112
Optical interface Ports
114
LC Connector
116
λ1,λ2,λ3,λ4
λ1,λ2,λ3,λ4
124
122
117

FIG. 1

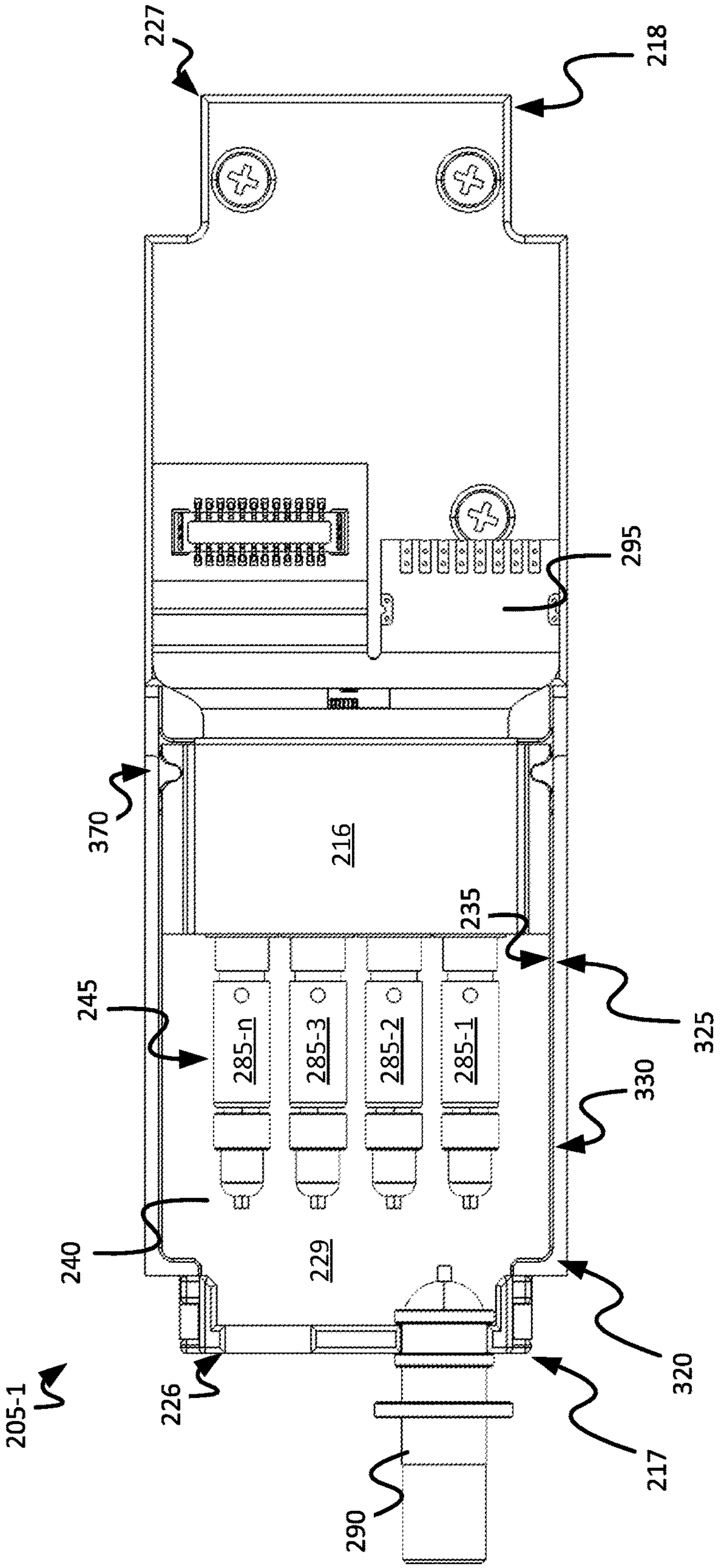
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FIG. 2A

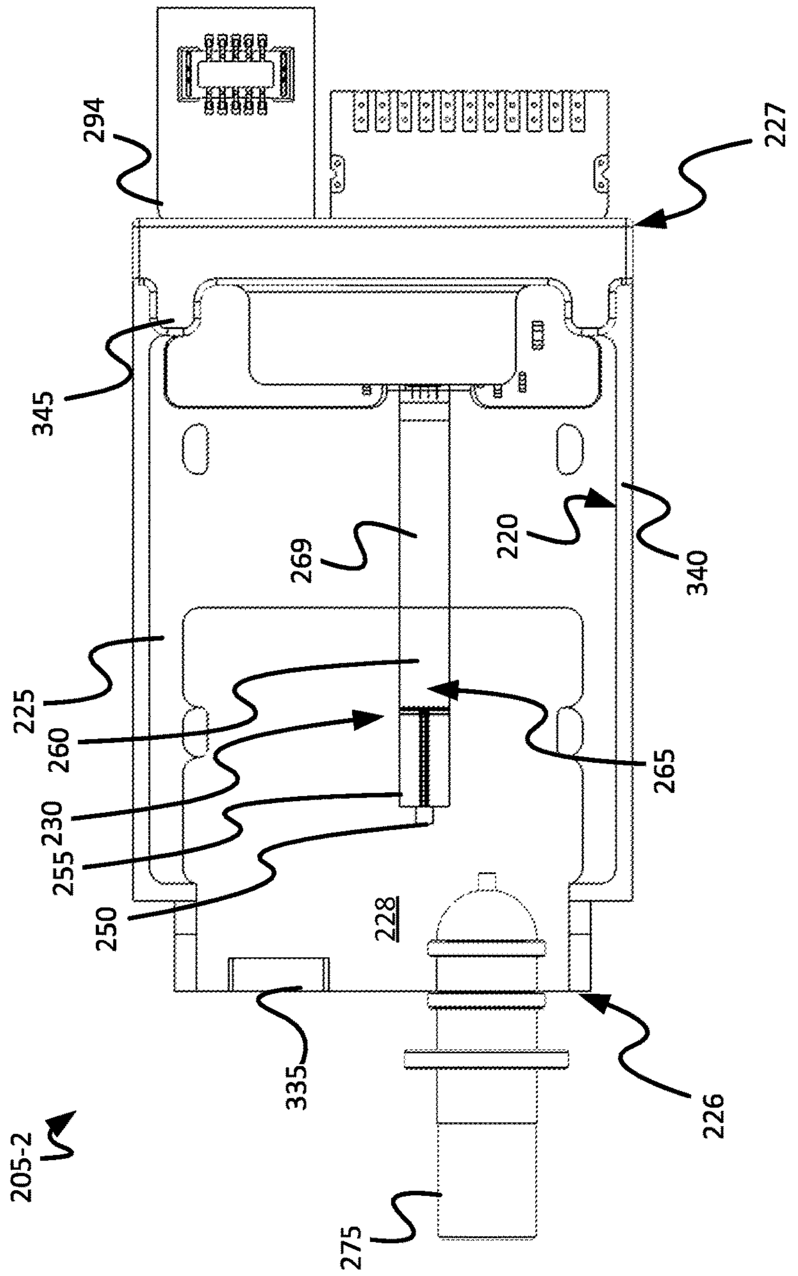
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FIG. 2B

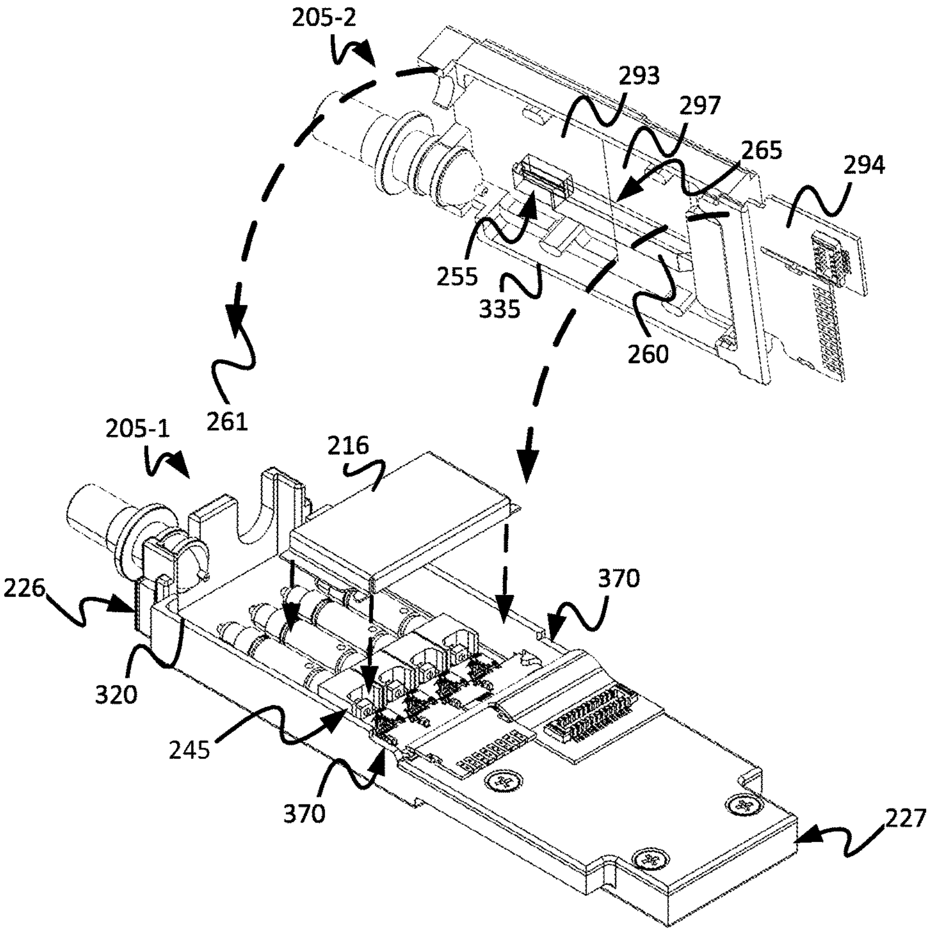
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FIG. 3A

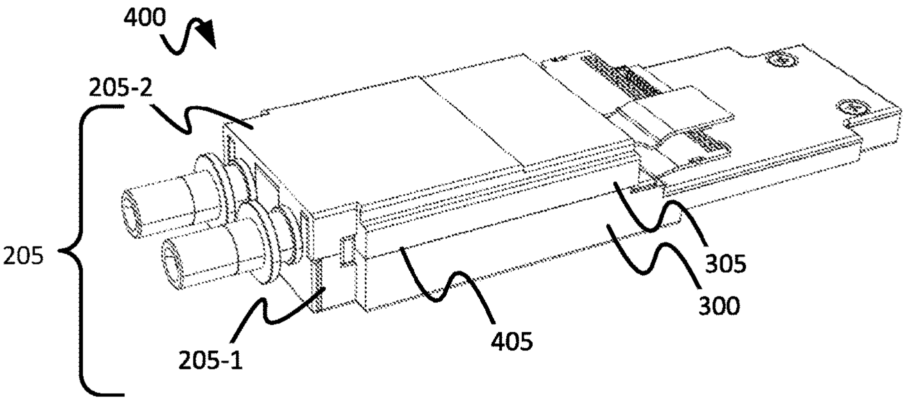
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FIG. 3B

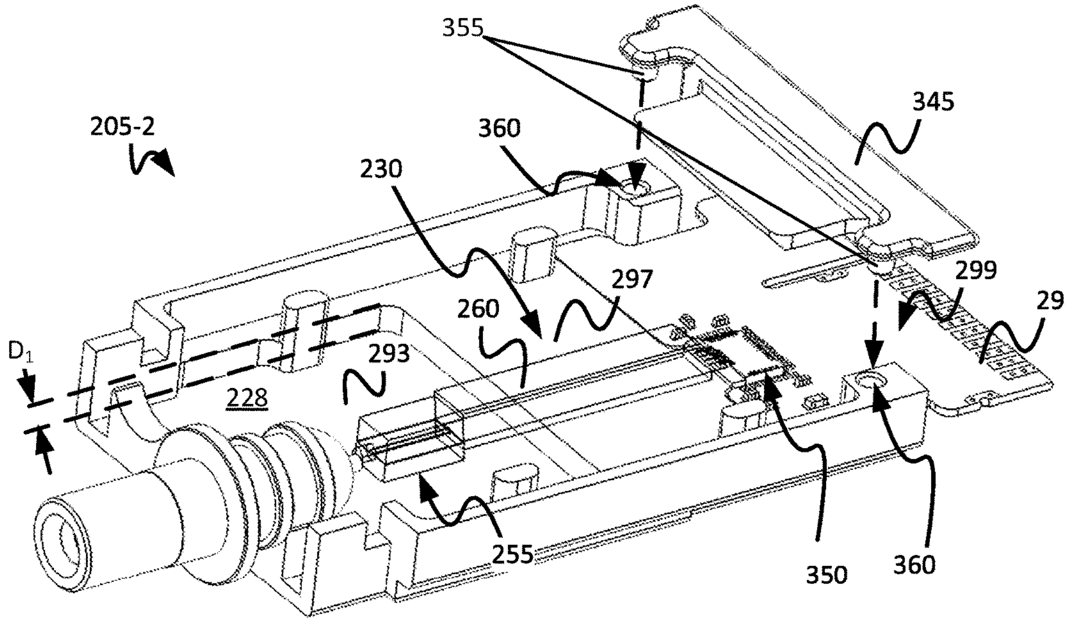
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FIG. 4

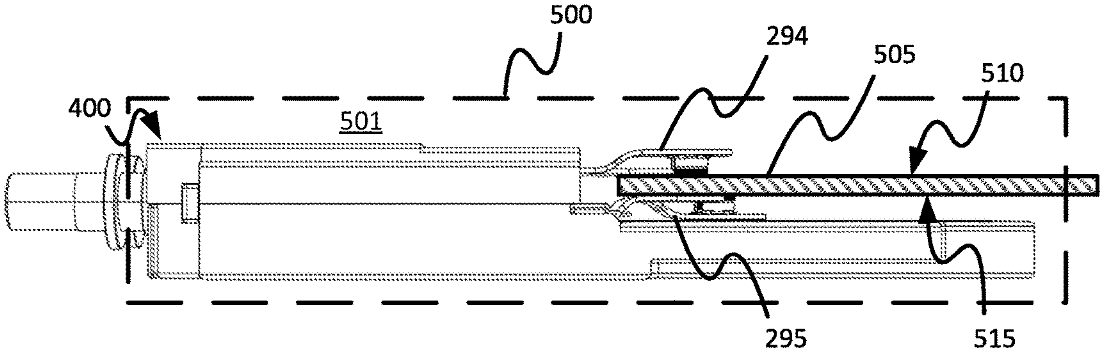
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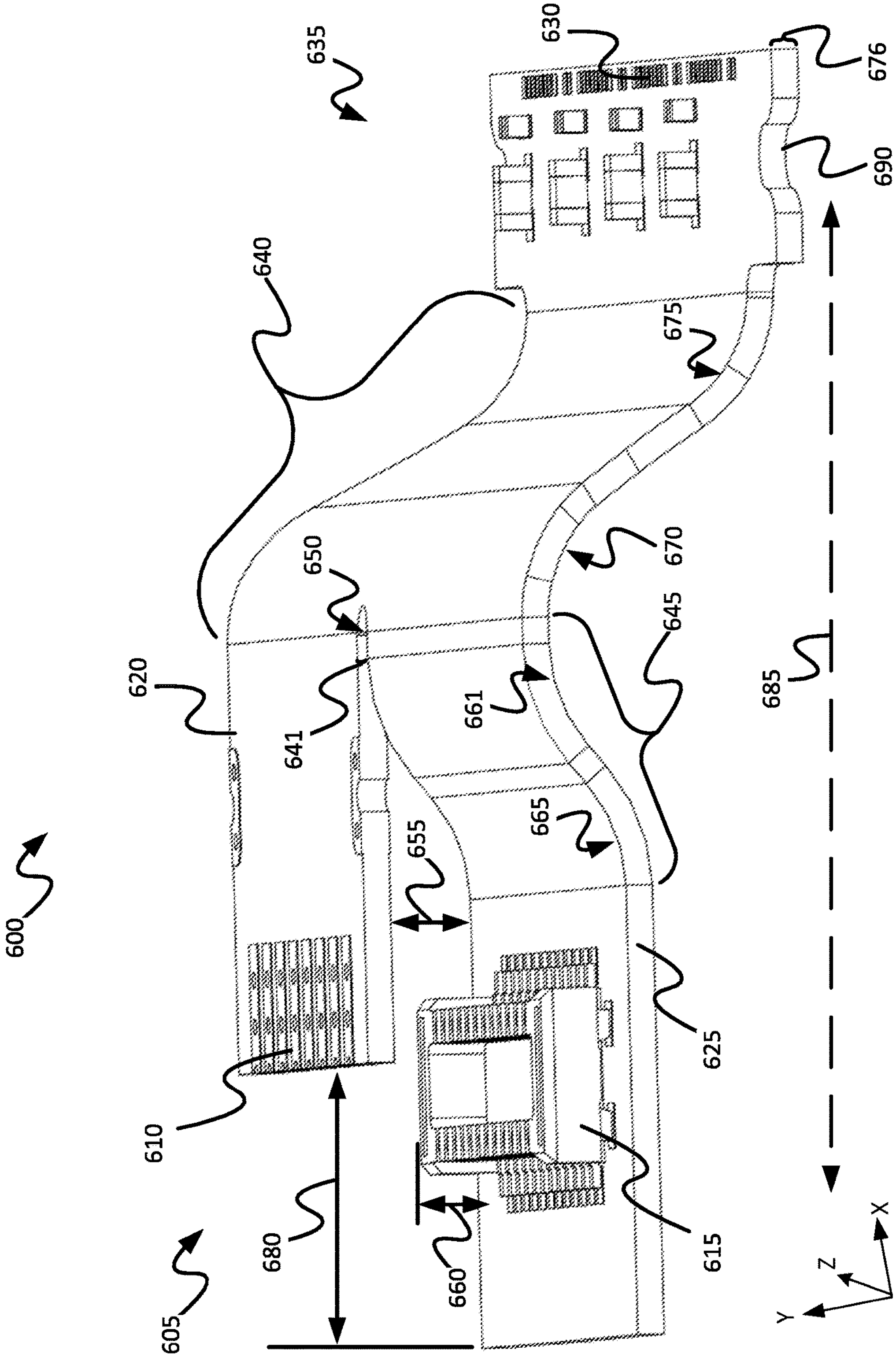
FIG. 5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X
Z
Y

FIG. 6

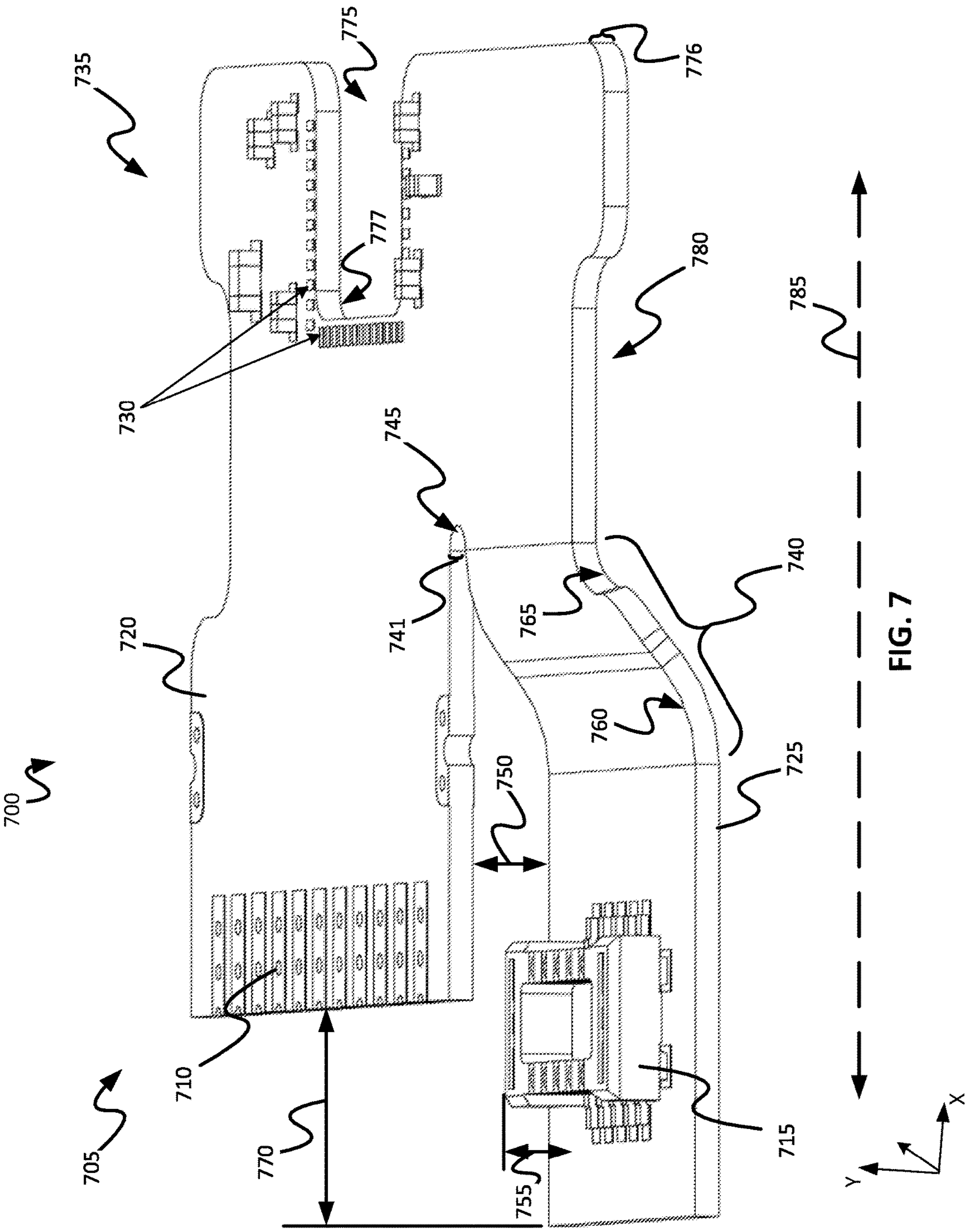
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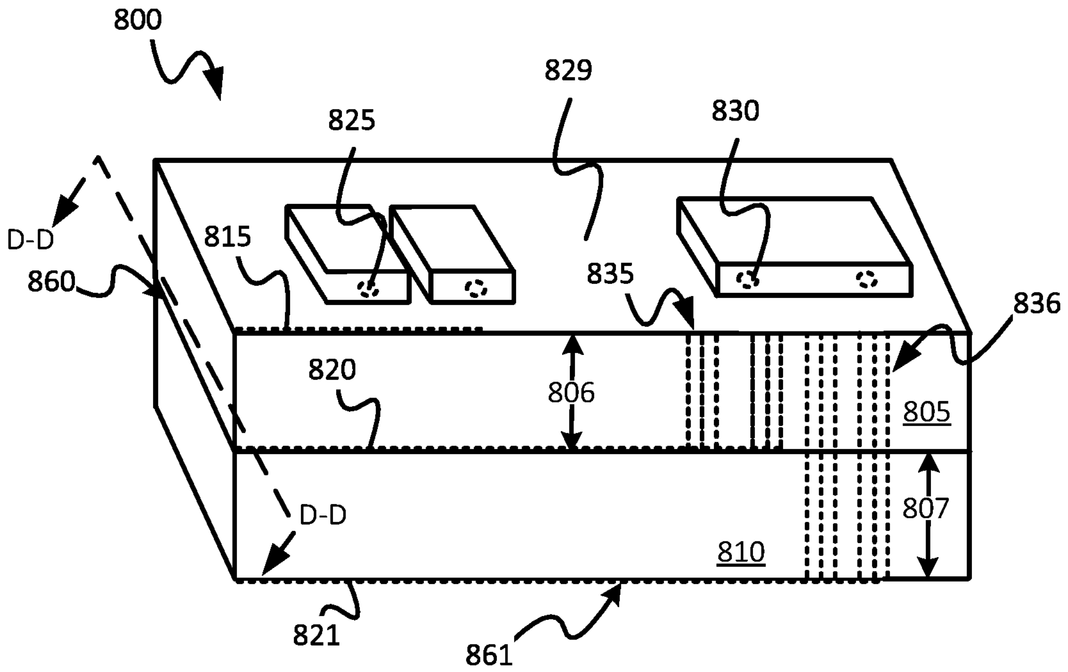
FIG. 7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D-D
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836
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806
805
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D-D
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821
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FIG. 8A

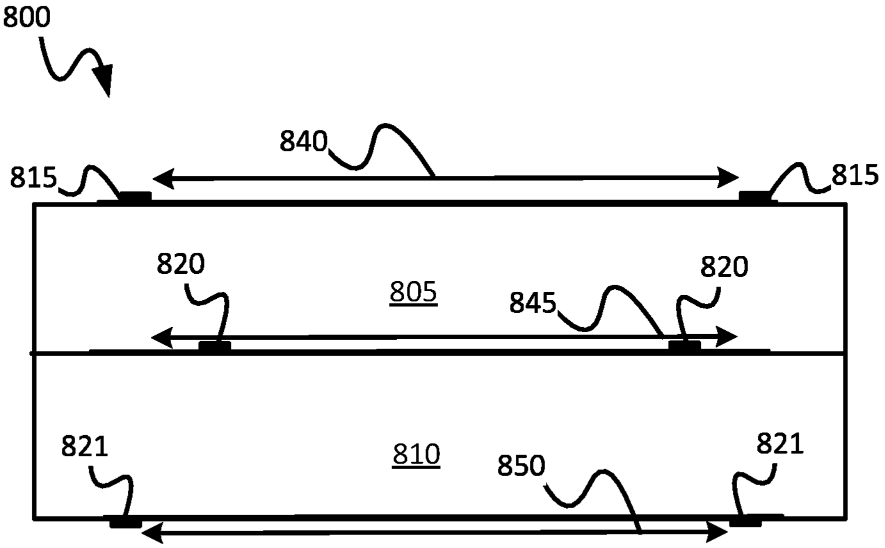
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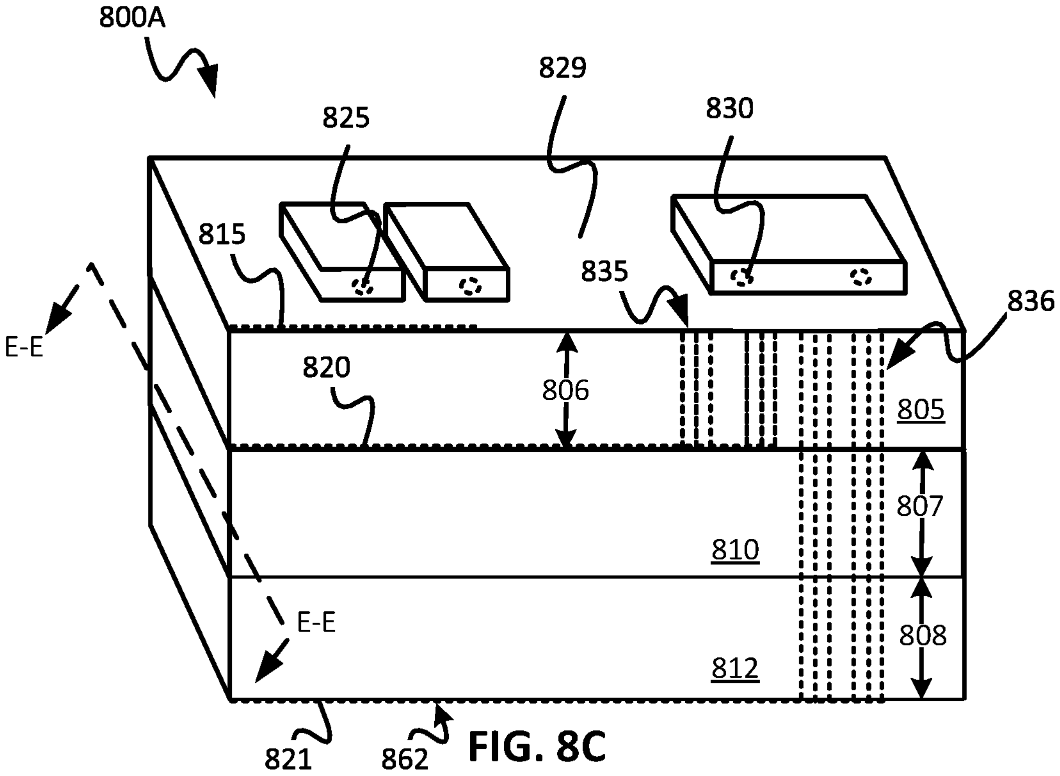
FIG. 8B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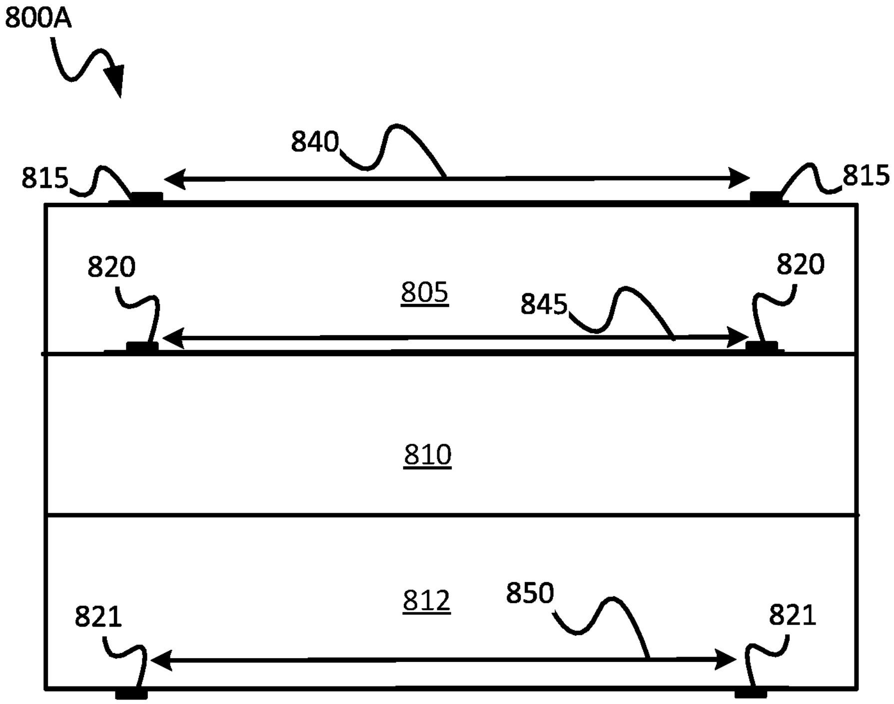
862

FIG. 8C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810
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821

FIG. 8D

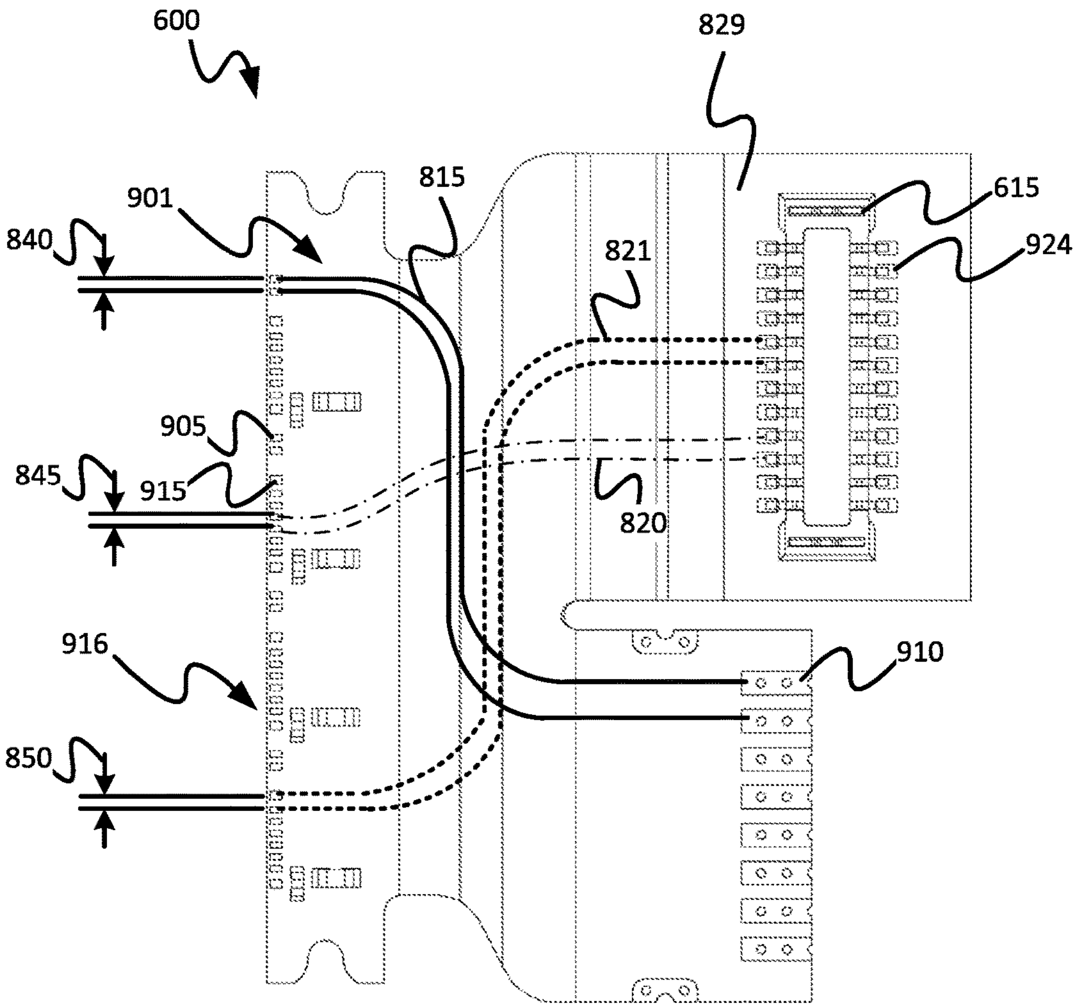
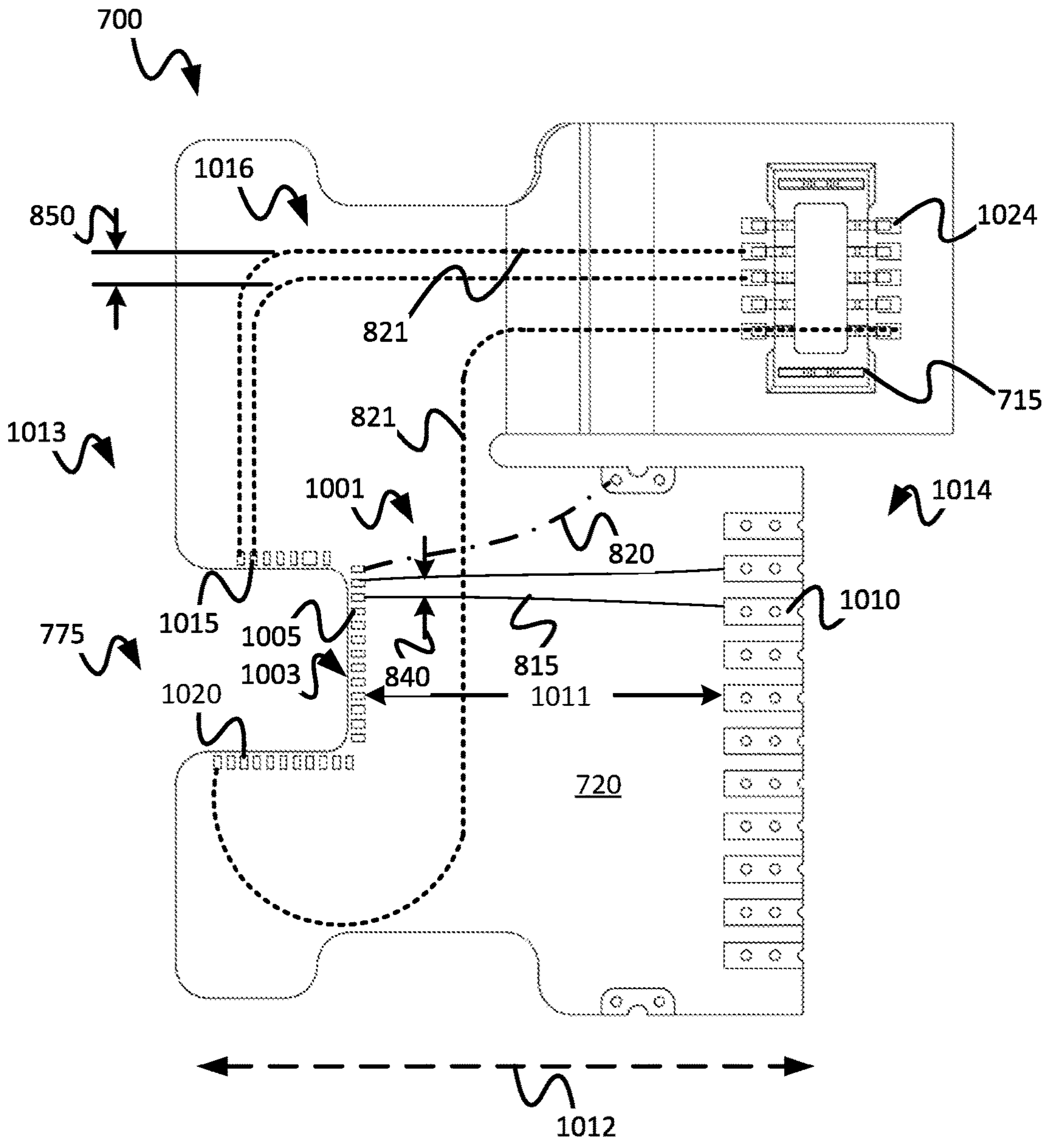


FIG. 9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1011
720
1012

FIG. 10

MULTILAYERED FLEXIBLE PRINTED CIRCUIT WITH BOTH RADIO FREQUENCY (RF) AND DC TRANSMISSION LINES ELECTRICALLY ISOLATED FROM EACH OTHER AND AN OPTICAL TRANSCEIVER USING SAME

TECHNICAL FIELD

The present disclosure is related to optical transceiver modules and more particularly to an optical transceiver module that includes a multilayered flexible printed circuit.

BACKGROUND

Optical transceivers are used to transmit and receive optical signals for various applications including, without limitation, internet data centers, cable TV broadband, and fiber to the home (FTTH) applications. Optical transceivers provide higher speeds and bandwidth over longer distances, for example, as compared to transmission over copper cables. The desire to provide higher speeds in smaller optical transceiver modules for a lower cost has presented challenges, for example, with respect to maintaining optical efficiency (power), thermal management, and manufacturing yield. Optical transceivers can include one or more transmitter optical subassemblies (TOSAs) and receiver optical subassemblies (ROSAs) for the purpose of transmitting and receiving optical signals. As channel density and increased speed becomes an increasingly important aspect of optical transceivers, the ability to scale-down while maintaining nominal transceiver performance raises numerous non-trivial challenges.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages will be better understood by reading the following detailed description, taken together with the drawings, wherein:

FIG. **1** schematically illustrates an embodiment of an optical transceiver including a multi-channel transmitter optical subassembly (TOSA) and multi-channel receiver optical subassembly (ROSA), in accordance with an embodiment of the present disclosure.

FIG. **2**A is a top plan view of a first portion of an optical transceiver module housing configured to couple to a transmitter optical subassembly (TOSA) arrangement, in accordance with an embodiment of the present disclosure.

FIG. **2**B is a top plan view of a second portion of an optical transceiver module housing configured to couple to a receiver optical subassembly (ROSA) arrangement, in accordance with an embodiment of the present disclosure.

FIG. **3**A shows a perspective view of the first and second portions of the optical transceiver module housing of FIGS. **2**A and **2**B, respectively, prior to coupling of the same to form an assembled optical transceiver module, in accordance with an embodiment of the present disclosure.

FIG. **3**B shows a perspective view of an assembled optical transceiver module, in accordance with an embodiment of the present disclosure.

FIG. **4** shows a perspective view of a second portion of the optical transceiver module housing of FIG. **2**B, in accordance with an embodiment of the present disclosure.

FIG. **5** is a side plan view of the assembled optical transceiver module of FIG. **3**B having a printed circuit board (PCB) assembly coupled thereto, in accordance with an embodiment of the present disclosure.

FIG. **6** is a perspective view of a flexible printed circuit (FPC) capable of being used to provide power and radio frequency (RF) signals to the TOSA arrangement of FIG. **2**A, in accordance with an embodiment of the present disclosure.

FIG. **7** is a perspective view of a FPC capable of being used with the ROSA arrangement of FIG. **2**B, in accordance with an embodiment of the present disclosure.

FIG. **8**A is an example cross-sectional view of a FPC configured to provide both power and RF signal lines in accordance with an embodiment of the present disclosure.

FIG. **8**B is an example cross-sectional view of the FPC of FIG. **8**A taken along the line D-D.

FIG. **8**C is an example cross-sectional view of a FPC configured to provide both power and RF signal lines in accordance with an embodiment of the present disclosure.

FIG. **8**D is an example cross-sectional view of the FPC of FIG. **8**B taken along the line E-E.

FIG. **9** shows a top plan view of the example FPC of FIG. **6** in accordance with an embodiment of the present disclosure.

FIG. **10** shows a top plan view of the example FPC of FIG. **8**A or **8**C in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

Optical transceiver modules often include transmitter optical subassemblies (TOSAs) and receiver optical subassemblies (ROSAs) within a housing or body. An optical transceiver module may operate as a single channel transceiver with one transmitter or one receiver, or as multi-channel transceiver with multiple transmitters and receivers such as the one outlined within the “QSFP+28 Gb/s 4× Pluggable Transceiver Solution (QSFP28)” specification published on Jun. 29, 2015 by the SFF Committee. Such small form-factor housings introduce significant dimensional constraints that reduce the overall workspace within a transceiver housing which increases manufacturing complexity, error rates, and overall time to produce each optical transceiver module.

One approach to increasing the workspace within the optical transceiver module involves using a bifurcated/multi-piece optical transceiver module housing having at least two separate portions. The TOSA is mounted to the first portion of the housing and the ROSA is mounted to the second portion of the housing, for example. In other words, the TOSA is coupled to a housing portion separate from that of the ROSA. As a result, the workspace available to a technician to couple the TOSA and the ROSA to respective portions of the housing is effectively increased when compared to the situation where the TOSA and the ROSA are each coupled to the same portion of the housing, e.g., in a stacked or sandwich configuration. In some instances, the workspace may be advantageously doubled. When the TOSA and ROSA are coupled to the respective portions of the housing, the first housing portion may be coupled to the second housing portion such that the ROSA housing portion is “flipped-over” the TOSA housing portion and attached in an up-side down fashion. In other words, when assembled, the TOSA is opposite the ROSA within the assembled housing. Therefore, the optical transceiver module may generally be described as having a flip-over housing, which is described in more detail in U.S. application Ser. No. 15/242,017 (’017 application) filed on Aug. 19, 2016, titled

"An Optical Transceiver Module Having a Partitioned Housing," which is herein incorporated by reference in its entirety.

Another component that complicates manufacture of optical transceiver modules includes interconnect devices for coupling power and RF signals to TOSA and ROSA components. For example, a first flexible printed circuit (FPC) is used to electrically couple laser devices of a TOSA device to associated driver circuitry and a second FPC is used to electrically power and control the laser devices. Accordingly, each of the first and second FPCs must be carefully routed and coupled within a transceiver housing to as to avoid sensitive components and prevent inadvertent damage to components. Moreover, each FPC takes up space within already highly-constrained SFF housings.

In accordance with an embodiment, a multi-layered flexible printed circuit (FPC) is disclosed that includes two or more insulating layers to route conductive traces carrying radio frequency (RF) signals, e.g., data signals, and conductive traces carrying direct current (DC) signals, e.g., power signals and low-frequency control signals, while sufficiently isolating the RF signals from electrical interference by the DC lines. This advantageously eliminates having two or more separate FPCs to electrically couple each optical subassembly, e.g., a receiver optical subassembly (ROSA) and transmitter optical subassembly (TOSA), to associated circuitry in a transceiver housing, which saves space and reduces manufacturing complexity, for example.

In an embodiment, a multi-layer FPC consistent with the present disclosure includes at least two insulating layers in a stacked/sandwich configuration. A first insulating layer, which may be referred to as a top layer, may include a mounting surface for mounting electrical components, terminals, and so on. A first plurality of conductive traces may be disposed on the first insulating layer to provide an RF signal to one or more electrical components mounted to the mounting surface. The first insulating layer may be disposed, e.g., directly or by one or more intermediate layers, on a second insulating layer, with the second insulating layer acting as an RF ground reference plane. In particular, a second plurality of conductive traces may be disposed on a first surface of the second insulating layer adjacent to the first insulating layer to provide a ground signal. A third plurality of conductive traces may be disposed on a second surface of the second insulating layer to transmit a DC signal, e.g., power and/or low-frequency control signaling, with the second surface being opposite the first surface. Vias may be utilized to route the conductive traces through the first and second insulating layers to the mounting surface to electrically couple to one or more electrical components mounted thereon.

When using an FPC having multiple layers as variously disclosed herein, e.g., having at least one layer for DC signals and at least one separate layer for RF signals, the separation (or offset) distance between conductive traces may be selected to ensure nominal performance. For example, a separation (or spacing) distance between conductive traces transmitting RF signals may be increased, e.g., to 1 mm or more, to minimize or otherwise eliminate interference between conductive traces in a same insulating layer. Conversely, conductive traces carrying low-frequency signals, e.g., ground, power and control signals, may not interfere with each other and may have separation distances that are relatively close to each other, e.g., within 0.1 mm or less.

An FPC having a multilayer configuration in accordance with the present disclosure may also increase the space available for routing each conductive trace. For example, separating conductive traces between insulating layers allows each type of trace (e.g., RF carrying traces, ground reference traces, power and low frequency control signal carrying traces) to be routed without necessarily being concerned with placement of other conductive traces that may potentially interfere and reduce signal integrity. Stated differently, each insulation layer provides associated conductive traces with a plane that is separate and isolated from other conductive traces in neighboring insulation layers. Moreover, having conductive traces that operate as an RF ground reference plane may further electrically isolate conductive traces carrying RF signals from those carrying DC power and low-frequency control signals.

An FPC configured in accordance with the present disclosures provides numerous advantageous over other approaches to electrical interconnection within optical transceivers and transmitters. For example, the use of a single FPC that provides both RF transmission and DC lines/traces reduces the overall number of components within a given optical transceiver (e.g., by eliminating the necessity of two or more FPCs per optical subassembly) which results in space savings and reduces the complexity of manufacturing. This may further result in increased yield as the potential for component damage is reduced and overall assembly time per unit is decreased.

While the disclosure herein generally refers to a transceiver module/housing having a flip-over housing, an multilayer FPC consistent with the present disclosure may be utilized by other types of housing configurations. The use the of the term DC to refer to traces that carry power signals is not intended to be limited to DC current and may also carry other forms of signaling including low-frequency control signals.

As used herein, "channel wavelengths" refer to the wavelengths associated with optical channels and may include a specified wavelength band around a center wavelength. In one example, the channel wavelengths may be defined by an International Telecommunication (ITU) standard such as the ITU-T dense wavelength division multiplexing (DWDM) grid or coarse wavelength division multiplexing (CWDM) grid. The term "coupled" as used herein refers to any connection, coupling, link or the like and "optically coupled" refers to coupling such that light from one element is imparted to another element. Such "coupled" devices are not necessarily directly connected to one another and may be separated by intermediate components or devices that may manipulate or modify such signals.

Now turning to FIG. **1**, there is an optical transceiver **100** consistent with embodiments of the present disclosure. In more detail, the optical transceiver **100** transmits and receives four (4) channels using four different channel wavelengths (λ_1, λ_2, λ_3, λ_4) and may be capable of transmission rates of at least about 25 gigabits (Gbs) per channel or more. In one example, the channel wavelengths λ_1, λ_2, λ_3, λ_4 may be 1271 nm, 1291 nm, 1311 nm, and 1331 nm, respectively. The optical transceiver **100** may also be capable of both short transmission distances of tens of meters, for example, to distances of 2 kilometers or more. The optical transceiver **100** may be used, for example, in internet data center applications or fiber to the home (FTTH) applications. In an embodiment, the optical transceiver **100** implements a Quad Small Form-Factor Pluggable (QSFP) transceiver. For example, the optical transceiver **100** may be implemented within a QSFP transceiver that comports with the QSFP28 specification as discussed above. The aspects and embodiments disclosed herein may be used within other transceiver types and is not necessarily limited to QSFP or QFSP+ transceivers. The optical transceiver **100** may be configured for dense wavelength division multiplexing (DWDM) or course wavelength division multiplexing (CWDM), depending on a desired configuration. Although aspects and scenarios disclosed herein discuss a four (4) channel configuration, other channel configurations, e.g., 2, 4, 8, 16, 32, and so on, are within the scope of this disclosure.

As shown, the optical transceiver **100** includes a transceiver housing **102** that may include a multi-channel TOSA arrangement **110** for transmitting optical signals on different channel wavelengths, and a multi-channel ROSA **112** for receiving optical signals on different channel wavelengths within a single transceiver housing, as will be discussed further herein. A transmit connecting circuit **104** and a receive connecting circuit **108** provide electrical connections to the multi-channel TOSA arrangement **110** and the multi-channel ROSA arrangement **112**, respectively, within the transceiver housing **102**. The transmit connecting circuit **104** and the receive connecting circuit **108** may communicate with external systems via data bus **103**. In some cases, data bus **103** is a 38-pin connector that comports with physical connector QSFP standards and data communication protocols.

In any event, the transmit connecting circuit **104** electrically couples to the electronic components in the multi-channel TOSA arrangement **110**, e.g., laser assemblies, and the receive connecting circuit **108** electrically couples to the electronic components in the multi-channel ROSA **112**, e.g., an arrayed waveguide grating (AWG), detectors, amplification circuitry and so on. The transmit connecting circuit **104** and the receive connecting circuit **108** include at least conductive paths to provide electrical connections, and may also include additional circuitry such as clock and data recovery circuitry. The multi-channel TOSA arrangement **110** transmits and multiplexes multiple different channel wavelengths, and is coupled to an optical interface port **114**. The optical interface port **114** may include an LC connector port, although other connector types are also within the scope of this disclosure.

In cases where the optical interface port **114** comprises a duplex, or bi-directional, LC receptacle, the LC connector receptacle provides optical connections to the multi-channel TOSA arrangement **110**, and provides optical connections to the multi-channel ROSA **112**. The LC connector receptacle may be configured to receive and be coupled to a mating LC connector **116** such that transmit optical fiber **122** of the external fibers **124** optically couples to the multi-channel arrangement TOSA **110**, and the receive optical fiber **117** of the external fibers **124** optically couples to the multi-channel ROSA **112**.

The multi-channel TOSA arrangement **110** can include multiple laser packages and optics for producing associated channel wavelengths, and can couple the same into the transmit optical fiber **122**. In particular, the lasers in the multi-channel TOSA arrangement **110** can convert electrical data signals (TX_D1 to TX_D4) received via the transmit connecting circuit **104** into modulated optical signals transmitted over transmit optical fiber **122**. The lasers may include, for example, distributed feedback (DFB) lasers with diffraction gratings. In other cases, the lasers may comprise electro-absorption modulated laser (EML) laser diode packages. The multi-channel TOSA arrangement **110** may also include monitor photodiodes for monitoring the light emitted by the lasers. The multi-channel TOSA arrangement **110** may further include one or more temperature control devices, such as a resistive heater and/or a thermoelectric cooler (TEC), for controlling a temperature of the lasers, for example, to control or stabilize the laser wavelengths.

The multi-channel ROSA **112** can include demultiplexing optics such as an AWG device and a plurality of detectors such as photodiode packages configured to receive de-multiplexed channel wavelengths. The ROSA **112** can use the detectors and associated circuitry (e.g., a TIA) to detect, amplify, and convert de-multiplexed channel wavelengths and can provide the same as electrical data signals, e.g., RX_D**1** to RX_D**4**.

Example Optical Transceiver Module Having a Partitioned Housing

Now turning to FIGS. **2**A and **2**B, first and second portions **205-1** and **205-2** of an optical transceiver module housing **205** (FIG. **3**B) are shown in accordance with an embodiment of the present disclosure. An example assembled optical transceiver module **400** having both the first and second portions **205-1** and **205-2** coupled together is shown and described in greater detail below with reference to FIG. **3**B. Each of the first and second portions **205-1** and **205-2** will now be discussed in turn.

FIG. **2**A shows a top plan view of a first portion **205-1** of an optical transceiver module housing **205** configured to couple to a transmitter optical subassembly (TOSA) arrangement, in accordance with an embodiment of the present disclosure. The first portion **205-1** may also be accurately referred to as a TOSA housing portion **205-1**. As shown, the TOSA housing portion **205-1** may include at least one sidewall **330** extending outwardly from a base **229** such that the base **229** and an interior surface **235** of the at least one sidewall **330** define a first compartment (or cavity) **240**. The at least one sidewall **330** may extend from the first end **217** to the second end **218** of the ROSA housing portion **205-2**. The first compartment **240** includes a TOSA arrangement **245** coupled to an interior surface the base **229** and/or the interior surface **235**. The TOSA arrangement **245** may extend longitudinally within the first compartment **240**. Additional aspects of the TOSA arrangement **245** are shown in greater detail in FIG. **4**, which illustrates the TOSA housing portion **205-1** without the shield member **216** attached.

As further shown in FIG. **2**A, the TOSA housing portion **205-1** of the housing **205** includes the TOSA **245** arrangement coupled thereto. The TOSA arrangement **245** may be coupled to the TOSA housing portion **205-1** via, for example, screws, adhesive, friction fit, tape, welds, or by any other suitable approach. The TOSA arrangement **245** may include one or more laser packages **285-1** to **285**-N configured to emit associated channel wavelengths. Each of the laser packages **285-1** to **285**-N may be configured to generate an associated channel wavelength. The laser packages **285-1** to **285**-N may include any suitable laser device, such as a DFB laser, as previously discussed.

Each of the laser packages **285-1** to **285**-N may optically couple to the optical interface port **290** by way of an intermediate fiber or suitable waveguide device (not shown). Each of the laser packages **285-1** to **285**-N may also electrically couple to a flexible printed circuit (FPC) **295** for power and signaling/driving purposes. The FPC **295** carries an electrical driving signal and/or power for each of the laser packages **285-1** to **285**-N. In some cases, the FPC **295** may also be coupled to the TOSA housing portion **205-1** in a manner similar to components of the TOSA arrangement **245** discussed above, which will not be repeated for brevity. However, the FPC **295** may also be simply coupled to the TOSA arrangement **245**, e.g., via wire bonding, without necessarily being also coupled to surfaces of the TOSA housing portion **205-1**. In any event, the first compartment **240** may be configured to receive the TOSA arrangement **245** and associated circuitry, and therefore, may generally be described as being a TOSA compartment **240**.

Turning to FIG. **2**B, a top plan view of the second portion **205-2** of an optical transceiver module housing **205** is shown and may be configured to receive and couple to a receiver optical subassembly (ROSA) arrangement, in accordance with an embodiment of the present disclosure. As shown, the ROSA housing portion **205-2** may include at least one sidewall **340** extending outwardly from a base **228** such that the base **228** and an interior surface **220** of the at least one sidewall **340** define a second compartment (or cavity) **225**. The at least one sidewall **340** may extend from the first end **226** to the second end **227** of the ROSA housing portion **205-2**. The ROSA arrangement **230** may be coupled to the base **228** and/or the interior surface **220** of the second compartment **225** of the housing **205**. As such, the first compartment **225** may be configured to receive the ROSA arrangement **230** and may be generally described as a ROSA compartment **230**. In an embodiment, the first and second compartments **240** and **225** advantageously provide a substantially equal amount of total surface area, or total mounting surface area, for attachment of associated optical component assemblies, optical fiber(s), associated circuitry including FPCs **294** and **295**, and so on. Further, the first and second compartments **240** and **225** may advantageously include a substantially equal volume. Stated differently, the first and second compartments **240** and **225** may provide a substantially similar amount of internal workspace for coupling and alignment of associated components.

Continuing with FIG. **2**B, the ROSA arrangement **230** includes an arrayed waveguide grating (AWG) device **260**, with the AWG device **260** including an optical coupling port **250**, an input coupling region **255**, an AWG chip region **269**, and an array of photodiodes and associated transimpedance amplifiers (TIAs) **350**, which are shown more clearly in FIG. **4**. An optical interface port **275**, e.g., an LC connector port, may be coupled to the ROSA housing portion **205-2** at the first end **226** of the transceiver housing **205**. The optical interface port **275** may be optically coupled to the optical coupling port **250** of the AWG device **260** by way of an intermediate fiber (not shown) or other suitable device such as a waveguide. The optical coupling port **250** of the AWG device **260** is optically coupled to the input coupling region **255**. The input coupling region **255** may be optically coupled to a first end of the AWG device **260** in order to launch an optical signal into waveguide gratings of the AWG device **260**. The AWG device **260** may be implemented in accordance with the AWG device disclosed in the co-pending U.S. application Ser. No. 15/137,823 titled "Techniques for Direct Optical Coupling of Photodetectors to Optical Demultiplexer Outputs and an Optical Transceiver Using the Same" filed on Apr. 25, 2016, the entirety of which is incorporated herein by reference.

In some instances, such as shown in FIG. **2**B, the input coupling region **255** is coupled to the AWG device **260** in an offset manner such that the input coupling region **255** protrudes beyond the surface **265** of the AWG chip region **269**, which can be more clearly seen in FIGS. **3**A and **4**. In a practical sense, this may prevent the AWG device **260** from being disposed flat against the mounting surface **297** (FIG. **4**) for coupling purposes. For example, as shown in FIG. **4** the ROSA housing portion **205-2** may include at least a first mounting surface **297** configured to couple to and support at least a portion of the AWG chip region **269** and/or associated

circuitry, e.g., the photodiodes and TIAs **350**. The ROSA housing portion **205-2** may further include a second mounting surface **293**, with the second mounting surface **293** being offset/recessed relative to the first mounting surface **297**. In some cases, the ROSA assembly **230** is directly coupled to a single mounting surface, e.g., mounting surface **297**, without necessarily including a recessed mounting region.

Thus, and as shown in FIG. **4**, the AWG device **260** may be disposed substantially flat on the first mounting surface **297** along at least a portion of its length with the second mounting surface **293** being recessed by an offset distance D_1 to receive (but not necessarily couple to) the optical input coupling region **255**. The offset distance D_1 may equal about 1.5 mm, although other offset distances may be used to account for dimensional constraints imposed by other AWG/ROSA components depending on a desired configuration. In some cases, the offset distance D_1 may be uniform, e.g., continuous, or may be discontinuous.

Continuing on with FIG. **4**, the AWG device **260** may be optically coupled to an array of photodiodes and associated TIAs **350** for the purposes of detecting, amplifying, and converting each of the channel wavelengths into an electrical signal. Each of the photodiodes and associated TIAs **350** may be electrically coupled to a flexible printed circuit (FPC) **294**. The FPC **294** may be coupled to the base **228** of the ROSA housing portion **205-2**. In some instances, the FPC **294** may be coupled to the ROSA housing portion **205-2** such that a surface **299** of the FPC **294** is substantially coplanar with at least one surface of the base **228**, e.g., surface **297**.

A shield **345** (or shield member **345**) may be coupled to the ROSA housing portion **205-2** and may cover the array of photodiodes and associated TIAs **350**. The shield **345** may include one or more protrusions **355** for coupling to corresponding openings **360** located adjacent an end of the ROSA housing portion **205-2**. Once received within the corresponding opening **360**, the protrusions may couple the shield **345** to the ROSA housing portion **205-2** by, for example, a friction fit or snap-fit. In some instances, an adhesive may be applied to the one or more protrusions **355** prior to coupling into the plurality of openings **360**. Therefore, in some instances, the shield **345** may be coupled to the ROSA housing portion **205-2** using a combination of an adhesive and a friction fit or a snap-fit. In other instances, the shield **345** may not include the one or more protrusions **355** and may, for example, be coupled to the ROSA housing portion **205-2** using an adhesive, a mechanical coupling means, such as, a screw, combinations thereof, or any other method of attachment.

Turning to FIG. **3**A, with additional reference to FIG. **4**, the TOSA housing portion **205-1** may include a groove **370** for receiving at least a portion of the shield **345** such that when the ROSA housing portion **205-2** is coupled to the TOSA housing portion **205-1**, the presence of gaps at an interface **405** (FIG. **3**B) between the ROSA housing portion **205-2** and the TOSA housing portion **205-1** are minimized.

Continuing with FIG. **3**A, the TOSA housing portion **205-1** of the housing **205** may include dimensions that generally correspond to ROSA housing portion **205-2** to allow for mating/coupling. For example, the TOSA housing portion **205-1** may also include one or more mating surfaces **320** defined by the sidewall **330** of the TOSA housing portion **205-1**. The one or more mating surfaces **320** of the TOSA housing portion **205-1** may couple to one or more corresponding mating surfaces **335** of the ROSA housing portion **205-2**. In some instances, a friction fit may be formed between the mating surface **320** of the TOSA housing portion **205-1** and the corresponding mating surface **335** of the ROSA housing portion **205-2**. In other instances, the mating surface **320** of the TOSA housing portion **205-1** and the mating surface **325** of the ROSA housing portion **205-2** may collectively form a snap-fit. In still other cases the mating surface **335** of the TOSA housing portion **205-1** and the mating surface **335** of the ROSA housing portion **205-2** may simply be coupled together via adhesive, fastening members (e.g., screws, pins, and so on), friction fit, snap fit, or any combination thereof.

In any event, and in accordance with an embodiment, each of the TOSA and ROSA housing portions **205-1** and **205-2** may be independently assembled and also may be tested to ensure nominal performance separate from each other. Thus each of the TOSA and ROSA housing portions **205-1** and **205-2** may be assembled in parallel, e.g., at about the same time, or may be assembled at different times. Therefore, each of the TOSA and ROSA housing portions **205-1** and **205-2** may be disposed flat on a work surface, such as a workbench or other such fixture, to provide a relatively simplified work surface to perform attachment of optical subassembly components and associated circuitry, cabling, fiber routing, and so on. This advantageously minimizes or otherwise reduces incidences of component damage and the necessity of rework iterations that characterize other approaches to optical transceiver modules that attempt to couple and optically align both TOSA and ROSA arrangements in a single housing portion. Accordingly, a finalization stage of an assembly process may then include “flipping” over the ROSA housing portion **205-2** onto the TOSA housing portion **205-1** as shown by directional arrows **261** after each respective component includes requisite components, circuitry, intermediate fibers and so on. The finalization stage may also include coupling shield **216** to the TOSA housing portion **205-1** prior to such flip-over coupling of the ROSA housing portion **205-2**. In a general sense, the ROSA housing portion **205-2** then becomes the cover for the assembled optical transceiver module **400**. As the ROSA arrangement **230** and associated components are coupled to what essentially becomes a cover portion, the ROSA arrangement **230** may be referred to as a having a flip-over configuration as the same is disposed upside down relative to the TOSA arrangement **245** coupled to the TOSA housing portion **205-1**. An assembly process in accordance with the aspects and scenarios disclosed herein may include manual stages, e.g., performed by one or more technicians, automated stages, e.g., by pick-and-place machines and other robotics, or any combination thereof.

Turning to FIG. **3**B, an optical transceiver module **400** is shown after a finalization stage couples the TOSA housing portion **205-1** to the ROSA housing portion **205-2**, in accordance with an embodiment of the present disclosure. Post finalization, that is to say when the TOSA housing portion **205-1** is coupled to the ROSA housing portion **205-2**, an external surface **300** of the TOSA housing portion **205-1** may be substantially coplanar with an external surface **305** of the ROSA housing portion **205-2**. As shown, at least a portion of the ROSA arrangement **230** (FIG. **2**) is disposed in a manner opposing the TOSA arrangement **245**, with each of the ROSA arrangement **230** and TOSA arrangement **245** extending towards an interface **405** between respective housing portions.

The interface **405** may circumscribe the housing **205** at a location generally corresponding to where the ROSA housing portion **205-2** mates with the TOSA housing portion **205-1**. The ROSA housing portion **205-2** may be coupled to the TOSA housing portion **205-1** using, for example, friction-fits, adhesives, mechanical couplers, such as, screws or snap fits, combinations thereof, and other like methods of attachment. The interface **405** may include one or more gaps and/or openings resulting from, for example, manufacturing tolerances. These gaps and/or openings may allow contaminants to enter the housing **205**. To prevent, mitigate, and/or otherwise reduce the ingress of contaminants into the transceiver housing **205**, a sealant and/or interstitial filler may be applied to the interface **405**. The sealant may or may not have adhesive properties. In some instances, there may be more than one interface **405**. In these situations, a sealant and/or interstitial filler may be applied to each of the interfaces **405**.

Turning to FIG. **5**, the finalization stage may also include coupling a printed circuit board assembly (PCBA) **505** to each of the FPCs **294** and **295**. The FPC **294** that corresponds to the ROSA arrangement **230** (FIG. **2**B) may be electrically coupled to a ROSA facing surface **510** of the PCBA **505**. The ROSA facing surface **510** is opposite a TOSA facing surface **515** of the PCBA **505**. The TOSA facing surface **515** may be electrically coupled to the FPC **295** that corresponds to the TOSA arrangement **245** (FIG. **2**A). In other words, the PCBA **505** may be disposed between each of the FPCs **294** and **295** such that the surface of the PCBA **505** that is proximal to the ROSA arrangement **230** relative to the TOSA arrangement **245** is electrically coupled to the FPC **294** that corresponds to the ROSA arrangement **230**, and on the other hand, the surface of the PCBA **505** that is proximal to the TOSA arrangement **245** relative to the ROSA arrangement **230** is electrically coupled to the FPC **295** that corresponds to the TOSA arrangement **245**. However, this example configuration is not intended to limit the present disclosure and other embodiments are within the scope of this disclosure.

In an embodiment, a secondary housing **500**, such as a QSFP housing or other SFF housing, may optionally enclose at least a portion of assembled optical transceiver module **400** and at least a portion of the PCBA **505** within a cavity **501** defined by the secondary housing. The secondary housing may further be referred to as a host housing **500**. Therefore, in some instances, a portion of the PCBA **505** extends outside of the secondary housing **500**. The portion of the PCBA **505** that extends beyond the secondary housing **500** may electrically couple to an external device such as a pluggable receptacle for receiving and electrically coupling to a QSFP optical transceiver.

While the present disclosure generally illustrates the housing **205** as being a two-portion, or bi-furcated, transceiver module housing, the transceiver housing **205** is not necessarily limited in this regard. In some instances, the housing **205** may include at least three separable portions. In some cases, the housing **205** may include a clam shell or hinged configuration whereby the TOSA and ROSA housing portions **205-1** and **205-2** are coupled via a hinge or other similar device along interface **405** (FIG. **3**B).

Turning now to FIG. **6**, an example of a flexible printed circuit (FPC) **600** is shown. The FPC **600** may be suitable for use as the FPC **295** of the TOSA arrangement **245** (FIG. **2**A). As shown, a system coupling end **605** of the FPC **600** includes conductive pads **610** and a pluggable controller socket **615**. The conductive pads **610** may electrically couple to a transmit connecting circuit, e.g., transmit connecting circuit **104**, to provide RF signals for purposes of driving associated laser devices, e.g., the laser packages **285-1** to **285**-N.

As further shown, the conductive pads **610** are disposed on a first arm **620** or first portion **620** of the FPC **600** and the pluggable controller socket **615** is provided on a second arm **625** or second portion **625** of the FPC **600**. The first and second portions **620** and **625** may be separated by an offset distance **655**, which is discussed in more detail further below. The conductive pads **610** and the pluggable connector **615** are electrically connected to transmit conductive pads **630** at a transmit end **635** of the FPC **600**. The transmit conductive pads **630** can be used to electrically couple the FPC **600** to, for example, the TOSA arrangement **245** of FIG. **2**A. For example, each of the laser assemblies of the TOSA arrangement **245** may be wire bonded to associated transmit conductive pads **630**.

The FPC **600** may include a first flexible region **640** extending between the transmit end **635** of the FPC **600** and the first arm **620**. The transmit end **635** and the first arm **620** may be more rigid than the first flexible region **640**, at least at those locations having the conductive pads **610**, **630**. For example, the rigidity of the first arm **620** and the transmit end **635**, at least at the locations having conductive pads **610**, **630**, may be increased using a stiffener such as, but not limited to, an epoxy glass laminate or a polyimide film. Additionally, or alternatively, the locations having the conductive pads **610**, **630** may be formed of a rigid circuit board electrically coupled to the first flexible region **640**. In other words, a hybrid circuit board assembly having both rigid and flexible regions may be formed.

The FPC **600** may also include a second flexible region **645** extending between the first flexible region **640** and the second arm **625**. The second arm **625** may also be more rigid than the second flexible region **645**, at least at those locations having the pluggable connector **615**. For example, the rigidity of the transmit end **635** may be increased, at least at those locations including the pluggable connector **615**, using a stiffener such as, but not limited to, an epoxy glass laminate or a polyimide film. Additionally, or alternatively, the locations having the pluggable connector **615** may be formed of a rigid circuit board electrically coupled to the second flexible region **645**. In other words, a hybrid circuit board assembly having both rigid and flexible regions may be formed. The FPC **600** may include a curvilinear shape/profile defined by the first and second flexible regions **640** and **645**. The curvilinear shape may also be accurately described as an arcuate region.

As shown, the second arm **625** and the second flexible region **645** may be separated from the first arm **620** by a gap **650** or offset **650** extending parallel to a longitudinal axis **685** for at least a portion of the longitudinal length of the FPC **600**. As shown, the gap **650** increases along the Y axis while remaining at a substantially constant distance, e.g., width **641**, along the X axis. Thus, a width **641** of the gap **650** may be substantially constant. In other instances, the width **641** of the gap **650** may be non-constant. For example, the width **641** of the gap **650** may increase and/or decrease linearly, exponentially, logarithmically, and/or irregularly (e.g., the width **641** both increases and decreases).

The gap **650** allows the second arm **625** to be displaced relative to the first arm **620** by introducing at least one bend into the second flexible region **645**. For example, the second flexible region **645** may be bent such that the second arm **625** is displaced from the first arm **620** by a separation distance **655** or offset **655**. In some embodiments, the separation distance **655** may be equal to or greater than a height **660** of the pluggable connector socket **615**. In other cases, the separation distance **655** is less than height **660**.

In some instances, the second flexible region **645** may be bent to include a first curvature **661** (or arcuate region **661**) and a second curvature **665** (or arcuate region **665**). The concavity of the first curvature **661** may be opposite the concavity of the second curvature **665** such that an "S" shape is generally formed. A radius of the first curvature **661** may be substantially equal to a radius of the second curvature **665**, or may be different. Each radius may be defined, at least in part, by the flexibility of the second flexible region **645**. In other words, as the flexibility of the second flexible region **645** decreases, the radius of the first and second curvatures **661**, **665** may increase to prevent the second flexible region **645** from fracturing. For example, a tensile modulus of the second flexible region **645** may be within the range of 480 MPa and 3400 MPa. In some embodiments, the radius of the first and/or second curvatures **661**, **665** may be at least ten times greater than a thickness **676** of the FPC **600**.

As shown, the inclusion of the second flexible region **645** results in the second arm **625** extending beyond the first arm **620** by an extension distance **680**. The first flexible region **640** may also be bent to include a first curvature **670** and a second curvature **675**. The concavity of the first curvature **670** may be opposite the concavity of the second curvature **665** such that an "S" shape is generally formed. A radius of the first curvature **670** may be substantially equal to a radius of the second curvature **675**, or may be different. Each radius may be defined, at least in part, by the flexibility of the first flexible region **640**. In other words, as the flexibility of the first flexible region **640** decreases, the radius of the first and second curvatures **670** and **675** may increase to prevent the first flexible region **640** from fracturing. For example, a tensile modulus of the first flexible region **640** may be within the range of 480 MPa and 3400 MPa. In some embodiments, the radius of the first and/or second curvatures **670**, **675** may be at least ten times greater than the thickness **676** of the FPC **600**.

As shown, the transmit end **635** of the FPC **600** includes one or more retention features **690**. The retention features **690** may engage a portion of the TOSA housing portion **205-1** (FIG. **2**A) such that movement of the FPC **600** parallel to the longitudinal axis **685** is prevented, reduced, or otherwise mitigated. By reducing/preventing movement parallel to the longitudinal axis **685**, the forces exerted on the wire bonds connecting the TOSA arrangements **245** to the FPC **600** may be prevented, reduced, or otherwise mitigated.

As shown, the conductive pads **630** are disposed at an end of the transmit end **635** of the FPC **600**. The conductive pads **630** may provide both RF and DC signals to laser assemblies adjacent the FPC. Therefore, the conductive pads **630** and associated laser assemblies may be coupled directly, wherein the direct connection includes a straight interconnection, e.g., wire bonding, that does not require an intermediate device. Moreover, the direct connection may include a distance of 1 mm or less between the conductive pads **630** and pads/terminals of associated laser packages.

Turning now to FIG. **7**, an example of a flexible printed circuit board (FPC) **700** is shown. The FPC **700** may be suitable for use as the FPC **294** of the ROSA arrangement **230** (FIG. **2**B). As shown, a system coupling end **705** of the FPC **700** includes conductive pads **710** and a pluggable connector **715**. The system coupling end **705** may electrically couple to the receive connecting circuit **108**. The conductive pads **710** are included on a first arm **720** of the FPC **700** and the pluggable connector **715** is provided on a second arm **725** of the FPC **700**. The transmit conductive pads **710** and the pluggable connector **715** are electrically connected to receive conductive pads **730** at an end **735** or ROSA end **735** of the FPC **700**. The receive conductive pads **730** can be used to electrically couple the FPC **700** to, for example, the ROSA arrangement **230** of FIG. **2**B.

The FPC **700** includes a flexible region **740** extending between the receive end **735** and the second arm **725**. The first arm **720**, the second arm **725**, and the ROSA end **735** may be more rigid than the flexible region **740**, at least at those locations having conductive pads **710**, **730** and the pluggable connector **715**. For example, the rigidity of the first arm **720**, second arm **725**, and/or the ROSA end **735** may be increased using a stiffener such as, but not limited to, an epoxy glass laminate or a polyimide film. Additionally, or alternatively, the locations having conductive pads **710**, **730** and the pluggable connector **715** may be formed of a rigid circuit board electrically coupled to the flexible region **740**. In other words, a hybrid circuit board assembly having both rigid and flexible regions may be formed.

As shown, the flexible region **740** and the second arm **725** may be separated from the first arm **720** by a gap **745** extending parallel to a longitudinal axis **785** for at least a portion of the longitudinal length of the FPC **700**. As shown, the gap **750** increases along the Y axis while remaining at a substantially constant distance, e.g., width **741**, along the X axis. Thus, a width **741** of the gap **750** may be substantially constant. In other instances, the width **741** of the gap **745** may be non-constant. For example, the width **741** of the gap **745** may increase and/or decrease linearly, exponentially, logarithmically, and/or irregularly (e.g., the width **741** both increases and decreases).

The gap **745** allows the second arm **725** to be displaced relative to the first arm **720** by bending the flexible region **740**. For example, the flexible region **740** may be bent such that the second arm **725** is displaced from the first arm **720** by a separation distance **750**. In some embodiments, the separation distance **750** may be equal to or greater than a height **755** of the pluggable connector **715**. In other cases, the separation distance **750** is less than height **750**.

In some instances, the flexible region **740** may be bent to include a first curvature **760** and a second curvature **765**. The concavity of the first curvature **760** may be opposite the concavity of the second curvature **765** such that an “S” shape is generally formed. A radius of the first curvature **760** may be substantially equal to a radius of the second curvature **765**. Each radius may be defined, at least in part, by the flexibility of the flexible region **740**. In other words, as the flexibility of the flexible region **740** decreases, the radius of the first and second curvatures **760** and **765** may increase to prevent the flexible region **740** from fracturing. For example, a tensile modulus of the flexible region **740** may be within the range of 480 MPa and 3400 MPa. In some embodiments, the radius of the first and/or second curvatures **760**, **765** may be at least ten times greater than a thickness **776** of the FPC **700**.

As shown, the inclusion of the flexible region **740** results in the second arm **725** extending beyond the first arm **720** by an extension distance **770**. As also shown, the ROSA end **735** of the FPC **700** includes a cut-out **775**, which may also be referred to as a notch or opening. The receive conductive pads **730** may be positioned around a perimeter of the cut-out **775**. When the FPC **700** is positioned, for example, within the ROSA portion **205-2** (FIG. **2**B), the array of photodiodes and associated TIAs **350** (FIG. **4**) may be positioned within the cut-out **775** such that the array of photodiodes and associated TIAs **350** may be wire bonded to the FPC **700**. In some cases, this includes direct coupling, e.g., of about 1 mm or less, between associated TIAs **350** and the conductive pads **730**. In some embodiments, at least a portion of, for example, the AWG chip region **269**, (FIG. **2**B) may also be positioned within the cut-out **775**. The inclusion of the cut-out **775** may also increase the workspace within the ROSA housing portion **205-2** for routing one or more optical fibers optically coupling the ROSA arrangement **230** to the optical interface port **275** (FIG. **2**B). The FPC **700** may include a curvilinear shape/profile defined by the first and second flexible regions **740** and **745**. The curvilinear shape may also be accurately described as an arcuate region.

As shown, the cut-out **775** may have a generally rectangular shape. In some instances, a rectangular cut-out **775** may include one or more chamfers and/or fillets **777** at, for example, one or more stress concentration points. In other embodiments, the cut-out **775** may have any combination of a circular shape, a triangular shape, a trapezoidal shape, a pentagonal shape, a hexagonal shape, or any other suitable shape.

The ROSA end **735** of the FPC **700** may also include one or more retention features **780**. The retention feature **780** may engage a portion of the ROSA housing portion **205-1** such that movement of the FPC **700** parallel to the longitudinal axis **785** is prevented. By reducing/preventing movement parallel to the longitudinal axis **785**, the forces exerted on the wire bonds connecting the array of photodiodes and associated TIAs **350** with the FPC **700** may be minimized or otherwise prevented.

The FPC **600** and the FPC **700** may be multilayered flexible printed circuits as variously disclosed herein. FIGS. **8**A and **8**B show a simplified example of a multilayered FPC **800** to illustrate how a FPC **600** and/or the FPC **700** can include multiple signal carrying layers. As shown, the FPC **800** includes at least a first insulating layer **805** and a second insulating layer **810**. The first insulating layer **805** is disposed directly, as shown, on a first surface **860** of the second insulating layer **810**.

The first and second insulating layer **805** and **810** may be arranged in a stack, such as shown. However, other embodiments are within the scope of this disclosure. For example, the FPC **800** may include N number of layers and is not necessarily limited to two insulating layers as shown. For example, as shown in FIGS. **8**A and **8**B the FPC **800**A may include three insulating layers. Further, the FPC **800** may include one or more intermediate layers between one or more of the first, second and third insulating layers **805**, **810**, and **812**. In any event, each insulation layer may comprise a same or different material. The insulating material may comprise, for example, a dialectical material or other suitable material.

In one non-limiting example embodiment, the first insulating layer **805** may have a thickness **806** that measures in the range of 1 to 3 mil. The second insulating layer **810** may have a thickness **807** that measures in the range of 1 to 3 mil. Each of the first and second insulating layers **805** and **810** may have the same thickness or different thicknesses depending on a desired configuration.

As further shown, the first insulating layer **805** includes a first set of conductive traces **815** or transmission lines **815** disposed on surface **829** (or external surface **829**) for carrying a first set of electrical signals. The second insulating layer **810** may include a second set of conductive traces **820** disposed on surface **850** (shown as hidden lines) for carrying a second set of electrical signals. The third set of conductive traces **821** (shown as hidden lines) may be disposed on surface **861**, which is opposite of surface **860**, and may be configured to carry a third set of electrical signals. The first and second set of conductive traces **815**, **820** may also be referred to as a first signal layer, and a second signal layer, respectively. The particular placement of the first and second sets of conductive traces **815**, **820** may be disposed at varying locations on an associated insulating layer and this disclosure is not necessarily limited to the embodiment shown in FIG. **8**A. In addition, although the FPC **800** is shown as having two insulation layers and three signal layers, such a configuration is non-limiting. For example, in some instances the FPC **800** may have more than three insulation layers, with each insulation layer having one or more associated signal layers, e.g., sets of conductive traces, disposed therein, such as shown in FIGS. **8**C and **8**D.

In an embodiment, the first set of electrical signals carried by the first set of conductive traces **815** are radio frequency (RF) signals (e.g., a data signal). The RF signals may be utilized to, for example, drive a laser diode at a high frequency in the context of a TOSA, or to receive detected channel wavelengths via photodiodes in the context of a ROSA. The RF signals may comprise high-frequency signals that benefit from relatively short and direct (e.g., without bends) trace routes. Vias, such as vias **835** and **836** may compromise the integrity of the RF signaling. To this end, the RF signals may be exclusively carried by the first set of conductive traces **815** on top of mounting surface **829** to mitigate signal degradation.

The second and third set of conductive traces may carry a direct current (DC) signal (e.g., power) and/or a low-frequency control signal. The low-frequency control signal may be utilized to switch optical components on and off, e.g., such as a laser diode, and to regulate laser power and other operating characteristics. In addition, one or both of the second and third set of conductive traces **820**, **821** may be used as an RF ground reference plane. For example, the second set of conductive traces **820** may be used as an RF ground reference plane and the third set of conductive traces **821** may be used to carry DC and/or other low-frequency control signals. In this instance, the second set of conductive traces **820** carrying the RF ground reference plane signal may advantageously isolate the RF signals carried by the first set of conductive traces **815** from the DC and other low-frequency control signals carried by the third set of conductive traces **821**. This may significantly minimize or otherwise reduce interference between RF signals being transmitted by the first set of conductive traces **815** and the DC and other low-frequency control signals carried by the third set of conductive traces **821**.

Continuing with FIG. **8**, the first insulating layer **805** may define a mounting surface **829** that includes one or more conductive terminals, such as conductive terminals **825** and **830**. The first and second conductive terminals **825**, **830** may be positioned on a single (or the same) side, e.g., surface **829**, of the FPC **800**. Each of the first and second set of conductive terminals may be electrically coupled one or more of the first, second and third set of conductive traces **815**, **820**, and **821**.

One or more vias **835** may extend from the second insulating layer **810** through the first insulating layer **805** to provide electrical connectivity between the second set of conductive traces **820** and the first and second set of conductive terminals **825**, **830**, for example. In addition, one or more vias **836** may extend through the second insulating layer **810** and the first insulating layer **805** to provide electrical connectivity between the third set of conductive traces **821** and the first and second set of conductive terminals **825**, **830**, for example. Thus, the vias **835** and **836** allow for a single surface, e.g., surface **829**, of the FPC **800** to mount a desired number of components and/or electrical connectors. In this embodiment, all of the desired components and/or electrical connectors may be disposed on a single side of the FPC **800** to the exclusion of other sides of the FPC **800**, and consequently, an overall thickness of the FPC **800** may be reduced compared to a situation where two or more sides of the FPC **800** include one or more components and/or electrical connectors. The FPC **800** may include N number of vias at various locations and the particular configuration shown in FIG. **8**A should not be construed as limiting.

As shown, the first conductive terminals **825** may be electrically coupled to a plurality of separate components. For example, the first conductive terminals **825** may be electrically coupled to conductive pads, for example conductive pads **610**, **630**, **710**, or **730** of FIGS. **6** and **7**. As also shown, the second conductive terminals **830** may be electrically coupled to a single component. For example, the second conductive terminals **830** may be electrically coupled a pluggable connector, e.g., the pluggable connector **615** or **715**. However, such a configuration is not required. For example, the first conductive terminals **825** may be electrically coupled to a single component and/or the second conductive terminals **830** may be electrically coupled to one or more conductive pads.

