802.3aq™

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 2: Physical Layer and Management Parameters for 10 Gb/s Operation, Type 10GBASE-LRM

IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

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IEEE Std 802.3aq™-2006
(Amendment to
IEEE Std 802.3™-2005)

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Approved 15 September 2006
IEEE-SA Standards Board

Abstract: This amendment to IEEE Std 802.3-2005 specifies a new PMD, 10GBASE-LRM, for serial, 10 Gb/s operation over up to 220 m of 62.5 μm and 50 μm multimode fiber, including installed, FDDI grade multimode fiber.

Keywords: 802.3aq, 10GBASE-LRM, 10 Gigabit Ethernet, multimode fiber, physical medium dependent (PMD) sublayer

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Introduction

This introduction is not part of IEEE Std 802.3aq-2006, IEEE Standard for Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements CSMA/CD Access Method and Physical Layer Specifications, Amendment 2: Physical Layer and Management Parameters for 10 Gb/s Operation, Type 10GBASE-LRM.

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 802.3aq-2006). A historical listing of projects that have added to or modified IEEE Std 802.3 is included in IEEE Std 802.3-2005.

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 protocol 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 IEEE Std 802.3-2005 and are not maintained as separate documents. This amendment adds additional capabilities for 10 Gb/s operation.

At the date of IEEE Std 802.3aq-2006 publication, IEEE Std 802.3 is comprised of the following documents:

Section One—Includes Clause 1 through Clause 20 and Annex A through Annex H and Annex 4a. Section One includes 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. It also includes specification of 802.3 link aggregation.

Section Four—Includes Clause 44 through Clause 54 and Annex 44A through Annex 50A. 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 67 and Annex 58A through Annex 67A. Section Five includes subscriber access physical layers and sublayers for operation from 512 kb/s to 1000 Mb/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.

IEEE Std 802.3-2005/Cor 1-2006

This corrigendum clarifies and corrects isolation text for twisted pair Ethernet physical interfaces, including harmonization for both powered and unpowered Medium Dependent interfaces.

IEEE Std 802.3an™-2006

This amendment includes changes to IEEE Std 802.3-2005 and adds Clause 55 and Annex 55A and Annex 55B. This amendment adds a new Physical Layer for 10 Gb/s operation over balanced twisted-pair structured cabling systems.

IEEE Std 802.3aq-2006

This amendment includes changes to IEEE Std 802.3-2005 and adds Clause 68. This amendment adds a new Physical Layer for 10 Gb/s operation over installed multimode fiber.

IEEE Std 802.3as™-2006

This amendment includes changes to IEEE Std 802.3-2005. It extends the size of the IEEE 802.3 frame format with an envelope frame.

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.

Conformance test methodology

An additional standard, IEEE Std 1802.3™-2001, provides conformance test information for 10BASE-T.

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Errata, if any, for this and all other standards can be accessed at the following URL:
http://standards.ieee.org/reading/ieee/updates/errata/index.html.

Users are encouraged to check this URL for errata periodically.

Downloads

Portions of this standard can be downloaded from the Internet. Material include PICS tables, data tables, and code. URLs are listed in the text in the appropriate sections.

Interpretations

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List of special symbols

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 fail to display correctly, the editors hope that this table will aid in interpreting any funny blobs and strokes appearing in the body of the document.

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
≠	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	Lambda	Symbol
µ	Micro	Times New Roman
Ω	Omega	Symbol

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Amendment 2: Physical Layer and Management Parameters for 10 Gb/s Operation, Type 10GBASE-LRM

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. 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. Editorial notes will not be carried over into future editions because the changes will be incorporated into the base standard.

1. Introduction

1.3 Normative references

Insert the following new entries into the reference list, in alphanumeric order:

IEC 60793-2-10 (2004), Optical fibres—Part 2-10: Product specifications—Sectional specification for category A1 multimode fibres.

IEC 60794-2-11 (2005), Optical fibre cables—Part 2-11: Indoor cables—Detailed specification for simplex and duplex cables for use in premises cabling.

IEC 60794-3-12 (2005), Optical fibre cables—Part 3-12: Outdoor fibre cables—Detailed specification for duct and directly buried optical telecommunication cables for use in premises cabling.

IEC 61280-1-4 (2003), Fibre optic communication subsystem test procedures—Part 1-4: General communication subsystems—Collection and reduction of two-dimensional nearfield data for multimode fibre laser transmitters.

IEC 61280-4-1 (2003), Fiber-optic communication subsystem test procedures—Part 4-1: Cable plant and links—Multimode fibre-optic cable plant attenuation measurement.

ITU-T Recommendation O.153, 1992—Basic parameters for the measurement of error performance at bit rates below the primary rate.

1.4 Definitions

Insert the following new definitions in alphanumerical order:

1.4.x.x 10GBASE-LRM: IEEE 802.3 Physical Layer specification for 10 Gb/s using 10GBASE-R encoding and long wavelength optics for multimode fiber (see IEEE 802.3 Clause 68).

1.4.x.x encircled flux: The optical power within a specified radius of a fiber center, as a percentage of that within 36 µm (for 62.5 µm fiber) or 29 µm (for 50 µm fiber).

1.5 Abbreviations

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

CRU clock recovery unit

TWDP transmitter waveform and dispersion penalty

30. Management

30.5.1.1.2 aMAUType

Insert a new entry into the list, following the 10GBASE-SR entry:

10GBASE-LRM R fiber over 1310 nm optics as specified in Clause 68

44. Introduction to 10 Gb/s baseband network

44.1.1 Scope

Change the first paragraph to include 10GBASE-LRM in list of Physical Layer entities, as follows (IEEE Std 802.3an™-2006):

10 Gigabit Ethernet uses the IEEE 802.3 MAC sublayer, connected through a 10 Gigabit Media Independent Interface (XGMII) to Physical Layer entities such as 10GBASE-SR, 10GBASE-LX4, 10GBASE-CX4, <u>10GBASE-LRM,</u> 10GBASE-LR, 10GBASE-ER, 10GBASE-SW, 10GBASE-LW, 10GBASE-EW, and 10GBASE-T.

44.1.3 Relationship of 10 Gigabit Ethernet to the ISO OSI reference model

Change list item d) to include Clause 68 and 10GBASE-LRM, as follows (IEEE Std 802.3an-2006):

d) The MDI as specified in Clause 53 for 10GBASE-LX4, in Clause 54 for 10GBASE-CX4, in Clause 55 for 10GBASE-T, <u>in Clause 68 for 10GBASE-LRM,</u> and in Clause 52 for other PMD types.

44.1.4.4 Physical Layer signaling systems

Change the third paragraph of this subclause to insert Clause 68 and 10GBASE-LRM into family of 10GBASE-R physical layers, as follows:

The term 10GBASE-R, specified in Clause 49, Clause 51, ~~and~~ Clause 52 <u>and Clause 68</u>, refers to a specific family of physical layer implementations based upon 64B/66B data coding method. The 10GBASE-R family of physical layer implementations is composed of 10GBASE-SR, 10GBASE-LR, ~~and~~ 10GBASE-ER <u>and 10GBASE-LRM</u>.

Change the fifth paragraph of this subclause as follows (IEEE Std 802.3an-2006):

Physical layer device specifications are contained in Clause 52, Clause 53, Clause 54, ~~and~~ Clause 55<u>, and Clause 68.</u>

Change Table 44–1 to include a column for Clause 68 and a row for 10GBASE-LRM, as given below (IEEE Std 802.3an-2006).

