INTERNATIONAL STANDARD

ISO/ IEC/IEEE 8802-3

Third edition
2021-02

AMENDMENT
2022-07

Telecommunications and exchange between information technology systems — Requirements for local and metropolitan area networks —

Part 3: Standard for Ethernet

AMENDMENT 11: Physical layers and management parameters for 100 Gb/s and 400 Gb/s operation over single-mode fiber at 100 Gb/s per wavelength

Télécommunications et échange entre systèmes informatiques — Exigences pour les réseaux locaux et métropolitains —

Partie 3: Norme pour Ethernet

AMENDEMENT 11: Couches physiques et paramètres de gestion pour le fonctionnement à 100 Gb/s et 400 Gb/s sur fibre unimodale à 100 Gb/s par longueur d'onde

Reference number
ISO/IEC/IEEE 8802-3:2021/Amd.11:2022(E)

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IEEE Std 802.3cu™-2021
(Amendment to IEEE Std 802.3™-2018
as amended by IEEE Std 802.3cb™-2018,
IEEE Std 802.3bt™-2018,
IEEE Std 802.3cd™-2018,
IEEE Std 802.3cn™-2019,
IEEE Std 802.3cg™-2019,
IEEE Std 802.3cq™-2020,
IEEE Std 802.3cm™-2020,
IEEE Std 802.3ch™-2020,
IEEE Std 802.3ca™-2020,
and IEEE Std 802.3cr™-2020)

IEEE Standard for Ethernet

Amendment 11: Physical Layers and Management Parameters for 100 Gb/s and 400 Gb/s Operation over Single-Mode Fiber at 100 Gb/s per Wavelength

Developed by the

LAN/MAN Standards Committee
of the
IEEE Computer Society

Approved 9 February 2021

IEEE SA Standards Board

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Abstract: This amendment to IEEE Std 802.3-2018 adds Physical Layer specifications and management parameters for 100 Gb/s and 400 Gb/s Ethernet optical interfaces for reaches up to 10 km based on 100 Gb/s per wavelength optical signaling.

Keywords: 100 Gb/s Ethernet, 100GBASE-FR1, 100GBASE-LR1, 400 Gb/s Ethernet, 400GBASE-FR4, 400GBASE-LR4-6, Energy-Efficient Ethernet (EEE), Ethernet, forward error correction (FEC), IEEE 802.3™, IEEE 802.3cu™, PAM4, Physical Medium Dependent (PMD) sublayer, single-mode fiber (SMF)

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PDF: ISBN 978-1-5044-7383-5 STD24602
Print: ISBN 978-1-5044-7384-2 STDPD24602

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Introduction

This introduction is not part of IEEE Std 802.3cu-2021, IEEE Standard for Ethernet—Amendment 11: Physical Layers and Management Parameters for 100 Gb/s and 400 Gb/s Operation over Single-Mode Fiber at 100 Gb/s per Wavelength.

IEEE Std 802.3™ was first published in 1985. Since the initial publication, many projects have added functionality or provided maintenance updates to the specifications and text included in the standard. Each IEEE 802.3 project/amendment is identified with a suffix (e.g., IEEE Std 802.3ba™-2010).

The half duplex Media Access Control (MAC) protocol specified in IEEE Std 802.3-1985 is Carrier Sense Multiple Access with Collision Detection (CSMA/CD). This MAC protocol was key to the experimental Ethernet developed at Xerox Palo Alto Research Center, which had a 2.94 Mb/s data rate. Ethernet at 10 Mb/s was jointly released as a public specification by Digital Equipment Corporation (DEC), Intel and Xerox in 1980. Ethernet at 10 Mb/s was approved as an IEEE standard by the IEEE Standards Board in 1983 and subsequently published in 1985 as IEEE Std 802.3-1985. Since 1985, new media options, new speeds of operation, and new capabilities have been added to IEEE Std 802.3. A full duplex MAC protocol was added in 1997.