As shown, each set of conductive traces include traces which are co-planar within a given insulation layer. For example, each of the conductive traces are shown in FIG. **8**B as co-planar relative to each other. In other cases conductive traces within a given layer may not necessarily be co-planar with each other. The first set of conductive traces **815** may be separated from each other by a separation distance **840**, with the separation distance **840** measuring in the range of 1.5 mm to 3 mm to prevent interference between traces. The second set of conductive traces **820** may include a separation distance **845** which is less than separation distance **840**. For example, the separation distance **845** may measure in the range of 0.1 mm to 0.3 mm. This relatively small separation distance may allow for closer patterning of traces without concern for interference between transmission lines in scenarios where the second set of conductive traces **820** carry a ground signal to act as an RF ground plane, for example. The third set of conductive traces **845** may include a separation distance **850** of 0.1 to 0.3 mm, for example.

In some instances, each of the separation distances **840**, **845**, and **850** measure substantially the same. In other cases, at least two of the separation distances **840**, **845** and **850** measure substantially the same. In still other cases, the separation distance **840** may measure larger than both of the separation distances **845** and **850**. For example, the separation distance **845** may measure about one fifth, or less, than that of the separation distance **840**. In another example, the separation distance **840** of the first set of conductive traces measures at least twice that of the separation distance **845** of the second set of conductive traces **820** and/or that of the separation distance **850** of the second set of traces **821**.

In some instances, one or more of the conductive traces included in the first, second and third set of conductive traces **815**, **820**, **821** may include electromagnetic shielding. For example, a solid copper or silver shield may be used. However, a solid copper or silver shield may decrease the flexibility of the FPC **800**. Therefore, in some instances, the copper or silver shield may be a crosshatched copper or silver shield. A crosshatched copper or silver shield may increase the flexibility of the FPC **800** relative to an FPC using a solid copper or silver shield.

Turning to FIGS. **8**C and **8**D, another example FPC **800**A is shown in accordance with an embodiment of the present disclosure. As shown, the FPC **800**A is substantially similar to that of the FPC **800** of FIGS. **8**C and **8**D, and for this reason the description of which will not be repeated for brevity. However, the FPC **800**A includes a third insulation layer **812**. The third insulation layer may include a thickness **808** the same as or different from the thickness of the insulation layers **805** and **810**. The third set of conductive traces **821** may be disposed on an outer layer **862** of the third insulation layer **812**. Vias **836** may extend through the first, second and third insulation layers **805**, **810** and **812**, to make electrical contact with one or more terminals, e.g., terminals **825**, **830**.

FIG. **9**, with additional reference to FIGS. **8A-8D**, shows an example plan view of the FPC **600** of FIG. **6** in accordance with an embodiment of the present disclosure. The FPC **600** may be implemented using the multi-layer configuration as discussed above with regard to the embodiments of FIGS. **8A-8D**. As shown, the FPC **600** includes an RF circuit **901** that may include one or more transmit RF conductive pads **905** electrically coupled to one or more receive RF conductive pads **910** using one or more of the conductive traces included in the first set of conductive traces **815**. The RF conductive pads **910** may receive one or more RF signals to be used for driving the laser packages **285-1** to **285**-N (FIG. **2**A). In other words, the RF signals are transmitted over one or more of the conductive traces included in the first set of conductive traces **815**. Therefore, the first set of conductive traces **815** may be disposed one the same layer of the multilayer FPC **600**.

In order to minimize or otherwise reduce electromagnetic interference between RF signals transmitted on the first set of conductive traces **815**, each of the conductive traces included in the first set of conductive traces **815** are separated at least by the separation distance **840**. In some instances, the separation distance **840** may increase as the first set of conductive traces **815** approach the receive RF conductive pads **910**, such as shown. In embodiments, the separation distance **840** is non-zero such that each of the conductive traces in the first set of conductive traces **815** do not cross over each other within RF circuit **901**.

As shown, the FPC **600** also includes a transmit DC circuit **916** having a set of DC conductive pads **915** and at least one conductive terminal **924**, which may be electrically coupled to the pluggable connector **615** of FIG. **6**. The set of DC conductive pads **915** may be electrically coupled to, for example, the at least one conductive terminal **924** using the third set of conductive traces **821**. However, as shown, at least one of the conductive traces within the third set of conductive traces **821** crosses at least one of the conductive traces within the first set of conductive traces **815** and/or the second set of conductive traces **820**. In other words, at least one of the conductive traces included in the third set of conductive traces **821** passes under (or over) at least one of the conductive traces included in the first set of conductive traces **815** and/or second set of conductive traces **820** by virtue of being positioned on different layers of the FPC **600**.

In some instances, at least one of the conductive traces in the third set of conductive traces **821** may be able to be routed such that it does not cross over any of the conductive traces included within the first set of conductive traces, e.g., using via **835**. As a result, at least one of the conductive traces included within the third set of conductive traces **821** may be routed through the same layer as the second set of conductive traces **820**, e.g., the second insulating layer **810** of FIG. **8**A.

In some embodiments, each of the third set of conductive traces **821** may be separated by the separation distance **850**. The separation distance **850** may increase or decrease along the length of the transmit DC circuit **916**. Therefore, in some instances, the conductive traces within the third set of conductive traces **821** may be relatively close to each other. In other words, the separation distance **850** may be about 0.1 mm or less, for example, at one or more locations in the DC circuit **916**.

FIG. **10** shows an example plan view of the FPC **700** of FIG. **7** in accordance with an embodiment of the present disclosure. The FPC **700** may be implemented using the multi-layer configuration as discussed above with regard to the embodiments of FIG. **8**A-**8**D. As shown, the FPC **700** includes a receive RF circuit **1001** that may include a set of receive RF conductive pads **1005** electrically coupled to receive RF conductive pads **1010** using the first set of conductive traces **815**. The receive RF conductive pads **1005** may receive one or more RF signals from the array of photodiodes and associated TIAs **350** (FIG. **4**). As shown, the first set of conductive traces **815** extend generally along a longitudinal axis **1012** from a receive end **1013** of the FPC **700** to a system coupling end **1014** of the first arm **720**, e.g., which may electrically couple to receive connecting circuit **108**. As shown, the receive RF conductive pads **1005** may be positioned at a distal end **1003** of the cut-out **775** such that a separation distance **1011** between the conductive pads **1005**, **1010** is minimized.

In order to minimize or otherwise reduce electromagnetic interference between RF signals transmitted on the first set of conductive traces **815**, each of the conductive traces in the first set of conductive traces **815** are separated at least by the separation distance **840**. As shown, the separation distance **840** may increase as the first set of conductive traces **815** get closer to the receive RF conductive pads **1010**. In other instances, the separation distance **840** may not change as the first set of conductive traces **815** get closer to the receive RF conductive pads **1010**. In embodiments, the separation distance **840** for the entire RF circuit **1001** is non-zero such that each of the conductive traces included in the first set of conductive traces **815** do not cross.

As shown, the FPC **700** also includes a receive DC circuit **1016** having a first set of DC conductive pads **1015**, a second set of DC conductive pads **1020**, and at least one conductive terminal **1024**, which may be electrically coupled to, for example, the pluggable connector **715** of FIG. **7**. In some instances, the first set of DC conductive pads **1015** are positioned opposite the second set of DC conductive pads **1020** across the cut-out **775**. The first set of DC conductive pads **1015** and the second set of DC conductive pads **1020** are electrically coupled to the at least one conductive terminal **1024** using one or more of the conductive traces included in the third set of conductive traces **821**. However, and as shown, in order for one or more of the conductive traces included in the third set of conductive traces **821** to electrically couple the DC conductive pads **1015**, **1020** to the at least one conductive terminal **1024**, at least one of the conductive traces within the third set of conductive traces **821** crosses at least one of the conductive traces of the first set of conductive traces **815**. In other words, at least one of the conductive traces in the third set of conductive traces **821** passes under (or over) at least one of the conductive traces in the first set of conductive traces **815** by virtue of being positioned within a different layer of the FPC **700** (e.g., the third layer **812** of FIG. **8**).

Additional Example Aspects

In accordance with an aspect of the present disclosure an optical transceiver module is disclosed. The optical transceiver module comprising a housing, a receive connecting circuit, a receiver optical subassembly (ROSA) arrangement disposed in the housing, and a first flexible printed circuit (FPC) having a first region electrically coupled to the receive connecting circuit and a second region electrically coupled to the ROSA arrangement, the first FPC comprising a first plurality of conductive traces for providing a radio frequency (RF) signal between the ROSA arrangement and the receive connecting circuit, a second plurality of conductive traces for providing a power waveform, and wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal.

In accordance with another aspect of this disclosure an optical transceiver module is disclosed. The optical transceiver module comprising a transmit connecting circuit and a receive connecting circuit each disposed at least partially within the housing, a receiver optical subassembly (ROSA) arrangement disposed in the housing, a first flexible printed circuit (FPC) having a first region electrically coupled to the receive connecting circuit and a second region electrically coupled to the ROSA arrangement, the first FPC comprising a first plurality of conductive traces for providing a radio frequency (RF) signal between the ROSA arrangement and the receive connecting circuit, a second plurality of conductive traces for providing a power waveform, and wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal, a transmitter optical subassembly (TOSA) arrangement disposed in the housing, and a second flexible printed circuit (FPC) having a first region electrically coupled to the transmit connecting circuit and a second region electrically coupled to the TOSA arrangement, the second FPC comprising a first plurality of conductive traces for providing a radio frequency (RF) signal between the transmit connecting circuit and the TOSA arrangement, a second plurality of conductive traces for providing a power waveform, and wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal.

In accordance with yet another aspect of the present disclosure and optical transceiver is disclosed. The optical transceiver comprising a housing, a transmit connecting circuit and a receive connecting circuit each disposed at least partially within the housing, a receiver optical subassembly (ROSA) arrangement disposed in the housing, a first flexible printed circuit (FPC) having a first region electrically coupled to the receive connecting circuit and a second region electrically coupled to the ROSA arrangement, the first FPC comprising a first plurality of conductive traces for providing a radio frequency (RF) signal between the ROSA arrangement and the receive connecting circuit, a second plurality of conductive traces for providing a power waveform, and wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal, a transmitter optical subassembly (TOSA) arrangement disposed in the housing, and a second flexible printed circuit (FPC) having a first region electrically coupled to the transmit connecting circuit and a second region electrically coupled to the TOSA arrangement, the second FPC comprising a first plurality of conductive traces for providing a radio frequency (RF) signal between the receive connecting circuit and the TOSA arrangement, a second plurality of conductive traces for providing a power waveform, and wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal, a printed circuit board assembly (PCBA) electrically coupled to the first and second FPCs.

While the principles of the disclosure have been described herein, it is to be understood by those skilled in the art that this description is made only by way of example and not as a limitation as to the scope of the disclosure. Other embodiments are contemplated within the scope of the present disclosure in addition to the exemplary embodiments shown and described herein. Modifications and substitutions by one of ordinary skill in the art are considered to be within the scope of the present disclosure, which is not to be limited except by the following claims.

What is claimed is:

1. An optical transceiver module comprising:

a housing;

a receive connecting circuit;

a receiver optical subassembly (ROSA) arrangement disposed in the housing; and

a first flexible printed circuit (FPC) having a first region electrically coupled to the receive connecting circuit and a second region electrically coupled to the ROSA arrangement, the first FPC comprising:

a first plurality of conductive traces for providing a radio frequency (RF) signal between the ROSA arrangement and the receive connecting circuit;

a second plurality of conductive traces for providing a power waveform;

at least one insulating layer disposed between the first and second plurality of conductive traces; and

wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal.

2. The optical transceiver module of claim **1**, wherein the first FPC further comprises an RF ground reference plane disposed between the first and second plurality of conductive traces to provide electrical isolation between the RF signal of the first plurality of conductive traces and the power waveform of the second plurality of conductive traces.

3. The optical transceiver module of claim **1**, wherein the first FPC includes a cut-out for receiving an array of photodiodes associated with the ROSA arrangement.

4. The optical transceiver module of claim **3**, wherein a plurality of conductive pads are disposed around a perimeter of the cut-out and are electrically coupled to respective conductive traces of the second plurality of conductive traces, and wherein a first conductive pad and a second conductive pad of the plurality of conductive pads are positioned on opposite sides of the cut-out from each other.

5. The optical transceiver module of claim **1**, wherein the at least one insulating layer comprises at least first and second insulating layers, the second insulating layer being disposed on the first insulating layer, and wherein the first plurality of conductive traces are disposed on an external surface of the first insulating layer and the second plurality of conductive traces are disposed on the second insulating layer.

6. The optical transceiver module of claim **5**, wherein the first FPC includes a conductive terminal disposed on the external surface of the first insulating layer, and wherein a conductive trace of the second plurality of conductive traces extends through the first insulating layer to electrically couple to the conductive terminal.

7. The optical transceiver module of claim **1**, wherein the first FPC further comprises a first arm portion and a second arm portion, the first and second arm portions extending along a longitudinal axis of the first FPC and separated from each other by a gap.

8. The optical transceiver module of claim **7**, wherein the first FPC further comprises a first flexible region extending between the first arm portion and an end of the FPC.

9. The optical transceiver module of claim **1**, wherein the first plurality of conductive traces include a separation spacing between conductive traces that is greater than a separation spacing between conductive traces of the second plurality of conductive traces.

10. An optical transceiver module comprising:

a housing;

a transmit connecting circuit and a receive connecting circuit each disposed at least partially within the housing;

a receiver optical subassembly (ROSA) arrangement disposed in the housing;

a first flexible printed circuit (FPC) having a first region electrically coupled to the receive connecting circuit and a second region electrically coupled to the ROSA arrangement, the first FPC comprising:

a first plurality of conductive traces for providing a radio frequency (RF) signal between the ROSA arrangement and the receive connecting circuit;

a second plurality of conductive traces for providing a power waveform; and

wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal;

a transmitter optical subassembly (TOSA) arrangement disposed in the housing; and

a second flexible printed circuit (FPC) having a first region electrically coupled to the transmit connecting circuit and a second region electrically coupled to the TOSA arrangement, the second FPC comprising:

a first plurality of conductive traces for providing a radio frequency (RF) signal between the transmit connecting circuit and the TOSA arrangement;

a second plurality of conductive traces for providing a power waveform; and

wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal.

11. The optical transceiver module of claim **10**, wherein the second FPC includes a cut-out for receiving an array of photodiodes associated with the ROSA arrangement.

12. The optical transceiver module of claim **11**, wherein a plurality of conductive pads is disposed around a perimeter of the cut-out of the first FPC, each of the plurality of conductive pads being electrically coupled to an associated conductive trace of the second plurality of conductive traces, and wherein a first conductive pad and a second conductive pad of the plurality of conductive pads are disposed on opposite sides of the cut-out from each other.

13. The optical transceiver module of claim **10**, wherein each of the first and second FPCs further comprise at least a first, second, and third insulating layer, the second insulating layer being coupled between the first and second insulating layers, and wherein the first plurality of conductive traces is disposed on the first insulating layer and the second plurality of conductive traces is disposed on the third insulating layer.

14. The optical transceiver module of claim **13**, wherein the first FPC includes a conductive terminal disposed on an external surface of the first insulating layer, and wherein a conductive trace of the second plurality of conductive traces extends through the first and second insulating layers to electrically couple to the conductive terminal.

15. The optical transceiver module of claim **10**, wherein the first FPC further comprises a first arm portion and a second arm portion, the first and second arm portions extending along a longitudinal axis of the first FPC and separated from each other by a gap.

16. The optical transceiver module of claim **10** implemented as a Quad Small Form-Factor Pluggable transceiver.

17. An optical transceiver comprising:

a housing;

a transmit connecting circuit and a receive connecting circuit each disposed at least partially within the housing;

a receiver optical subassembly (ROSA) arrangement disposed in the housing;

a first flexible printed circuit (FPC) having a first region electrically coupled to the receive connecting circuit and a second region electrically coupled to the ROSA arrangement, the first FPC comprising:

a first plurality of conductive traces for providing a radio frequency (RF) signal between the ROSA arrangement and the receive connecting circuit;

a second plurality of conductive traces for providing a power waveform; and

wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal;

a transmitter optical subassembly (TOSA) arrangement disposed in the housing; and

a second flexible printed circuit (FPC) having a first region electrically coupled to the transmit connecting circuit and a second region electrically coupled to the TOSA arrangement, the second FPC comprising:

a first plurality of conductive traces for providing a radio frequency (RF) signal between the receive connecting circuit and the TOSA arrangement;

a second plurality of conductive traces for providing a power waveform; and

wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal;

a printed circuit board assembly (PCBA) electrically coupled to the first and second FPCs.

18. The optical transceiver of claim **17**, wherein the first FPC includes a cut-out for receiving an array of photodiodes associated with the ROSA arrangement.

19. The optical transceiver of claim **18**, wherein a plurality of conductive pads is disposed around a perimeter of the cut-out of the first FPC, each of the plurality of conductive pads being electrically coupled to an associated conductive trace of the second plurality of conductive traces, and wherein a first conductive pad and a second conductive pad of the plurality of conductive pads are disposed on opposite sides of the cut-out from each other.

20. The optical transceiver module of claim **17** implemented as a Quad Small Form-Factor Pluggable transceiver.

* * * * *

Exhibit D

US010578818B1

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Chen et al.

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(54) **OPTICAL TRANSCEIVER**

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See application file for complete search history.

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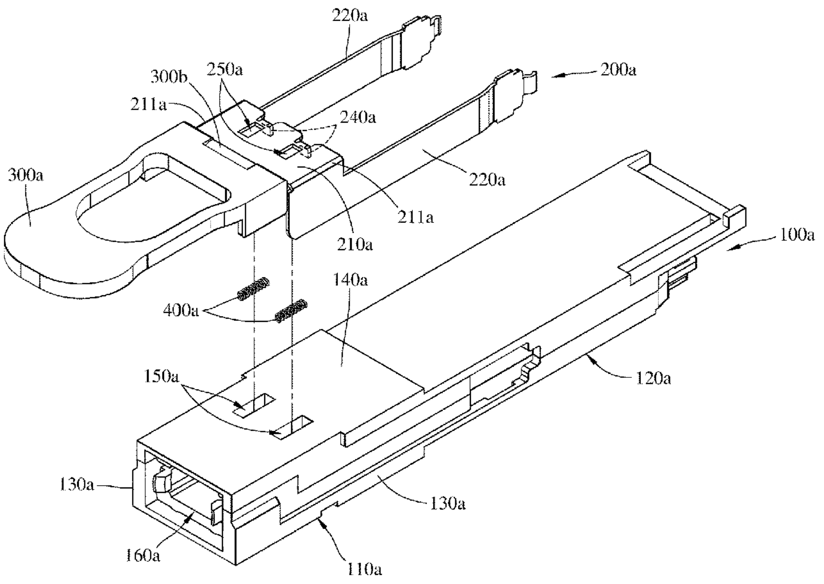
Primary Examiner — Robert Tavlykaev
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC

(57) **ABSTRACT**

An optical transceiver includes a main body, an elastic component and a fastening component. The main body includes two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defines a confined groove. The elastic component is disposed in the confined groove. The fastening component is movably disposed on the main body. The fastening component includes a linkage arm, two extending arms and a confined portion. The linkage arm is disposed on the outer surface of the main body, and the two extending arms are connected with the linkage arm. The two extending arms are respectively disposed on the two lateral surfaces. The confined portion is connected with the linkage arm and extends into the confined groove in order to press the elastic component. The two extending arms are detachably fasten-able with the cage.

12 Claims, 8 Drawing Sheets



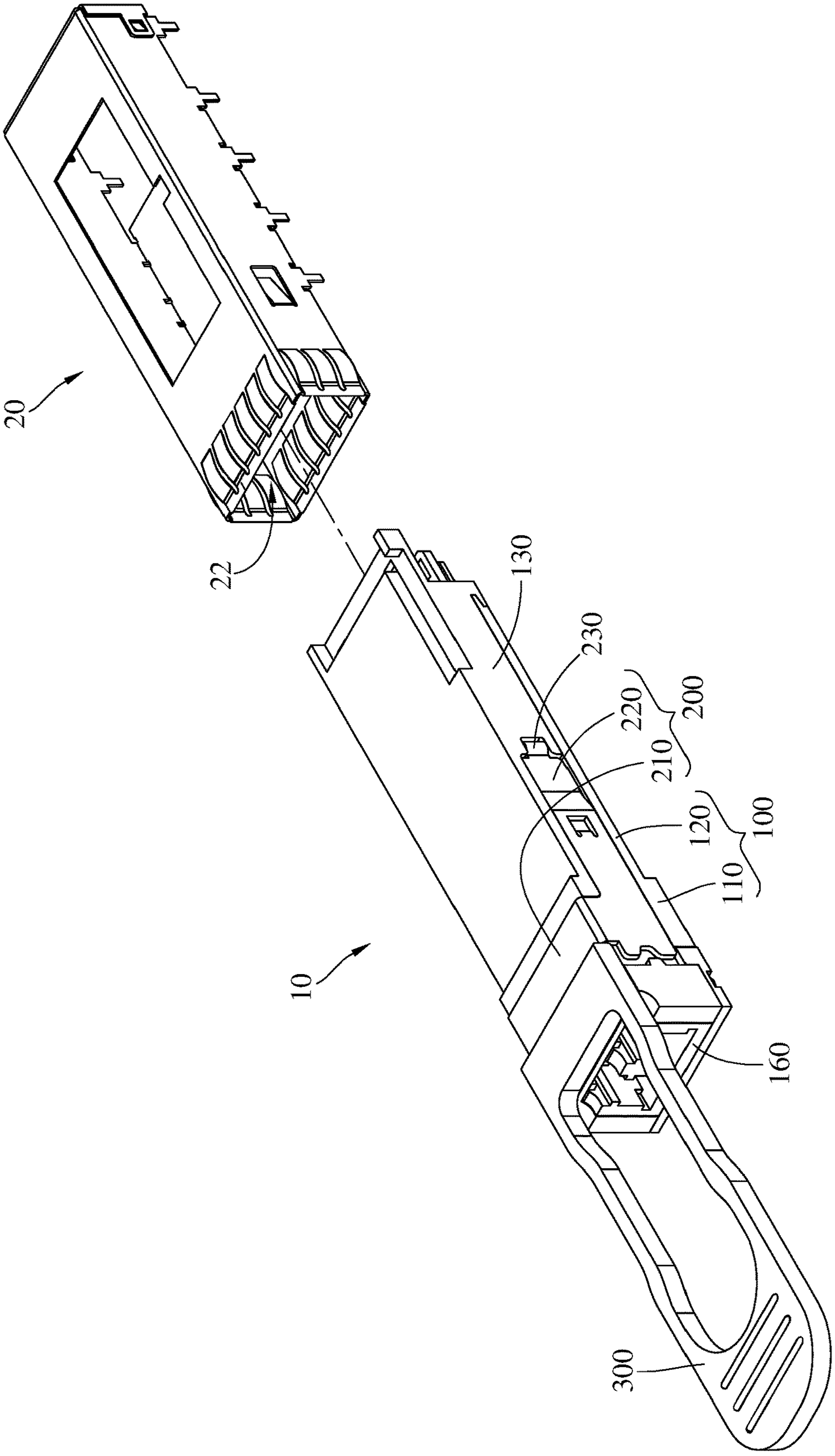


FIG. 1

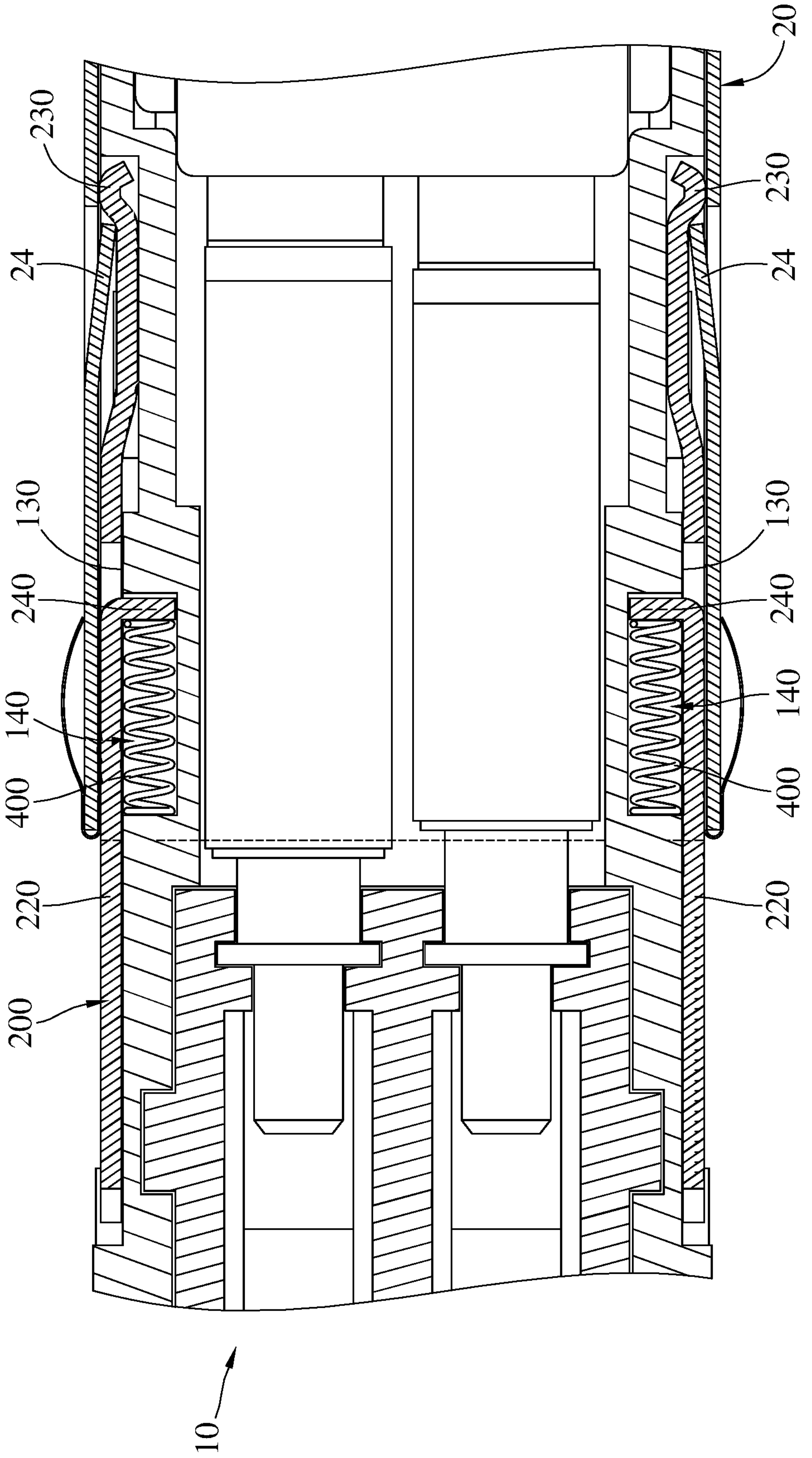


FIG. 2

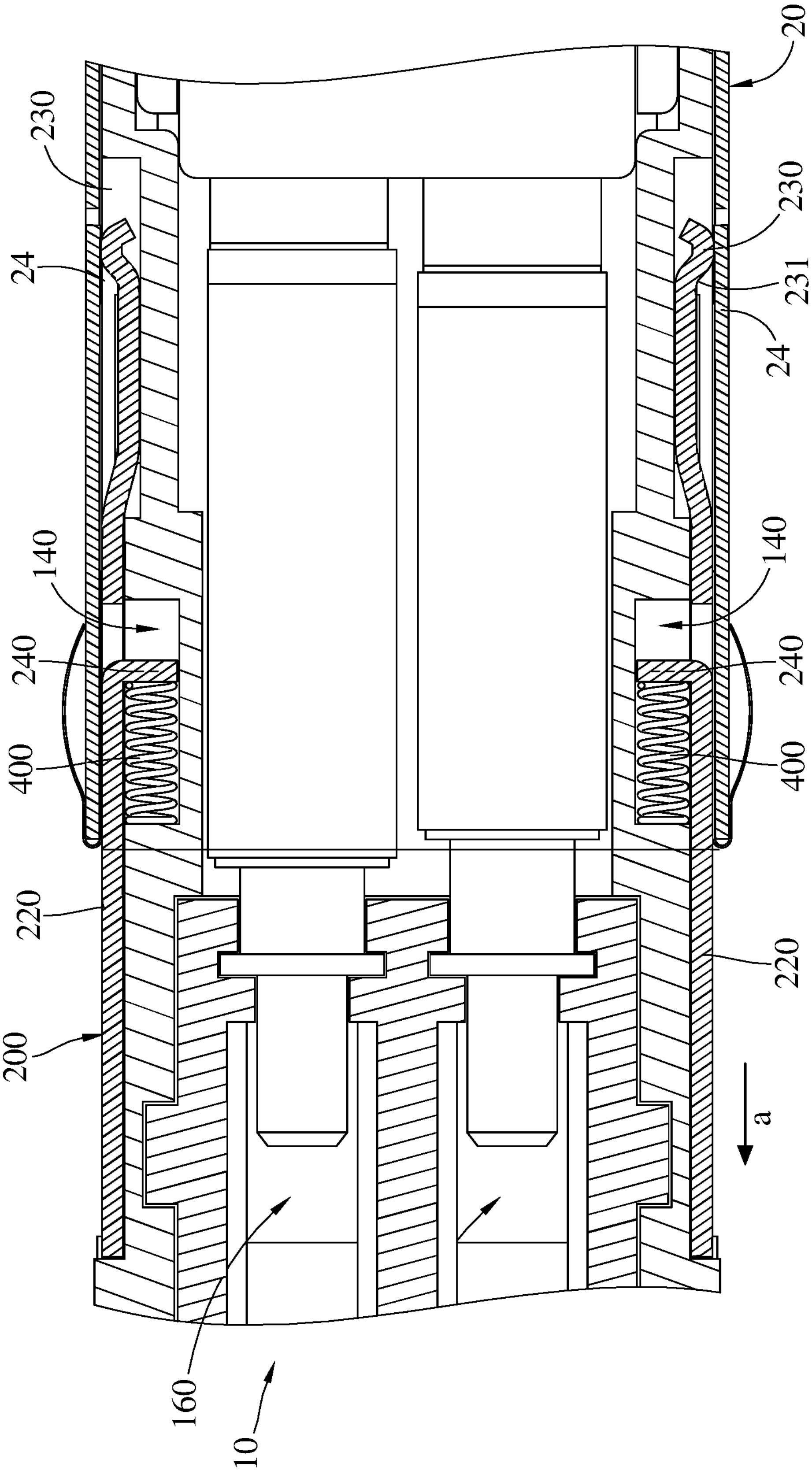


FIG. 3

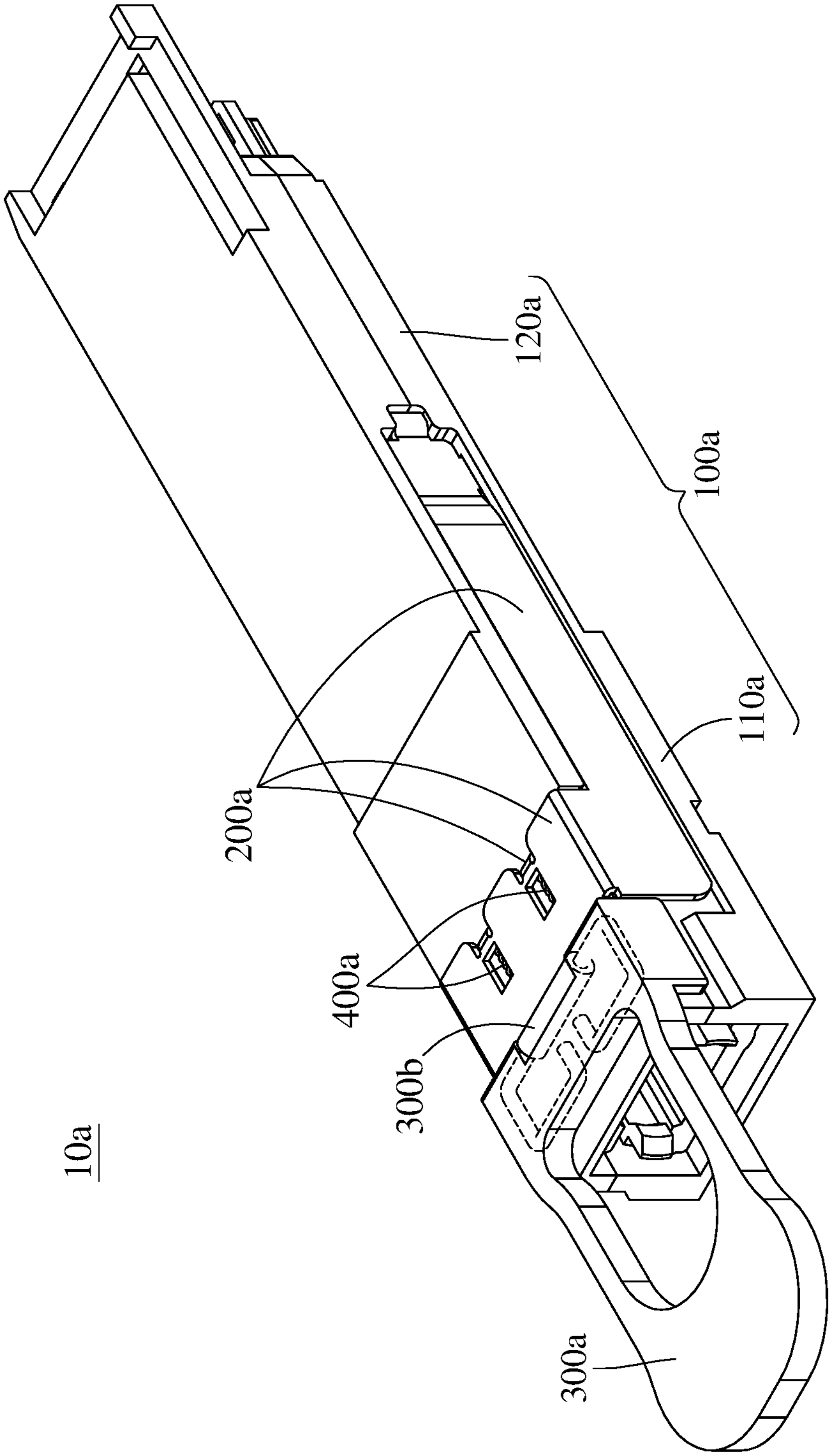
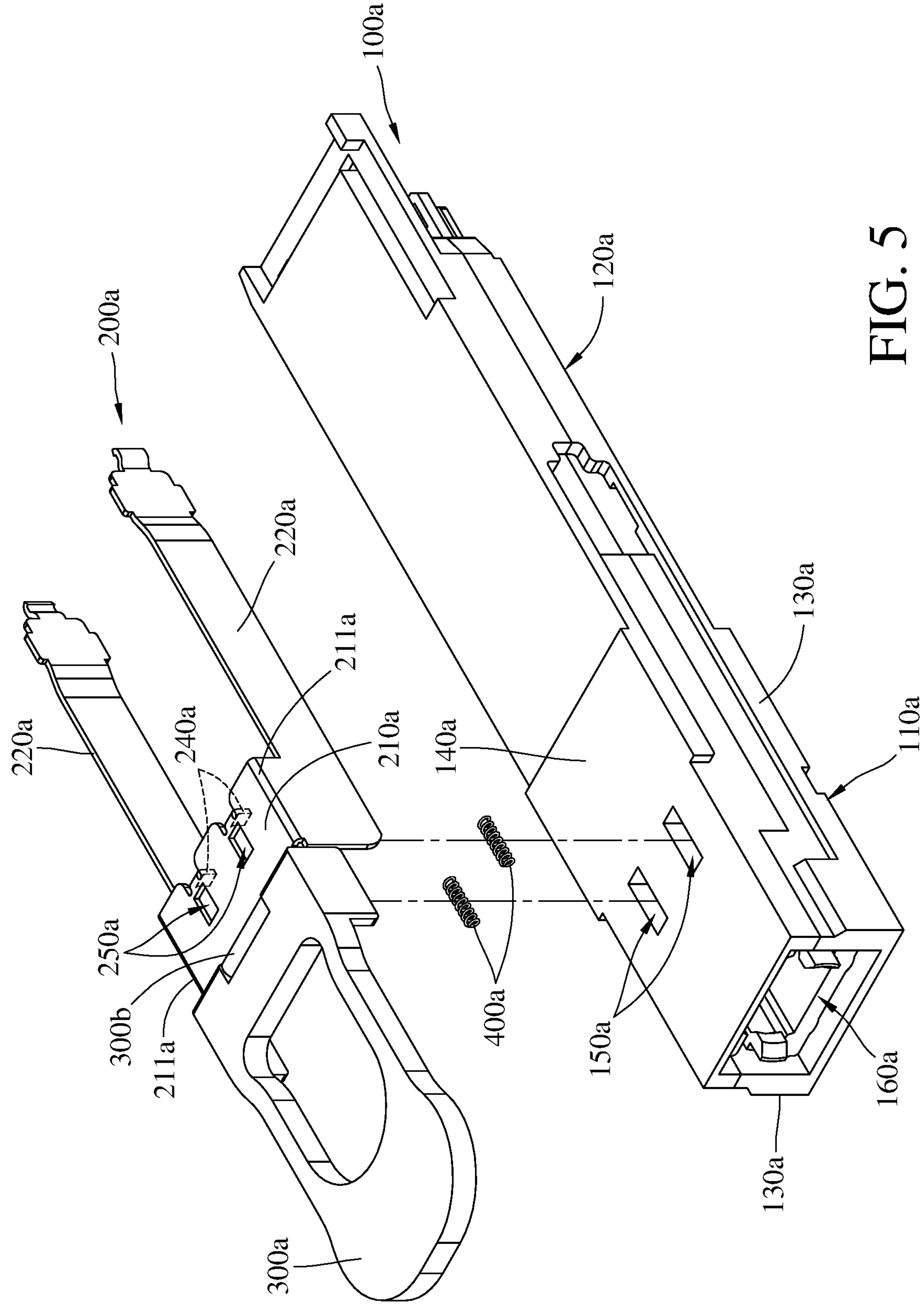


FIG. 4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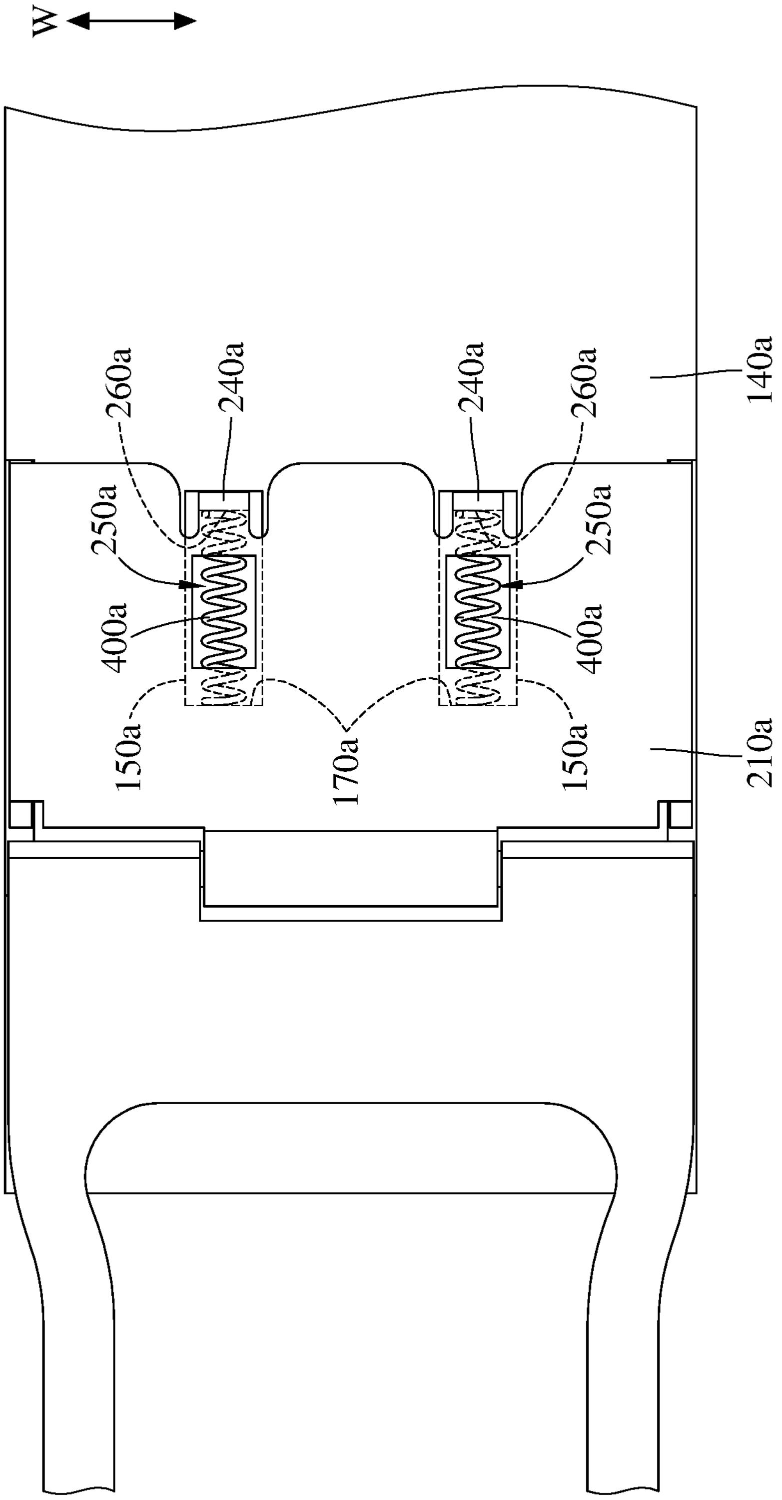
130a
300a

FIG. 5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400a
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210a

FIG. 6

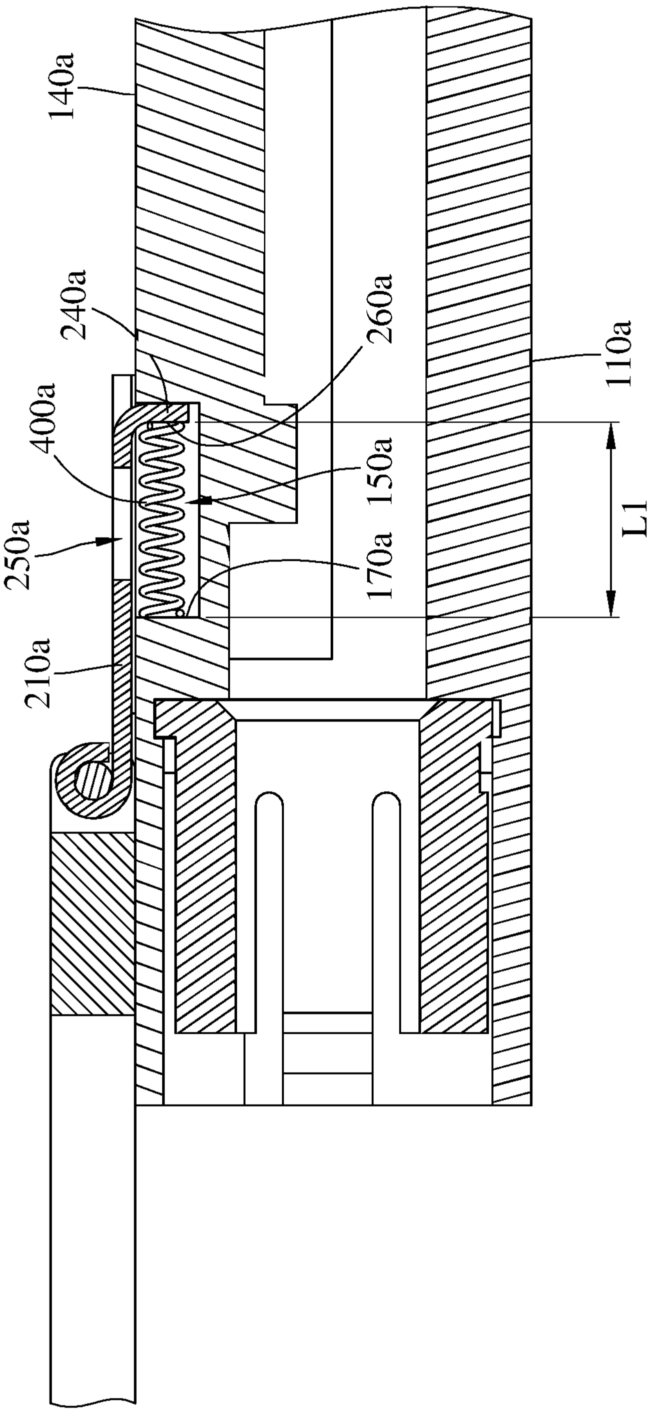

FIG. 7

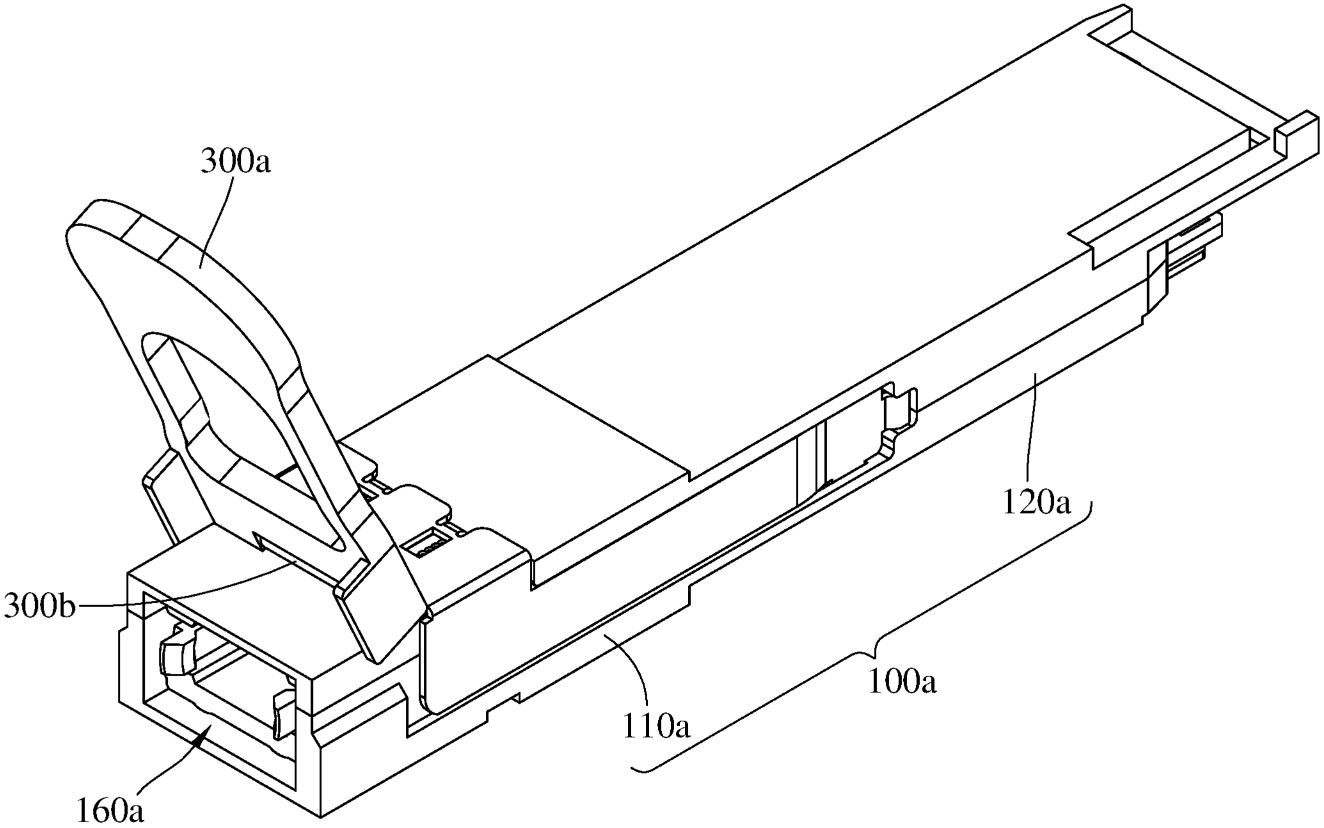

FIG. 8

OPTICAL TRANSCEIVER

TECHNICAL FIELD

The disclosure relates to an optical communication device, more particularly to a pluggable optical transceiver.

BACKGROUND

Optical transceivers are generally installed in electronic communication facilities in modern high-speed communication networks. In order to make flexible the design of an electronic communication facility and less burdensome the maintenance of the same, an optical transceiver is inserted into a corresponding cage that is disposed in the communication facility in a pluggable manner. In order to define the electrical-to-mechanical interface of the optical transceiver and the corresponding cage, different specifications such as XFP (10 Gigabit Small Form Factor Pluggable) used in 10 GB/s communication rate, QSFP (Quad Small Form-factor Pluggable), or other form factors at different communication rates.

A fastening mechanism is provided for securely fixing the optical transceiver to the cage. On the other hand, the optical transceiver must include a releasing mechanism so that the optical transceiver could be released from the cage smoothly when necessary.

SUMMARY

According to one aspect of the present disclosure, an optical transceiver is disclosed. Such disclosed optical transceiver in one embodiment includes a main body, an elastic component and a fastening component. The main body includes two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defines a confined groove. The elastic component is disposed in the confined groove. The fastening component is movably disposed on the main body. The fastening component includes a linkage arm, two extending arms and a confined portion. The linkage arm is disposed on the outer surface of the main body, and the two extending arms are connected with the linkage arm. The two extending arms are respectively disposed on the two lateral surfaces. The confined portion is connected with the linkage arm and extends in the confined groove in order to press the elastic component. The two extending arms are detachably fasten-able with the cage.

According to another aspect of the present disclosure, an optical transceiver is disclosed. Such disclosed optical transceiver in one embodiment includes a main body, two elastic components and a fastening component. The main body includes two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defines two confined grooves spaced apart from each other. The two elastic components are disposed in the two confined grooves, respectively. The fastening component is movably disposed on the main body. The fastening component includes a linkage arm, two extending arms and two confined portions. The linkage arm is disposed on the outer surface of the main body, and the two extending arms are connected with the linkage arm. The two extending arms are respectively disposed on the two lateral surfaces. The confined portions are connected with the linkage arm and are respectively extend into the two confined grooves in order to press the two elastic components. The two extending arms are detachably fasten-able with the cage.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description given below and the accompanying drawings which are given by way of illustration only and thus are not intending to limit the present disclosure and wherein:

FIG. **1** is a perspective view of an optical transceiver and a cage according to a first embodiment of the present disclosure;

FIG. **2** is a partially enlarged view of the optical transceiver in FIG. **1**, with a fastening component at a fastening position;

FIG. **3** is a partially enlarged cross-sectional view of the optical transceiver in FIG. **1**, with the fastening component at a releasing position;

FIG. **4** is a perspective view of an optical transceiver according to a second embodiment of the present disclosure;

FIG. **5** is an exploded view of the optical transceiver in FIG. **4**;

FIG. **6** is a partially enlarged cross-sectional view of the optical transceiver in FIG. **4** along line **6-6**;

FIG. **7** is a partially enlarged cross-sectional view of the optical transceiver in FIG. **4** along line **7-7**; and

FIG. **8** is a perspective view of the optical transceiver in FIG. **4**, with a bail at an upright position.

DETAILED DESCRIPTION

In the following detailed description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the disclosed embodiments. It will be apparent, however, that one or more embodiments may be practiced without these specific details. In other instances, well-known structures and devices are schematically shown in order to simplify the drawing.

Please refer to FIG. **1** and FIG. **2**. FIG. **1** is a perspective view of an optical transceiver and a cage according to a first embodiment of the present disclosure. FIG. **2** is a partially enlarged view of the optical transceiver in FIG. **1**, with a fastening component at a fastening position. In this embodiment, an optical transceiver **10** is disclosed, and the optical transceiver **10** is inserted into a cage **20** in pluggable manner. The optical transceiver **10** includes a main body **100**, a fastening component **200**, a bail **300** and two elastic components **400**.

The main body **100**, for example, is a housing including a head portion **110** and an insertion portion **120** connected with each other. The insertion portion **120** is configured to be inserted into a plugging slot **22** of the cage **20**. The head portion **110** of the optical transceiver **10** includes two lateral surfaces **130**, two sliding rails and two confined grooves **140**. The two sliding rails are respectively formed on the two lateral surfaces **130** and extend from the head part **110** to the insertion portion **120**. The two confined grooves **140** are respectively formed on the two lateral surfaces **130** for accommodating the two elastic components **400**.

The fastening component **200** includes a linkage arm **210** and two extending arms **220**. The two extending arms **220** are respectively connected with two opposite ends of the linkage arm **210**, such that the linkage arm **210** is located between the two extending arms **220**. The two extending arms **220** are movably disposed on the sliding rails at the lateral surfaces **130**, respectively. Each of the extending arms **220** includes a fastening portion **230** and a confined portion **240**. The fastening portion **230** extends along a direction far away from the lateral surface **130** to be detachably fasten-able with the cage **20**. The confined portion **240** extends into the confined groove **140** for pressing the elastic component **400**.

The bail **300** is connected with the linkage arm **210** of the fastening component **200** and extends outside from the main body **100**. The bail **300** is made of rubber and bendable to be in front of the head part **110** or on the top of the head part **110**.

The elastic components **400** constantly press the confined portion **240** of the fastening component **200**. It is worth noting that numbers of the confined grooves **140** and the elastic components **400** are not limited in view of embodiments in the present disclosure.

The fastening component **200** is movable relative to the main body **100** to be at either a fastening position (as shown in FIG. **2**) and a releasing position (as shown in FIG. **3**). Please refer to FIG. **2** and FIG. **3**. FIG. **3** is a partially enlarged cross-sectional view of the optical transceiver in FIG. **1**, with the fastening component at a releasing position.

In FIG. **2**, the two elastic components **400** respectively press the two confined portions **240** so that the fastening component **200** could be located at the fastening position, and thus the fastening portions **230** are securely fastened with the cage **20**. Therefore, the optical transceiver **10** is readily and reliably inserted into the plugging slot **22** of the cage **20**.

The bail **300** is able to be drawn along the direction indicated by an arrow a. In FIG. **3**, the fastening component **200** is moved by the bail **300** relative to the main body **200** to be at the releasing position. The fastening portion **230** presses a flexible arm **24** of the cage **20** so that the fastening component **200** slides along an inclined surface **231** of the fastening portion **230**. The fastening portion **230** bends the flexible arm **24** to allow the fastening component **200** to move to the releasing position. The insertion portion **120** of the main body **100** is removed from the cage **20** when the bail **300** is pulled much farther.

When the fastening component **200** is at the releasing position, the two confined portions **240** respectively compress the two elastic components **400**. As the bail **300** is released, the elastic energy stored in the elastic components **400** drives the fastening component **200** back to the fastening position.

The bail **300** could be moved around to be located above the head part **110** of the main body **100**, creating some room for an optical fiber plug (not shown in the drawings) to be plugged into an optical fiber terminal **160** more conveniently.

In the first embodiment, that the bail **300** could help move the fastening component **200** renders possible the fastening component to fasten to or be released from the cage.

In the first embodiment, the elastic component **400** is disposed in the confined groove **140** which is formed on the lateral surface **130** of the main body **100**, and the confined portion **240** of the extending arm **220** presses the elastic component **400**. However, since the trend of evolution of the optical transceiver **10** somewhat focuses on the reduction in size of the entire transceiver as well as the inside space of the main body **100**. In order to form the confined grooves **140** on the lateral surfaces **130**, the space inside the main body **100** is restricted in a width direction, such that it is unfavorable for the arrangement of electronic components such as multiple transmitters and multiple receivers.

Furthermore, the bail **300** could be moved around with respect to the main body **100** in the first embodiment. However, absent application of any external force may make the bail **300** simply go back to its initial position, such that extra maneuver of the bail **300** is required for any optical fiber to be plugged into the optical fiber terminal **160** (which might be a switch).

A configuration of the optical transceiver **10** could be improved. Please refer to FIG. **4** and FIG. **5**. FIG. **4** is a perspective view of an optical transceiver according to a second embodiment of the present disclosure. FIG. **5** is an exploded view of the optical transceiver in FIG. **4**. In this embodiment, an optical transceiver **10***a* is a QSFP-DD (Quad Small Form-factor Pluggable Double Density) optical transceiver, and the optical transceiver **10** is configured to be inserted into a cage (not shown in the drawings) in pluggable manner. The optical transceiver **10***a* includes a main body **100***a*, a fastening component **200***a*, a bail **300***a*, a pivot shaft **300***b* and two elastic components **400***a*.

Please further refer to FIG. **6** and FIG. **7**. FIG. **6** is a partially enlarged cross-sectional view of the optical transceiver in FIG. **4** along line **6-6**. FIG. **7** is a partially enlarged cross-sectional view of the optical transceiver in FIG. **4** along line **7-7**. The main body **100***a* includes a head portion **110***a* and an insertion portion **120***a* connected with each other. The head portion **110***a* of the main body **100***a* includes two lateral surfaces **130***a*, an outer surface **140***a* and an optical fiber terminal **160***a*. The outer surface **140***a* is between the two lateral surfaces **130***a*, and the outer surface **140***a* defines two confined grooves **150***a* which are spatially spaced apart from each other. The head portion **110***a* of the main body **100***a* further includes two first confined surfaces **170***a* with the two confined grooves **150***a* formed respectively. In this embodiment, the outer surface **140***a* is a top surface on an upper cover of the main body **100***a*, but the disclosure is not limited thereto. In some other embodiments, the outer surface is a bottom surface on a bottom cover of the main body **100***a*. An accommodation space inside the main body **100***a* allows for placement of components such as the optical fiber terminal **160***a*, a circuit board, photodiodes, laser emitters, and IC chips.

The fastening component **200***a* is movably disposed on the main body **100***a* and includes a linkage arm **210***a*, two extending arms **220***a* and two confined portions **240***a*. The two extending arms **220***a* are respectively connected with two opposite ends of the linkage arm **210***a*, such that the linkage arm **210***a* is located between the two extending arms **220***a*. The two extending arms **220** are movably disposed on the lateral surfaces **130***a* respectively, and the extending arms **220** are detachably fasten-able with the cage. The linkage arm **210***a* is disposed on the outer surface **140***a* of the main body **100***a*, and the linkage arm **210***a* includes two openings **250***a* respectively connected with the two confined groove **150***a*. The two confined portions **240***a* are connected with the linkage arm **210***a*, and the two confined portions **240***a* respectively extend into the confined grooves **150***a*. In this embodiment, a process of stamping is performed to cut and deform part of the linkage arm **210***a* to form the confined portions **240***a* and the openings **250***a* of the fastening component **200***a*. The opening **250***a* is located in proximity of the confined portion **240***a*.

The pivot shaft **300***b* is pivoted on the linkage arm **210***a* of the fastening component **200***a*, and the bail **300***a* disposed on the pivot shaft **300***b*. FIG. **8** is a perspective view of the optical transceiver in FIG. **4**, with a bail at an upright position. The bail **300***a* extends outside from the main body **100***a*. When the bail **300***a* is at a horizontal position, the bail **300***a* protects the optical fiber terminal **160***a* from dust, and the insertion portion **120***a* of the main body **100***a* is removed from the cage when the horizontal bail **300***a* is drawn. The bail **300***a* could be moved from the horizontal position to an upright position so as render convenient installation or removal of the optical fibers without requiring the bail **300***a* being held manually or by other means. With the pivot shaft **300***b*, the bail **300***a* could stay at the upright position even without any application of the external force to the bail **300***a*.

Each of the elastic components **400***a*, for example, is a spring compressed by the confined portion **240***a* of the fastening component **200***a*. In detail, each confined portion **240***a* of the fastening component **200***a* includes a second confined surface **260***a* facing toward the first confined surface **170***a* of the main body **100***a*. The elastic component **400***a* is disposed between the first confined surface **170***a* and the second confined surface **260***a*. When the fastening component **200***a* moves relative to the main body **100***a*, the confined portion **240***a* moves in the confined groove **150***a* and compresses the elastic component **400***a*.

It is worth noting that numbers of the confined grooves **150***a*, the extending arms **220***a*, the confined portions **240***a*, the openings **250***a* and the elastic components **400***a* are not limited because of the embodiments discussed in the present disclosure.

The opening **250***a* of the fastening component **200***a* exposes the elastic component **400***a* to outside. In detail, a method of positioning the elastic component **400***a* in the confined groove **150***a* is to compress the elastic component **400***a* by hand, and then put the elastic component **400***a* into the confined groove **150***a* through the opening **250***a*. Therefore, the elastic component **400***a* could be mounted or unmounted with more efficiency. As shown in FIG. **7**, to maintain the position of the elastic component **400***a*, a size of the opening **250***a* is smaller than a length L1 of the elastic component **400***a* in an uncompressed condition. The uncompressed condition is a condition that the confined portion **240***a* of the fastening component **200***a* does not compress the elastic component **400***a*.

Furthermore, as shown in FIG. **5**, the opening **250***a* is located between two ends **211***a* of the linkage arm **210***a* where the two extending arms **220***a* are respectively connected. Therefore, the opening **250***a* does not formed at an edge of the linkage arm **210***a*, such that it is favorable for an easier manufacture of the fastening component **200***a* since the edge of the linkage arm **210***a* is difficult to be processed due to higher internal stress.

According to the present disclosure, in the second embodiment, the elastic component **400***a* is disposed in the confined groove **150***a*, and the confined groove **150***a* is formed on the top surface of the main body **100***a* rather than on the lateral surface **130***a*. Therefore, more accommodation space inside the main body **100***a* could be provided in a width direction W to accommodate electronic components for high-speed communication, thereby meeting the requirements of compact optical transceiver **10***a* and proper space utilization of the same.

The embodiments are chosen and described in order to best explain the principles of the present disclosure and its practical applications, to thereby enable others skilled in the art to best utilize the present disclosure and various embodiments with various modifications as are suited to the particular use that is being contemplated. It is intended that the scope of the present disclosure is defined by the following claims and their equivalents.

What is claimed is:

1. An optical transceiver, configured to be inserted into a cage in a pluggable manner, comprising:

a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining a confined groove;

an elastic component disposed in the confined groove; and

a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and a confined portion, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portion is connected with the linkage arm and extends into the confined groove in order to press the elastic component, and the two extending arms are detachably fasten-able with the cage.

2. The optical transceiver according to claim **1**, wherein the outer surface is either a top surface or a bottom surface of the main body.

3. The optical transceiver according to claim **1**, wherein the main body comprises a first confined surface forming the confined groove, the confined portion of the fastening component comprises a second confined surface facing toward the first confined surface, and the elastic component is disposed between the first confined surface and the second confined surface.

4. The optical transceiver according to claim **1**, wherein a size of the opening is smaller than a length of the elastic component in an uncompressed condition.

5. The optical transceiver according to claim **1**, wherein the opening is located between two ends of the linkage arm where the two extending arms are connected.

6. The optical transceiver according to claim **1**, wherein the confined portion and the opening of the fastening component are formed by stamping.

7. The optical transceiver according to claim **1**, wherein the main body comprises a head portion and an insertion portion connected with each other, the insertion portion is configured to be inserted into the cage in a pluggable manner, the head portion comprises the outer surface, the two lateral surfaces and an optical fiber terminal.

8. The optical transceiver according to claim **1**, further comprising a pivot shaft pivoted on the linkage arm of the fastening component and a bail connected with the pivot shaft.

9. The optical transceiver according to claim **1**, wherein the optical transceiver is a QSFP-DD (Quad Small Form-factor Pluggable Double Density) optical transceiver.

10. An optical transceiver, comprising:

a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining two confined grooves spaced apart from each other;

two elastic components disposed in the two confined grooves, respectively; and

a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and two confined portions, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portions are connected with the linkage arm and respectively extend into the two confined grooves in order to press the two elastic components.

11. An optical transceiver, configured to be inserted into a cage in a pluggable manner, comprising:

a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining a confined groove;

an elastic component disposed in the confined groove;

a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and a confined portion, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portion is connected with the linkage arm and extends into the confined groove in order to press the elastic component, and the two extending arms are detachably fasten-able with the cage; and

a pivot shaft pivoted on the linkage arm of the fastening component and a bail connected with the pivot shaft, the bail having a horizontal position to allow the bail to be drawn for removal of the optical transceiver from the cage, and an upright position to allow for installation or removal of optical fibers into the optical transceiver.

12. The optical transceiver of claim **11**, wherein the bail is configured to remain in the upright position without application of external force.

* * * * *

Exhibit E

US010714890B1

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

(10) **Patent No.: US 10,714,890 B1**
(45) **Date of Patent: Jul. 14, 2020**

(54) **TRANSMITTER OPTICAL SUBASSEMBLY ARRANGEMENT WITH VERTICALLY-MOUNTED MONITOR PHOTODIODES**

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(72) Inventors: **Kai-Sheng Lin**, Sugar Land, TX (US); **Hsiu-Che Wang**, Rosenberg, TX (US); **Kevin Liu**, Houston, TX (US)

(73) Assignee: **Applied Optoelectronics, Inc.**, Sugar Land, TX (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.

(21) Appl. No.: **16/268,765**

(22) Filed: **Feb. 6, 2019**

(51) **Int. Cl.**

H01S 5/022	(2006.01)
H01S 5/024	(2006.01)
H01S 5/40	(2006.01)
H01S 5/00	(2006.01)

(52) **U.S. Cl.**
CPC ***H01S 5/02236*** (2013.01); ***H01S 5/0014*** (2013.01); ***H01S 5/02415*** (2013.01); ***H01S 5/4012*** (2013.01); ***H01S 5/4087*** (2013.01)

(58) **Field of Classification Search**
CPC H01S 5/02236; H01S 5/0014; H01S 5/02415; H01S 5/4012; H01S 5/4087; H01S 5/02208; H01S 5/02212
See application file for complete search history.

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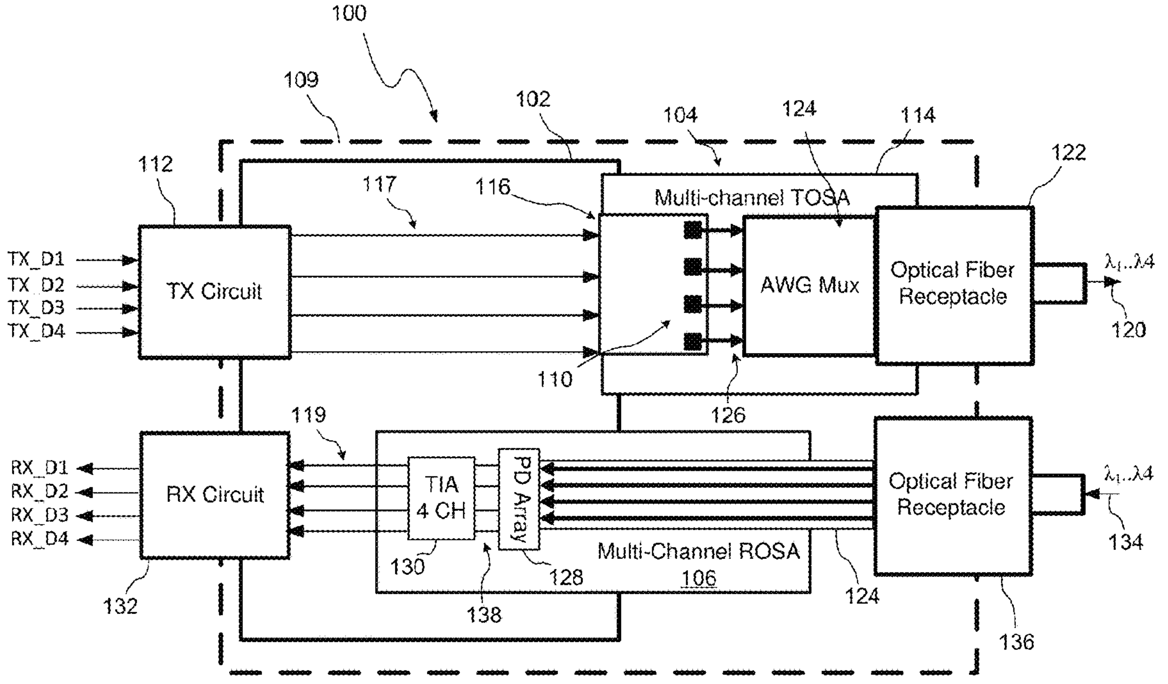
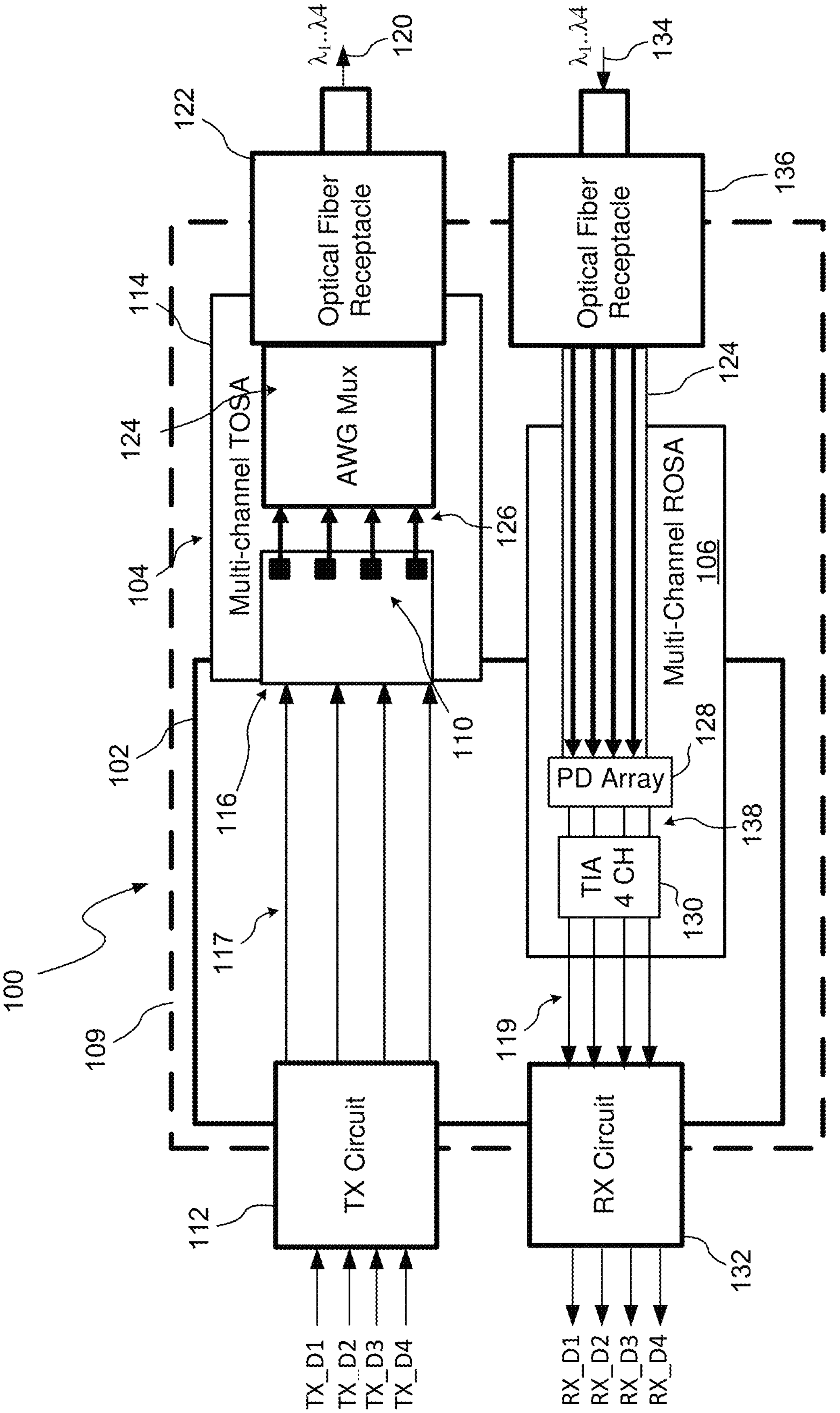
Primary Examiner — Armando Rodriguez
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC; Norman S. Kinsella

(57) **ABSTRACT**

The present disclosure is generally directed to a multi-channel TOSA with vertically-mounted MPDs to reduce TOSA housing dimensions and improve RF driving signal quality. In more detail, a TOSA housing consistent with the present disclosure includes at least one vertical MPD mounting surface that extends substantially transverse relative to a LD mounting surface, with the result being that a MPD coupled to the vertical MPD mounting surface gets positioned above an associated LD coupled to the LD mounting surface. The vertically-mounted MPD thus makes regions adjacent an LD that would otherwise be utilized to mount an MPD available for patterning of conductive RF traces to provide an RF driving signal to the LD. The conductive RF traces may therefore extend below the vertically-mounted MPD to a location that is proximate the LD to allow for relatively short wire bonds therebetween.