Table 44–1—Nomenclature and clause correlation

Nomenclature	Clause										
	48	**49**	**50**	**51**	**52**			**53**	**54**	**55**	**68**
	8B/10B PCS & PMA	**64B/66B PCS**	**WIS**	**Serial PMA**	**850 nm Serial PMD**	**1310 nm Serial PMD**	**1550 nm Serial PMD**	**1310 nm WDM PMD**	**4-Lane electrical PMD**	**Twisted-pair PCS & PMA**	**1310 nm Serial MMF PMD**
10GBASE-SR		M[a]		M	M						
10GBASE-SW		M	M	M	M						
10GBASE-LX4	M							M			
10GBASE-CX4	M								M		
10GBASE-LR		M		M		M					
10GBASE-LW		M	M	M		M					
10GBASE-ER		M		M			M				
10GBASE-EW		M	M	M			M				
10GBASE-T										M	
10GBASE-LRM		M		M							M

[a]M = Mandatory

44.3 Delay constraints

Change Table 44–2 as follows (IEEE Std 802.3an-2006):

Table 44–2—Round-trip delay constraints (informative)

Sublayer	Maximum (bit time)	Maximum (pause_quanta)	Notes
MAC, RS and MAC Control	8192	16	See 46.1.4.
XGXS and XAUI	4096	8	Round-trip of 2 XGXS and trace for both directions. See 47.2.2.
10GBASE-X PCS and PMA	2048	4	See 48.5.
10GBASE-R PCS	3584	7	See 49.2.15.
WIS	14336	28	See 50.3.7.
LX4 PMD	512	1	Includes 2 meters of fiber. See 53.2.
CX4 PMD	512	1	See 54.3
Serial PMA and PMD (except LRM)	512	1	Includes 2 meters of fiber. See 52.2.
LRM PMA and PMD	9216	18	Includes 2 meters of fiber. See 68.2.
10GBASE-T PHY	25 600	50	See 55.11.

44.4 Protocol implementation conformance statement (PICS) proforma

Change the first paragraph to include Clause 68 in the PICS list, as follows (IEEE Std 802.3an-2006):

The supplier of a protocol implementation that is claimed to conform to any part of IEEE Std 802.3, Clause 45 through Clause 55 and Clause 68, demonstrates compliance by completing a protocol implementation conformance statement (PICS) proforma.

44.5 Relation of 10 Gigabit Ethernet to other standards

Change Table 44–6 to include the row for 10GBASE-LRM, as given below (Table 44-4 in IEEE Std 802.3-2005, title changed and renumbered by IEEE Std 802.3an):

Table 44–6—Table F.4 of ISO/IEC 11801: 2002

Network application	Nominal transmission wavelength (nm)	Maximum channel length (m)	
		50 µm fibre	62.5 µm fibre
IEEE 802.3: 10GBASE-SR/SW	850	300	33
IEEE 802.3: 10GBASE-LX4	1300	300	300
IEEE 802.3: 10GBASE-LRM	1300	220	220

45. Management Data Input/Output (MDIO) Interface

45.2.1 PMA/PMD registers

45.2.1.6 PMA/PMD control 2 register (Register 1.7)

Change Table 45–7 to assign code for 10GBASE_LRM, as follows (IEEE Std 802.3an-2006):

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

Bit(s)	Name	Description	R/W[a]
1.7.15:4	Reserved	Value always 0, writes ignored	R/W
1.7.3:0	PMA/PMD type selection	3 2 1 0 1 1 1 1 = 10BASE-T PMA type 1 1 1 0 = 100BASE-TX PMA/PMD type 1 1 0 1 = Reserved 1 1 0 0 = 1000BASE-T PMA type 1 0 1 1 = Reserved 1 0 1 0 = Reserved 1 0 0 1 = 10GBASE-T PMA type 1 0 0 0 = ~~Reserved~~10GBASE-LRM PMA PMD type 0 1 1 1 = 10GBASE-SR PMA/PMD type 0 1 1 0 = 10GBASE-LR PMA/PMD type 0 1 0 1 = 10GBASE-ER PMA/PMD type 0 1 0 0 = 10GBASE-LX4 PMA/PMD type 0 0 1 1 = 10GBASE-SW PMA/PMD type 0 0 1 0 = 10GBASE-LW PMA/PMD type 0 0 0 1 = 10GBASE-EW PMA/PMD type 0 0 0 0 = 10GBASE-CX4 PMA/PMD type	R/W

[a]R/W = Read/Write

45.2.1.6.1 PMA/PMD type selection (1.7.3:0)

Change subclause text as follows (IEEE Std 802.3an-2006):

The PMA/PMD type of the PMA/PMD shall be selected using bits 3 through 0. The PMA/PMD type abilities of the PMA/PMD are advertised in bits 9 and 7 through 0 of the PMA/PMD status 2 register and bits 8 through 0 of the PMA/PMD extended ability register. A PMA/PMD shall ignore writes to the PMA/PMD type selection bits that select PMA/PMD types it has not advertised in the PMA/PMD status 2 register. It is the responsibility of the STA entity to ensure that mutually acceptable MMD types are applied consistently across all the MMDs on a particular PHY.

The PMA/PMD type selection defaults to a supported ability.

45.2.1.7 10G PMA/PMD status 2 register (Register 1.8)

45.2.1.7.4 Transmit fault (1.8.11)

Change the first paragraph to include a reference to Clause 68 for transmit fault, as follows (IEEE Std 802.3an-2006):

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 10GBASE-LRM serial PMDs is given 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 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)

Change the first paragraph to include a reference to Clause 68 for receive fault, as follows (IEEE Std 802.3an-2006):

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 10GBASE-LRM serial PMDs is given 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 receive fault bit shall be implemented with latching high behavior.

45.2.1.8 10G PMD transmit disable register (Register 1.9)

Change the first paragraph to include a reference to Clause 68 for transmit disable, as follows (IEEE Std 802.3an-2006):

The assignment of bits in the 10G PMD transmit disable register is shown in Table 45–10. 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 10G PMD transmit disable register and may return a value of zero for all bits. A PMD device that operates using a single wavelength and has implemented the transmit disable function shall use bit 1.9.0 to control the function. Such devices shall ignore writes to bits 1.9.4:1 and return a value of zero for those bits when they are read. The transmit disable function for 10GBASE-LRM serial PMDs is described in 68.4.7, and for other serial PMDs in 52.4.7. The transmit disable function for wide wavelength division multiplexing (WWDM) PMDs 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 the 10GBASE-T PMA is described in 55.4.2.3.

45.2.1.10 PMA/PMD extended ability register (Register 1.11)

Change Table 45–11 to include an entry for 10GBASE_LRM, and modify the "reserved" row, as follows (IEEE Std 802.3an-2006): .