Some of the major additions to IEEE Std 802.3 are identified in the marketplace with their project number. This is most common for projects adding higher speeds of operation or new protocols. For example, IEEE Std 802.3u™ added 100 Mb/s operation (also called Fast Ethernet), IEEE Std 802.3z added 1000 Mb/s operation (also called Gigabit Ethernet), IEEE Std 802.3ae added 10 Gb/s operation (also called 10 Gigabit Ethernet), IEEE Std 802.3ah™ specified access network Ethernet (also called Ethernet in the First Mile) and IEEE Std 802.3ba added 40 Gb/s operation (also called 40 Gigabit Ethernet) and 100 Gb/s operation (also called 100 Gigabit Ethernet). These major additions are all now included in and are superseded by IEEE Std 802.3-2018 and are not maintained as separate documents.

At the date of IEEE Std 802.3cu-2021 publication, IEEE Std 802.3 was composed of the following documents:

IEEE Std 802.3-2018

Section One—Includes Clause 1 through Clause 20 and Annex A through Annex H and Annex 4A. Section One includes the specifications for 10 Mb/s operation and the MAC, frame formats and service interfaces used for all speeds of operation.

Section Two—Includes Clause 21 through Clause 33 and Annex 22A through Annex 33E. Section Two includes management attributes for multiple protocols and speed of operation as well as specifications for providing power over twisted pair cabling for multiple operational speeds. It also includes general information on 100 Mb/s operation as well as most of the 100 Mb/s Physical Layer specifications.

Section Three—Includes Clause 34 through Clause 43 and Annex 36A through Annex 43C. Section Three includes general information on 1000 Mb/s operation as well as most of the 1000 Mb/s Physical Layer specifications.

Section Four—Includes Clause 44 through Clause 55 and Annex 44A through Annex 55B. Section Four includes general information on 10 Gb/s operation as well as most of the 10 Gb/s Physical Layer specifications.

Section Five—Includes Clause 56 through Clause 77 and Annex 57A through Annex 76A. Clause 56 through Clause 67 and Clause 75 through Clause 77, as well as associated annexes, specify subscriber

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access and other Physical Layers and sublayers for operation from 512 kb/s to 10 Gb/s, and defines services and protocol elements that enable the exchange of IEEE Std 802.3 format frames between stations in a subscriber access network. Clause 68 specifies a 10 Gb/s Physical Layer specification. Clause 69 through Clause 74 and associated annexes specify Ethernet operation over electrical backplanes at speeds of 1000 Mb/s and 10 Gb/s.

Section Six—Includes Clause 78 through Clause 95 and Annex 83A through Annex 93C. Clause 78 specifies Energy-Efficient Ethernet. Clause 79 specifies IEEE 802.3 Organizationally Specific Link Layer Discovery Protocol (LLDP) type, length, and value (TLV) information elements. Clause 80 through Clause 95 and associated annexes include general information on 40 Gb/s and 100 Gb/s operation as well the 40 Gb/s and 100 Gb/s Physical Layer specifications. Clause 90 specifies Ethernet support for time synchronization protocols.

Section Seven—Includes Clause 96 through Clause 115 and Annex 97A through Annex 115A. Clause 96 through Clause 98, Clause 104, and associated annexes, specify Physical Layers and optional features for 100 Mb/s and 1000 Mb/s operation over a single twisted pair. Clause 100 through Clause 103, as well as associated annexes, specify Physical Layers for the operation of the EPON protocol over coaxial distribution networks. Clause 105 through Clause 114 and associated annexes include general information on 25 Gb/s operation as well as 25 Gb/s Physical Layer specifications. Clause 99 specifies a MAC merge sublayer for the interspersing of express traffic. Clause 115 and its associated annex specify a Physical Layer for 1000 Mb/s operation over plastic optical fiber.

Section Eight—Includes Clause 116 through Clause 126 and Annex 119A through Annex 120E. Clause 116 through Clause 124 and associated annexes include general information on 200 Gb/s and 400 Gb/s operation as well the 200 Gb/s and 400 Gb/s Physical Layer specifications. Clause 125 and Clause 126 include general information on 2.5 Gb/s and 5 Gb/s operation as well as 2.5 Gb/s and 5 Gb/s Physical Layer specifications.

