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IEEE Standard for
Information technology—
Telecommunications and information exchange between systems
Local and metropolitan area networks—
Specific requirements

Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications

Amendment 6: Physical Layer and Management Parameters for Serial 40 Gb/s Ethernet Operation Over Single-Mode Fiber

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

IEEE
3 Park Avenue
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USA

31 March 2011

IEEE Std 802.3bg™-2011
(Amendment to
IEEE Std 802.3™-2008)

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Abstract: This amendment to IEEE Std 802.3-2008 specifies a new Physical Medium Dependent (PMD) sublayer, 40GBASE-FR, for serial 40 Gb/s operation over up to 2 km of single-mode fiber.
Keywords: 40 Gb/s Ethernet, 40GBASE-FR, IEEE 802.3bg, Optical Transport Network, OTN, Physical Medium Dependent sublayer, PMD sublayer, single-mode fiber, SMF

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Introduction

This introduction is not part of IEEE Std 802.3bg-2011, IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements, Part 3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications, Amendment 6: Physical Layer and Management Parameters for Serial 40 Gb/s Ethernet Operation Over Single-Mode Fiber.

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 802.3bg-2011).

The Media Access Control (MAC) protocol specified in IEEE Std 802.3 is Carrier Sense Multiple Access with Collision Detection (CSMA/CD). This MAC protocol was included in the experimental Ethernet developed at Xerox Palo Alto Research Center. While the experimental Ethernet had a 2.94 Mb/s data rate, IEEE Std 802.3-1985 specified operation at 10 Mb/s. Since 1985 new media options, new speeds of operation, and new capabilities have been added to IEEE Std 802.3.

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 802.3x™ specified full duplex operation and a flow control protocol, 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) and IEEE Std 802.3ah™ specified access network Ethernet (also called Ethernet in the First Mile). These major additions are all now included in, and are superseded by, IEEE Std 802.3-2008 and are not maintained as separate documents.

At the date of IEEE Std 802.3bg-2011 publication, IEEE Std 802.3 comprised the following documents:

IEEE Std 802.3-2008

Section One—Includes Clause 1 through Clause 20, 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 74 and Annex 57A through Annex 74A. Clause 56 through Clause 67 and associated annexes specify subscriber access and other Physical Layers and sublayers for operation from 512 kb/s to 1000 Mb/s and define services and protocol elements that enable the exchange of IEEE 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.

IEEE Std 802.3av™-2009

This amendment includes changes to IEEE Std 802.3-2008 and adds Clause 75 through Clause 77 and Annex 75A through Annex 76A. This amendment adds new Physical Layers for 10 Gb/s operation on point-to-multipoint passive optical networks.

IEEE Std 802.3bc™-2009

This amendment includes changes to IEEE Std 802.3-2008 and adds Clause 79. This amendment moves the Ethernet Organizationally Specific Type, Length, Value (TLV) information elements that were specified in IEEE Std 802.1AB™ to IEEE Std 802.3.

IEEE Std 802.3at™-2009

This amendment includes changes to IEEE Std 802.3-2008. This amendment augments the capabilities of IEEE Std 802.3-2008 with higher power levels and improved power management information.

IEEE Std 802.3™-2008/Cor 1-2009

This corrigendum corrects the PAUSE reaction timing delay value for the 10GBASE-T PHY type.

IEEE Std 802.3ba™-2010

This amendment includes changes to IEEE Std 802.3-2008 and adds Clause 80 through Clause 88, Annex 83A through Annex 83C, Annex 85A, and Annex 86A. This amendment adds MAC parameters, Physical Layers, and management parameters for the transfer of IEEE 802.3 format frames at 40 Gb/s and 100 Gb/s.

IEEE Std 802.3az™-2010

This amendment includes changes to IEEE Std 802.3-2008 and adds Clause 78. This amendment adds changes required to enable energy efficient operation of several existing Physical Layers.

IEEE Std 802.3bg™-2011

This amendment includes changes to IEEE Std 802.3-2008 and adds Clause 89. This amendment adds a new PMD type and management parameters for 40 Gb/s operation over single-mode fiber.

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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For the benefit of those who have received this document by electronic means, what follows is a list of special symbols and operators. If any of these symbols or operators fails to print out correctly on your machine, the editors apologize and hope that this table will at least help you to sort out the meaning of the resulting funny-shaped blobs and strokes.

Special symbols and operators

Printed character	Meaning	Font
*	Boolean AND	Symbol
+	Boolean OR, arithmetic addition	Symbol
^	Boolean XOR	Times New Roman
!	Boolean NOT	Symbol
×	Multiplication	Symbol
<	Less than	Symbol
≤	Less than or equal to	Symbol
>	Greater than	Symbol
≥	Greater than or equal to	Symbol
=	Equal to	Symbol
≈	Approximately equal to	Symbol
≠	Not equal to	Symbol
⇐	Assignment operator	Symbol
∈	Indicates membership	Symbol
∉	Indicates nonmembership	Symbol
±	Plus or minus (a tolerance)	Symbol
°	Degrees	Symbol
∑	Summation	Symbol
√	Square root	Symbol
—	Big dash (em dash)	Times New Roman
–	Little dash (en dash), subtraction	Times New Roman
|	Vertical bar	Times New Roman
†	Dagger	Times New Roman
‡	Double dagger	Times New Roman
α	Lower case alpha	Symbol
β	Lower case beta	Symbol
γ	Lower case gamma	Symbol
δ	Lower case delta	Symbol
ε	Lower case epsilon	Symbol
λ	Lower case lambda	Symbol
µ	Lower case micro	Times New Roman
Π	Upper case pi	Symbol
Ω	Upper case omega	Symbol

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(This amendment is based on IEEE Std 802.3™-2008.)

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

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 either 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. 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.[1]

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

1. Introduction

1.3 Normative references

Insert the following references in alphanumerical order:

ANSI/TIA-568-C.3-2008, Optical Fiber Cabling Components Standard.

IEC 60793-1-48:2007, Optical fibres—Part 1-48: Measurement methods and test procedures—Polarization mode dispersion.

1.4 Definitions

Change 1.4.3 as follows:

1.4.3 10BASE-F: IEEE 802.3 Physical Layer specification for a 10 Mb/s CSMA/CD local area network over multimode fiber optic cable. (See IEEE Std 802.3, Clause 15.)

Insert the following new definition into the definitions list, in alphanumerical order:

1.4.x 40GBASE-FR: IEEE 802.3 Physical Layer specification for 40 Gb/s serial transmission using 40GBASE-R encoding over one wavelength on single-mode fiber, with reach up to at least 2 km. (See IEEE Std 802.3, Clause 89.)

1.5 Abbreviations

Insert the following new abbreviations into the definitions list, in alphabetical order:

DGD differential group delay

30. Management

Insert new PHY type into "APPROPRIATE SYNTAX" section of 30.5.1.1.2 after 40GBASE-LR4 (inserted by IEEE Std 802.3ba-2010):

30.5.1.1.2 aMAUType

APPROPRIATE SYNTAX:

...
40GBASE-FR 40GBASE-R PCS/PMA over single-mode fiber PMD as specified in Clause 89
...

45. Management Data Input/Output (MDIO) Interface

45.2.1.6 PMA/PMD control 2 register (Register 1.7)

Change Table 45–7 (as modified by IEEE Std 802.3av-2009 and IEEE Std 802.3ba-2010) for 40GBASE-FR PMA/PMD type selection:

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

Bit(s)	Name	Description	R/W[a]
1.7.15:6	Reserved	Value always 0, writes ignored	R/W
1.7.5:0	PMA/PMD type selection	5 4 3 2 1 0 1 1 x x x x = reserved for future use 1 0 1 1 x x = reserved for future use 1 0 1 0 1 1 = 100GBASE-ER4 PMA/PMD type 1 0 1 0 1 0 = 100GBASE-LR4 PMA/PMD type 1 0 1 0 0 1 = 100GBASE-SR10 PMA/PMD type 1 0 1 0 0 0 = 100GBASE-CR10 PMA/PMD type ~~1 0 0 1 x x = reserved for future use~~ 1 0 0 1 1 x = reserved for future use 1 0 0 1 0 1 = reserved for future use 1 0 0 1 0 0 = 40GBASE-FR PMA/PMD type 1 0 0 0 1 1 = 40GBASE-LR4 PMA/PMD type 1 0 0 0 1 0 = 40GBASE-SR4 PMA/PMD type 1 0 0 0 0 1 = 40GBASE-CR4 PMA/PMD type 1 0 0 0 0 0 = 40GBASE-KR4 PMA/PMD type 0 1 1 1 x x = reserved 0 1 1 0 1 1 = reserved 0 1 1 0 1 0 = 10GBASE-PR-U3 0 1 1 0 0 1 = 10GBASE-PR-U1 0 1 1 0 0 0 = 10/1GBASE-PRX-U3 0 1 0 1 1 1 = 10/1GBASE-PRX-U2 0 1 0 1 1 0 = 10/1GBASE-PRX-U1 0 1 0 1 0 1 = 10GBASE-PR-D3 0 1 0 1 0 0 = 10GBASE-PR-D2 0 1 0 0 1 1 = 10GBASE-PR-D1 0 1 0 0 1 0 = 10/1GBASE-PRX-D3 0 1 0 0 0 1 = 10/1GBASE-PRX-D2 0 1 0 0 0 0 = 10/1GBASE-PRX-D1 0 0 1 1 1 1 = 10BASE-T PMA/PMD type 0 0 1 1 1 0 = 100BASE-TX PMA/PMD type 0 0 1 1 0 1 = 1000BASE-KX PMA/PMD type 0 0 1 1 0 0 = 1000BASE-T PMA/PMD type 0 0 1 0 1 1 = 10GBASE-KR PMA/PMD type 0 0 1 0 1 0 = 10GBASE-KX4 PMA/PMD type 0 0 1 0 0 1 = 10GBASE-T PMA type 0 0 1 0 0 0 = 10GBASE-LRM PMA/PMD type 0 0 0 1 1 1 = 10GBASE-SR PMA/PMD type 0 0 0 1 1 0 = 10GBASE-LR PMA/PMD type 0 0 0 1 0 1 = 10GBASE-ER PMA/PMD type 0 0 0 1 0 0 = 10GBASE-LX4 PMA/PMD type 0 0 0 0 1 1 = 10GBASE-SW PMA/PMD type 0 0 0 0 1 0 = 10GBASE-LW PMA/PMD type 0 0 0 0 0 1 = 10GBASE-EW PMA/PMD type 0 0 0 0 0 0 = 10GBASE-CX4 PMA/PMD type	R/W

[a]R/W = Read/Write

45.2.1.7 PMA/PMD status 2 register (Register 1.8)

Change 45.2.1.7.4 and 45.2.1.7.5 (as modified by IEEE Std 802.3ba-2010) as follows:

45.2.1.7.4 Transmit fault (1.8.11)

When read as a one, bit 1.8.11 indicates that the PMA/PMD has detected a fault condition on the transmit path. When read as a zero, bit 1.8.11 indicates that the PMA/PMD has not detected a fault condition on the transmit path. Detection of a fault condition on the transmit path is optional and the ability to detect such a condition is advertised by bit 1.8.13. A PMA/PMD that is unable to detect a fault condition on the transmit path shall return a value of zero for this bit. The description of the transmit fault function for the 10GBASE-KR PMD is given in 72.6.8, for 10GBASE-LRM serial PMDs in 68.4.8, and for other serial PMDs in 52.4.8. The description of the transmit fault function for WWDM PMDs is given in 53.4.10. The description of the transmit fault function for the 10GBASE-CX4 PMD is given in 54.5.10. The description of the transmit fault function for the 10GBASE-T PMA is given in 55.4.2.2. The description of the transmit fault function for the 10GBASE-KX4 PMD is given in 71.6.10. The description of the transmit fault function for the 40GBASE-KR4 PMD is given in 84.7.10. The description of the transmit fault function for the 40GBASE-CR4 and 100GBASE-CR10 PMDs is given in 85.7.10. The description of the transmit fault function for the 40GBASE-SR4 and 100GBASE-SR10 PMDs is given in 86.5.10. The description of the transmit fault function for the 40GBASE-LR4 PMD is given in 87.5.10. <u>The description of the transmit fault function for the 40GBASE-FR PMD is given in 89.5.8.</u> The description of the transmit fault function for the 100GBASE-LR4 and 100GBASE-ER4 PMDs is given in 88.5.10. The transmit fault bit shall be implemented with latching high behavior.

The default value of bit 1.8.11 is zero.

45.2.1.7.5 Receive fault (1.8.10)

When read as a one, bit 1.8.10 indicates that the PMA/PMD has detected a fault condition on the receive path. When read as a zero, bit 1.8.10 indicates that the PMA/PMD has not detected a fault condition on the receive path. Detection of a fault condition on the receive path is optional and the ability to detect such a condition is advertised by bit 1.8.12. A PMA/PMD that is unable to detect a fault condition on the receive path shall return a value of zero for this bit. The description of the receive fault function for the 10GBASE-KR PMD is given in 72.6.9, for 10GBASE-LRM serial PMDs in 68.4.9, and for other serial PMDs in 52.4.9. The description of the receive fault function for WWDM PMDs is given in 53.4.11. The description of the receive fault function for the 10GBASE-CX4 PMD is given in 54.5.11. The description of the receive fault function for the 10GBASE-T PMA is given in 55.4.2.4. The description of the receive fault function for the 10GBASE-KX4 PMD is given in 71.6.11. The description of the receive fault function for the 40GBASE-KR4 PMD is given in 84.7.11. The description of the receive fault function for the 40GBASE-CR4 and 100GBASE-CR10 PMDs is given in 85.7.11. The description of the receive fault function for the 40GBASE-SR4 and 100GBASE-SR10 PMDs is given in 86.5.11. The description of the receive fault function for the 40GBASE-LR4 PMD is given in 87.5.11. <u>The description of the receive fault function for the 40GBASE-FR PMD is given in 89.5.9.</u> The description of the receive fault function for the 100GBASE-LR4 and 100GBASE-ER4 PMDs is given in 88.5.11. The receive fault bit shall be implemented with latching high behavior.

Change 45.2.1.8 (as modified by IEEE Std 802.3ba-2010) as follows, making no further change to Table 45–9:

45.2.1.8 PMD transmit disable register (Register 1.9)

The assignment of bits in the PMD transmit disable register is shown in Table 45–9. The transmit disable functionality is optional and a PMD's ability to perform the transmit disable functionality is advertised in the PMD transmit disable ability bit 1.8.8. A PMD that does not implement the transmit disable functionality shall ignore writes to the PMD transmit disable register and may return a value of zero for all bits. A PMD device that operates using a single lane and has implemented the transmit disable function shall use bit 1.9.0 to control the function. Such devices shall ignore writes to bits 1.9.10:1 and return a value of zero for those bits when they are read. The transmit disable function for the 10GBASE-KR PMD is described in 72.6.5, for 10GBASE-LRM serial PMDs in 68.4.7, and for other serial PMDs in 52.4.7. The transmit disable function for the 10GBASE-LX4 PMD is described in 53.4.7. The transmit disable function for the 10GBASE-CX4 PMD is described in 54.5.6. The transmit disable function for 10GBASE-KX4 is described in 71.6.6. The transmit disable function for the 10GBASE-T PMA is described in 55.4.2.3. The transmit disable function for 40GBASE-KR4 is described in 84.7.6. The transmit disable function for 40GBASE-CR4 and 100GBASE-CR10 is described in 85.7.6. The transmit disable function for 40GBASE-SR4 and 100GBASE-SR10 is described in 86.5.7. The transmit disable function for 40GBASE-LR4 is described in 87.5.7. The transmit disable function for 40GBASE-FR is described in 89.5.6. The transmit disable function for 100GBASE-LR4 and 100GBASE-ER4 is described in 88.5.7.

NOTE—Disabling the transmitter on one or more lanes stops the entire link from carrying data.

45.2.1.11a 40G/100G PMA/PMD extended ability register (Register 1.13)

Change Table 45–12a (as inserted by IEEE Std 802.3ba-2010) to add 40GBASE-FR ability as follows:

Table 45–12a—40G/100G PMA/PMD extended ability register bit definitions

Bit(s)	Name	Description	R/W[a]
1.13.15	PMA remote loopback ability	1 = PMA has the ability to perform a remote loopback function 0 = PMA does not have the ability to perform a remote loopback function	RO
1.13.14:12	Reserved	Ignore on read	RO
1.13.11	100GBASE-ER4 ability	1 = PMA/PMD is able to perform 100GBASE-ER4 0 = PMA/PMD is not able to perform 100GBASE-ER4	RO
1.13.10	100GBASE-LR4 ability	1 = PMA/PMD is able to perform 100GBASE-LR4 0 = PMA/PMD is not able to perform 100GBASE-LR4	RO
1.13.9	100GBASE-SR10 ability	1 = PMA/PMD is able to perform 100GBASE-SR10 0 = PMA/PMD is not able to perform 100GBASE-SR10	RO
1.13.8	100GBASE-CR10 ability	1 = PMA/PMD is able to perform 100GBASE-CR10 0 = PMA/PMD is not able to perform 100GBASE-CR10	RO
1.13.7:54	Reserved	Ignore on read	RO
1.13.4	40GBASE-FR ability	1 = PMA/PMD is able to perform 40GBASE-FR 0 = PMA/PMD is not able to perform 40GBASE-FR	RO
1.13.3	40GBASE-LR4 ability	1 = PMA/PMD is able to perform 40GBASE-LR4 0 = PMA/PMD is not able to perform 40GBASE-LR4	RO
1.13.2	40GBASE-SR4 ability	1 = PMA/PMD is able to perform 40GBASE-SR4 0 = PMA/PMD is not able to perform 40GBASE-SR4	RO
1.13.1	40GBASE-CR4 ability	1 = PMA/PMD is able to perform 40GBASE-CR4 0 = PMA/PMD is not able to perform 40GBASE-CR4	RO
1.13.0	40GBASE-KR4 ability	1 = PMA/PMD is able to perform 40GBASE-KR4 0 = PMA/PMD is not able to perform 40GBASE-KR4	RO

[a]RO = Read only

Insert 45.2.1.11a.5a after 45.2.1.11a.5 (which was inserted by IEEE Std 802.3ba-2010) as follows:

45.2.1.11a.5a 40GBASE-FR ability (1.13.4)

When read as a one, bit 1.13.4 indicates that the PMA/PMD is able to operate as a 40GBASE-FR PMA/PMD type. When read as a zero, bit 1.13.4 indicates that the PMA/PMD is not able to operate as a 40GBASE-FR PMA/PMD type.

80. Introduction to 40 Gb/s and 100 Gb/s networks

Clause 80 was added to IEEE Std 802.3-2008 by IEEE Std 803.3ba-2010.

80.1 Overview

Change 80.1.2 to add the 2 km objective as follows and renumber the other objectives accordingly:

80.1.2 Objectives

The following are the objectives of 40 Gigabit and 100 Gigabit Ethernet:

a) Support the full duplex Ethernet MAC.
b) Preserve the IEEE 802.3 Ethernet frame format utilizing the IEEE 802.3 MAC.
c) Preserve minimum and maximum frame size of IEEE Std 802.3.
d) Support a BER better than or equal to 10^{-12} at the MAC/PLS service interface.
e) Provide appropriate support for Optical Transport Network (OTN).
f) Support a MAC data rate of 40 Gb/s.
g) Provide Physical Layer specifications that support 40 Gb/s operation over up to the following:
    1) At least 10 km on single-mode fiber (SMF)
    2) At least 2 km on single-mode fiber (SMF)
    3) At least 100 m on OM3 multimode fiber (MMF)
    4) At least 7 m over a copper cable assembly
    5) At least 1 m over a backplane
h) Support a MAC data rate of 100 Gb/s.
i) Provide Physical layer specifications that support 100 Gb/s operation over up to the following:
    1) At least 40 km on single-mode fiber (SMF)
    2) At least 10 km on single-mode fiber (SMF)
    3) At least 100 m on OM3 multimode fiber (MMF)
    4) At least 7 m over a copper cable assembly

80.1.3 Relationship of 40 Gigabit and 100 Gigabit Ethernet to the ISO OSI reference model

In 80.1.3 insert a new exception g) as follows and renumber the other exceptions accordingly:

g) The MDI as specified in Clause 89 for 40GBASE-FR uses a single lane data path.