19 Claims, 8 Drawing Sheets

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136
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Multi-Channel ROSA
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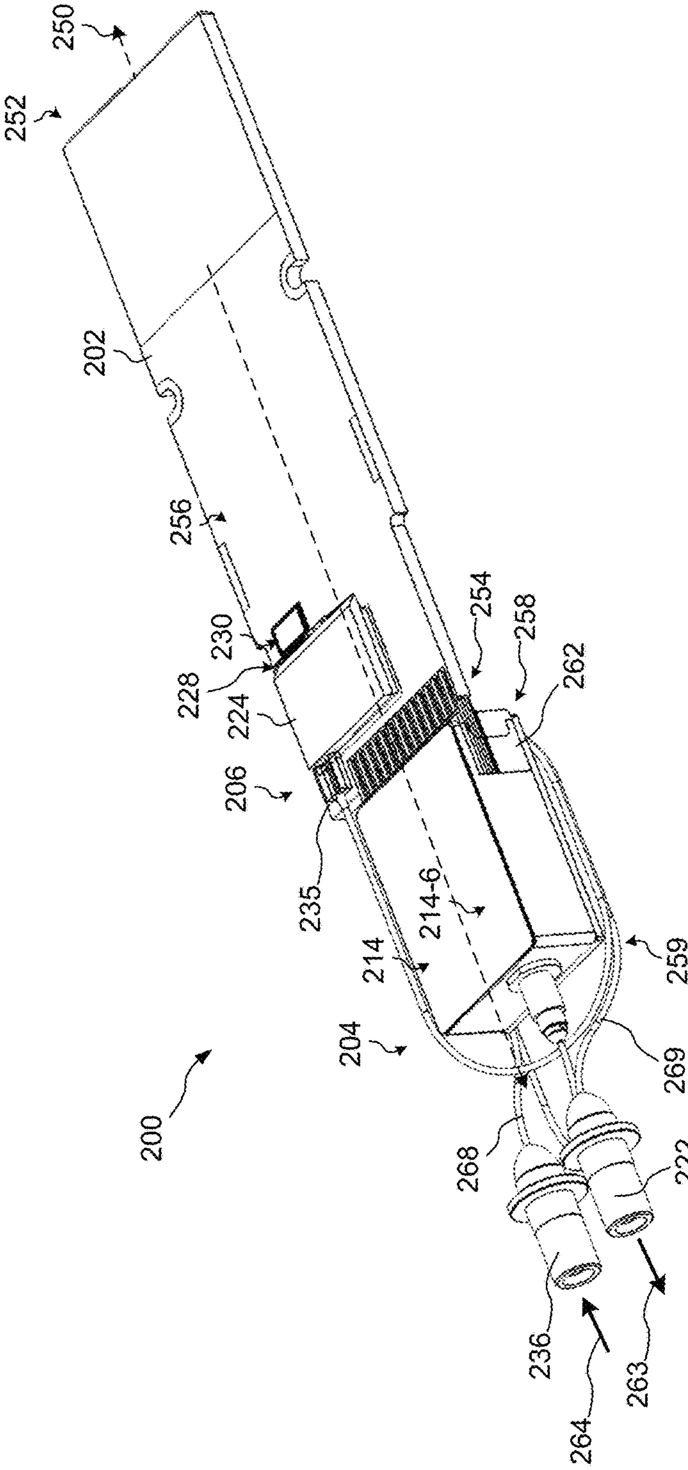
RX_D4

FIG. 1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214-6
214
204
259
269
268
222
200
236
264
263

FIG. 2

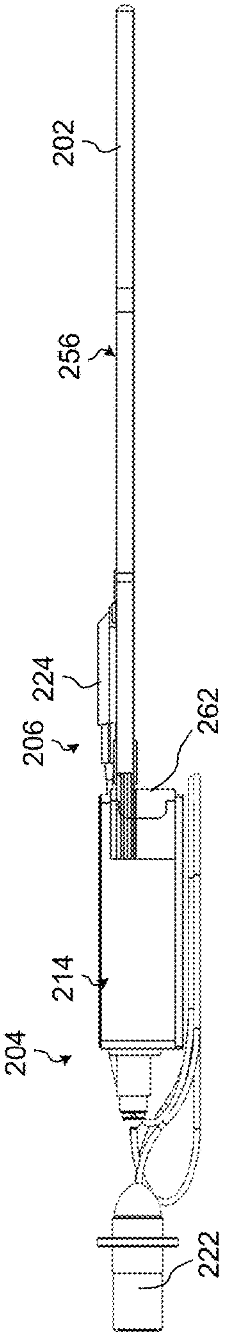
202
256
224
206
262
214
204
222

FIG. 3

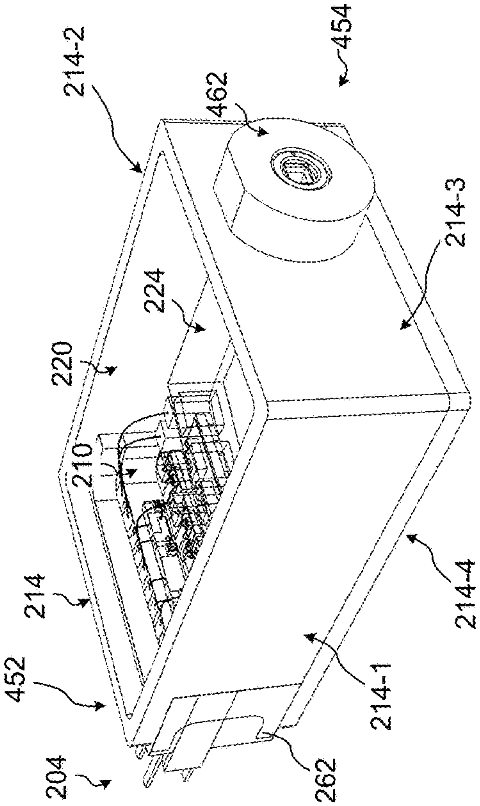
214-2
454
462
214-3
224
220
210
214
452
204
262
214-1
214-4

FIG. 4

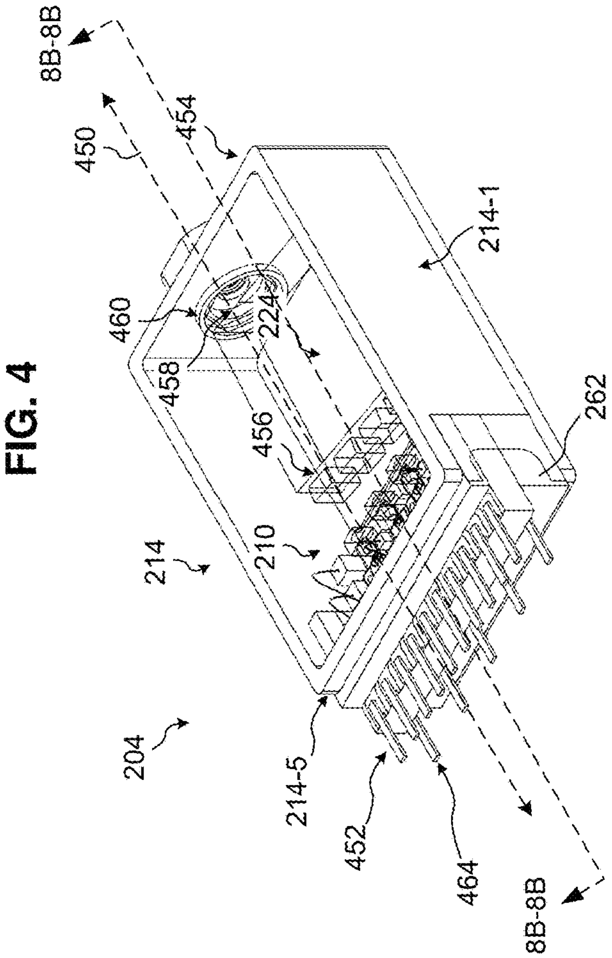
8B-8B
450
454
214-1
460
224
458
456
262
210
214
204
214-5
452
464
8B-8B

FIG. 5

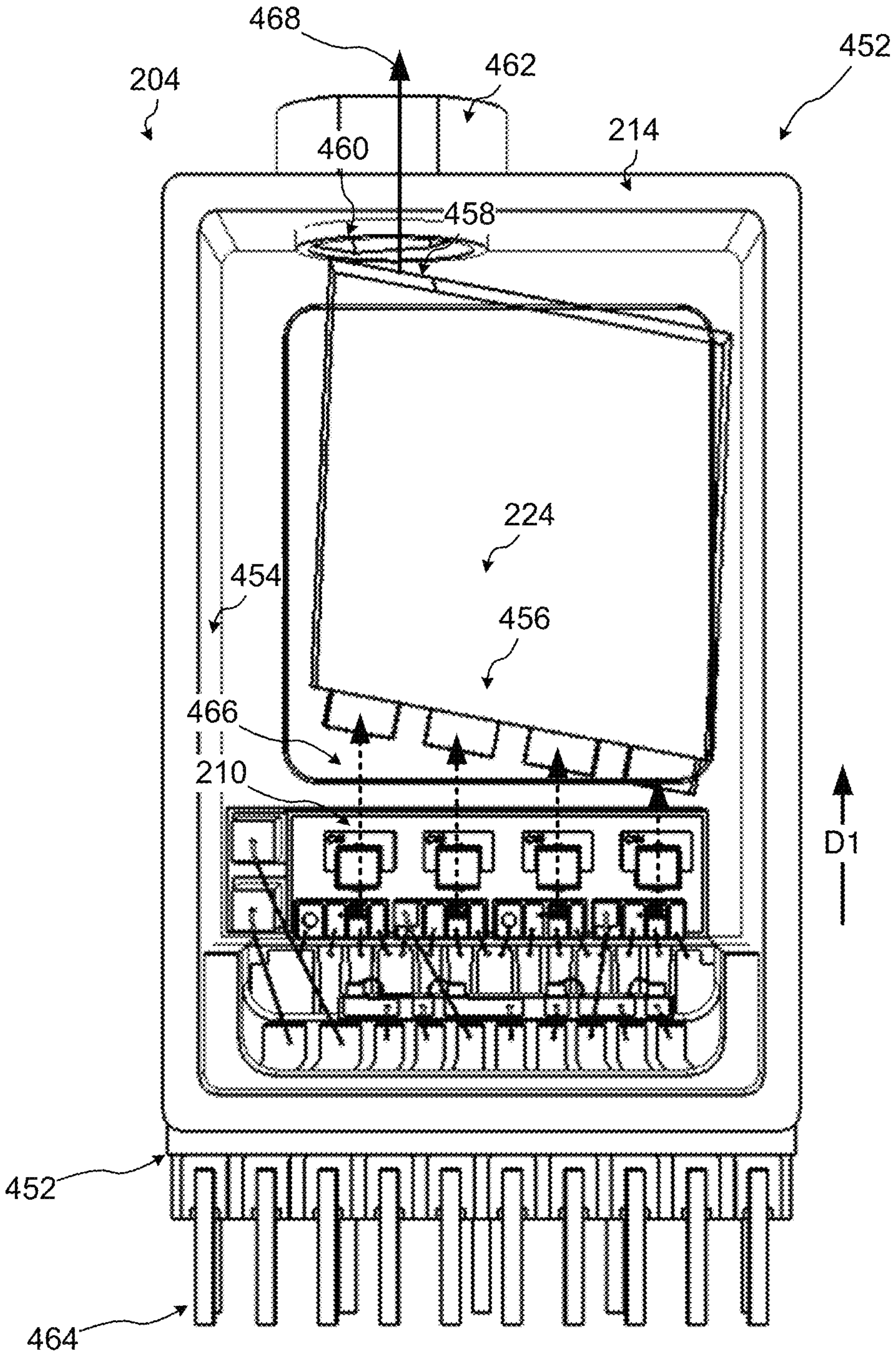

FIG. 6

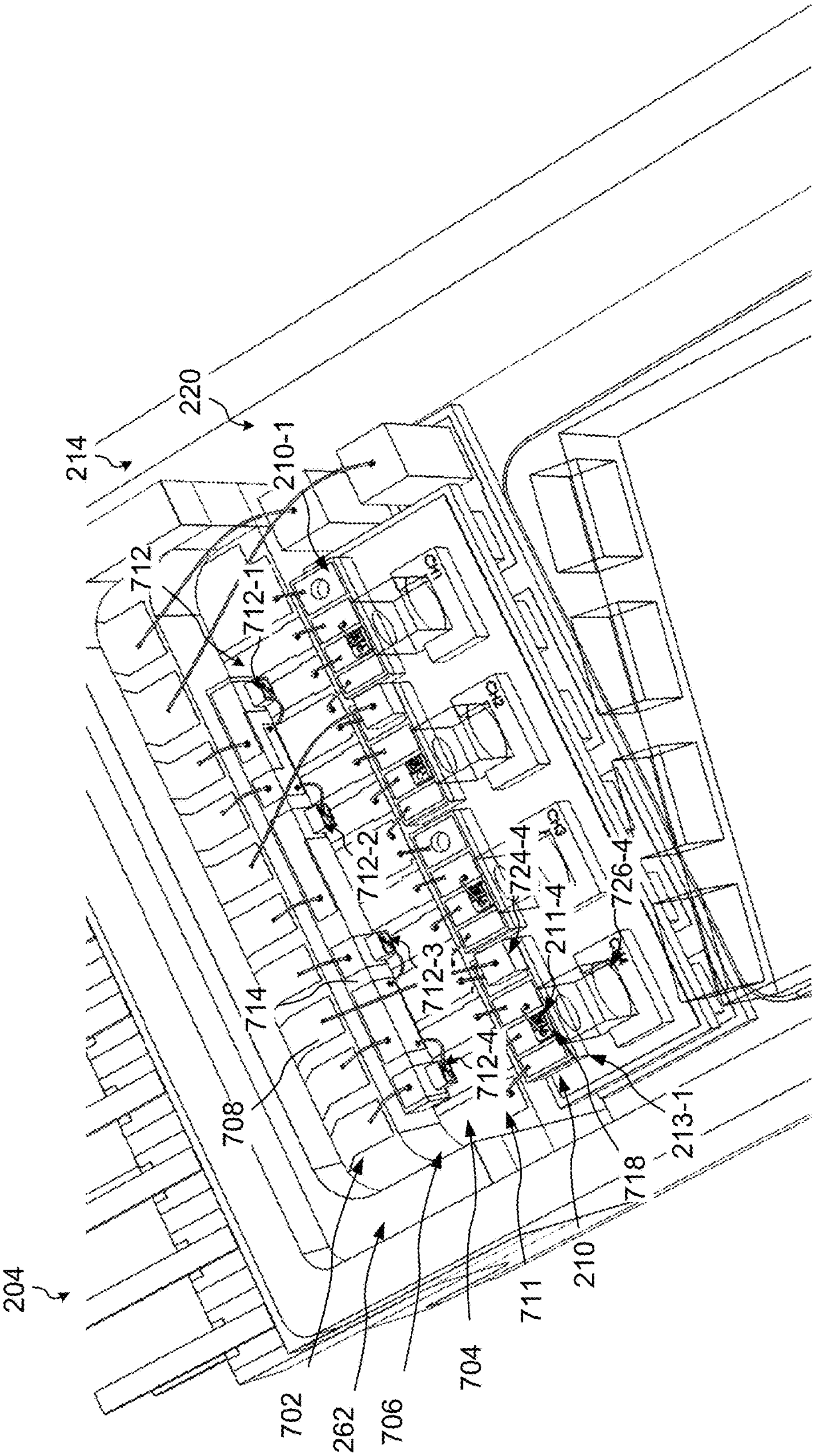
214
220
210-1
712
712-1
712-2
724-4
211-4
726-4
712-3
714
712-4
708
213-1
718
210
711
704
706
262
702
204

FIG. 7

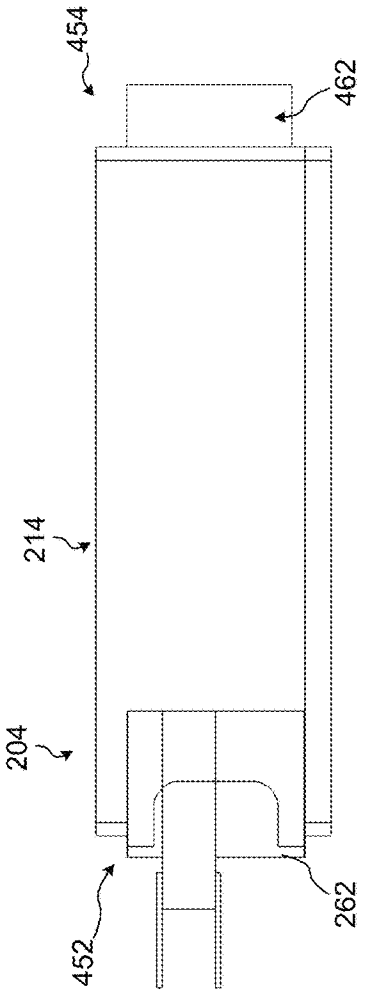
454
462
214
204
452
262

FIG. 8A

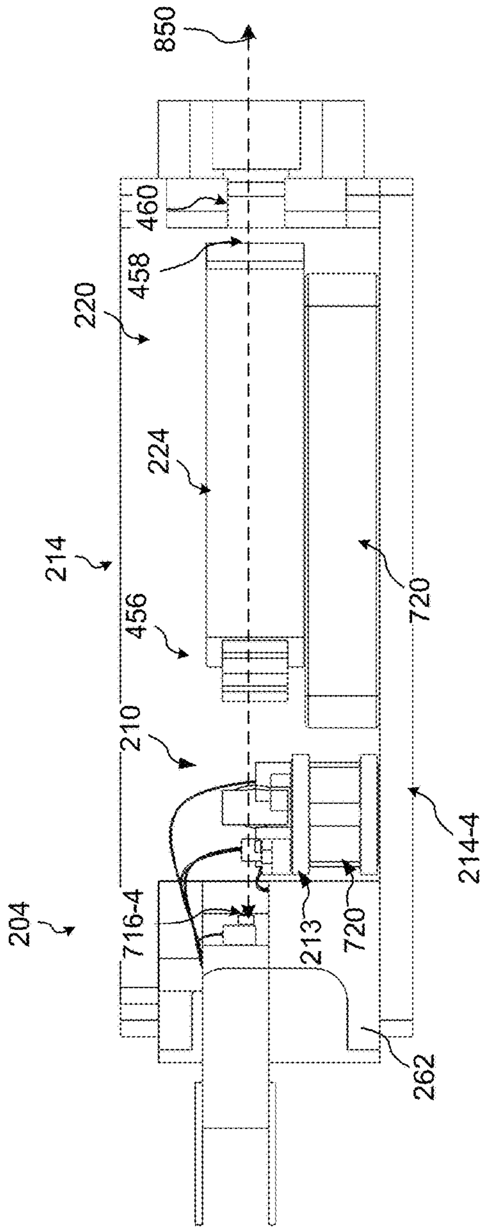
850
460
458
220
224
214
456
720
210
214-4
204
716-4
213
720
262

FIG. 8B

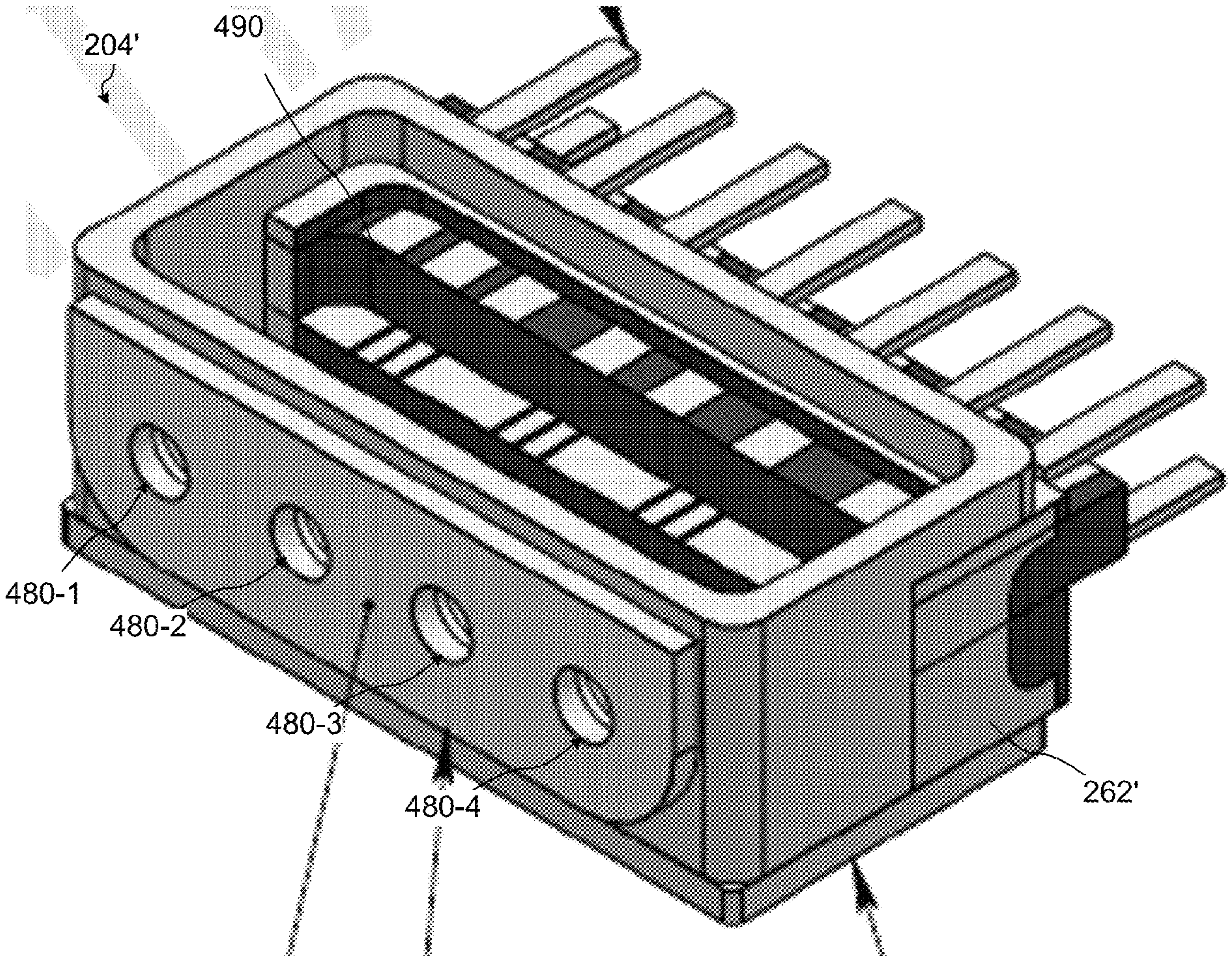

FIG. 9

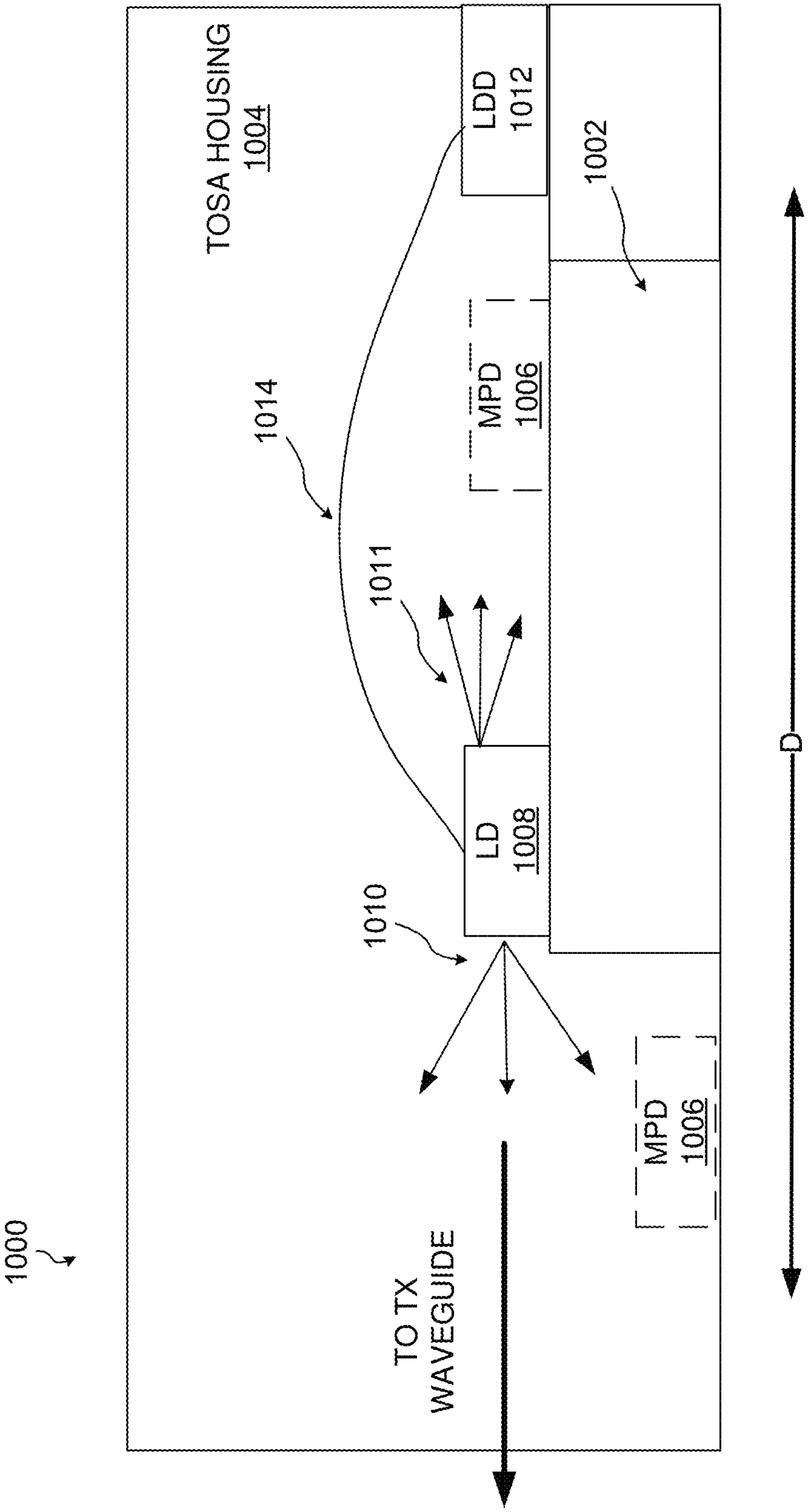
TOSA HOUSING
1004
LDD
1012
1002
MPD
1006
1014
1011
LD
1008
1010
MPD
1006
D
TO TX
WAVEGUIDE
1000

FIG. 10

TRANSMITTER OPTICAL SUBASSEMBLY ARRANGEMENT WITH VERTICALLY-MOUNTED MONITOR PHOTODIODES

TECHNICAL FIELD

The present disclosure relates to optical communications, and more particularly, to a transmitter optical subassembly (TOSA) arrangement having vertically-mounted monitor photodiodes to reduce housing dimensions and improve radio frequency (RF) drive signal quality.

BACKGROUND INFORMATION

Optical transceivers are used to transmit and receive optical signals for various applications including, without limitation, internet data center, cable TV broadband, and fiber to the home (FTTH) applications. Optical transceivers provide higher speeds and bandwidth over longer distances, for example, as compared to transmission over copper cables. The desire to provide higher transmit/receive speeds in increasingly space-constrained optical transceiver modules has presented challenges, for example, with respect to thermal management, insertion loss, RF driving signal quality and manufacturing yield.

Optical transceiver modules generally include one or more transmitter optical subassemblies (TOSAs) for transmitting optical signals. TOSAs can include one or more lasers to emit one or more channel wavelengths and associated circuitry for driving the lasers. Some optical applications, such as long-distance communication, can require TOSAs to include hermetically-sealed housings with arrayed waveguide gratings, temperature control devices, laser packages and associated circuitry disposed therein to reduce loss and ensure optical performance. However, the inclusion of hermetically-sealed components increases manufacturing complexity, cost, and raises numerous non-trivial challenges within space-constrained housings.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages will be better understood by reading the following detailed description, taken together with the drawings wherein:

FIG. **1** is a block diagram of a multi-channel optical transceiver module, consistent with embodiments of the present disclosure.

FIG. **2** is a perspective view of an optical transceiver module consistent with embodiments of the present disclosure.

FIG. **3** is a side view of the optical transceiver module of FIG. **2** in accordance with an embodiment of the present disclosure.

FIGS. **4-5** collectively show an example TOSA arrangement suitable for use in the optical transceiver module of FIGS. **2-3**, in accordance with an embodiment of the present disclosure.

FIG. **6** is a top view of the example TOSA arrangement of FIGS. **4-5**, consistent with embodiments of the present disclosure.

FIG. **7** shows an enlarged portion of a cavity of the example TOSA arrangement of FIGS. **4-6**, in accordance with an embodiment of the present disclosure.

FIG. **8**A is a side view of the example TOSA arrangement of FIGS. **4-7**, in accordance with an embodiment of the present disclosure.

FIG. **8**B is a cross-sectional view of the example TOSA arrangement of FIG. **5** taken along line **8**B-**8**B, in accordance with an embodiment of the present disclosure.

FIG. **9** is another example TOSA arrangement suitable for use in the optical transceiver module of FIGS. **2-3**, in accordance with an embodiment of the present disclosure.

FIG. **10** shows an existing approach to registering optical power of a laser arrangement.

DETAILED DESCRIPTION

As discussed above, some TOSAs can reach optical transmission distances of up to 10 km or more. Such TOSAs may be suitable for use in C form-factor pluggable (CFP), CFP2, CFP4 and quad small form-factor pluggable (QSFP) applications. In general, such TOSAs include a hermetic-sealed package (or housing) with an LC receptacle (or other suitable port) for optical coupling. The hermetic-sealed package can house laser packages, e.g., electro-absorption modulator integrated lasers (EMLs), power monitors photodiodes (PDs), thermoelectric coolers (TECs), an optical multiplexer such as an arrayed waveguide grating (AWG) for multiplexing multiple channel wavelengths, and electrical interconnects such as flexible printed circuit boards, and optical interconnects such as fiber stubs. Hermetic-sealed packages can include cavities specifically designed to house such components in a manner that optimizes the space constraints and promotes thermal communication. However, manufacturing hermetic-sealed packages with the dimensions necessary to fit the components of the light engine increases manufacturing cost and complexity.

One component in such TOSAs that can result in increased cost and complexity is monitor photodiodes (MPDs). MPDs can be used to monitor optical power of a corresponding laser diode. However, existing approaches tend to position MPDs behind, in front of, or otherwise adjacent an associated laser diode. In some cases, MPDs are mounted to the same substrate as the associated LD. For example, FIG. **10** shows one example of laser arrangement **1000** whereby a sidewall of a TOSA housing **1004** supports a substrate **1002** (or submount), and the substrate **1002** and/or the surface of the TOSA housing **1004** supports LD **1008** and the MPD **1006**. One position utilized for registering optical power from an LD by an MPD **1006** is directly behind the LD **1008** to receive a small portion of optical power **1011** emitted by the LD **1008** backwards away from a transmit (TX) waveguide, e.g., an optical fiber. Another position includes mounting the MPD **1006** below or otherwise in front of the LD **1008** to directly receive the optical power **1010** emitted by the LD **1008**.

In either case, the TOSA housing **1004** must be dimensioned to accommodate the position of the MPD **1006**, with the result being an overall increase in housing length along dimension D. This results in two significant challenges for TOSA designs. First, the position of the MPD, e.g., behind the LD **1008**, can require that interconnect circuitry such as wire bonds **1014** that extend from the laser diode driver (LDD) **1012** to the LD **1008** must be lengthened to route over/around the MPD **1006**. Extending and routing the wire bonds **1014** in this fashion can result in time-of-flight (TOF) delays and impedance matching issues as well as worse RF performance. Second, increasing the overall length can increase the overall volume of the TOSA housing cavity and the complexity in the manufacture of the TOSA. In scenarios where hermetically-sealed housings are utilized, this can result in a significantly higher cost and time per unit to manufacture, which can ultimately reduce yield.

Thus, the present disclosure is generally directed to a multi-channel TOSA with vertically-mounted MPDs to reduce TOSA housing dimensions and improve RF driving signal quality. In more detail, a TOSA housing consistent with the present disclosure includes at least one vertical MPD mounting surface that extends substantially transverse relative to a LD mounting surface, with the result being that a MPD coupled to the vertical MPD mounting surface gets positioned above an associated LD coupled to the LD mounting surface. The vertically-mounted MPD thus makes regions adjacent an LD that would otherwise be utilized to mount an MPD available for patterning of conductive RF traces to provide an RF driving signal to the LD. The conductive RF traces may therefore extend below the vertically-mounted MPD to a location that is proximate the LD to allow for relatively short wire bonds therebetween.

In a specific example embodiment, the vertical MPD mounting surface may be provided at least in part by a feedthrough device of the TOSA housing. The feedthrough device can be configured to be at least partially disposed in a hermetically-sealed cavity of the TOSA housing to provide electrical connectivity to optical components therein. The feedthrough device may also provide a conductive trace mounting surface that extends substantially transverse relative to the vertical MPD mounting surface for purposes of patterning the above-discussed conductive RF traces. Accordingly, an MPD may be securely mounted to the feedthrough device prior to insertion of the feedthrough device into a TOSA housing. Likewise, the conductive RF traces and other associated circuitry (e.g., filtering capacitors, conductive direct current (DC) traces, and so on) may be patterned/disposed when the feedthrough device is outside of the TOSA housing. Thus, insertion of the feedthrough device within the TOSA housing can result in the vertically-mounted MPD being passively optically aligned with an associated LD, and the conductive RF traces being brought within a predefined distance of the LD for electrical coupling purposes via, for instance, wire bonds.

The present disclosure therefore provides numerous advantageous over other TOSA approaches. For example, manufacturing of a TOSA may be conducted in a modular fashion whereby a feedthrough device and TOSA housing may be manufactured and configured separate from each other. For instance, components such as conductive traces and MPDs may be mounted/coupled to the feedthrough device in a parallel manufacturing process to allow for the TOSA housing and associated components to be completed apart from the feedthrough device, with the net result decreasing production time, reducing errors, and ultimately increasing yield. In addition, a TOSA housing with vertically-mounted MPDs consistent with the present disclosure advantageously reduces overall housing dimensions while allowing for LDs to be disposed in close proximity of conductive traces for electrical coupling purposes. RF signal quality may therefore be enhanced via relatively short wire bonds, for example, while simultaneously reducing cost, time-per-unit, and complexity to manufacture each TOSA.

As used herein, the terms hermetic-sealed and hermetically-sealed may be used interchangeably and refer to a housing that releases a maximum of about 5*10−8 cc/sec of filler gas. The filler gas may comprise an inert gas such as nitrogen, helium, argon, krypton, xenon, or various mixtures thereof, including a nitrogen-helium mix, a neon-helium mix, a krypton-helium mix, or a xenon-helium mix.

As used herein, "channel wavelengths" refer to the wavelengths associated with optical channels and may include a specified wavelength band around a center wavelength. In one example, the channel wavelengths may be defined by an International Telecommunication (ITU) standard such as the ITU-T dense wavelength division multiplexing (DWDM) grid. This disclosure is equally applicable to coarse wavelength division multiplexing (CWDM). In one specific example embodiment, the channel wavelengths are implemented in accordance with local area network (LAN) wavelength division multiplexing (WDM), which may also be referred to as LWDM.

The term "coupled" as used herein refers to any connection, coupling, link or the like and "optically coupled" refers to coupling such that light from one element is imparted to another element. Such "coupled" devices are not necessarily directly connected to one another and may be separated by intermediate components or devices that may manipulate or modify such signals. On the other hand, the term "direct optical coupling" refers to an optical coupling via an optical path between two elements that does not include such intermediate components or devices, e.g., a mirror, waveguide, and so on, or bends/turns along the optical path between two elements.

The term substantially, as generally referred to herein, refers to a degree of precision within acceptable tolerance that accounts for and reflects minor real-world variation due to material composition, material defects, and/or limitations/peculiarities in manufacturing processes. Such variation may therefore be said to achieve largely, but not necessarily wholly, the stated characteristic. To provide one non-limiting numerical example to quantify "substantially," minor variation may cause a deviation of up to and including ±5% from a particular stated quality/characteristic unless otherwise provided by the present disclosure.

Referring to the Figures, FIG. **1**, an optical transceiver **100**, consistent with embodiments of the present disclosure, is shown and described. In this embodiment, the optical transceiver **100** includes a multi-channel TOSA arrangement and a multi-channel ROSA arrangement **106** coupled to a substrate **102**, which may also be referred to as an optical module substrate. The substrate **102** may comprise, for example, a printed circuit board (PCB) or PCB assembly (PCBA). The substrate **102** may be configured to be "pluggable" for insertion into an optional transceiver cage **109**.

In the embodiment shown, the optical transceiver **100** transmits and receives four (4) channels using four different channel wavelengths (**λ1**, **λ2**, **λ3**, **λ4**) via the multi-channel TOSA arrangement **104** and the multi-channel ROSA arrangement **106**, respectively, and may be capable of transmission rates of at least about 25 Gbps per channel. In one example, the channel wavelengths **λ1**, **λ2**, **λ3**, **λ4** may be 1270 nm, 1290 nm, 1310 nm, and 1330 nm, respectively. Other channel wavelengths are within the scope of this disclosure including those associated with local area network (LAN) wavelength division multiplexing (WDM). The optical transceiver **100** may also be capable of transmission distances of 2 km to at least about 10 km. The optical transceiver **100** may be used, for example, in Internet data center applications or fiber to the home (FTTH) applications. Although the following examples and embodiments show and describe a 4-channel optical transceiver, this disclosure is not limited in this regard. For example, the present disclosure is equally applicable to 2, 6, or 8-channel configurations.

In more detail, the multi-channel TOSA arrangement **104** includes a TOSA housing **114** with a plurality of sidewalls that define an optical component cavity **220**, which may be referred to as simply a cavity (See FIG. **4**). The cavity **220** includes a plurality of laser arrangements **110** disposed therein, which will be discussed in more detail below, with each laser arrangement of the plurality of laser arrangements **110** being configured to transmit optical signals having different associated channel wavelengths. Each laser arrangement may include passive and/or active optical components such as a laser diode (LD), monitor photodiode (MPD), laser diode driver (LDD), and so on. Additional components comprising each laser arrangement include filters, focusing lenses, filtering capacitors, and so on.

To drive the plurality of laser arrangements **110**, the optical transceiver **100** includes a transmit connecting circuit **112** to provide electrical connections to the plurality of laser arrangements **110** within the housing **114**. The transmit connecting circuit **112** may be configured to receive driving signals (e.g., TX_D1 to TX_D4) from, for example, circuitry within the optical transceiver cage **109**. As shown, the housing **114** may be hermetically sealed to prevent ingress of foreign material, e.g., dust and debris. Therefore, a plurality of transit (TX) traces **117** (or electrically conductive paths) are patterned on at least one surface of the substrate **102** and are electrically coupled with a feedthrough device **116** of the TOSA housing **114** to bring the transmit connecting circuit **112** into electrical communication with the plurality of laser arrangements **110**, and thus, electrically interconnect the transmit connecting circuit **112** with the multi-channel TOSA arrangement **104**. The feedthrough device **116** may comprise, for instance, ceramic, metal, or any other suitable material.

In operation, the multi-channel TOSA arrangement **104** may then receive driving signals (e.g., TX_D1 to TX_D4), and in response thereto, generates and launches multiplexed channel wavelengths on to an output waveguide **120** such as a transmit optical fiber. The generated multiplexed channel wavelengths may be combined based on a multiplexing device **124** such as an arrayed waveguide grating (AWG) that is configured to receive emitted channel wavelengths **126** from the plurality of laser assemblies **110** and output a signal carrying the multiplexed channel wavelengths on to the output waveguide **120** by way of optical fiber receptacle **122**.

Continuing on, the multi-channel ROSA arrangement **106** includes a demultiplexing device **124**, e.g., an arrayed waveguide grating (AWG), a photodiode (PD) array **128**, and an amplification circuitry **130**, e.g., a transimpedance amplifier (TIA). An input port of the demultiplexing device **124** may be optically coupled with a receive waveguide **134**, e.g., an optical fiber, by way of an optical fiber receptacle **136**. An output port of the demultiplexing device **124** may be configured to output separated channel wavelengths on to the PD array **128**. The PD array **128** may then output proportional electrical signals to the TIA **130**, which then may be amplified and otherwise conditioned. The PD array **128** and the transimpedance amplifier **136** detect and convert optical signals received from the receive waveguide **134**, e.g., an optical fiber, into electrical data signals (RX_D1 to RX_D4) that are output via the receive connecting circuit **108**. In operation, the PD array **128** may then output electrical signals carrying a representation of the received channel wavelengths to a receive connecting circuit **132** by way of conductive traces **119** (which may be referred to as conductive paths).

Referring now to FIGS. **2-3**, an example optical transceiver module **200** is shown consistent with an embodiment of the present disclosure. The optical transceiver module **200** may be implemented as the optical transceiver **100** of FIG. **1**, the discussion of which is equally applicable to FIGS. **2-3** and will not be repeated for purposes of brevity. As shown, the optical transceiver module **200** includes a substrate **202** that extends from a first end **252** to a second end **254** along a longitudinal axis **250**. The first end **252** may electrically couple to a transceiver cage to receive driving signals, e.g., TX_D1 to TX_D4, and therefore, may be referred to as an electrical coupling end. On the other hand, the second end **254** includes a multi-channel TOSA arrangement **204** and a multi-channel ROSA arrangement **206** for sending and receiving channel wavelengths, respectively, and therefore may be referred to as an optical coupling end.

In more detail, the substrate includes at least a first mounting surface **256** for mounting of optical components, patterning of conductive traces (e.g., conductive traces **117**, **119**). Disposed adjacent the first end **252**, the substrate **202** includes a plurality of pads/terminals for electrically communicating with, for instance, associated circuitry in a transceiver cage. The substrate **202** includes a multi-channel TOSA arrangement **204** and multi-channel ROSA arrangement **206** disposed adjacent the second end. The multi-channel ROSA arrangement includes amplification circuitry **230**, a PD array **228**, and a demultiplexing device **224** disposed thereon. An input port **235** of the demultiplexing device **224** may be coupled to an optical coupling receptacle **236** by way of a receive intermediate fiber **268**. Accordingly, the demultiplexing device **224** can receive a multiplexed signal **264** from a receive waveguide, e.g., the receive waveguide **134** of FIG. **1**. An output port of the demultiplexing device **224** may be optically aligned with the PD array **228** and output separated channel wavelengths thereon. Electrical signals representative of the separated channel wavelengths may then be amplified/filtered by the amplification circuitry before being passed to the receive connecting circuit **132**.

As shown, the TOSA housing **214** is defined by a plurality of sidewalls. A first end **258** of the TOSA housing edge mounts to, and electrically couples with, the second end **258** of the substrate **202**. A second end **259** of the TOSA housing **214** couples to an optical coupling receptacle **222** by way of a transmit intermediate fiber **269**. The first end **258** of the TOSA housing **214** may also be referred to as an electrical coupling end, and the second end **259** may also be referred to as an optical coupling end. In an embodiment, the TOSA housing **214** may be securely attached to the substrate **202** via one or more electrical interconnect devices as discussed and described in greater detail in co-pending U.S. patent application. Ser. No. 16/116,087 filed on Aug. 29, 2018 and entitled "Transmitter Optical Subassembly with Hermetically-Sealed Light Engine and External Arrayed Waveguide Grating", the teaching of which are hereby incorporated in their entirety.

In an embodiment, the TOSA housing **214** of the multi-channel TOSA arrangement **204** may be hermetically sealed, although in other embodiments the housing may not necessarily be hermetically sealed. Accordingly, the multi-channel TOSA arrangement **204** may also be referred to as a hermetically-sealed light engine that may be particularly well suited for long-distance transmission, e.g., up to and beyond 10 km. The TOSA housing **214** can include a feedthrough device **262** at least partially disposed in a cavity of the TOSA housing **214** to allow for electrical interconnection between the substrate **202** and the multi-channel TOSA arrangement **204**. The housing **214** may include a longitudinal axis that extends substantially parallel relative to the longitudinal axis **250** of the substrate **202**. The housing **214** may comprise, for example, metal, plastic, ceramic, or any other suitable material. The housing **214** may be formed from multiple pieces, or a single piece, of material.

The housing **214** may further define a laser cavity **220** (FIG. **4**) which may be filled with an inert gas to form an inert atmosphere. In one embodiment, the inert atmosphere sealed within the hermetically-sealed container comprises nitrogen, and preferably, 1 atmosphere (ATM) of nitrogen. The inert atmosphere may also be formed from nitrogen, helium, argon, krypton, xenon, or various mixtures thereof, including a nitrogen-helium mix, a neon-helium mix, a krypton-helium mix, or a xenon-helium mix. The inert gas or gas mix included within the hermetically-sealed cavity **220** may be selected for a particular refractive index or other optical property. Gases may also be selected based on their ability to promote thermal insulation. For instance, Helium is known to promote heat transfer may be utilized alone or in addition to others of the aforementioned gases. In any event, the terms hermetic-sealed and hermetically-sealed may be used interchangeably and refers to a housing that releases a maximum of about 5*10–8 cc/sec of filler gas.

Turning to FIGS. **4**-**7**, an example embodiment of the TOSA housing **214** of the multi-channel TOSA arrangement **204** is shown in isolation. As shown, the housing **214** extends from a first end **452** to a second end **454** along a longitudinal axis **450**. A plurality of sidewalls **214-1** to **214-6** define the TOSA housing **214** and a cavity **220** therebetween. Note, the embodiment shown in FIG. **4** omits the sidewall **214-6** (FIG. **2**) that forms a cover portion merely for purposes of clarity.

The feedthrough device **262** at least partially defines the first end **452** of the TOSA housing **214** and includes a plurality of electrical interconnects **464**, e.g., bus bars, external to the cavity **220** for mounting to and electrically coupling with the substrate **102**. The plurality of electrical interconnects **464** can provide power and radio frequency (RF) driving signals to the plurality of laser arrangements **210**. The feedthrough device **262** further includes at least one mounting surface such as a vertical monitor photodiode (MPD) mounting surface, which will be discussed in greater detail below.

Following the feedthrough device **262** within the cavity **220**, a plurality of laser arrangements **210** are disposed on and are supported by a mounting surface provided at least in part by the sidewall **214-4**. A multiplexing device **224** is also disposed on and supported by the mounting surface provided at least by the sidewall **214-4**. The multiplexing device **224** includes a plurality of input ports **456**, with each input port being optically aligned with an associated laser arrangement of the plurality of laser arrangements **210**. The multiplexing device **224** further includes an output port **458** which is shown more clearly in FIG. **6**. The output port **458** of the multiplexing device **224** is optically aligned with an aperture **462** defined by the sidewall **214-3** of the TOSA housing **214**. The aperture **462** may then transition to a fiber coupling receptacle **462**, with the fiber coupling receptacle **462** being configured to receive the intermediate optical fiber **269** (FIG. **2**).

Thus, in operation, the multiplexing device **224** receives channel wavelengths **466** emitted by the plurality of laser assemblies along direction D1 at the plurality of inputs and then outputs a multiplexed signal **468** having each of the emitted channel wavelengths **466** for transmission via an external transmit optical fiber, for example.

FIG. **7** shows an enlarged perspective view of the cavity **220** of the housing **214** in accordance with an embodiment. As shown, the feedthrough device **262** includes a step/shoulder configuration defined by a first mounting surfacing **702** that extends in parallel with the longitudinal axis **450** of the TOSA housing **214**, a second mounting surface **704** that extends parallel with the first mounting surface, and a third mounting surface **706** that adjoins the first and second mounting surfaces **702**, **704** and extends substantially transverse to each of the same. Thus, the first, second and third mounting surfaces **702**, **704** and **706** provide a multi-tiered or multi-step mounting structure for coupling to optical components. Each of the mounting surfaces of the feedthrough device **262** will now be discussed in turn.

The first mounting surface **702** includes a first plurality of conductive traces/paths **708** patterned thereon. The first plurality of conductive traces **708** may be configured to provide power from the substrate **202** and to pass data signals from a plurality of MPDs **712** that are mounted to and supported by the third mounting surface. To this end, the first mounting surface **702** may also be referred to as a MPD trace mounting surface/section. The second mounting surface **704** includes a second plurality of conductive traces/paths **711** disposed thereon. The second plurality of conductive traces/paths **711** may be configured to provide power and data signals from the substrate **202** to each of the plurality of lasers arrangements **210**. To this end, the second mounting surface **704** may be referred to as a LD trace mounting surface/section.

Continuing on, the third mounting surface **706** extends substantially transverse relative to the first and second mounting surfaces **702**, **704** and adjoins the same, as discussed above. The third mounting surface **706** may be configured to mount and support a plurality of MPDs shown collectively as **712** and individually as **712-1** to **712-4**. Each MPD of the plurality of MPDs **712** may be supported by a MPD submount **714**, with the MPD submount **714** providing electrical traces for electrically interconnecting MPDs to associated conductive traces of the MPD trace mounting section **708**. The MPD submount **714** may be a single piece, e.g., a single PCB or other suitable substrate, or may be multiple pieces. One advantage of a single piece MPD submount **714** is that attachment and alignment of MPDs to the feedthrough device **262** can be simplified as each MPD may be placed on to the MPD submount **714** at predefined positions prior to insertion of the feedthrough device **262** into the cavity **202** of the housing **214**. Accordingly, coupling the MPD submount **714** to the feedthrough device **262** optically aligns each of the MPDs disposed thereon without necessarily performing additional alignment steps.

As further shown, each MPD of the plurality of MPDs **712** includes a light receiving region, e.g., light receiving surface **716-4** of MPD **712-4** shown in FIG. **8**B, on an upper/top surface of each chip that is optically aligned with a corresponding laser arrangement of the plurality of laser arrangements **210**. This vertical mounting of each MPD allows for a smaller overall footprint for the feedthrough device **262**, and by extension, shortens the overall length of the TOSA housing **214**. This vertical mounting configuration achieves housing size reduction by freeing the space behind/adjacent each laser arrangement to permit the LD traces of the second mounting surface **704** to extend below the plurality of MPDs **712** and be disposed in close proximity of the plurality of laser assemblies **201**. This removal of the MPDs from being behind/adjacent a corresponding laser arrangement also advantageously allows for relatively short electrical interconnection via wire bonding between the LD traces of the second mounting surface **704** and each laser arrangement, which reduces issues such as time of flight (TOF) and impedance mismatching that can ultimately degrade RF signal quality.

Continuing on, each of the plurality of laser arrangements **210** includes a laser diode supported by a laser submount

213 and optional thermoelectric cooling (TEC) arrangement. For instance, the laser arrangement **210-4** associated with channel **4** (CH**4**) includes a laser diode **211-4** mounted to and supported by the laser diode submount **213**. As shown in the cross-sectional view of FIG. **8**B, the laser diode submount **213** is mounted to and is supported by TEC devices **720**. In turn, TEC devices **720** are mounted to and supported by a surface provided by sidewall **214-4** of the TOSA housing **214**. The laser diode submount may also support thermistors such as thermistor **724-4** (FIG. **7**). Following the plurality of laser assemblies **210**, each laser arrangement can include a focusing lens e.g., focusing lens **726-4**, mounted to and supported by the laser diode submount **713**. The laser submount **213** may comprise a single piece, such as shown, or may be formed from multiple pieces.

Following the plurality of laser arrangements **210**, the multiplexing device **224** is mounted to and is supported by a multiplexing submount **720**. The input ports **456** of the multiplexing device **224** are optically aligned with the plurality of laser arrangements **210**. To this end, a plurality of optical paths **850** extend longitudinally through the cavity **220**, with each optical path extending from a corresponding laser diode. A portion of optical power, e.g., 2% or less, gets emitted from a surface opposite the emission face of each LD (also known as a back-side emission surface) and is registered by each MPD, e.g., converted to a proportional electrical current, to form a feedback loop to ensure optical power. Thus, each of the plurality of optical paths **850** also intersects with the vertically mounted MPDs **712**, and more particularly, a light receiving region of each corresponding vertically mounted MPDs **712**, e.g., light receiving region **716-4**.

During operation, channel wavelengths emitted by each of the plurality of laser assemblies **210** is launched on to a corresponding path of the plurality of optical paths **850**, with each of the plurality of optical paths **850** extending substantially parallel relative to each other. As discussed above, a portion of the optical power gets emitted from a surface opposite of the emission surface of each laser diode, which may be referred to as a back-side emission surface, thus launching a portion of optical power towards the MPDs **712**. Each light receiving region of the MPDs, e.g., light receiving region **716-4**, then registers this portion of optical power for purposes of providing a feedback loop, e.g., by converting optical power to a proportional electrical current. The emitted channel wavelengths then get received via input ports **456** of the multiplexing device **224**. The multiplexing device **224** then combines the received channel wavelengths into a multiplexed optical signal **263** (see FIG. **2**). At an output **458** of the multiplexing device **224** the multiplexed signal **263** is output via the aperture on to the intermediate optical fiber **269** (See FIG. **2**), and then ultimately to an external transmit optical fiber (not shown).

FIG. **9** shows another example embodiment of a TOSA housing **204'** in accordance with aspects of the present disclosure. As shown, the TOSA housing **204'** includes a plurality of sidewalls to provide a cavity therebetween, which is substantially similar to that of the TOSA housing **204**. However, the TOSA housing **204'** does not include a multiplexing device within the cavity and instead couples to a first end of a plurality of waveguides (not shown), e.g., optical fibers, via apertures **480-1** to **480-4**. A second end of the plurality of waveguides may be optically coupled to an external multiplexing device, such as an AWG. This allows the TOSA **204'** to have a relatively small overall footprint, which can significantly reduce overall costs and complexity that characterizes hermetically-sealed housing. Put simply, the lesser the volume and number of passive/optical components within the cavity of the TOSA housing **204'**, the less the complexity, time and cost necessary to manufacture the TOSA housing **204'**. The feedthrough device **262'** may be configured substantially similar to that of the feedthrough device **262**, the description of which is equally applicable to the embodiment of FIG. **9** but will not be repeated for brevity. For instance, the vertical MPD mounting surface **490** allows for MPDs to be mounted thereon to advantageously reduce the overall length of the TOSA housing **204'** relative to other approaches that place MPDs behind or otherwise adjacent corresponding LDs.

In accordance with an aspect of the present disclosure a transmitter optical subassembly (TOSA) module is disclosed. The TOSA module comprising a laser diode (LD) mounting surface, at least a first LD disposed on the LD mounting surface, the first LD having a back-side emission surface for emitting a portion of optical power along a first optical path, a base portion providing a vertical MPD mounting surface, and a first MPD disposed on the vertical MPD mounting surface, the first MPD having a light receiving region optically aligned with the first LD via the first optical path based at least in part on the vertical MPD mounting surface extending substantially transverse relative to the LD mounting surface such that the first optical path intersects with the light receiving region of the first MPD.

In accordance with another aspect of the present disclosure a method for optically coupling monitor photodiodes (MPDs) to corresponding laser diodes (LDs) in a multichannel optical transceiver (TOSA) housing is disclosed. The method comprising mounting at least one MPD to a vertical MPD mounting surface provided by a feedthrough device, patterning a plurality of conductive traces on to one or more surfaces of the feedthrough device, and inserting the feedthrough device into a cavity of the TOSA housing to bring the plurality of conductive traces into close proximity with the LDs in the TOSA, wherein inserting the feedthrough device into the cavity causes each of the at least one MPDs mounted to the vertical MPD mounting surface to optically couple with a back-side emission surface of each corresponding LD.

In accordance with yet another aspect of the present disclosure a multi-channel optical transceiver module is disclosed. The multi-channel optical transceiver including a printed circuit board assembly (PCBA), a transmitter optical subassembly (TOSA) arrangement coupled to the PCBA, the TOSA arrangement comprising a laser diode (LD) mounting surface, at least a first LD disposed on the LD mounting surface, the first LD having a back-side emission surface for emitting a portion of optical power along a first optical path, a base portion providing a vertical MPD mounting surface, a first MPD disposed on the vertical MPD mounting surface, the first MPD having a light receiving region optically aligned with the first LD via the first optical path based at least in part on the vertical MPD mounting surface extending substantially transverse relative to the LD mounting surface such that the first optical path intersects with the light receiving region of the first MPD.

While the principles of the disclosure have been described herein, it is to be understood by those skilled in the art that this description is made only by way of example and not as a limitation as to the scope of the disclosure. Other embodiments are contemplated within the scope of the present disclosure in addition to the exemplary embodiments shown and described herein. Modifications and substitutions by one of ordinary skill in the art are considered to be within the scope of the present disclosure, which is not to be limited except by the following claims.

What is claimed is:

1. A transmitter optical subassembly (TOSA) module, the TOSA module comprising:

- a laser diode (LD) mounting surface;
- at least a first LD disposed on the LD mounting surface, the first LD having a back-side emission surface for emitting a portion of optical power along a first optical path;
- a base portion comprising a feedthrough device, the feedthrough device providing a vertical MPD mounting surface; and
- a first MPD disposed on the vertical MPD mounting surface, the first MPD having a light receiving region optically aligned with the first LD via the first optical path based at least in part on the vertical MPD mounting surface extending substantially transverse relative to the LD mounting surface such that the first optical path intersects with the light receiving region of the first MPD.

2. The TOSA module of claim **1**, further comprising:

- a housing having a plurality of sidewalls that define a cavity, the LD mounting surface being disposed in the cavity; and
- wherein the feedthrough device is configured to at least partially be disposed in the cavity of the housing, and wherein a first end of the feedthrough device provides an electrical coupling region to electrically couple to an optical module substrate to receive a radio frequency (RF) driving signal to drive the first LD, and a second end of the feedthrough device defines the vertical MPD mounting surface, the vertical MPD mounting surface being disposed in the cavity.

3. The TOSA module of claim **2**, wherein the cavity of the housing is hermetically sealed to prevent ingress of contaminants.

4. The TOSA module of claim **2**, wherein at least one sidewall of the plurality of sidewalls of the housing provides a thermoelectric cooler (TEC) mounting section, and wherein the TOSA provides:

- a thermoelectric cooler (TEC) arrangement mounted to the TEC mounting section; and
- a LD submount disposed on the TEC arrangement, the LD submount being in thermal communication with the TEC arrangement, and wherein the LD submount provides the LD mounting surface.

5. The TOSA module of claim **1**, further comprising a plurality of transmit (TX) radio frequency (RF) traces, the TX RF traces being disposed on a surface of the base that extends away from the vertical mounting surface along a direction that is substantially parallel with the LD mounting surface.

6. The TOSA module of claim **5**, wherein the plurality of TX RF traces are disposed below the MPD when mounted to the vertical MPD mounting surface to allow the plurality of TX RF traces to extend towards the LD mounting surface, and wherein a portion of the plurality of TX RF traces are disposed adjacent the LD mounting surface.

7. The TOSA module of claim **1**, further comprising a second LD disposed on the LD mounting surface and a second MPD disposed on the vertical MPD mounting surface, the second LD being configured to emit an associated channel wavelength different from that of the first LD, and wherein the second LD and second MPD are optically aligned via a second optical path such that the second optical path extends from a back-side emission surface of the second LD and intersects with a light receiving region of the second MPD.

8. The TOSA module of claim **7**, further comprising a multiplexing arrangement, the multiplexing arrangement having at least first and second input ports optically aligned with the first and second optical paths, respectively, to receive and combine channel wavelengths emitted by the first and second LDs into a multiplexed optical signal for output via an output port.

9. The TOSA module of claim **8**, wherein the multiplexing arrangement includes an arrayed waveguide grating AWG to multiplex the received channel wavelengths, and wherein AWG provides the output port and passes the multiplexed optical signal on to a transmit waveguide coupled to the output port.

10. The TOSA module of claim **8**, wherein the first and second input ports of the multiplexing arrangement are angled relative to the light emitting region of the first and second LDs such that incident channel wavelengths received along the first and second optical paths intersect at an angle of about 8 degrees to prevent back reflection.

11. A method for optically coupling monitor photodiodes (MPDs) to corresponding laser diodes (LDs) in a multichannel optical transceiver (TOSA) housing, the method comprising:

- mounting at least one MPD to a vertical MPD mounting surface provided by a feedthrough device;
- patterning a plurality of conductive traces on to one or more surfaces of the feedthrough device; and
- inserting the feedthrough device into a cavity of the TOSA housing to bring the plurality of conductive traces into close proximity with the LDs in the TOSA, wherein inserting the feedthrough device into the cavity causes each of the at least one MPDs mounted to the vertical MPD mounting surface to optically couple with a back-side emission surface of each corresponding LD.

12. The method of claim **11**, further comprising introducing an inert gas into the cavity to form a hermetic seal.

13. The method of claim **11**, further comprising introducing wire bonds between the LDs and the plurality of conductive traces after insertion of the feedthrough device into the cavity of the TOSA housing.

14. The method of claim **11**, wherein patterning the plurality of conductive traces includes disposing each conductive trace of the plurality of conductive traces on to a surface that extends below the vertical MPD mounting surface.

15. A multi-channel optical transceiver module comprising:

- a printed circuit board assembly (PCBA);
- a multi-channel transmitter optical subassembly (TOSA) arrangement coupled to the PCBA, the TOSA arrangement comprising:
  - a laser diode (LD) mounting surface;
  - at least a first LD disposed on the LD mounting surface, the first LD having a back-side emission surface for emitting a portion of optical power along a first optical path;
  - a base portion comprising a feedthrough device, the feedthrough device providing a vertical MPD mounting surface;
  - a first MPD disposed on the vertical MPD mounting surface, the first MPD having a light receiving region optically aligned with the first LD via the first optical path based at least in part on the vertical MPD

mounting surface extending substantially transverse relative to the LD mounting surface such that the first optical path intersects with the light receiving region of the first MPD; and

a multi-channel receiver optical subassembly arrangement.

16. The multi-channel optical transceiver of claim **15**, wherein the TOSA arrangement further comprises:

a TOSA housing having a plurality of sidewalls that define a cavity, the LD mounting surface being disposed in the cavity; and

wherein the feedthrough device is configured to at least partially be disposed in the cavity of the TOSA housing, and wherein a first end of the feedthrough device provides an electrical coupling region to electrically couple to an optical module substrate to receive a radio frequency (RF) driving signal to drive the first LD, and a second end of the feedthrough device defines the vertical MPD mounting surface, the vertical MPD mounting surface being disposed in the cavity of the TOSA housing.

17. The multi-channel optical transceiver of claim **16**, wherein the cavity of the TOSA housing is hermetically sealed to prevent ingress of contaminants.

18. The multi-channel optical transceiver of claim **16**, wherein at least one sidewall of the plurality of sidewalls of the TOSA housing provides a thermoelectric cooler (TEC) mounting section, and wherein the TOSA provides:

a thermoelectric cooler (TEC) arrangement mounted to the TEC mounting section; and

a LD submount disposed on the TEC arrangement, the LD submount being in thermal communication with the TEC arrangement, and wherein the LD submount provides the LD mounting surface.

19. The multi-channel optical transceiver of claim **15**, further comprising a plurality of transmit (TX) radio frequency (RF) traces, the TX RF traces being disposed on a surface of the base portion that extends away from the vertical mounting surface along a direction that is substantially parallel with the LD mounting surface, and wherein the TX RF traces are disposed below the MPD when mounted to the vertical MPD mounting surface to allow the TX RF traces to extend towards the LD mounting surface.

* * * * *

Exhibit F

US011177887B2

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

(10) **Patent No.: US 11,177,887 B2**
(45) **Date of Patent: Nov. 16, 2021**

(54) **SUBSTRATE WITH STEPPED PROFILE FOR MOUNTING TRANSMITTER OPTICAL SUBASSEMBLIES AND AN OPTICAL TRANSMITTER OR TRANSCEIVER IMPLEMENTING SAME**

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(73) Assignee: **Applied Optoelectronics, Inc.**, Sugar Land, TX (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.

(21) Appl. No.: **16/737,438**

(22) Filed: **Jan. 8, 2020**

(65) **Prior Publication Data**

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(51) **Int. Cl.**

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H04B 10/40	(2013.01)
H04B 10/80	(2013.01)
H04B 10/50	(2013.01)
H01L 23/52	(2006.01)

(52) **U.S. Cl.**
CPC ***H04B 10/40*** (2013.01); ***H01L 23/52*** (2013.01); ***H04B 10/503*** (2013.01); ***H04B 10/801*** (2013.01)

(58) **Field of Classification Search**
CPC H04B 10/40; H04B 10/503; H04B 10/801; H01L 23/52
USPC 398/135
See application file for complete search history.

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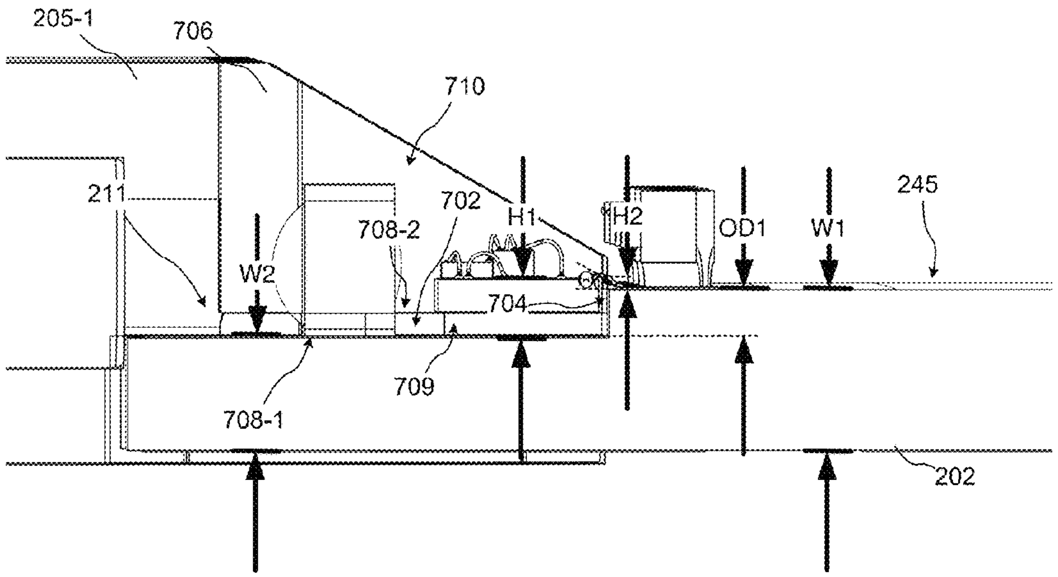
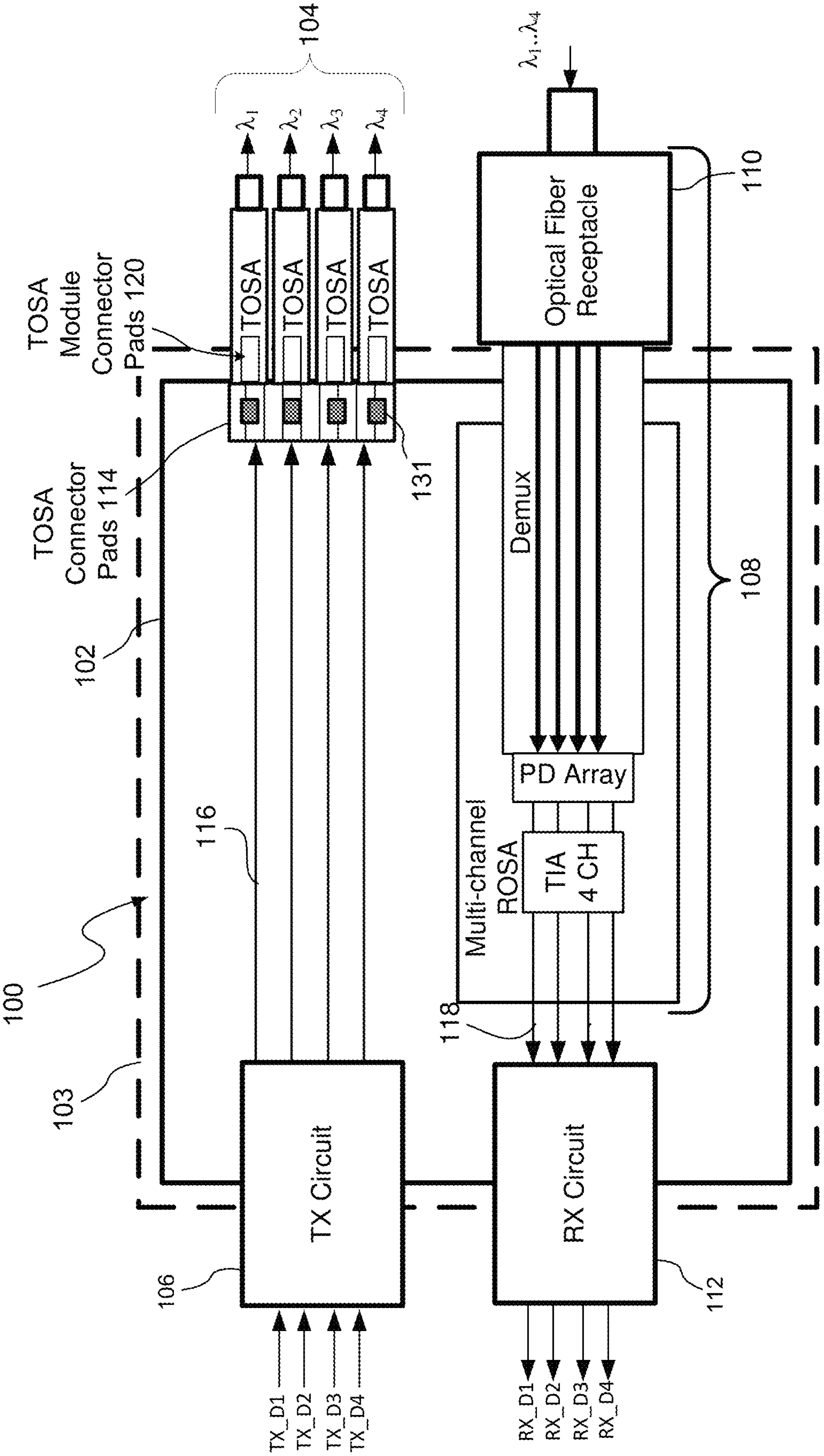
Primary Examiner — Mohammad R Sedighian
(74) *Attorney, Agent, or Firm* — Grossman Tucker Perreault & Pfleger, PLLC; Norman S. Kinsella

(57) **ABSTRACT**

The present disclosure is generally directed to a stepped profile for substrates that support "on board" optical subassembly arrangements. The stepped profile enables mounting TOSA modules to the substrate in a recessed orientation to reduce the overall distance between terminals of the substrate and associated components of the TOSA, e.g., RF terminals of the substrate and an LDD of the TOSA. In an embodiment, the stepped profile further simplifies mounting and optical alignment of TOSA modules by providing at least one mechanical stop to engage surfaces of the TOSA modules and limit travel by the same along one or more axis.

13 Claims, 7 Drawing Sheets

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λ_3
λ_4
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TOSA
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Optical Fiber Receptacle
110
TOSA Connector Pads 114
131
Demux
108
102
PD Array
116
Multi-channel ROSA
TIA 4 CH
100
118
103
TX Circuit
RX Circuit
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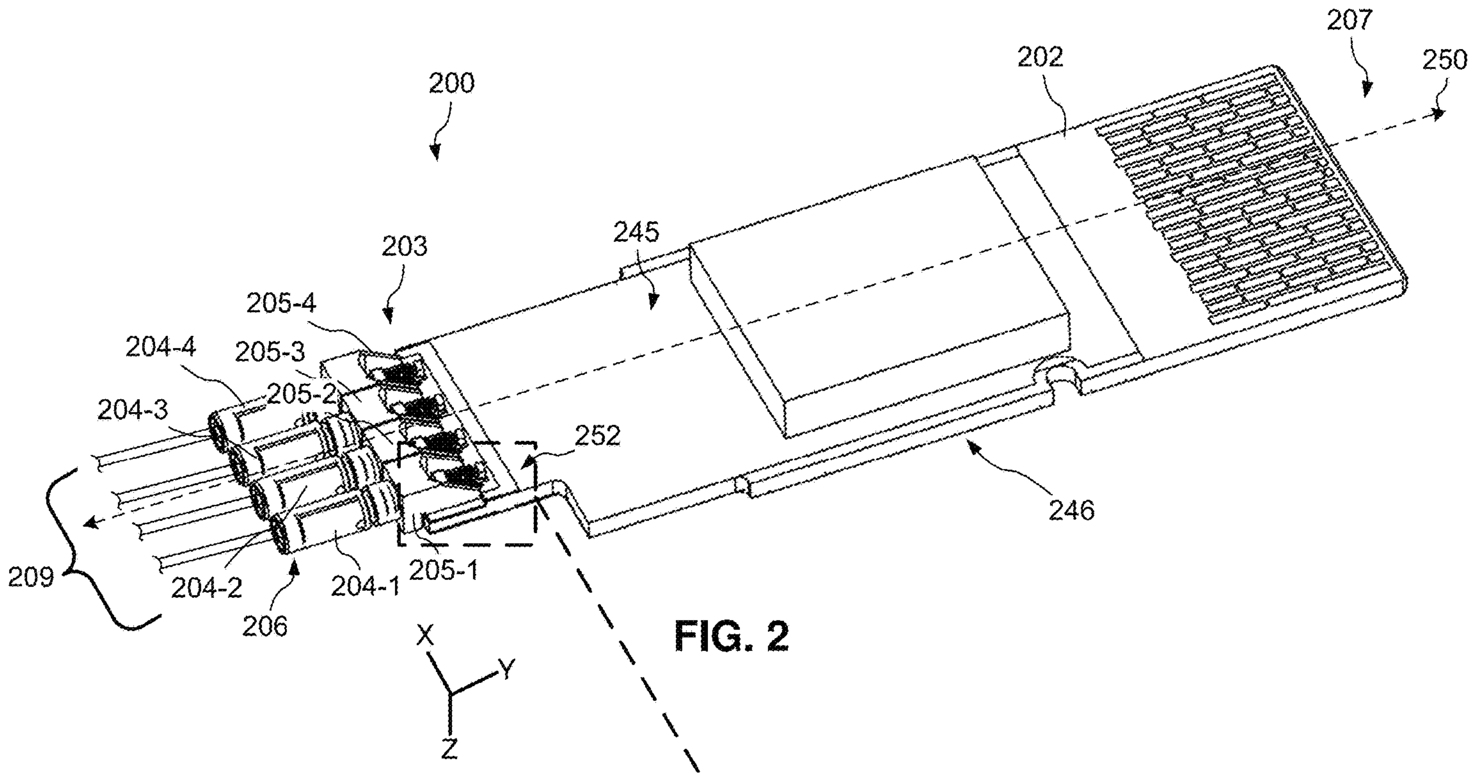
RX_D1
RX_D2
RX_D3
RX_D4

FIG. 1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Y
Z

FIG. 2

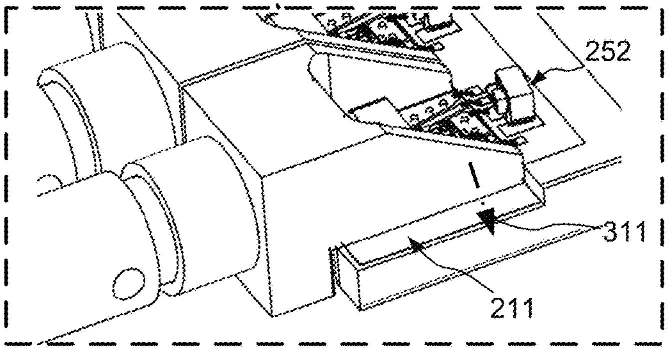
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FIG. 3

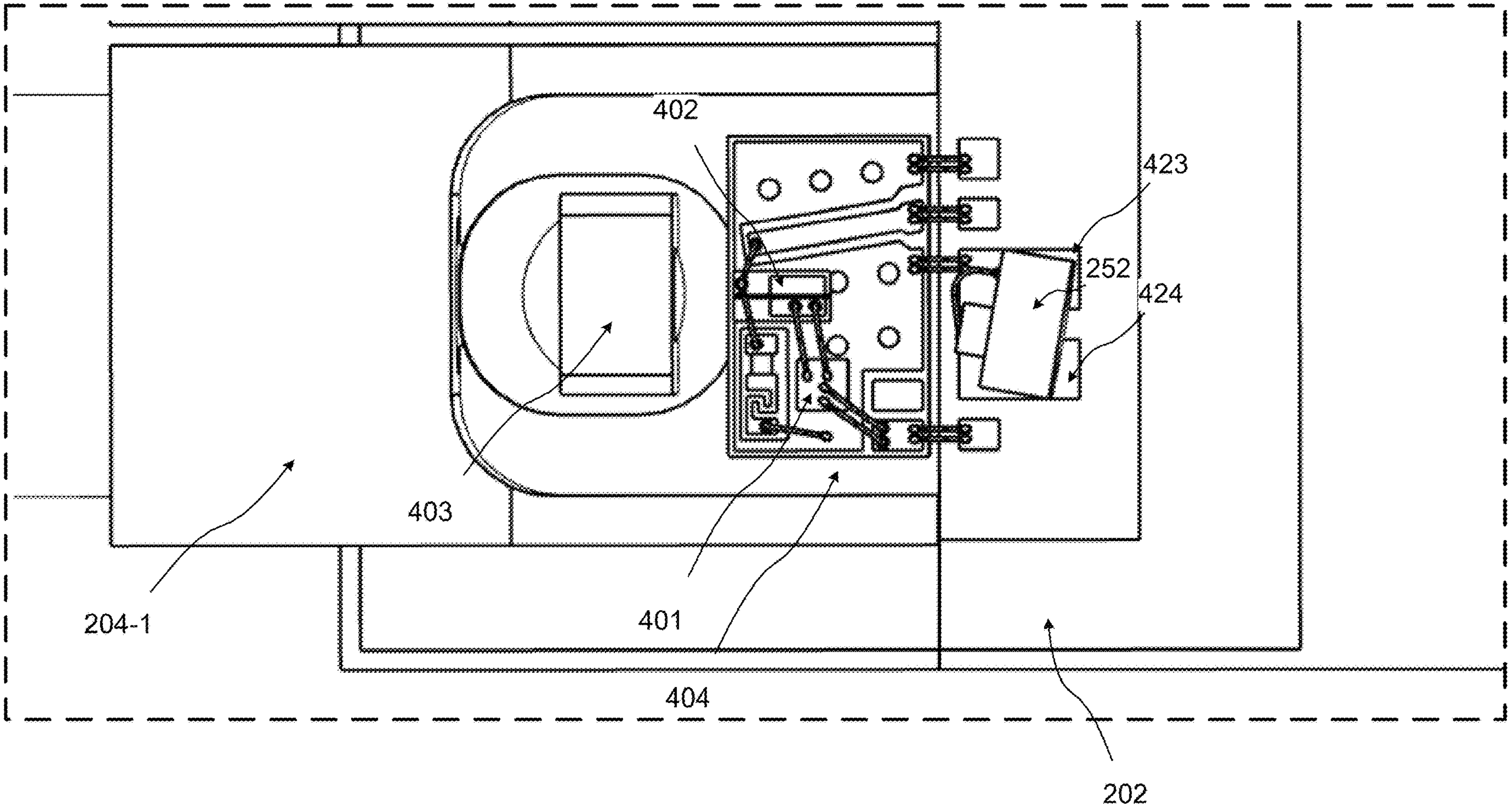


FIG. 4

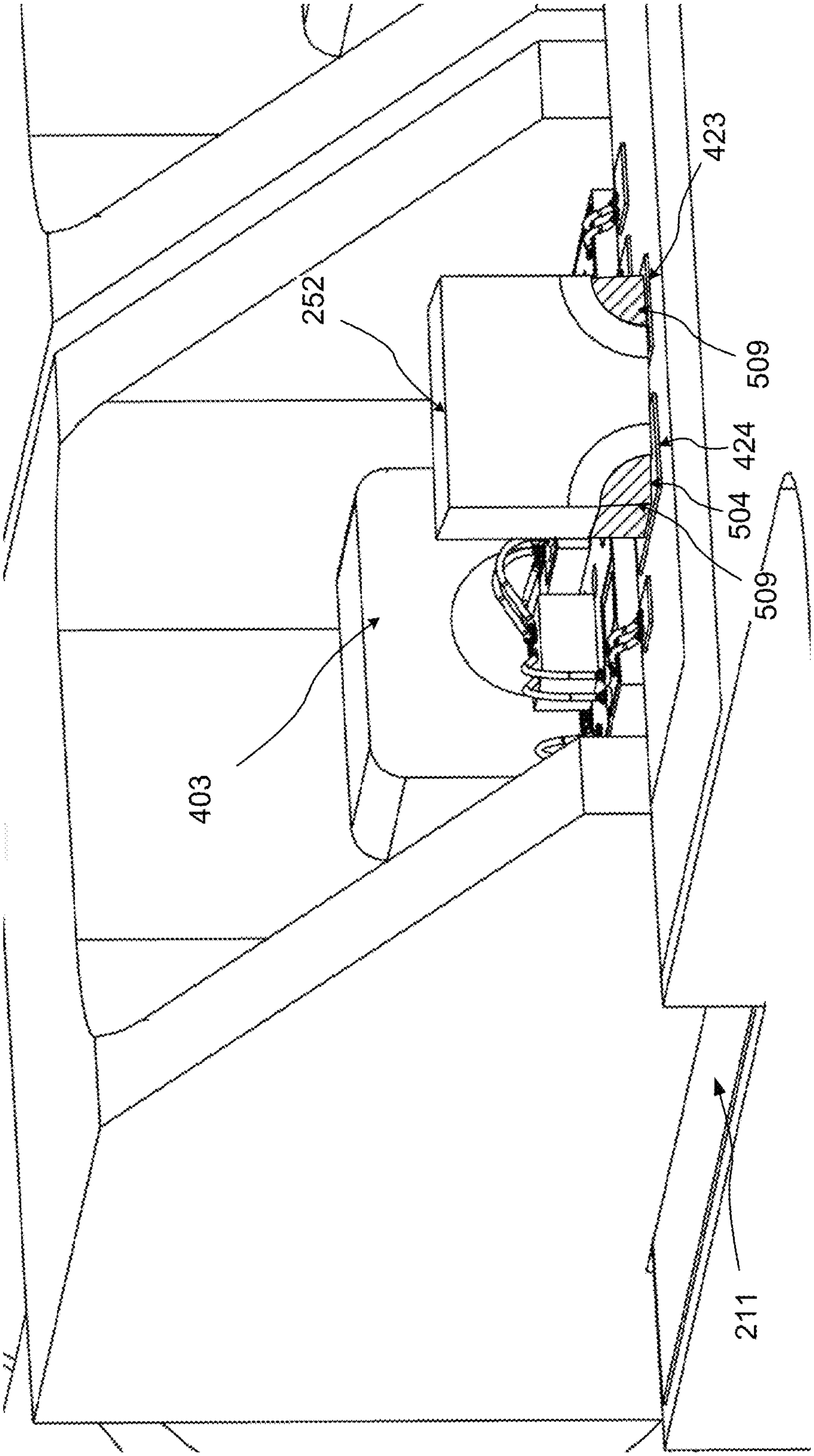


FIG. 5

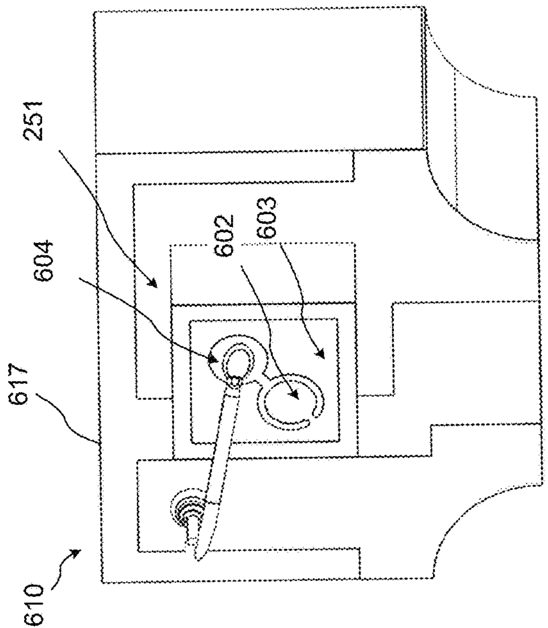


FIG. 6B

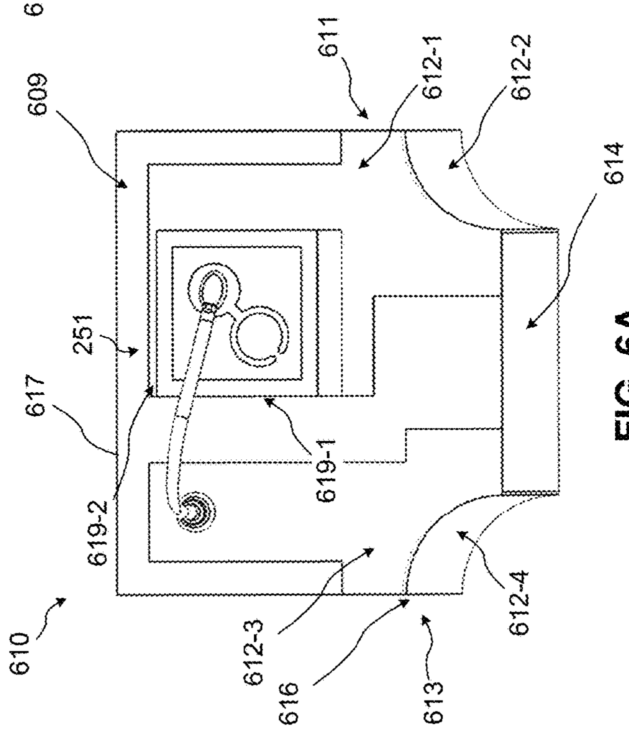


FIG. 6A

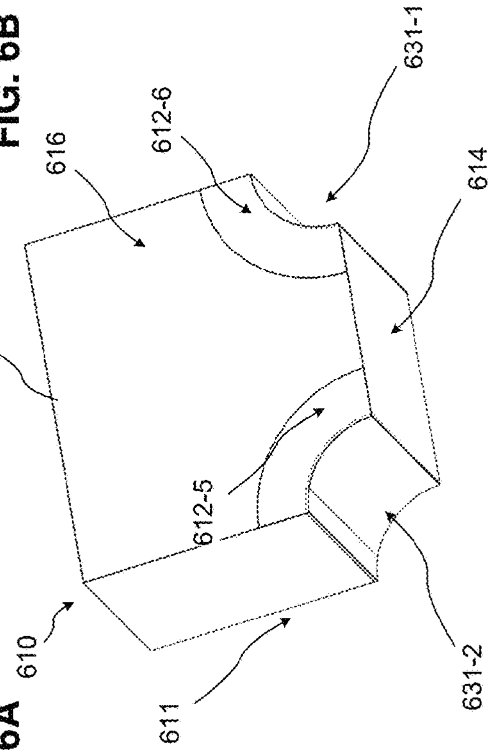
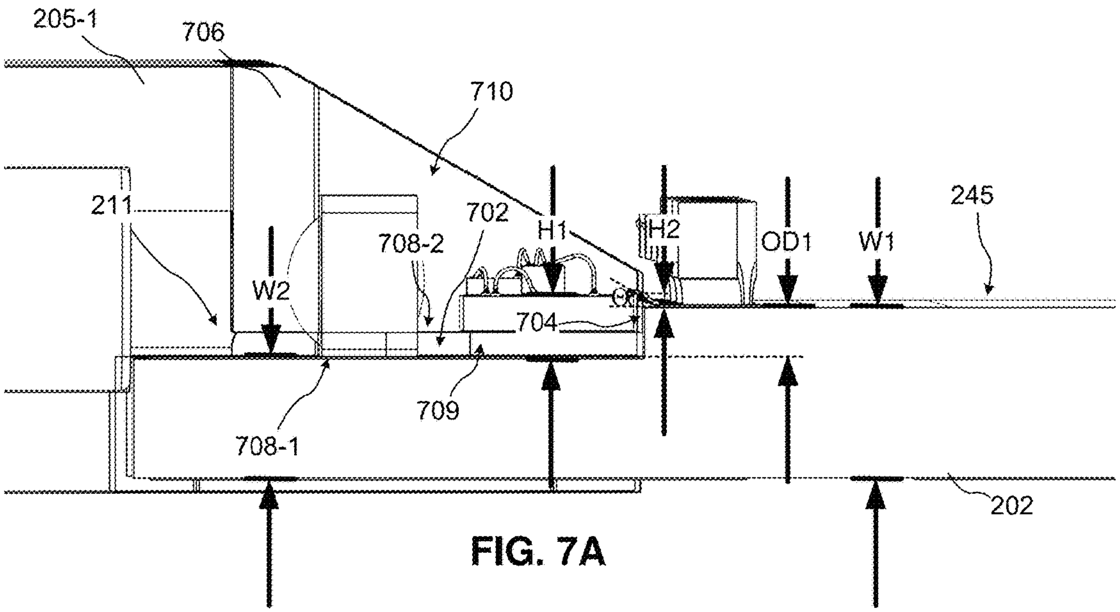


FIG. 6C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H2
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W1
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W2
704
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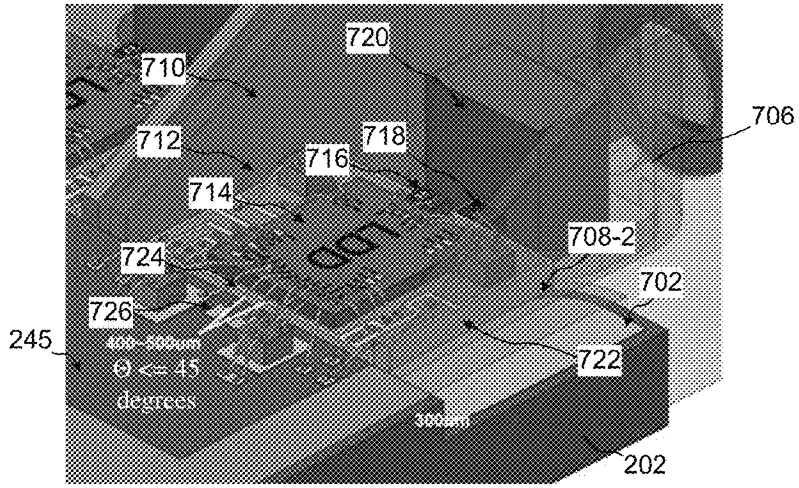
709
708-1
202

FIG. 7A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710
706
712
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718
714
708-2
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245
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Θ <= 45
degrees
722
300um
202

FIG. 7B

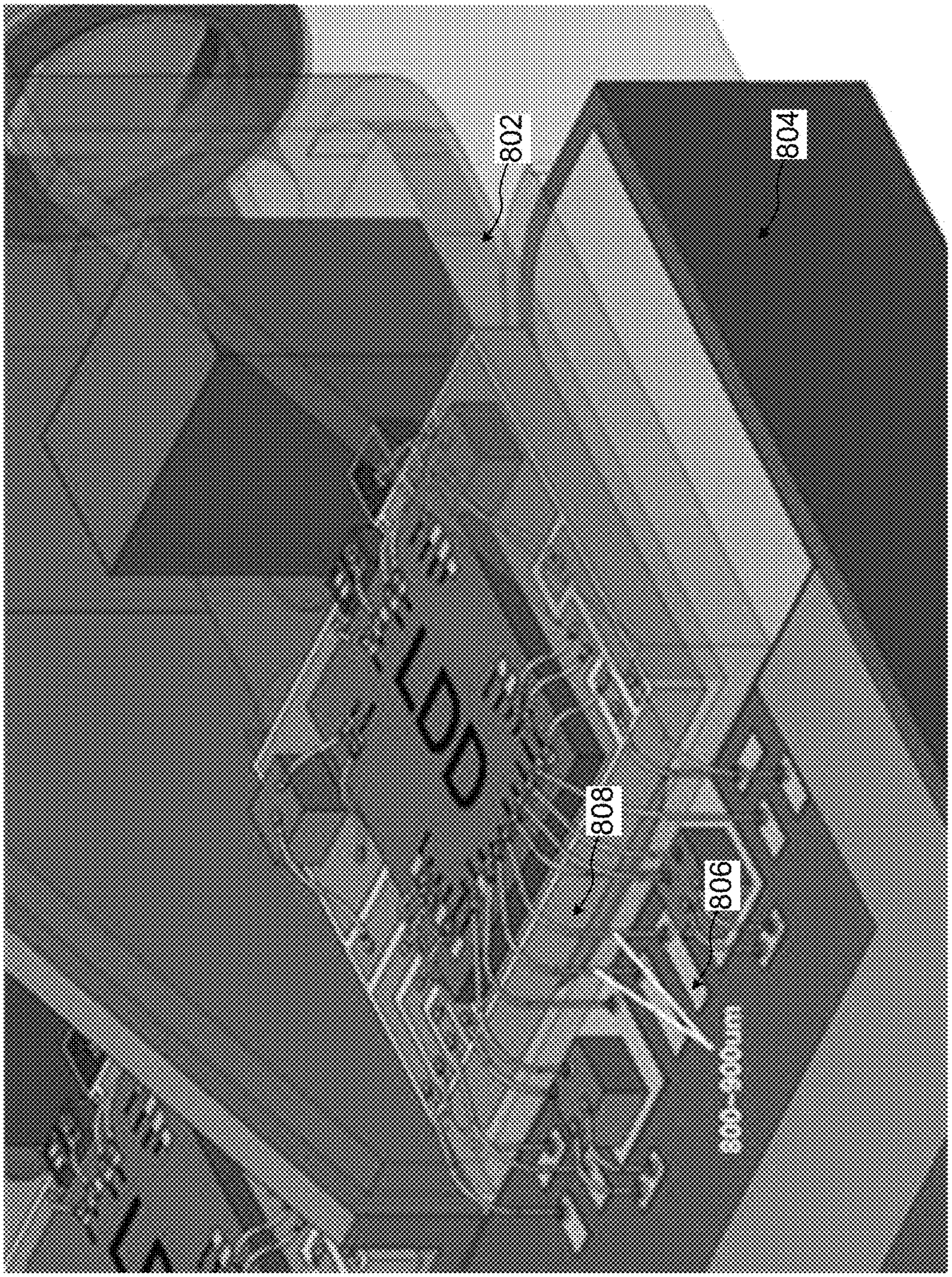


FIG. 8

SUBSTRATE WITH STEPPED PROFILE FOR MOUNTING TRANSMITTER OPTICAL SUBASSEMBLIES AND AN OPTICAL TRANSMITTER OR TRANSCEIVER IMPLEMENTING SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is related to co-pending application Ser. No. 16/737,414 entitled “Monitor Photodiode (MPD) Submount for Vertical Mounting and Alignment of Monitoring Photodiodes” filed concurrently herewith on Jan. 8, 2020, the disclosure of which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

The present disclosure relates to optical communication devices, and more particularly, to a substrate with a stepped profile for simplifying mounting and alignment of transmitter optical subassemblies (TOSA) modules, e.g., via edge mounting, and to reduce the vertical offset between TOSA modules and radio frequency (RF) terminals of the substrate to allow for relatively short electrical interconnect lengths, e.g., via wire bonds.