IEEE Std 802.3cb™-2018

Amendment 1—This amendment includes changes to IEEE Std 802.3-2018 and its amendments, and adds Clause 127 through Clause 130, Annex 127A, Annex 128A, Annex 128B, and Annex 130A. This amendment adds new Physical Layers for operation at 2.5 Gb/s and 5 Gb/s over electrical backplanes.

IEEE Std 802.3bt™-2018

Amendment 2—This amendment includes changes to IEEE Std 802.3-2018 and adds Clause 145, Annex 145A, Annex 145B, and Annex 145C. This amendment adds power delivery using all four pairs in the structured wiring plant, resulting in greater power being available to end devices. This amendment also allows for lower standby power consumption in end devices and adds a mechanism to better manage the available power budget.

IEEE Std 802.3cd™-2018

Amendment 3—This amendment includes changes to IEEE Std 802.3-2018 and adds Clause 131 through Clause 140 and Annex 135A through Annex 136D. This amendment adds MAC parameters, Physical Layers, and management parameters for the transfer of IEEE 802.3 format frames at 50 Gb/s, 100 Gb/s, and 200 Gb/s.

IEEE Std 802.3cn™-2019

Amendment 4—This amendment includes changes to IEEE Std 802.3-2018 and adds 50 Gb/s, 200 Gb/s, and 400 Gb/s Physical Layer specifications and management parameters for operation over single-mode fiber with reaches of at least 40 km.

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IEEE Std 802.3cg™-2019

Amendment 5—This amendment includes changes to IEEE Std 802.3-2018 and its amendments and adds Clause 146 through Clause 148 and Annex 146A and Annex 146B. This amendment adds 10 Mb/s Physical Layer specifications and management parameters for operation on a single balanced pair of conductors.

IEEE Std 802.3cq™-2020

Amendment 6—This amendment includes editorial and technical corrections, refinements, and clarifications to Clause 33 and related portions of the standard.

IEEE Std 802.3cm™-2020

Amendment 7—This amendment includes changes to IEEE Std 802.3-2018 and adds Clause 150. This amendment adds Physical Layer (PHY) specifications and management parameters for 400 Gb/s operation on four pairs (400GBASE-SR4.2) and eight pairs (400GBASE-SR8) of multimode fiber, over reaches of at least 100 m.

IEEE Std 802.3ch™-2020

Amendment 8—This amendment includes changes to IEEE Std 802.3-2018 and adds Clause 149, Annex 149A, Annex 149B, and Annex 149C. This amendment adds physical layer specifications and management parameters for operation at 2.5 Gb/s, 5 Gb/s, and 10 Gb/s over a single balanced pair of conductors.

IEEE Std 802.3ca™-2020

Amendment 9—This amendment to IEEE Std 802.3-2018 extends the operation of Ethernet passive optical networks (EPONs) to multiple channels of 25 Gb/s providing both symmetric and asymmetric operation for the following data rates (downstream/upstream): 25/10 Gb/s, 25/25 Gb/s, 50/10 Gb/s, 50/25 Gb/s, and 50/50 Gb/s. This amendment specifies the 25 Gb/s EPON Multi-Channel Reconciliation Sublayer (MCRS), Nx25G-EPON Physical Coding Sublayers (PCSs), Physical Media Attachment (PMA) sublayers, and Physical Medium Dependent (PMD) sublayers that support both symmetric and asymmetric data rates while maintaining backward compatibility with already deployed 10 Gb/s EPON equipment. The EPON operation is defined for distances of at least 20 km, and for a split ratio of at least 1:32.

IEEE Std 802.3cr™-2021

Amendment 10—This amendment includes changes to IEEE Std 802.3-2018 and adds Annex J. This amendment replaces references to the IEC 60950 series of standards (including IEC 60950-1 “Information technology equipment—Safety—Part 1: General requirements”) with appropriate references to the IEC 62368 “Audio/video, information and communication technology equipment” series and makes appropriate changes to the standard corresponding to the new references.