Table 45–11—PMA/PMD Extended ability register bit definitions

Bit(s)	Name	Description	R/W[a]
1.11.15:9	Reserved	Ignore on read	RO
1.11.8	10BASE-T	1 = PMA/PMD is able to perform 10BASE-T 0 = PMA/PMD is not able to perform 10BASE-T	RO
1.11.7	100BASE-TX	1 = PMA/PMD is able to perform 100BASE-TX 0 = PMA/PMD is not able to perform 100BASE-TX	RO
1.11.6	Reserved	Ignore on read	RO
1.11.5	1000BASE-T	1 = PMA/PMD is able to perform 1000BASE-T 0 = PMA/PMD is not able to perform 1000BASE-T	RO
1.11.4	Reserved	Ignore on read	RO
1.11.3	Reserved	Ignore on read	RO
1.11.2	10GBASE-T ability	1 = PMA/PMD is able to perform 10GBASE-T 0 = PMA/PMD is not able to perform 10GBASE-T	RO
1.11.1	~~Reserved~~ 10GBASE-LRM ability	~~Ignore on read~~ 1 = PMA/PMD is able to perform 10GBASE-LRM 0 = PMA/PMD is not able to perform 10GBASE-LRM	RO
1.11.0	10GBASE-CX4 ability	1 = PMA/PMD is able to perform 10GBASE-CX4 0 = PMA/PMD is not able to perform 10GBASE-CX4	RO

[a]RO = Read Only

Insert new subclause 45.1.10.5 and renumber as required (IEEE Std 802.3an-2006):

45.2.1.10.5 10GBASE-LRM ability (1.11.1)

When read as a one, bit 1.11.1 indicates that the PMA/PMD is able to operate as 10GBASE-LRM. When read as a zero, bit 1.11.1 indicates that the PMA/PMD is not able to operate as 10GBASE-LRM.

45.2.3.11 10GBASE-R and 10GBASE-T PCS status 1 register (Register 3.32)

Change the last sentence of the paragraph to include the PRBS9 test pattern mode (IEEE Std 802.3an-2006):

The assignment of bits in the 10GBASE-R and 10GBASE-T PCS status 1 register is shown in Table 45–78. All the bits in the 10GBASE-R and 10GBASE-T PCS status 1 register are read only; a write to the 10GBASE-R and 10GBASE-T PCS status 1 register shall have no effect. A PCS device that does not implement 10GBASE-R or the 10GBASE-T shall return a zero for all bits in the 10GBASE-R and 10GBASE-T PCS status 1 register. It is the responsibility of the STA management entity to ensure that a port type is supported by all MMDs before interrogating any of its status bits. The contents of register 3.32 are undefined when the 10GBASE-R PCS or the 10GBASE-T PCS is operating in seed test-pattern mode, ~~or~~ PRBS31 test-pattern mode, or PRBS9 test pattern mode.

Change Table 45–78 by adding a row for PRBS9, and modifying the reserved bits description, as follows (IEEE Std 802.3an-2006):

Table 45–78—10GBASE-R and 10GBASE-T PCS status 1 register bit definitions

Bit(s)	Name	Description	R/W[a]
3.32.15:13	Reserved	Value always 0, writes ignored	RO
3.32.12	10GBASE-R and 10GBASE-T receive link status	1 = 10GBASE-R or 10GBASE-T PCS receive link up 0 = 10GBASE-R or 10GBASE-T PCS receive link down	RO
3.32.11:~~3~~4	Reserved	Ignore when read	RO
3.32.3	PRBS9 pattern testing ability	1 = PCS is able to support PRBS9 pattern testing 0 = PCS is not able to support PRBS9 pattern testing	RO
3.32.2	PRBS31 pattern testing ability	1 = PCS is able to support PRBS31 pattern testing 0 = PCS is not able to support PRBS31 pattern testing	RO
3.32.1	10GBASE-R and 10GBASE-T PCS high BER	1 = 10GBASE-R or 10GBASE-T PCS reporting a high BER 0 = 10GBASE-R or 10GBASE-T PCS not reporting a high BER	RO
3.32.0	10GBASE-R and 10GBASE-T PCS block lock	1 = 10GBASE-R or 10GBASE-T PCS locked to received blocks 0 = 10GBASE-R or 10GBASE-T PCS not locked to received blocks	RO

[a]RO = Read Only

Insert new subclause 45.2.3.11.2 on the PRBS9 pattern testing ability, and renumber subclauses 45.2.3.11.2 to 45.2.3.11.4. (These will become 45.2.3.11.3 to 45.2.3.11.5.)

45.2.3.11.2 PRBS9 pattern testing ability (3.32.3)

When read as a one, bit 3.32.3 indicates that the PCS is able to support PRBS9 pattern testing of its transmitter. When read as a zero, bit 3.32.3 indicates that the PCS is not able to support PRBS9 pattern testing of its transmitter. If the PCS is able to support PRBS9 pattern testing of its transmitter then the pattern generation is controlled using bit 3.42.6.

45.2.3.12 10GBASE-R and 10GBASE-T PCS status 2 register (Register 3.33)

Change the last sentence of the paragraph to include the PRBS9 test pattern mode (IEEE Std 802.3an-2006):

The assignment of bits in the 10GBASE-R and 10GBASE-T PCS status 2 register is shown in Table 45–79. All the bits in the 10GBASE-R and 10GBASE-T PCS status 2 register are read only; a write to the 10GBASE-R and 10GBASE-T PCS status 2 register shall have no effect. A PCS device that does not implement 10GBASE-R or 10GBASE-T shall return a zero for all bits in the 10GBASE-R and 10GBASE-T PCS status 2 register. It is the responsibility of the STA management entity to ensure that a port type is supported by all MMDs before interrogating any of its status bits. The contents of register 3.33 are undefined when the 10GBASE-R or the 10GBASE-T PCS is operating in seed test-pattern mode, ~~or~~ PRBS31 test-pattern mode, or PRBS9 test pattern mode.

45.2.3.15 10GBASE-R PCS test-pattern control register (Register 3.42)

Change Table 45–82 by adding row for PRBS9 and modifying the reserved bits description, as follows:

Table 45–82—10GBASE-R PCS test-pattern control register bit definitions

Bit(s)	Name	Description	R/W[a]
3.42.15:~~6~~7	Reserved	Value always 0, writes ignored	R/W
3.42.6	PRBS9 transmit test-pattern enable	1 = Enable PRBS9 test-pattern mode on the transmit path 0 = Disable PRBS9 test-pattern mode on the transmit path	R/W
3.42.5	PRBS31 receive test-pattern enable	1 = Enable PRBS31 test-pattern mode on the receive path 0 = Disable PRBS31 test-pattern mode on the receive path	R/W
3.42.4	PRBS31 transmit test-pattern enable	1 = Enable PRBS31 test-pattern mode on the transmit path 0 = Disable PRBS31 test-pattern mode on the transmit path	R/W
3.42.3	Transmit test-pattern enable	1 = Enable transmit test pattern 0 = Disable transmit test pattern	R/W
3.42.2	Receive test-pattern enable	1 = Enable receive test-pattern testing 0 = Disable receive test-pattern testing	R/W
3.42.1	Test-pattern select	1 = Square wave test pattern 0 = Pseudo random test pattern	R/W
3.42.0	Data pattern select	1 = Zeros data pattern 0 = LF data pattern	R/W

[a]R/W = Read/Write

Insert new subclause 45.2.3.15.1 on the PRBS9 transmit test-pattern enable, and renumber subclauses 45.2.3.15.1 to 45.2.3.15.6. (These will become 45.2.3.15.2 to 45.2.3.15.7.)

45.2.3.15.1 PRBS9 transmit test-pattern enable (3.42.6)

If the PCS supports the optional PRBS9 pattern testing (indicated by bit 3.32.3), the mandatory transmit test-pattern enable bit (3.42.3) is not one, and the optional PRBS31 transmit test-pattern enable bit (3.42.4) is not one, then when bit 3.42.6 is set to one the PCS shall transmit PRBS9. When bit 3.42.6 is set to zero, the PCS shall not generate PRBS9. The PRBS9 test-pattern is specified in 68.6.1. The behavior of the PCS when in PRBS9 test-pattern mode is specified in Clause 49.