BACKGROUND

Optical transceivers are used to transmit and receive optical signals for various application including, without limitation, internet data center, cable TV broadband, and fiber to the home (FTTH) applications. Optical transceivers provide higher speeds and bandwidth over longer distances, for example, as compared to transmission over copper cables. The desire to provide higher speeds in smaller optical transceiver modules has presented challenges, for example, with respect to space management and manufacturing yield.

Optical transceiver modules generally include one or more transmitter optical subassemblies (TOSAs) for transmitting optical signals and one or more receiver optical subassemblies (ROSAs) for receiving optical signals. In general, TOSAs include one or more lasers to emit one or more channel wavelengths and associated circuitry for driving the lasers and monitoring power to ensure nominal performance. However, continued scaling and the standardization of transmission speeds of up to and exceeding 400 Gbp/s presents numerous technical challenges that complicates mounting and electrical interconnection between TOSA modules and a supporting substrate, e.g., a printed circuit board (PCB).

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages will be better understood by reading the following detailed description, taken together with the drawings wherein:

FIG. **1** shows a block diagram of an example multi-channel optical transceiver module in accordance with an embodiment of the present disclosure.

FIG. **2** is a perspective view of a multi-channel optical transceiver module for use in the multi-channel optical transceiver of FIG. **1**, in accordance with an embodiment of the present disclosure.

FIG. **3** shows an enlarged region of the multi-channel optical transceiver module of FIG. **2** in accordance with an embodiment of the present disclosure.

FIG. **4** shows a top view of the enlarged portion shown in FIG. **3**, in accordance with an embodiment of the present disclosure.

FIG. **5** shows another enlarged region of the multi-channel optical transceiver module of FIG. **2** in accordance with an embodiment of the present disclosure.

FIG. **6A** shows a front view of a monitor photodiode submount suitable for use in the multi-channel optical transceiver module of FIG. **2**, in accordance with an embodiment.

FIG. **6B** shows a perspective view of the monitor photodiode submount of FIG. **6A** in accordance with an embodiment.

FIG. **6C** shows another perspective view of a rear side of the monitor photodiode submount of FIG. **6A** in accordance with an embodiment.

FIG. **7A** shows a cross-sectional view of the multi-channel optical transceiver module of FIG. **2** in accordance with an embodiment.

FIG. **7B** shows an enlarged portion of a multi-channel optical transceiver module consistent with an embodiment of the present disclosure.

FIG. **8** shows an example approach to mounting and electrical coupling of transmitter optical subassemblies (TOSA) modules on a transceiver substrate.

DETAILED DESCRIPTION

As discussed above, scaling and increased transmission speeds raise numerous challenges in optical subassembly design. One such challenge includes reducing the impact of electrical interconnection devices, e.g., wire bonds, on high frequency signals such as radio frequency (RF) signals that drive TOSA modules.

These challenges are better understood by way of illustration. FIG. **8** shows a portion of a transceiver substrate **804**, e.g., a printed circuit board, that edge-mounts to a plurality of TOSA modules, e.g., TOSA module **802**. In this example, the TOSA modules **802** can be at least partially formed/configured separate from the transceiver substrate **804** and then subsequently coupled “on board” the transceiver substrate **804**. Such “on board” mounting of optical subassemblies can significantly simply manufacturing and design of transceivers and other devices that transmit and/or receive optical signals.

As further shown in FIG. **8**, this on-board mounting can include the laser diode driver (LDD) of each TOSA module electrically coupling with adjacent RF terminals, e.g., RF terminals **806**, to receive RF driving signals to modulate an associated laser by way of wire bonds **808**. However, electrical interconnects such as wire bonds **808** can introduce time of flight (ToF) issues for RF signals, as well as impedance matching issues which can significantly degrade signaling performance. Wire bonds also tend to be fragile and can easily break by inadvertent contact.

In the context of wire bonding specifically, one approach to mitigate the impact of such issues on signaling performance includes having wire bonds with relatively short overall lengths. While this solution seems relatively simple, space constraints and other factors such as component layout can complicate or otherwise prevent shortening wire bond lengths. For instance, in the context of FIG. **8**, the TOSA **802** includes a submount that vertically displaces the LDD, and importantly, the electrodes of the LDD that receive RF signaling. This vertical displacement results in wire bonds **808** extending at substantially 90 degrees from the RF terminals and having an overall length of about 800-900 microns to reach corresponding LDD terminals. Such overall wire bond lengths significantly impact signal quality, particularly high frequency RF signals, and ultimately can limit the maximum achievable transmission speeds of the TOSA module.

Continued development to achieve ever-higher optical transmission speeds, e.g., up to and beyond 400 Gbp/s, depends at least in part on optical subassembly module designs that significantly reduce the length of electrical interconnections between associated components without increasing design and manufacturing complexity. Moreover, continued development and rapid adoption of such high-speed transmission systems further depends at least in part on optical subassembly module designs that both shorten electrical interconnect lengths and allow for continued scaling without substantial redesign of existing components, such as PCBs and TOSA modules.

Thus, in accordance with an embodiment, a stepped profile for substrates that support "on board" optical subassembly arrangements is disclosed that allows for mounting of TOSA modules to the substrate in a recessed orientation to reduce the overall distance between terminals of the substrate and associated components of the TOSA, e.g., RF terminals of the substrate and an LDD of the TOSA. In an embodiment, the substrate comprises a printed circuit board PCB or PCB assembly (PCBA) that includes an electrical coupling end to electrically couple with external circuitry and an optical coupling end to couple to one or more TOSA modules. The substrate provides at least a first component mounting surface for coupling to circuitry to provide power and driving signals to the one or more TOSA modules. The substrate further defines a recessed TOSA mounting surface at the optical coupling end. The TOSA mounting surface extends substantially parallel with the first component mounting surface, and is offset from the same by a first predetermined offset distance. Thus, TOSA modules mount to the substrate via the recessed TOSA mounting surface, and components such as LDDs that would otherwise have a vertical offset relative to the supporting traces of the substrate (e.g., as shown in FIG. **8**) get displaced towards the same based on the first predetermined offset distance. The TOSA module components may therefore get "countersunk" via the recessed TOSA mounting surface to allow for relatively shorter electrical interconnection with the substrate.

Substrates having stepped profiles consistent with the present disclosure advantageously utilize the recessed TOSA mounting surface to allow for mounting of TOSA modules in a manner that maintains the advantages and simplicity of "on board" TOSA arrangements while also significantly reducing the overall length of electrical interconnections to provide RF and/or power signals to the same. In an embodiment, the stepped profile reduces electrical interconnection lengths by up to and exceeding 50% relative to approaches that do not feature substrates with stepped profiles (e.g., compare FIG. **8** with FIG. **7**B), and as a result, the stepped profile significantly reduces the introduction of signal degradation when utilizing relatively longer electrical interconnections.

As used herein, "channel wavelengths" refer to the wavelengths associated with optical channels and may include a specified wavelength band around a center wavelength. In one example, the channel wavelengths may be defined by an International Telecommunication (ITU) standard such as the ITU-T dense wavelength division multiplexing (DWDM) grid. This disclosure is equally applicable to coarse wavelength division multiplexing (CWDM). In one specific example embodiment, the channel wavelengths are implemented in accordance with local area network (LAN) wavelength division multiplexing (WDM), which may also be referred to as LWDM. The term "coupled" as used herein refers to any connection, coupling, link or the like and "optically coupled" refers to coupling such that light from one element is imparted to another element. Such "coupled" devices are not necessarily directly connected to one another and may be separated by intermediate components or devices that may manipulate or modify such signals.

The term substantially, as generally referred to herein, refers to a degree of precision within acceptable tolerance that accounts for and reflects minor real-world variation due to material composition, material defects, and/or limitations/peculiarities in manufacturing processes. Such variation may therefore be said to achieve largely, but not necessarily wholly, the stated characteristic. To provide one non-limiting numerical example to quantify "substantially," minor variation may cause a deviation of up to and including ±5% from a particular stated quality/characteristic unless otherwise provided by the present disclosure.

Referring to the Figures, FIG. **1** illustrates an optical transceiver module **100**, consistent with embodiments of the present disclosure. The optical transceiver module **100** is shown in a highly simplified form for clarity and ease of explanation and not for purposes of limitation. In this embodiment, the optical transceiver module **100** can be pluggable (e.g., comports with pluggable small form factor (SFFP) standards) and transmits and receives four (4) channels using four different channel wavelengths (λ1, λ2, λ3, λ4) and may be capable of transmission rates of at least about 25 Gbps per channel. In one example, the channel wavelengths λ1, λ2, λ3, λ4 may be within a ±13 nm range and have respective channel wavelengths of 1270 nm, 1290 nm, 1310 nm, and 1330 nm, respectively. Other channel wavelengths and configurations are within the scope of this disclosure including those associated with local area network (LAN) wavelength division multiplexing (WDM). For instance, the optical transceiver module **100** can include up to eight (8) or more channels and provide transmission rates of at least 25 Gbps per channel.

The optical transceiver module **100** may also be capable of transmission distances of 2 km to at least about 10 km. The optical transceiver module **100** may be used, for example, in internet data center applications or fiber to the home (FTTH) applications.

In an embodiment, the optical transceiver module **100** is disposed in a transceiver housing **103**. The transceiver housing **103** can be configured with one or more cavities to receive one or more optical transceiver modules, depending on a desired configuration.

The optical transceiver module **100** may include a number of components to support transceiver operations. The optical transceiver module **100** may include an optical transceiver substrate **102**, a plurality of transmitter optical subassemblies (TOSA) modules **104** for transmitting optical signals having different channel wavelengths, transmit connecting circuit **106**, a multi-channel receiver optical subassembly (ROSA) arrangement **108** for receiving optical signals on different channel wavelengths, an optical fiber receptacle **110** to receive and align a fiber connector (e.g., a ferrule) with the ROSA, and a receiver connecting circuit **112**.

The optical transceiver substrate **102** includes traces, connector pads, and other circuitry to support transceiver operations. The optical transceiver substrate **102** may include TOSA connector pads **114** (or terminals **114**) that enable each of the TOSA modules **104** to mount and electrically couple to the optical transceiver substrate **102**. The TOSA connector pads **114** may also be referred to herein as a simply connector pads. The optical transceiver substrate **102** may include traces **116** that couple the TOSA connector pads **114** to the transmit connecting circuit **106**. As discussed in greater detail below, monitor photodiode (PD) submounts/modules may be disposed on (e.g., directly) the traces **116** and/or the TOSA connector pads **114**.

The optical transceiver substrate **102** may include traces **118** that electrically couple the ROSA arrangement **108** to the receiver connecting circuit **112**. The optical transceiver substrate **102** may provide an optical transceiver module that may be "plugged" into an optical transceiver cage. Therefore, the transmit connecting circuit **106** and the receiver connecting circuit **112** may electrically couple to external circuitry of the optical transceiver cage. The optical transceiver substrate **102** may be manufactured from a multilayer printed circuitry board (PCB), although other types of substrates may be utilized and are within the scope of this disclosure.

Each of the TOSA modules **104** may be configured to receive driving electrical signals (TX_D1 to TX_D4), convert the electrical signals to a multiplexed optical signal (e.g., a signal with channel wavelengths λ1 . . . λn) and output the same to a multiplexer (not shown). Each of the TOSA modules **104** may be electrically coupled to the TOSA connector pads **114** and to the traces **116** through TOSA module connector pads **120**. Each of the TOSA modules **104** may include a laser diode device and supporting circuitry. The laser diode devices of the TOSA modules **104** may include distributed feedback lasers (DFBs), Vertical External-cavity Surface-emitting lasers (VECSEL) or other suitable laser devices. In an embodiment, monitor photodiodes **131** may be used to monitor the lasers' output power, as discussed below.

Referring to FIG. **2**, an example embodiment of a multichannel optical transceiver module for use in the multichannel optical transceiver of FIG. **1** is shown. As shown, the multi-channel optical transceiver module **200** includes an optical transceiver substrate **202** coupled to a TOSA arrangement **206**. The optical transceiver substrate **202** may also be referred to herein as a substrate. The optical transceiver substrate **202** may be manufactured from a multilayer printed circuitry board, although other types of substrates may be utilized and are within the scope of this disclosure.

The optical transceiver substrate **202** includes a first end **203** that extends to a second end **207** along a longitudinal axis **250**. The first end **203** couples to one or more TOSA modules, such as shown, for launching channel wavelengths onto transmit waveguides, e.g., optical fibers **209**. The second end **207** includes terminals/pads for electrical coupling with external circuitry to receive power and data signals. Accordingly, the first end **203** may also be referred to herein as an optical coupling end, and the second end **207** may be referred to as an electrical coupling end.

The transceiver substrate **202** further includes at least a first mounting surface **245** disposed opposite a second mounting surface **246** for supporting passive and/or active optical components. The first and second mounting surfaces **245**, **246** may also be referred to as first and second component mounting surfaces. Although not shown in the embodiment of FIG. **2**, the optical transceiver substrate **202** can include a multi-channel ROSA arrangement mounted to and supported by the first and/or second mounting surfaces **245**, **246**.

Continuing on, the TOSA arrangement **206** includes a plurality of TOSA modules **205-1** to **205-4**. Each TOSA module of the plurality of TOSA modules **205-1** to **205-4** includes a base/body portion, and in the particular embodiment illustrated in FIG. **2**, cuboid-type base portions. The plurality of TOSA modules **205-1** to **205-4** each support and align an associated laser arrangement with optical coupling ports **204-1** to **204-4**, respectively. Thus, channel wavelengths generated by the laser arrangements get launched on to associated optical fibers **209** by way of optical coupling receptacles **204-1** to **204-5**. Each laser arrangement may be configured to emit a different channel wavelength and can be monitored by an associated MPD module of an array of MPD modules to ensure nominal optical power, as will be discussed in greater detail below.

Continuing on, each of the plurality of TOSA modules **205-1** to **205-4** mount, e.g., edge mount, to the first end **203** of the substrate. The transceiver substrate **202** further includes a stepped profile, with the stepped profile being at least partially defined by a step/shoulder **211** proximate the first end **203**. Additional aspects of the stepped profile are discussed below with reference to FIGS. **7A-7B**. Each of the TOSA modules **205-1** to **205-4** can include a base with a plurality of sidewalls that define a generally L-shaped profile that corresponds with the step **211**. The profile of the base may therefore advantageously align along at least two axis, e.g., the X and Z axis, by simply engaging/bottoming out against surfaces of the step **211**, e.g., vertical surface **704** shown and discussed below with reference to FIG. **7A**, that operate as an alignment guide by providing mechanical stops/limits to limit travel along at least one axis. Alignment along the remaining axis, e.g., the Y axis, may therefore be performed by relatively simply lateral movement (e.g., along the X axis) of each TOSA module **205-1** to **205-4**.

Once aligned, each of the plurality of TOSA modules electrically couple to the transceiver substrate **202**, and more particularly TOSA module connector pads disposed proximate the first end **203** of the transceiver substrate **202**, which is shown more clearly in FIGS. **3** and **4**. The TOSA module connector pads allow each of the TOSA modules **204-1** to **204-5** to receive driving signals and power from transmit connecting circuitry, e.g., via traces **116** and TX connecting circuit **106** (See FIG. **1**).

Referring to FIGS. **3-4**, an enlarged region of the multichannel optical transceiver module of FIG. **2** is shown in accordance with embodiments of the present disclosure. As shown, each TOSA module of the TOSA arrangement **206** includes a laser arrangement having, for example, a filtering capacitor **401**, laser diode (LD) **402**, and focusing lens **403**. One such laser arrangement **712** is shown in further detail in FIG. **7A**. The components of the TOSA arrangement **206**, such as LD **402**, can directly mount to the body of the associated TOSA module, or indirectly via an LD submount **404**, such as shown. The LD submount **404** can support components of each laser arrangement and provide electrical traces and other circuitry to support TOSA operations. Note the LD submount **404** may also couple directly to the body of the TOSA module, or indirectly by way of one or more baseplates, such as base plate **709** shown more clearly in FIG. **7A**.

The LD **402** can be implemented as a distributed feedback lasers (DFBs), Vertical External-cavity Surface-emitting lasers (VECSEL) or other suitable laser devices. Preferably, the LD **402** is implemented as an electro-absorption modulator laser (EML). In an embodiment, the LD **402** can be uncooled (e.g., operate without an associated thermoelectric cooler). Instead, the LD **402** is in thermal communication with the body of the TOSA module to dissipate heat. In addition, the body of the TOSA module may also be in thermal communication with the transceiver substrate **202** via the step **211** to further increase heat dissipation. Accordingly, in an embodiment each TOSA module can provide a thermal communication path **311** that extends between each LD and the transceiver substrate **202** by way of an associated LD submount, TOSA body, and the step **211** of the transceiver substrate **202**.

Continuing with reference to FIGS. **3-5**, the components of each laser arrangement may be disposed coaxially, or substantially coaxially and be aligned with a longitudinal center line of a corresponding optical coupling receptacle (See FIG. **2**). Each TOSA module of the TOSA arrangement **206** may therefore also be referred to as cuboid-type coaxial TOSA assemblies, or simply coaxial TOSA assemblies. Notably, cuboid-type TOSA bases allow for each laser assembly to be mounted in close proximity with adjacent cuboid-type TOSAs, e.g., directly contacting each other in a side-by-side relationship. Alternatively, spacing between the cuboid-type TOSA bases can provide for thermal isolation between adjacent TOSA modules (e.g., based on an air gap) while ensuring a relatively small overall footprint for the TOSA arrangement **206**.

In operation, each TOSA module **205-1** to **205-4** of the TOSA arrangement **206** can emit associated channel wavelengths and launch the same along optical fibers **209**, for example. Associated MPDs monitor and ensure nominal power for each of the TOSA modules **205-1**, **205-4**. As discussed above, each of the TOSA modules includes at least a LD, e.g., LD **402**, and at least one corresponding monitor photodiode (MPD), e.g., provided by MPD module **252**, to monitor the optical output power. As shown in FIG. **3**, for example, the MPD module **252** optically aligns with a back surface of the LD **402** to receive and measure a small percentage of light emitted therefrom, e.g., 1-3%. Laser threshold current and slope efficiency are both functions of temperature and aging time. To maintain nominal optical output power, the electrical bias current and modulation current applied to the laser may be varied to compensate the change brought about by the variations in temperature and/or aging time. The optical transceiver module **200** can vary the current applied to the LD **402** based on the measured light to, for instance, maintain a stable output power based on an average output current of the MPD module **252**.

Referring to FIGS. **6A-6C**, an example monitor photodiode submount **610** suitable for use with the MPD module **252** is shown in accordance with an embodiment. The monitor photodiode (MPD) submount **610** is configured to couple to and align a MPD **251** with an associated laser diode, as discussed above. The MPD submount **610** comprises a base **617** having a plurality of sidewalls to provide at least one mounting surface for supporting an MPD and supporting circuitry and at least one mating surface for coupling to an associated transceiver substrate. The base **617** can comprise, for instance, Silicon (Si), or any other non-conductive suitably rigid material. The base **617** may be formed monolithically from a single piece of material or from multiple pieces. While the following discussion includes reference to disposing/patterning metallic material on to a non-conductive base, e.g., formed from Si to provide electrically conductive paths, the base **617** may be at least partially formed from a conductive material such as a metal to provide integrated traces. In this instance, multiple independent electrical traces/paths may be provided by disposing an electrical insulating layer therebetween.

Continuing on, at least one sidewall defining the base **617** of the submount **610** provides a mounting surface **609** for coupling to and supporting MPD **251**, such as shown. At least one sidewall defining the base **617** of the submount **610** further provides mating surface **614** for mounting to and being supported by TOSA connecting pads, as will be discussed in greater detail below. As shown, the mounting surface **609** extends substantially transverse relative to the mating surface **614** to provide a vertical mounting orientation for the MPD **251**.

The base **617** further provides at least first and second electrically conductive paths **611**, **613** disposed along multiple sidewalls of the base **617** using a plurality of conductive traces disposed/patterned thereon. In particular, the first electrically conductive path **611** is collectively provided by at least first and second conductive traces **612-1**, **612-2** (or conductive segments) disposed on the base **617**. Likewise, the second electrically conductive path **613** is collectively provided by at least third and fourth conductive traces **612-3** and **612-4** (or conductive segments) disposed on the base **617**. Patterning of the conductive traces **612-1** to **612-4** can comprise deposition of one or more layers of metallic material such as copper, silver, or other suitable material on to sidewalls of the base **617**.

At least a portion of the first conductive trace **612-1** defines the mounting surface **609** for both physically and electrically coupling to the MPD **251**. Further, the first conductive trace **612-1** includes a region with a relatively rectangular profile having a width that is about 1.2× to 1.3× the width of the MPD **251**. This rectangular profile may be dimensioned such that corner(s) of the same get disposed at substantially a center of the mounting surface **609**. Alignment of the MPD **251** relative to the base **617**, and more importantly relative to an associated laser diode, may therefore be initially accomplished along the X, Y and Z axis by ensuring that the edges **619-1** and **619-2** of MPD **251** mount substantially flush with a far edge of rectangular pad provided by the first conductive trace **612-1**. Stated differently, alignment of MPD **251** can include mounting the same at a predetermined position on the first conductive trace **612-1** such that edges **619-1** and **612-2** extend parallel with the edges defining the rectangular pad and include a relatively uniform gap therebetween measuring about 0 to 100 microns. The first conductive trace **612-1** may therefore provide a visual alignment indicator, e.g., in the form of a rectangular pad or other regular or non-regular geometric shape, to provide a visual representation of a predefined mounting location for the MPD to simplify mounting and alignment of the same.

The above-discussed mounting and alignment of MPD **251** on to the MPD submount **610** can occur prior to attachment to the transceiver substrate **202** (FIG. **2**). The MPD submount **610** may therefore get mounted to the transceiver substrate **202** with the MPD **251** being aligned along at least the X and Z axis with the associated laser diode. Alignment along the Y axis can include simply shifting the MPD submount **610** laterally until nominal optical coupling with an associated laser diode gets achieved.

Continuing on, the first conductive trace **612-1** extends towards the transceiver substrate **202** when the MPD submount is coupled thereto. The first conductive trace **612-1** also extends substantially transverse relative to the first mounting surface **245** of substrate **202** when coupled thereto (See FIG. **3**). The first conductive trace **612-1** then transitions to the second conductive trace **612-2** based on an edge/intersection between associated sidewalls of the base

617. The second conductive trace **612-2** extends substantially transverse relative to the mounting surface **609**, and substantially parallel relative to the first mounting surface **245** of the transceiver substrate **202** when coupled thereto (See e.g., FIGS. **3-5**).

As further shown, third and fourth conductive traces **612-3** and **612-4** are disposed on the base **617** to collectively define a second electrically conductive path to electrically couple the MPD **251** to the transceiver substrate **202**. The third conductive trace **612-3** is disposed on the mounting surface **609** and is configured to electrically couple to the MPD **251** via, for instance, wire bonding such as shown. The third conductive trace **612-3** extends towards the transceiver substrate **202** when the MPD submount **610** is coupled thereto. The third conductive trace **612-3** transitions to the fourth conductive trace **612-4** at an edge/intersection between sidewalls of the base **617**. The fourth conductive trace **612-4** extends substantially transverse relative to the mounting surface **609** and substantially parallel relative to the first mounting surface **245** of the transceiver substrate **202**.

The first and second conductive paths **611**, **613** therefore include at least one region/segment that extend substantially in parallel, and proximate, to an interface formed between the mating surface **614** and the first mounting surface **245** of the transceiver substrate **202** when the MPD submount **610** is coupled thereto. As discussed in greater detail below, the first and second conductive paths **611**, **613** can be electrically coupled to the transceiver substrate **202** utilizing a conductive epoxy or other conductive material that can be disposed around MPD submount **610**.

The MPD **251** can comprise a surface MPD having a detecting surface/region **603** having a receiving area **602** that is configured to be optically coupled with an associated laser diode by being aligned along the X, Y and Z axis. In particular, alignment includes the receiving area being disposed at a position that intersects with an optical path extending from a back surface of the associated laser diode towards the MPD. An anode **604** is disposed on the detecting surface **603**. A cathode (not shown) of the MPD **251** is provided on a surface opposite the detecting surface **603**. The MPD **251** mounts (e.g., directly) on the first conductive trace **612-1**, with the associated cathode electrically connected to the first conductive path **611**. The anode **604** electrically couples to the second conductive path **613** by wire bonding, for instance.

As shown in FIGS. **6A-6C**, the body **617** of the MPD submount **610** can include channels/notches **631-1**, **631-2**. The channels **631-1**, **631-2** extend substantially transverse relative to mounting surface **609** and include a curved/arcuate profile (such as shown). Other shapes and configurations for the channels **631-1**, **631-2** are within the scope of this disclosure. As further shown, the second conductive trace **612-2** and the fourth conductive trace **612-4** are at least partially disposed on the channels **631-1**, **631-2**. The channels **631-1**, **631-2** can advantageously facilitate flow and adhesion of a layer of epoxy **509** (FIG. **5**) to securely attach the MPD submount **610** to an associated transceiver substrate, e.g., transceiver substrate **202**. In addition, the channels **631-1**, **631-2** reduce the overall footprint of the mating surface **614** by providing a taper, and by extension, reducing the overall footprint of the MPD submount **610** when coupled to the transceiver substrate **202** (See FIG. **5**). The channels **631-1**, **631-2**, may thus define a tapered region that at least partially defines the mating surface **614**.

When the MPD submount **610** mounts to the transceiver substrate **202** via mating surface **614**, conductive epoxy **509** can flow into the channels **631-1**, **631-2** to securely attached the MPD submount **610** at a predetermined position, as discussed further below. The rounded profile/shape of the channels **631-1**, **631-2** can encourage increased adhesion and allow for a relatively larger amount of conductive epoxy to be utilized and substantially confined without the same inadvertently contacting adjacent conductive pads/traces. Note that while the embodiment of FIGS. **6A-6C** show two channels **631-1**, **631-2**, this disclosure is not limited in this regard. An MPD submount consistent with the present disclosure can have a single channel, or a plurality of channels (as shown), or no channels depending on a desired configuration.

As shown in FIG. **6C**, the first and second conductive paths **611**, **613** can also include fifth and sixth conductive traces **612-5**, **612-6**, respectively. The fifth and sixth conductive traces **612-5**, **612-6** can be disposed on back surface **616**, with back surface **616** being disposed opposite the mounting surface **609**. In this embodiment, the fifth and sixth conductive traces **612-5**, **612-6** can further increase electrical conductivity via the conductive epoxy and can balance bonding stresses applied to the MPD submount **610**.

Referring back to FIGS. **3-5**, with additional reference to FIGS. **6A-6C**, the MPD submount **610** is shown implemented as MPD module **252**. These MPD module **252** is configured to be disposed on the TOSA connector pads **423**, **424**, and when coupled thereto, an interface **504** gets formed between the MPD module **252** and the surfaces defining the transceiver substrate **202** (See FIG. **5**). A layer of conductive epoxy **509**, e.g., silver epoxy, may be disposed along the interface **504** between MPD module **252** and surfaces defining the transceiver substrate **202**, and in particular, the connector pads **423**, **424**.

Therefore, the first and the second conductive paths **611**, **613** (FIG. **6A**) electrically couple to a pad/trace of the transceiver substrate based at least in part on the layer of conductive epoxy **509**. Minor adjustment to MPD orientation along the Y axis, e.g., relative to an associated laser diode, can be achieved while the layer of conductive epoxy **509** cures, thus allowing for greater tolerances and multiple manufacturing phases to occur at potentially the same time. To avoid or otherwise reduce reflection losses, the receiving area **602** may be disposed at an angle with respect to the light path of the laser diode. The angle may be, for example, 0-15°, and preferably about 8° relative to normal.

Stepped Profile Architecture

Turning to FIG. **7A** an enlarged cross-sectional view of the substrate **202** is shown in accordance with an embodiment. Note, the embodiment of FIG. **7A** shows a laser arrangement having a vertically-mounted monitored photodiode, as discussed above. However, the stepped profile is equally applicable to other TOSA configurations including designs where an MPD is mounted to the TOSA body (e.g., See FIG. **7B**).

As shown in FIG. **7A**, the first component mounting surface **245** defines at least a portion of a first mounting region to allow for mounting of components and to provide traces for electrical interconnection with external circuitry. The first mounting region can therefore extend from the electrical coupling end **207** to a second mounting region disposed at the optical coupling end **203**.

The second mounting region is defined at least in part by the step **211**. The step **211** defines at least a portion of the stepped profile which can simplify alignment and coupling processes for TOSA modules, as discussed above. The stepped profile, and in particular, step **211** is defined at least in part by a recessed TOSA mounting surface **702**, which may be referred to herein as simply a recessed mounting surface. The recessed mounting surface **702** is offset/recessed from the first component mounting surface **245** by a first offset distance (OD**1**). The offset distance OD**1** measures between 10 and 50 microns, and preferably, 10-20 microns

The stepped profile may therefore be provided by the recessed TOSA mounting surface **702** extending substantially parallel with the first component mounting surface **245** and substantially transverse relative to vertical surface **704**, with the vertical surface **704** adjoining the recessed mounting surface **702** and the first component mounting surface **245**. The overall height of vertical surface **704** can be predetermined to establish the first offset distance OD**1**. As shown in FIGS. **2** and **7**A, the first mounting region is shown as the portion of the substrate **202** having a first overall width W**1**. The first mounting region preferably includes a uniform width, or may vary along the longitudinal axis **250** (See FIG. **2**) up to a maximum width equal to W**1**. On the other hand, the second mounting region is shown as the portion of the substrate **202** having a second overall width W**2**, with the second overall width W**2** being less than the first overall width. The second mounting region also includes, preferably, a uniform width although this disclosure is not limited in this regard and the second overall width W**2** can vary along the longitudinal axis up to a maximum width equal to W**2**.

As further shown in FIG. **7**A, the first TOSA module **205-1** includes a body **706** (or base) configured to securely mount, e.g., edge mount, to the second mounting region of the substrate **202**. The body **706** includes a plurality of sidewalls that provide a substrate mating surface **708-1** and a component mounting surface **708-2**. The substrate mating surface **708-1** is disposed opposite the component mounting surface **708-2**, and in the embodiment shown in FIGS. **7**A-**7**B, the component mounting surface is accessible via an opening **710** defined by sidewalls of the body **706** that extend substantially transverse from the component mounting surface **708-2**.

Thus, the recessed TOSA mounting surface **702** underlies and supports at least a portion of the substrate mating surface **708-1**, and thus by extension, the body **706** of the at least one TOSA module **205-1**. In an embodiment, epoxy or other adhesive material may be disposed between the recessed TOSA mounting surface **702** and the substrate mating surface **708-1** to securely attach the body **706** to the substrate **202**, although other attachment methods are within the scope of this disclosure such as welding. In this embodiment, the stepped profile operates, in a general sense, as a dam to prevent epoxy from contacting other surfaces such as the substrate mating surface **708-1**. Accordingly, the stepped profile also aids in containing and confining epoxy during manufacturing, which can reduce component failure and the time required for post-processing stages to remove excess epoxy.

The recessed TOSA mounting surface **702** can include one or more layers of metallic material disposed thereon (See FIG. **7**B), e.g., such as Gold (Au) or Copper (Cu), to increase thermal communication between the TOSA module **205-1** and the substrate **202** and/or to allow for attachment via welding/soldering.

Turning to FIG. **7**B, with additional reference to FIG. **7**A, the body **706** includes at least one laser arrangement **712** mounted to the component mounting surface **708-2** of the body **706**. As shown, the laser arrangement **712** includes a laser diode driver **714**, a laser diode **716**, a monitor photodiode **718** and a focus lens **720**. The laser arrangement **712** may include more or fewer active and/or passive optical components depending on a desired configuration, and the embodiment shown in FIG. **7**B is not intended to be limiting.

As further shown, the at least one laser arrangement **712** mounts to the body **706**, and more particularly, the component mounting surface **708-2** by way of a submount **722** and optional base plate **709**. The submount **722** can provide traces/terminals for electrical connectivity with components of the at least one laser arrangement **712**. The overall height H**1** of the submount **722** (e.g., including the base plate **709**) may therefore measure substantially equal to or greater than the first offset distance OD**1**. Accordingly, an invisible line drawn at the first component mounting surface **245**, and parallel thereto, can intersect with the submount **722** and/or at least one component of the at least one laser arrangement **712** such as the LDD **714** and LD **716**.

Stated differently, the submount **722** vertically displaces the components of the at least one laser arrangement **712** relative to the component mounting surface **708-2** of the body **706**, e.g., by overall height H**1**, but the vertical displacement gets ‘offset’ based on stepped profile of the substrate **202**, and more particularly, the first offset distance (OD**1**) of the recessed TOSA mounting surface **702** relative to the first component mounting surface **245** of the substrate **202**. Stated simply, the recessed TOSA mounting surface **702** gets countersunk relative to the first component mounting surface **245**. The overall height H**2** between the first component mounting surface **245** and a top surface of the submount **722** that supports the optical components of the at least one laser arrangement **712** is less than 400 microns, and preferably, less than 200 microns.

Accordingly, relatively short electrical interconnects, e.g., wire bonds **724**, electrically couple the LDD **714** to RF terminals/traces **726** disposed on the first component mounting surface **245**. In the shown embodiment, the overall length of each of the wire bonds **724** measures between 400 and 500 microns, and preferably, less than 400 microns. In addition, each of the wire bonds **724** extend at an angle θ relative to the first component surface **245**, with angle θ being less than or equal to 45 degrees.

Substrates having stepped profiles consistent with the present disclosure advantageously position components such as LDDs in close proximity with supporting terminals of the substrate **202**. By way of contrast, consider the embodiment of FIG. **8** which shows a substrate and TOSA modules with a substantially similar size and dimension to that of the embodiments shown in FIGS. **7**A-**7**B. However, the stepped profile of the substrate **202** shown in FIGS. **7**A and **7**B allows for wire bonds **724** to be shortened/reduced in length by up to and exceeding 50% relative to wire bonds **808** of FIG. **8**. Moreover, the wire bonds **724** extend at a relatively acute angle θ to provide a low-profile implementation. On the other hand, the wire bonds **808** shown in FIG. **8** extend from substrate **804** at roughly a 90 degree angle, which increases the risk of inadvertent contact and damage. In any event, this reduction in wire bond length translates directly to improved signal quality, and in addition, enables maximum transmission speeds otherwise unachievable with longer electrical interconnections.

In accordance with an aspect of the present disclosure an optical subassembly module is disclosed. The optical subassembly module comprising a substrate having an electrical coupling end for electrically coupling to external circuitry and an optical coupling end for launching at least one channel wavelength on a waveguide, the electrical coupling end disposed opposite the optical coupling end, a first mounting region at the electrical coupling end of the substrate to provide traces for electrical interconnection with the external circuitry, the first mounting region defined at least in part by a component mounting surface provided by a sidewall of the substrate, a second mounting region at the optical coupling end of the substrate to couple to and support at least one transmitter optical subassembly (TOSA) module via a recessed TOSA mounting surface, the recessed TOSA mounting surface being disposed offset from the component mounting surface by first offset distance (OD**1**) based on a stepped profile, the stepped profile defined at least in part by the recessed TOSA mounting surface extending substantially parallel with the component mounting surface and substantially transverse relative to a vertical surface adjoining the recessed TOSA mounting surface and the component mounting surface.

In accordance with another aspect of the present disclosure an optical transceiver is disclosed. The optical transceiver comprising a transceiver substrate having an optical coupling end disposed opposite an electrical coupling end, at least one component mounting surface provided by the transceiver substrate extending between the optical coupling end and the electrical coupling end, and a recessed transmitter optical subassembly (TOSA) mounting surface at the optical coupling end of the substrate for coupling to and supporting at least one TOSA module, and wherein the recessed TOSA mounting surface extends substantially parallel with the at least one component mounting surface and substantially transverse relative to a vertical surface adjoining the recessed TOSA mounting surface and the at least one component mounting surface, at least one TOSA module coupled to optical coupling end of the transceiver substrate, and a receiver optical subassembly arrangement coupled to the transceiver substrate.

While the principles of the disclosure have been described herein, it is to be understood by those skilled in the art that this description is made only by way of example and not as a limitation as to the scope of the disclosure. Other embodiments are contemplated within the scope of the present disclosure in addition to the exemplary embodiments shown and described herein. Modifications and substitutions by one of ordinary skill in the art are considered to be within the scope of the present disclosure, which is not to be limited except by the following claims.

What is claimed is:

1. An optical subassembly module, the optical subassembly module comprising:

a substrate having an electrical coupling end for electrically coupling to external circuitry and an optical coupling end for launching at least one channel wavelength on a waveguide, the electrical coupling end disposed opposite the optical coupling end;

a first mounting region at the electrical coupling end of the substrate to provide traces for electrical interconnection with the external circuitry, the first mounting region defined at least in part by a component mounting surface provided by a sidewall of the substrate;

a second mounting region at the optical coupling end of the substrate to couple to and support at least one transmitter optical subassembly (TOSA) module via a recessed TOSA mounting surface, the recessed TOSA mounting surface being disposed offset from the component mounting surface by first offset distance (OD**1**) based on a stepped profile, the stepped profile defined at least in part by the recessed TOSA mounting surface extending substantially parallel with the component mounting surface and substantially transverse relative to a vertical surface adjoining the recessed TOSA mounting surface and the component mounting surface; and

wherein the vertical surface provides a mechanical stop to engage a surface of the least one TOSA module and limit travel of the at least one TOSA module along one or more axis, and wherein the second mounting region at the optical coupling end of the substrate is configured to edge mount to the at least one TOSA module.

2. The optical subassembly module of claim **1**, wherein the optical subassembly module further comprises the at least one TOSA module edge mounted to the second mounting region of the substrate, the at least one TOSA module having a body that includes a component mounting surface to couple to a laser arrangement and a substrate mating surface disposed opposite the component mounting surface of the body, the substrate mating surface of the body to couple to the recessed TOSA mounting surface of the optical coupling end of the substrate and extend from the substrate along an axis that is substantially parallel with a longitudinal axis of the substrate.

3. The optical subassembly module of claim **2**, wherein the substrate mating surface of the body is vertically offset from the component mounting surface of the substrate by the first offset distance.

4. The optical subassembly module of claim **2**, wherein the laser arrangement of the at least one TOSA module comprises a laser diode driver (LDD) disposed on the component mounting surface of the TOSA module.

5. The optical subassembly of claim **4**, wherein the LDD is electrically coupled to radio frequency (RF) terminals disposed on the component mounting surface of the substrate adjacent the optical coupling end via a plurality of wire bonds.

6. The optical subassembly of claim **5**, wherein each of the plurality of wire bonds extend from the component mounting surface of the substrate at an angle less than or equal to 45 degrees.

7. The optical subassembly of claim **5**, wherein each of the plurality of wire bonds has an overall length of less than 500 microns.

8. The optical subassembly of claim **1**, wherein the second mounting region is configured to couple to and support a plurality of TOSA modules.

9. The optical subassembly of claim **1**, wherein the substrate is a printed circuit board, and wherein the optical subassembly is a multi-channel optical transmitter or multi-channel optical transceiver capable of transmitting multiple channel wavelengths.

10. An optical transceiver, the optical transceiver comprising:

a transceiver substrate having an optical coupling end disposed opposite an electrical coupling end;

at least one component mounting surface provided by the transceiver substrate extending between the optical coupling end and the electrical coupling end; and

a recessed transmitter optical subassembly (TOSA) mounting surface at the optical coupling end of the substrate for coupling to and supporting at least one TOSA module, and wherein the recessed TOSA mounting surface extends substantially parallel with the at least one component mounting surface and substantially transverse relative to a vertical surface adjoining the recessed TOSA mounting surface and the at least one component mounting surface;

at least one TOSA module edge mounted to the optical coupling end of the transceiver substrate, wherein the vertical surface provides a mechanical stop to engage a surface of the least one TOSA module and limit travel of the at least one TOSA module along one or more axis; and

a receiver optical subassembly arrangement coupled to the transceiver substrate.

11. The optical transceiver of claim **10**, further comprising radio frequency (RF) terminals disposed on the at least one component mounting surface proximate to the optical coupling end, wherein the at least one TOSA module electrically couples with the RF terminals via one or more wire bonds.

12. The optical transceiver of claim **10**, wherein the recessed TOSA mounting surface is vertically offset relative to the at least one component mounting surface of the transceiver substrate by a first offset distance.

13. The optical transceiver of claim **10**, wherein the at least one TOSA module comprises a plurality of TOSA modules, and wherein each TOSA module of the plurality of TOSA modules include a submount and a laser diode driver (LDD) coupled to the submount.

* * * * *

Exhibit G

Representative Claim Chart for U.S. Patent No. 9,448,367

<u>EOPTOLINK 100G CWDM4 (QP85060003)</u>

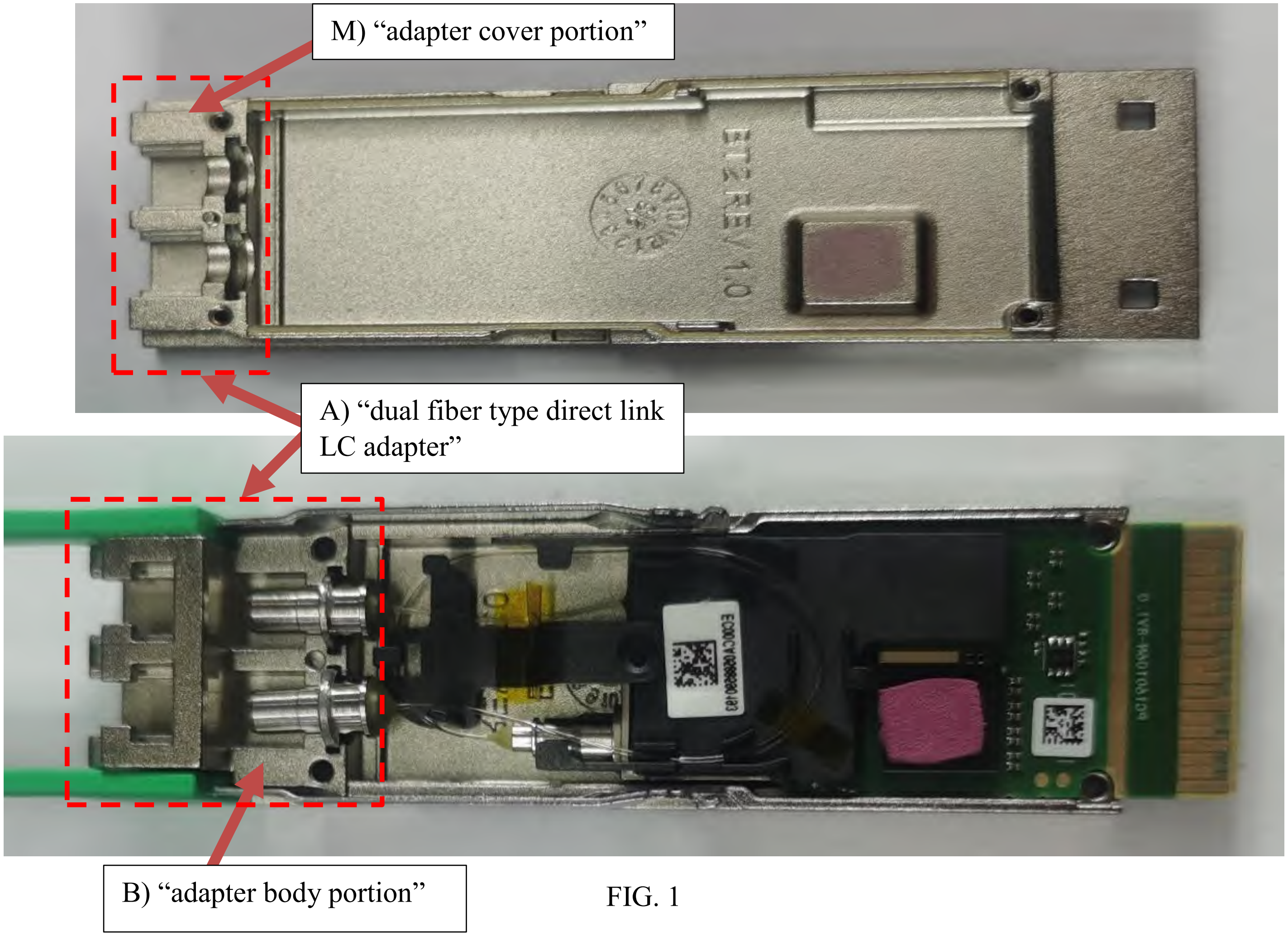


FIG. 1

Representative Claim Chart for U.S. Patent No. 9,448,367

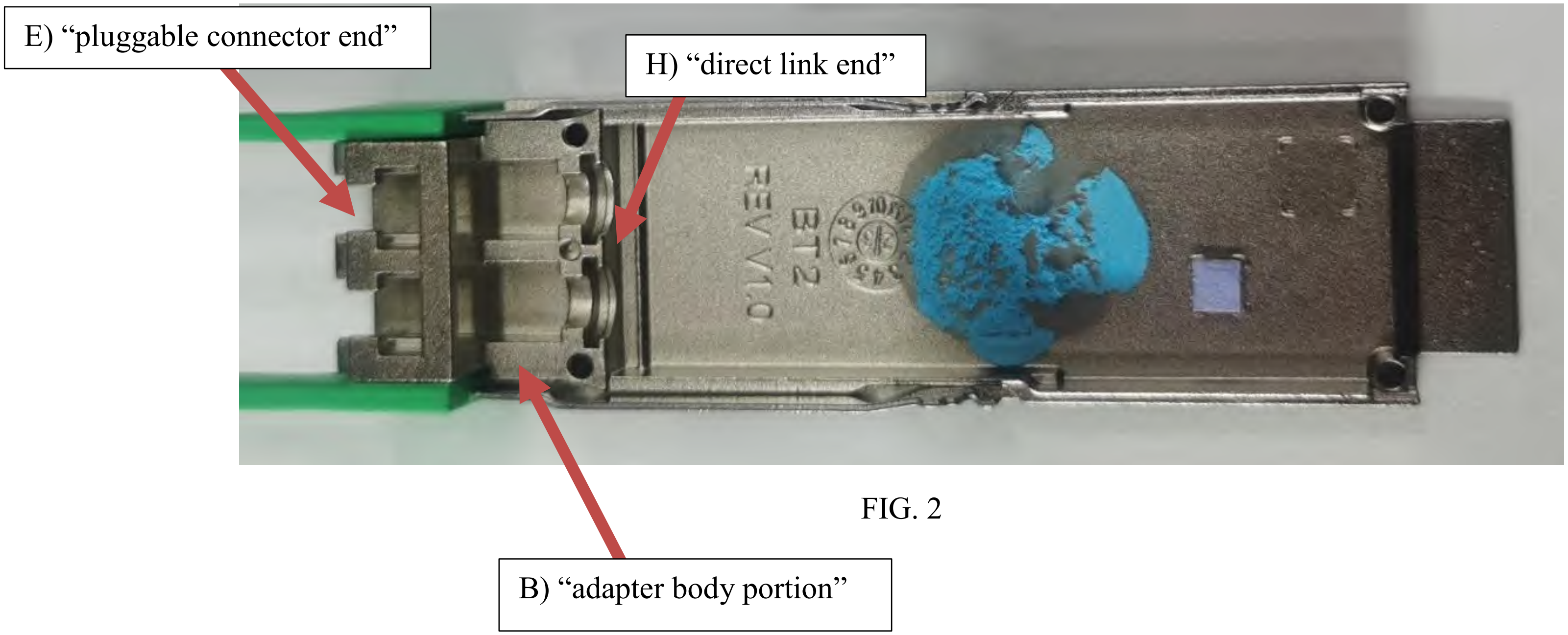


FIG. 2

Representative Claim Chart for U.S. Patent No. 9,448,367

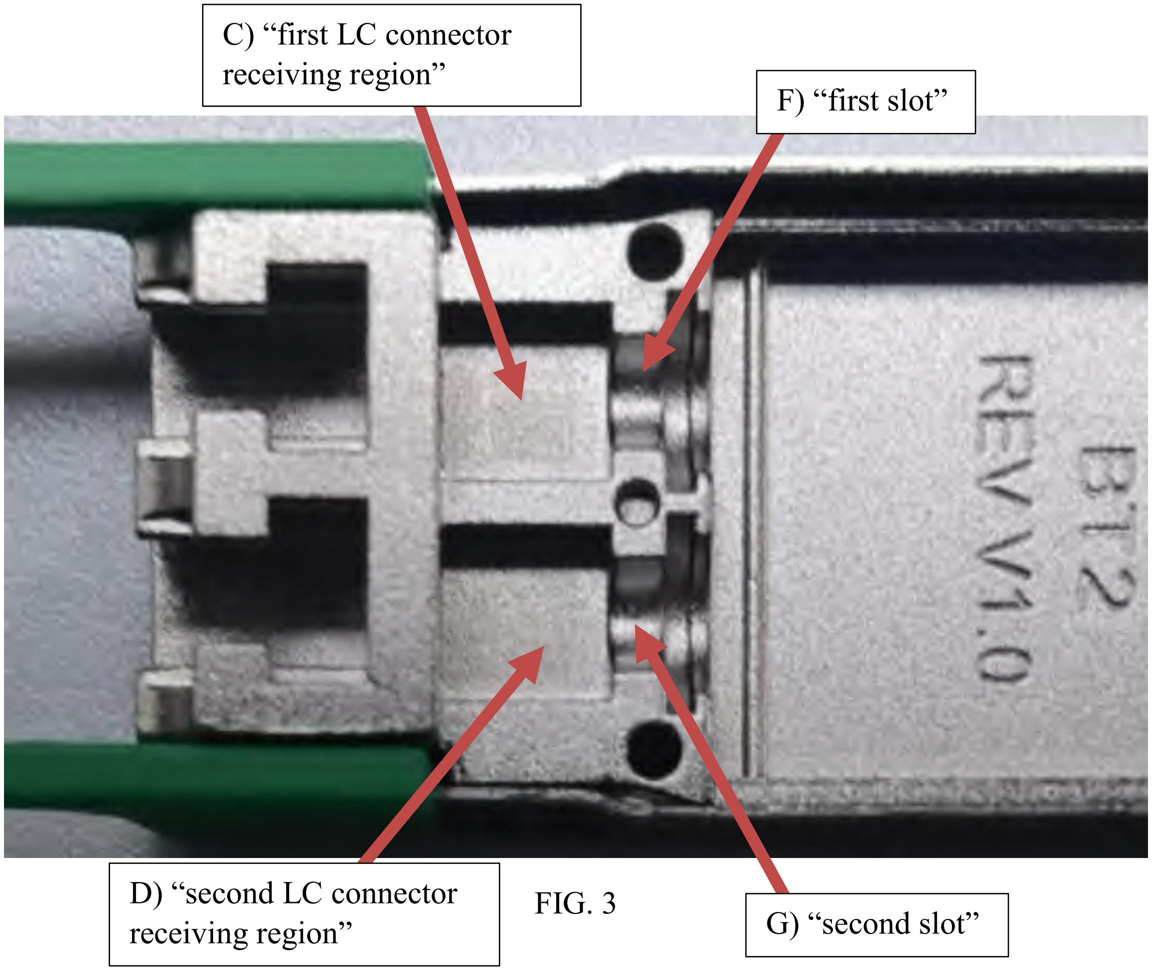


FIG. 3

Representative Claim Chart for U.S. Patent No. 9,448,367

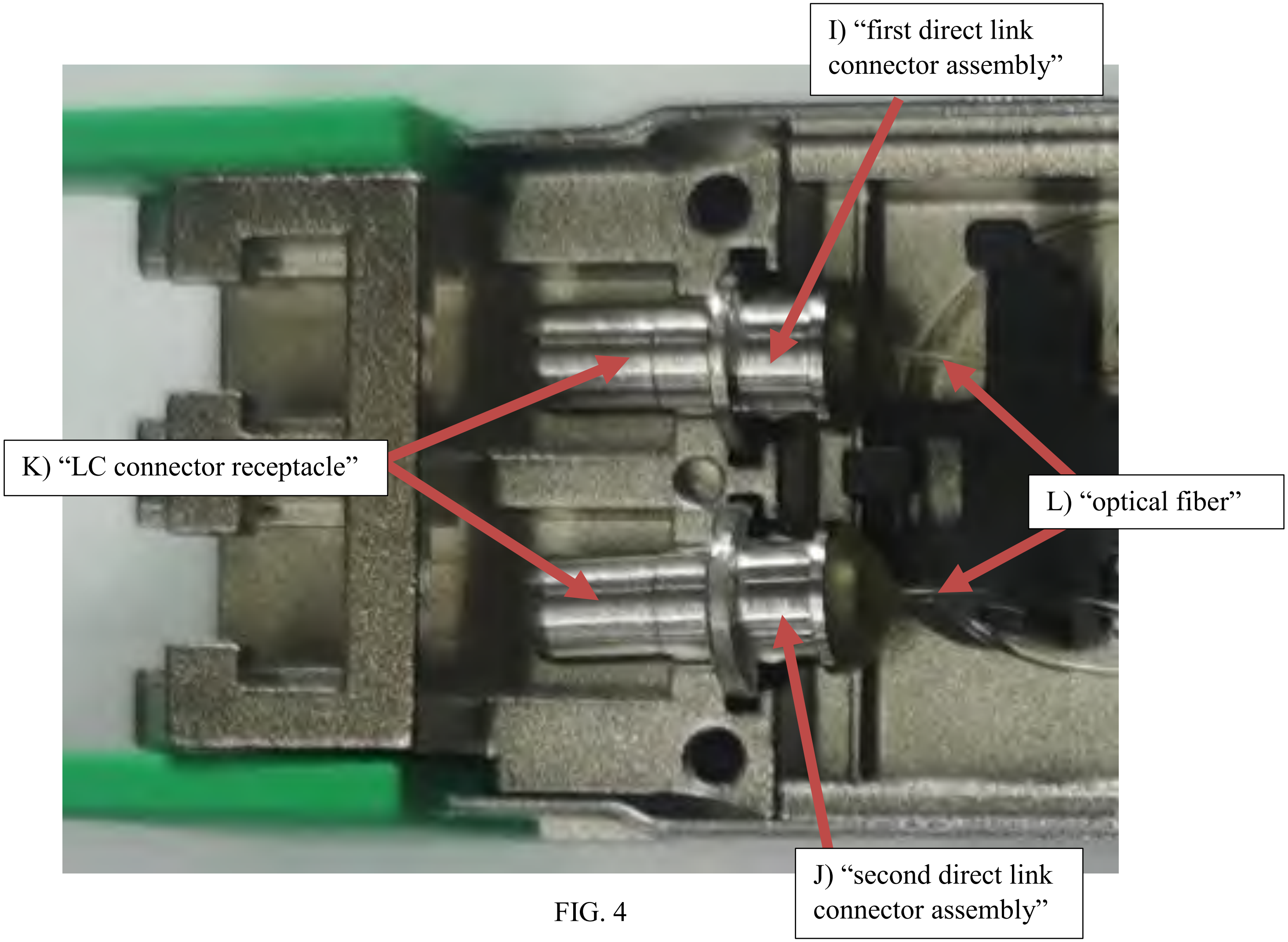


FIG. 4

Representative Claim Chart for U.S. Patent No. 9,448,367

U.S. Patent No. 9,448,367 Claim 1	EOPTOLINK 100G CWDM4 (QP85060003)
A dual fiber type direct link LC adapter comprising:	A dual fiber type direct link LC adapter **(A)**. See FIG. 1.
an adapter body portion defining first and second LC connector receiving regions at a pluggable connector end and defining first and second slots at a direct link end;	An adapter body portion **(B)** defines a first LC connector receiving region **(C)** and a second LC connector receiving region **(D)** at a pluggable connector end **(E)**, and defines a first slot **(F)** and a second slot **(G)** at a direct link end **(H)**. See FIGS. 2 and 3.
first and second direct link connector assemblies configured to be received in the first and second slots, respectively, each of the direct link connector assemblies defining an LC connector receptacle at one end, wherein the LC connector receptacle extends into a respective one of the LC connector receiving regions and is configured to receive a portion of an LC connector for optical coupling, and wherein each of the direct link connector assemblies is configured to be mechanically coupled to an optical fiber at another end; and	A first direct link connector assembly **(I)** and a second direct link connector assembly **(J)** are configured to be received in the first and second slots **(F, G)**, respectively. See FIGS. 3 and 4. Each of the direct link connector assemblies **(I, J)** defines an LC connector receptacle **(K)** at one end. The LC connector receptacle **(K)** extends into a respective one of the LC connector receiving regions **(C, D)** and is configured to receive a portion of an LC connector for optical coupling. Each of the direct link connector assemblies **(I, J)** is configured to be mechanically coupled to an optical fiber **(L)** at another end. See FIGS. 3 and 4.
an adapter cover portion configured to cover the first and second slots for retaining the direct link connector assemblies in the respective slots.	an adapter cover portion **(M)** configured to cover the first and second slots **(F, G)** for retaining the direct link connector assemblies **(I, J)** in the respective slots **(F, G)**. See FIGS. 1–4.

Exhibit H

Representative Claim Chart for U.S. Patent No. 9,448,367

EOPTOLINK 400G QSFP-DD FR4

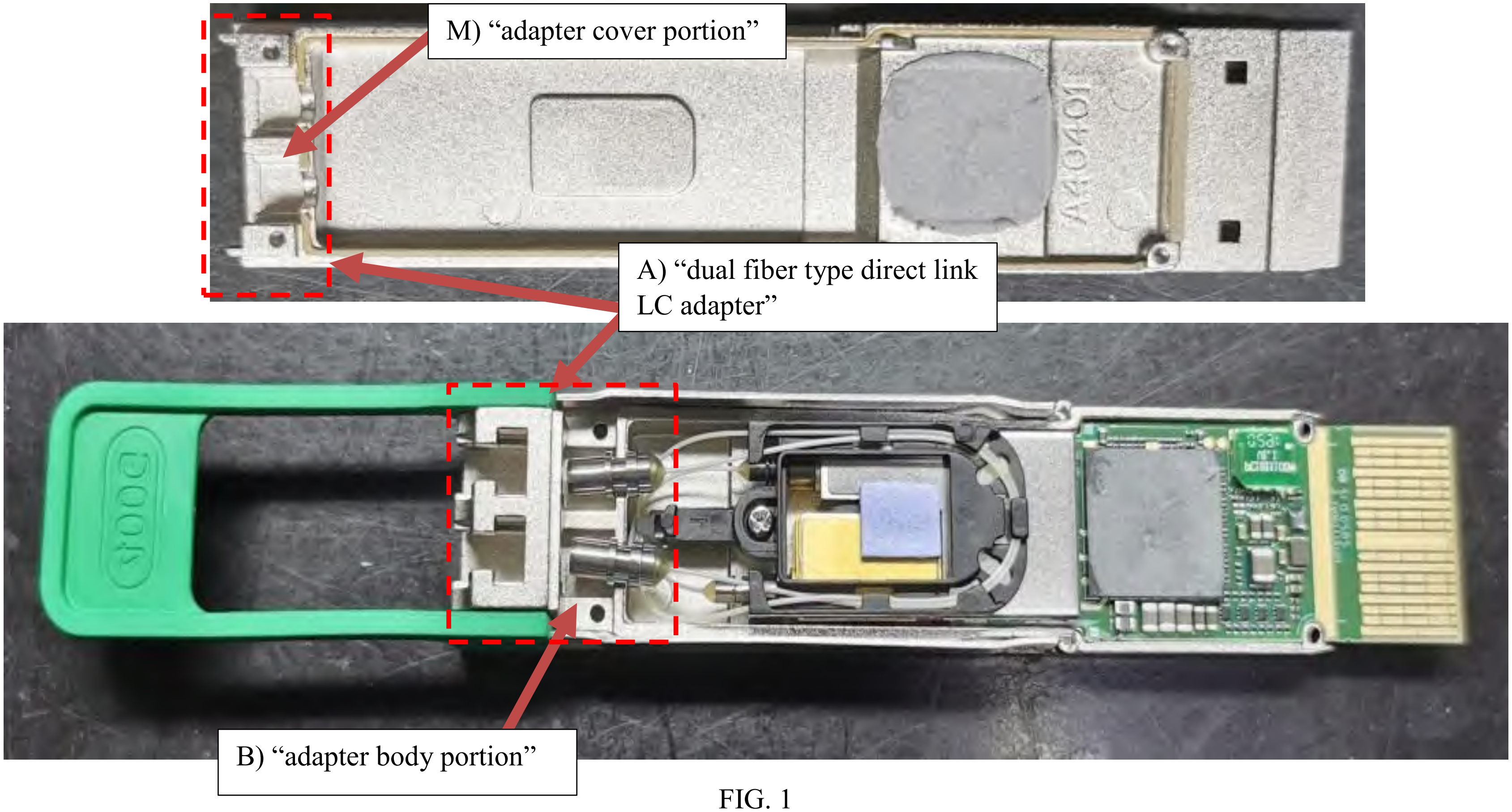


FIG. 1

Representative Claim Chart for U.S. Patent No. 9,448,367

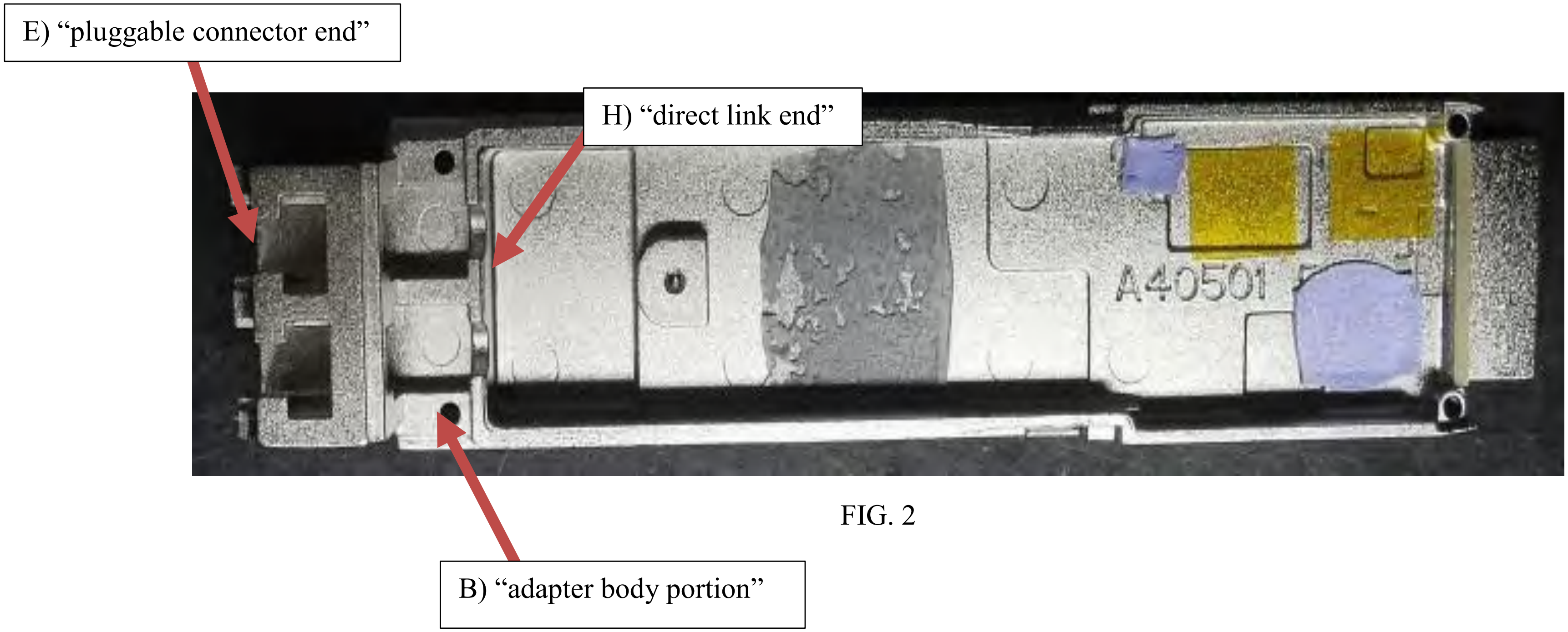


FIG. 2

Representative Claim Chart for U.S. Patent No. 9,448,367

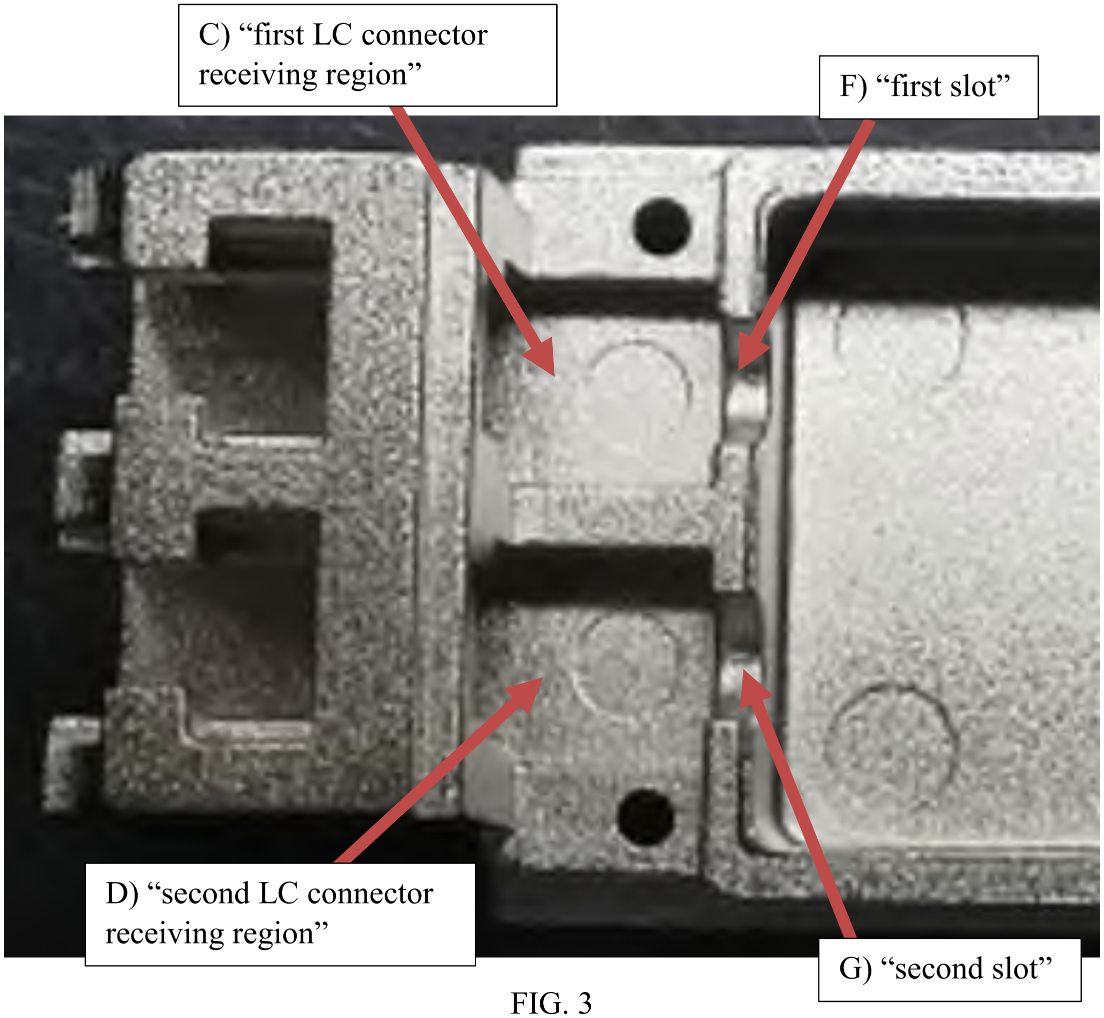
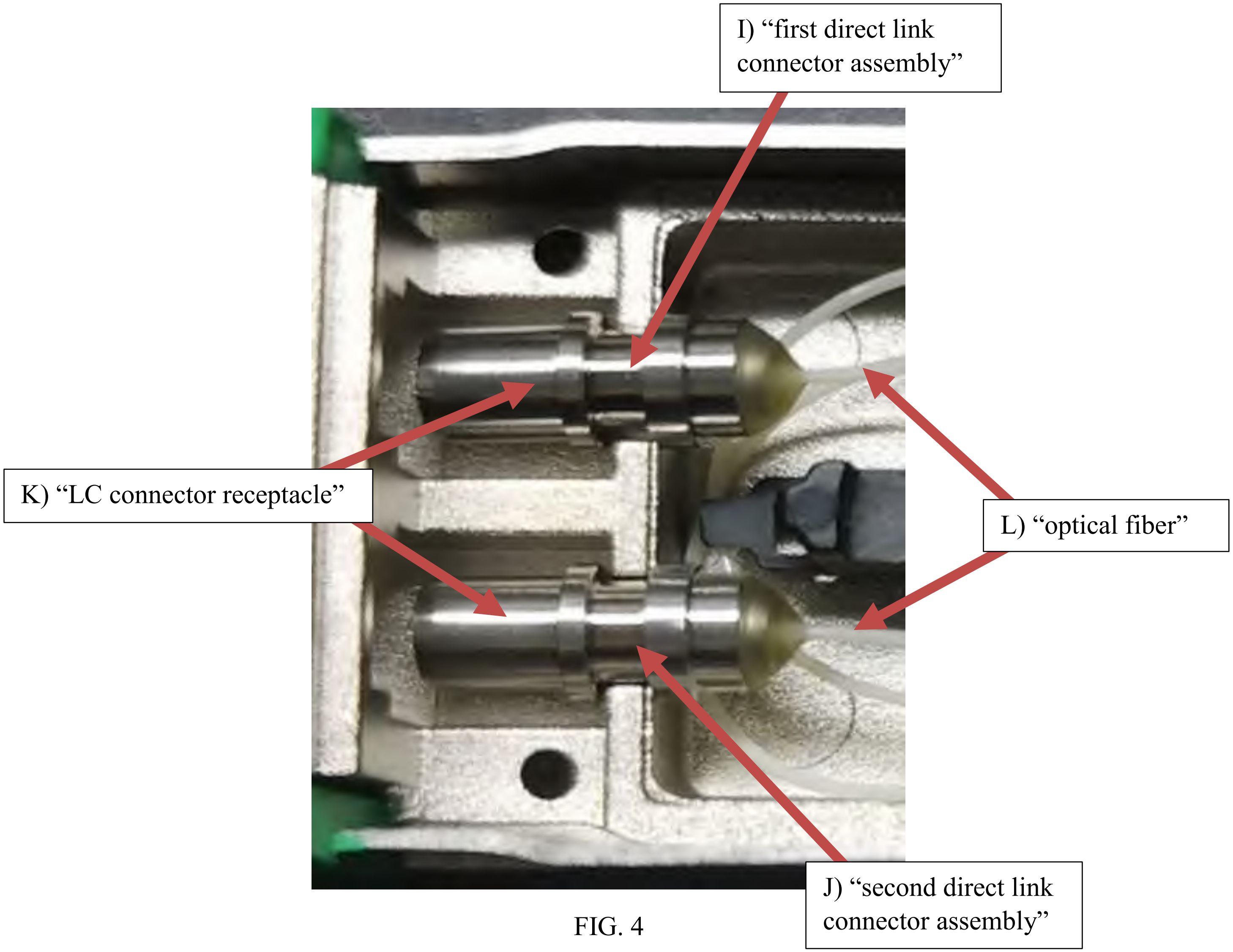


FIG. 3

Representative Claim Chart for U.S. Patent No. 9,448,367



I) “first direct link connector assembly”

K) “LC connector receptacle”

L) “optical fiber”

J) “second direct link connector assembly”

FIG. 4

Representative Claim Chart for U.S. Patent No. 9,448,367

U.S. Patent No. 9,448,367 Claim 1	EOPTOLINK 400G QSFP-DD FR4
A dual fiber type direct link LC adapter comprising:	A dual fiber type direct link LC adapter **(A)**. See FIG. 1.
an adapter body portion defining first and second LC connector receiving regions at a pluggable connector end and defining first and second slots at a direct link end;	An adapter body portion **(B)** defines a first LC connector receiving region **(C)** and a second LC connector receiving region **(D)** at a pluggable connector end **(E)**, and defines a first slot **(F)** and a second slot **(G)** at a direct link end **(H)**. See FIGS. 2 and 3.
first and second direct link connector assemblies configured to be received in the first and second slots, respectively, each of the direct link connector assemblies defining an LC connector receptacle at one end, wherein the LC connector receptacle extends into a respective one of the LC connector receiving regions and is configured to receive a portion of an LC connector for optical coupling, and wherein each of the direct link connector assemblies is configured to be mechanically coupled to an optical fiber at another end; and	A first direct link connector assembly **(I)** and a second direct link connector assembly **(J)** are configured to be received in the first and second slots **(F, G)**, respectively. See FIGS. 3 and 4. Each of the direct link connector assemblies **(I, J)** defines an LC connector receptacle **(K)** at one end. The LC connector receptacle **(K)** extends into a respective one of the LC connector receiving regions **(C, D)** and is configured to receive a portion of an LC connector for optical coupling. Each of the direct link connector assemblies **(I, J)** is configured to be mechanically coupled to an optical fiber **(L)** at another end. See FIGS. 3 and 4.
an adapter cover portion configured to cover the first and second slots for retaining the direct link connector assemblies in the respective slots.	an adapter cover portion **(M)** configured to cover the first and second slots **(F,G)** for retaining the direct link connector assemblies **(I, J)** in the respective slots **(F, G)**. See FIGS. 1–4.

Exhibit I

Representative Claim Chart for U.S. Patent No. 9,448,367

EOPTOLINK 400G QSFP-DD LR4

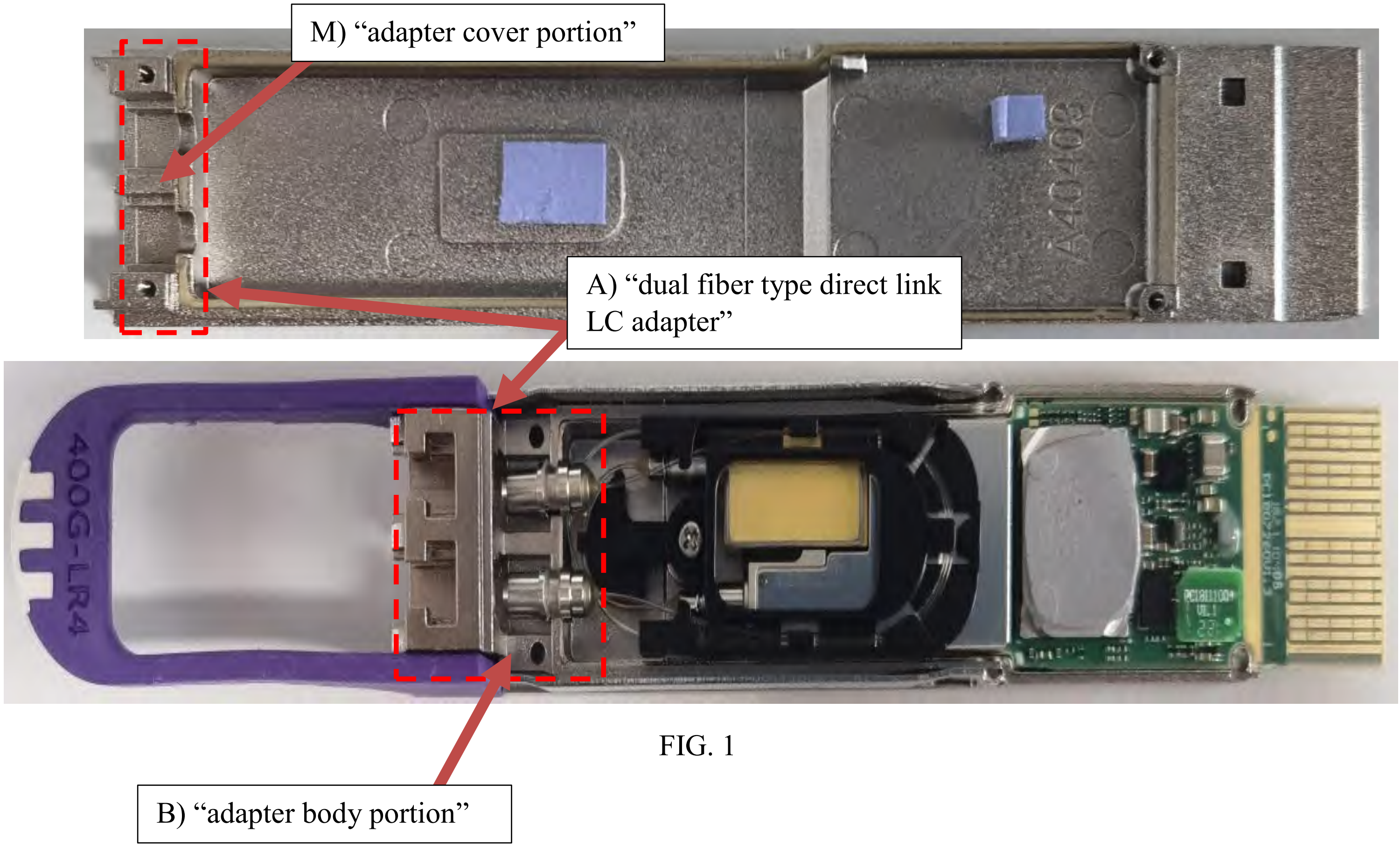


FIG. 1

Representative Claim Chart for U.S. Patent No. 9,448,367

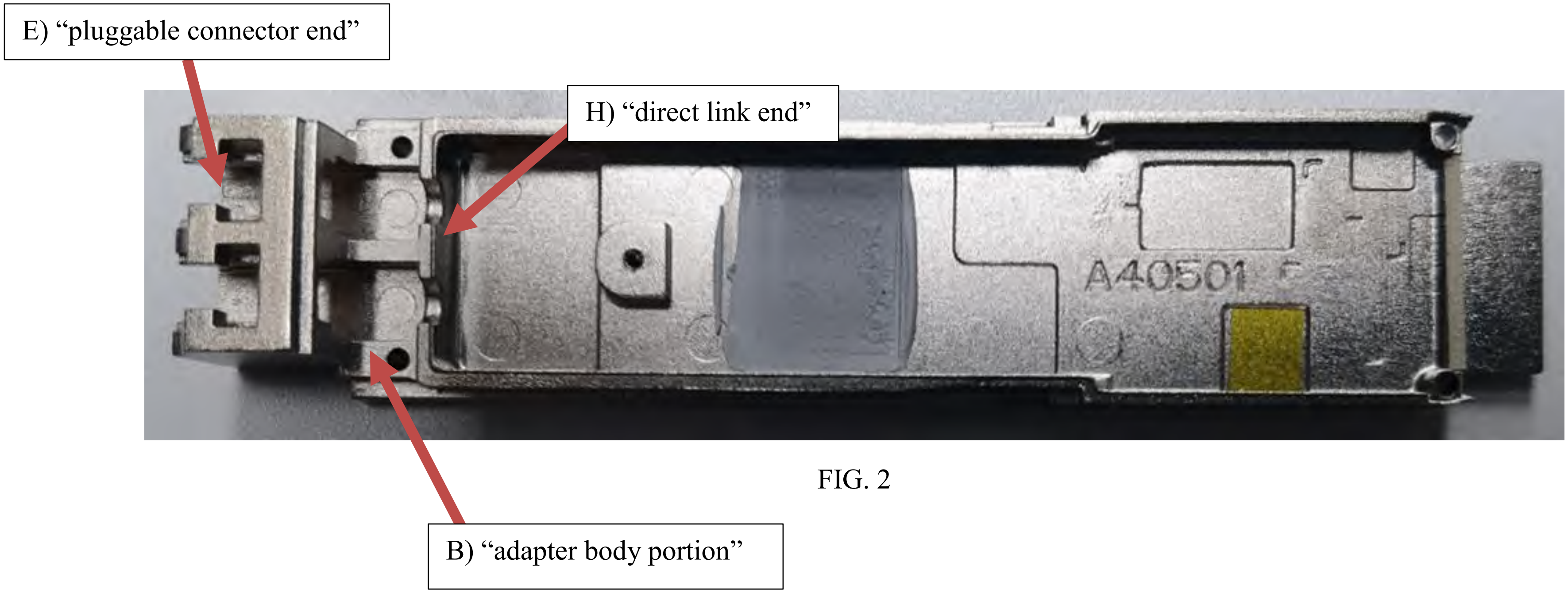


FIG. 2

Representative Claim Chart for U.S. Patent No. 9,448,367

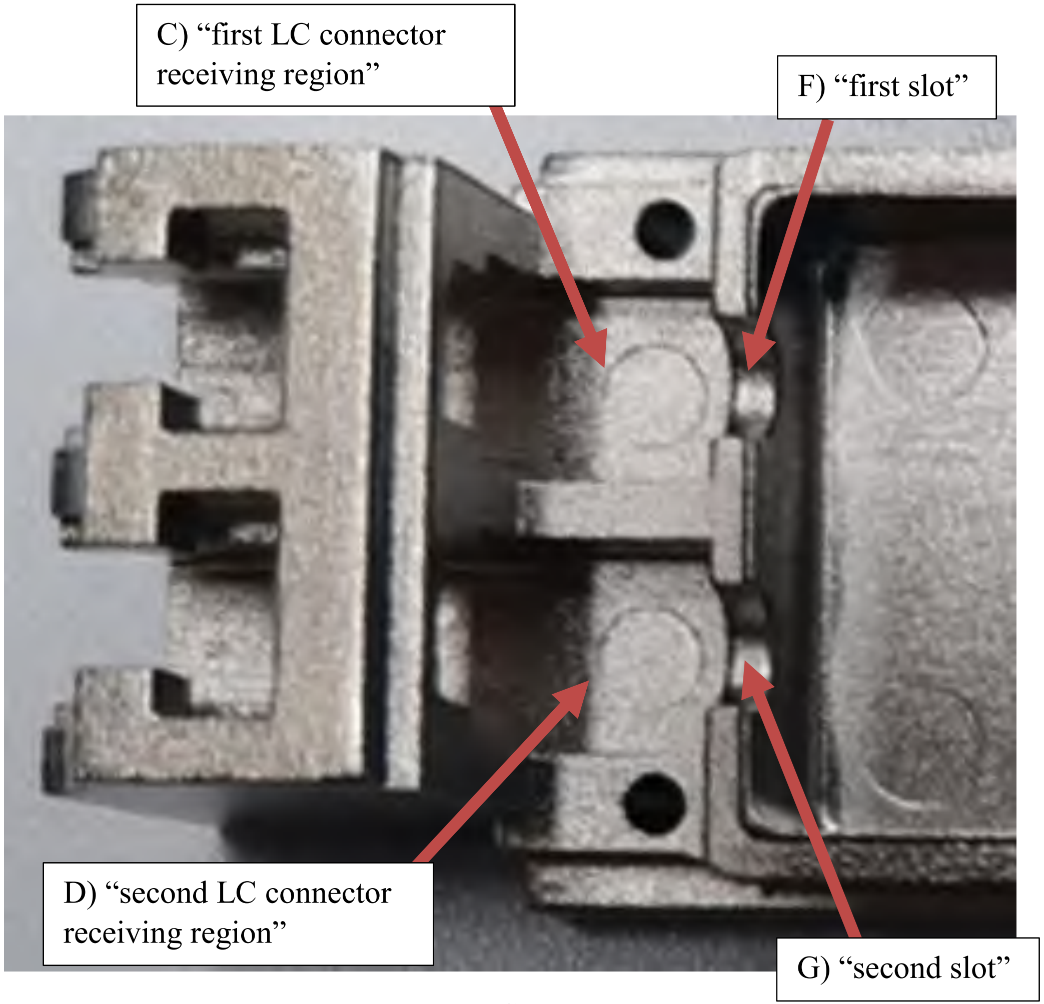


FIG. 3

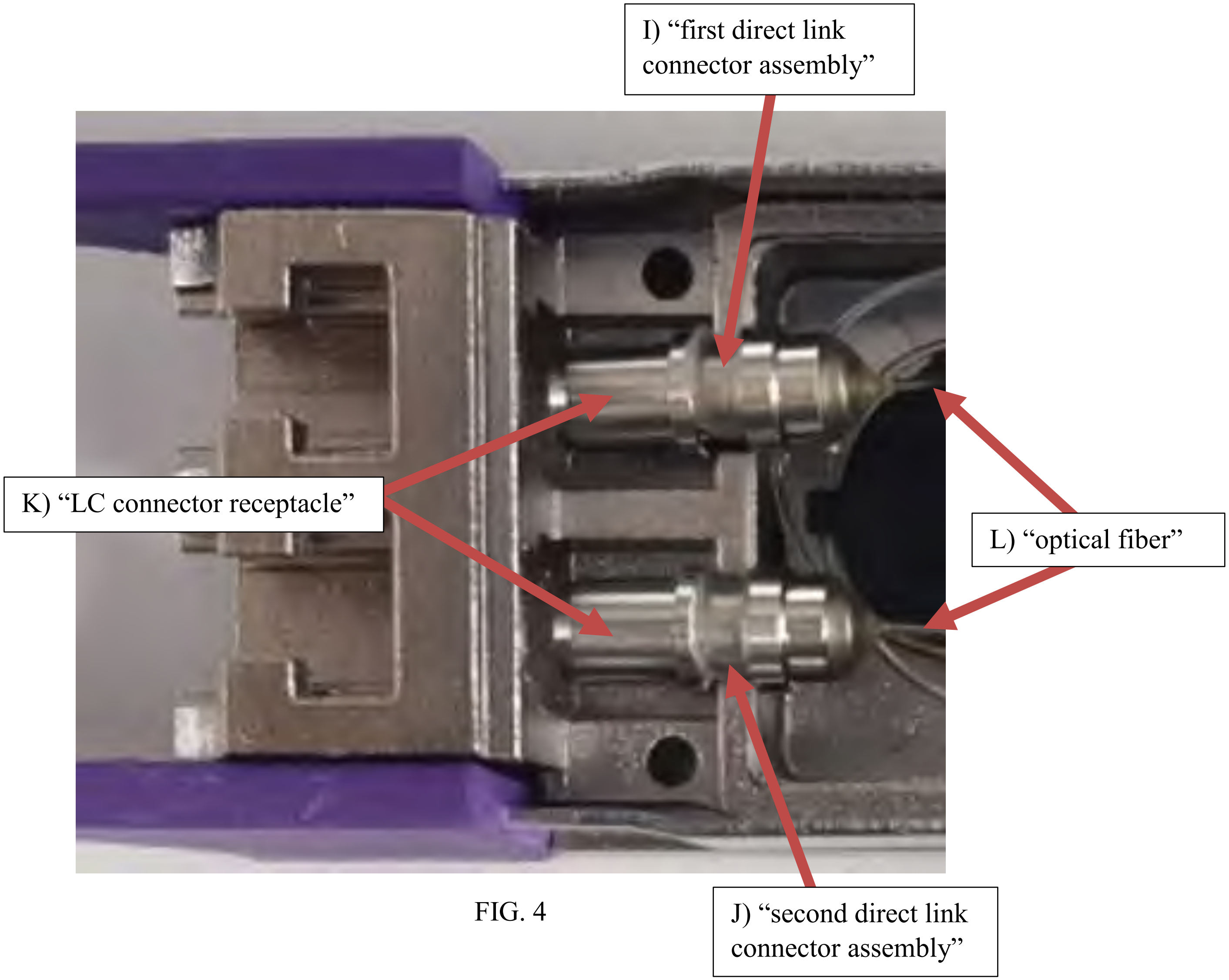

I) "first direct link connector assembly"
K) "LC connector receptacle"
L) "optical fiber"
J) "second direct link connector assembly"

FIG. 4

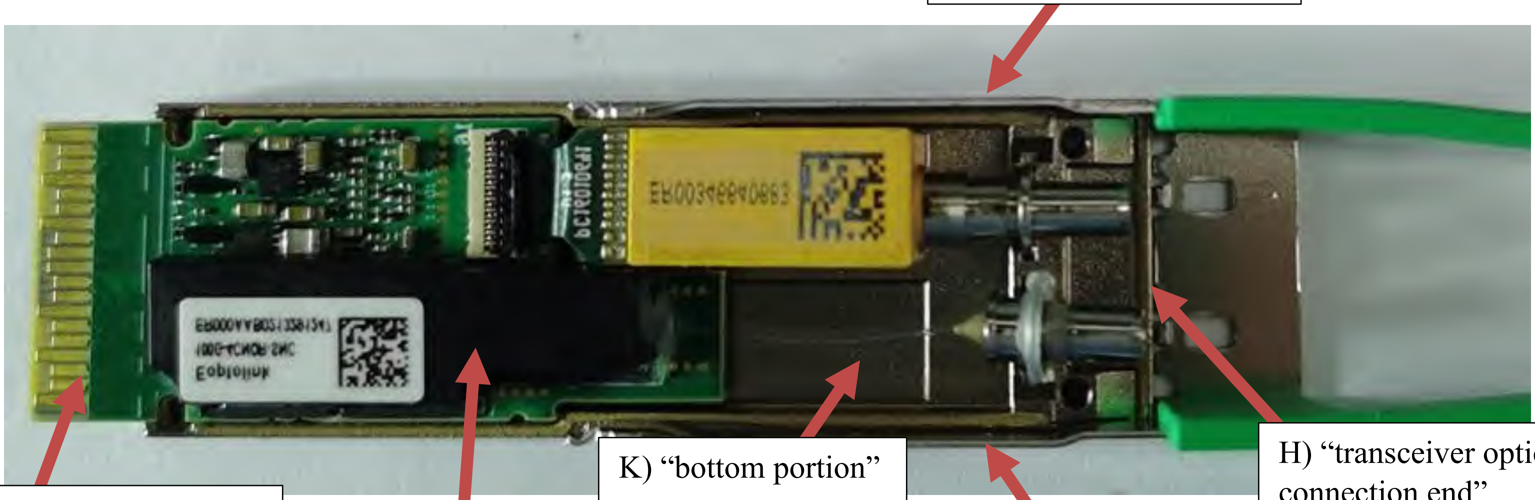
Representative Claim Chart for U.S. Patent No. 9,448,367

U.S. Patent No. 9,448,367 Claim 1	**EOPTOLINK 400G QSFP-DD LR4**
A dual fiber type direct link LC adapter comprising:	A dual fiber type direct link LC adapter **(A)**. See FIG. 1.
an adapter body portion defining first and second LC connector receiving regions at a pluggable connector end and defining first and second slots at a direct link end;	An adapter body portion **(B)** defines a first LC connector receiving region **(C)** and a second LC connector receiving region **(D)** at a pluggable connector end **(E)** and defines a first slot **(F)** and a second slot **(G)** at a direct link end **(H)**. See FIGS. 2 and 3.
first and second direct link connector assemblies configured to be received in the first and second slots, respectively, each of the direct link connector assemblies defining an LC connector receptacle at one end, wherein the LC connector receptacle extends into a respective one of the LC connector receiving regions and is configured to receive a portion of an LC connector for optical coupling, and wherein each of the direct link connector assemblies is configured to be mechanically coupled to an optical fiber at another end; and	A first direct link connector assembly **(I)** and a second direct link connector assembly **(J)** are configured to be received in the first and second slots **(F, G)**, respectively. See FIGS. 3 and 4. Each of the direct link connector assemblies **(I, J)** defines an LC connector receptacle **(K)** at one end. The LC connector receptacle **(K)** extends into a respective one of the LC connector receiving regions **(C, D)** and is configured to receive a portion of an LC connector for optical coupling. Each of the direct link connector assemblies **(I, J)** is configured to be mechanically coupled to an optical fiber **(L)** at another end. See FIGS. 3 and 4.
an adapter cover portion configured to cover the first and second slots for retaining the direct link connector assemblies in the respective slots.	an adapter cover portion **(M)** is configured to cover the first and second slots **(F,G)** for retaining the direct link connector assemblies **(I, J)** in the respective slots **(F, G)**. See FIGS. 1–4.