80.1.4 Nomenclature

Change Table 80–1 to add the 40GBASE-FR PMD as follows:

Table 80–1—40 Gb/s and 100 Gb/s PHYs

Name	Description
40GBASE-KR4	40 Gb/s PHY using 40GBASE-R encoding over four lanes of an electrical backplane, with reach up to at least 1 m (see Clause 84)
40GBASE-CR4	40 Gb/s PHY using 40GBASE-R encoding over four lanes of shielded balanced copper cabling, with reach up to at least 7 m (see Clause 85)
40GBASE-SR4	40 Gb/s PHY using 40GBASE-R encoding over four lanes of multimode fiber, with reach up to at least 100 m (see Clause 86)
<u>40GBASE-FR</u>	<u>40 Gb/s PHY using 40GBASE-R encoding over one lane on single-mode fiber, with reach up to at least 2 km (see Clause 89)</u>
40GBASE-LR4	40 Gb/s PHY using 40GBASE-R encoding over four WDM lanes on single-mode fiber, with reach up to at least 10 km (see Clause 87)
100GBASE-CR10	100 Gb/s PHY using 100GBASE-R encoding over ten lanes of shielded balanced copper cabling, with reach up to at least 7 m (see Clause 85)
100GBASE-SR10	100 Gb/s PHY using 100GBASE-R encoding over ten lanes of multimode fiber, with reach up to at least 100 m (see Clause 86)
100GBASE-LR4	100 Gb/s PHY using 100GBASE-R encoding over four WDM lanes on single-mode fiber, with reach up to at least 10 km (see Clause 88)
100GBASE-ER4	100 Gb/s PHY using 100GBASE-R encoding over four WDM lanes on single-mode fiber, with reach up to at least 40 km (see Clause 88)

80.1.5 Physical Layer signaling systems

Change Table 80–2 to add the 40GBASE-FR PMD as follows:

Table 80–2—Nomenclature and clause correlation

Nomenclature	Clause[a]																							
	73	74	81			82		83		83A		83B		84	85		86		86A		87	88		89
	Auto-Negotiation	BASE-R FEC	RS	XLGMII	CGMII	40GBASE-R PCS	100GBASE-R PCS	40GBASE-R PMA	100GBASE-R PMA	XLAUI	CAUI	XLAUI	CAUI	40GBASE-KR4 PMD	40GBASE-CR4 PMD	100GBASE-CR10 PMD	40GBASE-SR4 PMD	100GBASE-SR10 PMD	XLPPI	CPPI	40GBASE-LR4 PMD	100GBASE-LR4 PMD	100GBASE-ER4 PMD	40GBASE-FR PMD
40GBASE-KR4	M	O	M	O		M		M		O				M										
40GBASE-CR4	M	O	M	O		M		M		O					M									
40GBASE-SR4			M	O		M		M		O		O					M		O					
40GBASE-FR			M	O		M		M		O		O												M
40GBASE-LR4			M	O		M		M		O		O							O		M			
100GBASE-CR10	M	O	M		O		M		M		O					M								
100GBASE-SR10			M		O		M		M		O		O					M		O				
100GBASE-LR4			M		O		M		M		O		O									M		
100GBASE-ER4			M		O		M		M		O		O										M	

[a]O = Optional, M = Mandatory

80.2 Summary of 40 Gigabit and 100 Gigabit Ethernet sublayers

Change 80.2.5 to include Clause 89 in the range of PMD clauses as follows:

80.2.5 Physical Medium Dependent (PMD) sublayer

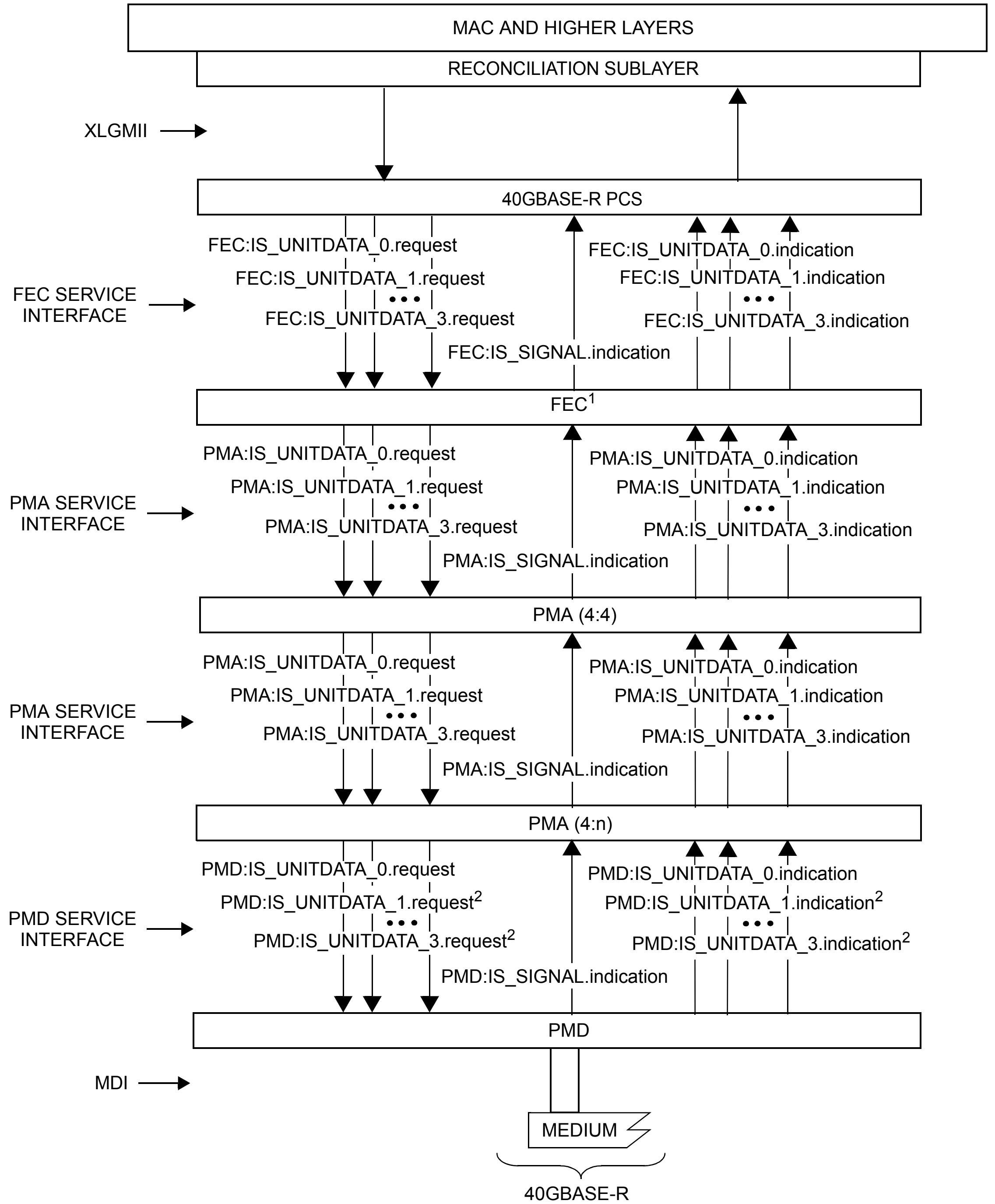
The Physical Medium Dependent sublayer is responsible for interfacing to the transmission medium. The PMD is located just above the Medium Dependent Interface (MDI). The MDI, logically subsumed within each PMD subclause, is the actual medium attachment for the various supported media.

The 40GBASE-R and 100GBASE-R PMDs and their corresponding media are specified in Clause 84 through Clause 89.

80.3 Service interface specification method and notation

80.3.2 Instances of the Inter-sublayer service interface

Replace Figure 80–2 (to add NOTE 2) as follows:



FEC = FORWARD ERROR CORRECTION
MAC = MEDIA ACCESS CONTROL
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT

XLGMII = 40 Gb/s MEDIA INDEPENDENT INTERFACE
n = NUMBER OF PARALLEL STREAMS OF DATA UNITS

NOTE 1—OPTIONAL OR OMITTED DEPENDING ON PHY TYPE
NOTE 2—DOES NOT EXIST FOR 40GBASE-FR PMD

Figure 80–2—40GBASE-R inter-sublayer service interfaces

80.4 Delay constraints

Insert an additional row as follows into Table 80–3 below 40GBASE-SR4 PMD:

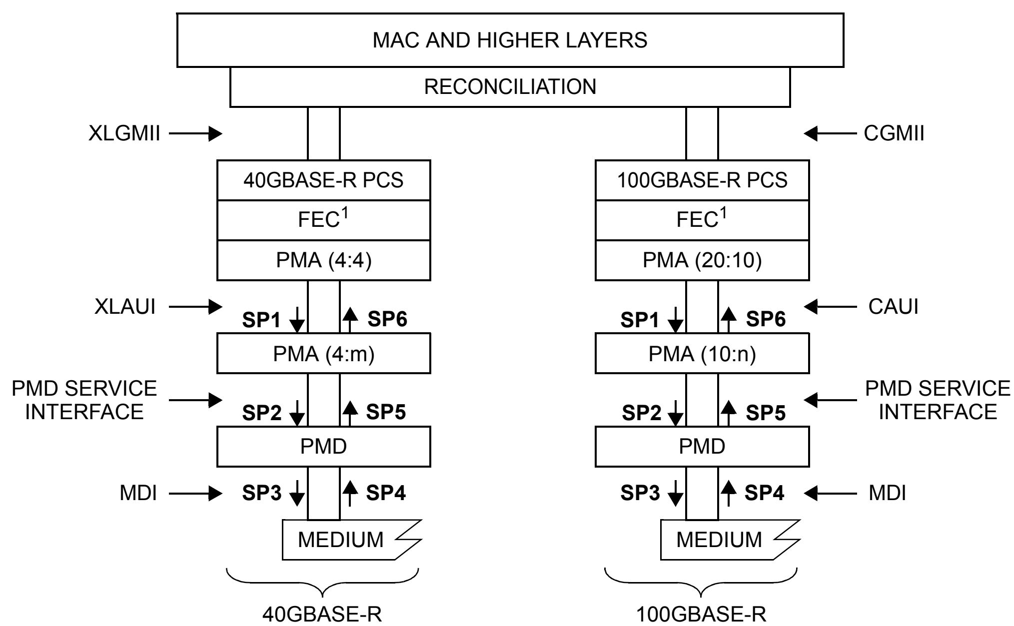
Table 80–3—Sublayer delay constraints

Sublayer	Maximum (bit time)[a]	Maximum (pause_quanta)[b]	Maximum (ns)	Notes[c]
40GBASE-FR PMD	1024	2	25.6	Includes 2 m of fiber. See 89.3.1.

[a] Note that for 40GBASE-R, 1 bit time (BT) is equal to 25 ps and for 100GBASE-R, 1 bit time (BT) is equal to 10 ps. (See 1.4.81 for the definition of bit time.)
[b] Note that for 40GBASE-R, 1 pause_quantum is equal to 12.8 ns and for 100GBASE-R, 1 pause_quantum is equal to 5.12 ns. (See 31B.2 for the definition of pause_quanta.)
[c] Should there be a discrepancy between this table and the delay requirements of the relevant sublayer clause, the sublayer clause prevails.