45.5.3.6 PCS options

Change the PICS table by inserting new row for PRBS9, as follows:

Item	Feature	Subclause	Value/Comment	Status	Support
*CR	Implementation of 10GBASE-R PCS	45.2.3		PCS:O	Yes [ ] No [ ] N/A [ ]
*CT	Implementation of the 10GBASE-T PCS	45.2.3		PCS:O	Yes [ ] No [ ] N/A [ ]
*CX	Implementation of 10GBASE-X PCS	45.2.3		PCS:O	Yes [ ] No [ ] N/A [ ]
*XP	Implementation of 10GBASE-X pattern testing	45.2.3		PCS* CX:O	Yes [ ] No [ ] N/A [ ]
*PPT	Implementation of PRBS31 pattern testing	45.2.3		PCS:O	Yes [ ] No [ ] N/A [ ]
<u>*PTT</u>	<u>Implementation of PRBS9 pattern testing</u>	<u>45.2.3</u>		<u>PCS:O</u>	<u>Yes [ ]</u> <u>No [ ]</u> <u>N/A [ ]</u>
*EPC	Implementation of the 10BASE-TS/2BASE-TL PCS	45.2.3.17		PCS:O	Yes [ ] No [ ] N/A [ ]
*PAF	Implementation of the PME aggregation function	45.2.3.17		PCS*EPC:O	Yes [ ] No [ ] N/A [ ]

45.5.3.7 PCS management functions

Change the PICS table by inserting two new rows for PRBS9, as follows (only last three rows of table in IEEE Std 802.3-2005 are shown here).

Item	Feature	Subclause	Value/Comment	Status	Support
RM74	Bits held to one upon overflow	45.2.3.27		PCS*PAF:M	Yes [ ] N/A [ ]
RM75	Bits reset to zero when read or upon MMD reset	45.2.3.28		PCS*PAF:M	Yes [ ] N/A [ ]
RM76	Bits held to one upon overflow	45.2.3.28		PCS*PAF:M	Yes [ ] N/A [ ]
RM77	Setting bit 3.42.6 to a one enables PRBS9 transmit pattern testing if bit 3.32.3 is a one and bit 3.42.3 is not a one and bit 3.42.4 is not a one	45.2.3.15.7		PCS* PTT:M	Yes [ ] N/A [ ]
RM78	Setting bit 3.42.6 to a zero disables PRBS9 transmit pattern testing	45.2.3.15.7		PCS* PTT:M	Yes [ ] N/A [ ]

49. Physical Coding Sublayer (PCS) for 64B/66B, type 10GBASE-R

49.1.1 Scope

Change the first paragraph as follows:

This clause specifies the Physical Coding Sublayer (PCS) that is common to a family of 10 Gb/s Physical Layer implementations, known as 10GBASE-R. This PCS can connect directly to one of the 10GBASE-R Physical Layers: 10GBASE-SR, 10GBASE-LR, ~~and~~ 10GBASE-ER, and 10GBASE-LRM. Alternatively, this PCS can connect to a ~~Wan~~ WAN Interface Sublayer (WIS), which will produce the 10GBASE-W encoding (10GBASE-R encoded data stream encapsulated into frames compatible with SONET and SDH networks) for transport by the 10GBASE-W Physical Layers: 10GBASE-SW, 10GBASE-LW, and 10GBASE-EW. The term 10GBASE-R is used when referring generally to physical layers using the PCS defined here.

49.1.2 Objectives

Change item d) of the list of objectives of 10GBASE-R to include Clause 68, as follows:

d) Support cable plants using optical fiber compliant with ISO/IEC 11801: 1995 as specified in Clause 52 and Clause 68.

49.1.4 Summary of 10GBASE-R and 10GBASE-W sublayers

Replace Figure 49-1 with the following:

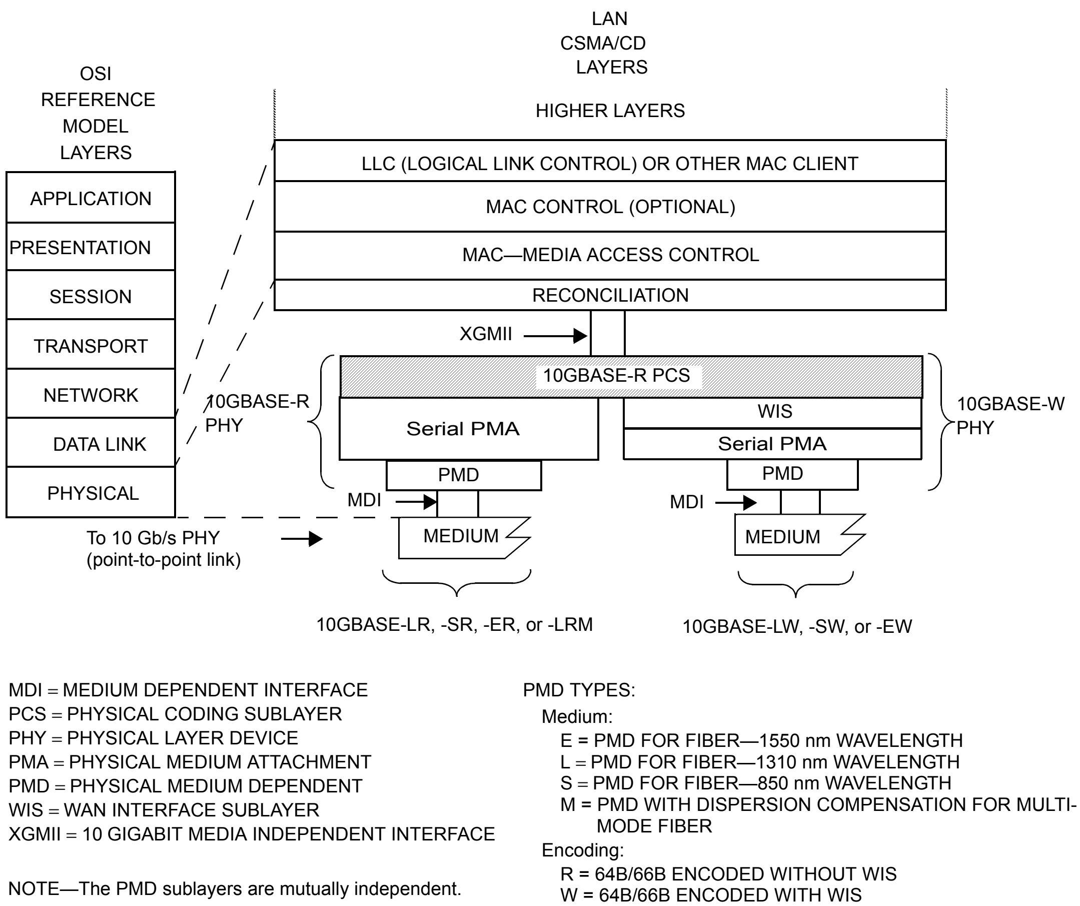

Figure 49–1—10GBASE-R PCS relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model and IEEE 802.3 CSMA/CD LAN model

49.1.4.4 Physical Medium Dependent (PMD) sublayer

***Change the first paragraph to include reference to Clause 68, as follows*:**

The PMD and its media are specified in Clause 52 <u>and Clause 68</u>.