Exhibit J

Representative Claim Chart for U.S. Patent No. 9,509,433

1. EOPTOLINK 100G CWDM4 (QMBK440002)



A) “multi-channel optical transceiver module”

I) “transceiver electrical connection end”

C) “ROSA housing”

K) “bottom portion”

G) “transceiver housing”

H) “transceiver optical connection end”

FIG. 1

Representative Claim Chart for U.S. Patent No. 9,509,433

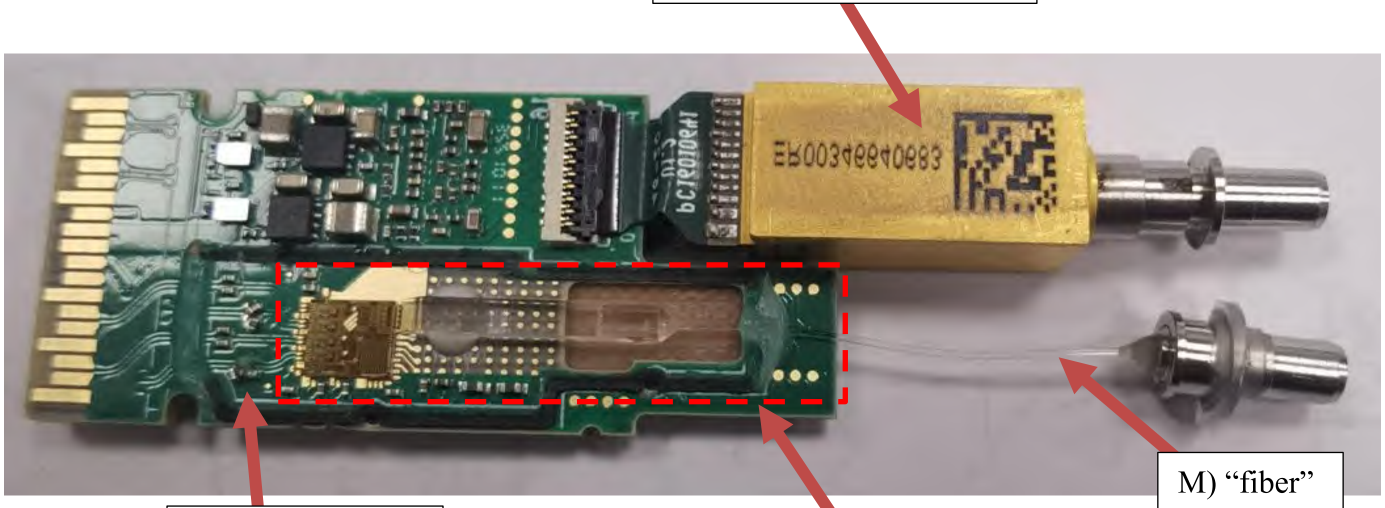
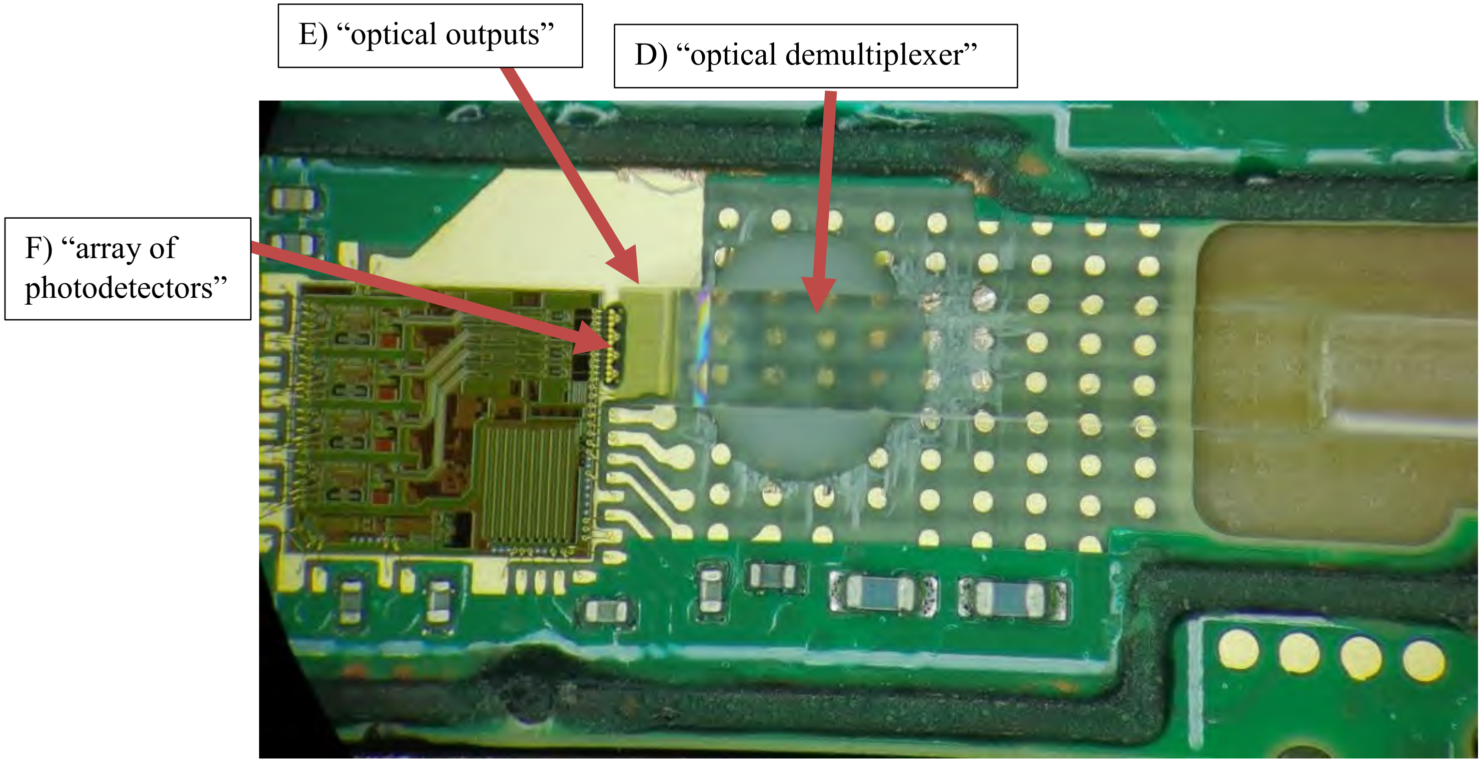


FIG. 2

Representative Claim Chart for U.S. Patent No. 9,509,433



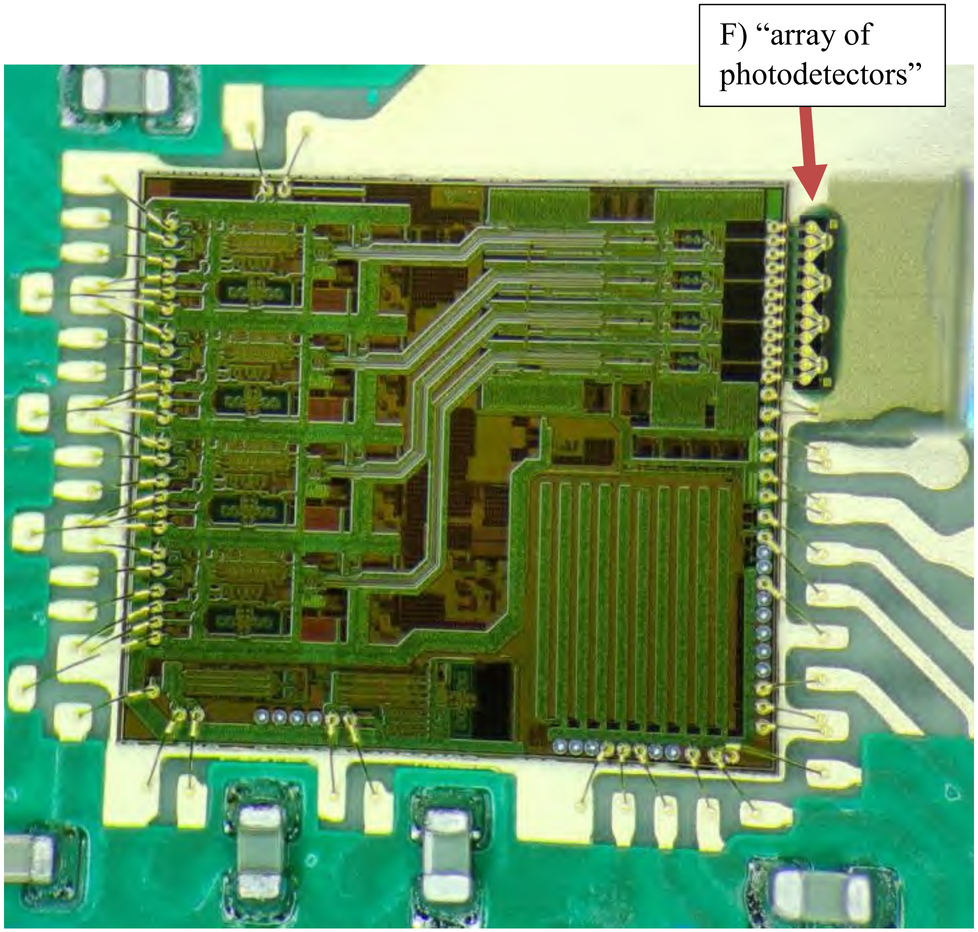
E) "optical outputs"

D) "optical demultiplexer"

F) "array of photodetectors"

FIG. 3

Representative Claim Chart for U.S. Patent No. 9,509,433



F) "array of photodetectors"

FIG. 4

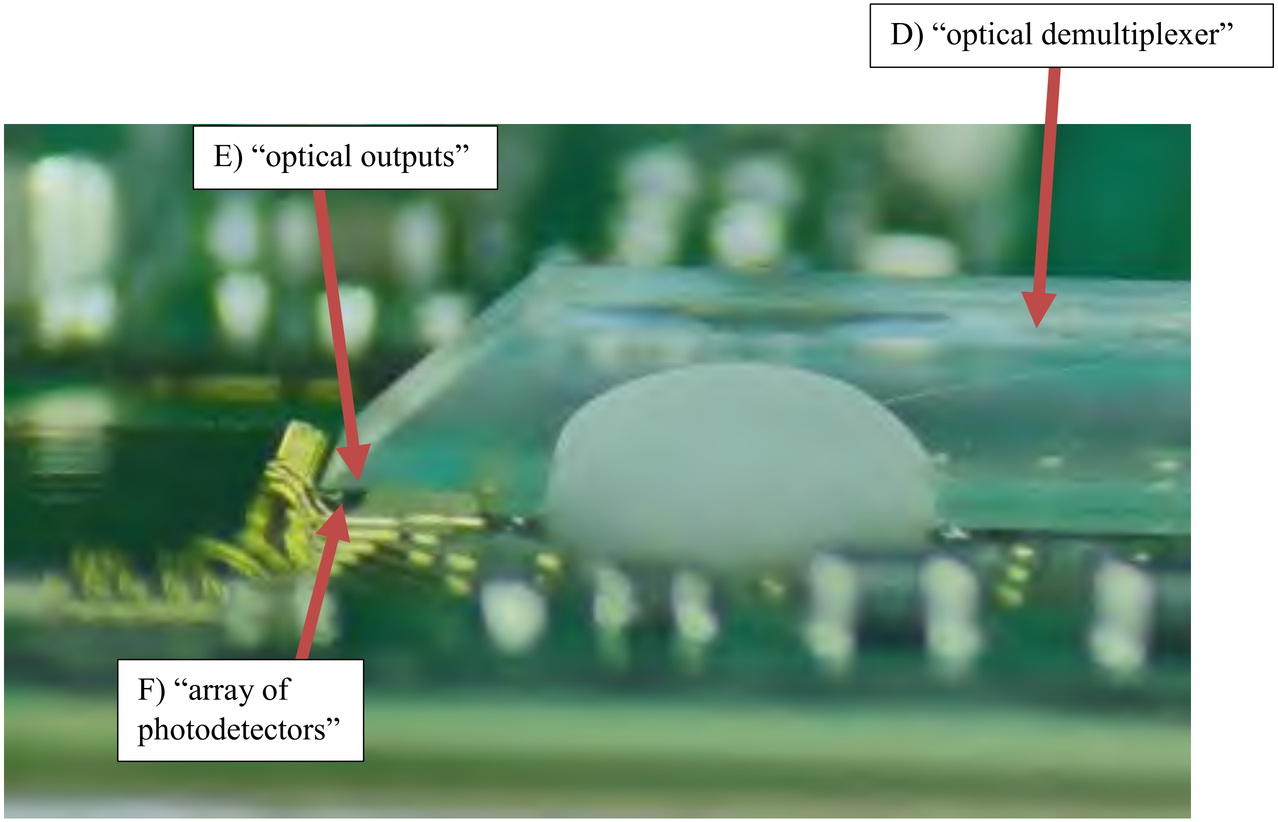

D) “optical demultiplexer”
E) “optical outputs”
F) “array of photodetectors”

FIG. 5

Representative Claim Chart for U.S. Patent No. 9,509,433

U.S. Patent No. 9,509,433

U.S. Patent No. 9,509,433 Claim 1	EOPTOLINK 100G CWDM4 (QMBK440002)
A multi-channel receiver optical subassembly (ROSA) comprising:	A multi-channel receiver (at least four channels) ROSA **(B)**. See FIG. 2.
a ROSA housing;	A cover above ROSA **(B)** and TOSA **(L)** is a ROSA housing **(C)**. See FIGS. 1 and 2.
an optical demultiplexer located in the ROSA housing, the optical demultiplexer including multiple optical outputs corresponding to multiple channels, the optical demultiplexer being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths, respectively; and	An optical demultiplexer **(D)** is located in the ROSA housing **(C)**. See FIGS. 1 and 3. The optical demultiplexer **(D)** includes multiple optical outputs **(E)** corresponding to multiple channels, the optical demultiplexer **(D)** being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths through a fiber **(M)** and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths. See FIGS. 2 and 3.
an array of photodetectors located in the ROSA housing and spaced from the optical demultiplexer, the array of photodetectors aligned with and directly optically coupled to the multiple optical outputs, respectively, of the optical demultiplexer.	An array of photodetectors **(F)** located in the ROSA housing **(C)** and spaced from the optical demultiplexer **(D)**, the array of photodetectors **(F)** is aligned with and optically coupled to the multiple optical outputs **(E)**, respectively, of the optical demultiplexer **(D)**. See FIGS. 1 and 3.

U.S. Patent No. 9,509,433 Claim 13	EOPTOLINK 100G CWDM4 (QMBK440002)
A multi-channel optical transceiver module comprising:	A multi-channel optical transceiver module **(A)**. See FIG. 1.
a transceiver housing having a transceiver optical connection end and a transceiver electrical connection end, the transceiver optical connection end of the transceiver housing being configured to provide an optical connection and the transceiver electrical connection end of the transceiver housing being configured to provide an electrical connection;	A transceiver housing **(G)** has a transceiver optical connection end **(H)** and a transceiver electrical connection end **(I)**. The transceiver optical connection end **(H)** is configured to provide an optical connection and the transceiver electrical connection end **(I)** is configured to provide an electrical connection. See FIG. 1.

Representative Claim Chart for U.S. Patent No. 9,509,433

a circuit board located in the transceiver housing proximate the transceiver housing bottom portion, wherein the circuit board includes RF inputs located proximate the transceiver electrical connection end of the transceiver housing;	A circuit board **(J)** is located in the transceiver housing **(G)** proximate the transceiver housing bottom portion **(K)**. The circuit board includes RF inputs located proximate the transceiver electrical connection end **(I)**. See FIGS. 1 and 2.
a multi-channel transmitter optical subassembly (TOSA) located in the transceiver housing and electrically connected to the circuit board, the TOSA being configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths; and	A multi-channel (at least four channels) TOSA **(L)** is located in the transceiver housing **(G)** and electrically connected to the circuit board **(J)**, the TOSA **(L)** is configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths. See FIGS. 1 and 2.
a multi-channel receiver optical subassembly (ROSA) located in the transceiver housing and electrically connected to the circuit board, the ROSA being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths,	A multi-channel (at least four channels) ROSA **(B)** is located in the transceiver housing **(G)** and electrically connected to the circuit board **(J)**, the ROSA **(B)** is configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths. See FIGS. 1 and 2.
wherein the ROSA comprises: an optical demultiplexer including multiple optical outputs corresponding to multiple channels, the optical demultiplexer being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths, respectively; and	An optical demultiplexer **(D)** includes multiple optical outputs **(E)** corresponding to multiple channels, the optical demultiplexer **(D)** is configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths through a fiber **(M)** and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths. See FIGS. 2 and 3.
an array of photodetectors aligned with and directly optically coupled to the multiple optical outputs, respectively, of the optical demultiplexer.	An array of photodetectors **(F)** is aligned with and optically coupled to the multiple optical outputs **(E)**, respectively, of the optical demultiplexer. See FIGS. 4 and 5.

Exhibit K

Representative Claim Chart for U.S. Patent No. 9,509,433

EOPTOLINK 100G CWDM4 (QP85060003)

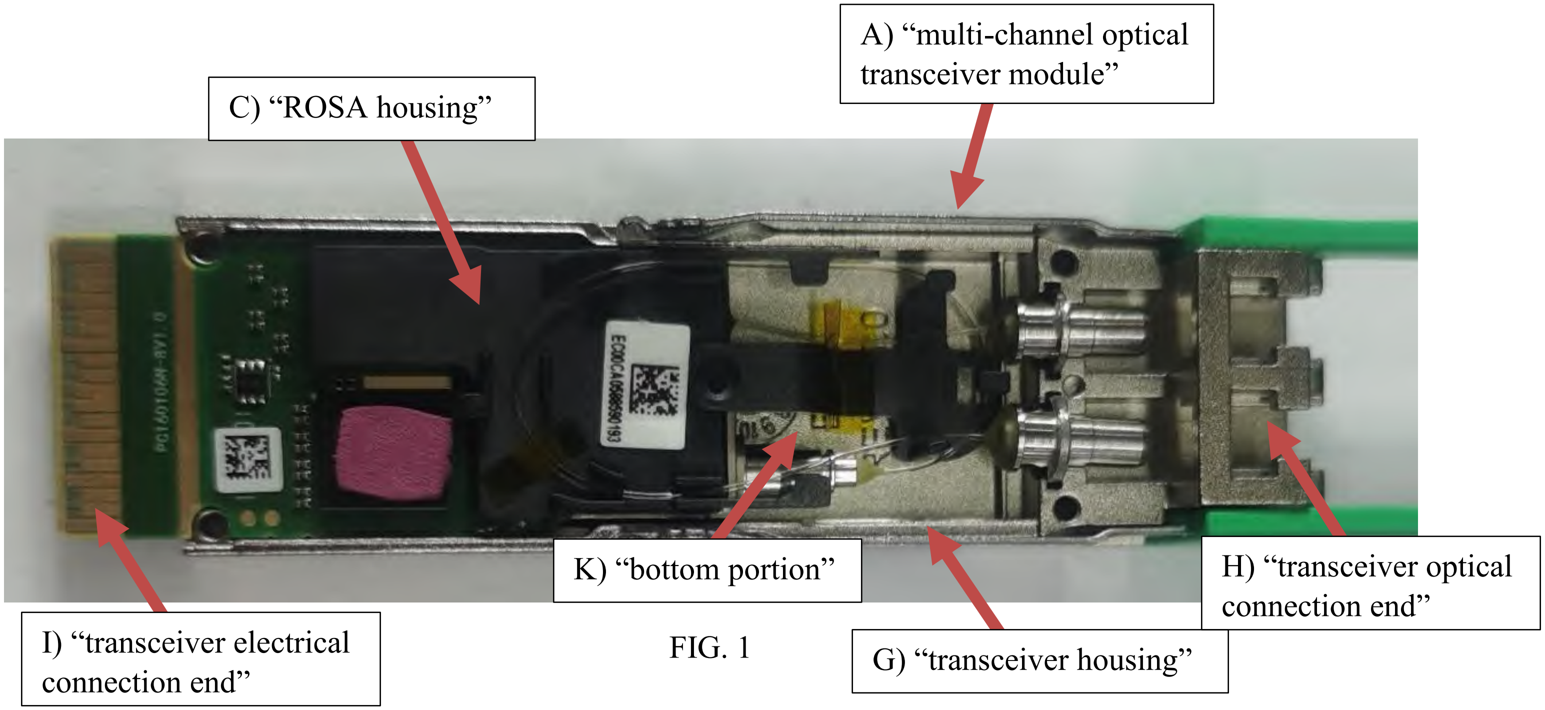


FIG. 1

Representative Claim Chart for U.S. Patent No. 9,509,433

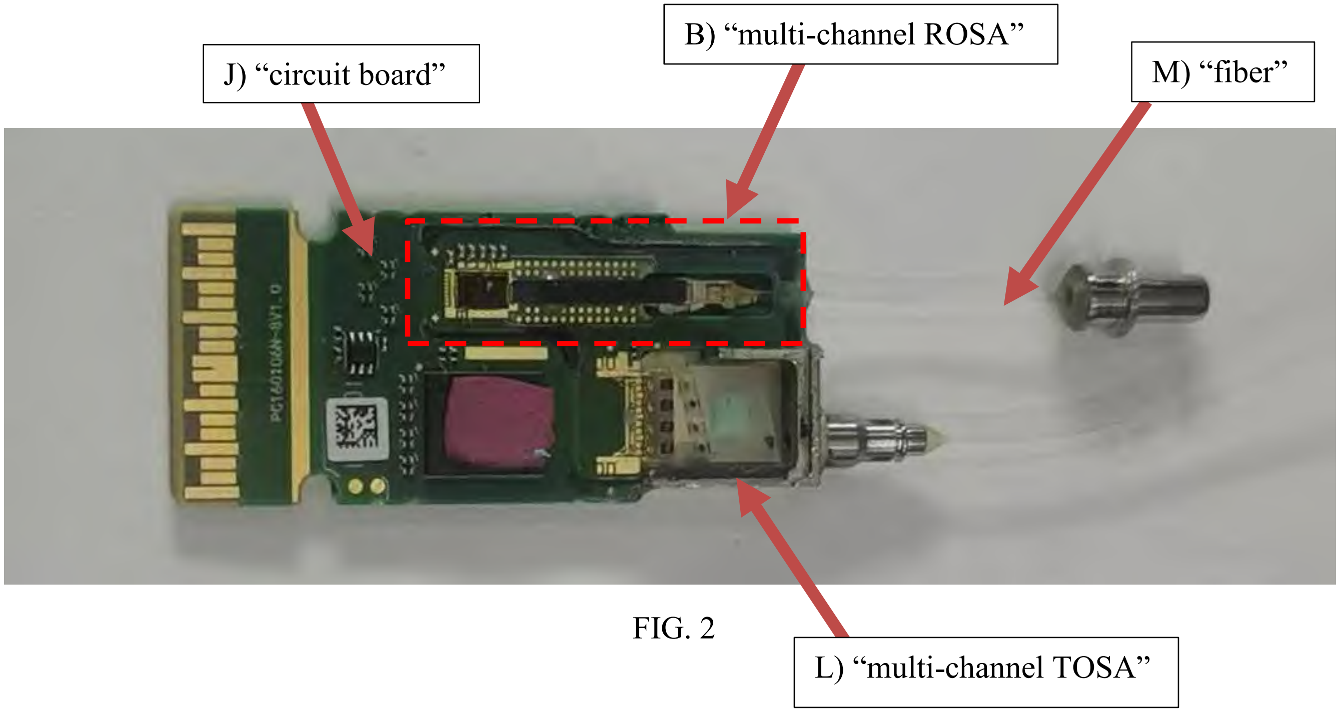


FIG. 2

Representative Claim Chart for U.S. Patent No. 9,509,433

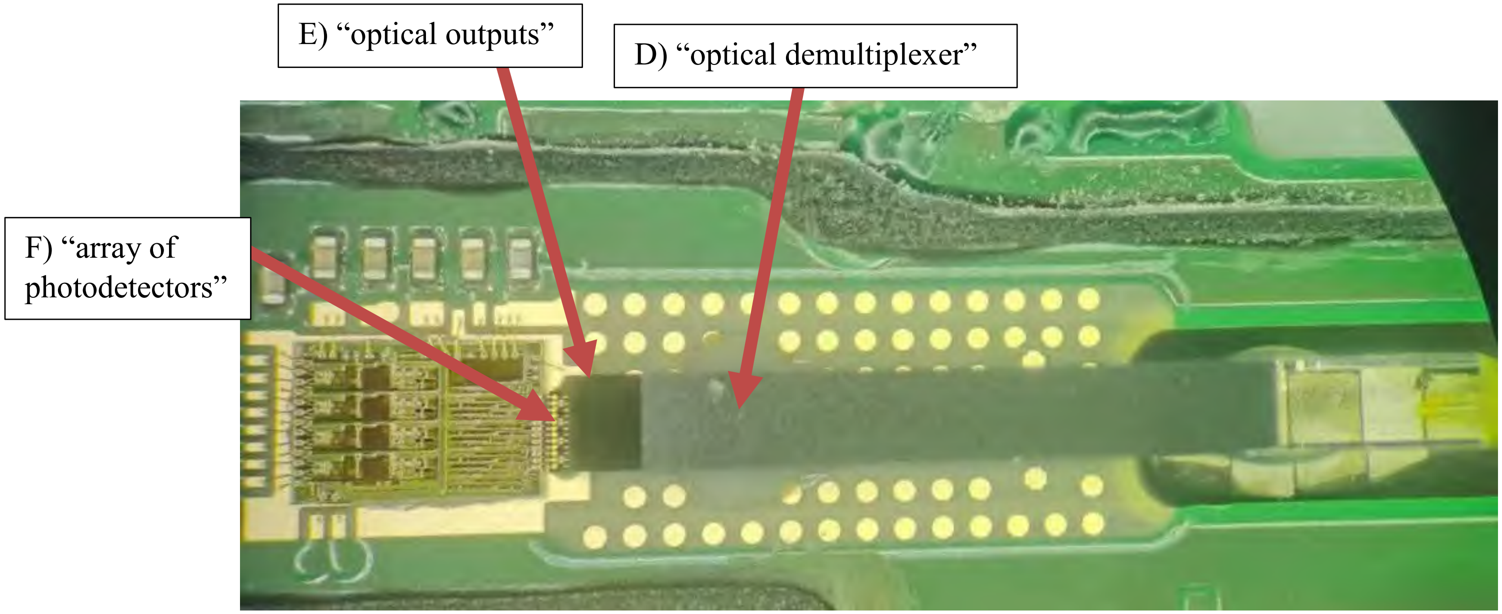


FIG. 3

Representative Claim Chart for U.S. Patent No. 9,509,433

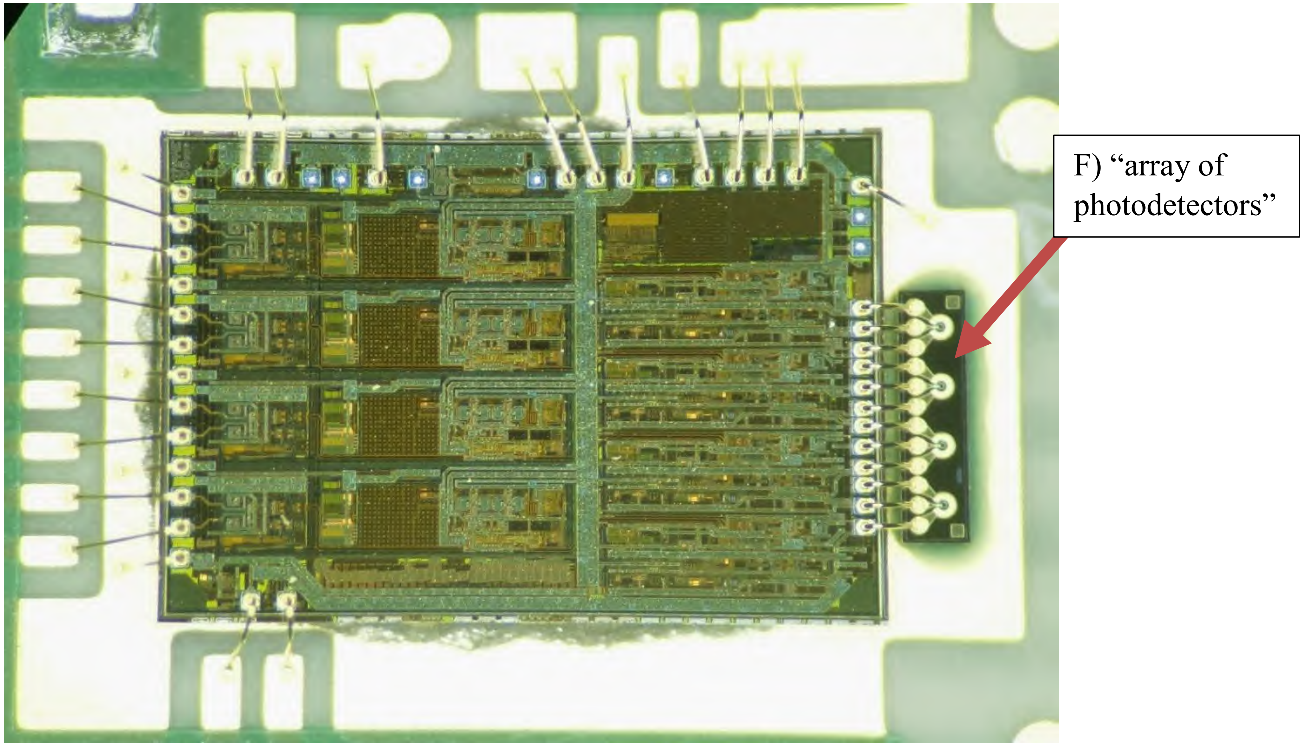


FIG. 4

Representative Claim Chart for U.S. Patent No. 9,509,433

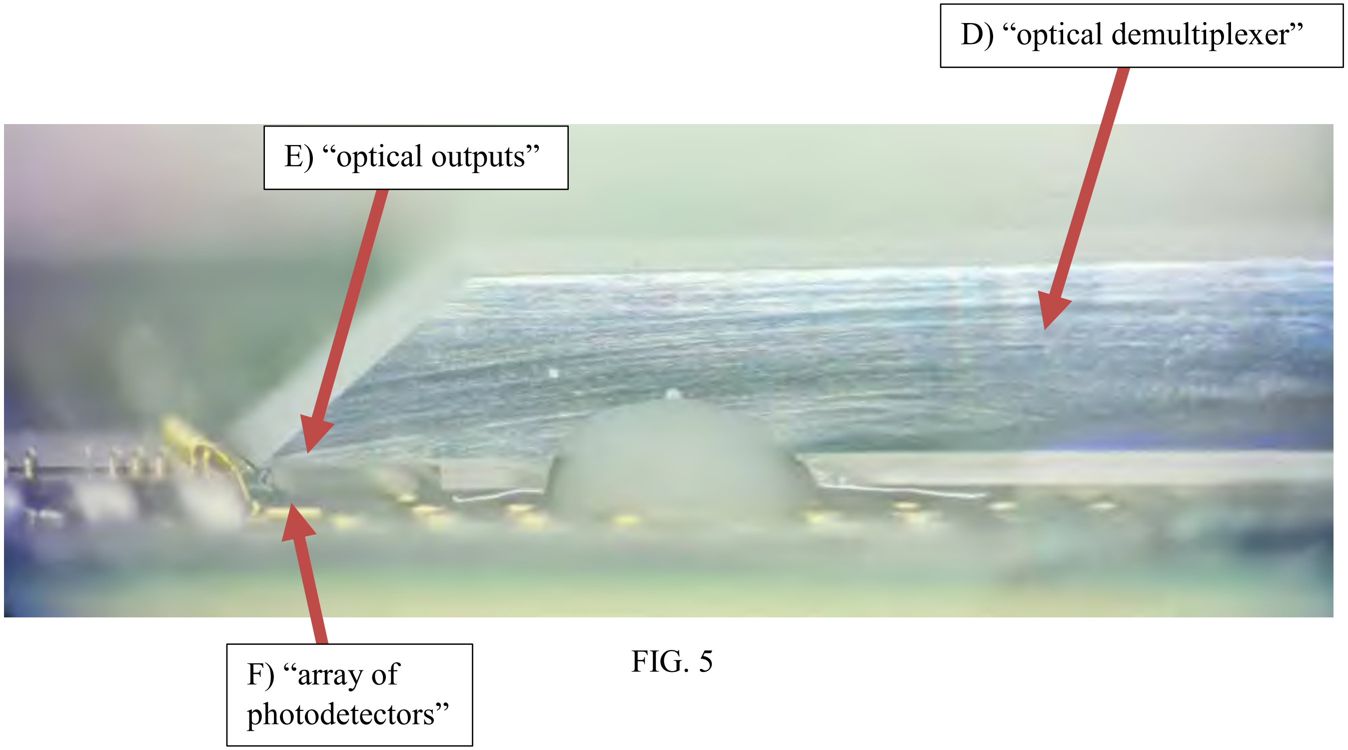


FIG. 5

Representative Claim Chart for U.S. Patent No. 9,509,433

U.S. Patent No. 9,509,433 Claim 1	**EOPTOLINK 100G CWDM4 (QP85060003)**
A multi-channel receiver optical subassembly (ROSA) comprising:	A multi-channel receiver (at least four channels) ROSA **(B)**. See FIG. 2.
a ROSA housing;	A cover above ROSA **(B)** and TOSA **(L)** is a ROSA housing **(C)**. See FIGS. 1 and 2.
an optical demultiplexer located in the ROSA housing, the optical demultiplexer including multiple optical outputs corresponding to multiple channels, the optical demultiplexer being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths, respectively; and	An optical demultiplexer **(D)** is located in the ROSA housing **(C)**. See FIGS. 1 and 3. The optical demultiplexer **(D)** includes multiple optical outputs **(E)** corresponding to multiple channels, the optical demultiplexer **(D)** being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths through a fiber **(M)** and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths. See FIGS. 2 and 3.
an array of photodetectors located in the ROSA housing and spaced from the optical demultiplexer, the array of photodetectors aligned with and directly optically coupled to the multiple optical outputs, respectively, of the optical demultiplexer.	An array of photodetectors **(F)** is located in the ROSA housing **(C)** and spaced from the optical demultiplexer **(D)**. The array of photodetectors **(F)** is aligned with and optically coupled to the multiple optical outputs **(E)**, respectively, of the optical demultiplexer **(D)**. See FIGS. 1 and 3.

U.S. Patent No. 9,509,433 Claim 13	**EOPTOLINK 100G CWDM4 (QP85060003)**
A multi-channel optical transceiver module comprising:	A multi-channel optical transceiver module **(A)**. See FIG. 1.
a transceiver housing having a transceiver optical connection end and a transceiver electrical connection end, the transceiver optical connection end of the transceiver housing being configured to provide an optical connection and the transceiver electrical connection end of the transceiver housing being configured to provide an electrical connection;	A transceiver housing **(G)** has a transceiver optical connection end **(H)** and a transceiver electrical connection end **(I)**. The transceiver optical connection end **(H)** is configured to provide an optical connection and the transceiver electrical connection end **(I)** is configured to provide an electrical connection. See FIG. 1.

Representative Claim Chart for U.S. Patent No. 9,509,433

a circuit board located in the transceiver housing proximate the transceiver housing bottom portion, wherein the circuit board includes RF inputs located proximate the transceiver electrical connection end of the transceiver housing;	A circuit board **(J)** is located in the transceiver housing **(G)** proximate the transceiver housing bottom portion **(K)**. The circuit board includes RF inputs located proximate the transceiver electrical connection end **(I)**. See FIGS. 1 and 2.
a multi-channel transmitter optical subassembly (TOSA) located in the transceiver housing and electrically connected to the circuit board, the TOSA being configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths; and	A multi-channel (at least four channels) TOSA **(L)** is located in the transceiver housing **(G)** and electrically connected to the circuit board **(J)**. The TOSA **(L)** is configured to transmit a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths. See FIGS. 1 and 2.
a multi-channel receiver optical subassembly (ROSA) located in the transceiver housing and electrically connected to the circuit board, the ROSA being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths,	A multi-channel (at least four channels) ROSA **(B)** is located in the transceiver housing **(G)** and electrically connected to the circuit board **(J)**. The ROSA **(B)** is configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths. See FIGS. 1 and 2.
wherein the ROSA comprises: an optical demultiplexer including multiple optical outputs corresponding to multiple channels, the optical demultiplexer being configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths, respectively; and	An optical demultiplexer **(D)** includes multiple optical outputs **(E)** corresponding to multiple channels, the optical demultiplexer **(D)** is configured to receive a wavelength division multiplexed (WDM) optical signal on multiple channel wavelengths through a fiber **(M)** and to demultiplex the WDM optical signal to produce demultiplexed optical signals on the multiple channel wavelengths. See FIGS. 2 and 3.
an array of photodetectors aligned with and directly optically coupled to the multiple optical outputs, respectively, of the optical demultiplexer.	An array of photodetectors **(F)** is aligned with and optically coupled to the multiple optical outputs **(E)**, respectively, of the optical demultiplexer **(D)**. See FIGS. 4 and 5.

Exhibit L

Representative Claim Chart for U.S. Patent No. 10,230,470

EOPTOLINK 100G QSFP LR4 (QJ3D490147)

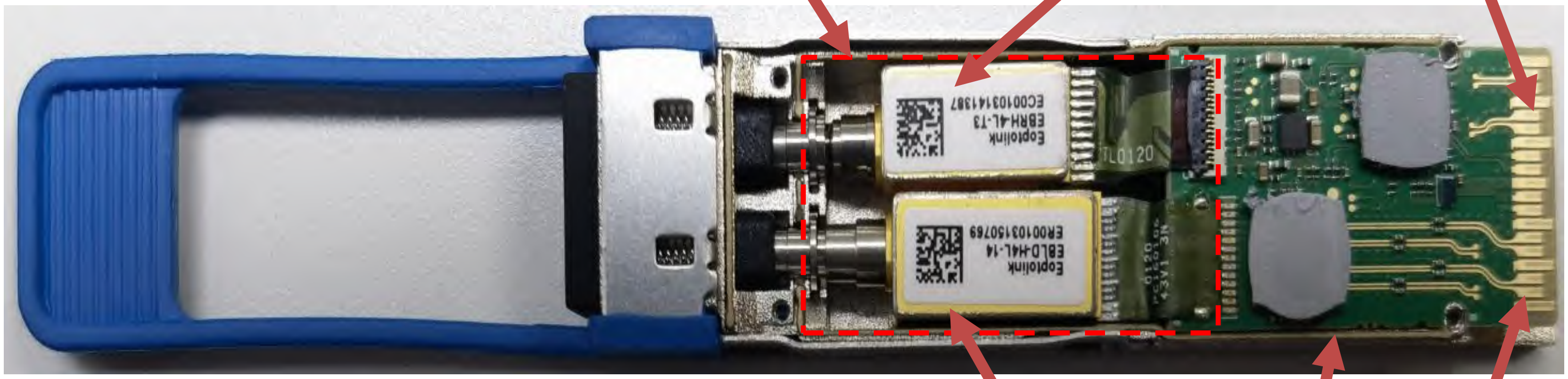


FIG. 1

Representative Claim Chart for U.S. Patent No. 10,230,470

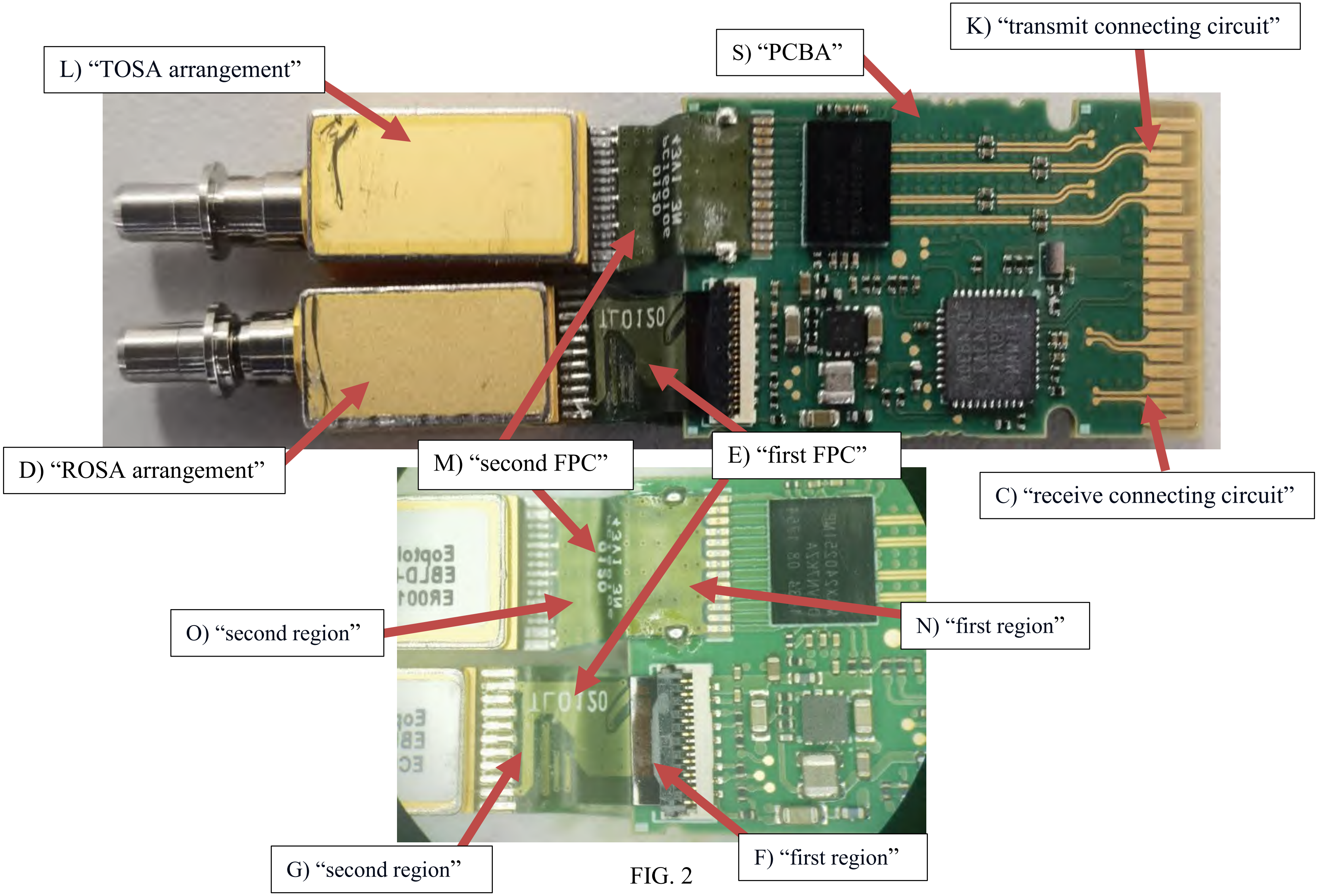


FIG. 2

Representative Claim Chart for U.S. Patent No. 10,230,470

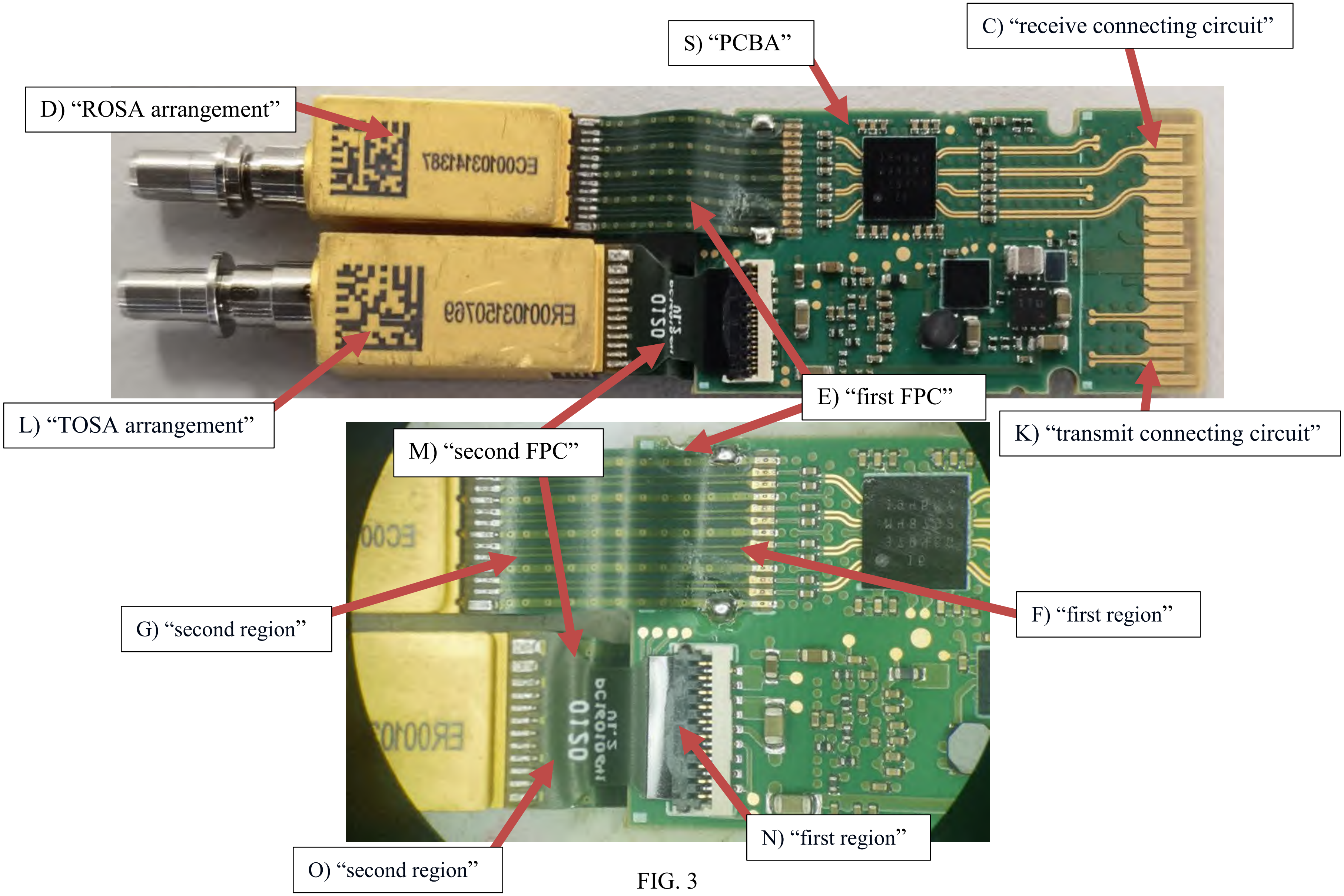


FIG. 3

Representative Claim Chart for U.S. Patent No. 10,230,470

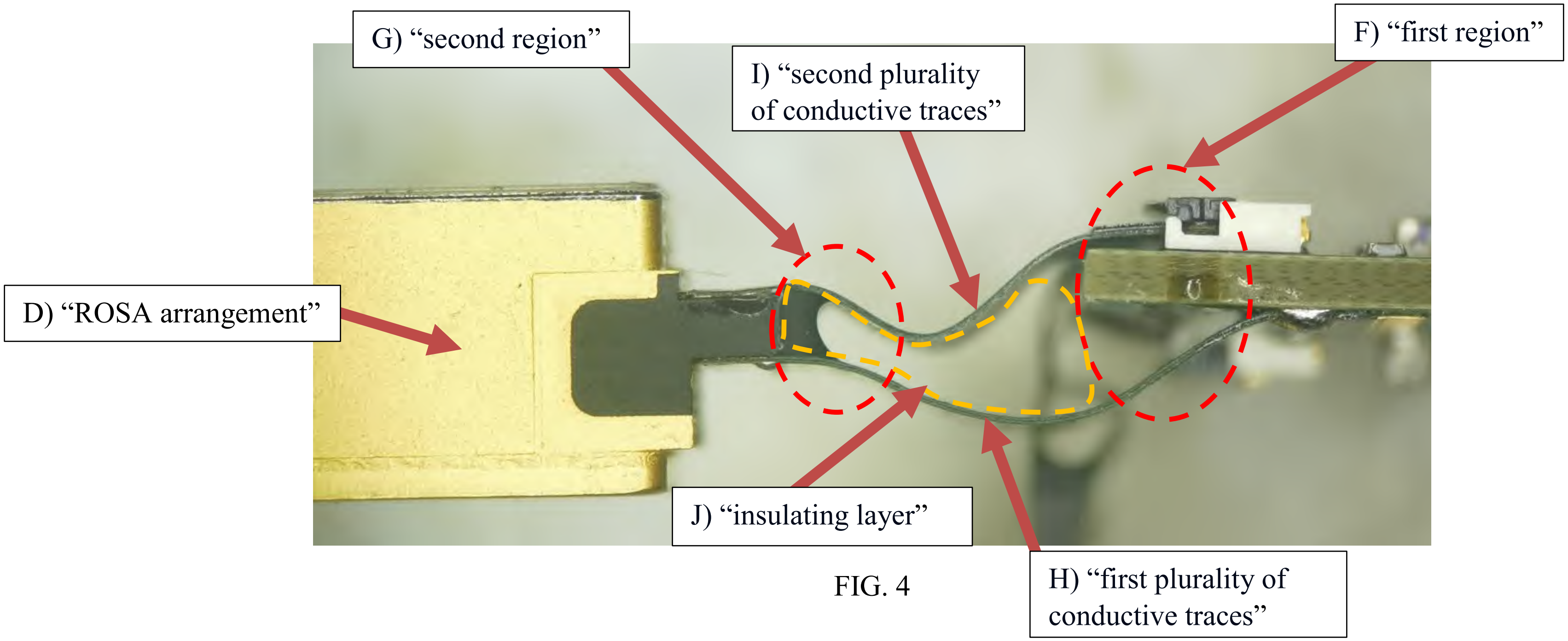


FIG. 4

Representative Claim Chart for U.S. Patent No. 10,230,470

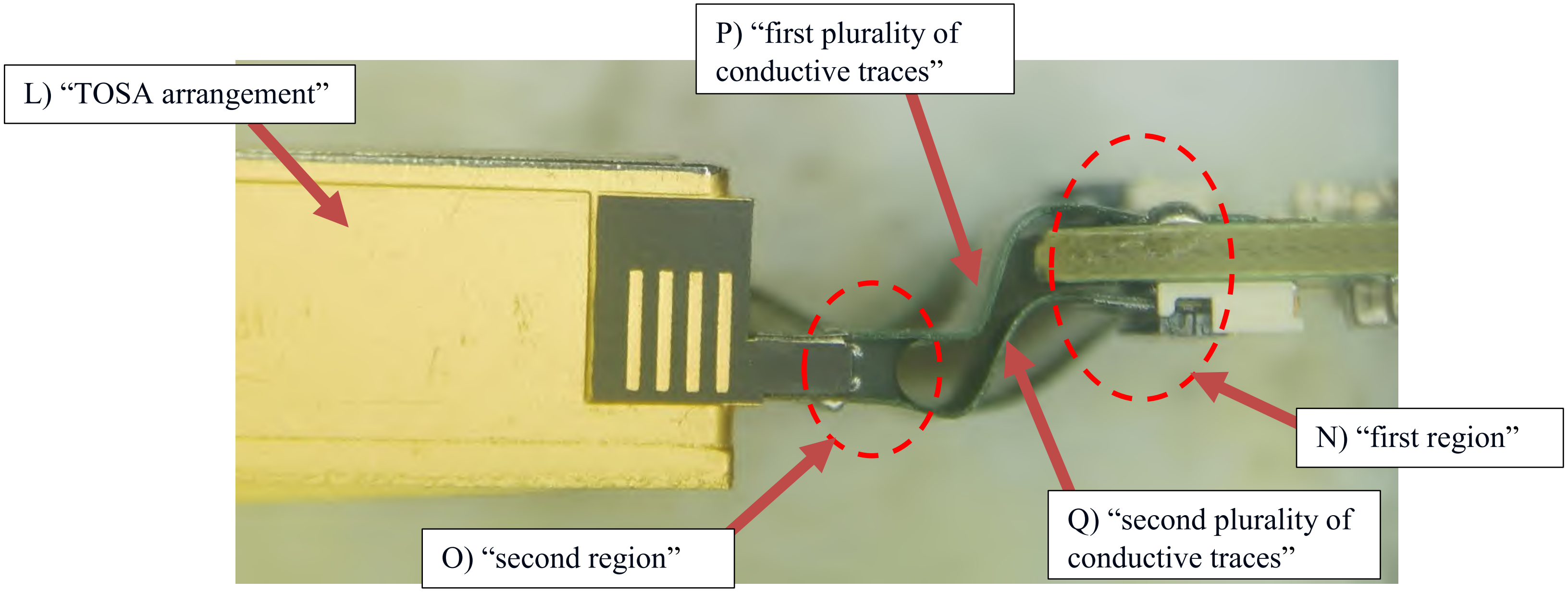


FIG. 5

Representative Claim Chart for U.S. Patent No. 10,230,470

U.S. Patent No. 10,230,470 Claim 1	**EOPTOLINK 100G QSFP LR4 (QJ3D490147)**
An optical transceiver module comprising:	An optical transceiver module **(A)**. See FIG. 1.
a housing;	A housing **(B)**. See FIG. 1.
a receive connecting circuit;	A receive connecting circuit **(C)**. See FIGS. 1–3.
a receiver optical subassembly (ROSA) arrangement disposed in the housing; and	A ROSA arrangement **(D)** is disposed in the housing **(B)**. See FIGS. 1–3.
a first flexible printed circuit (FPC) having a first region electrically coupled to the receive connecting circuit and a second region electrically coupled to the ROSA arrangement,	A first FPC **(E)** has a first region **(F)** electrically coupled to the receive connecting circuit **(C)** and a second region **(G)** electrically coupled to the ROSA arrangement **(D)**. See FIGS. 2–4.
the first FPC comprising: a first plurality of conductive traces for providing a radio frequency (RF) signal between the ROSA arrangement and the receive connecting circuit;	The first FPC **(E)** includes a first plurality of conductive traces **(H)** for providing an RF signal between the ROSA arrangement **(D)** and the receive connecting circuit **(C)**. See FIGS. 3 and 4.
a second plurality of conductive traces for providing a power waveform;	The first FPC **(E)** includes a second plurality of conductive traces **(I)** for providing a power waveform. See FIGS. 3 and 4.
at least one insulating layer disposed between the first and second plurality of conductive traces; and	The first FPC **(E)** includes an insulating layer **(J)** disposed between the first and second plurality of conductive traces **(H, I)**. See FIGS. 3 and 4.
wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal.	The first plurality of conductive traces **(H)** is electrically isolated from the second plurality of conductive traces **(I)** to prevent interference with the RF signal. See FIG. 4.

U.S. Patent No. 10,230,470 Claim 10	**EOPTOLINK 100G QSFP LR4 (QJ3D490147)**
An optical transceiver module comprising:	An optical transceiver module **(A)**. See FIG. 1.
a housing;	A housing **(B)**. See FIG. 1.

Representative Claim Chart for U.S. Patent No. 10,230,470

U.S. Patent No. 10,230,470 Claim 10	EOPTOLINK 100G QSFP LR4 (QJ3D490147)
a transmit connecting circuit and a receive connecting circuit each disposed at least partially within the housing;	A transmit connecting circuit **(K)** and a receive connecting circuit **(C)** each disposed at least partially within the housing **(B)**. See FIGS. 1–3.
a receiver optical subassembly (ROSA) arrangement disposed in the housing;	A ROSA arrangement **(D)** is disposed in the housing **(B)**. See FIGS. 1–3.
a first flexible printed circuit (FPC) having a first region electrically coupled to the receive connecting circuit and a second region electrically coupled to the ROSA arrangement,	A first FPC **(E)** has a first region **(F)** electrically coupled to the receive connecting circuit **(C)** and a second region **(G)** electrically coupled to the ROSA arrangement **(D)**. See FIGS. 2–4.
the first FPC comprising: a first plurality of conductive traces for providing a radio frequency (RF) signal between the ROSA arrangement and the receive connecting circuit;	The first FPC **(E)** includes a first plurality of conductive traces **(H)** for providing an RF signal between the ROSA arrangement **(D)** and the receive connecting circuit **(C)**. See FIGS. 3 and 4.
a second plurality of conductive traces for providing a power waveform; and	The first FPC **(E)** includes a second plurality of conductive traces **(I)** for providing a power waveform. See FIGS. 3 and 4.
wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal;	The first plurality of conductive traces **(H)** is electrically isolated from the second plurality of conductive traces **(I)** to prevent interference with the RF signal. See FIG. 4.
a transmitter optical subassembly (TOSA) arrangement disposed in the housing; and	A TOSA arrangement **(L)** is disposed in the housing **(B)**. See FIGS. 1–3.
a second flexible printed circuit (FPC) having a first region electrically coupled to the transmit connecting circuit and a second region electrically coupled to the TOSA arrangement,	A second FPC **(M)** has a first region **(N)** electrically coupled to the transmit connecting circuit **(K)** and a second region **(O)** electrically coupled to the TOSA arrangement **(L)**. See FIGS. 2, 3 and 5.
the second FPC comprising: a first plurality of conductive traces for providing a radio frequency (RF) signal between the transmit connecting circuit and the TOSA arrangement;	The second FPC **(M)** includes a first plurality of conductive traces **(P)** for providing RF signal between the transmit connecting circuit **(K)** and the TOSA arrangement **(L)**. See FIGS. 2 and 5.
a second plurality of conductive traces for providing a power waveform; and	The second FPC **(M)** includes a second plurality of conductive traces **(Q)** for providing a power waveform. See FIGS. 2 and 5.

Representative Claim Chart for U.S. Patent No. 10,230,470

U.S. Patent No. 10,230,470 Claim 10	EOPTOLINK 100G QSFP LR4 (QJ3D490147)
wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal.	The first plurality of conductive traces **(P)** is electrically isolated from the second plurality of conductive traces **(Q)** to prevent interference with the RF signal. See FIG. 5.

U.S. Patent No. 10,230,470 Claim 17	EOPTOLINK 100G QSFP LR4 (QJ3D490147)
An optical transceiver comprising:	An optical transceiver **(R)**. See FIG. 1.
a housing;	A housing **(B)**. See FIG. 1.
a transmit connecting circuit and a receive connecting circuit each disposed at least partially within the housing;	A transmit connecting circuit **(K)** and a receive connecting circuit **(C)** each disposed at least partially within the housing **(B)**. See FIGS. 1–3.
a receiver optical subassembly (ROSA) arrangement disposed in the housing;	A ROSA arrangement **(D)** is disposed in the housing **(B)**. See FIGS. 1–3.
a first flexible printed circuit (FPC) having a first region electrically coupled to the receive connecting circuit and a second region electrically coupled to the ROSA arrangement,	A first FPC **(E)** has a first region **(F)** electrically coupled to the receive connecting circuit **(C)** and a second region **(G)** electrically coupled to the ROSA arrangement **(D)**. See FIGS. 2–4.
the first FPC comprising: a first plurality of conductive traces for providing a radio frequency (RF) signal between the ROSA arrangement and the receive connecting circuit;	The first FPC **(E)** includes a first plurality of conductive traces **(H)** for providing RF signal between the ROSA arrangement **(D)** and the receive connecting circuit **(C)**. See FIGS. 3 and 4.
a second plurality of conductive traces for providing a power waveform; and	The first FPC **(E)** includes a second plurality of conductive traces **(Q)** for providing a power waveform. See FIGS. 3 and 4.
wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal;	The first plurality of conductive traces **(H)** is electrically isolated from the second plurality of conductive traces **(Q)** to prevent interference with the RF signal. See FIG. 4.
a transmitter optical subassembly (TOSA) arrangement disposed in the housing; and	A TOSA arrangement **(L)** is disposed in the housing **(B)**. See FIGS. 1–3.

Representative Claim Chart for U.S. Patent No. 10,230,470

U.S. Patent No. 10,230,470 Claim 17	EOPTOLINK 100G QSFP LR4 (QJ3D490147)
a second flexible printed circuit (FPC) having a first region electrically coupled to the transmit connecting circuit and a second region electrically coupled to the TOSA arrangement,	A second FPC **(M)** has a first region **(N)** electrically coupled to the transmit connecting circuit **(K)** and a second region **(O)** electrically coupled to the TOSA arrangement **(L)**. See FIGS. 2, 3 and 5.
the second FPC comprising: a first plurality of conductive traces for providing a radio frequency (RF) signal between the receive connecting circuit and the TOSA arrangement;	The second FPC **(M)** includes a first plurality of conductive traces **(P)** for providing RF signal between the transmit connecting circuit **(K)** and the TOSA arrangement **(L)**. See FIGS. 2 and 5.
a second plurality of conductive traces for providing a power waveform; and	The second FPC **(M)** includes a second plurality of conductive traces **(I)** for providing a power waveform. See FIGS. 2 and 5.
wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal;	The first plurality of conductive traces **(P)** is electrically isolated from the second plurality of conductive traces **(I)** to prevent interference with the RF signal. See FIG. 5.
a printed circuit board assembly (PCBA) electrically coupled to the first and second FPCs.	A PCBA **(S)** is electrically coupled to the first and second FPCs (**E, M**). See FIGS. 2 and 3.

Exhibit M

Representative Claim Chart for U.S. Patent No. 10,230,470

<u>EOPTOLINK 100G QSFP LR4 (QL97099330)</u>

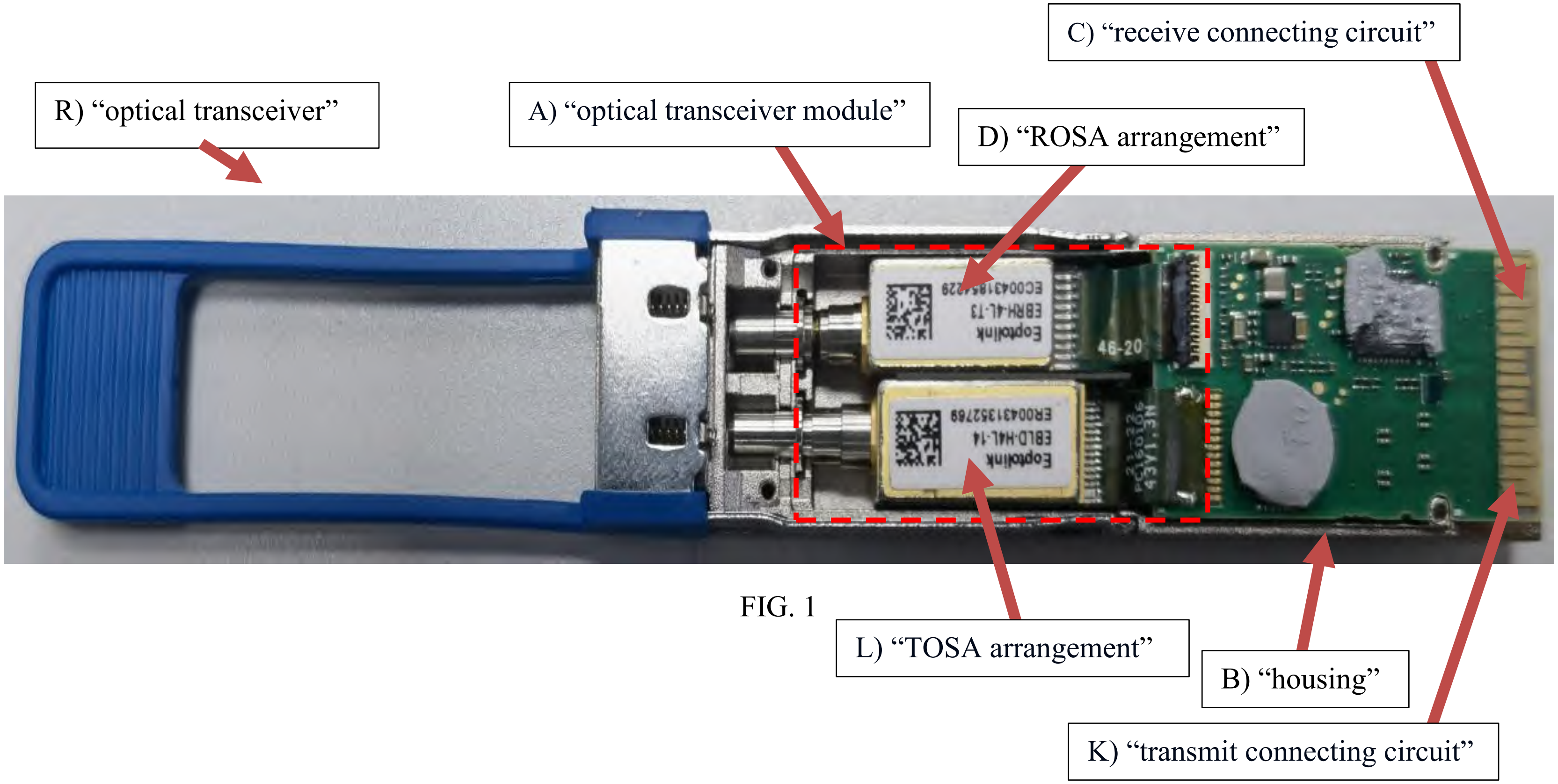


FIG. 1

Representative Claim Chart for U.S. Patent No. 10,230,470

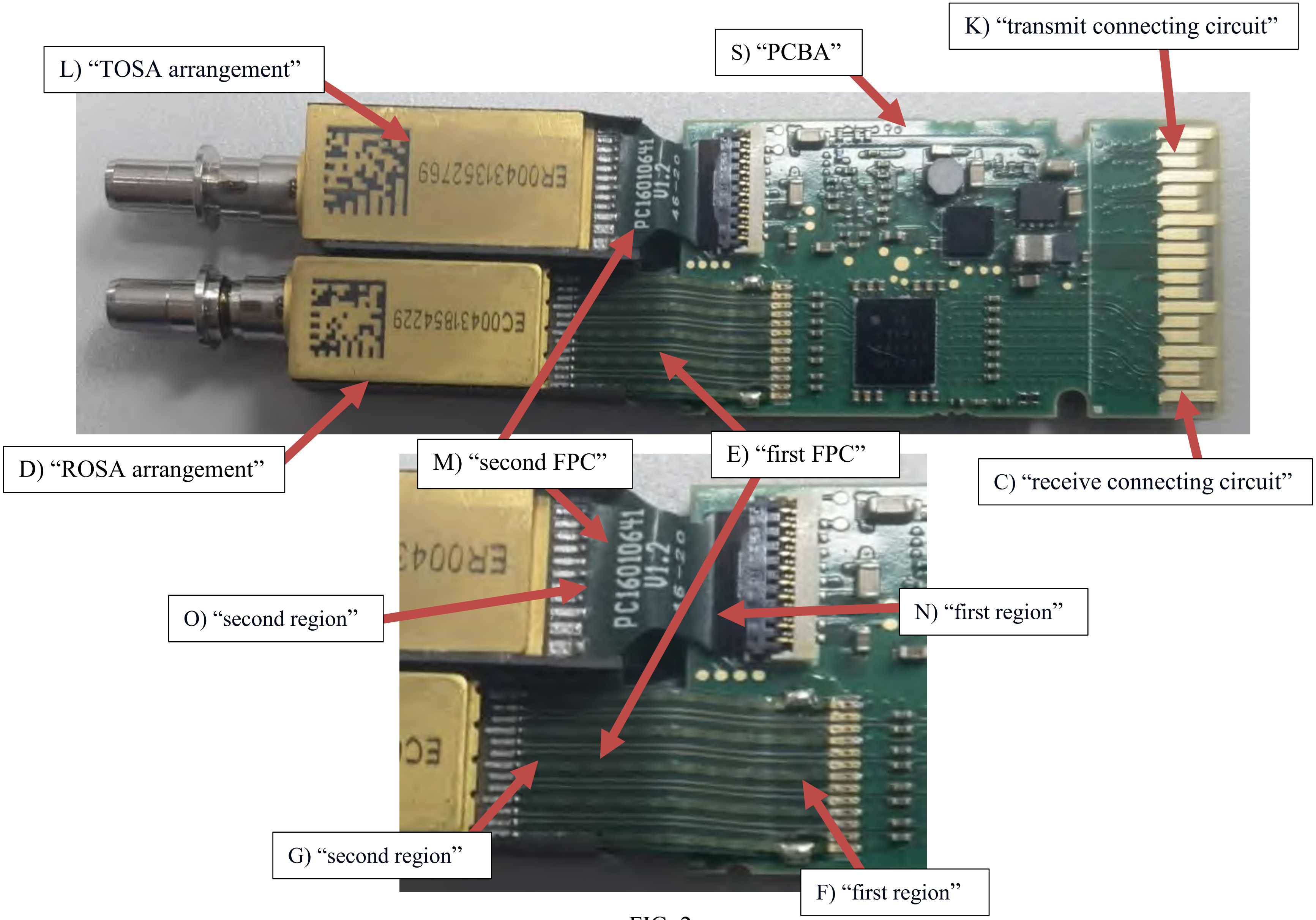


FIG. 2

Representative Claim Chart for U.S. Patent No. 10,230,470

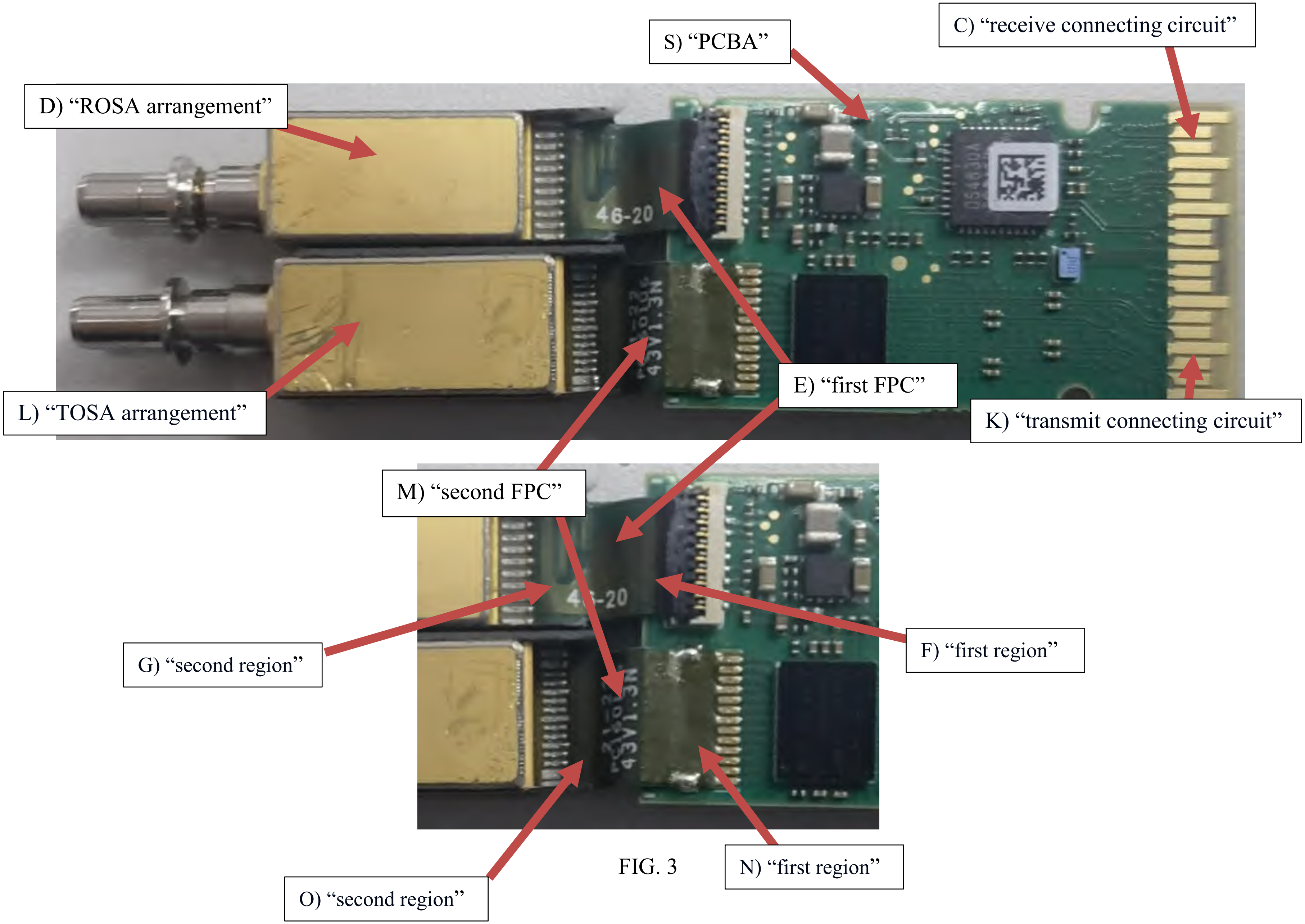


FIG. 3

Representative Claim Chart for U.S. Patent No. 10,230,470

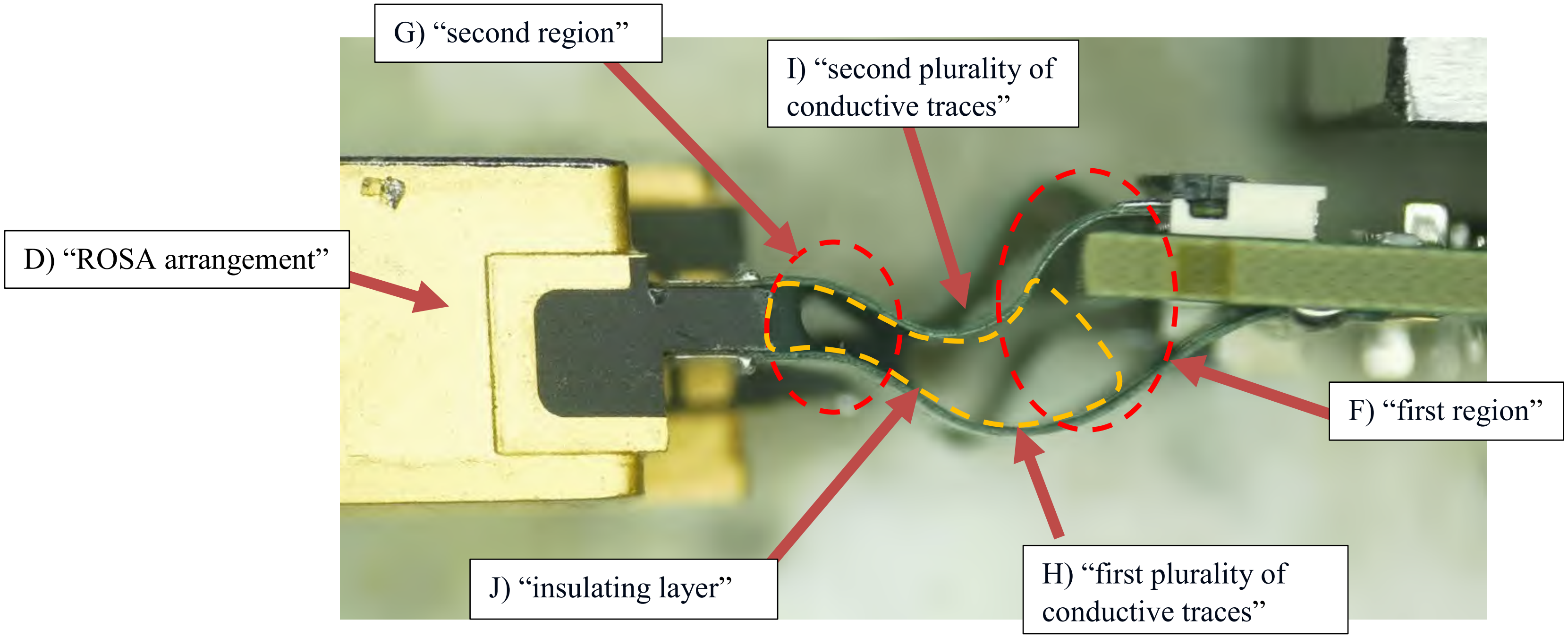


FIG. 4

Representative Claim Chart for U.S. Patent No. 10,230,470

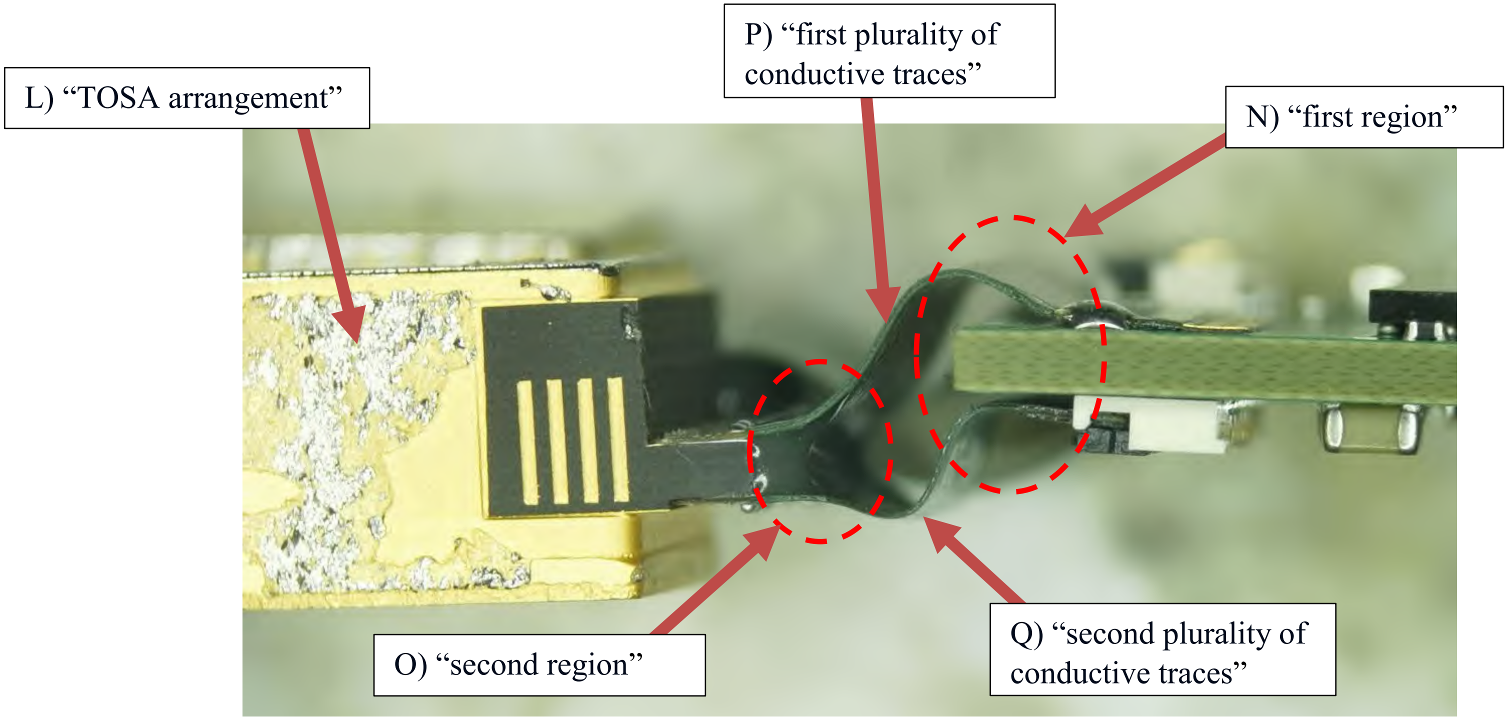


FIG. 5

Representative Claim Chart for U.S. Patent No. 10,230,470

U.S. Patent No. 10,230,470 Claim 1	**EOPTOLINK 100G QSFP LR4 (QL97099330)**
An optical transceiver module comprising:	An optical transceiver module **(A)**. See FIG. 1.
a housing;	A housing **(B)**. See FIG. 1.
a receive connecting circuit;	A receive connecting circuit **(C)**. See FIGS. 1–3.
a receiver optical subassembly (ROSA) arrangement disposed in the housing; and	A ROSA arrangement **(D)** is disposed in the housing **(B)**. See FIGS. 1–3.
a first flexible printed circuit (FPC) having a first region electrically coupled to the receive connecting circuit and a second region electrically coupled to the ROSA arrangement,	A first FPC **(E)** has a first region **(F)** electrically coupled to the receive connecting circuit **(C)** and a second region **(G)** electrically coupled to the ROSA arrangement **(D)**. See FIGS. 2-4.
the first FPC comprising: a first plurality of conductive traces for providing a radio frequency (RF) signal between the ROSA arrangement and the receive connecting circuit;	The first FPC **(E)** includes a first plurality of conductive traces **(H)** for providing RF signal between the ROSA arrangement **(D)** and the receive connecting circuit **(C)**. See FIG. 4.
a second plurality of conductive traces for providing a power waveform;	The first FPC **(E)** includes a second plurality of conductive traces **(I)** for providing a power waveform. See FIGS. 3 and 4.
at least one insulating layer disposed between the first and second plurality of conductive traces; and	The first FPC **(E)** includes an insulating layer **(J)** disposed between the first and second plurality of conductive traces **(H, I)**. See FIGS. 3 and 4.
wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal.	The first plurality of conductive traces **(H)** is electrically isolated from the second plurality of conductive traces **(I)** to prevent interference with the RF signal. See FIG. 4.