IEEE Std 802.3cu™-2021

Amendment 11—This amendment includes changes to IEEE Std 802.3-2018 and adds Clause 151. This amendment adds Physical Layer (PHY) specifications and management parameters for 100 Gb/s and 400 Gb/s operation over single-mode fiber, based on 100 Gb/s per wavelength optical signaling.

Two companion documents exist, IEEE Std 802.3.1 and IEEE Std 802.3.2. IEEE Std 802.3.1 describes Ethernet management information base (MIB) modules for use with the Simple Network Management

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Protocol (SNMP). IEEE Std 802.3.2 describes YANG data models for Ethernet. IEEE Std 802.3.1 and IEEE Std 802.3.2 are updated to add management capability for enhancements to IEEE Std 802.3 after approval of those enhancements.

IEEE Std 802.3 will continue to evolve. New Ethernet capabilities are anticipated to be added within the next few years as amendments to this standard.

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IEEE Standard for Ethernet

Amendment 11: Physical Layers and Management Parameters for 100 Gb/s and 400 Gb/s Operation over Single-Mode Fiber at 100 Gb/s per Wavelength

(This amendment is based on IEEE Std 802.3™-2018 as amended by IEEE Std 802.3cb™-2018, IEEE Std 802.3bt™-2018, IEEE Std 802.3cd™-2018, IEEE Std 802.3cn™-2019, IEEE Std 802.3cg™-2019, IEEE Std 802.3cq™-2020, IEEE Std 802.3cm™-2020, IEEE Std 802.3ch™-2020, IEEE Std 802.3ca™-2020, and IEEE Std 802.3cr™-2020.)

NOTE—The editing instructions contained in this amendment define how to merge the material contained therein into the existing base standard and its amendments to form the comprehensive standard.

The editing instructions are shown in ***bold italic***. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~strikethrough~~ (to remove old material) and underscore (to add new material). ***Delete*** removes existing material. ***Insert*** adds new material without disturbing the existing material. Deletions and insertions may require renumbering. If so, renumbering instructions are given in the editing instruction. ***Replace*** is used to make changes in figures or equations by removing the existing figure or equation and replacing it with a new one. Editing instructions, change markings, and this NOTE will not be carried over into future editions because the changes will be incorporated into the base standard.

Cross references that refer to clauses, tables, equations, or figures not covered by this amendment are highlighted in green.[1]

[1] Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

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1. Introduction

1.4 Definitions

Insert the following new definition after 1.4.27 "100GBASE-ER4":

1.4.27a 100GBASE-FR1: IEEE 802.3 Physical Layer specification for 100 Gb/s serial transmission using 100GBASE-R encoding and 4-level pulse amplitude modulation over one wavelength on single-mode fiber, with reach up to at least 2 km. (See IEEE Std 802.3, Clause 140.)

Insert the following new definition after 1.4.29 "100GBASE-KR4":

1.4.29a 100GBASE-LR1: IEEE 802.3 Physical Layer specification for 100 Gb/s serial transmission using 100GBASE-R encoding and 4-level pulse amplitude modulation over one wavelength on single-mode fiber, with reach up to at least 10 km. (See IEEE Std 802.3, Clause 140.)

Insert the following new definition after 1.4.106a "400GBASE-ER8" as inserted by IEEE Std 802.3cn-2019:

1.4.106b 400GBASE-FR4: IEEE 802.3 Physical Layer specification for 400 Gb/s using 400GBASE-R encoding and 4-level pulse amplitude modulation over four WDM lanes on single-mode fiber, with reach up to at least 2 km. (See IEEE Std 802.3, Clause 151.)

Insert the following new definition after 1.4.107 "400GBASE-FR8":

1.4.107a 400GBASE-LR4-6: IEEE 802.3 Physical Layer specification for 400 Gb/s using 400GBASE-R encoding and 4-level pulse amplitude modulation over four WDM lanes on single-mode fiber, with reach up to at least 6 km. (See IEEE Std 802.3, Clause 151.)