49.2.2 Functions within the PCS

***Change last paragraph to include the support for PRBS9, as follows*:**

A PCS that supports direct connection to a PMA shall provide transmit test-pattern mode for the square wave and pseudo-random patterns, and shall provide receive test-pattern mode for the pseudo-random pattern. <u>The PCS may provide support for the PRBS9 transmit test pattern.</u> It may provide support for the PRBS31 test pattern. Support of the optional PRBS31 test pattern shall include both the transmit and the receive capability for that pattern. Test-pattern mode is activated separately for transmit and receive. A PCS that supports direct connection to a PMA shall support transmit test-pattern mode and receive test-pattern mode operating simultaneously <u>(if applicable)</u> so as to support loopback testing. Test-pattern mode is provided by the WIS when a WIS is present.

49.2.8 Test-pattern generators

Change the second paragraph to include a reference to test patterns specified in Clause 68, and use correct style, as follows:

There are two types of required transmit test patterns: square wave and pseudo-random. The square wave pattern is intended to aid in conducting certain transmitter tests. It is not intended for receiver tests and the receiver is not expected to receive this test pattern. The pseudo-random test-pattern mode is suitable for receiver tests and for certain transmitter tests. There is an optional PRBS9 transmit test pattern that may be used for some transmitter tests. There is also an optional PRBS31 test pattern, which may be used for some transmit and receiver tests. When this option is supported, both the PRBS31 test-pattern generator and the PRBS31 test-pattern checker shall be provided. See ~~Clause~~ 52.9 and 68.6 for recommendations on the appropriate pattern for tests.

Insert a (short) new paragraph at the end of 49.2.8:

The optional PRBS9 pattern is defined in 68.6.1.

49.3.5 Test-pattern modes

Change PICS table by adding two new rows, as follows:

Item	Feature	Subclause	Value/Comment	Status	Support
JT1	Square wave and pseudo-random transmit test-pattern generators are implemented	49.2.8	Performs as in 49.2.8	JTM:M	Yes [ ] No [ ] N/A[ ]
JT2	Pseudo-random receive test-pattern checker is implemented	49.2.12	Performs as in 49.2.12	JTM:M	Yes [ ] No [ ] N/A[ ]
JT3	Transmit and receive test-pattern modes can operate simultaneously	49.2.2		JTM:M	Yes [ ] No [ ] N/A[ ]
JT3	Reject transmit test-pattern mode when WIS is attached	49.2.8		JTM:O	Yes [ ] No [ ] N/A[ ]
JT4	Reject receive test-pattern mode when WIS is attached	49.2.12		JTM:O	Yes [ ] No [ ] N/A[ ]
*JT5	Support for PRBS31 test pattern	49.2.8		JTM:O	Yes [ ] No [ ] N/A[ ]
JT6	PRBS31 test-pattern generator is implemented	49.2.8	Performs as in 49.2.8	JT5:M	Yes [ ] No [ ] N/A[ ]
JT7	PRBS31 test-pattern checker is implemented	49.2.12	Performs as in 49.2.12	JT5:M	Yes [ ] No [ ] N/A[ ]
*JT8	Support for PRBS9 transmit test pattern	49.2.8		JTM:O	Yes [ ] No [ ] N/A[ ]
JT9	PRBS9 transmit test pattern is implemented	49.2.8	Performs as in 49.2.8	JT8:M	Yes [ ] No [ ] N/A[ ]

51. Physical Medium Attachment (PMA) sublayer, type Serial

51.3 Functions within the PMA

Change the NOTE to read as follows:

NOTE—Strict adherence to manufacturer-supplied guidelines for the operation and use of PMA serializer components is required to meet the jitter specifications of the respective PMD clause~~Clause 52~~. The supplied guidelines should address the quality of power supply filtering associated with the transmit clock generator, and also the purity of reference clock fed to the transmit clock generator.

51.3.3 Delay Constraints

Change the last paragraph to read as follows:

Predictable operation of the MAC Control PAUSE operation (Clause 31, Annex 31B) demands that there be an upper bound on the propagation delays through the network. This implies that MAC, MAC Control sublayer, and PHY implementers will conform to certain delay maxima, and that network planners and administrators conform to constraints regarding the cable topology and concatenation of devices. The sum of transmit and receive delay constraints for the serial PMA/PMD sublayer shall meet the requirements as specified in the respective PMD clause ~~be no more than 512 BT~~. The serial PMA/PMD sublayer includes the serial PMA, the serial PMD, and two meters of fiber.

51.10.4.4 PMA delay constraints

Change the Value/Comment table entry as follows:

Item	Feature	Subclause	Value/Comment	Status	Support
PD1	Maximum delay for PMA/ PMD functions	51.3.3	~~transmit and receive including PMD and fiber shall be less than 512 BT (bit times)~~ Meets the requirements of the respective PMD clause.	M	Yes [ ]

Annex A

(informative)

Bibliography

Insert the following informative reference in alphanumerical order as follows:

[B45a] Swenson, N, et al., "Explanation of IEEE 802.3, Clause 68 TWDP", 2005.
URL: http://ieee802.org/3/aq/public/tools/TWDP.pdf

Annex 30B

(normative)

GDMO and ASN.1 definitions for management

30B.2 ASN.1 module for CSMA/CD managed objects

Insert new entry within list headed "TypeValue::= ENUMERATED", following 10GBASE-SR entry:

10GBASE-LRM (494), --R fiber over 1310 nm optics as specified in Clause 68

68. Physical medium dependent (PMD) sublayer type 10GBASE-LRM

68.1 Overview

This clause specifies the 10GBASE-LRM PMD and the associated multimode fiber media. In order to form a complete physical layer, the PMD is combined with the sublayers appropriate for 10GBASE-R, as specified in Table 52–2, and optionally with the management functions that may be accessible through the management interface defined in Clause 45.

Figure 68–1 depicts the relationships of the PMD (shown hatched) with other sublayers and the ISO/IEC Open System Interconnection (OSI) reference model. Clause 44 contains an introduction to 10 Gigabit Ethernet and the relationship of the 10GBASE-LRM PMD to other sublayers. Further relevant information may be found in Clause 1 (i.e., terminology and conventions, references, definitions and abbreviations) and Annex A (i.e., bibliography, entries referenced here in the format [B*n*]).

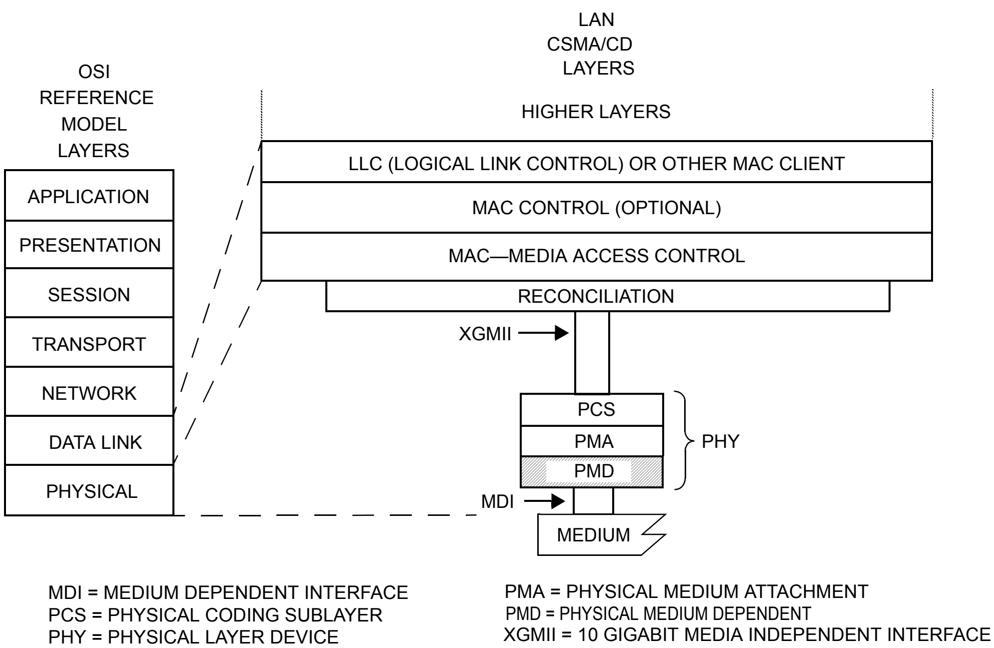

Figure 68–1—10GBASE-LRM PMD relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model and the IEEE 802.3 CSMA/CD LAN model

68.1.1 Physical Medium Dependent (PMD) sublayer service interface

The PMD service interface is the 10GBASE-R PMD service interface as described in 52.1.1.