U.S. Patent No. 10,230,470 Claim 10	**EOPTOLINK 100G QSFP LR4 (QL97099330)**
An optical transceiver module comprising:	An optical transceiver module **(A)**. See FIG. 1.
a housing;	A housing **(B)**. See FIG. 1.

Representative Claim Chart for U.S. Patent No. 10,230,470

U.S. Patent No. 10,230,470 **Claim 10**	**EOPTOLINK 100G QSFP LR4 (QL97099330)**
a transmit connecting circuit and a receive connecting circuit each disposed at least partially within the housing;	A transmit connecting circuit **(K)** and a receive connecting circuit **(C)** each disposed at least partially within the housing **(B)**. See FIGS. 1-3.
a receiver optical subassembly (ROSA) arrangement disposed in the housing;	A ROSA arrangement **(D)** is disposed in the housing **(B)**. See FIGS. 1–3.
a first flexible printed circuit (FPC) having a first region electrically coupled to the receive connecting circuit and a second region electrically coupled to the ROSA arrangement,	A first FPC **(E)** has a first region **(F)** electrically coupled to the receive connecting circuit **(C)** and a second region **(G)** electrically coupled to the ROSA arrangement **(D)**. See FIGS. 2–4.
the first FPC comprising: a first plurality of conductive traces for providing a radio frequency (RF) signal between the ROSA arrangement and the receive connecting circuit;	The first FPC **(E)** includes a first plurality of conductive traces **(H)** for providing RF signal between the ROSA arrangement **(D)** and the receive connecting circuit **(C)**. See FIG. 4.
a second plurality of conductive traces for providing a power waveform; and	The first FPC **(E)** includes a second plurality of conductive traces **(I)** for providing a power waveform. See FIGS. 3 and 4.
wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal;	The first plurality of conductive traces **(H)** is electrically isolated from the second plurality of conductive traces **(I)** to prevent interference with the RF signal. See FIGS. 3 and 4.
a transmitter optical subassembly (TOSA) arrangement disposed in the housing; and	A TOSA arrangement **(L)** is disposed in the housing **(B)**. See FIGS. 1–3.
a second flexible printed circuit (FPC) having a first region electrically coupled to the transmit connecting circuit and a second region electrically coupled to the TOSA arrangement,	A second FPC **(M)** has a first region **(N)** electrically coupled to the transmit connecting circuit **(K)** and a second region **(O)** electrically coupled to the TOSA arrangement **(L)**. See FIGS. 2, 3 and 5.
the second FPC comprising: a first plurality of conductive traces for providing a radio frequency (RF) signal between the transmit connecting circuit and the TOSA arrangement;	The second FPC **(M)** includes a first plurality of conductive traces **(P)** for providing RF signal between the transmit connecting circuit **(K)** and the TOSA arrangement **(L)**. See FIGS. 2 and 5.
a second plurality of conductive traces for providing a power waveform; and	The second FPC **(M)** includes a second plurality of conductive traces **(Q)** for providing a power waveform (power signal). See FIGS. 2 and 5.

Representative Claim Chart for U.S. Patent No. 10,230,470

U.S. Patent No. 10,230,470 Claim 10	EOPTOLINK 100G QSFP LR4 (QL97099330)
wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal.	The first plurality of conductive traces **(P)** is electrically isolated from the second plurality of conductive traces **(Q)** to prevent interference with the RF signal. See FIG. 5.

U.S. Patent No. 10,230,470 Claim 17	EOPTOLINK 100G QSFP LR4 (QL97099330)
An optical transceiver comprising:	An optical transceiver **(R)**. See FIG. 1.
a housing;	A housing **(B)**. See FIG. 1.
a transmit connecting circuit and a receive connecting circuit each disposed at least partially within the housing;	A transmit connecting circuit **(K)** and a receive connecting circuit **(C)** each disposed at least partially within the housing **(B)**. See FIGS. 1–3.
a receiver optical subassembly (ROSA) arrangement disposed in the housing;	A ROSA arrangement **(D)** is disposed in the housing **(B)**. See FIG. 1 through FIG. 3.
a first flexible printed circuit (FPC) having a first region electrically coupled to the receive connecting circuit and a second region electrically coupled to the ROSA arrangement,	A first FPC **(E)** has a first region **(F)** electrically coupled to the receive connecting circuit **(C)** and a second region **(G)** electrically coupled to the ROSA arrangement **(D)**. See FIGS. 2–4.
the first FPC comprising: a first plurality of conductive traces for providing a radio frequency (RF) signal between the ROSA arrangement and the receive connecting circuit;	The first FPC **(E)** includes a first plurality of conductive traces **(H)** for providing RF signal between the ROSA arrangement **(D)** and the receive connecting circuit **(C)**. See FIGS. 3 and 4.
a second plurality of conductive traces for providing a power waveform; and	The first FPC **(E)** includes a second plurality of conductive traces **(I)** for providing a power waveform. See FIGS. 3 and 4.
wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal;	The first plurality of conductive traces **(H)** is electrically isolated from the second plurality of conductive traces **(I)** to prevent interference with the RF signal. See FIG. 4.
a transmitter optical subassembly (TOSA) arrangement disposed in the housing; and	A TOSA arrangement **(L)** is disposed in the housing **(B)**. See FIGS. 1–3.

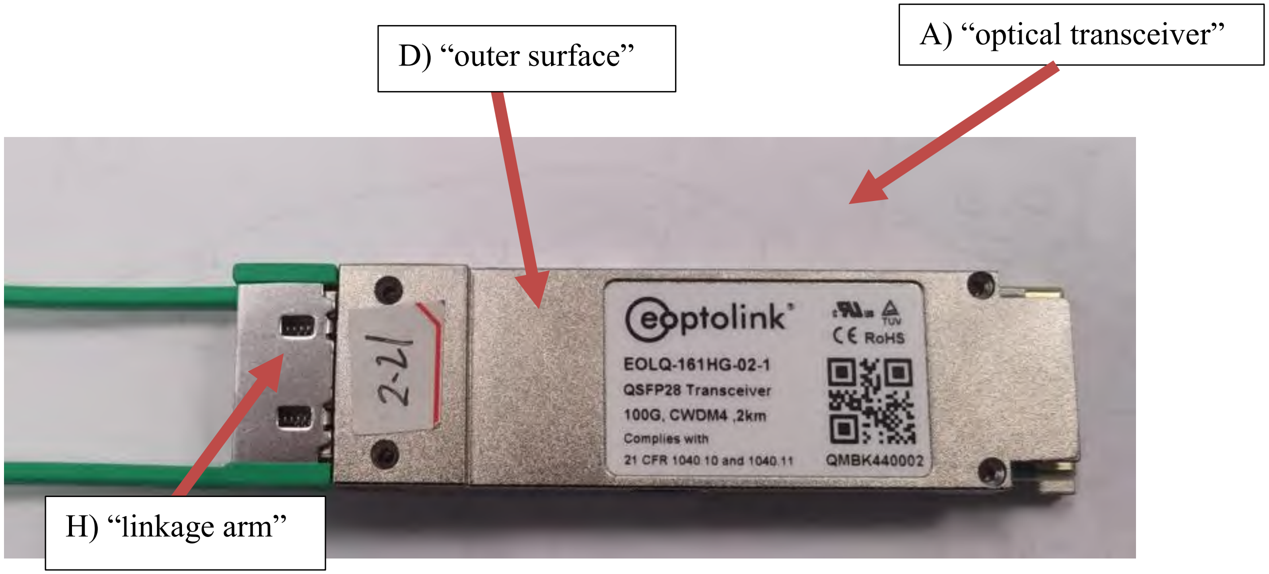
Representative Claim Chart for U.S. Patent No. 10,230,470

U.S. Patent No. 10,230,470 Claim 17	**EOPTOLINK 100G QSFP LR4 (QL97099330)**
a second flexible printed circuit (FPC) having a first region electrically coupled to the transmit connecting circuit and a second region electrically coupled to the TOSA arrangement,	A second FPC **(M)** has a first region **(N)** electrically coupled to the transmit connecting circuit **(K)** and a second region **(O)** electrically coupled to the TOSA arrangement **(L)**. See FIGS. 2, 3 and 5.
the second FPC comprising: a first plurality of conductive traces for providing a radio frequency (RF) signal between the receive connecting circuit and the TOSA arrangement;	The second FPC **(M)** includes a first plurality of conductive traces **(P)** for providing RF signal between the transmit connecting circuit **(K)** and the TOSA arrangement **(L)**. See FIGS. 2 and 5.
a second plurality of conductive traces for providing a power waveform; and	The second FPC **(M)** includes a second plurality of conductive traces **(Q)** for providing a power waveform. See FIGS. 2 and 5.
wherein the first plurality of conductive traces is electrically isolated from the second plurality of conductive traces to prevent interference with the RF signal;	The first plurality of conductive traces **(P)** is electrically isolated from the second plurality of conductive traces **(Q)** to prevent interference with the RF signal. See FIG. 5.
a printed circuit board assembly (PCBA) electrically coupled to the first and second FPCs.	A PCBA **(S)** is electrically coupled to the first and second FPCs (**E, M**). See FIGS. 2 and 3.

Exhibit N

Representative Claim Chart for U.S. Patent No. 10,578,818

EOPTOLINK 100G CWDM4 (QMBK440002)


D) “outer surface”

A) “optical transceiver”

H) “linkage arm”

FIG. 1

Representative Claim Chart for U.S. Patent No. 10,578,818

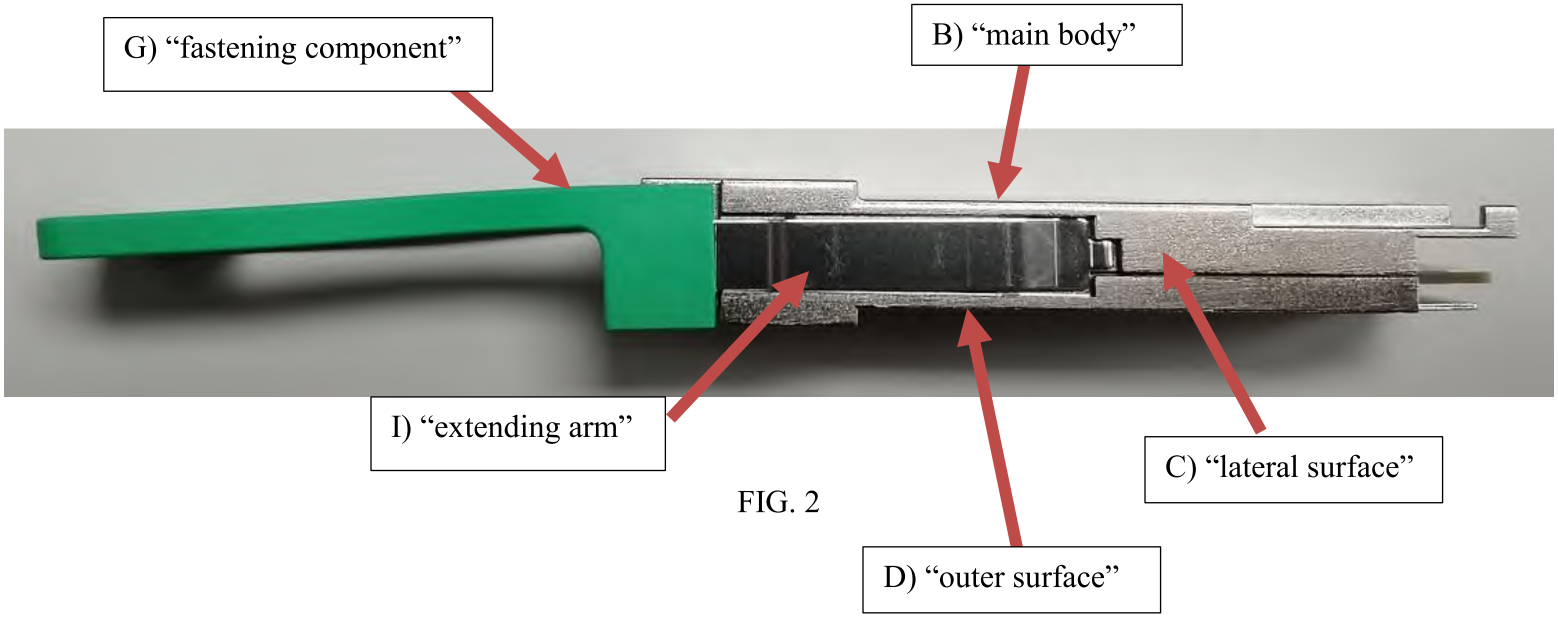


FIG. 2

Representative Claim Chart for U.S. Patent No. 10,578,818

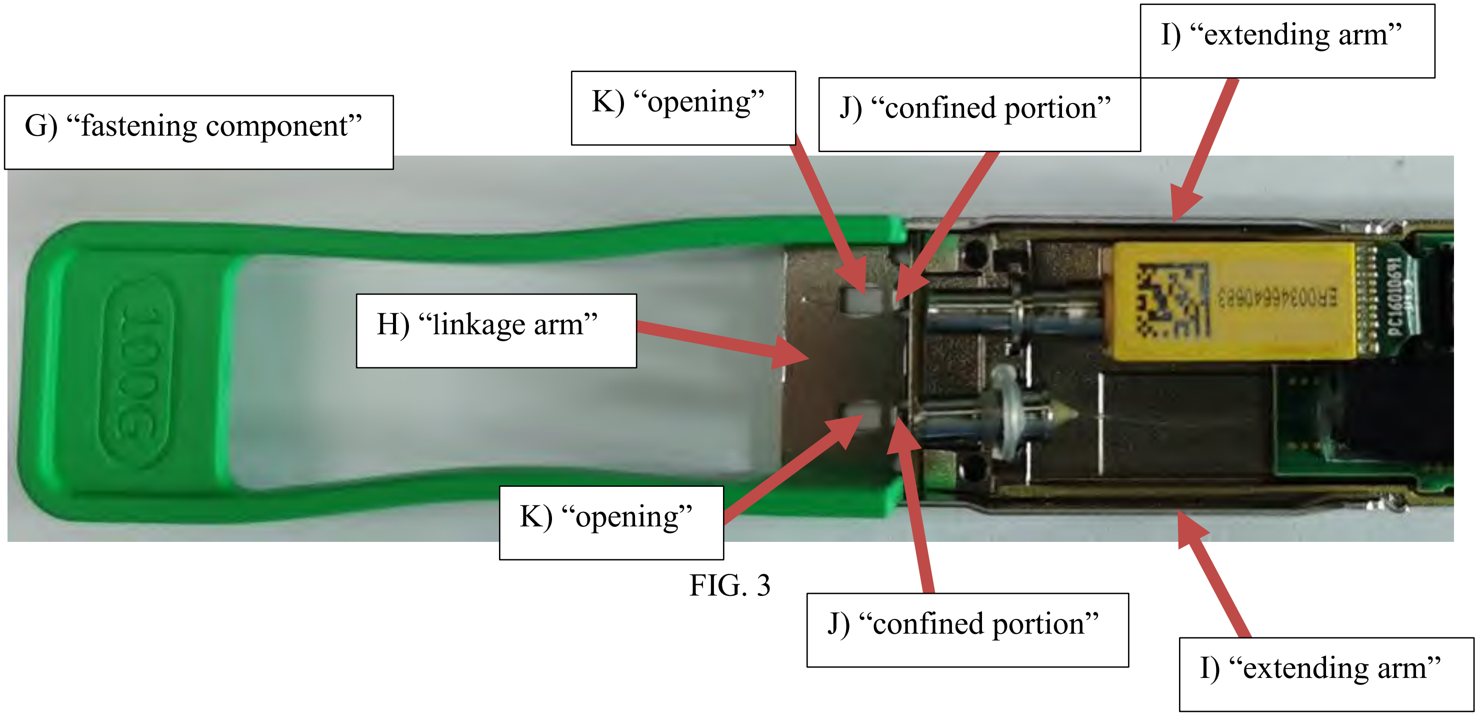


FIG. 3

Representative Claim Chart for U.S. Patent No. 10,578,818

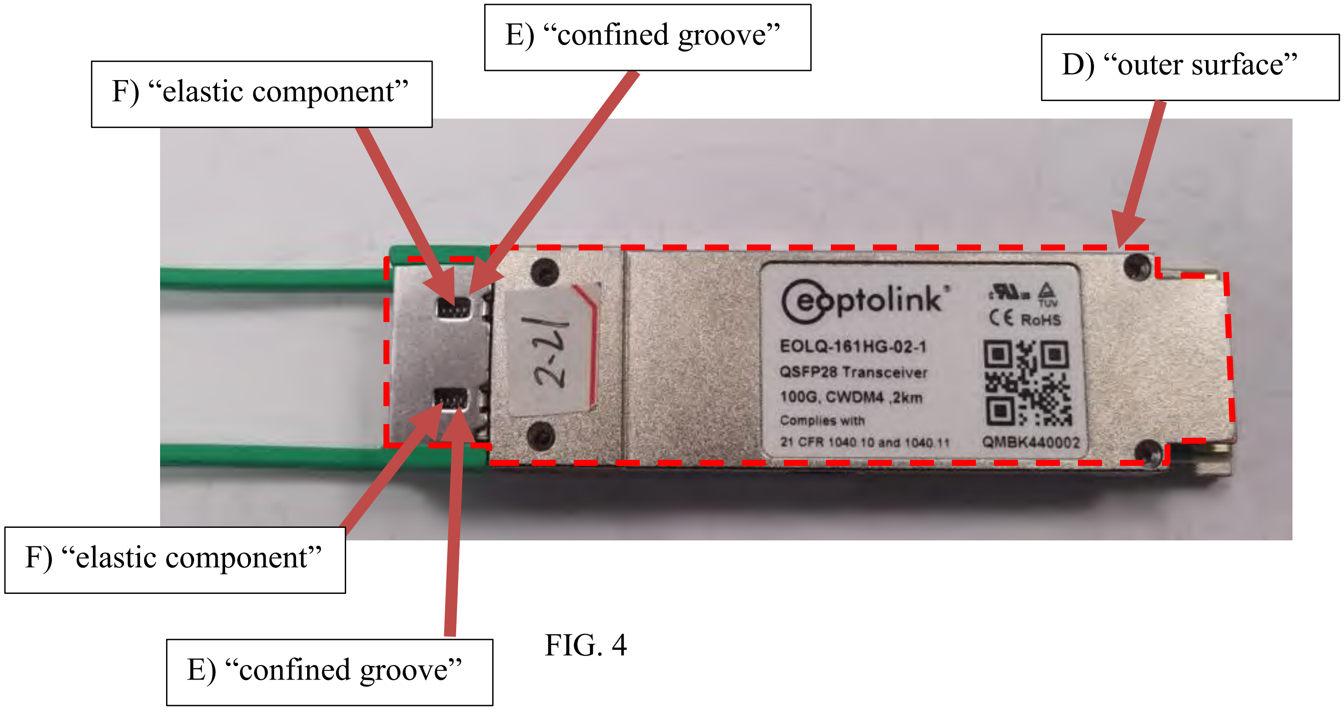


FIG. 4

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 Claim 1	EOPTOLINK 100G CWDM4 (QMBK440002)
An optical transceiver, configured to be inserted into a cage in a pluggable manner, comprising:	On information and belief, an optical transceiver **(A)** is able to be inserted into a cage in a pluggable manner. See FIGS. 1–4.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining a confined groove;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** between the two lateral surfaces **(C)**, and the outer surface **(D)** defines a confined groove **(E)**. See FIGS. 2 and 4.
an elastic component disposed in the confined groove; and	An elastic component **(F)** is disposed in the confined groove **(E)**. See FIG. 4.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and a confined portion, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portion is connected with the linkage arm and extends into the confined groove in order to press the elastic component, and the two extending arms are detachably fasten-able with the cage.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and a confined portion **(J)**. See FIG. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIG. 1–4. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–4. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portion **(J)** is connected with the linkage arm **(H)** and extends into the confined groove **(E)** in order to press the elastic component **(F)**. On information and belief, the two extending arms **(I)** are detachably fasten-able with the cage. See FIGS. 2-4.

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 **Claim 10**	**EOPTOLINK 100G CWDM4 (QMBK440002)**
An optical transceiver, comprising:	An optical transceiver **(A)**. See FIGS. 1–4.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining two confined grooves spaced apart from each other;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** and the outer surface **(D)** defines two confined grooves **(E)** spaced apart from each other. See FIG. 2 and 4.
two elastic components disposed in the two confined grooves, respectively; and	The two elastic components **(F)** are disposed in the two confined grooves **(E)**. See FIG. 4.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and two confined portions, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portions are connected with the linkage arm and respectively extend into the two confined grooves in order to press the two elastic components.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and two confined portions **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–4. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–4. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portions **(J)** are connected with the linkage arm **(H)** and respectively extend into the confined grooves **(E)** in order to press the elastic components **(F)**. See FIGS. 2–4.

Exhibit O

Representative Claim Chart for U.S. Patent No. 10,578,818

EOPTOLINK 100G CWDM4 (QP85060003)

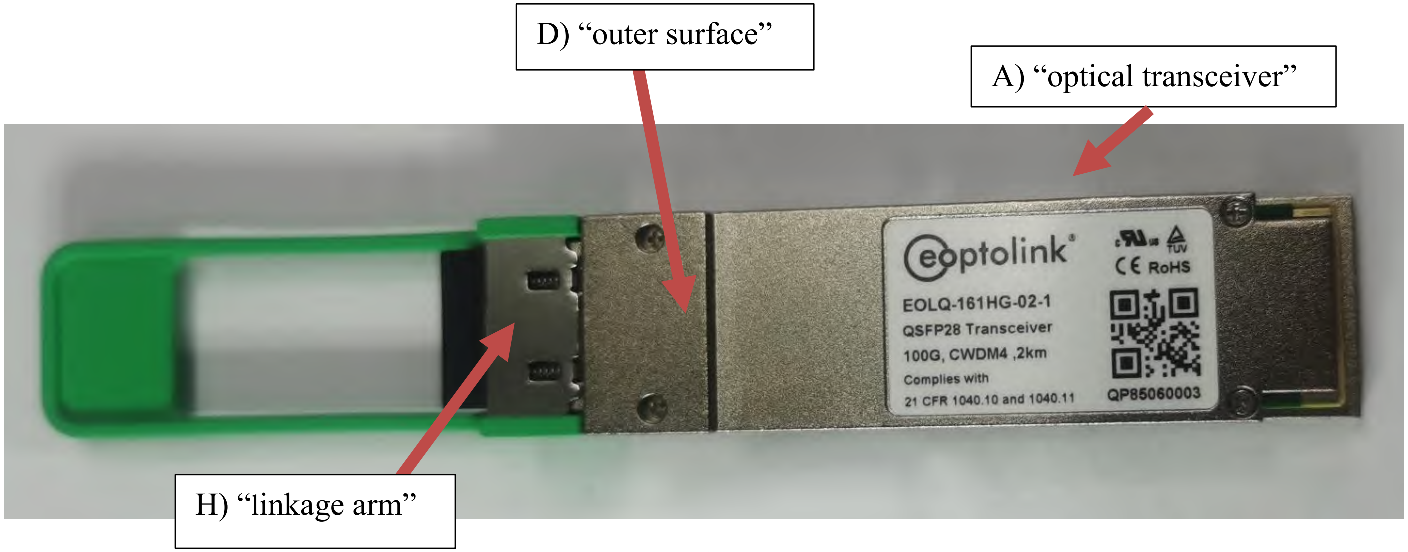


FIG. 1

Representative Claim Chart for U.S. Patent No. 10,578,818

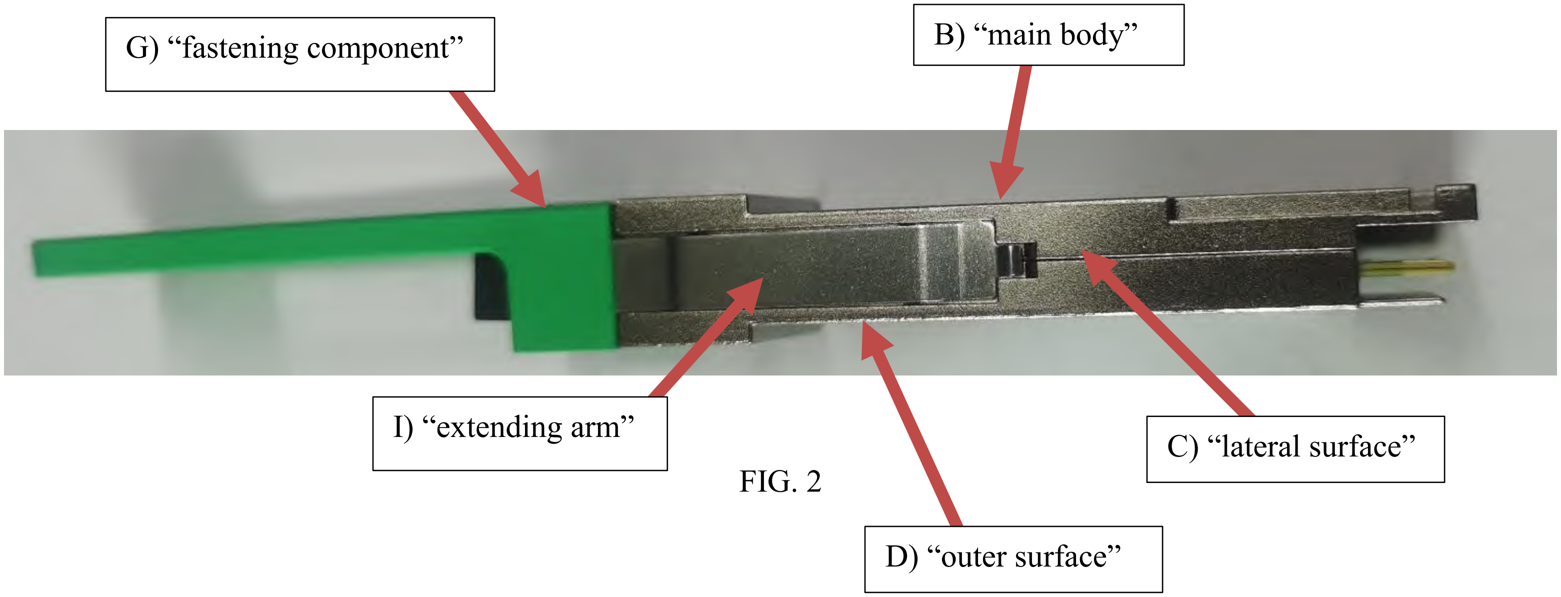


FIG. 2

Representative Claim Chart for U.S. Patent No. 10,578,818

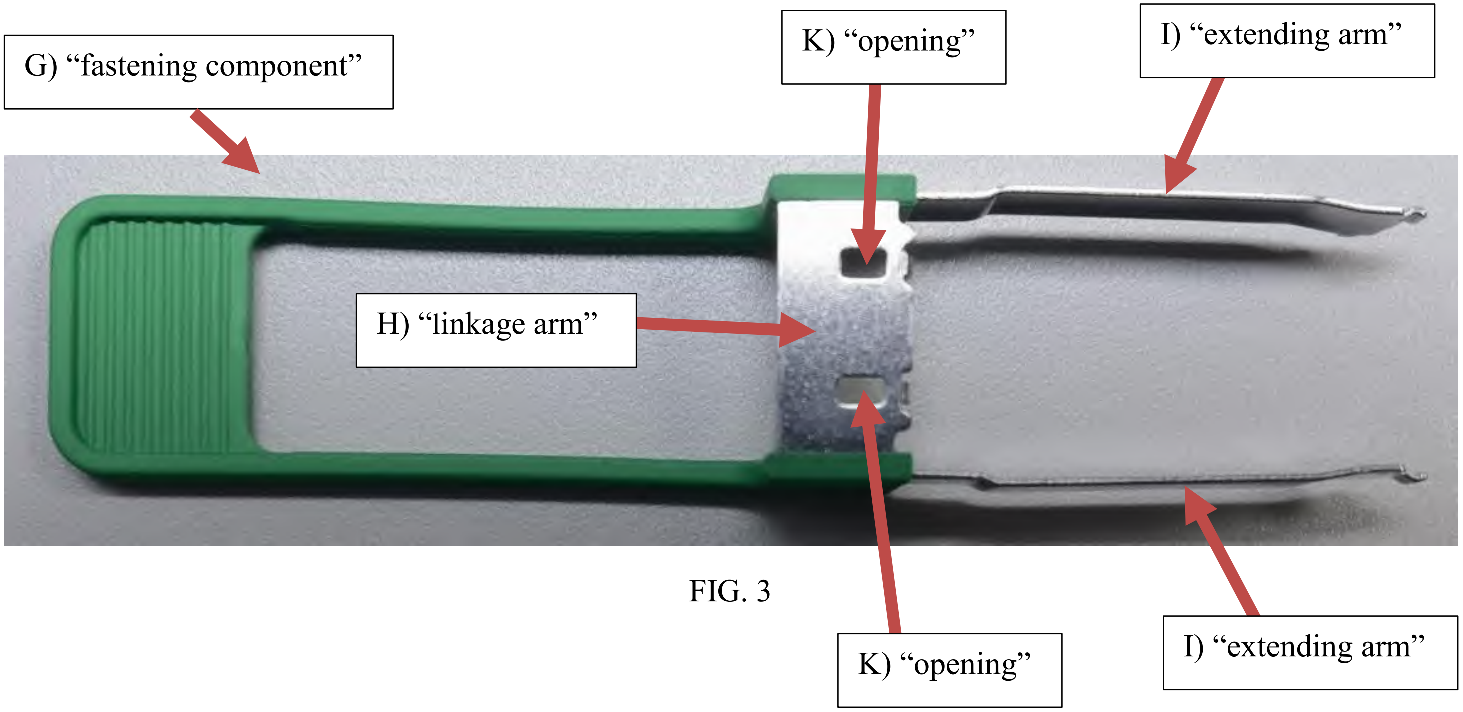


FIG. 3

Representative Claim Chart for U.S. Patent No. 10,578,818

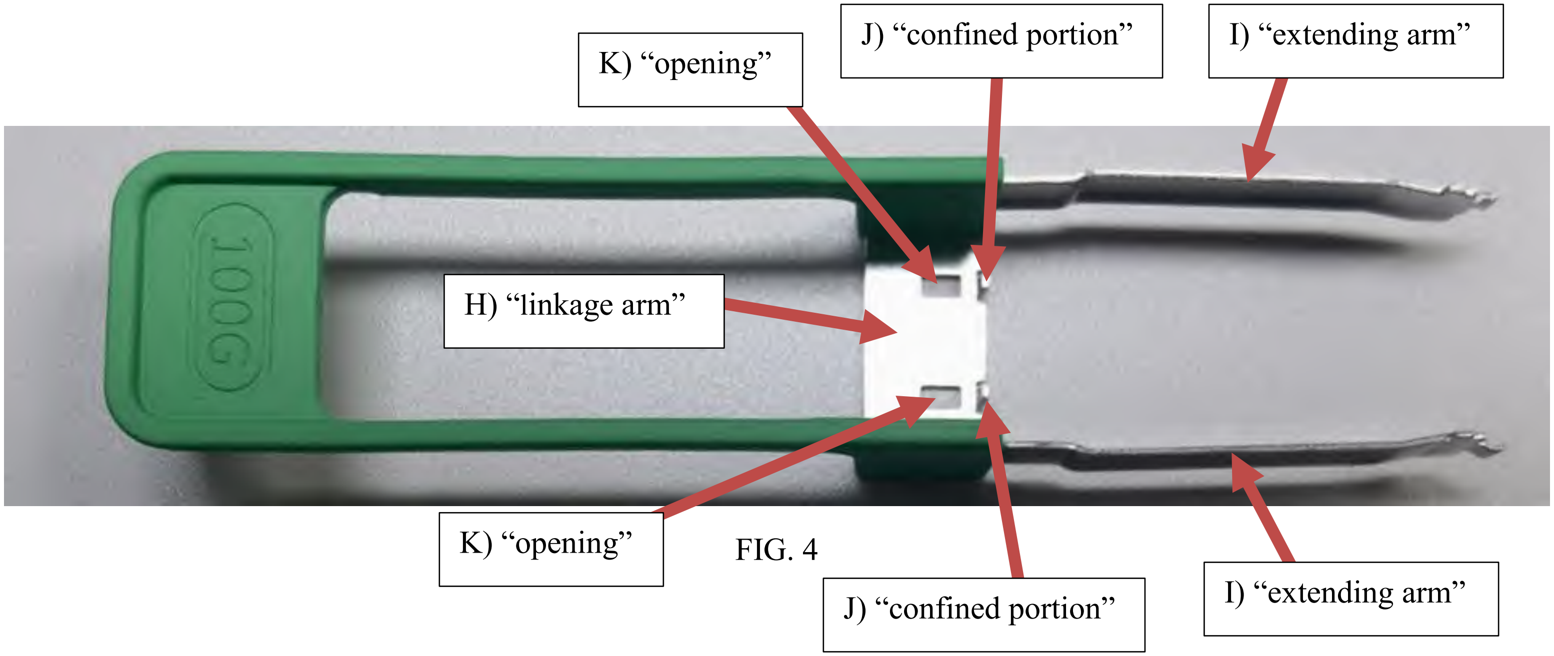


FIG. 4

Representative Claim Chart for U.S. Patent No. 10,578,818

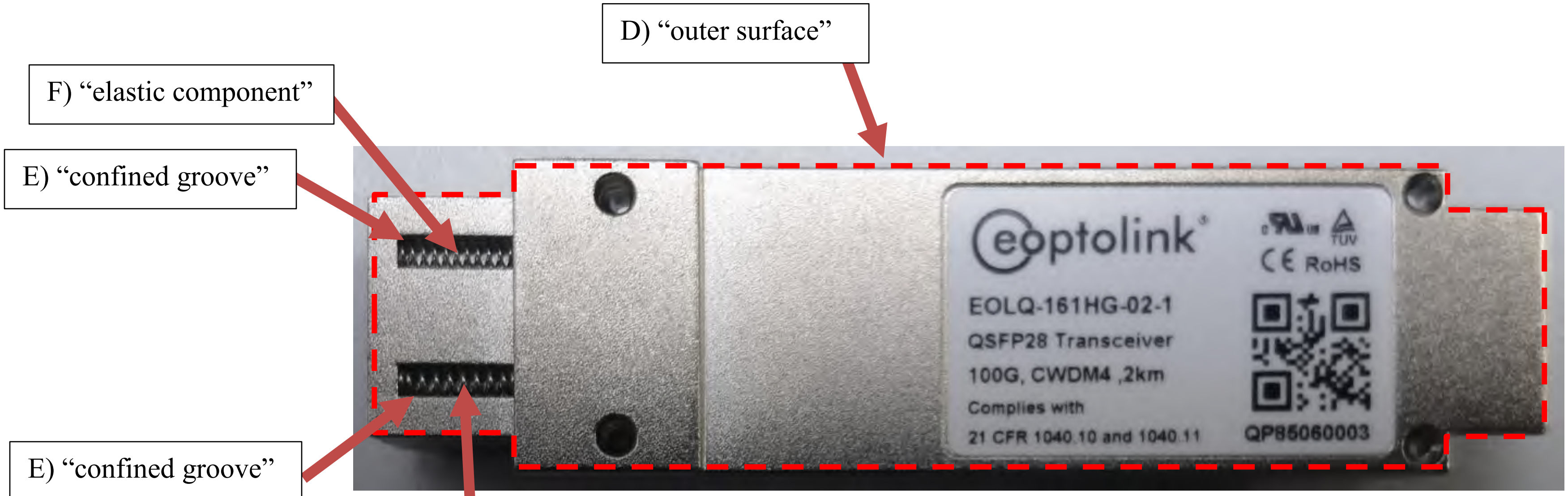


FIG. 5

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 **Claim 1**	**EOPTOLINK 100G CWDM4 (QP85060003)**
An optical transceiver, configured to be inserted into a cage in a pluggable manner, comprising:	On information and belief, optical transceiver **(A)** can be inserted into a cage in a pluggable manner. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining a confined groove;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** between the two lateral surfaces **(C)**, and the outer surface **(D)** defines a confined groove **(E)**. See FIGS. 2 and 5.
an elastic component disposed in the confined groove; and	An elastic component **(F)** is disposed in the confined groove **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and a confined portion, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portion is connected with the linkage arm and extends into the confined groove in order to press the elastic component, and the two extending arms are detachably fasten-able with the cage.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and a confined portion **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portion **(J)** is connected with the linkage arm **(H)** and extends into the confined groove **(E)** in order to press the elastic component **(F)**. On information and belief, the two extending arms **(I)** are detachably fasten-able with the cage. See FIGS. 2–5.

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 **Claim 10**	**EOPTOLINK 100G CWDM4 (QP85060003)**
An optical transceiver, comprising:	An optical transceiver **(A)**. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining two confined grooves spaced apart from each other;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** and the outer surface **(D)** defines two confined grooves **(E)** spaced apart from each other. See FIGS. 2 and 5.
two elastic components disposed in the two confined grooves, respectively; and	The two elastic components **(F)** are disposed in the two confined grooves **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and two confined portions, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portions are connected with the linkage arm and respectively extend into the two confined grooves in order to press the two elastic components.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and two confined portions **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portions **(J)** are connected with the linkage arm **(H)** and respectively extend into the confined grooves **(E)** in order to press the elastic components **(F)**. See FIGS. 2–5.

Exhibit P

Representative Claim Chart for U.S. Patent No. 10,578,818

EOPTOLINK 100G QSFP DR1+

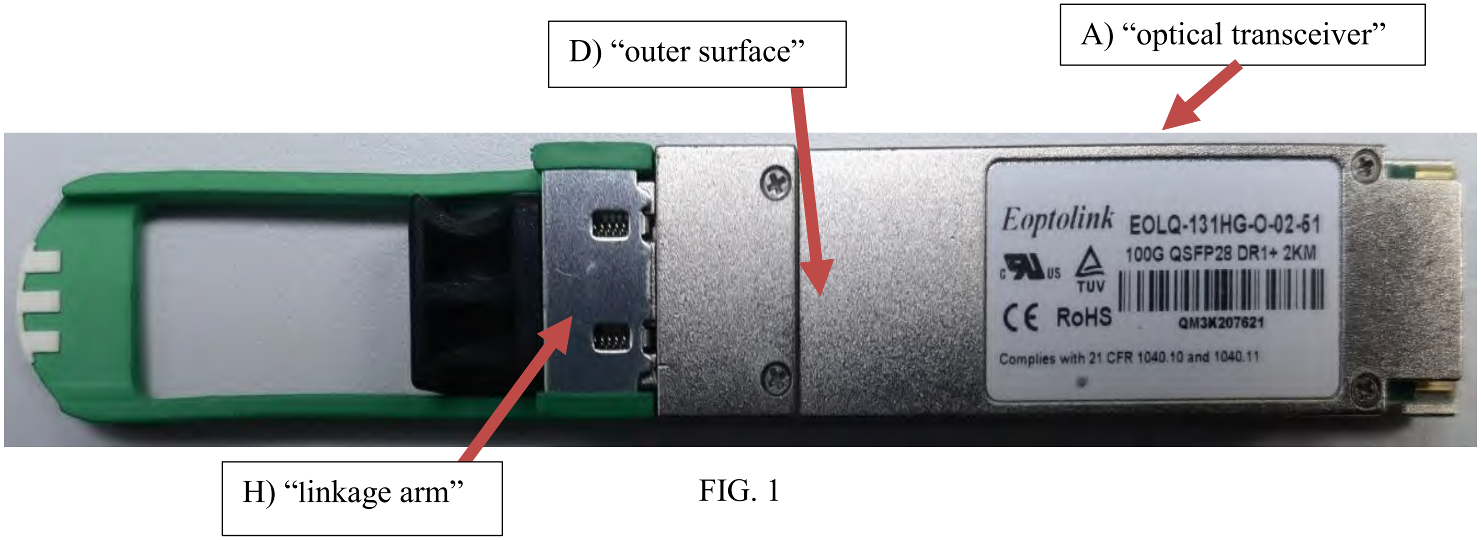


FIG. 1

Representative Claim Chart for U.S. Patent No. 10,578,818

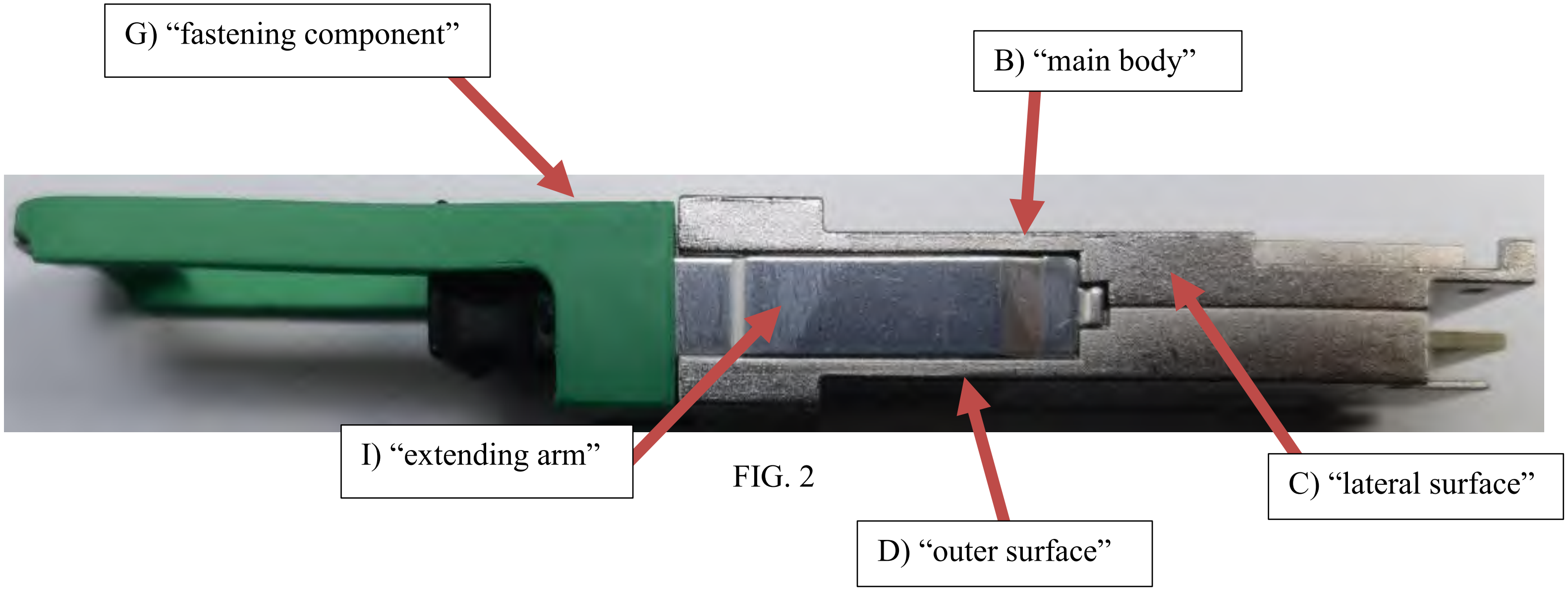


FIG. 2

Representative Claim Chart for U.S. Patent No. 10,578,818

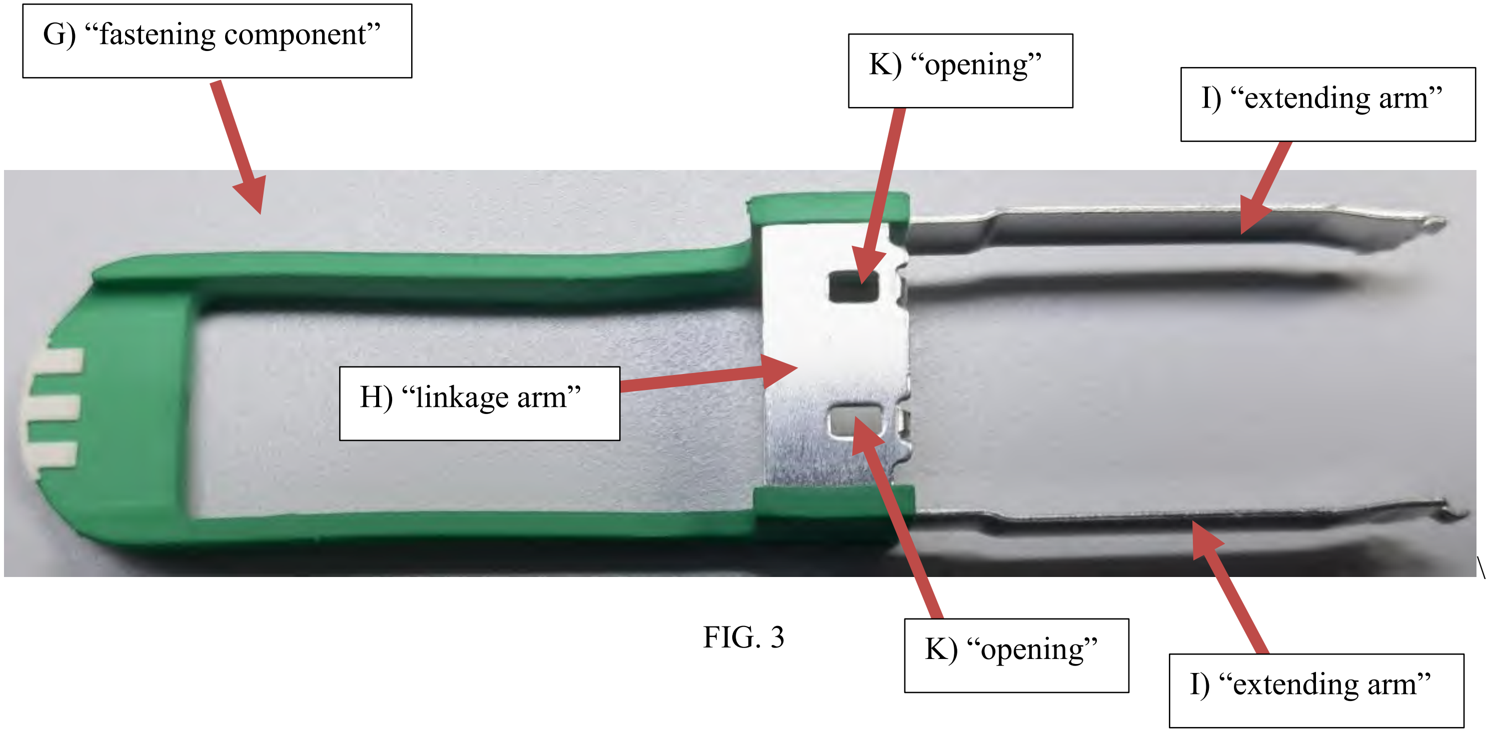


FIG. 3

Representative Claim Chart for U.S. Patent No. 10,578,818

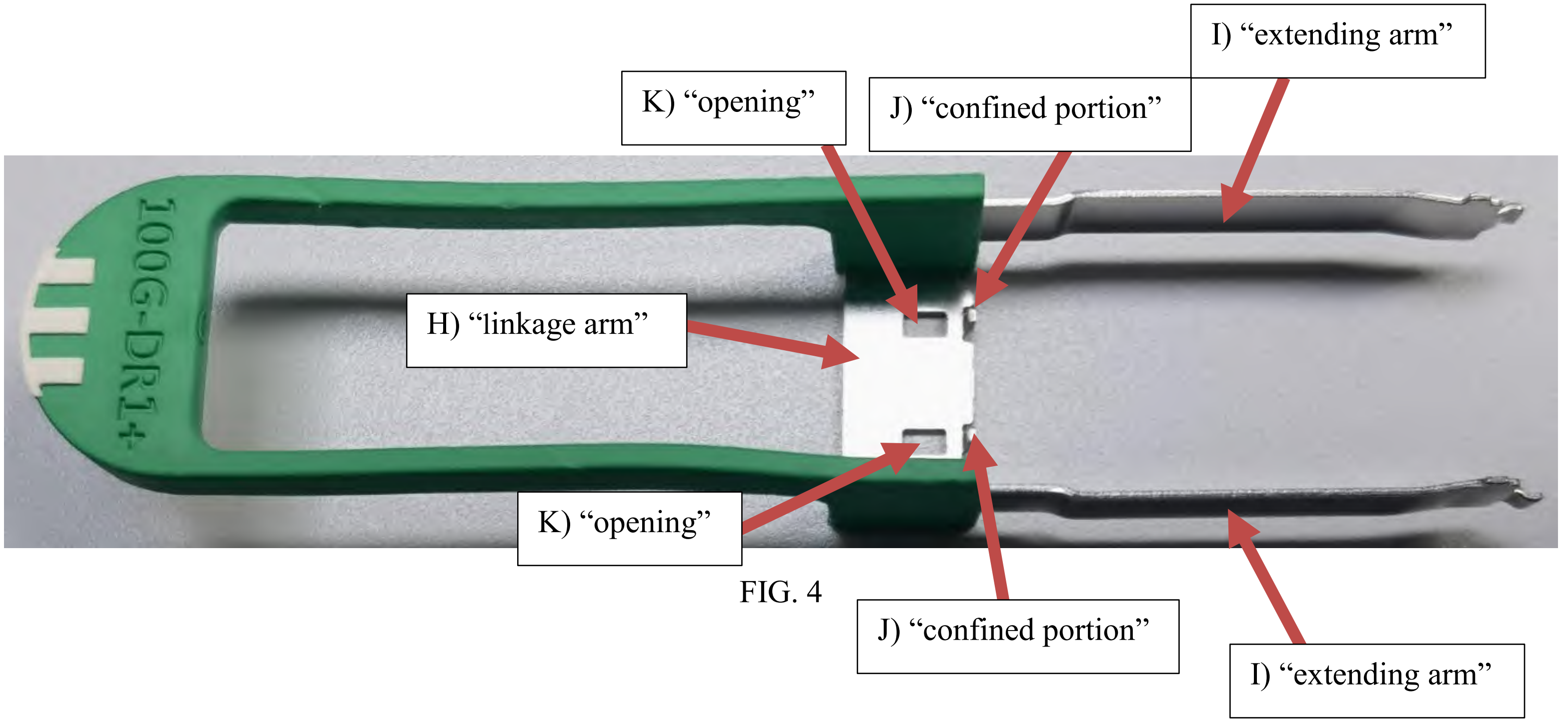


FIG. 4

Representative Claim Chart for U.S. Patent No. 10,578,818

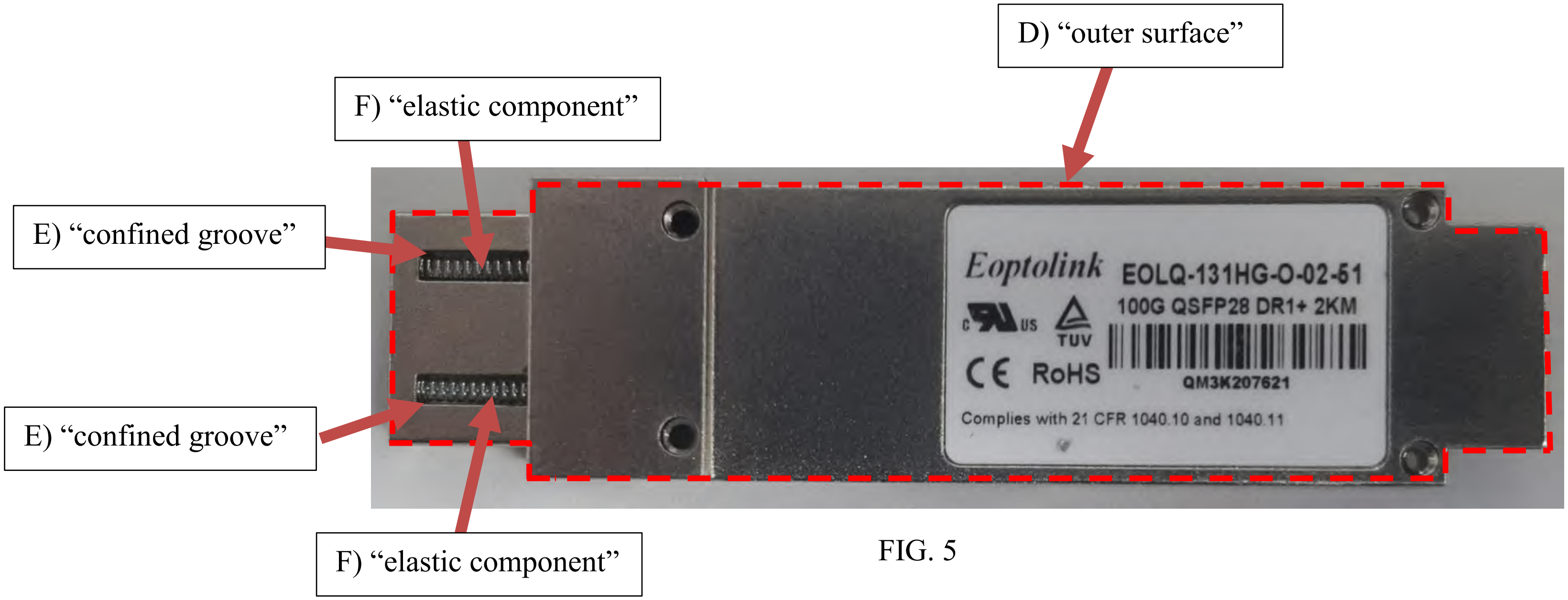


FIG. 5

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 Claim 1	EOPTOLINK 100G QSFP DR1+
An optical transceiver, configured to be inserted into a cage in a pluggable manner, comprising:	On information and belief, optical transceiver **(A)** can be inserted into a cage in a pluggable manner. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining a confined groove;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** between the two lateral surfaces **(C)** and the outer surface **(D)** defines a confined groove **(E)**. See FIGS. 2 and 5.
an elastic component disposed in the confined groove; and	An elastic component **(F)** is disposed in the confined groove **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and a confined portion, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portion is connected with the linkage arm and extends into the confined groove in order to press the elastic component, and the two extending arms are detachably fasten-able with the cage.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and a confined portion **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portion **(J)** is connected with the linkage arm **(H)** and extends into the confined groove **(E)** in order to press the elastic component **(F)**. On information and belief, the two extending arms **(I)** are detachably fasten-able with the cage. See FIGS. 2–5.

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 Claim 10	EOPTOLINK 100G QSFP DR1+
An optical transceiver, comprising:	An optical transceiver **(A)**. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining two confined grooves spaced apart from each other;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** and the outer surface **(D)** defines two confined grooves **(E)** spaced apart from each other. See FIGS. 2 and 5.
two elastic components disposed in the two confined grooves, respectively; and	The two elastic components **(F)** are disposed in the two confined grooves **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and two confined portions, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portions are connected with the linkage arm and respectively extend into the two confined grooves in order to press the two elastic components.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and two confined portions **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portions **(J)** are connected with the linkage arm **(H)** and respectively extend into the confined grooves **(E)** in order to press the elastic components **(F)**. See FIGS. 2–5.

Exhibit Q

Representative Claim Chart for U.S. Patent No. 10,578,818

EOPTOLINK 100G LR4 (QJ3D490147)

D) “outer surface”

A) “optical transceiver”

H) “linkage arm”

FIG. 1

Representative Claim Chart for U.S. Patent No. 10,578,818

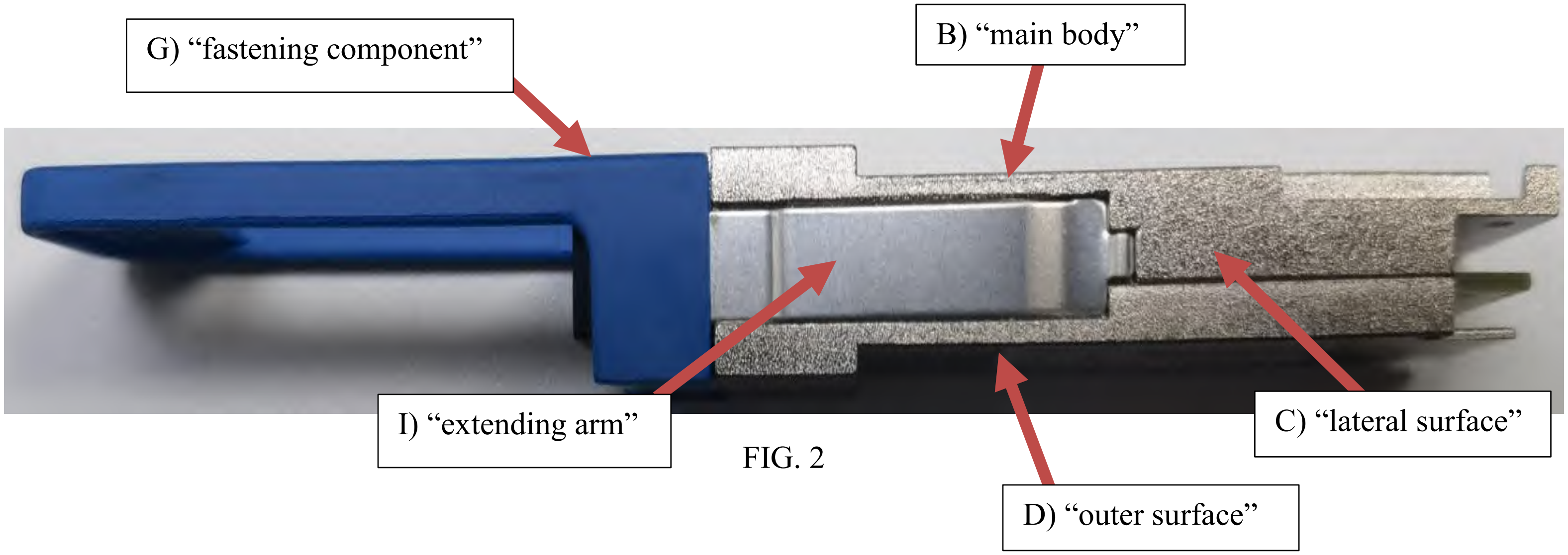


FIG. 2

Representative Claim Chart for U.S. Patent No. 10,578,818

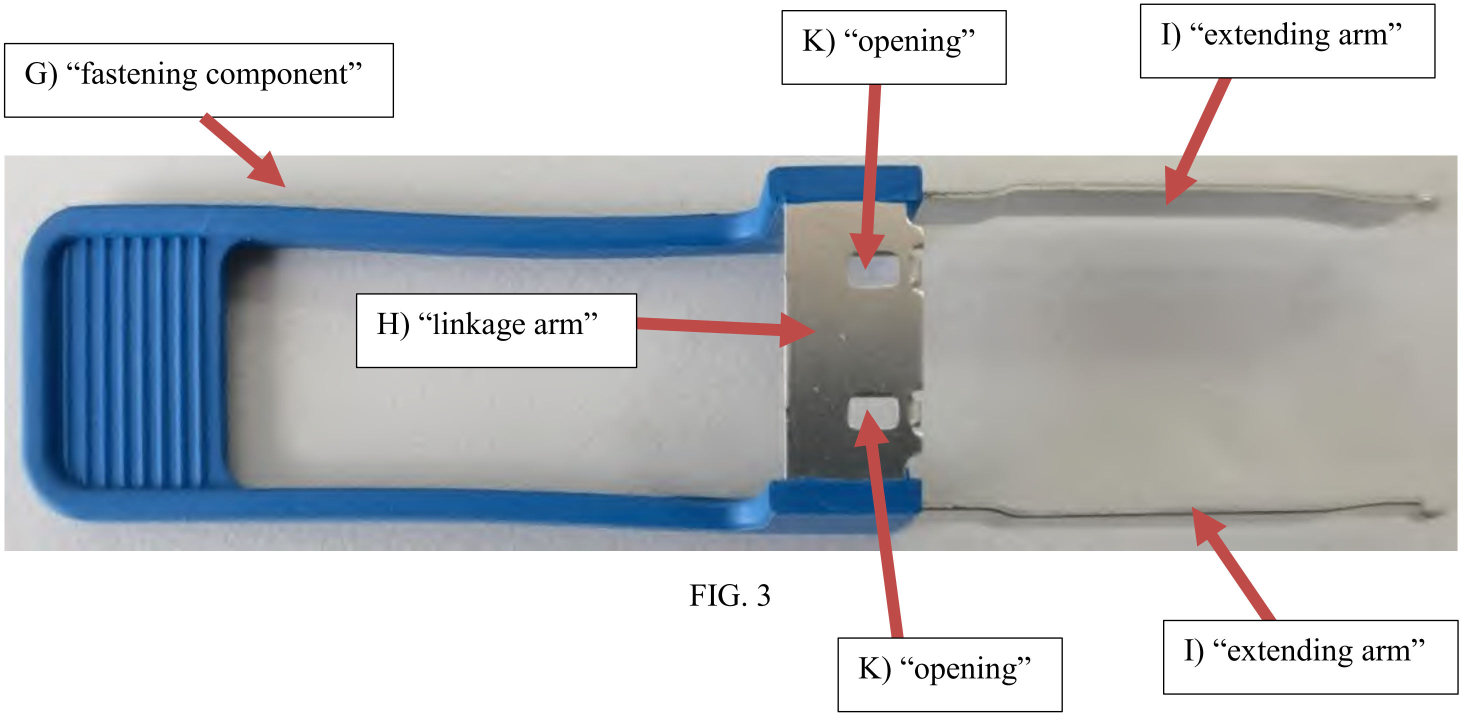


FIG. 3

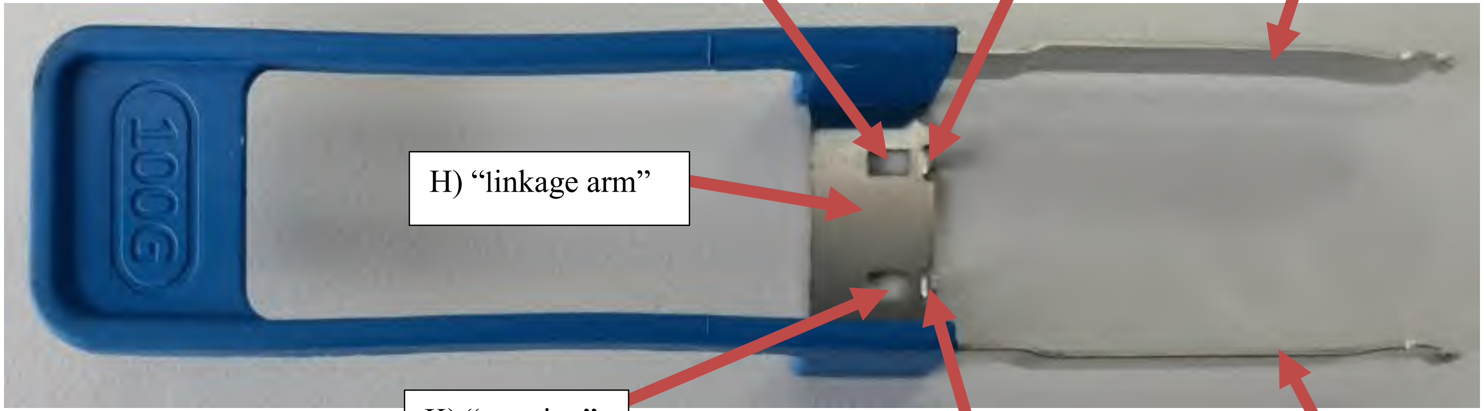
Representative Claim Chart for U.S. Patent No. 10,578,818

K) “opening”

J) “confined portion”

I) “extending arm”

H) “linkage arm”



K) “opening”

J) “confined portion”

I) “extending arm”

FIG. 4

Representative Claim Chart for U.S. Patent No. 10,578,818

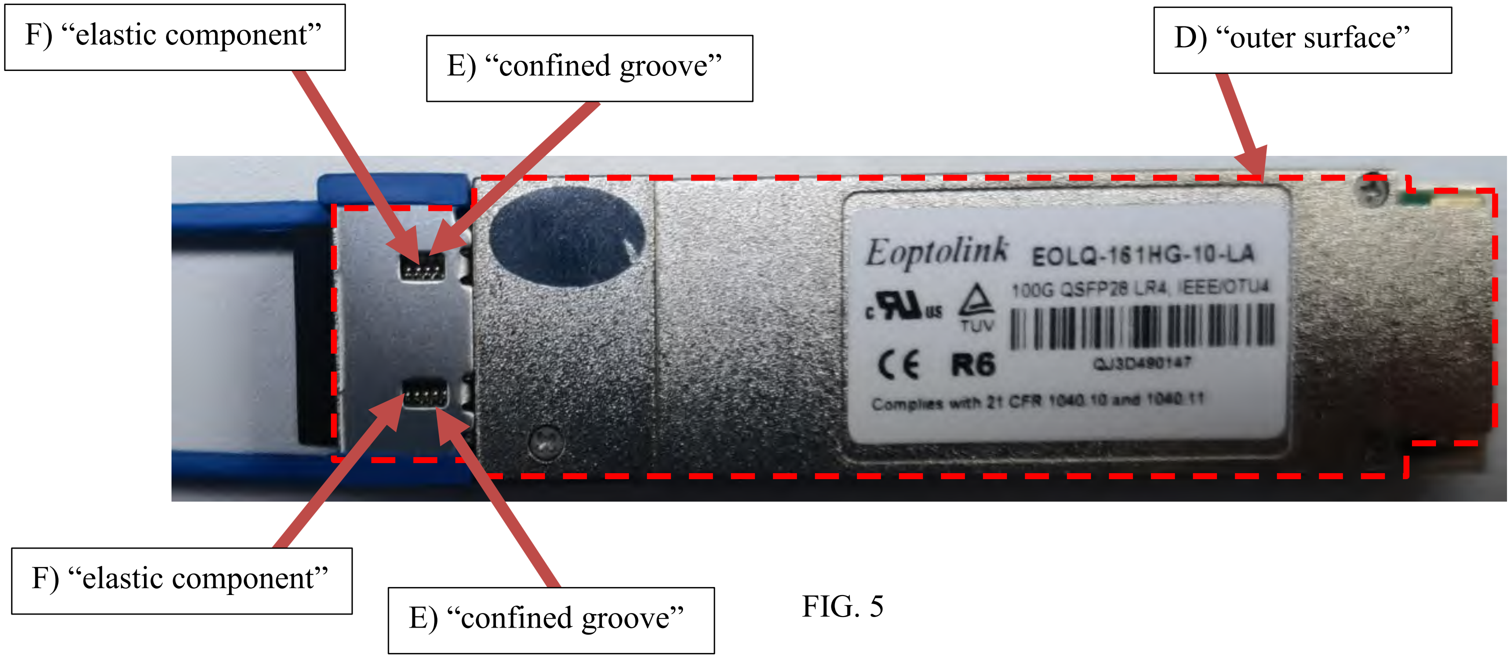


FIG. 5

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 Claim 1	EOPTOLINK 100G LR4 (QJ3D490147)
An optical transceiver, configured to be inserted into a cage in a pluggable manner, comprising:	On information and belief, an optical transceiver **(A)** can be inserted into a cage in a pluggable manner. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining a confined groove;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** between the two lateral surfaces **(C),** and the outer surface **(D)** defines a confined groove **(E)**. See FIGS. 2 and 5.
an elastic component disposed in the confined groove; and	An elastic component **(F)** is disposed in the confined groove **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and a confined portion, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portion is connected with the linkage arm and extends into the confined groove in order to press the elastic component, and the two extending arms are detachably fasten-able with the cage.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and a confined portion **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portion **(J)** is connected with the linkage arm **(H)** and extends into the confined groove **(E)** in order to press the elastic component **(F)**. On information and belief, the two extending arms **(I)** are detachably fasten-able with the cage. See FIGS. 2–5.

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 **Claim 10**	**EOPTOLINK 100G LR4 (QJ3D490147)**
An optical transceiver, comprising:	An optical transceiver **(A)**. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining two confined grooves spaced apart from each other;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** and the outer surface **(D)** defines two confined grooves **(E)** spaced apart from each other. See FIGS. 2 and 5.
two elastic components disposed in the two confined grooves, respectively; and	The two elastic components **(F)** are disposed in the two confined grooves **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and two confined portions, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portions are connected with the linkage arm and respectively extend into the two confined grooves in order to press the two elastic components.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and two confined portions **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1 and 4. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portions **(J)** are connected with the linkage arm **(H)** and respectively extend into the confined grooves **(E)** in order to press the elastic components **(F)**. See FIGS. 2–5.

Exhibit R

Representative Claim Chart for U.S. Patent No. 10,578,818

1. EOPTOLINK 100G LR4 (QL97099330)

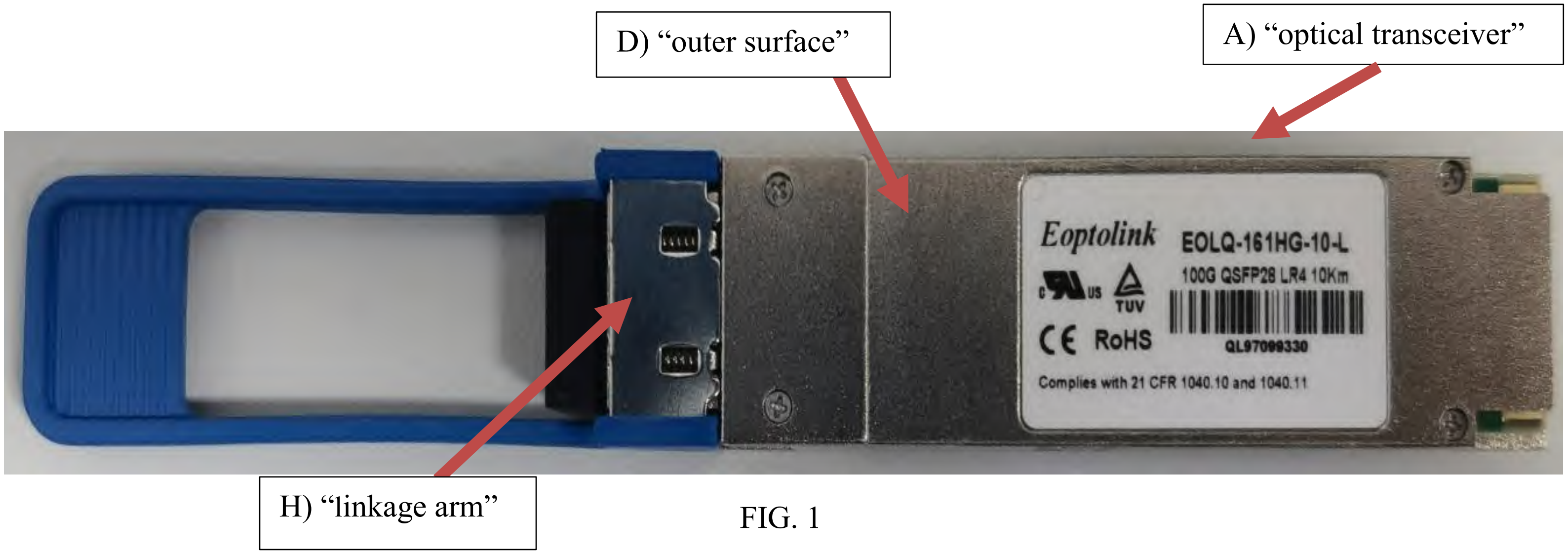


FIG. 1

Representative Claim Chart for U.S. Patent No. 10,578,818

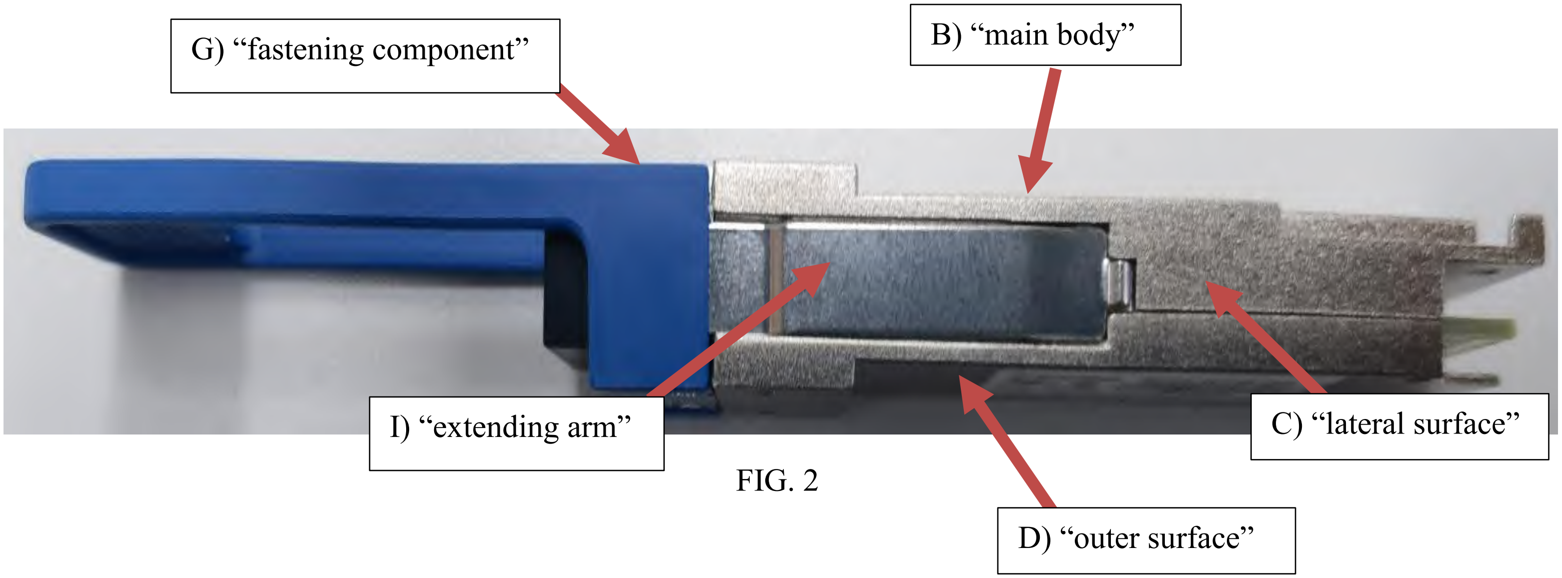


FIG. 2

Representative Claim Chart for U.S. Patent No. 10,578,818

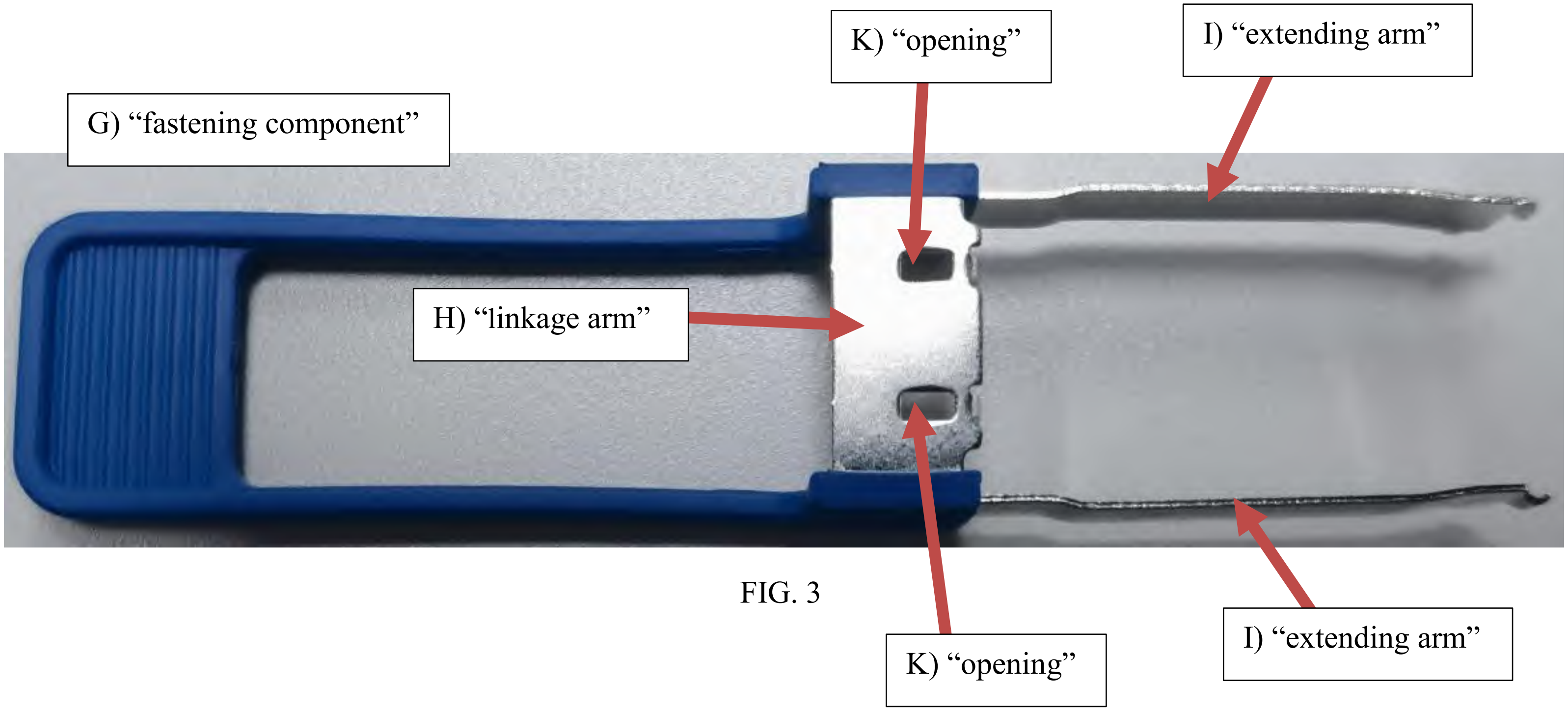


FIG. 3

Representative Claim Chart for U.S. Patent No. 10,578,818

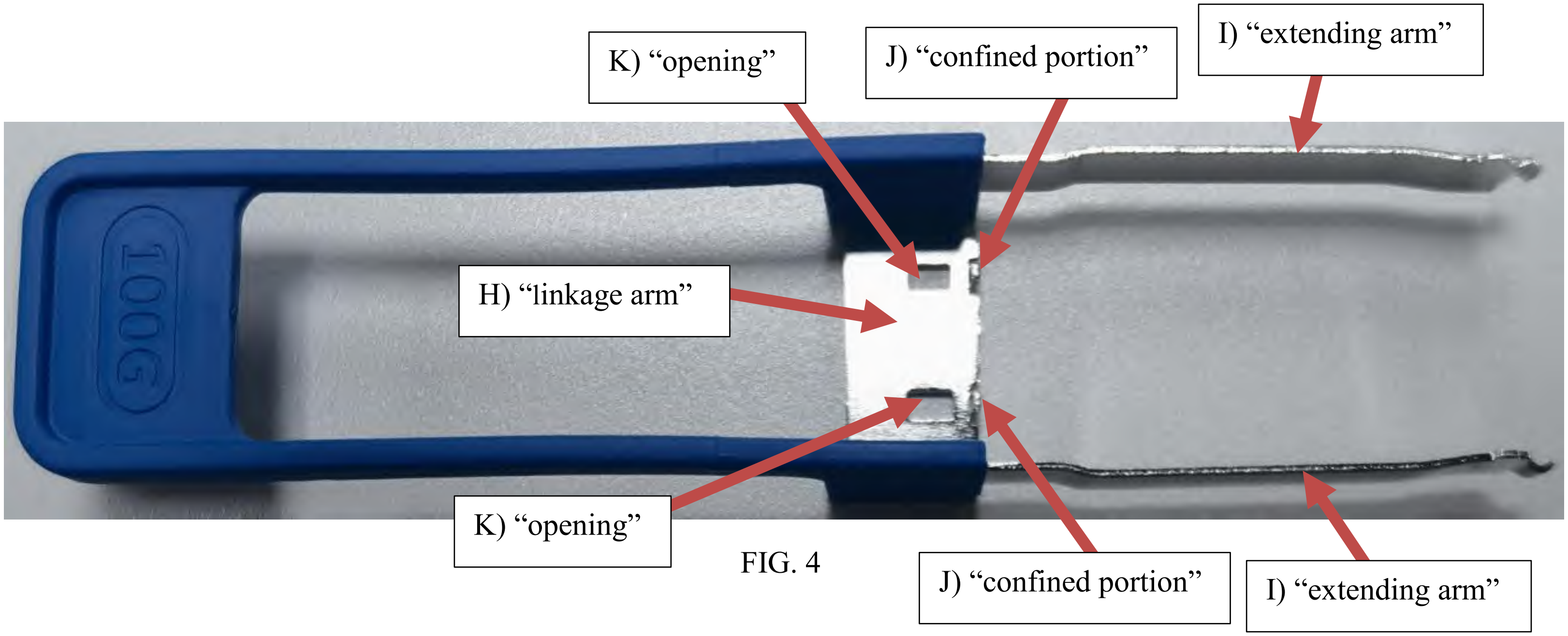


FIG. 4

Representative Claim Chart for U.S. Patent No. 10,578,818

F) “elastic component”

E) “confined groove”

D) “outer surface”

F) “elastic component”

E) “confined groove”

FIG. 5

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 Claim 1	**EOPTOLINK 100G LR4 (QL97099330)**
An optical transceiver, configured to be inserted into a cage in a pluggable manner, comprising:	On information and belief, an optical transceiver **(A)** can be inserted into a cage in a pluggable manner. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining a confined groove;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** between the two lateral surfaces **(C)**, and the outer surface **(D)** defines a confined groove **(E)**. See FIGS. 2 and 5.
an elastic component disposed in the confined groove; and	An elastic component **(F)** is disposed in the confined groove **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and a confined portion, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portion is connected with the linkage arm and extends into the confined groove in order to press the elastic component, and the two extending arms are detachably fasten-able with the cage.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and a confined portion **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portion **(J)** is connected with the linkage arm **(H)** and extends into the confined groove **(E)** in order to press the elastic component **(F)**. On information and belief, the two extending arms **(I)** are detachably fasten-able with the cage. See FIGS. 2–5.