80.5 Skew constraints

Replace Figure 80–4 to include a PMA(4:1) option as follows:

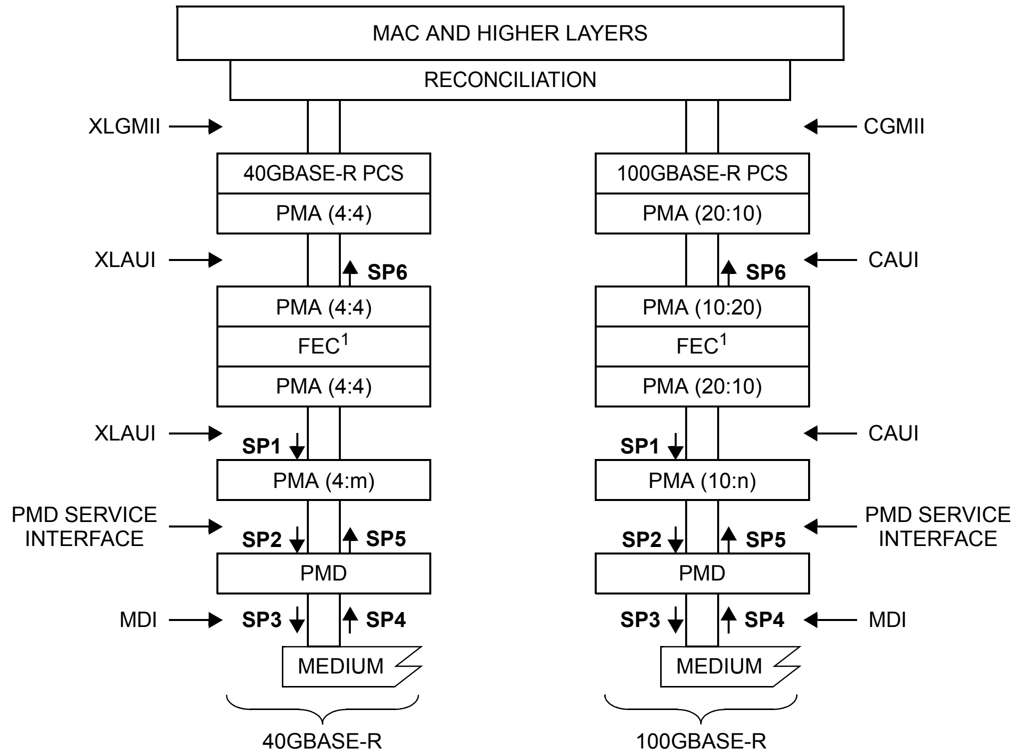


CAUI = 100 Gb/s ATTACHMENT UNIT INTERFACE
CGMII = 100 Gb/s MEDIA INDEPENDENT INTERFACE
FEC = FORWARD ERROR CORRECTION
MAC = MEDIA ACCESS CONTROL
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT
XLAUI = 40 Gb/s ATTACHMENT UNIT INTERFACE
XLGMII = 40 Gb/s MEDIA INDEPENDENT INTERFACE
m = 1 or 4
n = 4 or 10

NOTE1—OPTIONAL OR OMITTED DEPENDING ON PHY TYPE

Figure 80–4—40GBASE-R and 100GBASE-R Skew points for single XLAUI or CAUI

Replace Figure 80–5 to include a PMA(4:1) option as follows:



CAUI = 100 Gb/s ATTACHMENT UNIT INTERFACE
CGMII = 100 Gb/s MEDIA INDEPENDENT INTERFACE
FEC = FORWARD ERROR CORRECTION
MAC = MEDIA ACCESS CONTROL
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT
XLAUI = 40 Gb/s ATTACHMENT UNIT INTERFACE
XLGMII = 40 Gb/s MEDIA INDEPENDENT INTERFACE
m = 1 or 4
n = 4 or 10

NOTE1—OPTIONAL OR OMITTED DEPENDING ON PHY TYPE

Figure 80–5—40GBASE-R and 100GBASE-R Skew points for multiple XLAUI or CAUI

Change Table 80–4 and Table 80–5 as below to include references to the 40GBASE-FR Skew subclause:

Table 80–4—Summary of Skew constraints

Skew points	Maximum Skew (ns)[a]	Maximum Skew for 40GBASE-R PCS lane (UI)[b]	Maximum Skew for 100GBASE-R PCS lane (UI)[c]	Notes[d]
SP1	29	≈ 299	≈ 150	See 83.5.3.1
SP2	43	≈ 443	≈ 222	See 83.5.3.3 or 84.5 or 85.5 or 86.3.2 or 87.3.2 or 88.3.2 or 89.3.2
SP3	54	≈ 557	≈ 278	See 84.5 or 85.5 or 86.3.2 or 87.3.2 or 88.3.2 or 89.3.2
SP4	134	≈ 1382	≈ 691	See 84.5 or 85.5 or 86.3.2 or 87.3.2 or 88.3.2 or 89.3.2
SP5	145	≈ 1495	≈ 748	See 84.5 or 85.5 or 86.3.2 or 87.3.2 or 88.3.2 or 89.3.2
SP6	160	≈ 1649	≈ 824	See 83.5.3.5
At PCS receive	180	≈ 1856	≈ 928	See 82.2.12

[a]The Skew limit includes 1 ns allowance for PCB traces that are associated with the Skew points.
[b]Note that ≈ indicates approximate equivalent of maximum Skew in UI for 40GBASE-R, based on 1 UI equals 96.969697 ps at PCS lane signaling rate of 10.3125 GBd.
[c]Note that ≈ indicates approximate equivalent of maximum Skew in UI for 100GBASE-R, based on 1 UI equals 193.939394 ps at PCS lane signaling rate of 5.15625 GBd.
[d]Should there be a discrepancy between this table and the Skew requirements of the relevant sublayer clause, the sublayer clause prevails.

Table 80–5—Summary of Skew Variation constraints

Skew points	Maximum Skew Variation (ns)	Maximum Skew Variation for 10.3125 GBd PMD lane (UI)[a]	Maximum Skew Variation for 25.78125 GBd PMD lane (UI)[b]	Notes[c]
SP1	0.2	≈ 2	N/A	See 83.5.3.1
SP2	0.4	≈ 4	≈ 10	See 83.5.3.3 or 84.5 or 85.5 or 86.3.2 or 87.3.2 or 88.3.2~~.~~ or 89.3.2
SP3	0.6	≈ 6	≈ 15	See 84.5 or 85.5 or 86.3.2 or 87.3.2 or 88.3.2 or 89.3.2
SP4	3.4	≈ 35	≈ 88	See 84.5 or 85.5 or 86.3.2 or 87.3.2 or 88.3.2 or 89.3.2
SP5	3.6	≈ 37	≈ 93	See 83.5.3.4 or 84.5 or 85.5 or 86.3.2 or 87.3.2 or 88.3.2 or 89.3.2
SP6	3.8	≈ 39	N/A	See 83.5.3.5
At PCS receive	4	≈ 41	N/A	See 82.2.12

[a]Note that ≈ indicates approximate equivalent of maximum Skew Variation in UI for 40GBASE-R, based on 1 UI equals 96.969697 ps at PMD lane signaling rate of 10.3125 GBd.
[b]Note that ≈ indicates approximate equivalent of maximum Skew Variation in UI for 100GBASE-R, based on 1 UI equals 38.787879 ps at PMD lane signaling rate of 25.78125 GBd.
[c]Should there be a discrepancy between this table and the Skew requirements of the relevant sublayer clause, the sublayer clause prevails.

Change the first paragraph of 80.7 as follows:

80.7 Protocol implementation conformance statement (PICS) proforma

The supplier of a protocol implementation that is claimed to conform to any part of IEEE Std 802.3, Clause 45, Clause 73, Clause 74, Clause 81 through Clause 89, and related annexes demonstrates compliance by completing a protocol implementation conformance statement (PICS) proforma.

83. Physical Medium Attachment (PMA) sublayer, type 40GBASE-R and 100GBASE-R

Clause 83 was added to IEEE Std 802.3-2008 by IEEE Std 803.3ba-2010.

83.7 Protocol implementation conformance statement (PICS) proforma for Clause 83, Physical Medium Attachment (PMA) sublayer, type 40GBASE-R and 100GBASE-R[2]

Change PICS item LANES_DOWNSTREAM as follows to include the option of 1 lane:

83.7.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
LANES_ DOWN- STREAM	Number of lanes in direction of PMD	83.1.4	Divisor of number of PCS lanes	PMA40:M	1 [ ] 4 [ ]
				PMA100:M	4 [ ] 10 [ ] 20 [ ]

[2]*Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

Insert the following new clause (Clause 89) after Clause 88:

89. Physical Medium Dependent (PMD) sublayer and medium, type 40GBASE-FR

89.1 Overview

This clause specifies the 40GBASE-FR PMD together with the single-mode fiber medium. It is intended that devices compliant with this specification could be implemented to also be used for application VSR2000-3R2 as defined in ITU-T G.693 [Bx1] (but that is beyond the scope of this standard). The 40GBASE-FR PMD is defined using a specification and test methodology that is similar to that used in ITU-T G.693 [Bx1], which is different from the specification and test methodologies used for other optical PMDs at 1000 Mb/s and above in IEEE Std 802.3. For example, the transmitter specifications for 40GBASE-FR do not include OMA or TDP parameters but do include a dispersion penalty limit, and the receiver specifications for 40GBASE-FR do not include stressed receiver sensitivity parameters but do include a part-stressed sensitivity limit and a separate jitter tolerance limit. See 89.6.4.

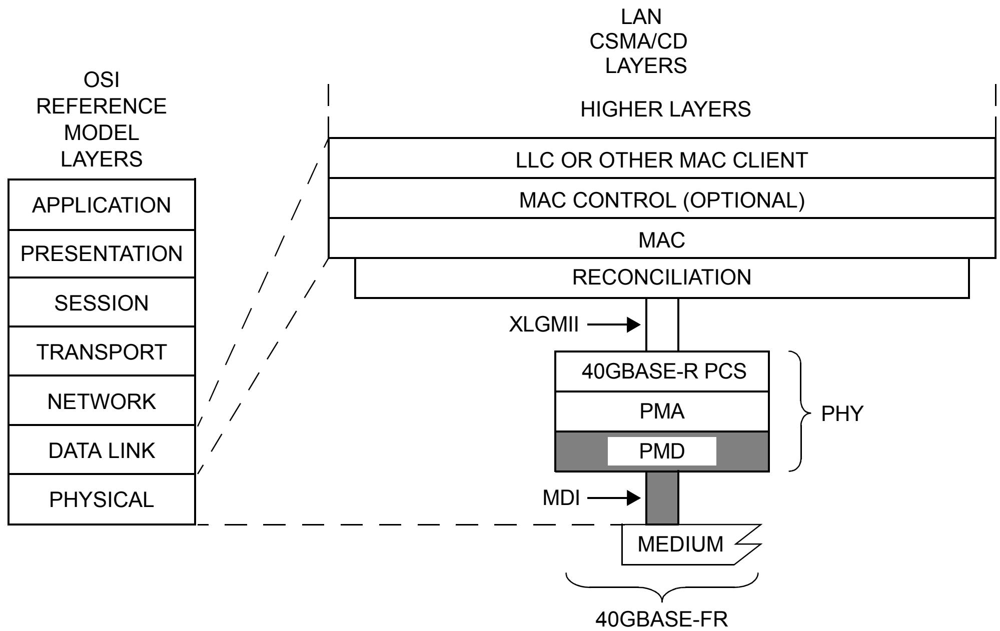
When forming a complete Physical Layer, a PMD shall be connected to the appropriate PMA as shown in Table 89–1, to the medium through the MDI and to the management functions that are optionally accessible through the management interface defined in Clause 45, or equivalent.