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30. Management

30.5 Layer management for medium attachment units (MAUs)

30.5.1 MAU managed object class

30.5.1.1 MAU attributes

30.5.1.1.2 aMAUType

Insert 100GBASE-FR1 PHY type into the "APPROPRIATE SYNTAX" section of 30.5.1.1.2 after 100GBASE-SR10 as follows:

APPROPRIATE SYNTAX:

...

100GBASE-FR1	100GBASE-R PCS/PMA over single-mode fiber PMD with reach up to at least 2 km as specified in Clause 140

...

Insert 100GBASE-LR1 PHY type into the "APPROPRIATE SYNTAX" section of 30.5.1.1.2 after 100GBASE-LR4 as follows:

APPROPRIATE SYNTAX:

...

100GBASE-LR1	100GBASE-R PCS/PMA over single-mode fiber PMD with reach up to at least 10 km as specified in Clause 140

...

Insert 400GBASE-FR4 and 400GBASE-LR4-6 PHY types into the "APPROPRIATE SYNTAX" section of 30.5.1.1.2 after 400GBASE-FR8 as follows:

APPROPRIATE SYNTAX:

...

400GBASE-FR4	400GBASE-R PCS/PMA over 4 WDM lane single-mode fiber PMD with reach up to at least 2 km as specified in Clause 151
400GBASE-LR4-6	400GBASE-R PCS/PMA over 4 WDM lane single-mode fiber PMD with reach up to at least 6 km as specified in Clause 151

...

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45. Management Data Input/Output (MDIO) Interface

45.2 MDIO Interface Registers

45.2.1 PMA/PMD registers

45.2.1.6 PMA/PMD control 2 register (Register 1.7)

Change the indicated reserved rows of Table 45–7 (as modified by IEEE Std 802.3cd-2018, IEEE Std 802.3cn-2019, and IEEE Std 802.3cm-2020) as follows (unchanged rows not shown):

Table 45–7—PMA/PMD control 2 register bit definitions

Bit(s)	Name	Description	R/W[a]
…			
1.7.6:0	PMA/PMD type selection	6 5 4 3 2 1 0 … 1 1 0 0 0 1 0 = 400GBASE-LR4-6 PMA/PMD~~reserved~~ 1 1 0 0 0 0 1 = 400GBASE-FR4 PMA/PMD~~reserved~~ … ~~1 0 0 1 1 x x = reserved~~ 1 0 0 1 1 1 x = reserved 1 0 0 1 1 0 1 = 100GBASE-LR1 PMA/PMD 1 0 0 1 1 0 0 = 100GBASE-FR1 PMA/PMD …	R/W

[a]R/W = Read/Write, RO = Read only

45.2.1.7 PMA/PMD status 2 register (Register 1.8)

45.2.1.7.4 Transmit fault (1.8.11)

Change the row for 100GBASE-DR in Table 45–9 (as inserted by IEEE Std 802.3cd-2018) and insert a new row for 400GBASE-FR4 and 400GBASE-LR4-6 at the end of Table 45–9 as follows (unchanged rows not shown):

Table 45–9—Transmit fault description location

PMA/PMD	Description location
…	
100GBASE-DR, 100GBASE-FR1, 100GBASE-LR1	140.5.8
…	
400GBASE-FR4, 400GBASE-LR4-6	151.5.10

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45.2.1.7.5 Receive fault (1.8.10)

Change the row for 100GBASE-DR in Table 45–10 (as inserted by IEEE Std 802.3cd-2018) and insert a new row for 400GBASE-FR4 and 400GBASE-LR4-6 at the end of Table 45–10 as follows (unchanged rows not shown):

Table 45–10—Receive fault description location

PMA/PMD	Description location
…	
100GBASE-DR, 100GBASE-FR1, 100GBASE-LR1	140.5.9
…	
400GBASE-FR4, 400GBASE-LR4-6	151.5.11