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 Claim 10	**EOPTOLINK 100G LR4 (QL97099330)**
An optical transceiver, comprising:	An optical transceiver **(A)**. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining two confined grooves spaced apart from each other;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** and the outer surface **(D)** defines two confined grooves **(E)** spaced apart from each other. See FIGS. 2 and 5.
two elastic components disposed in the two confined grooves, respectively; and	The two elastic components **(F)** are disposed in the two confined grooves **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and two confined portions, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portions are connected with the linkage arm and respectively extend into the two confined grooves in order to press the two elastic components.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component includes **(G)** a linkage arm **(H)**, two extending arms **(I)** and two confined portions **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portions **(J)** are connected with the linkage arm **(H)** and respectively extend into the confined grooves **(E)** in order to press the elastic components **(F)**. See FIGS. 2–5.

Exhibit S

Representative Claim Chart for U.S. Patent No. 10,578,818

EOPTOLINK 400G QSFP-DD DR4

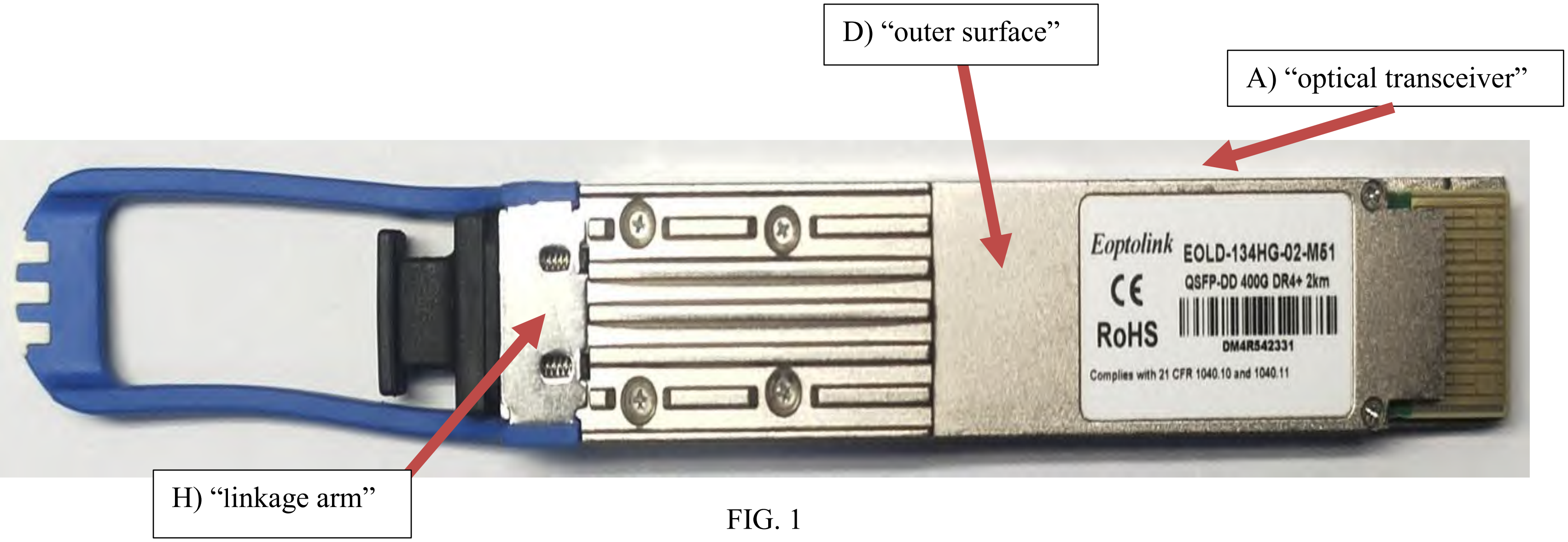


FIG. 1

Representative Claim Chart for U.S. Patent No. 10,578,818

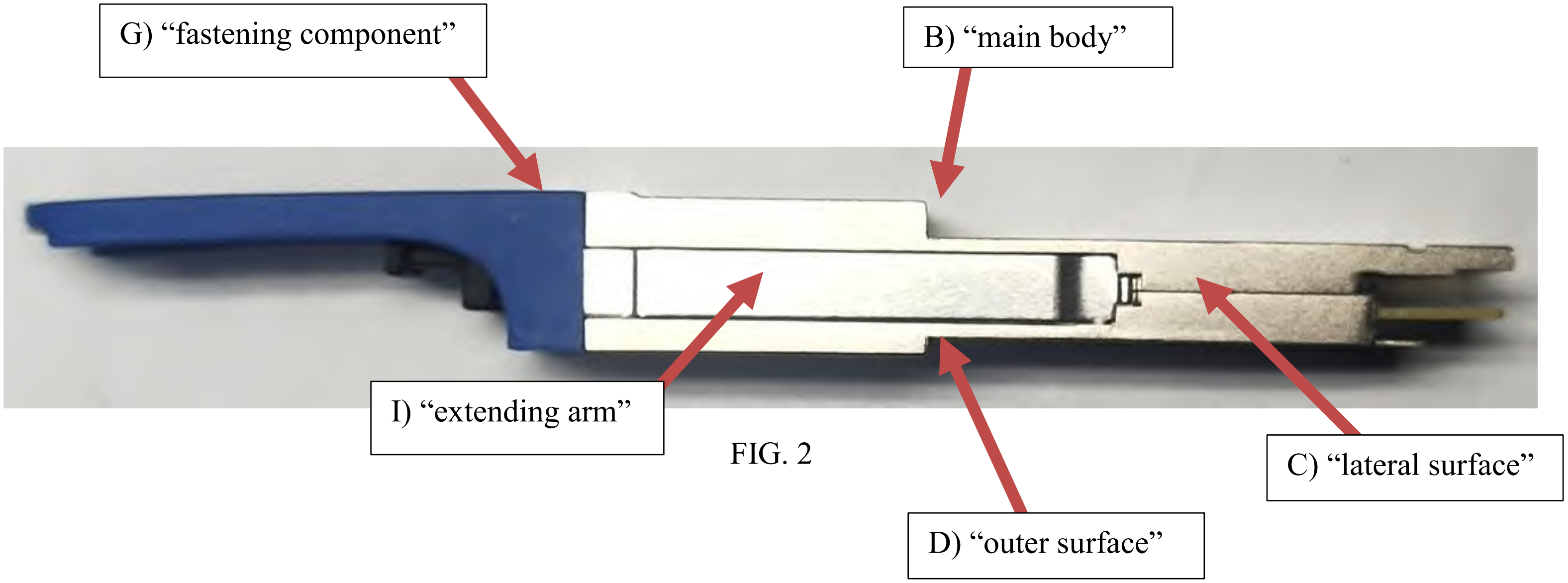


FIG. 2

Representative Claim Chart for U.S. Patent No. 10,578,818

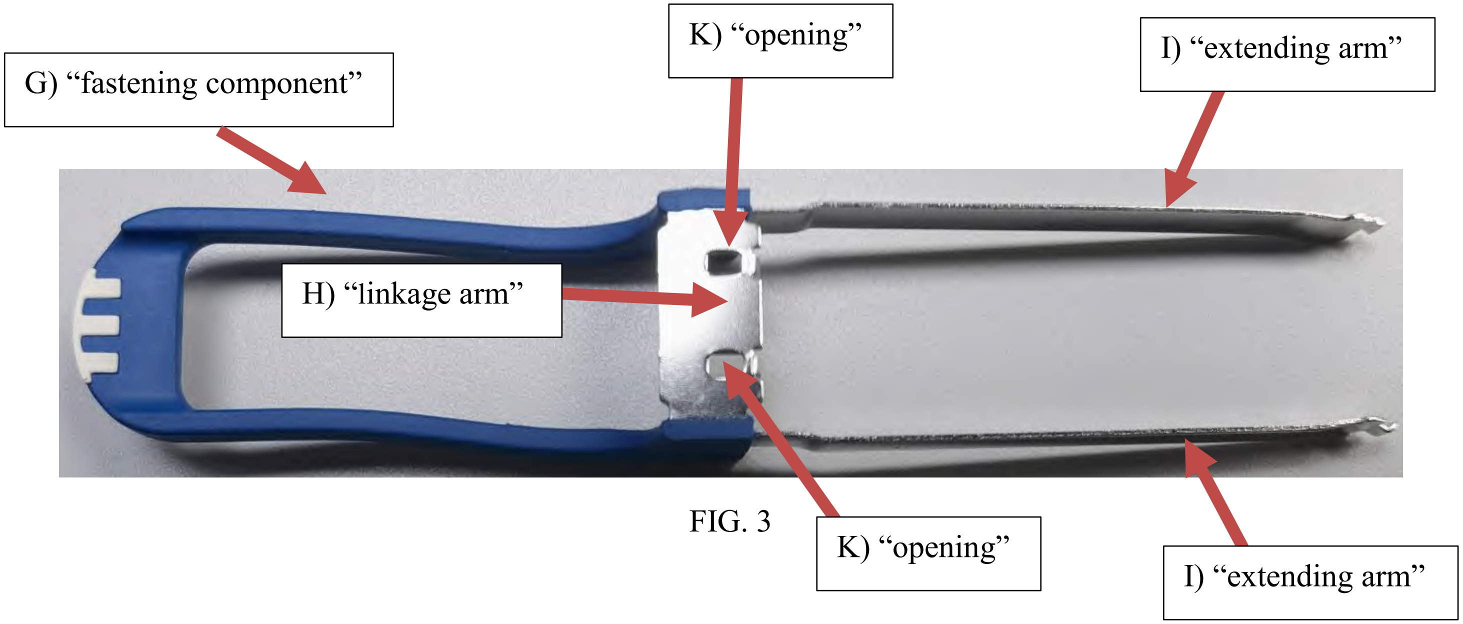


FIG. 3

Representative Claim Chart for U.S. Patent No. 10,578,818

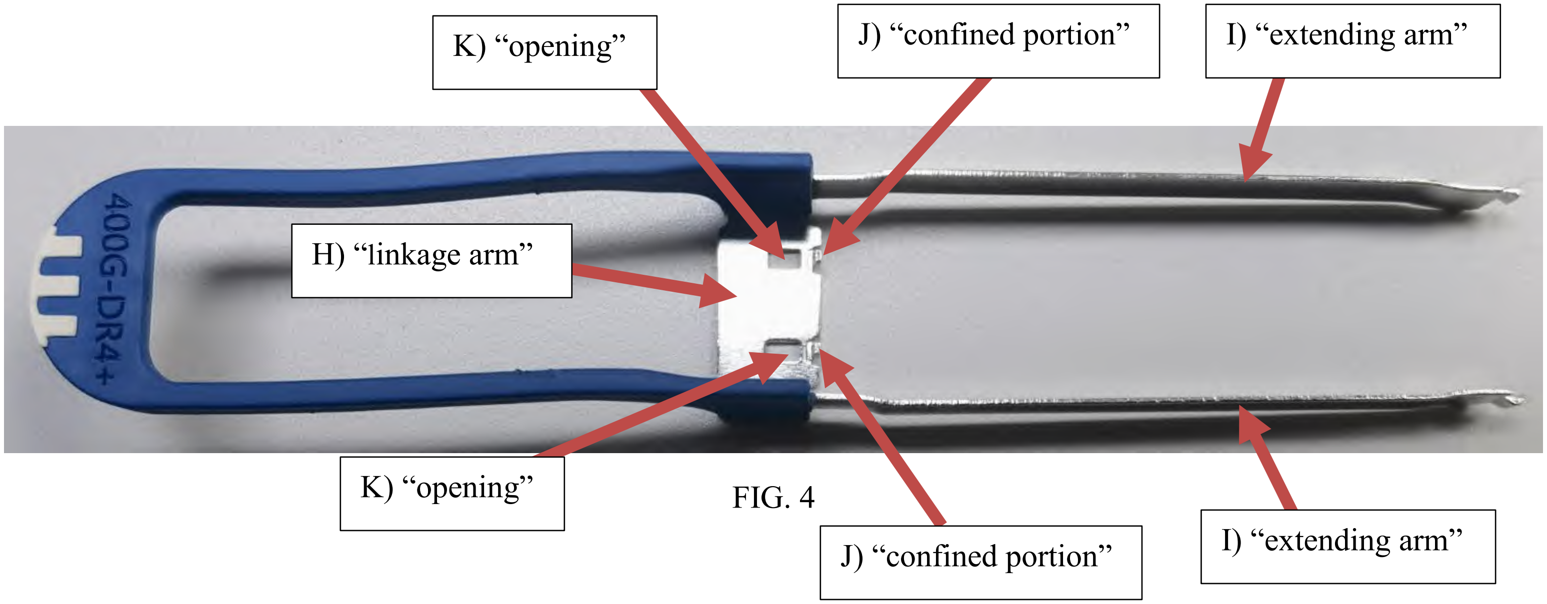


FIG. 4

Representative Claim Chart for U.S. Patent No. 10,578,818

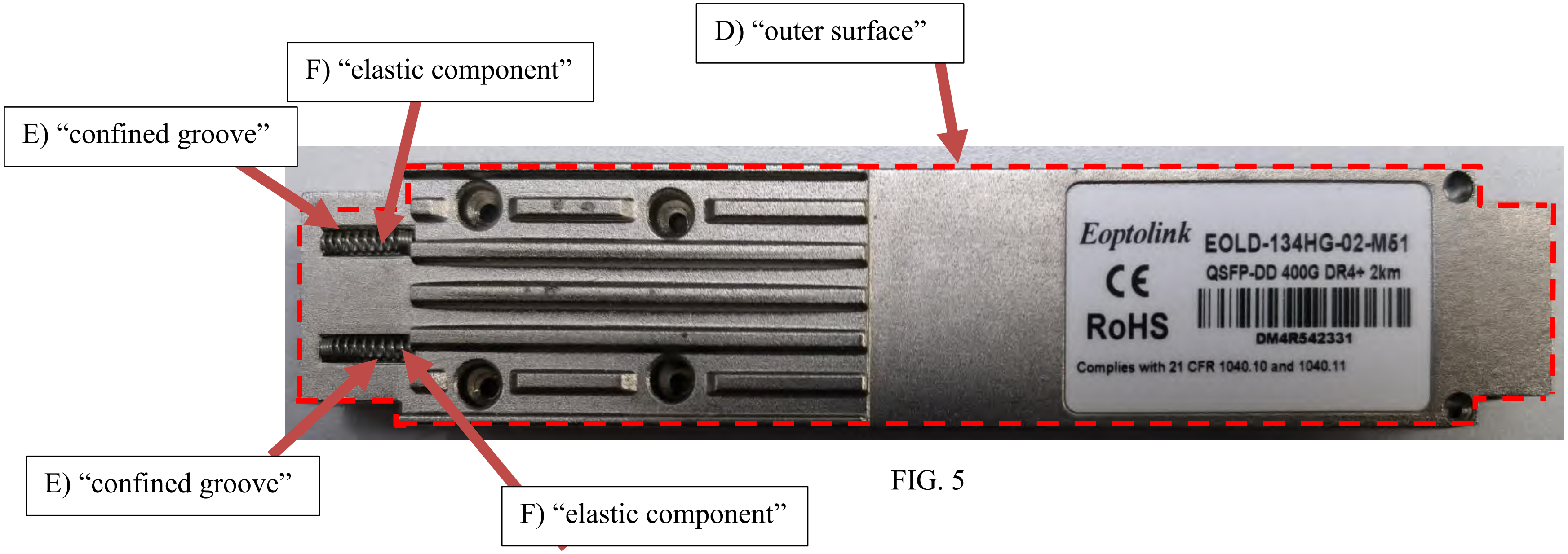


FIG. 5

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 Claim 1	EOPTOLINK 400G QSFP-DD DR4
An optical transceiver, configured to be inserted into a cage in a pluggable manner, comprising:	On information and belief, an optical transceiver **(A)** can be inserted into a cage in a pluggable manner. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining a confined groove;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** between the two lateral surfaces **(C)**, and the outer surface **(D)** defines a confined groove **(E)**. See FIGS. 2 and 5.
an elastic component disposed in the confined groove; and	An elastic component **(F)** is disposed in the confined groove **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and a confined portion, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portion is connected with the linkage arm and extends into the confined groove in order to press the elastic component, and the two extending arms are detachably fasten-able with the cage.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and a confined portion **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portion **(J)** is connected with the linkage arm **(H)** and extends into the confined groove **(E)** in order to press the elastic component **(F)**. On information and belief, the two extending arms **(I)** are detachably fasten-able with the cage. See FIGS. 2–5.

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 **Claim 10**	**EOPTOLINK 400G QSFP-DD DR4**
An optical transceiver, comprising:	An optical transceiver **(A)**. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining two confined grooves spaced apart from each other;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** and the outer surface **(D)** defines two confined grooves **(E)** spaced apart from each other. See FIGS. 2 and 5.
two elastic components disposed in the two confined grooves, respectively; and	The two elastic components **(F)** are disposed in the two confined grooves **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and two confined portions, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portions are connected with the linkage arm and respectively extend into the two confined grooves in order to press the two elastic components.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component includes **(G)** a linkage arm **(H)**, two extending arms **(I)** and two confined portions **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portions **(J)** are connected with the linkage arm **(H)** and respectively extend into the confined grooves **(E)** in order to press the elastic components **(F)**. See FIGS. 2–5.

Exhibit T

Representative Claim Chart for U.S. Patent No. 10,578,818

EOPTOLINK 400G QSFP-DD FR4

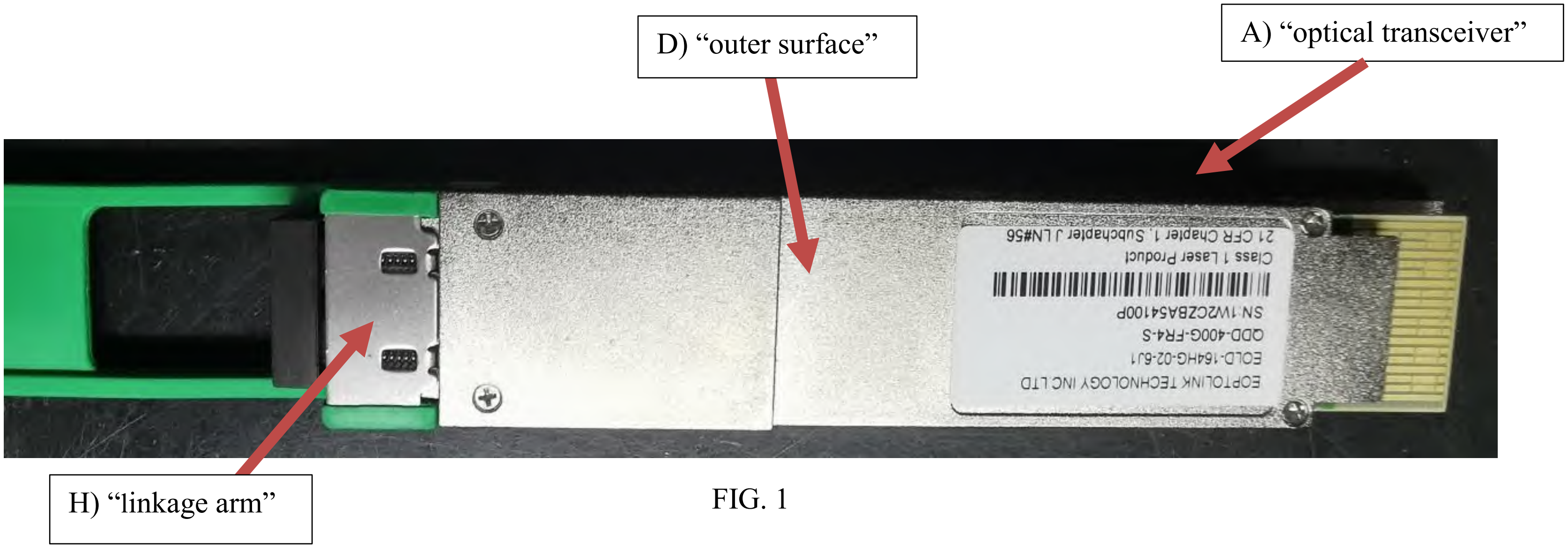


FIG. 1

Representative Claim Chart for U.S. Patent No. 10,578,818

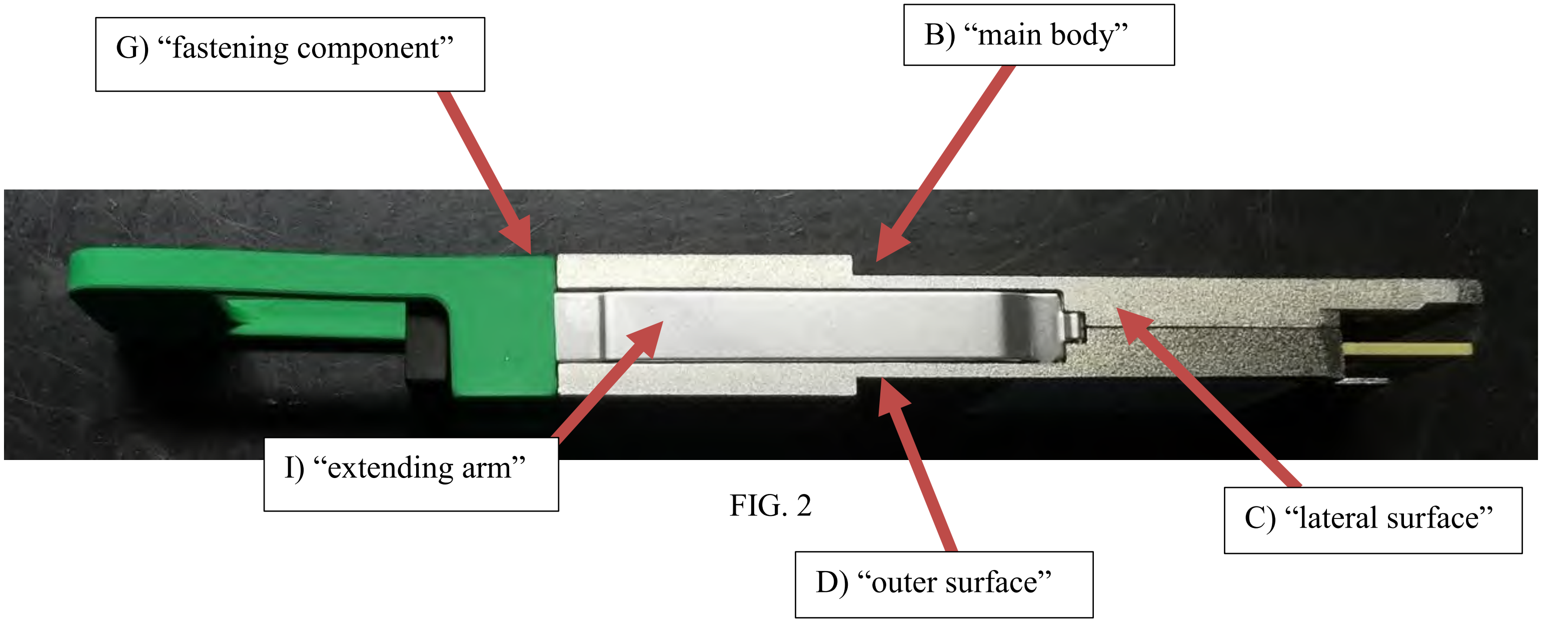


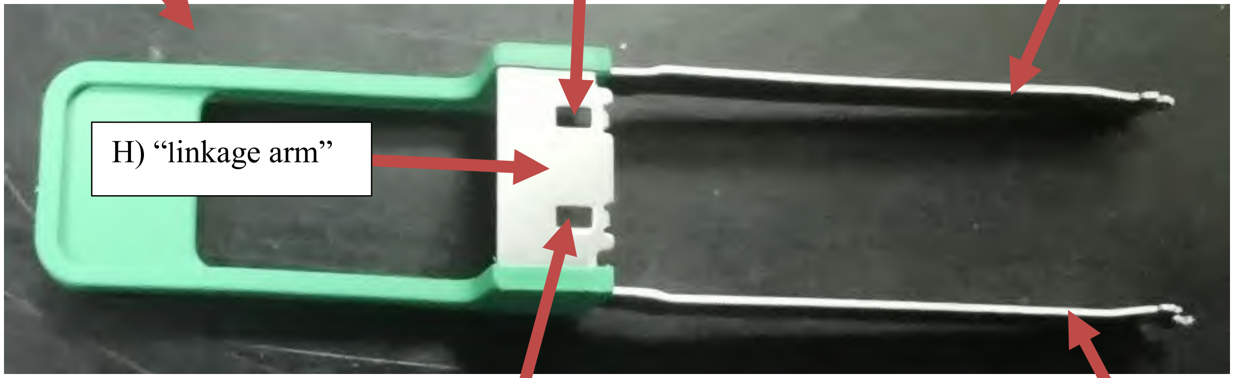
FIG. 2

Representative Claim Chart for U.S. Patent No. 10,578,818

K) "opening"

G) "fastening component"

I) "extending arm"



H) "linkage arm"

FIG. 3

K) "opening"

I) "extending arm"

Representative Claim Chart for U.S. Patent No. 10,578,818

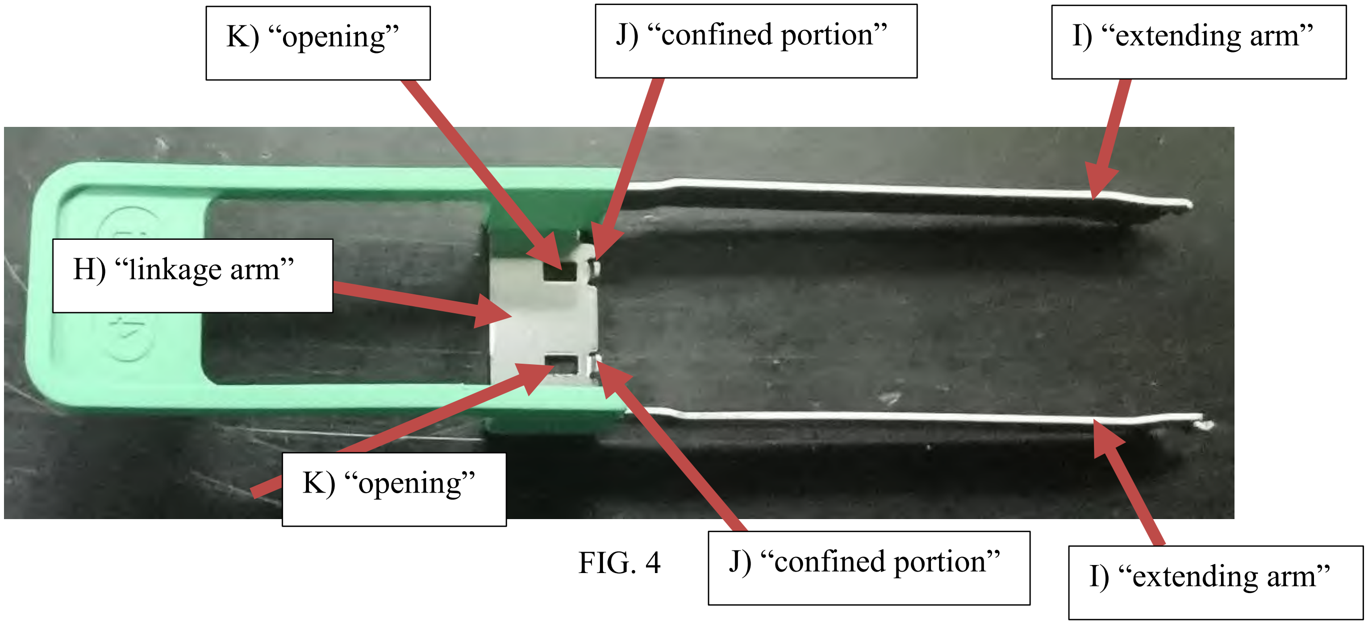


FIG. 4

Representative Claim Chart for U.S. Patent No. 10,578,818

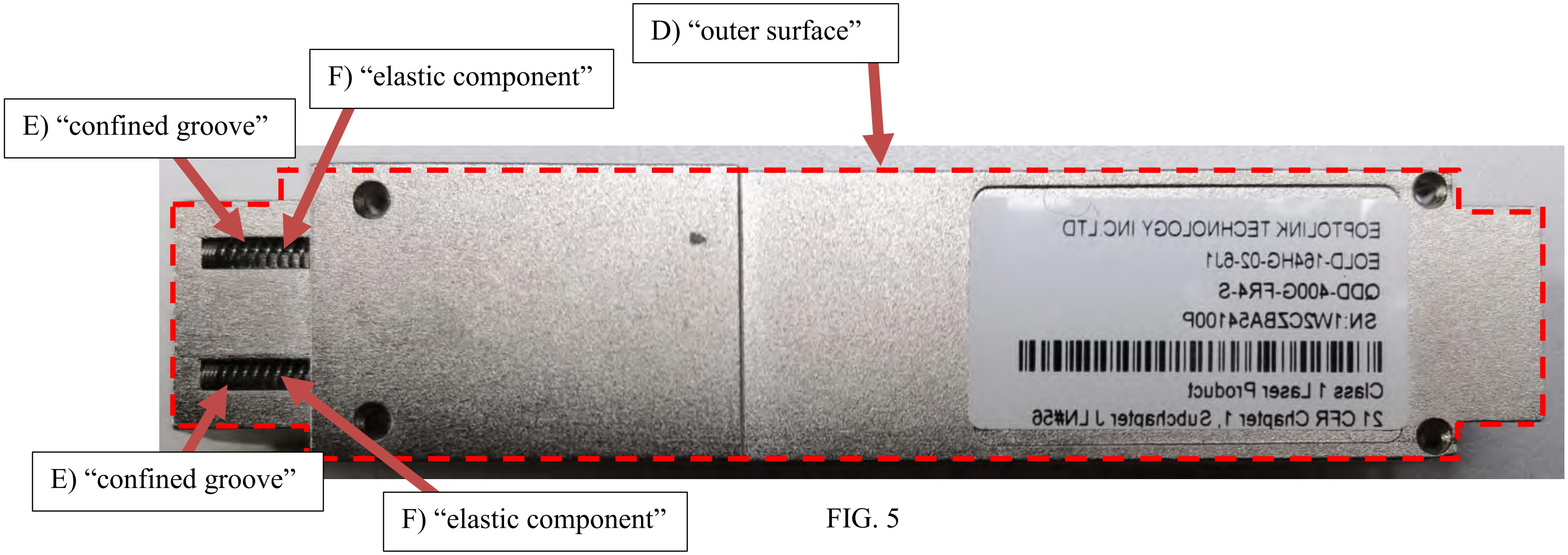


FIG. 5

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 Claim 1	EOPTOLINK 400G QSFP-DD FR4
An optical transceiver, configured to be inserted into a cage in a pluggable manner, comprising:	On information and belief, an optical transceiver **(A)** can be inserted into a cage in a pluggable manner. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining a confined groove;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** between the two lateral surfaces **(C)**, and the outer surface **(D)** defines a confined groove **(E)**. See FIGS. 2 and 5.
an elastic component disposed in the confined groove; and	An elastic component **(F)** is disposed in the confined groove **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and a confined portion, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portion is connected with the linkage arm and extends into the confined groove in order to press the elastic component, and the two extending arms are detachably fasten-able with the cage.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and a confined portion **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portion **(J)** is connected with the linkage arm **(H)** and extends into the confined groove **(E)** in order to press the elastic component **(F)**. On information and belief, the two extending arms **(I)** are detachably fasten-able with the cage. See FIGS. 2–5.

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 **Claim 10**	**EOPTOLINK 400G QSFP-DD FR4**
An optical transceiver, comprising:	An optical transceiver **(A)**. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining two confined grooves spaced apart from each other;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** and the outer surface **(D)** defines two confined grooves **(E)** spaced apart from each other. See FIGS. 2 and 5.
two elastic components disposed in the two confined grooves, respectively; and	The two elastic components **(F)** are disposed in the two confined grooves **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and two confined portions, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portions are connected with the linkage arm and respectively extend into the two confined grooves in order to press the two elastic components.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and two confined portions **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portions **(J)** are connected with the linkage arm **(H)** and respectively extend into the confined grooves **(E)** in order to press the elastic components **(F)**. See FIGS. 2–5.

Exhibit U

Representative Claim Chart for U.S. Patent No. 10,578,818

EOPTOLINK 400G QSFP-DD LR4

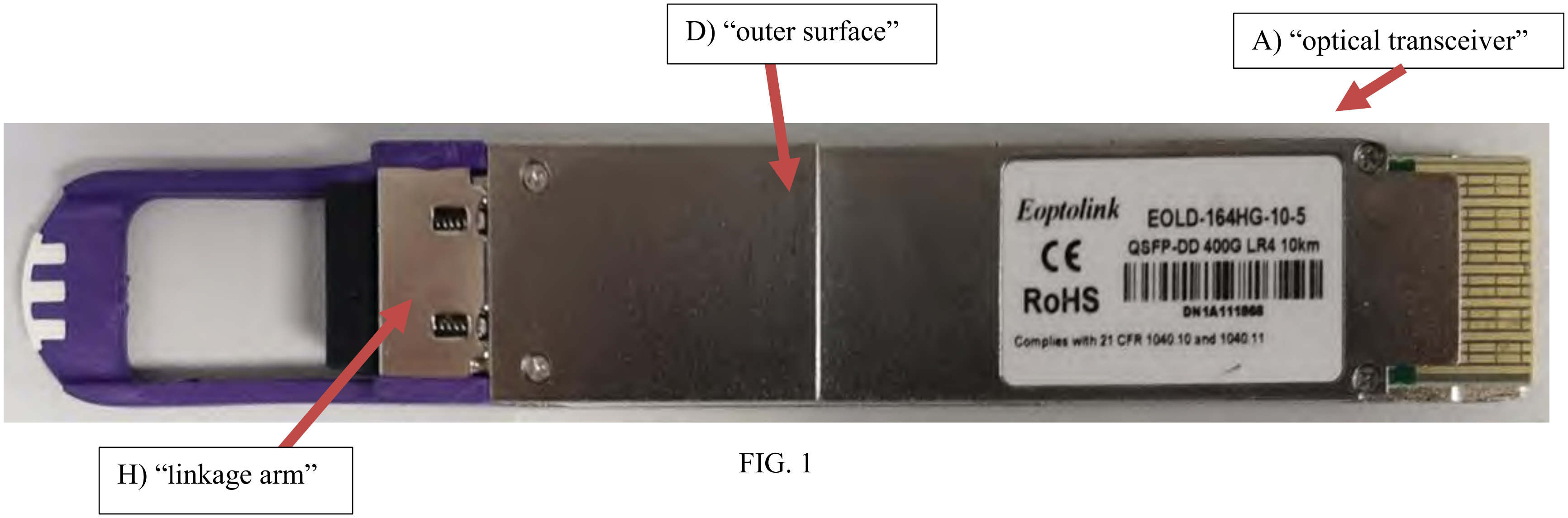
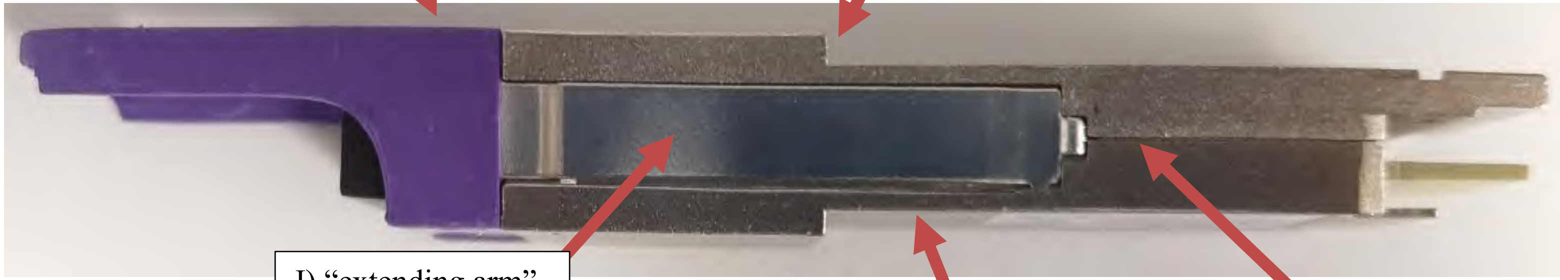


FIG. 1

Representative Claim Chart for U.S. Patent No. 10,578,818



G) “fastening component”

B) “main body”

I) “extending arm”

C) “lateral surface”

D) “outer surface”

FIG. 2

Representative Claim Chart for U.S. Patent No. 10,578,818

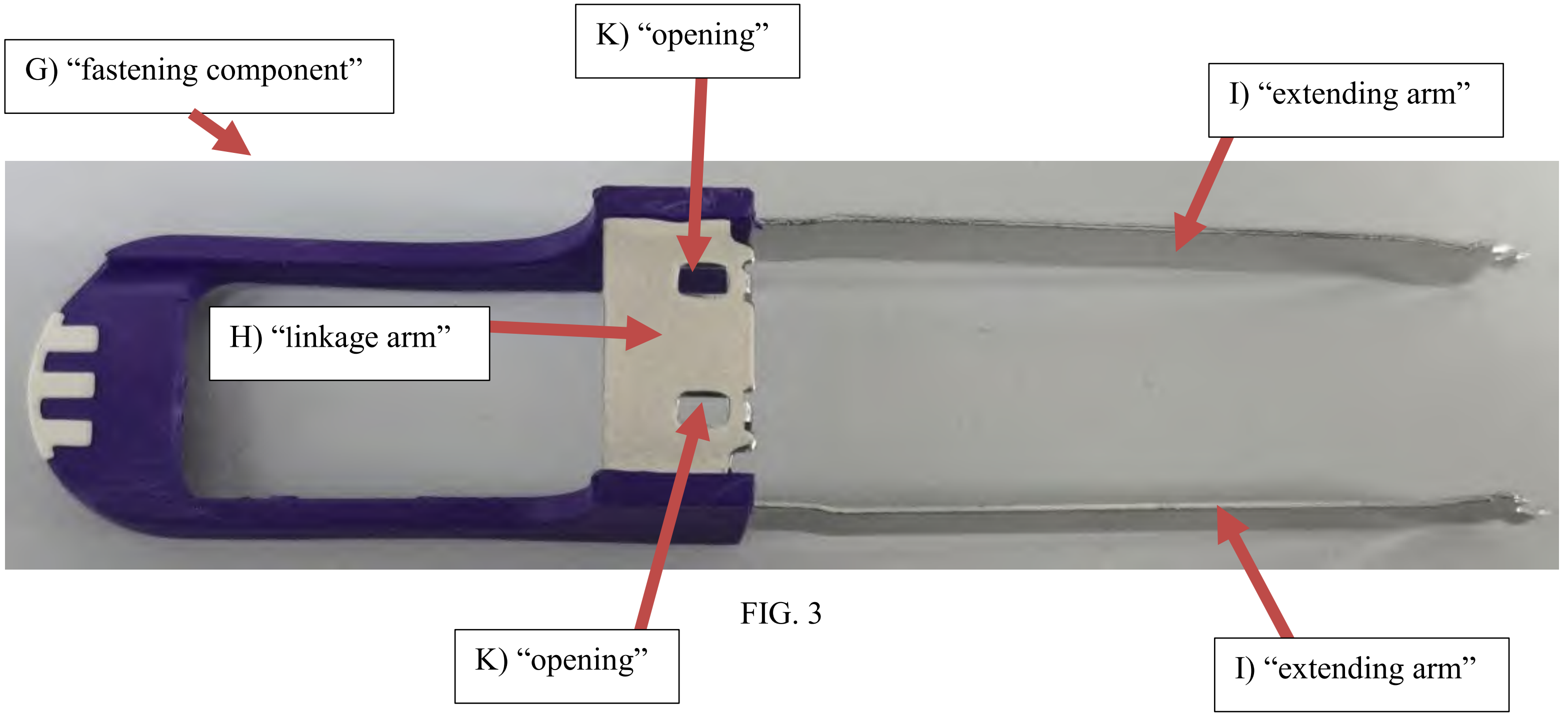


FIG. 3

Representative Claim Chart for U.S. Patent No. 10,578,818

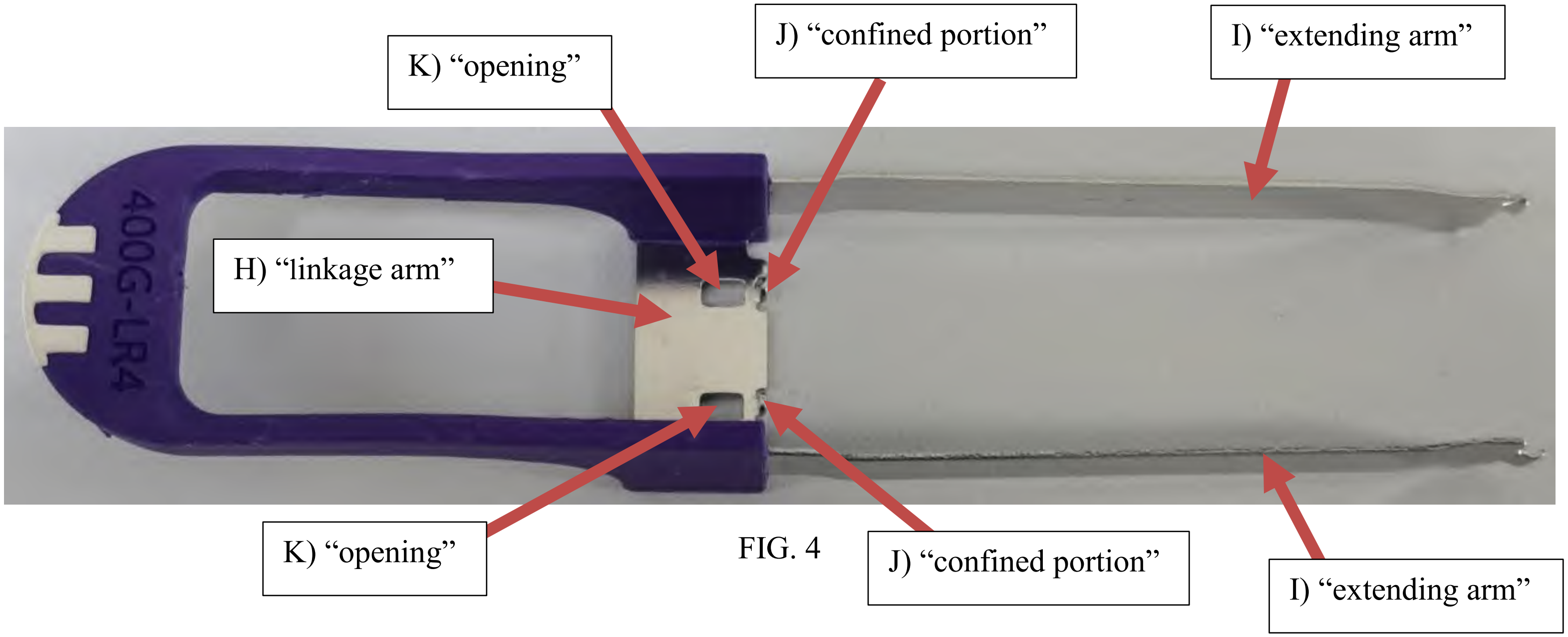


FIG. 4

Representative Claim Chart for U.S. Patent No. 10,578,818

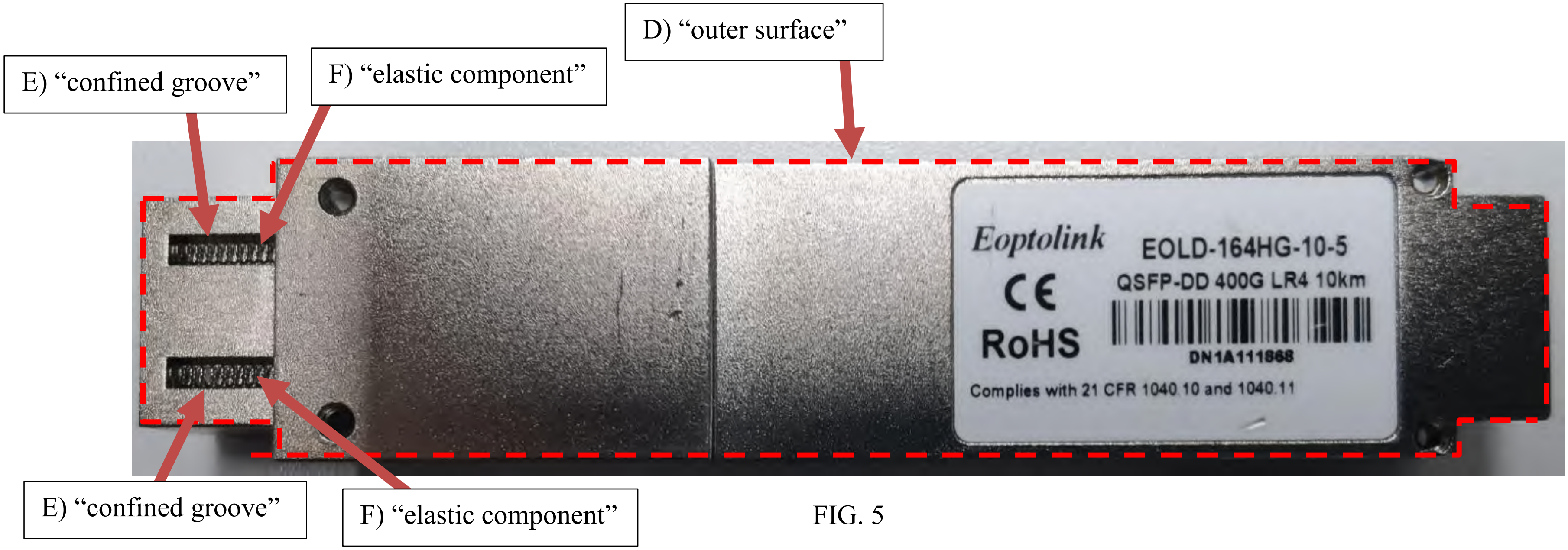


FIG. 5

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 Claim 1	EOPTOLINK 400G QSFP-DD LR4
An optical transceiver, configured to be inserted into a cage in a pluggable manner, comprising:	On information and belief, optical transceiver **(A)** can be inserted into a cage in a pluggable manner. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining a confined groove;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** between the two lateral surfaces **(C)** and the outer surface **(D)** defines a confined groove **(E)**. See FIGS. 2 and 5.
an elastic component disposed in the confined groove; and	An elastic component **(F)** is disposed in the confined groove **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and a confined portion, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portion is connected with the linkage arm and extends into the confined groove in order to press the elastic component, and the two extending arms are detachably fasten-able with the cage.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and a confined portion **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portion **(J)** is connected with the linkage arm **(H)** and extends into the confined groove **(E)** in order to press the elastic component **(F)**. On information and belief, the two extending arms **(I)** are detachably fasten-able with the cage. See FIGS. 2–5.

Representative Claim Chart for U.S. Patent No. 10,578,818

U.S. Patent No. 10,578,818 **Claim 10**	**EOPTOLINK 400G QSFP-DD LR4**
An optical transceiver, comprising:	An optical transceiver **(A)**. See FIGS. 1–5.
a main body comprising two lateral surfaces and an outer surface between the two lateral surfaces, and the outer surface defining two confined grooves spaced apart from each other;	A main body **(B)** includes two lateral surfaces **(C)** and an outer surface **(D)** and the outer surface **(D)** defines two confined grooves **(E)** spaced apart from each other. See FIGS. 2 and 5.
two elastic components disposed in the two confined grooves, respectively; and	The two elastic components **(F)** are disposed in the two confined grooves **(E)**. See FIG. 5.
a fastening component movably disposed on the main body, the fastening component comprising a linkage arm, two extending arms and two confined portions, wherein the linkage arm is disposed on the outer surface of the main body, and wherein the linkage arm comprises an opening in communication with the confined groove of the main body to allow the elastic component to pass through the opening and be disposed in the confined groove, the two extending arms are connected with the linkage arm, the two extending arms are respectively disposed on the two lateral surfaces, the confined portions are connected with the linkage arm and respectively extend into the two confined grooves in order to press the two elastic components.	A fastening component **(G)** is movably disposed on the main body **(B)**. The fastening component **(G)** includes a linkage arm **(H)**, two extending arms **(I)** and two confined portions **(J)**. See FIGS. 2–4. The linkage arm **(H)** is disposed on the outer surface **(D)** of the main body **(B)**. The linkage arm **(H)** includes an opening **(K)** in communication with the confined groove **(E)**. See FIGS. 1–5. The compressed elastic component **(F)** can be disposed through the opening **(K)** to be in the confined groove **(E)** allowing the opening **(K)** to be in communication with the confined groove **(E)** of the main body **(B)** to allow the elastic component **(F)** to pass through the opening **(K)** and be disposed in the confined groove **(E)**. See FIGS. 2–5. The two extending arms **(I)** are connected with the linkage arm **(H)** and respectively disposed on the two lateral surfaces **(C)**. The confined portions **(J)** are connected with the linkage arm **(H)** and respectively extend into the confined grooves **(E)** in order to press the elastic components **(F)**. See FIGS. 2–5.

Exhibit V

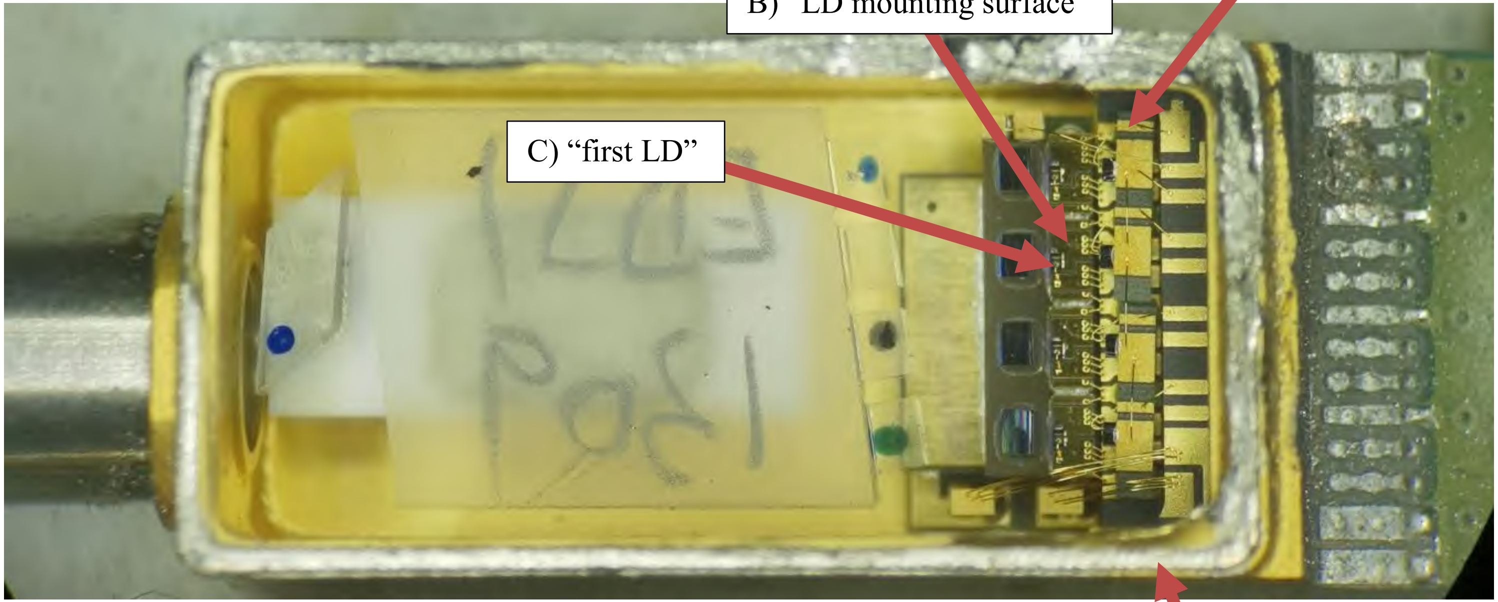
Representative Claim Chart for U.S. Patent No. 10,714,890

EOPTOLINK 100G QSFP LR4 (QL97099330)

FIG. 1

A) “TOSA module”

Representative Claim Chart for U.S. Patent No. 10,714,890



A) “TOSA module”

F) “feedthrough device”

B) “LD mounting surface”

C) “first LD”

FIG. 2

E) “base portion”

Representative Claim Chart for U.S. Patent No. 10,714,890

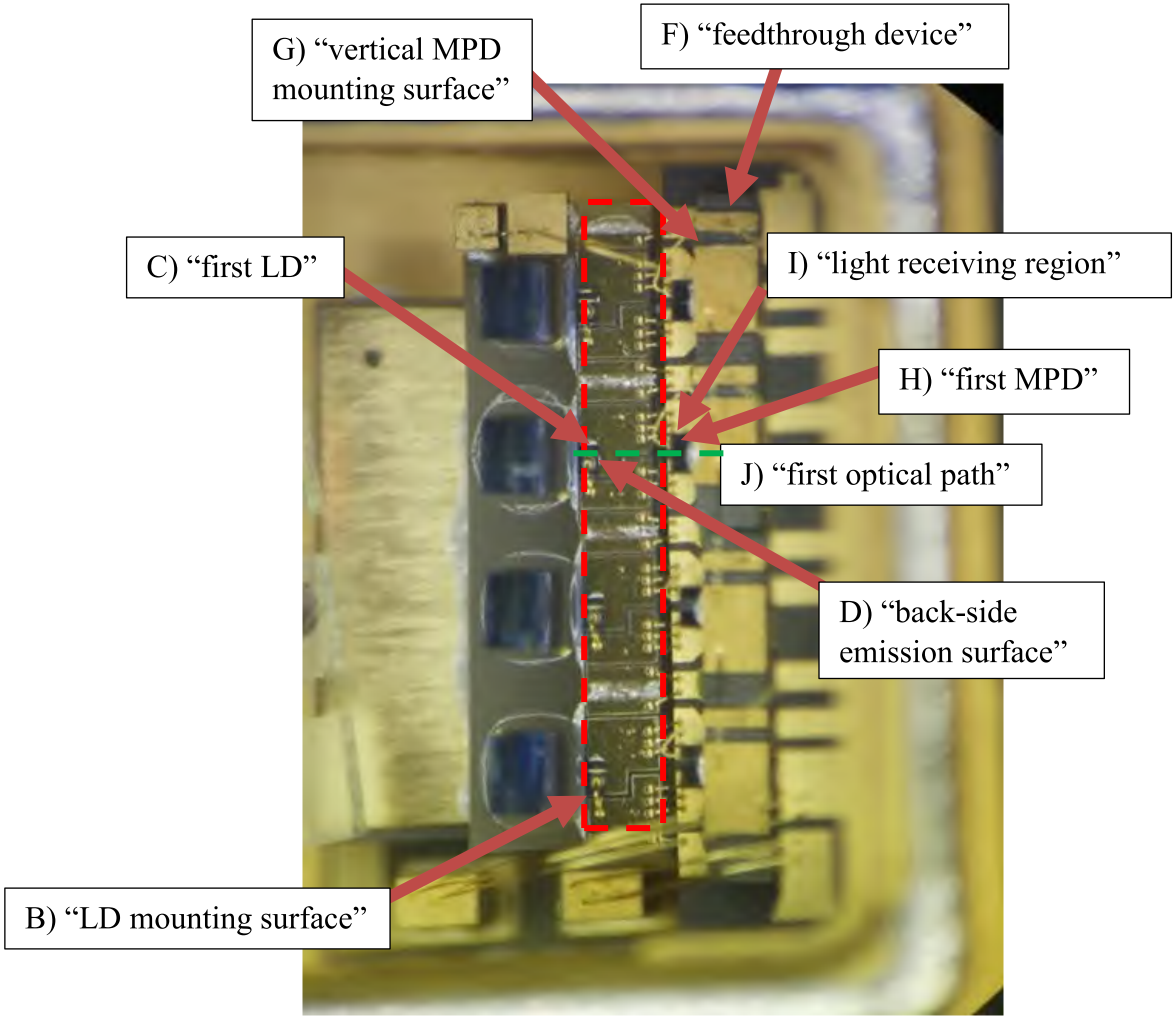


FIG. 3

Representative Claim Chart for U.S. Patent No. 10,714,890

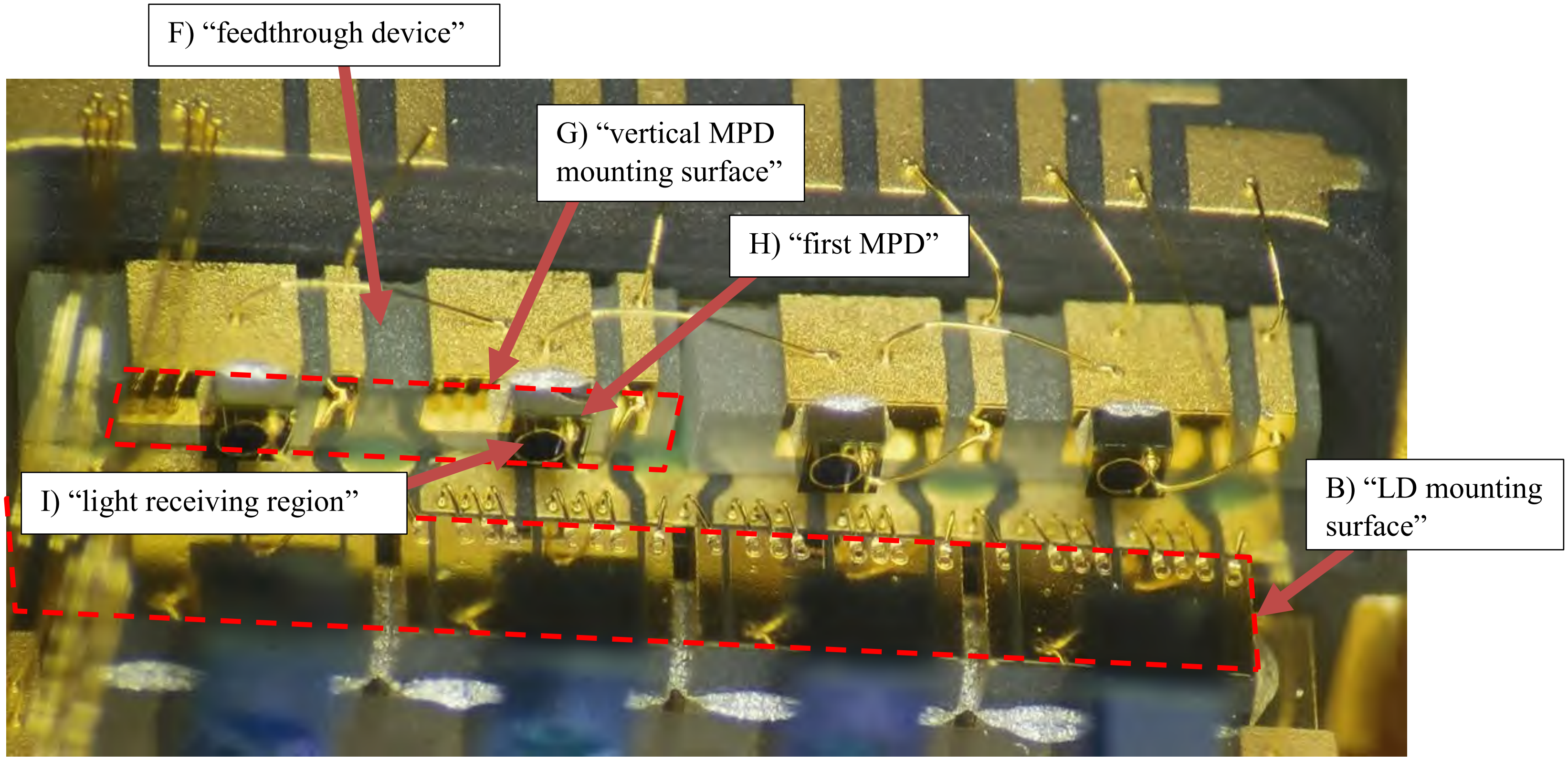


FIG. 4

Representative Claim Chart for U.S. Patent No. 10,714,890

U.S. Patent No. 10,714,890 Claim 1	EOPTOLINK 100G QSFP LR4 (QL97099330)
A transmitter optical subassembly (TOSA) module, the TOSA module comprising:	A TOSA module **(A)**. See FIGS. 1–4.
a laser diode (LD) mounting surface;	a LD mounting surface **(B)** in the TOSA module **(A)**. See FIGS. 2–4.
at least a first LD disposed on the LD mounting surface, the first LD having a back-side emission surface for emitting a portion of optical power along a first optical path;	A first LD **(C)** is disposed on the LD mounting surface **(B)**. The first LD **(C)** has a back-side emission surface **(D)** for emitting a portion of optical power along a first optical path **(J)**. See FIGS. 2 and 3.
a base portion comprising a feedthrough device, the feedthrough device providing a vertical MPD mounting surface; and	A base portion **(E)** includes a feedthrough device **(F)** providing a vertical MPD mounting surface **(G)**. See FIGS. 2–4.
a first MPD disposed on the vertical MPD mounting surface, the first MPD having a light receiving region optically aligned with the first LD via the first optical path based at least in part on the vertical MPD mounting surface extending substantially transverse relative to the LD mounting surface such that the first optical path intersects with the light receiving region of the first MPD.	A first MPD **(H)** is disposed on the vertical MPD mounting surface **(G)**. The first MPD **(H)** has a light receiving region **(I)** optically aligned with the first LD **(C)** via the first optical path **(J)** based at least in part on the vertical MPD mounting surface **(G)** extending substantially transverse relative to the LD mounting surface **(B)** such that the first optical path **(J)** intersects with the light receiving region **(I)** of the first MPD **(H)**. See FIGS. 3 and 4.

Exhibit W

Representative Claim Chart for U.S. Patent No. 10,714,890

<u>EOPTOLINK 100G QSFP LR4 (QJ3D490147)</u>

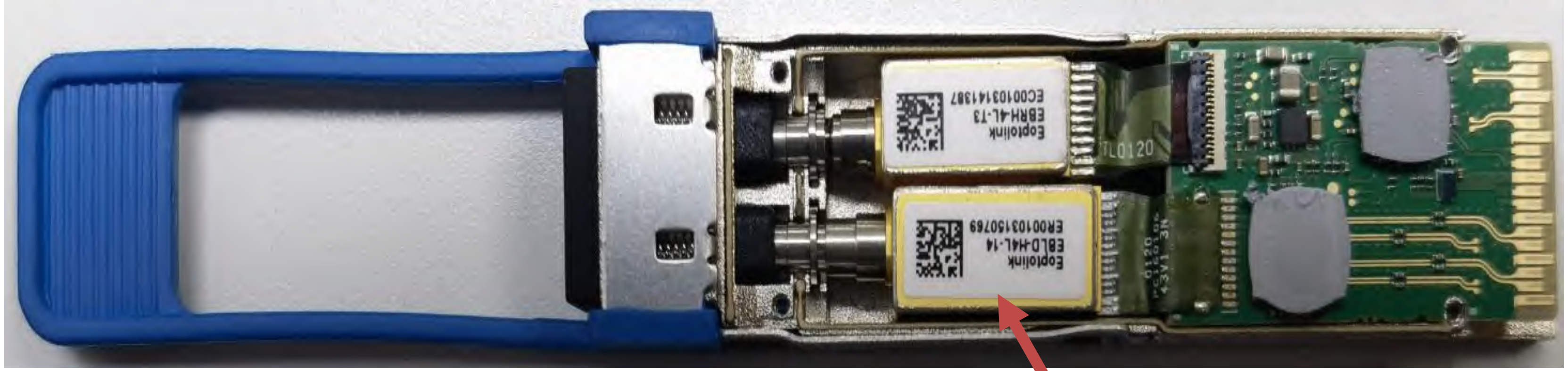


FIG. 1

A) “TOSA module”

Representative Claim Chart for U.S. Patent No. 10,714,890

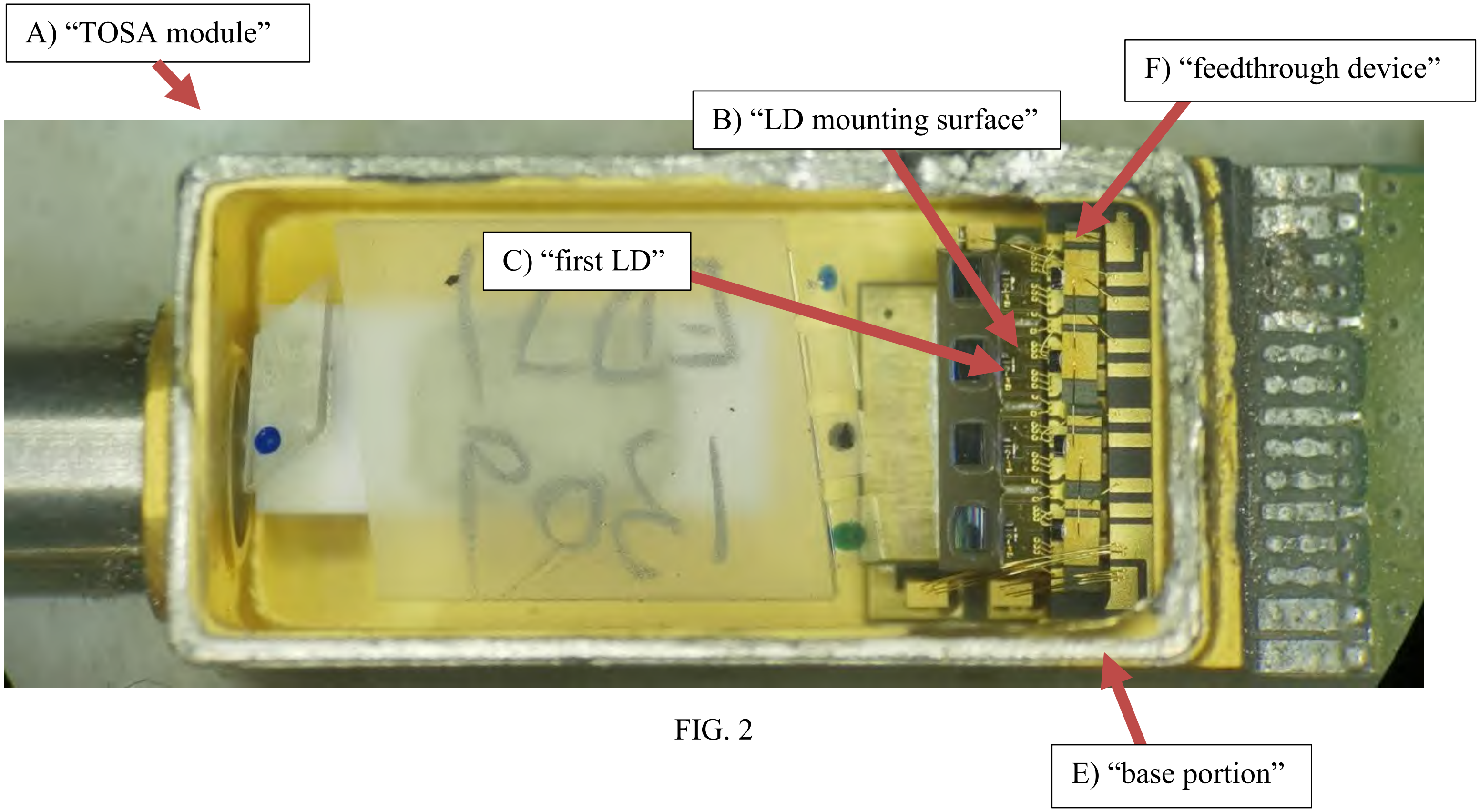


FIG. 2

Representative Claim Chart for U.S. Patent No. 10,714,890

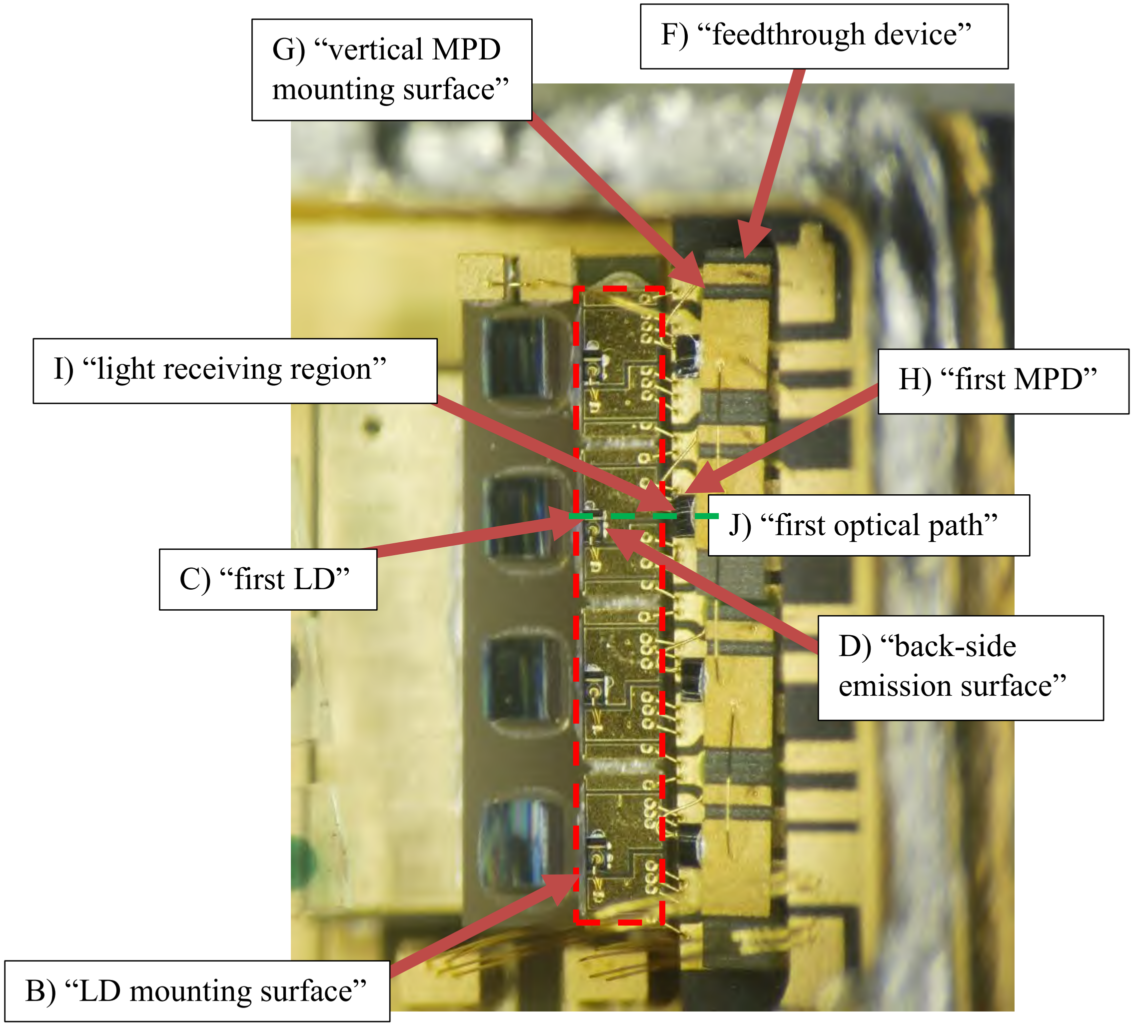


FIG. 3

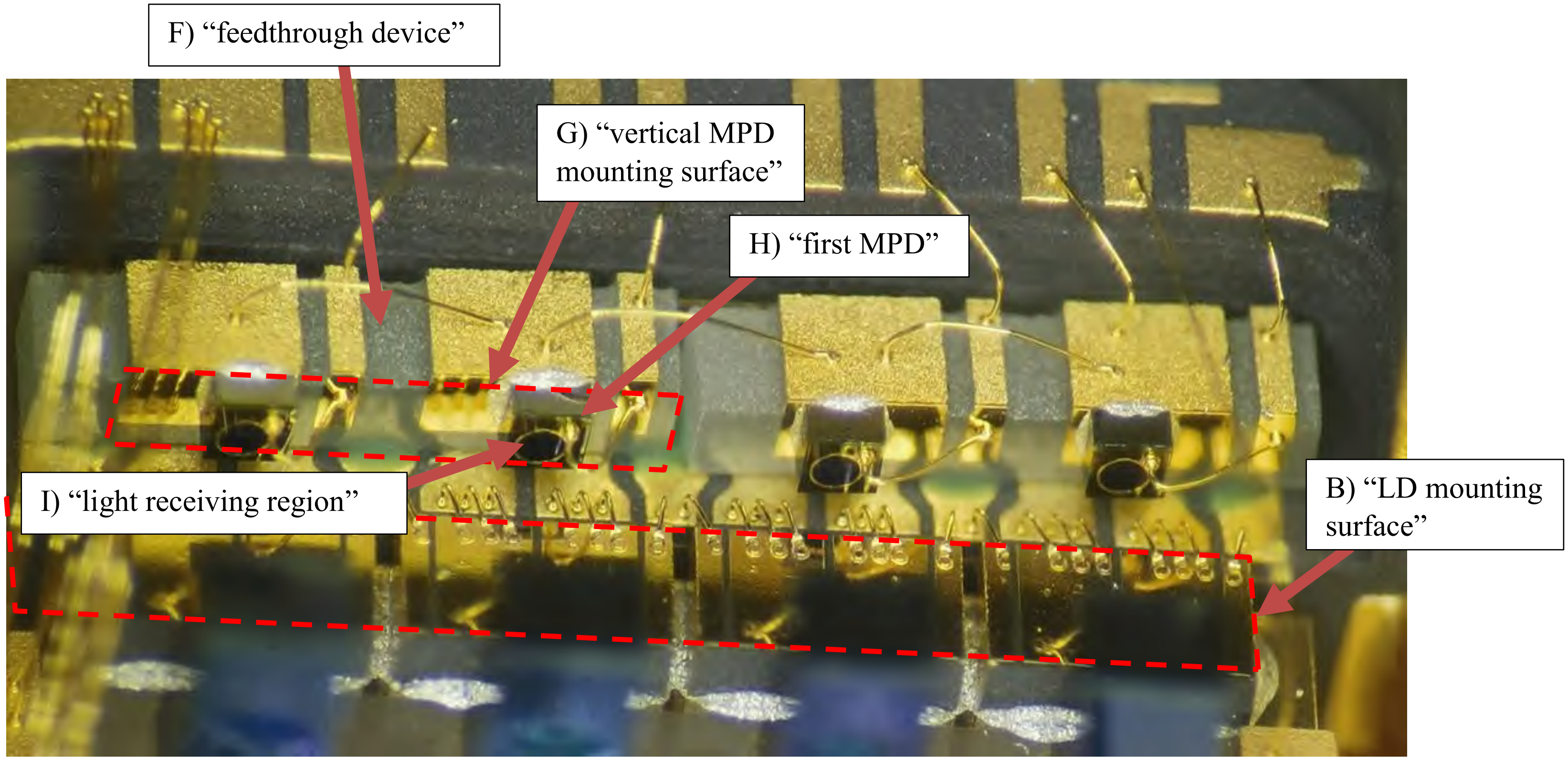

F) “feedthrough device”
G) “vertical MPD mounting surface”
H) “first MPD”
I) “light receiving region”
B) “LD mounting surface”

FIG. 4

Representative Claim Chart for U.S. Patent No. 10,714,890

U.S. Patent No. 10,714,890 Claim 1	**EOPTOLINK 100G QSFP LR4 (QJ3D490147)**
A transmitter optical subassembly (TOSA) module, the TOSA module comprising:	A TOSA module **(A)** of an optical transceiver. See FIGS.1–4.
a laser diode (LD) mounting surface;	a LD mounting surface **(B)** in the TOSA module **(A)**. See FIGS. 2–4.
at least a first LD disposed on the LD mounting surface, the first LD having a back-side emission surface for emitting a portion of optical power along a first optical path;	A first LD **(C)** is disposed on the LD mounting surface **(B)**. The first LD **(C)** has a back-side emission surface **(D)** for emitting a portion of optical power along a first optical path (**J**). See FIGS. 2 and 3.
a base portion comprising a feedthrough device, the feedthrough device providing a vertical MPD mounting surface; and	A base portion **(E)** includes a feedthrough device **(F)** providing a vertical MPD mounting surface **(G)**. See FIGS. 2–4.
a first MPD disposed on the vertical MPD mounting surface, the first MPD having a light receiving region optically aligned with the first LD via the first optical path based at least in part on the vertical MPD mounting surface extending substantially transverse relative to the LD mounting surface such that the first optical path intersects with the light receiving region of the first MPD.	A first MPD **(H)** is disposed on the vertical MPD mounting surface **(G)**. The first MPD **(H)** has a light receiving region **(I)** optically aligned with the first LD (**C**) via the first optical path (**J**) based at least in part on the vertical MPD mounting surface **(G)** extending substantially transverse relative to the LD mounting surface **(B)** such that the first optical path (**J**) intersects with the light receiving region **(I)** of the first MPD **(H)**. See FIGS. 3 and 4.