Table 89–1—Physical Layer clauses associated with the 40GBASE-FR PMD

Associated clause	40GBASE-FR
81—RS	Required
81—XLGMII[a]	Optional
82—PCS for 40GBASE-R	Required
83—PMA for 40GBASE-R	Required
83A—XLAUI	Optional
83B—Chip to module XLAUI	Optional

[a]The XLGMII is an optional interface. However, if the XLGMII is not implemented, a conforming implementation must behave functionally as though the RS and XLGMII were present.

Figure 89–1 shows the relationship of the PMD and MDI (shown shaded) with other sublayers to the ISO/IEC Open System Interconnection (OSI) reference model. 40 Gb/s and 100 Gb/s Ethernet is introduced in Clause 80 and the purpose of each PHY sublayer is summarized in 80.2.



LLC = LOGICAL LINK CONTROL
MAC = MEDIA ACCESS CONTROL
MDI = MEDIUM DEPENDENT INTERFACE
PCS = PHYSICAL CODING SUBLAYER
PHY = PHYSICAL LAYER DEVICE
PMA = PHYSICAL MEDIUM ATTACHMENT
PMD = PHYSICAL MEDIUM DEPENDENT
XLGMII = 40 Gb/s MEDIA INDEPENDENT INTERFACE
FR = PMD FOR SINGLE-MODE FIBER — 2 km

Figure 89–1—40GBASE-FR PMD relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model and IEEE 802.3 CSMA/CD LAN model

89.2 Physical Medium Dependent (PMD) service interface

This subclause specifies the services provided by the 40GBASE-FR PMD. The service interface for this PMD is described in an abstract manner and does not imply any particular implementation. The PMD service interface supports the exchange of encoded data between the PMA entity that resides just above the PMD, and the PMD entity. The PMD translates the encoded data to and from signals suitable for the specified medium.

The PMD service interface is an instance of the inter-sublayer service interface defined in 80.3. The PMD service interface primitives are summarized as follows:

PMD:IS_UNITDATA_0.request
PMD:IS_UNITDATA_0.indication
PMD:IS_SIGNAL.indication

In the transmit direction, the PMA continuously sends a single serial stream of bits to the PMD at a nominal signaling rate of 41.25 GBd. The PMD converts this stream of bits into an appropriate signal on the MDI.

In the receive direction, the PMD continuously sends a single serial stream of bits to the PMA corresponding to the signal received from the MDI at a nominal signaling rate of 41.25 GBd.

The SIGNAL_DETECT parameter defined in this clause maps to the SIGNAL_OK parameter in the PMD:IS_SIGNAL.indication(SIGNAL_OK) inter-sublayer service primitive defined in 80.3.

The SIGNAL_DETECT parameter can take on one of two values: OK or FAIL. When SIGNAL_DETECT = FAIL, the rx_bit parameter is undefined.

NOTE—SIGNAL_DETECT = OK does not guarantee that the rx_bit parameter is known to be good. It is possible for a poor quality link to provide sufficient light for a SIGNAL_DETECT = OK indication and still not meet the 10^{-12} BER objective.

89.3 Delay and skew

89.3.1 Delay constraints

The sum of the transmit and the receive delays at one end of the link contributed by the 40GBASE-FR PMD including 2 m of fiber in one direction shall be no more than 1024 bit times (2 pause_quanta or 25.6 ns). A description of overall system delay constraints and the definitions for bit times and pause_quanta can be found in 80.4 and its references.

89.3.2 Skew constraints

The Skew (relative delay) between the PCS lanes must be kept within limits so that the information on the lanes can be reassembled by the PCS. The Skew Variation must also be limited to ensure that a given PCS lane always traverses the same physical lane. Skew and Skew Variation are defined in 80.5 and specified at the points SP1 to SP6 shown in Figure 80–4 and Figure 80–5.

If the PMD service interface is physically instantiated so that the Skew at SP2 can be measured, then the Skew at SP2 is limited to 43 ns as defined by 83.5.3.3. Since the signal at the PMD service interface represents a serial bit stream, there is no Skew Variation at this point.

The Skew at SP3 (the transmitter MDI) shall be less than 54 ns. Since the signal at the MDI represents a serial bit stream, there is no Skew Variation at this point.

The Skew at SP4 (the receiver MDI) shall be less than 134 ns. Since the signal at the MDI represents a serial bit stream, there is no Skew Variation at this point.

If the PMD service interface is physically instantiated so that the Skew at SP5 can be measured, then the Skew at SP5 shall be less than 145 ns. Since the signal at the PMD service interface represents a serial bit stream, there is no Skew Variation at this point.

For more information on Skew and Skew Variation, see 80.5. The measurements of Skew and Skew Variation are defined in 89.7.2.

89.4 PMD MDIO function mapping

The optional MDIO capability described in Clause 45 defines several variables that may provide control and status information for and about the PMD. If the MDIO interface is implemented, the mapping of MDIO control variables to PMD control variables shall be as shown in Table 89–2, and the mapping of MDIO status variables to PMD status variables shall be as shown in Table 89–3.

Table 89–2—MDIO/PMD control variable mapping

MDIO control variable	PMA/PMD register name	Register/bit number	PMD control variable
Reset	PMA/PMD control 1 register	1.0.15	PMD_reset
Global PMD transmit disable	PMD Transmit disable register	1.9.0	PMD_global_transmit_disable

Table 89–3—MDIO/PMD status variable mapping

MDIO status variable	PMA/PMD register name	Register/ bit number	PMD status variable
Fault	PMA/PMD status 1 register	1.1.7	PMD_fault
Transmit fault	PMA/PMD status 2 register	1.8.11	PMD_transmit_fault
Receive fault	PMA/PMD status 2 register	1.8.10	PMD_receive_fault
Global PMD receive signal detect	PMD receive signal detect register	1.10.0	PMD_global_signal_detect

89.5 PMD functional specifications

The 40GBASE-FR PMD performs the Transmit and Receive functions, which convey data between the PMD service interface and the MDI.

89.5.1 PMD block diagram

The PMD block diagram is shown in Figure 89–2. For purposes of system conformance, the PMD sublayer is standardized at the points described in this subclause. The optical transmit signal is defined at the output end of a single-mode fiber patch cord (TP2), between 2 m and 5 m in length. Unless specified otherwise, all transmitter measurements and tests defined in 89.7 are made at TP2. The optical receive signal is defined at the output of the fiber optic cabling (TP3) at the MDI (see 89.10.3). Unless specified otherwise, all receiver measurements and tests defined in 89.7 are made at TP3.

TP1 and TP4 are informative reference points that may be useful to implementors for testing components (these test points will not typically be accessible in an implemented system).

89.5.2 PMD transmit function

The PMD Transmit function shall convert the bit stream requested by the PMD service interface message PMD:IS_UNITDATA_0.request into an optical signal stream and deliver it to the MDI, according to the transmit optical specifications in this clause. The higher optical power level in the signal stream shall correspond to tx_bit = one.

89.5.3 PMD receive function

The optical signal stream received from the MDI shall be converted into a bit stream for delivery to the PMD service interface using the message PMD:IS_UNITDATA_0.indication, according to the receive optical specifications in this clause. The higher optical power level in the signal stream shall correspond to rx_bit = one.

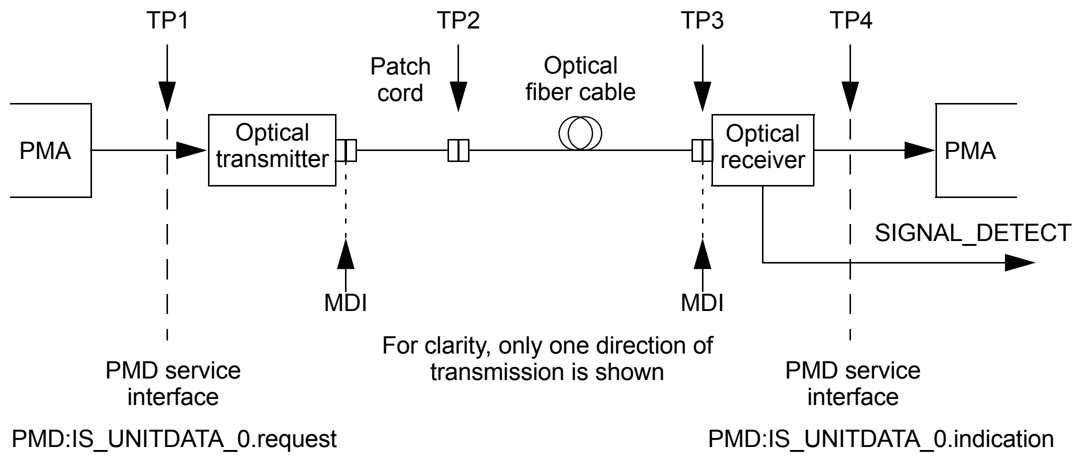


Figure 89–2—Block diagram for 40GBASE-FR transmit/receive paths

89.5.4 PMD global signal detect function

The PMD global signal detect function shall report the state of SIGNAL_DETECT via the PMD service interface. The SIGNAL_DETECT parameter is signaled continuously, while the PMD:IS_SIGNAL.indication message is generated when a change in the value of SIGNAL_DETECT occurs. The SIGNAL_DETECT parameter defined in this clause maps to the SIGNAL_OK parameter in the inter-sublayer service interface primitives defined in 80.3.

SIGNAL_DETECT is an indicator of the presence of an optical signal. The value of the SIGNAL_DETECT parameter shall be generated according to the conditions defined in Table 89–4. The PMD receiver is not required to verify whether a compliant 40GBASE-R signal is being received. This standard imposes no response time requirements on the generation of the SIGNAL_DETECT parameter.

Table 89–4—SIGNAL_DETECT value definition

Receive conditions	SIGNAL_DETECT value
Average optical power at TP3 ≤ –30 dBm	FAIL
(Optical power at TP3 ≥ receiver sensitivity (average power) (max) in Table 89–7) AND (compliant 40GBASE–R signal input)	OK
All other conditions	Unspecified

As an unavoidable consequence of the requirements for the setting of the SIGNAL_DETECT parameter, implementations must provide adequate margin between the input optical power level at which the SIGNAL_DETECT parameter is set to OK and the inherent noise level of the PMD including the effects of crosstalk, power supply noise, etc.