45.2.1.8 PMD transmit disable register (Register 1.9)

Change the row for 100GBASE-DR in Table 45–12 (as inserted by IEEE Std 802.3cd-2018) and insert a new row for 400GBASE-FR4 and 400GBASE-LR4-6 at the end of Table 45–12 as follows (unchanged rows not shown):

Table 45–12—Transmit disable description location

PMA/PMD	Description location
…	
100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1	140.5.6
…	
400GBASE-FR4 and 400GBASE-LR4-6	151.5.7

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45.2.1.21 400G PMA/PMD extended ability register (Register 1.24)

Change the row for bits 1.24.9:8 in Table 45–24 (as modified by IEEE Std 802.3cm-2020) as follows (unchanged rows not shown):

Table 45–24—400G PMA/PMD extended ability register bit definitions

Bit(s)	Name	Description	R/W[a]
…			
~~1.24.9:8~~	~~Reserved~~	~~Value always 0~~	~~RO~~
1.24.9	400GBASE-LR4-6 ability	1 = PMA/PMD is able to perform 400GBASE-LR4-6 0 = PMA/PMD is not able to perform 400GBASE-LR4-6	RO
1.24.8	400GBASE-FR4 ability	1 = PMA/PMD is able to perform 400GBASE-FR4 0 = PMA/PMD is not able to perform 400GBASE-FR4	RO
…			

[a]RO = Read only

Insert 45.2.1.21.1a1 and 45.2.1.21.1a2 after 45.2.1.21.1a (as inserted by IEEE Std 802.3cn-2019) and before 45.2.1.21.1b (as inserted by IEEE Std 802.3cm-2020) as follows:

45.2.1.21.1a1 400GBASE-LR4-6 ability (1.24.9)

When read as a one, bit 1.24.9 indicates that the PMA/PMD is able to operate as a 400GBASE-LR4-6 PMA/PMD type. When read as a zero, bit 1.24.9 indicates that the PMA/PMD is not able to operate as a 400GBASE-LR4-6 PMA/PMD type.

45.2.1.21.1a2 400GBASE-FR4 ability (1.24.8)

When read as a one, bit 1.24.8 indicates that the PMA/PMD is able to operate as a 400GBASE-FR4 PMA/PMD type. When read as a zero, bit 1.24.8 indicates that the PMA/PMD is not able to operate as a 400GBASE-FR4 PMA/PMD type.

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45.2.1.21b 40G/100G PMA/PMD extended ability 2 (Register 1.26)

Change the row for bits 1.26.6:4 in Table 45–24b (as inserted by IEEE Std 802.3cn-2019) as follows (unchanged rows not shown):

Table 45–24b—40G/100G PMA/PMD extended ability 2 register bit definitions

Bit(s)	Name	Description	R/W[a]
…			
~~1.26.6:4~~ 1.26.6	Reserved	Value always 0	RO
1.26.5	100GBASE-LR1 ability	1 = PMA/PMD is able to perform 100GBASE-LR1 0 = PMA/PMD is not able to perform 100GBASE-LR1	RO
1.26.4	100GBASE-FR1 ability	1 = PMA/PMD is able to perform 100GBASE-FR1 0 = PMA/PMD is not able to perform 100GBASE-FR1	RO
…			

[a]RO = Read only

Insert 45.2.1.21b.3a and 45.2.1.21b.3b after 45.2.1.21b.3 (as inserted by IEEE Std 802.3cn-2019) as follows:

45.2.1.21b.3a 100GBASE-LR1 ability (1.26.5)

When read as a one, bit 1.26.5 indicates that the PMA/PMD is able to operate as a 100GBASE-LR1 PMA/PMD type. When read as a zero, bit 1.26.5 indicates that the PMA/PMD is not able to operate as a 100GBASE-LR1 PMA/PMD type.

45.2.1.21b.3b 100GBASE-FR1 ability (1.26.4)

When read as a one, bit 1.26.4 indicates that the PMA/PMD is able to operate as a 100GBASE-FR1 PMA/PMD type. When read as a zero, bit 1.26.4 indicates that the PMA/PMD is not able to operate as a 100GBASE-FR1 PMA/PMD type.

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