Exhibit X

Representative Claim Chart for U.S. Patent No. 11,177,887

EOPTOLINK 400G QSFP-DD FR4

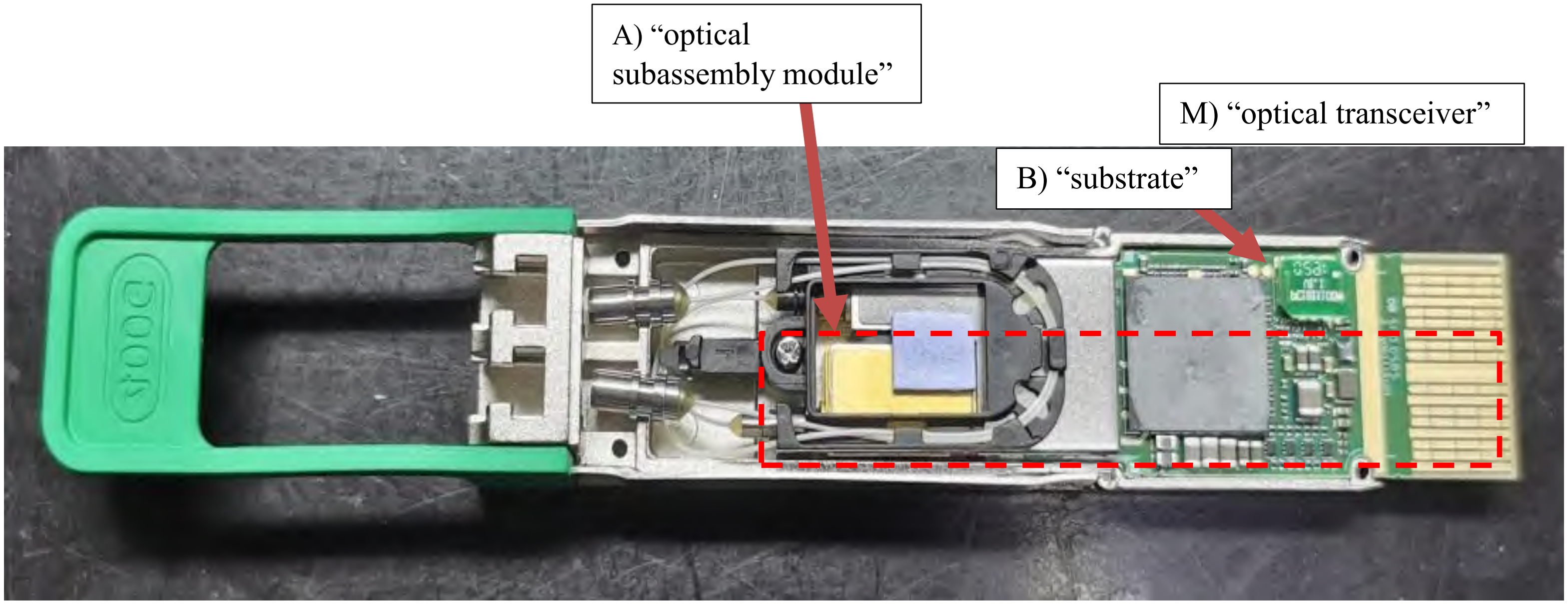


FIG. 1

Representative Claim Chart for U.S. Patent No. 11,177,887

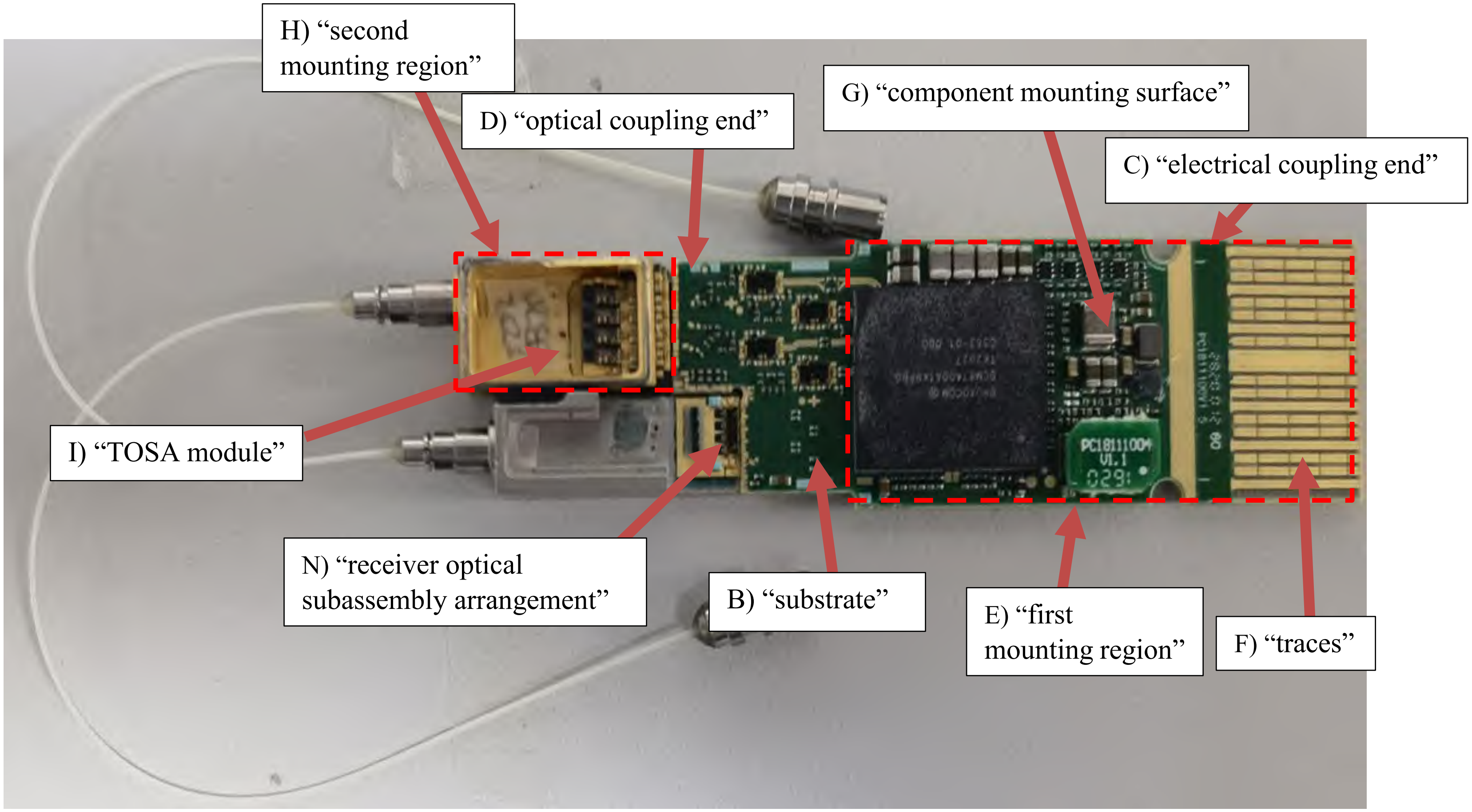


FIG. 2

Representative Claim Chart for U.S. Patent No. 11,177,887

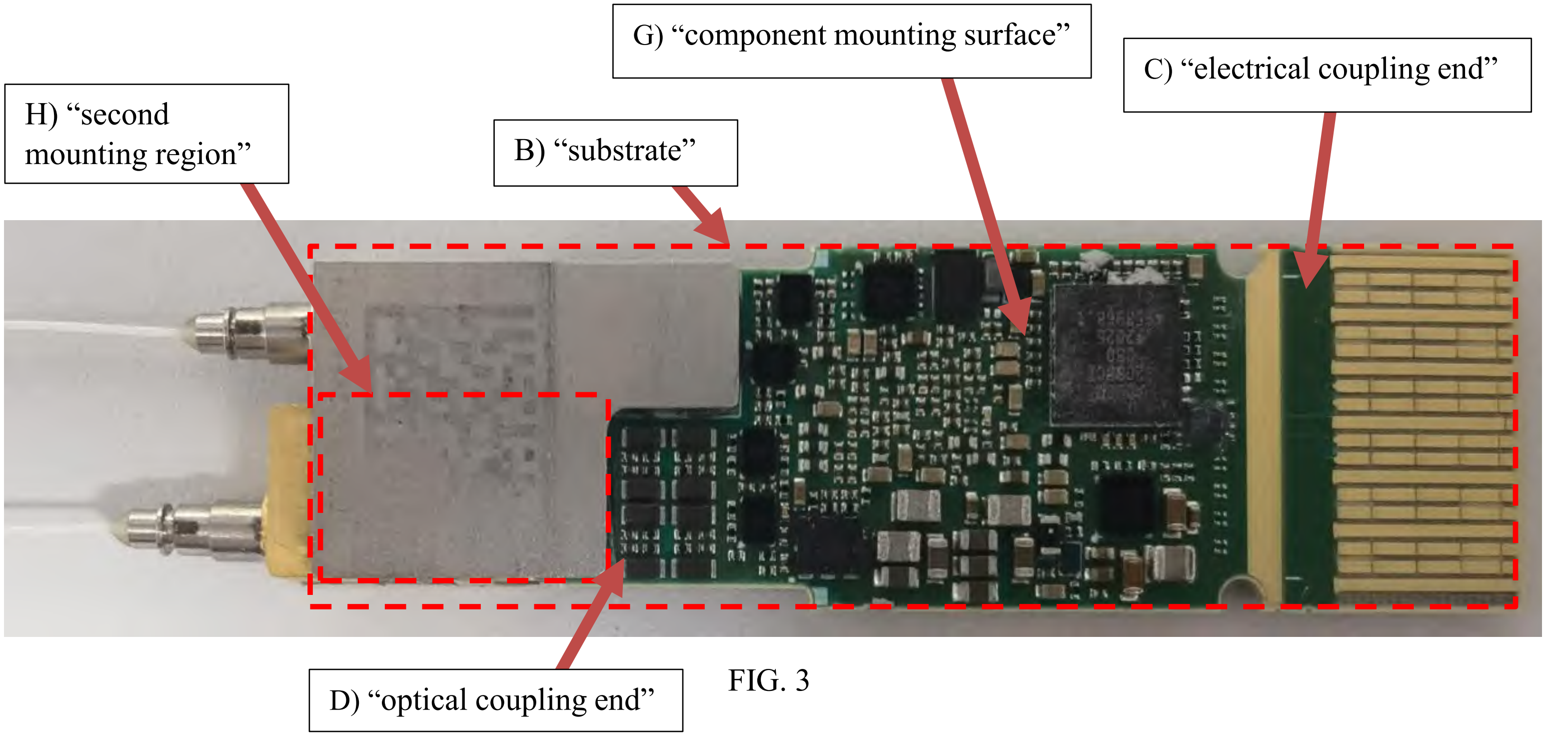


FIG. 3

Representative Claim Chart for U.S. Patent No. 11,177,887

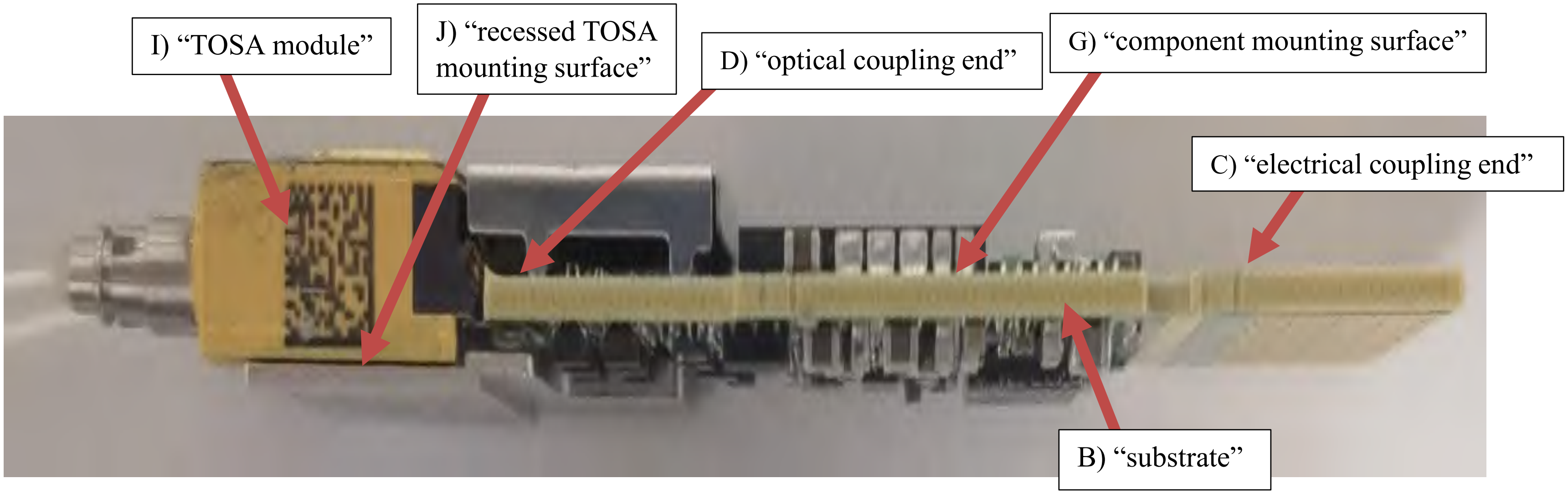


FIG. 4

Representative Claim Chart for U.S. Patent No. 11,177,887

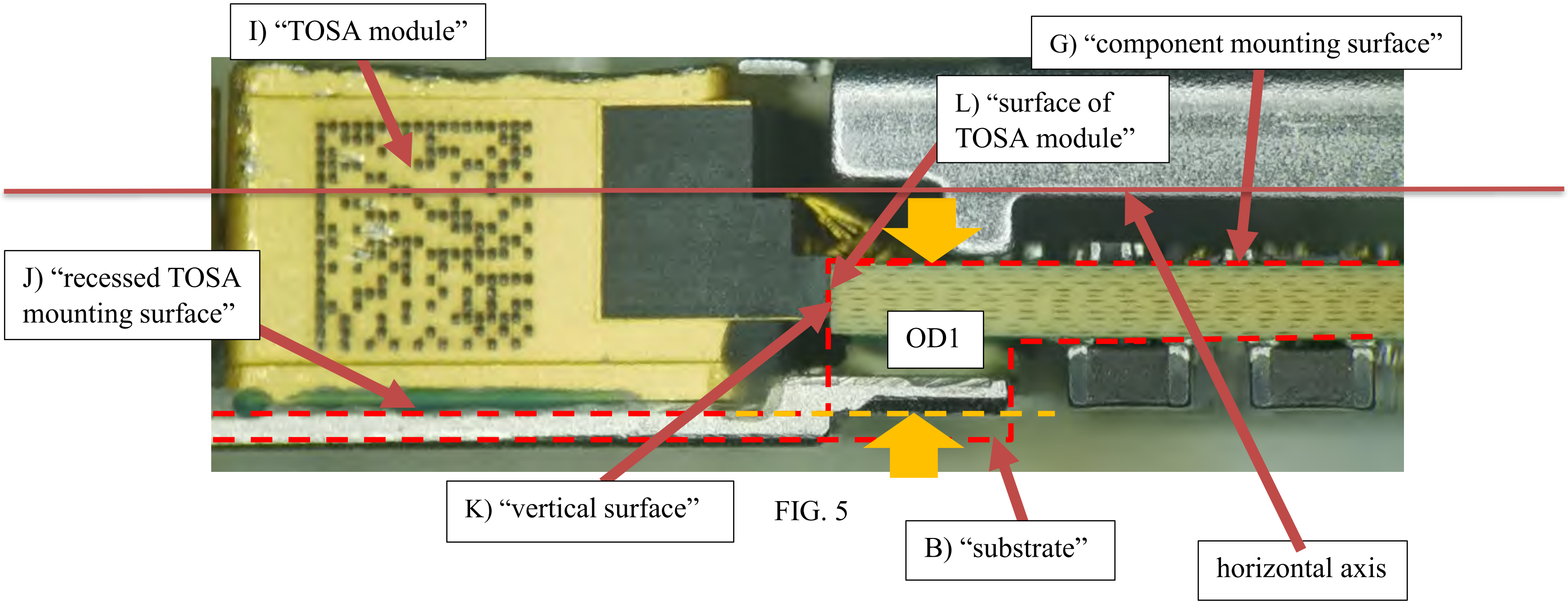


FIG. 5

Representative Claim Chart for U.S. Patent No. 11,177,887

U.S. Patent No. 11,177,887 Claim 1	EOPTOLINK 400G QSFP-DD FR4
An optical subassembly module, the optical subassembly module comprising:	An optical subassembly module **(A)** of an optical transceiver **(M)**. See FIGS. 1–5.
a substrate having an electrical coupling end for electrically coupling to external circuitry and an optical coupling end for launching at least one channel wavelength on a waveguide, the electrical coupling end disposed opposite the optical coupling end;	A substrate **(B)** has an electrical coupling end **(C)** for electrically coupling to external circuitry and an optical coupling end **(D)** for launching at least one channel wavelength on a waveguide. The electrical coupling end **(C)** is disposed opposite the optical coupling end **(D)**. See FIGS. 2–4.
a first mounting region at the electrical coupling end of the substrate to provide traces for electrical interconnection with the external circuitry, the first mounting region defined at least in part by a component mounting surface provided by a sidewall of the substrate;	A first mounting region **(E)** is at the electrical coupling end **(C)** of the substrate **(B)** to provide traces **(F)** for electrical interconnection with the external circuitry. The first mounting region **(E)** is defined at least in part by a component mounting surface **(G)** provided by a sidewall of the substrate **(B)**. See FIGS. 2–4.
a second mounting region at the optical coupling end of the substrate to couple to and support at least one transmitter optical subassembly (TOSA) module via a recessed TOSA mounting surface, the recessed TOSA mounting surface being disposed offset from the component mounting surface by first offset distance (OD1) based on a stepped profile, the stepped profile defined at least in part by the recessed TOSA mounting surface extending substantially parallel with the component mounting surface and substantially transverse relative to a vertical surface adjoining the recessed TOSA mounting surface and the component mounting surface; and	A second mounting region **(H)** is at the optical coupling end **(D)** of the substrate **(B)** to couple to and support at least one TOSA module **(I)** via a recessed TOSA mounting surface **(J)**. The recessed TOSA mounting surface **(J)** is disposed offset from the component mounting surface **(G)** by first offset distance (**OD1**) based on a stepped profile. See FIGS. 2–5. The stepped profile is defined at least in part by the recessed TOSA mounting surface **(J)** extending substantially parallel with the component mounting surface **(G)** and substantially transverse relative to a vertical surface **(K)** adjoining the recessed TOSA mounting surface **(J)** and the component mounting surface **(G)**. See FIGS. 2–5.
wherein the vertical surface provides a mechanical stop to engage a surface of the least one TOSA module and limit travel of the at least one TOSA module along one or more axis, and wherein the second	The vertical surface **(K)** provides a mechanical stop to engage a surface **(L)** of the least one TOSA module **(I)** and limit travel of the at least one TOSA module **(I)** along one or more axes (e.g.,

Representative Claim Chart for U.S. Patent No. 11,177,887

U.S. Patent No. 11,177,887 Claim 1	**EOPTOLINK 400G QSFP-DD FR4**
mounting region at the optical coupling end of the substrate is configured to edge mount to the at least one TOSA module.	horizontal axis in FIG. 5). The second mounting region **(H)** at the optical coupling end **(D)** is configured to edge mount to the at least one TOSA module **(I)**. See FIGS. 2, 3, and 5.

U.S. Patent No. 11,177,887 Claim 10	**EOPTOLINK 400G QSFP-DD FR4**
An optical transceiver, the optical transceiver comprising:	An optical transceiver **(M)**. See FIGS. 1–5.
a transceiver substrate having an optical coupling end disposed opposite an electrical coupling end;	a transceiver substrate **(B)** has an optical coupling end **(D)** disposed opposite an electrical coupling end **(C)**. See FIGS. 2–4.
at least one component mounting surface provided by the transceiver substrate extending between the optical coupling end and the electrical coupling end; and	At least one component mounting surface **(G)** is provided by the transceiver substrate **(B)** extending between the optical coupling end **(D)** and the electrical coupling end **(C)**. See FIGS. 2–4.
a recessed transmitter optical subassembly (TOSA) mounting surface at the optical coupling end of the substrate for coupling to and supporting at least one TOSA module, and wherein the recessed TOSA mounting surface extends substantially parallel with the at least one component mounting surface and substantially transverse relative to a vertical surface adjoining the recessed TOSA mounting surface and the at least one component mounting surface;	A recessed TOSA mounting surface **(J)** is at the optical coupling end **(D)** for coupling to and supporting at least one TOSA module **(I)**. The recessed TOSA mounting surface **(J)** extends substantially parallel with the at least one component mounting surface **(G)** and substantially transverse relative to a vertical surface **(K)** adjoining the recessed TOSA mounting surface **(J)** and the at least one component mounting surface **(G)**. See FIGS. 3–5.
at least one TOSA module edge mounted to the optical coupling end of the transceiver substrate, wherein the vertical surface provides a mechanical stop to engage a surface of the least one TOSA module and limit travel of the at least one TOSA module along one or more axis; and	The TOSA module **(I)** is edge mounted to the optical coupling end **(D)**. The vertical surface **(K)** provides a mechanical stop to engage a surface **(L)** of the least one TOSA module **(I)** and limit travel of the at least one TOSA module **(I)** along one or more axes (e.g., horizontal axis in FIG. 5). See FIGS. 3–5.
a receiver optical subassembly arrangement coupled to the transceiver substrate.	A receiver optical subassembly arrangement **(N)** is coupled to the transceiver substrate **(B)**. See FIG. 2.

Exhibit Y

Representative Claim Chart for U.S. Patent No. 11,177,887

<u>EOPTOLINK 100G QSFP DR1+</u>

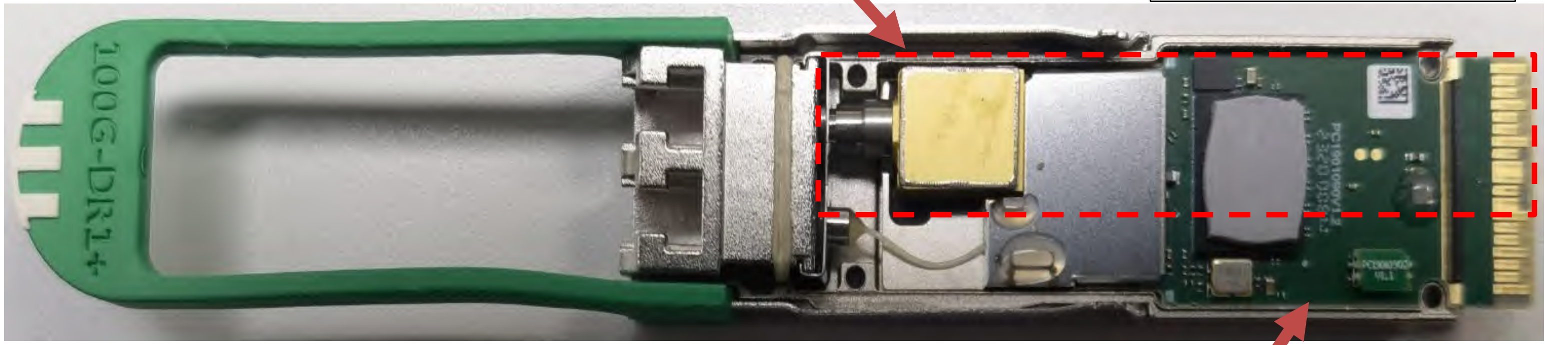


FIG. 1

Representative Claim Chart for U.S. Patent No. 11,177,887

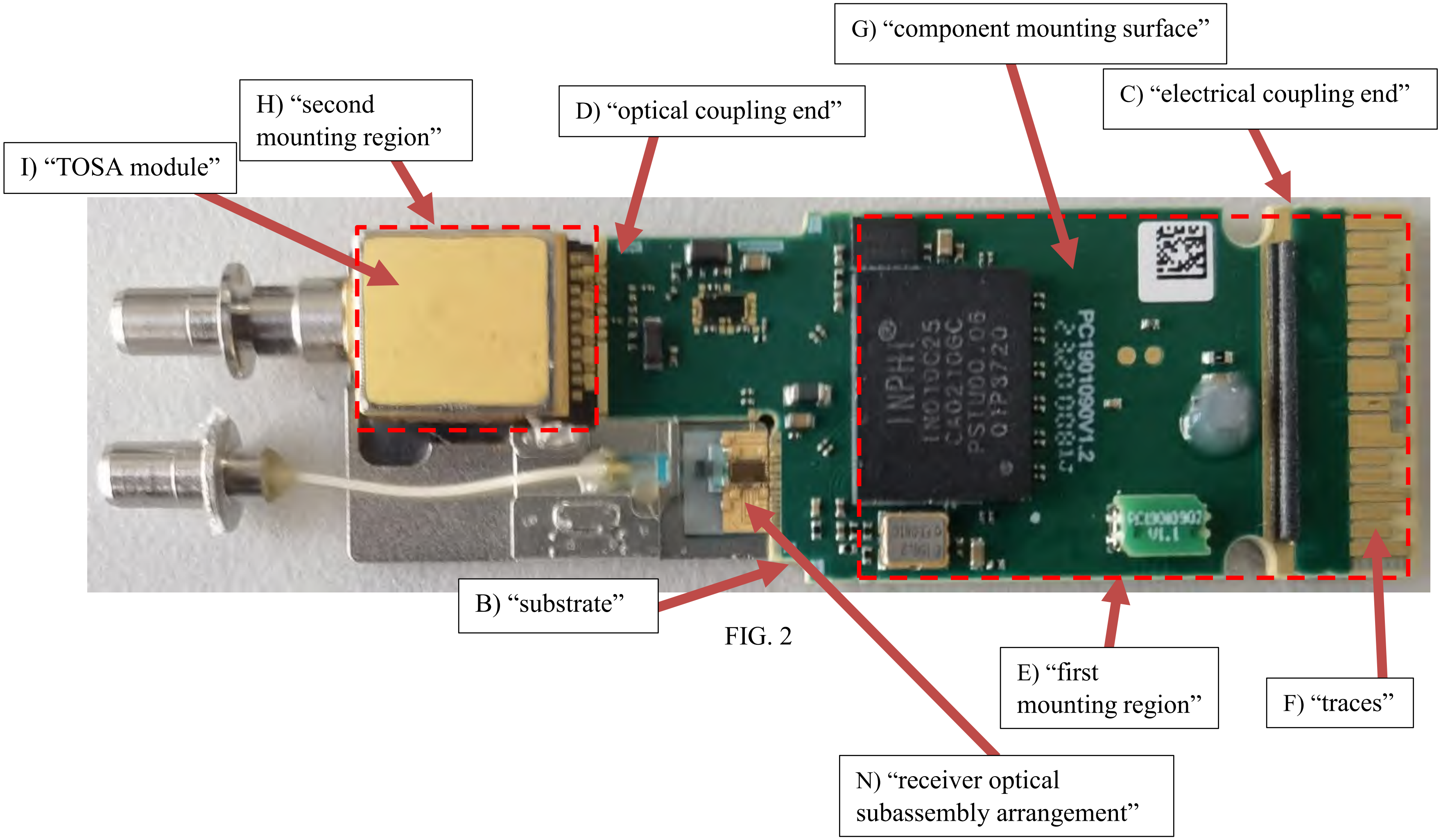


FIG. 2

Representative Claim Chart for U.S. Patent No. 11,177,887

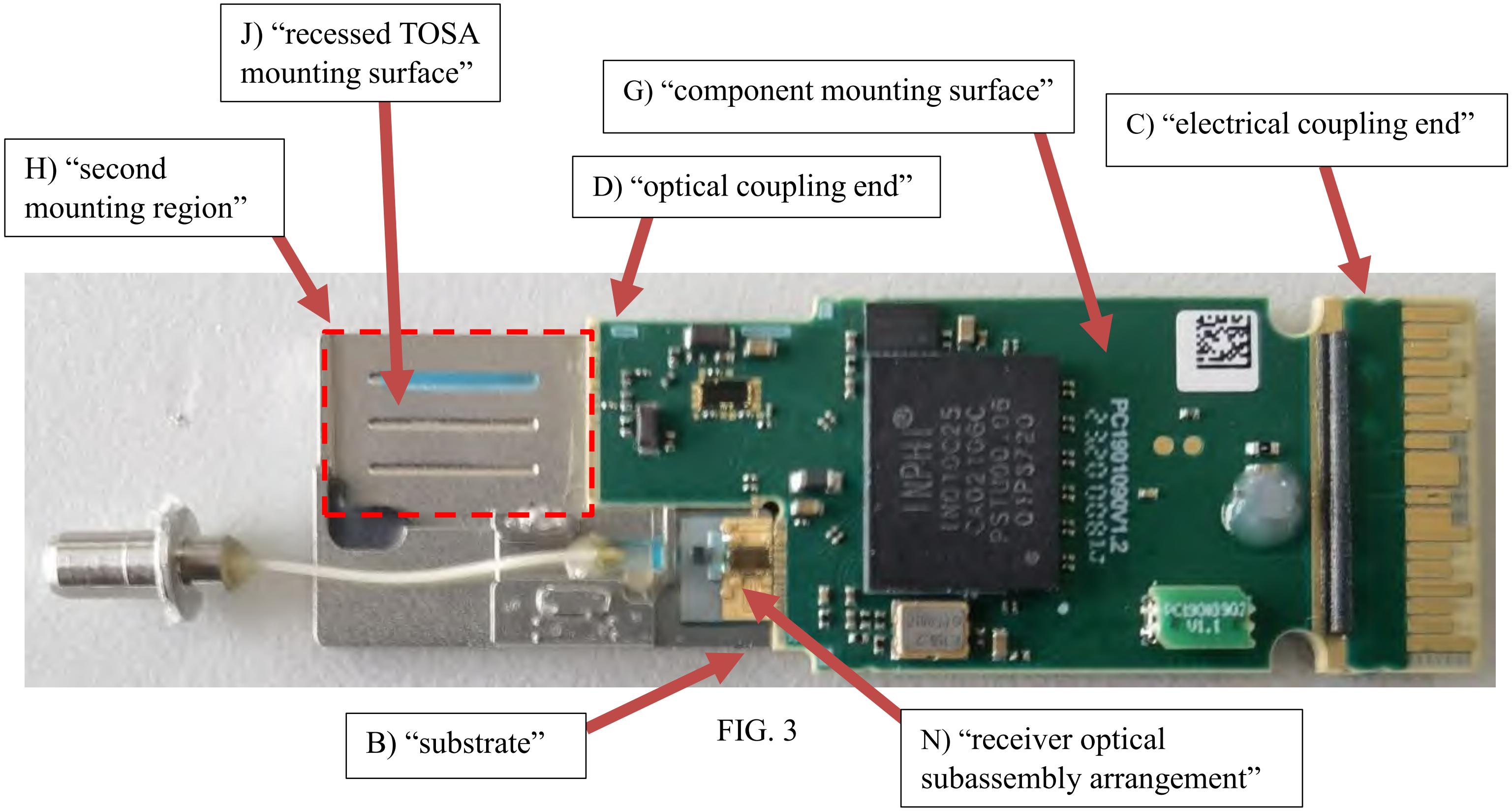


FIG. 3

Representative Claim Chart for U.S. Patent No. 11,177,887

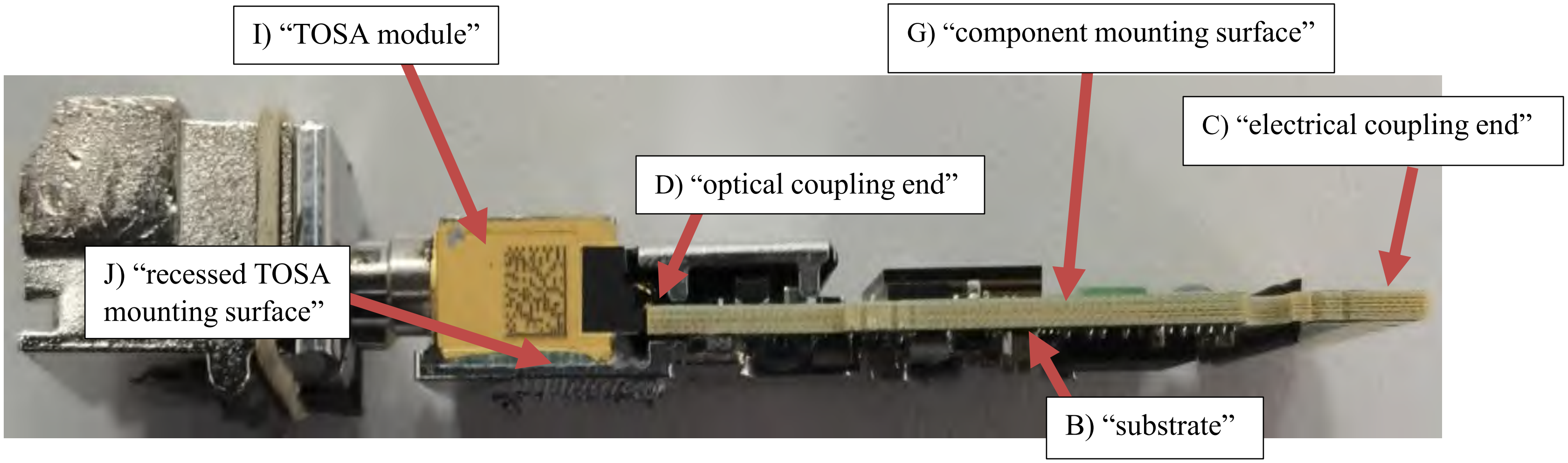


FIG. 4

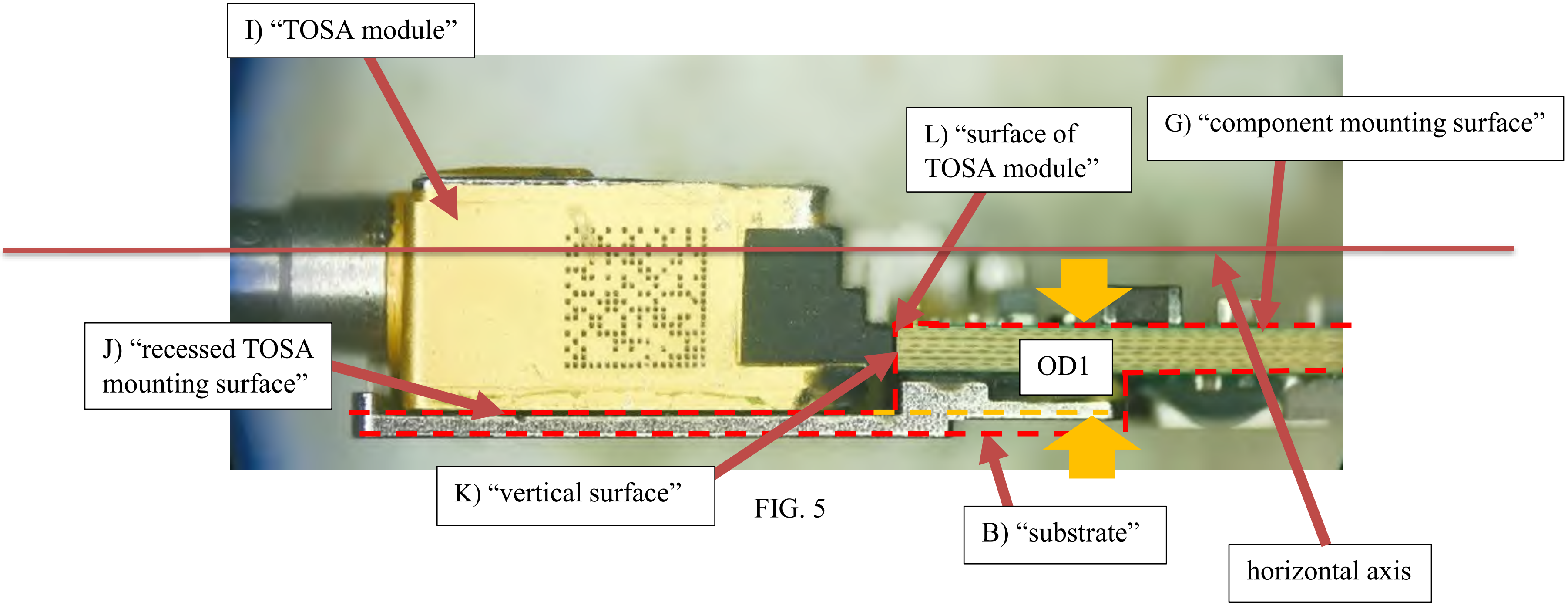

I) “TOSA module”
L) “surface of TOSA module”
G) “component mounting surface”
J) “recessed TOSA mounting surface”
OD1
K) “vertical surface”
B) “substrate”
horizontal axis

FIG. 5

Representative Claim Chart for U.S. Patent No. 11,177,887

U.S. Patent No. 11,177,887 Claim 1	EOPTOLINK 100G QSFP DR1+
An optical subassembly module, the optical subassembly module comprising:	An optical subassembly module **(A)** of an optical transceiver **(M)**. See FIGS. 1–5.
a substrate having an electrical coupling end for electrically coupling to external circuitry and an optical coupling end for launching at least one channel wavelength on a waveguide, the electrical coupling end disposed opposite the optical coupling end;	A substrate **(B)** has an electrical coupling end **(C)** for electrically coupling to external circuitry and an optical coupling end **(D)** for launching at least one channel wavelength on a waveguide. The electrical coupling end **(C)** is disposed opposite the optical coupling end **(D)**. See FIGS. 2–4.
a first mounting region at the electrical coupling end of the substrate to provide traces for electrical interconnection with the external circuitry, the first mounting region defined at least in part by a component mounting surface provided by a sidewall of the substrate;	A first mounting region **(E)** is at the electrical coupling end **(C)** of the substrate **(B)** to provide traces **(F)** for electrical interconnection with the external circuitry. The first mounting region **(E)** is defined at least in part by a component mounting surface **(G)** provided by a sidewall of the substrate **(B)**. See FIGS. 2–4.
a second mounting region at the optical coupling end of the substrate to couple to and support at least one transmitter optical subassembly (TOSA) module via a recessed TOSA mounting surface, the recessed TOSA mounting surface being disposed offset from the component mounting surface by first offset distance (OD1) based on a stepped profile, the stepped profile defined at least in part by the recessed TOSA mounting surface extending substantially parallel with the component mounting surface and substantially transverse relative to a vertical surface adjoining the recessed TOSA mounting surface and the component mounting surface; and	A second mounting region **(H)** is at the optical coupling end **(D)** of the substrate **(B)** to couple to and support at least one TOSA module **(I)** via a recessed TOSA mounting surface **(J)**. The recessed TOSA mounting surface **(J)** is disposed offset from the component mounting surface **(G)** by first offset distance (**OD1**) based on a stepped profile. See FIGS. 2–5. The stepped profile is defined at least in part by the recessed TOSA mounting surface **(J)** extending substantially parallel with the component mounting surface **(G)** and substantially transverse relative to a vertical surface **(K)** adjoining the recessed TOSA mounting surface **(J)** and the component mounting surface **(G)**. See FIGS. 2–5.
wherein the vertical surface provides a mechanical stop to engage a surface of the least one TOSA module and limit travel of the at least one TOSA module along one or more axis, and wherein the second	The vertical surface **(K)** provides a mechanical stop to engage a surface **(L)** of the least one TOSA module **(I)** and limit travel of the at least one TOSA module **(I)** along one or more axes (e.g.,

Representative Claim Chart for U.S. Patent No. 11,177,887

U.S. Patent No. 11,177,887 Claim 1	**EOPTOLINK 100G QSFP DR1+**
mounting region at the optical coupling end of the substrate is configured to edge mount to the at least one TOSA module.	horizontal axis in FIG. 5). The second mounting region **(H)** at the optical coupling end **(D)** is configured to edge mount to the at least one TOSA module **(I)**. See FIGS. 2, 3, and 5.

U.S. Patent No. 11,177,887 Claim 10	**EOPTOLINK 100G QSFP DR1+**
An optical transceiver, the optical transceiver comprising:	An optical transceiver **(M)**. See FIGS. 1–5.
a transceiver substrate having an optical coupling end disposed opposite an electrical coupling end;	a transceiver substrate **(B)** has an optical coupling end **(D)** disposed opposite an electrical coupling end **(C)**. See FIGS. 2–4.
at least one component mounting surface provided by the transceiver substrate extending between the optical coupling end and the electrical coupling end; and	At least one component mounting surface **(G)** is provided by the transceiver substrate **(B)** extending between the optical coupling end **(D)** and the electrical coupling end **(C)**. See FIGS. 2–4.
a recessed transmitter optical subassembly (TOSA) mounting surface at the optical coupling end of the substrate for coupling to and supporting at least one TOSA module, and wherein the recessed TOSA mounting surface extends substantially parallel with the at least one component mounting surface and substantially transverse relative to a vertical surface adjoining the recessed TOSA mounting surface and the at least one component mounting surface;	A recessed TOSA mounting surface **(J)** is at the optical coupling end **(D)** for coupling to and supporting at least one TOSA module **(I)**. The recessed TOSA mounting surface **(J)** extends substantially parallel with the at least one component mounting surface **(G)** and substantially transverse relative to a vertical surface **(K)** adjoining the recessed TOSA mounting surface **(J)** and the at least one component mounting surface **(G)**. See FIGS. 3–5.
at least one TOSA module edge mounted to the optical coupling end of the transceiver substrate, wherein the vertical surface provides a mechanical stop to engage a surface of the least one TOSA module and limit travel of the at least one TOSA module along one or more axis; and	The TOSA module **(I)** is edge mounted to the optical coupling end **(D)**. The vertical surface **(K)** provides a mechanical stop to engage a surface **(L)** of the least one TOSA module **(I)** and limit travel of the at least one TOSA module **(I)** along one or more axes (e.g., horizontal axis in FIG. 5). See FIGS. 3–5.
a receiver optical subassembly arrangement coupled to the transceiver substrate.	A receiver optical subassembly arrangement **(N)** is coupled to the transceiver substrate **(B)**. See FIGS. 2–3.

Exhibit Z

Representative Claim Chart for U.S. Patent No. 11,177,887

EOPTOLINK 400G QSFP-DD DR4

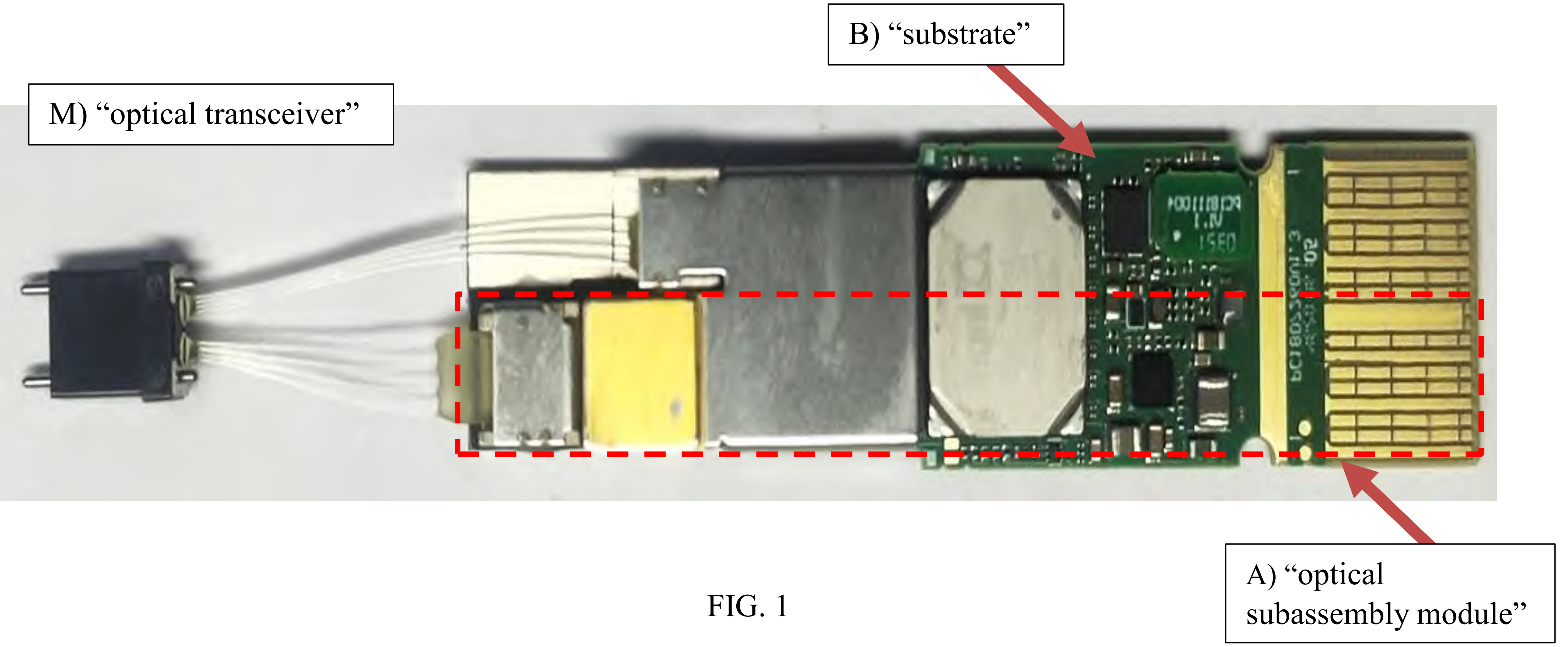


FIG. 1

Representative Claim Chart for U.S. Patent No. 11,177,887

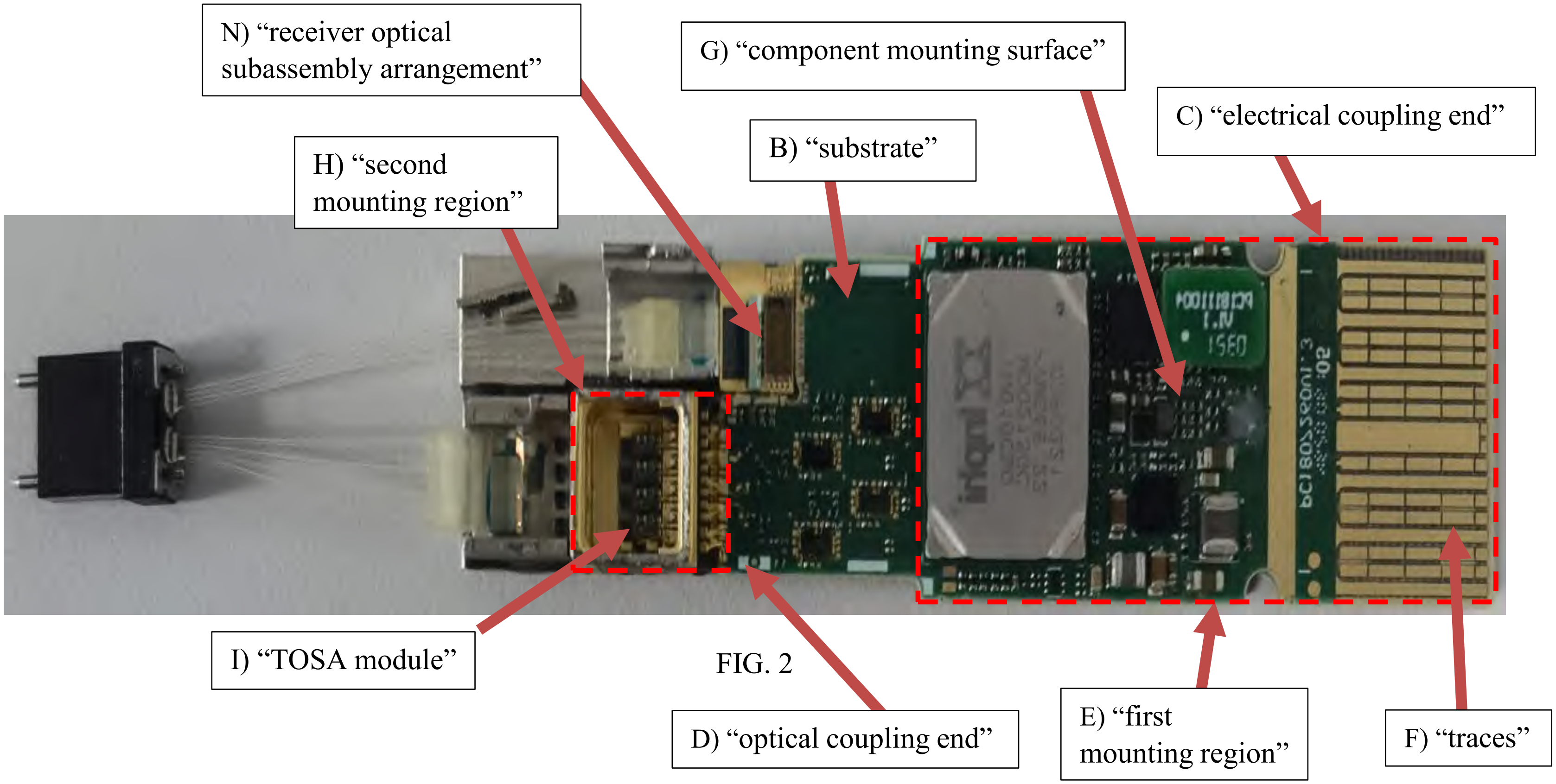


FIG. 2

Representative Claim Chart for U.S. Patent No. 11,177,887

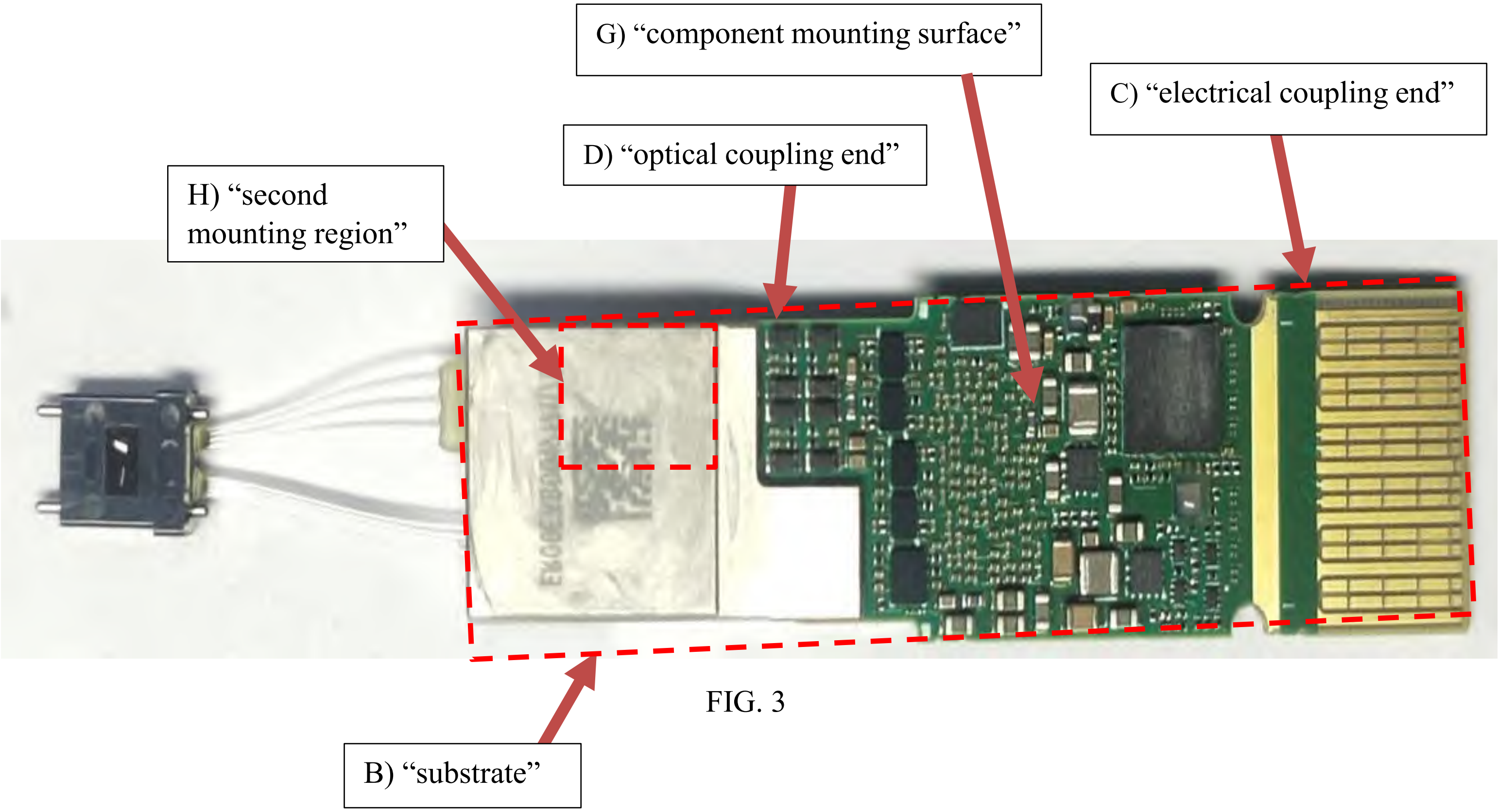


FIG. 3

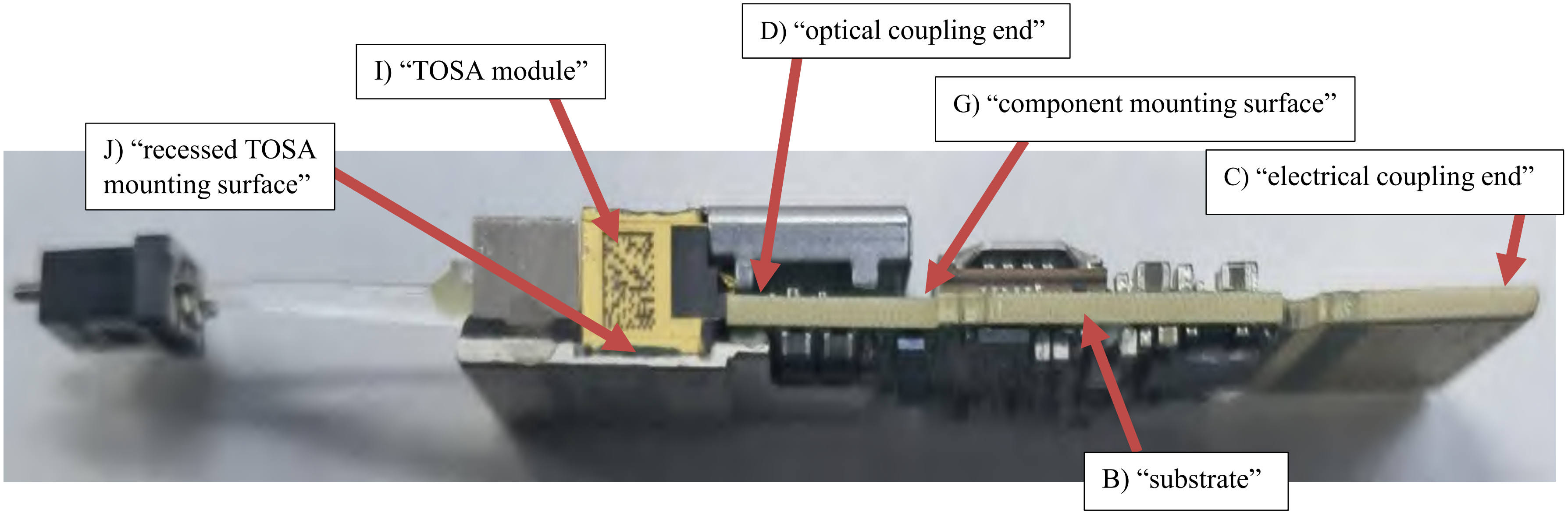

D) "optical coupling end"
I) "TOSA module"
G) "component mounting surface"
J) "recessed TOSA mounting surface"
C) "electrical coupling end"
B) "substrate"

FIG. 4

Representative Claim Chart for U.S. Patent No. 11,177,887

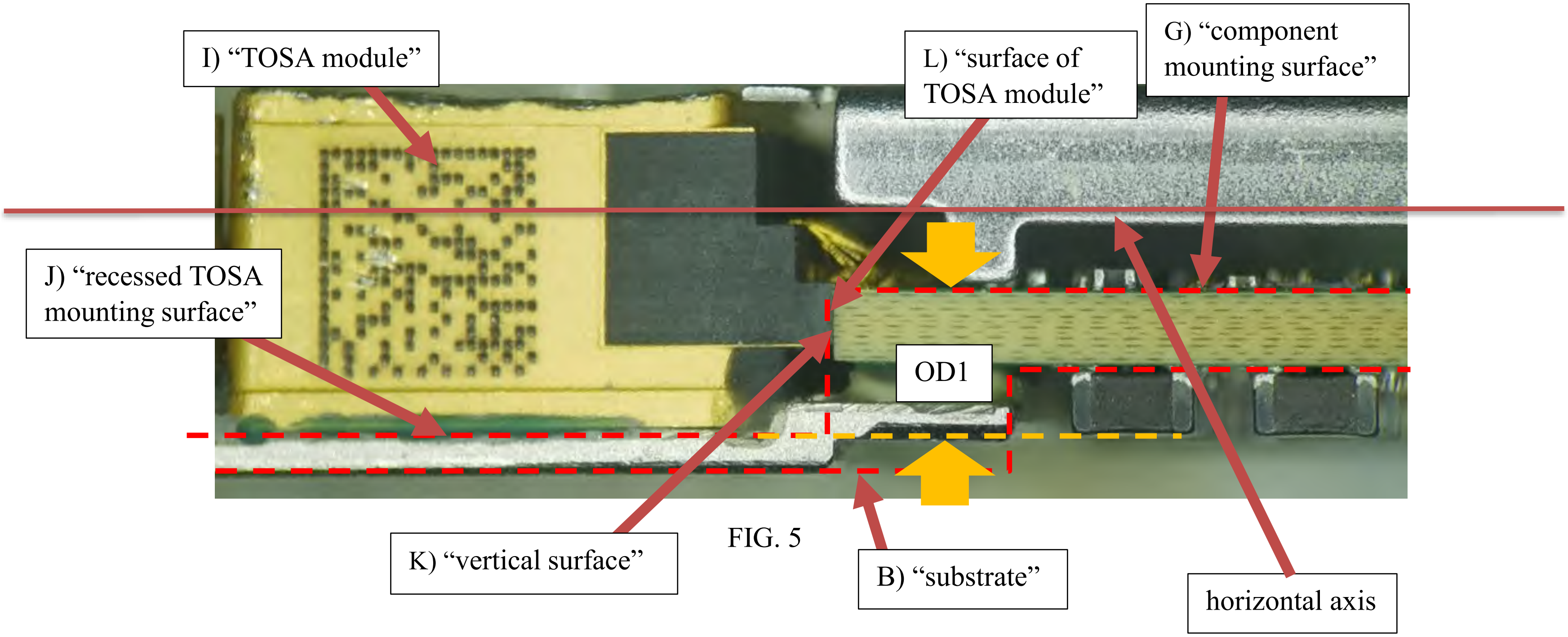


FIG. 5

Representative Claim Chart for U.S. Patent No. 11,177,887

U.S. Patent No. 11,177,887 Claim 1	EOPTOLINK 400G QSFP-DD DR4
An optical subassembly module, the optical subassembly module comprising:	An optical subassembly module **(A)** of an optical transceiver **(M)**. See FIGS. 1–5.
a substrate having an electrical coupling end for electrically coupling to external circuitry and an optical coupling end for launching at least one channel wavelength on a waveguide, the electrical coupling end disposed opposite the optical coupling end;	A substrate **(B)** has an electrical coupling end **(C)** for electrically coupling to external circuitry and an optical coupling end **(D)** for launching at least one channel wavelength on a waveguide. The electrical coupling end **(C)** is disposed opposite the optical coupling end **(D)**. See FIGS. 2–3.
a first mounting region at the electrical coupling end of the substrate to provide traces for electrical interconnection with the external circuitry, the first mounting region defined at least in part by a component mounting surface provided by a sidewall of the substrate;	A first mounting region **(E)** is at the electrical coupling end **(C)** of the substrate **(B)** to provide traces **(F)** for electrical interconnection with the external circuitry. The first mounting region **(E)** is defined at least in part by a component mounting surface **(G)** provided by a sidewall of the substrate **(B)**. See FIGS. 2–4.
a second mounting region at the optical coupling end of the substrate to couple to and support at least one transmitter optical subassembly (TOSA) module via a recessed TOSA mounting surface, the recessed TOSA mounting surface being disposed offset from the component mounting surface by first offset distance (OD1) based on a stepped profile, the stepped profile defined at least in part by the recessed TOSA mounting surface extending substantially parallel with the component mounting surface and substantially transverse relative to a vertical surface adjoining the recessed TOSA mounting surface and the component mounting surface; and	A second mounting region **(H)** is at the optical coupling end **(D)** of the substrate **(B)** to couple to and support at least one TOSA module **(I)** via a recessed TOSA mounting surface **(J)**. The recessed TOSA mounting surface **(J)** is disposed offset from the component mounting surface **(G)** by first offset distance (**OD1**) based on a stepped profile. See FIGS. 2–5. The stepped profile is defined at least in part by the recessed TOSA mounting surface **(J)** extending substantially parallel with the component mounting surface **(G)** and substantially transverse relative to a vertical surface **(K)** adjoining the recessed TOSA mounting surface **(J)** and the component mounting surface **(G)**. See FIGS. 2–5.
wherein the vertical surface provides a mechanical stop to engage a surface of the least one TOSA module and limit travel of the at least one TOSA module along one or more axis, and wherein the second	The vertical surface **(K)** provides a mechanical stop to engage a surface **(L)** of the least one TOSA module **(I)** and limit travel of the at least one TOSA module **(I)** along one or more axes (e.g.,

Representative Claim Chart for U.S. Patent No. 11,177,887

U.S. Patent No. 11,177,887 Claim 1	EOPTOLINK 400G QSFP-DD DR4
mounting region at the optical coupling end of the substrate is configured to edge mount to the at least one TOSA module.	horizontal axis in FIG. 5). The second mounting region **(H)** at the optical coupling end **(D)** is configured to edge mount to the at least one TOSA module **(I)**. See FIGS. 2, 3, and 5.

U.S. Patent No. 11,177,887 Claim 10	EOPTOLINK 400G QSFP-DD DR4
An optical transceiver, the optical transceiver comprising:	An optical transceiver **(M)**. See FIGS. 1–5.
a transceiver substrate having an optical coupling end disposed opposite an electrical coupling end;	a transceiver substrate **(B)** has an optical coupling end **(D)** disposed opposite an electrical coupling end **(C)**. See FIGS. 2–4.
at least one component mounting surface provided by the transceiver substrate extending between the optical coupling end and the electrical coupling end; and	At least one component mounting surface **(G)** is provided by the transceiver substrate **(B)** extending between the optical coupling end **(D)** and the electrical coupling end **(C)**. See FIGS. 2–4.
a recessed transmitter optical subassembly (TOSA) mounting surface at the optical coupling end of the substrate for coupling to and supporting at least one TOSA module, and wherein the recessed TOSA mounting surface extends substantially parallel with the at least one component mounting surface and substantially transverse relative to a vertical surface adjoining the recessed TOSA mounting surface and the at least one component mounting surface;	A recessed TOSA mounting surface **(J)** is at the optical coupling end **(D)** for coupling to and supporting at least one TOSA module **(I)**. The recessed TOSA mounting surface **(J)** extends substantially parallel with the at least one component mounting surface **(G)** and substantially transverse relative to a vertical surface **(K)** adjoining the recessed TOSA mounting surface **(J)** and the at least one component mounting surface **(G)**. See FIGS. 3–5.
at least one TOSA module edge mounted to the optical coupling end of the transceiver substrate, wherein the vertical surface provides a mechanical stop to engage a surface of the least one TOSA module and limit travel of the at least one TOSA module along one or more axis; and	The TOSA module **(I)** is edge mounted to the optical coupling end **(D)**. The vertical surface **(K)** provides a mechanical stop to engage a surface **(L)** of the least one TOSA module **(I)** and limit travel of the at least one TOSA module **(I)** along one or more axes (e.g., horizontal axis in FIG. 5). See FIGS. 3–5.
a receiver optical subassembly arrangement coupled to the transceiver substrate.	A receiver optical subassembly arrangement **(N)** is coupled to the transceiver substrate **(B)**. See FIG. 2.

Exhibit AA

Representative Claim Chart for U.S. Patent No. 11,177,887

EOPTOLINK 400G QSFP-DD LR4

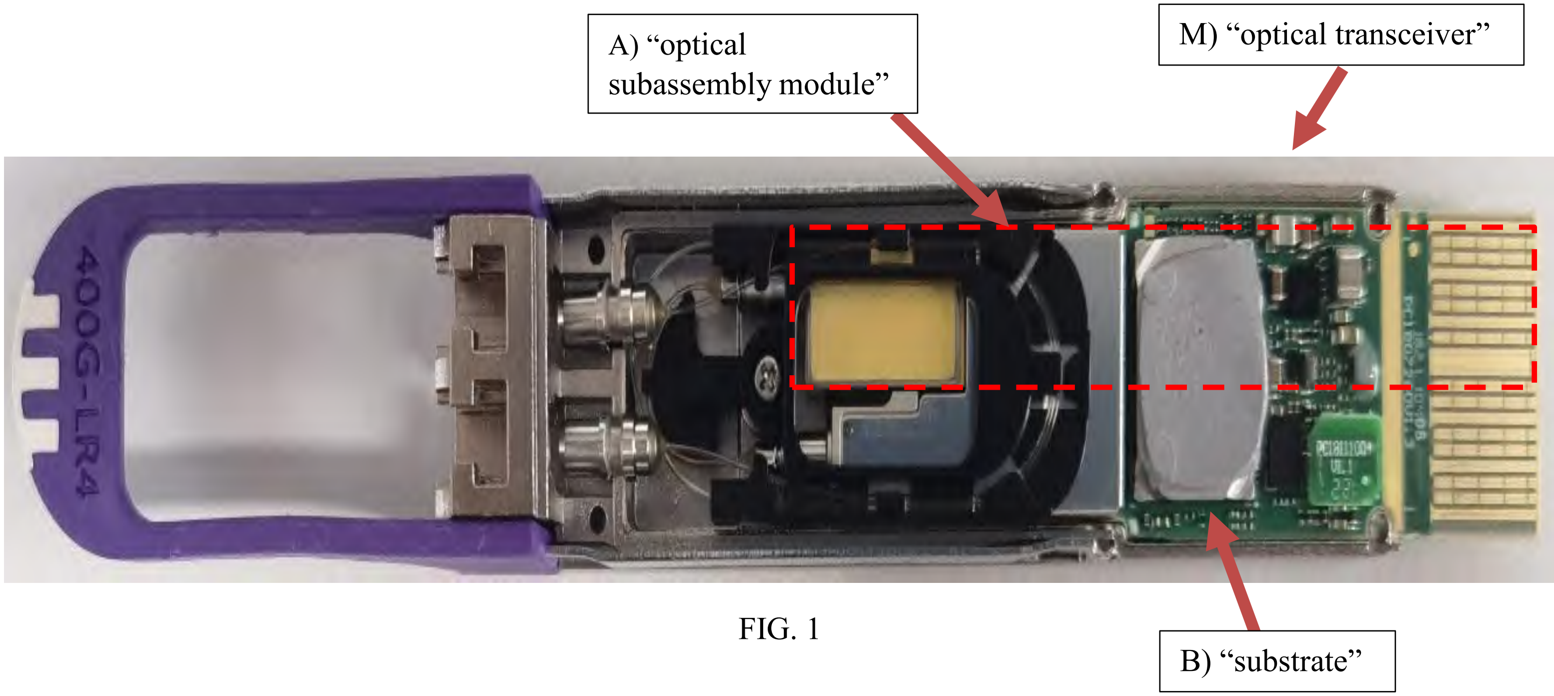


FIG. 1

Representative Claim Chart for U.S. Patent No. 11,177,887

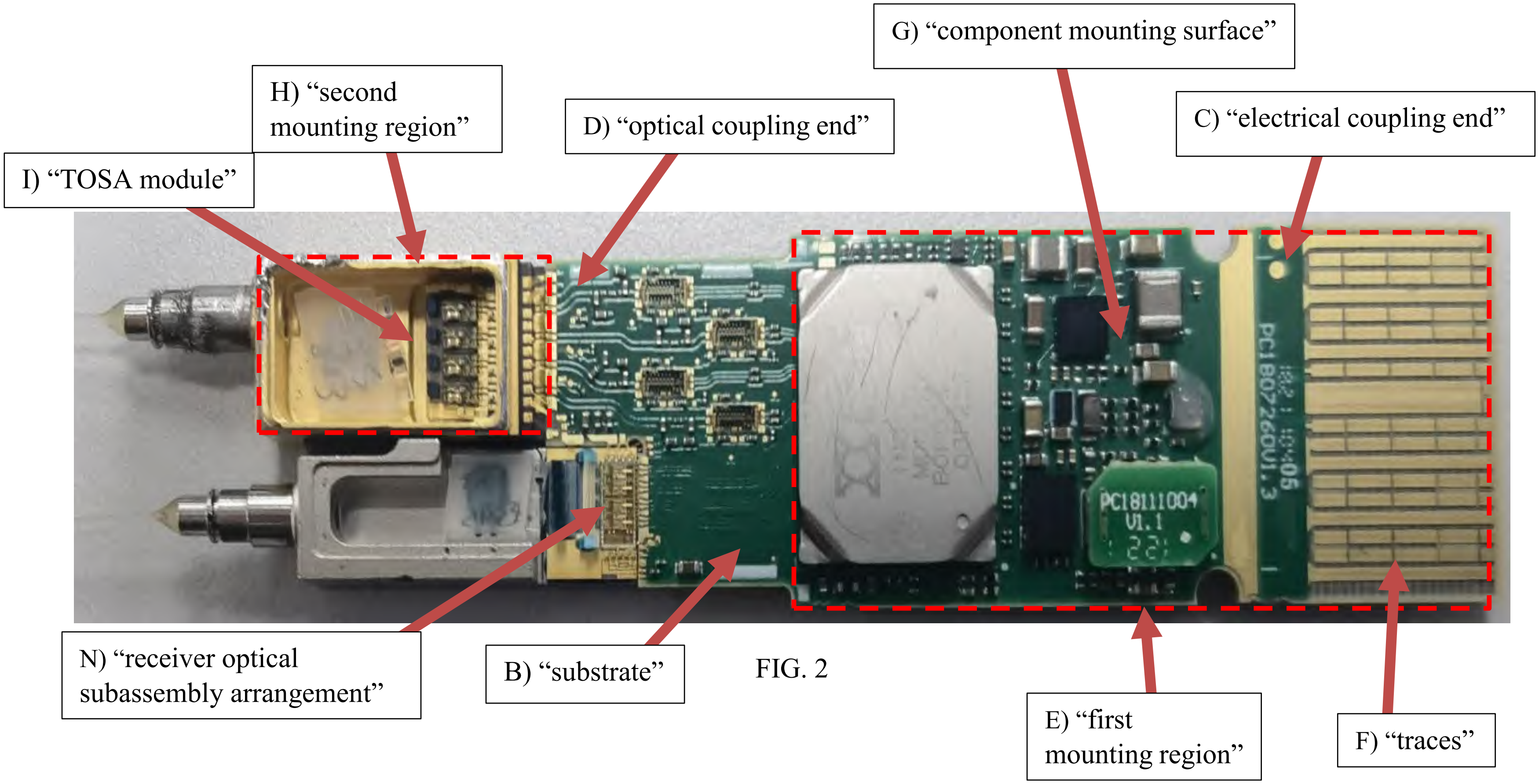


FIG. 2

Representative Claim Chart for U.S. Patent No. 11,177,887

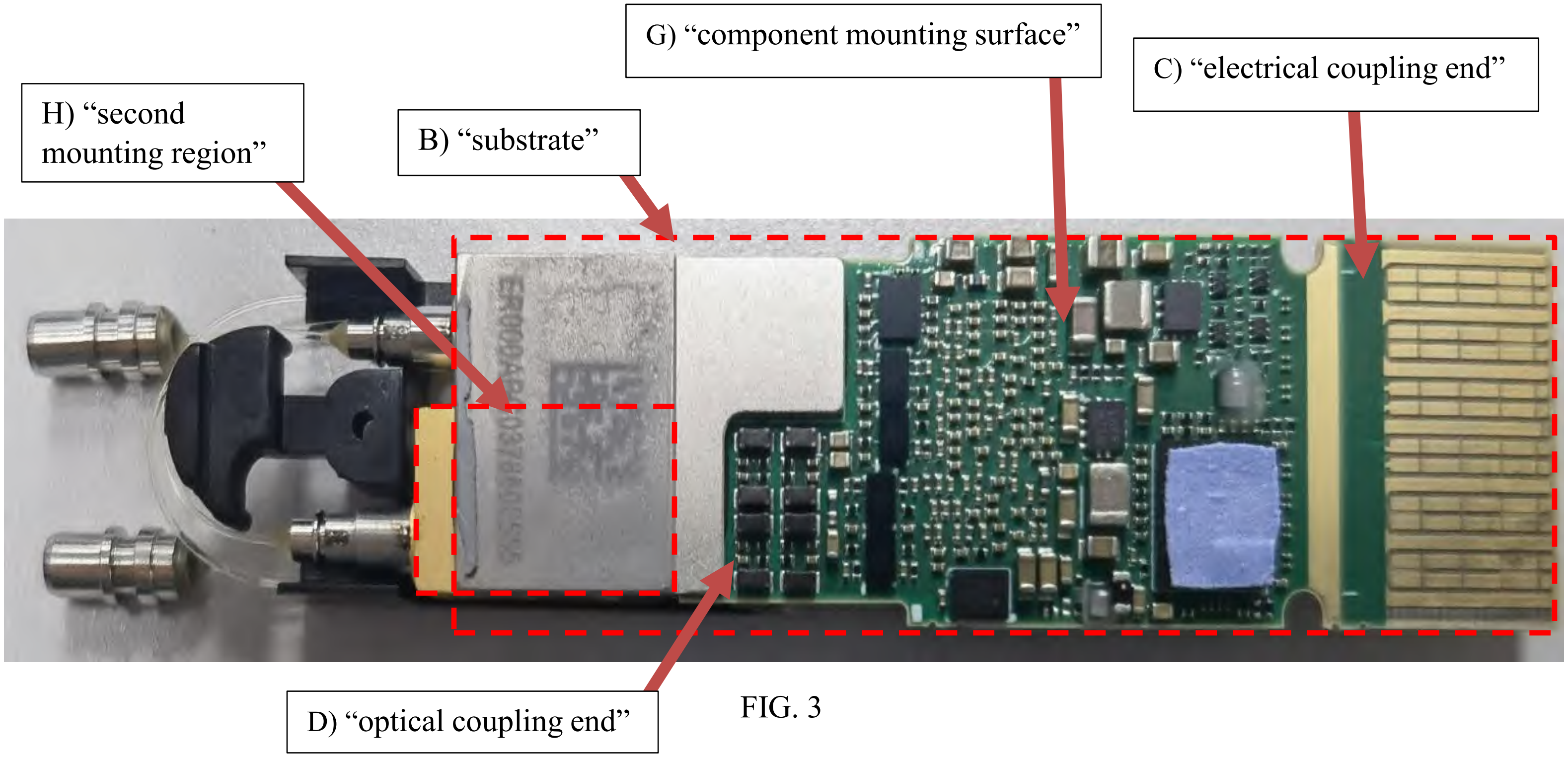


FIG. 3

Representative Claim Chart for U.S. Patent No. 11,177,887

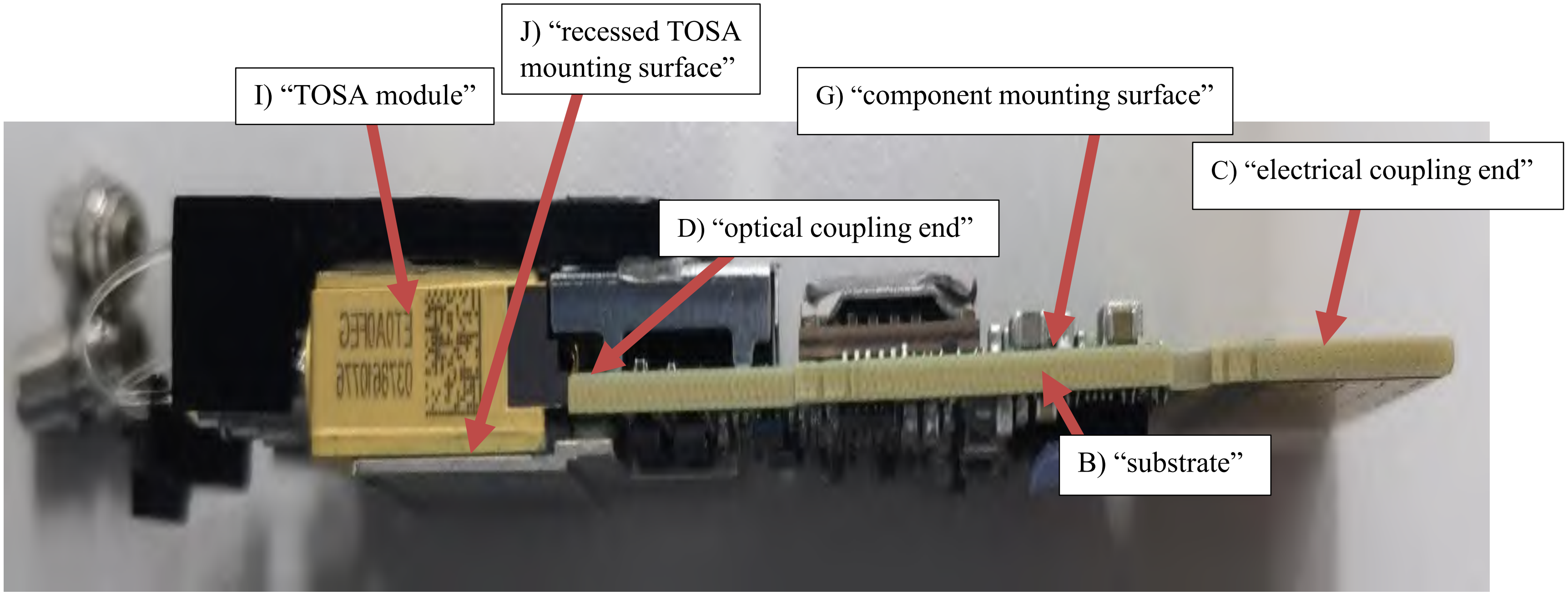


FIG. 4

Representative Claim Chart for U.S. Patent No. 11,177,887

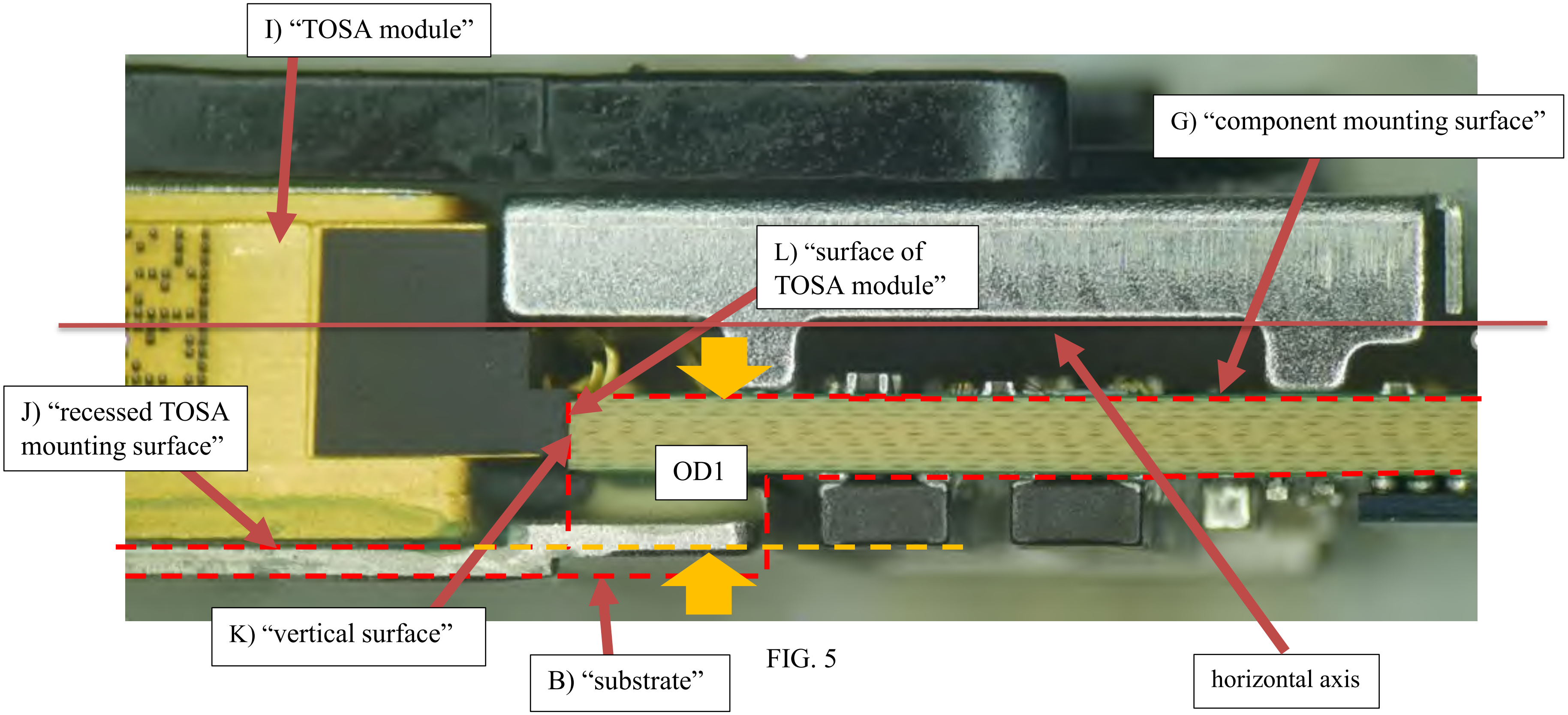


FIG. 5

Representative Claim Chart for U.S. Patent No. 11,177,887

U.S. Patent No. 11,177,887 Claim 1	EOPTOLINK 400G QSFP-DD LR4
An optical subassembly module, the optical subassembly module comprising:	An optical subassembly module **(A)** of an optical transceiver **(M)**. See FIGS. 1–5.
a substrate having an electrical coupling end for electrically coupling to external circuitry and an optical coupling end for launching at least one channel wavelength on a waveguide, the electrical coupling end disposed opposite the optical coupling end;	A substrate **(B)** has an electrical coupling end **(C)** for electrically coupling to external circuitry and an optical coupling end **(D)** for launching at least one channel wavelength on a waveguide. The electrical coupling end **(C)** is disposed opposite the optical coupling end **(D)**. See FIGS. 2–4.
a first mounting region at the electrical coupling end of the substrate to provide traces for electrical interconnection with the external circuitry, the first mounting region defined at least in part by a component mounting surface provided by a sidewall of the substrate;	A first mounting region **(E)** is at the electrical coupling end **(C)** of the substrate **(B)** to provide traces **(F)** for electrical interconnection with the external circuitry. The first mounting region **(E)** is defined at least in part by a component mounting surface **(G)** provided by a sidewall of the substrate **(B)**. See FIGS. 2–4.
a second mounting region at the optical coupling end of the substrate to couple to and support at least one transmitter optical subassembly (TOSA) module via a recessed TOSA mounting surface, the recessed TOSA mounting surface being disposed offset from the component mounting surface by first offset distance (OD1) based on a stepped profile, the stepped profile defined at least in part by the recessed TOSA mounting surface extending substantially parallel with the component mounting surface and substantially transverse relative to a vertical surface adjoining the recessed TOSA mounting surface and the component mounting surface; and	A second mounting region **(H)** is at the optical coupling end **(D)** of the substrate **(B)** to couple to and support at least one TOSA module **(I)** via a recessed TOSA mounting surface **(J)**. The recessed TOSA mounting surface **(J)** is disposed offset from the component mounting surface **(G)** by first offset distance (**OD1**) based on a stepped profile. See FIGS. 2–5. The stepped profile is defined at least in part by the recessed TOSA mounting surface **(J)** extending substantially parallel with the component mounting surface **(G)** and substantially transverse relative to a vertical surface **(K)** adjoining the recessed TOSA mounting surface **(J)** and the component mounting surface **(G)**. See FIGS. 2–5.
wherein the vertical surface provides a mechanical stop to engage a surface of the least one TOSA module and limit travel of the at least	The vertical surface **(K)** provides a mechanical stop to engage a surface **(L)** of the least one TOSA module **(I)** and limit travel of

Representative Claim Chart for U.S. Patent No. 11,177,887

U.S. Patent No. 11,177,887 Claim 1	EOPTOLINK 400G QSFP-DD LR4
one TOSA module along one or more axis, and wherein the second mounting region at the optical coupling end of the substrate is configured to edge mount to the at least one TOSA module.	the at least one TOSA module **(I)** along one or more axes (e.g., horizontal axis in FIG. 5). The second mounting region **(H)** at the optical coupling end **(D)** is configured to edge mount to the at least one TOSA module **(I)**. See FIGS. 2, 3, and 5.

U.S. Patent No. 11,177,887 Claim 10	EOPTOLINK 400G QSFP-DD LR4
An optical transceiver, the optical transceiver comprising:	An optical transceiver **(M)**. See FIGS. 1–5.
a transceiver substrate having an optical coupling end disposed opposite an electrical coupling end;	a transceiver substrate **(B)** has an optical coupling end **(D)** disposed opposite an electrical coupling end **(C)**. See FIGS. 2–4.
at least one component mounting surface provided by the transceiver substrate extending between the optical coupling end and the electrical coupling end; and	At least one component mounting surface **(G)** is provided by the transceiver substrate **(B)** extending between the optical coupling end **(D)** and the electrical coupling end **(C)**. See FIGS. 2–4.
a recessed transmitter optical subassembly (TOSA) mounting surface at the optical coupling end of the substrate for coupling to and supporting at least one TOSA module, and wherein the recessed TOSA mounting surface extends substantially parallel with the at least one component mounting surface and substantially transverse relative to a vertical surface adjoining the recessed TOSA mounting surface and the at least one component mounting surface;	A recessed TOSA mounting surface **(J)** is at the optical coupling end **(D)** for coupling to and supporting at least one TOSA module **(I)**. The recessed TOSA mounting surface **(J)** extends substantially parallel with the at least one component mounting surface **(G)** and substantially transverse relative to a vertical surface **(K)** adjoining the recessed TOSA mounting surface **(J)** and the at least one component mounting surface **(G)**. See FIGS. 3–5.
at least one TOSA module edge mounted to the optical coupling end of the transceiver substrate, wherein the vertical surface provides a mechanical stop to engage a surface of the least one TOSA module and limit travel of the at least one TOSA module along one or more axis; and	The TOSA module **(I)** is edge mounted to the optical coupling end **(D)**. The vertical surface **(K)** provides a mechanical stop to engage a surface **(L)** of the least one TOSA module **(I)** and limit travel of the at least one TOSA module **(I)** along one or more axes (e.g., horizontal axis in FIG. 5). See FIGS. 3–5.
a receiver optical subassembly arrangement coupled to the transceiver substrate.	A receiver optical subassembly arrangement **(N)** is coupled to the transceiver substrate **(B)**. See FIG. 2.