Various implementations of the Signal Detect function are permitted by this standard, including implementations that generate the SIGNAL_DETECT parameter values in response to the amplitude of the modulation of the optical signal and implementations that respond to the average optical power of the modulated optical signal.

89.5.5 PMD reset function

If the MDIO interface is implemented and if PMD_reset is asserted, the PMD shall be reset as defined in 45.2.1.1.1.

89.5.6 PMD global transmit disable function (optional)

The PMD_global_transmit_disable function is optional and allows the optical transmitter to be disabled.

a) When the PMD_global_transmit_disable variable is set to one, this function shall turn off the optical transmitter so that it meets the requirements of the average launch power of the OFF transmitter in Table 89–6.
b) If a PMD_fault is detected, then the PMD may set the PMD_global_transmit_disable to one, turning off the optical transmitter.

If the MDIO interface is implemented, then this function shall map to the PMD_global_transmit_disable bit as specified in 45.2.1.8.5.

NOTE—The PMD lane-by-lane transmit disable function is not used for serial PMDs.

89.5.7 PMD fault function (optional)

If the PMD has detected a local fault on either the transmit or receive path, the PMD shall set PMD_fault to one. If the MDIO interface is implemented, PMD_fault shall be mapped to the fault bit as specified in 45.2.1.2.1.

89.5.8 PMD transmit fault function (optional)

If the PMD has detected a local fault on the transmitter, the PMD shall set the PMD_transmit_fault variable to one. If the MDIO interface is implemented, PMD_transmit_fault shall be mapped to the transmit fault bit as specified in 45.2.1.7.4.

89.5.9 PMD receive fault function (optional)

If the PMD has detected a local fault on the receiver, the PMD shall set the PMD_receive_fault variable to one. If the MDIO interface is implemented, PMD_receive_fault shall be mapped to the receive fault bit as specified in 45.2.1.7.5.

89.6 PMD to MDI optical specifications for 40GBASE-FR

The required operating range for the 40GBASE-FR PMD is defined in Table 89–5. A 40GBASE-FR compliant PMD operates on IEC 60793-2-50 type B1.1, B1.3 or B6_a single-mode fibers according to the specifications defined in Table 89–13. A PMD that exceeds the required operating range while meeting all other optical specifications is considered compliant (e.g., operating at 2.5 km meets the operating range requirement of 2 m to 2 km).

Table 89–5—40GBASE-FR required operating range

PMD type	Required operating range
40GBASE-FR	2 m to 2 km

89.6.1 40GBASE-FR transmitter optical specifications

The 40GBASE-FR transmitter shall meet the specifications defined in Table 89–6 per the definitions in 89.7.

Table 89–6—40GBASE-FR transmit characteristics

Description	Value	Unit
Signaling rate (range)	41.25 ± 100 ppm	GBd
Center wavelength (range)	1530 to 1565	nm
Side-mode suppression ratio (SMSR), (min)	35	dB
Average launch power (max)	3	dBm
Average launch power (min)	0	dBm
Dispersion penalty (max)	2	dB
Average launch power of OFF transmitter (max)	–30	dBm
Extinction ratio (min)	8.2	dB
$RIN_{20}OMA$ (max)	–132	dB/Hz
Optical return loss tolerance (max)	20	dB
Transmitter reflectance[a] (max)	–12	dB
Transmitter eye mask definition {X1, X2, X3, Y1, Y2, Y3}	{0.25, 0.4, 0.45, 0.22, 0.25, 0.4}	

[a]Transmitter reflectance is defined looking into the transmitter.

89.6.2 40GBASE-FR receive optical specifications

The 40GBASE-FR receiver shall meet the specifications defined in Table 89–7 per the definitions in 89.7.

Table 89–7—40GBASE-FR receive characteristics

Description	Value	Unit
Signaling rate (range)	41.25 ± 100 ppm	GBd
Center wavelength (range)	1290 to 1330 and 1530 to 1565	nm
Damage threshold[a] (min)	4	dBm
Average receive power (max)	3	dBm
Receiver reflectance (max)	–26	dB
Receiver sensitivity (average power)[b] (max)	–6	dBm
Receiver jitter tolerance (max)	1	dB
Receiver 3 dB electrical upper cutoff frequency (max)	49	GHz

[a]The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having this average power level.
[b]Receiver sensitivity (average power) is defined in 89.7.9 and is to be met with a transmitter with worst-case transmit eye, extinction ratio, transmitter reflectance, and $RIN_{20}OMA$. This is a different definition of receiver sensitivity from that used in other clauses (e.g., that in Clause 38). See 89.6.4 for a comparison.

89.6.3 40GBASE-FR illustrative link power budget

An illustrative power budget and penalties for 40GBASE-FR channels are shown in Table 89–8.

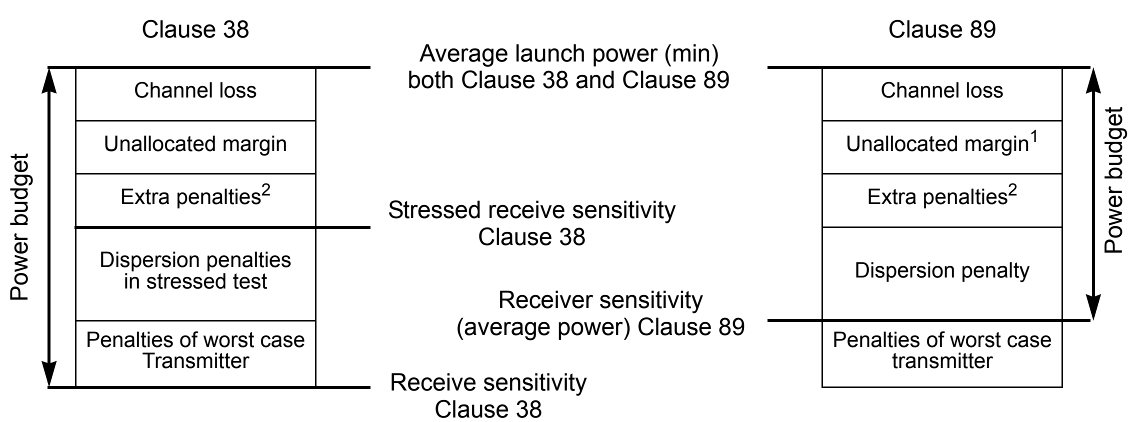
Table 89–8—40GBASE-FR illustrative power budget

Parameter	Value	Unit
Power budget[a]	6	dB
Operating distance	2	km
Channel insertion loss[b]	4	dB
Maximum discrete reflectance	–26	dB
Path penalty[a, c]	2	dB
Additional insertion loss allowed	0	dB

[a]This budget does not include the effect of a non-ideal transmitter waveform. See 89.6.4.
[b]The channel insertion loss is calculated using the maximum distance specified in Table 89–5 and cabled optical fiber attenuation of 0.5 dB/km at 1530 nm plus an allocation for connection and splice loss given in 89.10.2.1.
[c]Path penalty is the combined penalty caused by chromatic dispersion and polarization mode dispersion.

89.6.4 Comparison of power budget methodology

This clause uses the budgeting methodology that is used for application VSR2000-3R2 in ITU-T G.693 [Bx1], which is different from the methodology used in other clauses of this standard (e.g., Clause 38, Clause 52, Clause 86, Clause 87, Clause 88). Figure 89–3 compares the terminology used in this clause with Clause 38. Receiver sensitivity in this clause is specified with a worst-case transmitter input whereas in the other clauses it is specified with a perfect signal without penalties. Stressed receiver sensitivity is not specified in this clause but is specified as the key requirement in the other clauses with a signal that includes both transmitter and link penalties.



NOTE 1—For Clause 89 unallocated margin is zero and not mentioned in the rest of this clause.

NOTE 2—For Clause 38 extra penalties are any penalties that are not included in the stressed test while for Clause 89 extra penalties are any penalties that are not included in the dispersion penalty test.

Figure 89–3—Optical power budget methodology comparison with Clause 38

89.7 Definition of optical parameters and measurement methods

All transmitter optical measurements shall be made through a short patch cable, between 2 m and 5 m in length, unless otherwise specified.

89.7.1 Test patterns for optical parameters

Compliance is to be achieved in normal operation. Table 89–10 gives the test patterns to be used in each measurement, unless otherwise specified, and also lists references to the subclauses in which each parameter is defined. Any of the test patterns given for a particular test in Table 89–10 may be used to perform that test. The test patterns used in this clause are shown in Table 89–9.

Table 89–9—Test patterns

Pattern	Pattern description	Defined in
Square wave	Square wave (8 ones, 8 zeros)	83.5.10
3	PRBS31	83.5.10
4	PRBS9	83.5.10
5	Scrambled idle	82.2.10

Table 89–10—Test-pattern definitions and related subclauses

Parameter	Pattern	Related subclause
Wavelength	3, 5 or valid 40GBASE-R signal	89.7.3
Side mode suppression ratio	3, 5 or valid 40GBASE-R signal	—
Average optical power	3, 5 or valid 40GBASE-R signal	89.7.4
Dispersion penalty	3 or 5	89.7.5
Extinction ratio	3, 5 or valid 40GBASE-R signal	89.7.6
$RIN_{20}OMA$	Square wave or 4	89.7.7
Transmitter optical waveform	3, 5 or valid 40GBASE-R signal	89.7.8
Receiver sensitivity	3 or 5	89.7.9
Receiver jitter tolerance	3 or 5	89.7.10
Receiver 3 dB electrical upper cutoff frequency	3, 5 or valid 40GBASE-R signal	89.7.11

89.7.2 Skew and Skew Variation

Skew and Skew Variation are defined in 80.5 and are required to remain within the limits given in 89.3.2 over the time that the link is in operation. Since the signal for this PMD is a serial bit stream at the PMD service interface and the MDI, there is no Skew Variation at skew points SP2, SP3, SP4, and SP5. The measurement of Skew is made by acquiring the data on the single lane using a clock and data recovery unit with high-frequency corner bandwidth of 16 MHz and a slope of –20 dB/decade. The arrival times of the one to zero transition of the alignment marker sync bits on each PCS lane are then compared. This arrangement ensures that any high-frequency jitter that is present on the signals is not included in the Skew measurement.

89.7.3 Wavelength

The center wavelength shall be within the range given in Table 89–6 if measured per TIA/EIA-455-127-A or IEC 61280-1-3 using the test pattern referenced in Table 89–10.

89.7.4 Average optical power

The average optical power shall be within the limits given in Table 89–6 and Table 89–7 if measured using the methods given in IEC 61280-1-1 using the test pattern referenced in Table 89–10.