68.2 Delay constraints

An upper bound to the delay through the PMA and PMD is required for predictable operation of the MAC Control PAUSE operation. The PMA and PMD shall incur a round-trip delay (transmit and receive) of not more than 9216 bit times, or 18 pause_quanta, while including two meters of fiber. A description of overall system delay constraints and the definitions for bit times and pause_quanta can be found in 44.3.

68.3 PMD MDIO function mapping

If present, the 10GBASE-LRM PMD MDIO function mapping shall be as specified in 52.3.

68.4 PMD functional specifications

The 10GBASE-LRM PMD performs the transmit and receive functions that convey data between the PMD service interface and the MDI.

68.4.1 PMD block diagram

For the purposes of system conformance, the PMD sublayer is standardized at test points TP2 and TP3, as shown in Figure 68–2. The optical transmit signal is defined at the output end of a patch cord (TP2), of between 2 m and 5 m in length. The optical launch condition at TP2 is either the preferred launch or the alternative launch (at the user's choice), as specified in 68.5.1. A compliant PMD shall support both options. The launch is selected by using either a single-mode fiber offset-launch mode-conditioning patch cord or a regular multimode fiber patch cord inserted between the MDI and TP2, consistent with the media type. Unless specified otherwise, all transmitter measurements and tests defined in 68.6 are made at TP2. The optical receive signal is defined at the output of the fiber optic cabling (TP3) that is the input to the MDI of the optical receiver. Unless specified otherwise, for all receiver measurements and tests defined in 68.6, the test stimulus is applied at TP3.

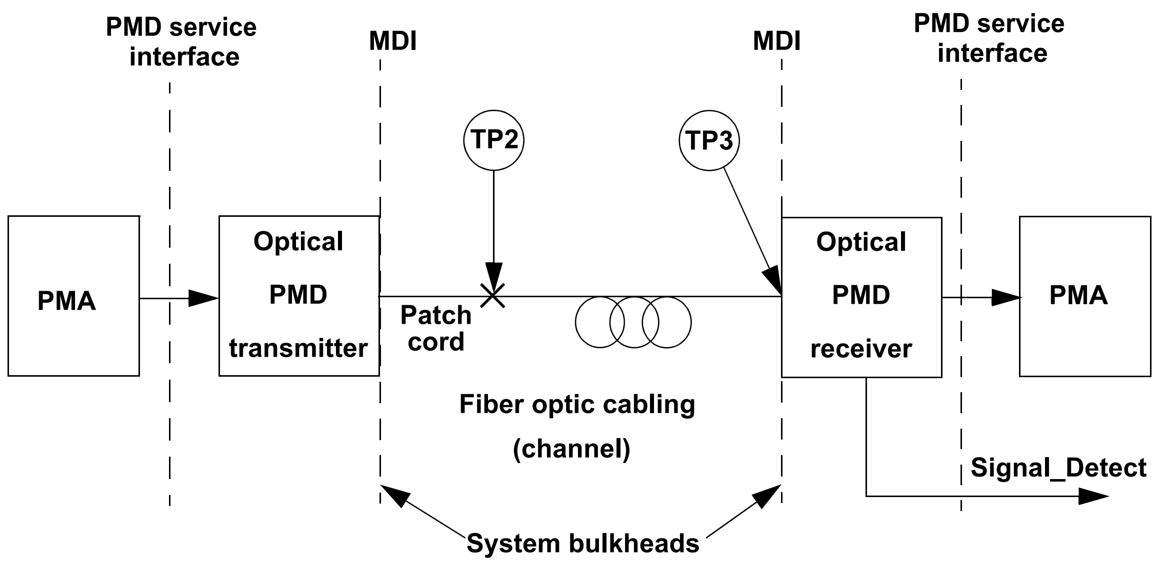

Figure 68–2—Block diagram

68.4.2 PMD transmit function

The PMD transmit function shall convey the bits requested by the PMD service interface message PMD_UNITDATA.request(tx_bit) to the MDI according to the optical specifications in this clause. The higher optical power level shall correspond to tx_bit = ONE.

68.4.3 PMD receive function

The PMD receive function shall convey the bits received from the MDI according to the optical specifications in this clause to the PMD service interface using the message PMD_UNITDATA.indication(rx_bit). The higher optical power level shall correspond to rx_bit = ONE.

68.4.4 PMD signal detect function

The PMD signal detect function shall report to the PMD service interface using the message PMD_SIGNAL.indication(SIGNAL_DETECT), which is signaled continuously. PMD_SIGNAL.indication is intended to be an indicator of optical signal presence. If the MDIO interface is implemented, then PMD_global_signal_detect (1.10.0) shall be continuously set to the value of SIGNAL_DETECT as described in 45.2.1.9.5.

The value of the SIGNAL_DETECT parameter shall be generated according to the conditions defined in Table 68–1. The PMD receiver is not required to verify whether a compliant 10GBASE-R signal is being received. This standard imposes no response time requirements on the generation of the SIGNAL_DETECT parameter.

Table 68–1—SIGNAL_DETECT value definition

Receive conditions	SIGNAL_DETECT value
Input average power < –30 dBm	FAIL
Compliant 10GBASE-R input signal with optical power in OMA > stressed sensitivity in OMA in Table 68–5	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 optical power level at which the SIGNAL_DETECT parameter is set to OK, and the inherent noise level of the PMD due to crosstalk, power supply noise, etc.

Various implementations of the signal detect function are permitted, including implementations that generate the SIGNAL_DETECT parameter values in response to the amplitude of the modulation of the received optical signal and implementations that respond to the average power of the received optical signal.

68.4.5 PMD_reset function

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

68.4.6 PMD_fault function

If the MDIO is implemented, PMD_fault is the logical OR of PMD_receive_fault, PMD_transmit_fault, and any other implementation-specific fault.

68.4.7 PMD_global_transmit_disable function

The PMD_global_transmit_disable function is optional. When asserted, this function shall turn off the optical transmitter so that it meets the requirements of the average launch power of OFF transmitter in Table 68–3.

If a PMD_transmit_fault (optional) is detected, then the PMD_global_transmit_disable function should also be asserted.

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.

68.4.8 PMD_transmit_fault function

The PMD_transmit_fault function is optional. The faults detected by this function are implementation specific, but should not include the assertion of the PMD_global_transmit_disable function.

If a PMD_transmit_fault (optional) is detected, then the PMD_global_transmit_disable function should also be asserted.

If the MDIO interface is implemented, then this function shall be mapped to the PMD_transmit_fault bit as specified in 45.2.1.7.4.