89.7.5 Dispersion penalty

The dispersion penalty of a transmitter is defined as the difference in sensitivity (at a BER of 10^{-12}) of a reference receiver as defined in 89.7.5.2 when receiving the signal from that transmitter via the channel defined in 89.7.5.1 compared to the sensitivity obtained when receiving the signal via an attenuator only.

89.7.5.1 Channel requirements

The transmitter is tested using an optical channel that meets the requirements listed in Table 89–11.

Table 89–11—Transmitter compliance channel specifications

PMD type	Dispersion[a] (ps/nm)		Insertion loss[b]	Optical return loss[c]	Max mean DGD
	Minimum	Maximum			
40GBASE-FR	$0.0465 \times \lambda \times [1 - (1324 / \lambda)^4]$	$0.0465 \times \lambda \times [1 - (1300 / \lambda)^4]$	Minimum	20 dB	0.5 ps

[a]The dispersion is measured for the wavelength of the device under test (λ in nm). The coefficient assumes a maximum operating distance of 2 km.
[b]There is no intent to stress the sensitivity of the BERT's optical receiver.
[c]The optical return loss is applied at TP2.

A 40GBASE-FR transmitter is to be compliant with a total dispersion at least as negative as the "minimum dispersion" and at least as positive as the "maximum dispersion" columns specified in Table 89–11 for the wavelength of the device under test. This may be achieved with channels consisting of fibers with lengths chosen to meet the dispersion requirements.

To verify that the fiber has the correct amount of dispersion, the measurement method defined in IEC 60793-1-42 may be used. The measurement is made in the linear power regime of the fiber.

The channel provides an optical return loss specified in Table 89–11. The state of polarization of the back reflection is adjusted to create the greatest RIN.

The mean DGD of the channel is to be less than the value specified in Table 89–11.

89.7.5.2 Reference receiver requirements

The reference receiver is required to have the bandwidth given in 89.7.8. The sensitivity of the reference receiver is limited by Gaussian noise. The receiver has minimal threshold offset, deadband, hysteresis, baseline wander, deterministic jitter, or other distortions. Decision sampling has minimal uncertainty and setup/hold times.

The clock recovery unit (CRU) used in the dispersion penalty measurement has a corner frequency of 16 MHz and a slope of 20 dB/decade. When using a clock recovery unit as a clock for BER measurements, passing of low-frequency jitter from the signal to the clock removes this low-frequency jitter from the measurement.

89.7.5.3 Test procedure

To measure the dispersion penalty, the following procedure shall be used:

a) Configure the test equipment as described above and illustrated in Figure 89–4.
b) With a short patch cable rather than the test fiber and with no reflection, adjust the attenuation of the optical attenuator to obtain a BER of 10^{-12}.
c) Record the optical power at the input to the reference receiver, P_ND, in dBm.
d) With the test fiber and reflection in place, adjust the attenuation of the optical attenuator to obtain a BER of 10^{-12}.
e) Record the optical power at the input to the reference receiver, P_D, in dBm.
f) If P_D is larger than P_ND, the dispersion penalty for the transmitter under test is P_D – P_ND. Otherwise, the dispersion penalty is zero.

It is to be ensured that the measurements are made in the linear power regime of the fiber.

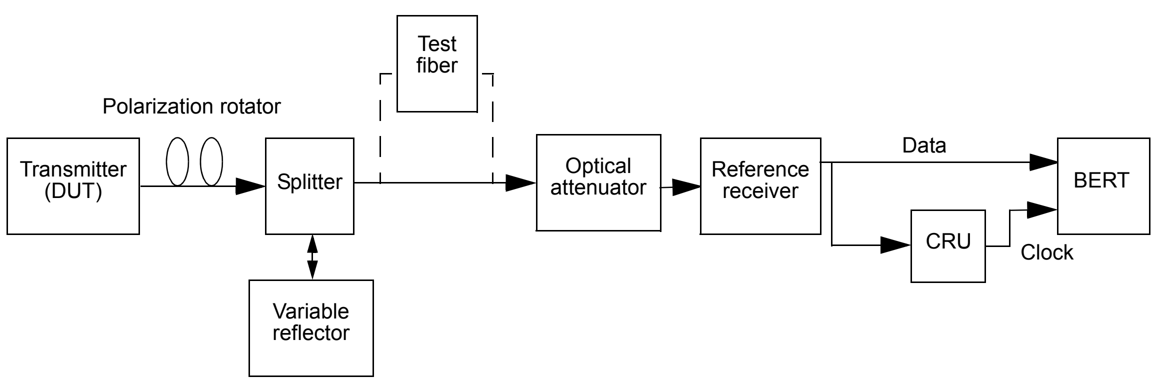


Figure 89–4—Test setup for measurement of dispersion penalty

89.7.6 Extinction ratio

The extinction ratio shall be within the limits given in Table 89–6 if measured using the methods specified in IEC 61280-2-2 using the test pattern referenced in Table 89–10.

NOTE—Extinction ratio and OMA are defined with different test patterns (see Table 89–10).

89.7.7 Relative Intensity Noise ($RIN_{20}OMA$)

The RIN measurement methodology shall be as defined in 52.9.6 with the following exceptions:

a) The optical return loss is 20 dB.
b) The upper –3 dB limit of the measurement apparatus is to be approximately equal to the signaling rate (i.e., 41.25 GHz).

89.7.8 Transmitter optical waveform (transmit eye)

The required optical transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram as shown in Figure 86–4. The transmitter optical waveform of a port transmitting the test pattern specified in Table 89–10 shall meet specifications according to the methods specified in 86.8.4.6.1 with the filter nominal reference frequency f_r of 30.94 GHz and filter tolerances as specified for STM–64 in ITU–T G.691. Compensation may be made for variation of the reference receiver filter response from an ideal fourth-order Bessel-Thomson response.

89.7.9 Receiver sensitivity

Receiver sensitivity is defined as the minimum value of mean received power at TP3 to achieve a BER of 10^{-12}. This shall be met with a transmitter with worst-case transmit eye, extinction ratio, transmitter reflectance, and $RIN_{20}OMA$. The receiver sensitivity does not have to be met in the presence of dispersion, as this effect is specified separately as the dispersion penalty.

Receiver sensitivity is defined with the transmit section in operation. Pattern 3, or Pattern 5, or a valid 40GBASE–R signal is sent from the transmit section of the PMD under test. The signal being transmitted is asynchronous to the received signal.

89.7.10 Receiver jitter tolerance

Receiver jitter tolerance is defined as the largest increase in received optical power required to maintain a BER of 10^{-10} when the sinusoidal jitter defined in Table 89–12 is applied to the signal from a reference transmitter across the defined range of jitter frequencies.

The reference transmitter is a high-quality instrument-grade device, which can be implemented by a CW laser modulated by a high-performance modulator. The following basic requirements apply:

a) Rise/fall times are less than 10 ps at 20% to 80%.
b) The output optical eye is symmetric and passes the transmitter optical waveform test of 89.7.8.
c) In the center 20% region of the eye, the worst-case vertical eye closure penalty as defined in 52.9.9.2 is less than 0.5 dB.
d) Total Jitter is less than 0.2 UI peak-to-peak.

The receiver jitter tolerance shall be within the limits given in Table 89–7 if measured according to the above definition.

NOTE—Receiver jitter tolerance as defined here is made without additional amplitude stress.

89.7.11 Receiver 3 dB electrical upper cutoff frequency

The receiver 3dB electrical upper cutoff frequency shall be within the limits given in Table 89–7 if measured as described in 52.9.11 with the exception that the optical power level used in 52.9.11 b) is approximately equal to the receiver sensitivity level in Table 89–7.

Table 89–12—Applied sinusoidal jitter

Frequency range	Sinusoidal jitter, peak-to-peak (UI)
$f < 480$ kHz	Not specified
480 kHz $< f \leq 16$ MHz	$2.88 \times 10^6 / f$
16 MHz $< f < 10$ *LB*[a]	0.18

[a]*LB* = loop bandwidth; upper frequency bound for added sinusoidal jitter should be at least 10 times the loop bandwidth of the receiver being tested.

89.8 Safety, installation, environment, and labeling

89.8.1 General safety

All equipment subject to this clause shall conform to IEC 60950-1.

89.8.2 Laser safety

40GBASE-FR optical transceivers shall conform to Class 1 laser requirements as defined in IEC 60825-1 and IEC 60825-2, under any condition of operation. This includes single-fault conditions whether coupled into a fiber or out of an open bore.

Conformance to additional laser safety standards may be required for operation within specific geographic regions.

Laser safety standards and regulations require that the manufacturer of a laser product provide information about the product's laser, safety features, labeling, use, maintenance, and service. This documentation explicitly defines requirements and usage restrictions on the host system necessary to meet these safety certifications.[3]

89.8.3 Installation

It is recommended that proper installation practices, as defined by applicable local codes and regulation, be followed in every instance in which such practices are applicable.

89.8.4 Environment

Normative specifications in Clause 89 shall be met by a system integrating a 40GBASE-FR PMD over the life of the product while the product operates within the manufacturer's range of environmental, power, and other specifications.

It is recommended that manufacturers indicate, in the literature associated with the PHY, the operating environmental conditions to facilitate selection, installation, and maintenance.

It is recommended that manufacturers indicate, in the literature associated with the components of the optical link, the distance and operating environmental conditions over which the specifications of Clause 89 will be met.

[3]A host system that fails to meet the manufacturers requirements and/or usage restrictions may emit laser radiation in excess of the safety limits of one or more safety standards. In such a case, the host manufacturer is required to obtain its own laser safety certification.

89.8.4.1 Electromagnetic emission

A system integrating a 40GBASE-FR PMD shall comply with applicable local and national codes for the limitation of electromagnetic interference.

89.8.4.2 Temperature, humidity, and handling

The optical link is expected to operate over a reasonable range of environmental conditions related to temperature, humidity, and physical handling (such as shock and vibration). Specific requirements and values for these parameters are considered to be beyond the scope of this standard.

89.8.5 PMD labeling requirements

It is recommended that each PHY (and supporting documentation) be labeled in a manner visible to the user, with at least the applicable safety warnings and the applicable port type designation (e.g., 40GBASE-FR).

Labeling requirements for Class 1 lasers are given in the laser safety standards referenced in 89.8.2.

89.9 Fiber optic cabling model

The fiber optic cabling model is shown in Figure 89–5.