68.4.9 PMD_receive_fault function

The PMD_receive_fault function is optional. PMD_receive_fault is the logical OR of NOT SIGNAL_DETECT and any implementation-specific fault.

If the MDIO interface is implemented, then this function shall contribute to the PMA/PMD receive fault bit as specified in 45.2.1.7.5.

68.5 PMD to MDI optical specifications

The operating ranges for 10GBASE-LRM are given in Table 68–2. A PMD that exceeds the operational range requirements given in this clause, while meeting all other specifications, is considered compliant.

Table 68–2—10GBASE-LRM fiber types and operating ranges

Multimode fiber type[a]	ISO/IEC 11801: 2002 fiber type	Operating range (m)	Maximum channel insertion loss (dB)[b]
62.5 µm 160/500[c]		0.5 to 220	1.9
62.5 µm 200/500	OM1	0.5 to 220	1.9
50 µm 500/500	OM2	0.5 to 220	1.9
50 µm 400/400		0.5 to 100	1.7
50 µm 1500/500[d]	OM3	0.5 to 220	1.9

[a]Each fiber type is identified by its core diameter followed by a pair of OFL bandwidth values separated by "/". The OFL bandwidths are in MHz · km and are for 850 nm and 1300 nm respectively.
[b]Channel insertion loss includes cable attenuation and an allocation of 1.5 dB for connectors.
[c]160/500, 62.5 µm fiber is commonly referred to as "FDDI-grade" fiber.
[d]The OM3 fiber specification includes the 850 nm laser launch bandwidth in addition to the OFL bandwidths.

68.5.1 Transmitter optical specifications

The 10GBASE-LRM transmitter shall meet the specifications given in Table 68–3 and Figure 68–3, per definitions in 68.6.

Table 68–3—10GBASE-LRM transmit characteristics

Description	Type	Value	Unit
Signaling speed	nom	10.3125	GBd
Signaling speed variation from nominal	max	± 100	ppm
Center wavelength	range	1260 to 1355	nm
RMS spectral width[a] at 1260 nm RMS spectral width between 1260 nm and 1300 nm RMS spectral width between 1300 nm and 1355 nm	max max max	2.4 Figure 68–3 4	nm nm nm
Launch power in OMA[b]	max	1.5	dBm
Launch power in OMA[b]	min	–4.5	dBm
Average launch power[b]	max	0.5	dBm
Average launch power[b]	min	–6.5	dBm
Average launch power[b] of OFF transmitter	max	–30	dBm
Extinction ratio	min	3.5	dB
Peak launch power[bc]	max	3	dBm
$RIN_{20}OMA$	max	–128	dB/Hz
Eye mask parameters {X1, X2, X3, Y1, Y2, Y3}		{0.25, 0.40, 0.45, 0.25, 0.28, 0.80}	
Transmitter waveform and dispersion penalty (TWDP)	max	4.7	dB
Uncorrelated jitter (rms)	max	0.033	UI
Optical launch for OM1 and 160/500, 62.5 m fiber Preferred[d] Encircled flux[e] for alternative launch	 — min min	 62.5 µm mode-conditioning patch cord, as specified in 68.9.3 30% within 5 µm radius 81% within 11 µm radius	
Optical launch for OM2, and 400/400, 50 µm fiber Preferred[d] Encircled flux[e] for alternative launch	 — min min	 50 µm mode-conditioning patch cord, as specified in 68.9.3 30% within 5 µm radius 81% within 11 µm radius	
Optical launch for OM3, 50 µm, fiber Encircled flux[e]	 min min	 30% within 5 µm radius 81% within 11 µm radius	
Optical return loss tolerance	min	20	dB

[a]RMS spectral width is the standard deviation of the spectrum.
[b]The OMA, average launch power and peak launch power specifications apply at TP2. This is after each type of patch cord. For information: Patch cord losses, between MDI and TP2, differ. The range of losses must be accounted for to ensure compliance to TP2.

[c]Peak optical power can be determined as the maximum value from the waveform capture for the TWDP test, or equivalent method.
[d]The PMD must support both the preferred and alternative launch types by the use of a single-mode fiber offset-launch mode-conditioning patch cord, or a regular multimode fiber patch cord, between the MDI and TP2.
[e]This encircled flux specification, measured per IEC 61280-1-4, defines the near field light distribution at TP2 when the MDI is coupled directly into a 50 µm patch cord and when the MDI is coupled directly into a 62.5 µm patch cord.

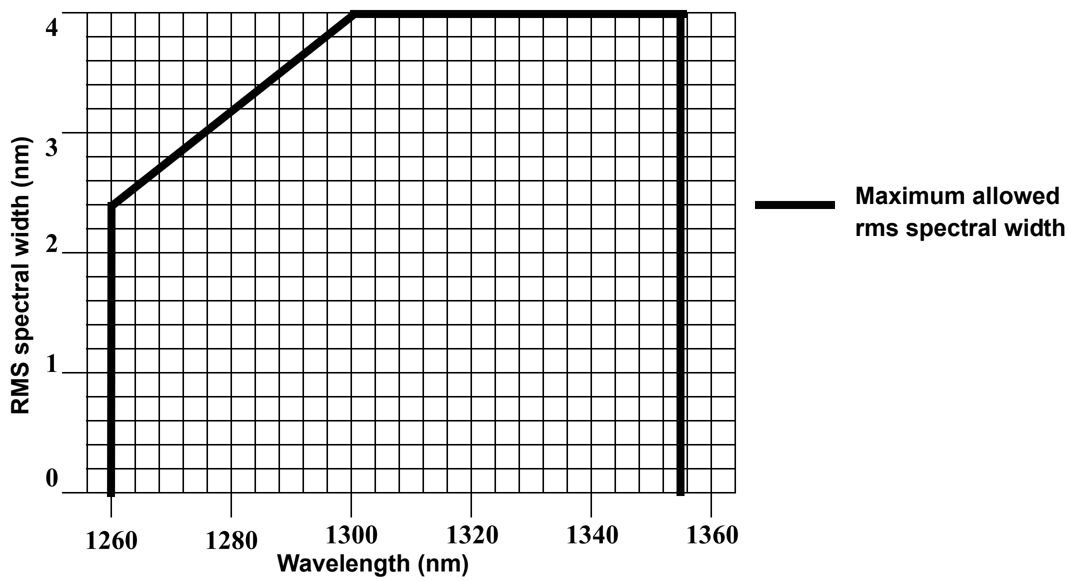

Figure 68–3—10GBASE-LRM Transmitter spectral limits

68.5.2 Characteristics of signal within, and at the receiving end of, a compliant 10GBASE-LRM channel (informative)

Table 68–4 gives the characteristics of a signal within, and at the receiving end of, a compliant 10GBASE-LRM channel. A signal with power in OMA and average power not within the ranges given cannot be compliant. However, a signal with power values within the ranges is not necessarily compliant.

Table 68–4—Characteristics of signal within, and at the receiving end of, a compliant 10GBASE-LRM channel (informative)

Description	Type	Value	Unit
Highest power in OMA	max	1.5	dBm
Lowest power in OMA	min	–6.4	dBm
Highest average power	max	0.5	dBm
Lowest average power	min	–8.4	dBm
Peak power	max	3	dBm

68.5.3 Receiver optical specifications

The 10GBASE-LRM receiver shall meet the specifications given in Table 68–5, per definitions in 68.6.