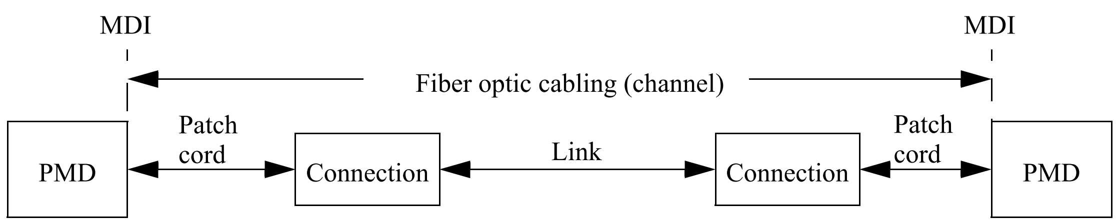


Figure 89–5—Fiber optic cabling model

The channel insertion loss is given in Table 89–13. A channel may contain additional connectors as long as the optical characteristics of the channel, such as attenuation, dispersion, reflections, and polarization mode dispersion, meet the specifications. Insertion loss measurements of installed fiber cables are made in accordance with ANSI/TIA/EIA-526-7 method A–1, chromatic dispersion is measured in accordance with IEC 60793-1-42, and polarization mode dispersion is measured in accordance with IEC 60793-1-48. The fiber optic cabling model (channel) defined here is the same as a simplex fiber optic link segment. The term *channel* is used here for consistency with generic cabling standards.

89.10 Characteristics of the fiber optic cabling (channel)

The 40GBASE-FR fiber optic cabling shall meet the specifications defined in Table 89–13. The fiber optic cabling consists of one or more sections of fiber optic cable and any intermediate connections required to connect sections together.

89.10.1 Optical fiber cable

The fiber optic cable requirements are satisfied by cables containing IEC 60793-2-50 type B1.1 (dispersion un-shifted single-mode), type B1.3 (low water peak single-mode), or type B6_a (bend insensitive) fibers and the requirements in Table 89–14 where they differ.

Table 89–13—Fiber optic cabling (channel) characteristics for 40GBASE-FR

Description	Value	Unit
Operating distance (max)	2	km
Channel insertion loss[a, b](max)	4	dB
Channel insertion loss (min)	0	dB
Dispersion[b] (max)	38	ps/nm
DGD_max[c]	3	ps
Optical return loss (min)	21	dB

[a]These channel insertion loss values include cable, connectors, and splices.
[b]Over the wavelength range 1530 nm to 1565 nm.
[c]Differential Group Delay (DGD) is the time difference at reception between the fractions of a pulse that were transmitted in the two principal states of polarization of an optical signal. DGD_max is the maximum differential group delay that the system must tolerate.

Table 89–14—Optical fiber and cable characteristics for 40GBASE-FR

Description	Value	Unit
Nominal fiber specification wavelength	1550	nm
Cabled optical fiber attenuation (max)	0.5[a]	dB/km
Zero dispersion wavelength (λ_0)	$1300 \leq \lambda_0 \leq 1324$	nm
Dispersion slope (max) (S_0)	0.093	ps/nm^2 km

[a]The 0.5 dB/km attenuation is provided for Outside Plant cable as defined in ANSI/TIA-568-C.3-2008.

89.10.2 Optical fiber connection

An optical fiber connection, as shown in Figure 89–5, consists of a mated pair of optical connectors.

89.10.2.1 Connection insertion loss

The maximum link distances for single-mode fiber are calculated based on an allocation of 3 dB total connection and splice loss. For example, this allocation supports six connections with an average insertion loss per connection of 0.5 dB. Connections with different loss characteristics may be used provided the requirements of Table 89–13 are met.

89.10.2.2 Maximum discrete reflectance

The maximum discrete reflectance shall be less than –26 dB.

89.10.3 Medium Dependent Interface (MDI) requirements

The 40GBASE-FR PMD is coupled to the fiber optic cabling at the MDI. The MDI is the interface between the PMD and the “fiber optic cabling” (as shown in Figure 89–5). Examples of an MDI include the following:

a) Connectorized fiber pigtail
b) PMD receptacle

When the MDI is a connector plug and receptacle connection, it shall meet the interface performance specifications of IEC 61753-1-1 and IEC 61753-021-2.

NOTE—Transmitter compliance testing is performed at TP2 as defined in 89.5.1, not at the MDI.

89.11 Protocol implementation conformance statement (PICS) proforma for Clause 89, Physical Medium Dependent (PMD) sublayer and medium, type 40GBASE-FR[4]

89.11.1 Introduction

The supplier of a protocol implementation that is claimed to conform to Clause 89, Physical Medium Dependent sublayer and medium, type 40GBASE-FR, shall complete the following protocol implementation conformance statement (PICS) proforma.

A detailed description of the symbols used in the PICS proforma, along with instructions for completing the PICS proforma, can be found in Clause 21.

89.11.2 Identification

89.11.2.1 Implementation identification

Supplier[1]	
Contact point for enquiries about the PICS[1]	
Implementation Name(s) and Version(s)[1,3]	
Other information necessary for full identification—e.g., name(s) and version(s) for machines and/or operating systems; System Name(s)[2]	
NOTE 1—Required for all implementations. NOTE 2—May be completed as appropriate in meeting the requirements for the identification. NOTE 3—The terms Name and Version should be interpreted appropriately to correspond with a supplier’s terminology (e.g., Type, Series, Model).	

[4]*Copyright release for PICS proformas:* Users of this standard may freely reproduce the PICS proforma in this subclause so that it can be used for its intended purpose and may further publish the completed PICS.

89.11.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3bg-2011, Clause 89, Physical Medium Dependent sublayer and medium, type 40GBASE-FR
Identification of amendments and corrigenda to this PICS proforma that have been completed as part of this PICS	
Have any Exception items been required? No [ ] Yes [ ] (See Clause 21; the answer Yes means that the implementation does not conform to IEEE Std 802.3bg-2011.)	

Date of Statement	

89.11.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
*INS	Installation / cable	89.9	Items marked with INS include installation practices and cable specifications not applicable to a PHY manufacturer	O	Yes [ ] No [ ]
XLDC	Delay constraints	89.3.1	Device conforms to delay constraints	M	Yes [ ]
XLSC	Skew constraints	89.3.2	Device conforms to Skew and Skew Variation constraints	M	Yes [ ]
*MD	MDIO capability	89.4	Registers and interface supported	O	Yes [ ] No [ ]

89.11.4 PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 40GBASE-FR

89.11.4.1 PMD functional specifications

Item	Feature	Subclause	Value/Comment	Status	Support
XLF1	Compatible with 40GBASE-R PCS and PMA	89.1		M	Yes [ ]
XLF2	Integration with management functions	89.1		O	Yes [ ] No [ ]
XLF3	Transmit function	89.5.2	Conveys bits from PMD service interface to MDI	M	Yes [ ]
XLF4	Mapping between optical signal and logical signal for transmitter	89.5.2	Higher optical power is a one	M	Yes [ ]
XLF5	Receive function	89.5.3	Conveys bits from MDI to PMD service interface	M	Yes [ ]
XLF6	Mapping between optical signal and logical signal for receiver	89.5.3	Higher optical power is a one	M	Yes [ ]
XLF7	Global Signal Detect function	89.5.4	Report to the PMD service interface the message PMD:IS_SIGNAL.indication(SIGNAL_DETECT)	M	Yes [ ]
XLF8	Global Signal Detect behavior	89.5.4	SIGNAL_DETECT is an indicator of the presence of an optical signal	M	Yes [ ]
XLF9	PMD_reset function	89.5.5	Resets the PMD sublayer	MD:O	Yes [ ] No [ ] N/A [ ]

89.11.4.2 Management functions

Item	Feature	Subclause	Value/Comment	Status	Support
XLM1	Management register set	89.4		MD:M	Yes [ ] N/A [ ]
XLM2	Global transmit disable function	89.5.6	Disables the optical transmitter with the PMD_global_transmit_disable variable	MD:O	Yes [ ] No [ ] N/A [ ]
XLM3	PMD_fault function	89.5.7	Sets PMD_fault to one if any local fault is detected	MD:O	Yes [ ] No [ ] N/A [ ]
XLM4	PMD_transmit_fault function	89.5.8	Sets PMD_transmit_fault to one if a local transmitter fault is detected	MD:O	Yes [ ] No [ ] N/A [ ]
XLM5	PMD_receive_fault function	89.5.9	Sets PMD_receive_fault to one if a local receiver fault is detected	MD:O	Yes [ ] No [ ] N/A [ ]

89.11.4.3 PMD to MDI optical specifications for 40GBASE-FR

Item	Feature	Subclause	Value/Comment	Status	Support
XLLR1	Transmitter meets specifications in Table 89–6	89.6.1	Per definitions in 89.7	M	Yes [ ] N/A [ ]
XLLR2	Receiver meets specifications in Table 89–7	89.6.2	Per definitions in 89.7	M	Yes [ ] N/A [ ]

89.11.4.4 Optical measurement methods

Item	Feature	Subclause	Value/Comment	Status	Support
XLOM1	Measurement cable	89.7	2 m to 5 m in length	M	Yes [ ]
XLOM2	Center wavelength	89.7.3	Per TIA-455-127-A or IEC 61280-1-3	M	Yes [ ]
XLOM3	Average optical power	89.7.4	Per IEC 61280-1-1	M	Yes [ ]
XLOM4	Dispersion penalty	89.7.5.3		M	Yes [ ]
XLOM5	Extinction ratio	89.7.6	Per IEC 61280-2-2	M	Yes [ ]
XLOM6	$RIN_{20}OMA$	89.7.7		M	Yes [ ]
XLOM7	Transmit eye	89.7.8		M	Yes [ ]
XLOM8	Receiver sensitivity	89.7.9		M	Yes [ ]
XLOM9	Receiver jitter tolerance	89.7.10		M	Yes [ ]
XLOM10	Receiver 3 dB electrical upper cutoff frequency	89.7.11		M	Yes [ ]

89.11.4.5 Environmental specifications

Item	Feature	Subclause	Value/Comment	Status	Support
XLES1	General safety	89.8.1	Conforms to IEC 60950-1	M	Yes [ ]
XLES2	Laser safety—IEC Class 1	89.8.2	Conforms to Class 1 laser requirements defined in IEC 60825-1 and IEC 60825-2	M	Yes [ ]
XLES3	Electromagnetic interference	89.8.4.1	Complies with applicable codes for the limitation of electromagnetic interference	M	Yes [ ]

89.11.4.6 Characteristics of the fiber optic cabling and MDI

Item	Feature	Subclause	Value/Comment	Status	Support
XLOC1	Fiber optic cabling	89.10	Meets the requirements specified in Table 89–13	INS:M	Yes [ ] N/A [ ]
XLOC2	Maximum discrete reflectance	89.10.2.2	Less than –26 dB	INS:M	Yes [ ] N/A [ ]
XLOC3	MDI requirements	89.10.3	Meets the interface performance specifications listed	INS:M	Yes [ ] N/A [ ]

Annex A

(informative)

Bibliography

Insert the following references in alphabetical order and renumber the list:

[Bx1] ITU-T G.693—Optical interfaces for intra-office systems.