Table 68–5—10GBASE-LRM receive characteristics

Description		Type	Value	Unit
Signaling speed		nom	10.3125	GBd
Signaling speed variation from nominal		max	±100	ppm
Center wavelength		range	1260 to 1355	nm
Stressed sensitivity in OMA		—	–6.5	dBm
Stressed sensitivity in OMA for symmetrical test		—	–6	dBm
Overload in OMA		—	1.5	dBm
Conditions of comprehensive stressed receiver tests:				
	Bandwidth of Gaussian white noise source[a]	min	10	GHz
	Test transmitter signal to noise ratio, Q_{sq}[b]	—	26.3	
	Tap spacing, Δt, of ISI generator	—	0.75	UI
	Pre-cursor tap weights {A1, A2, A3, A4}	—	{0.158, 0.176, 0.499, 0.167}	
	Symmetrical tap weights {A1, A2, A3, A4}	—	{0.00, 0.513, 0.00, 0.487}	
	Post-cursor tap weights {A1, A2, A3, A4}	—	{0.254, 0.453, 0.155, 0.138}	
Conditions of simple stressed receiver test:				
	Signal rise and fall times (20% to 80%)	—	115	ps
Conditions of receiver jitter tolerance test:				
	Jitter frequency and peak to peak amplitude	—	(75, 5)	(kHz, UI)
	Jitter frequency and peak to peak amplitude	—	(375, 1)	(kHz, UI)
Received average power for damage[c]		—	1.5	dBm
Receiver reflectance		max	–12	dB

[a]Bandwidth of Gaussian white noise source refers to the –3 dB (electrical) frequency of the noise spectrum before any subsequent filtering.
[b]Transmitter signal to noise ratio, Q_{sq}, is defined in 68.6.7 and its use here is qualified by 68.6.9.3.
[c]The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having this average received power level.

68.5.3.1 Dynamic response

Channel responses are expected to vary with time at rates of up to 10 Hz. It is highly recommended that receivers tolerate such time varying channel responses.

68.6 Definitions of optical parameters and measurement methods

The following definitions and measurement methods apply to the transmitter and receiver optical parameters given in Table 68–3 and Table 68–5.

68.6.1 Test patterns and related subclauses for optical parameters

Compliance is to be achieved in normal operation. Table 68–6 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. The test patterns include pattern 1, pattern 2, pattern 3, and square waves, defined in 52.9.1.1 and 52.9.1.2, as well as the PRBS9 pattern.

NOTE—The longer test patterns are designed to emulate system operation; however, they do not form valid 10GBASE-R frames.

Table 68–6—Test-pattern definitions and related subclauses

Test	Pattern	Related subclause
Transmitter OMA (modulated optical power)	Square	68.6.2
Calibration of OMA for receiver tests	Square, eight ONEs and eight ZEROs	68.6.9 and 68.6.10
Calibration of noise for receiver tests	Square, eight ONEs and eight ZEROs	68.6.9
Transmitter noise	Square	68.6.7
Transmitter uncorrelated jitter	1, 2, or PRBS9[a]	68.6.8
Extinction ratio	1 or 3	68.6.3
Average optical power	1 or 3	52.9.3
Transmitted waveform (eye mask)	1 or 3	68.6.5
Transmitter waveform and dispersion penalty (TWDP) Pattern 1 subsequence Pattern 1 subsequence key	1 or PRBS9[a] 348 bits, beginning at bit 3258 101010111011011, beginning immediately before the sub-sequence at bit 3243	68.6.6
Encircled flux	Not specified here	See IEC 61280-1-4
Wavelength, spectral width	1 or 3	52.9.2
Receiver jitter tolerance	1 or 3	68.6.11
Comprehensive stressed receiver sensitivity	2 or 3	68.6.9
Comprehensive stressed receiver overload	1 or 3	68.6.9

Table 68–6—Test-pattern definitions and related subclauses *(continued)*

Test	Pattern	Related subclause
Simple stressed receiver sensitivity	1 or 3	68.6.10
Simple stressed receiver overload	1 or 3	68.6.10

[a]The PRBS9 pattern is optional. If used, it is generated by the polynomial $x^9 + x^5 + 1$ as specified in ITU-T O.153. The binary (0,1) data sequence $d(n)$ is given by $d(n) = d(n - 9) + d(n - 5)$, modulo 2. The pattern has a run of nine ones in its length of 511 bits.

68.6.2 Optical modulation amplitude (OMA)

For the purposes of Clause 68, OMA is defined by the measurement method given in 52.9.5, and as illustrated in Figure 68–4. The mean logic ONE and mean logic ZERO values are measured over the center 20% of the two time intervals of the square wave. The OMA is the difference between these two means.

NOTE—An estimate of the OMA value is provided by the variable MeasuredOMA in 68.6.6.2.

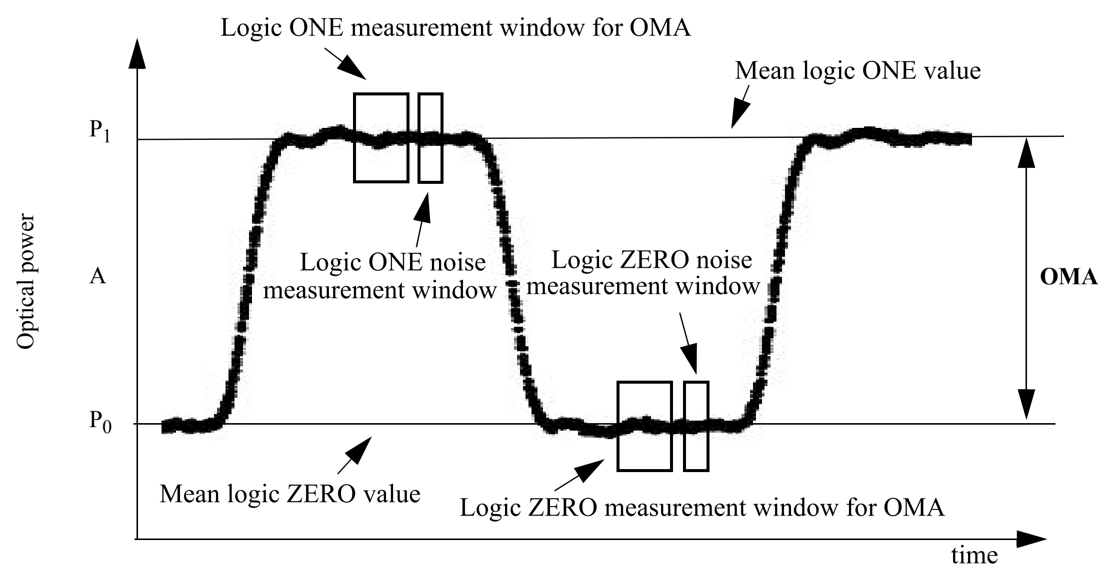

Figure 68–4—Positions of logic ZERO and logic ONE measurement windows for OMA and transmitter noise measurements

68.6.3 Extinction ratio measurement

The extinction ratio shall meet specifications according to 52.9.4.

NOTE—Extinction ratio and OMA are defined with different test patterns (see Table 68–6).

68.6.4 Relationship between OMA, extinction ratio and average power (informative)

The relationship between OMA, extinction ratio and average power is described in 58.7.6. Note that the difference between Clause 68 and Clause 58 measurement methods for OMA causes the equations in 58.7.6 to become approximations for transmitter signals with undershoot, overshoot, or intersymbol interference. It is recommended that these equations not be used for signals at TP3. Figure 68–5 illustrates the approximate region of transmitter compliance and also the approximate relationships between OMA, extinction ratio, and average power.

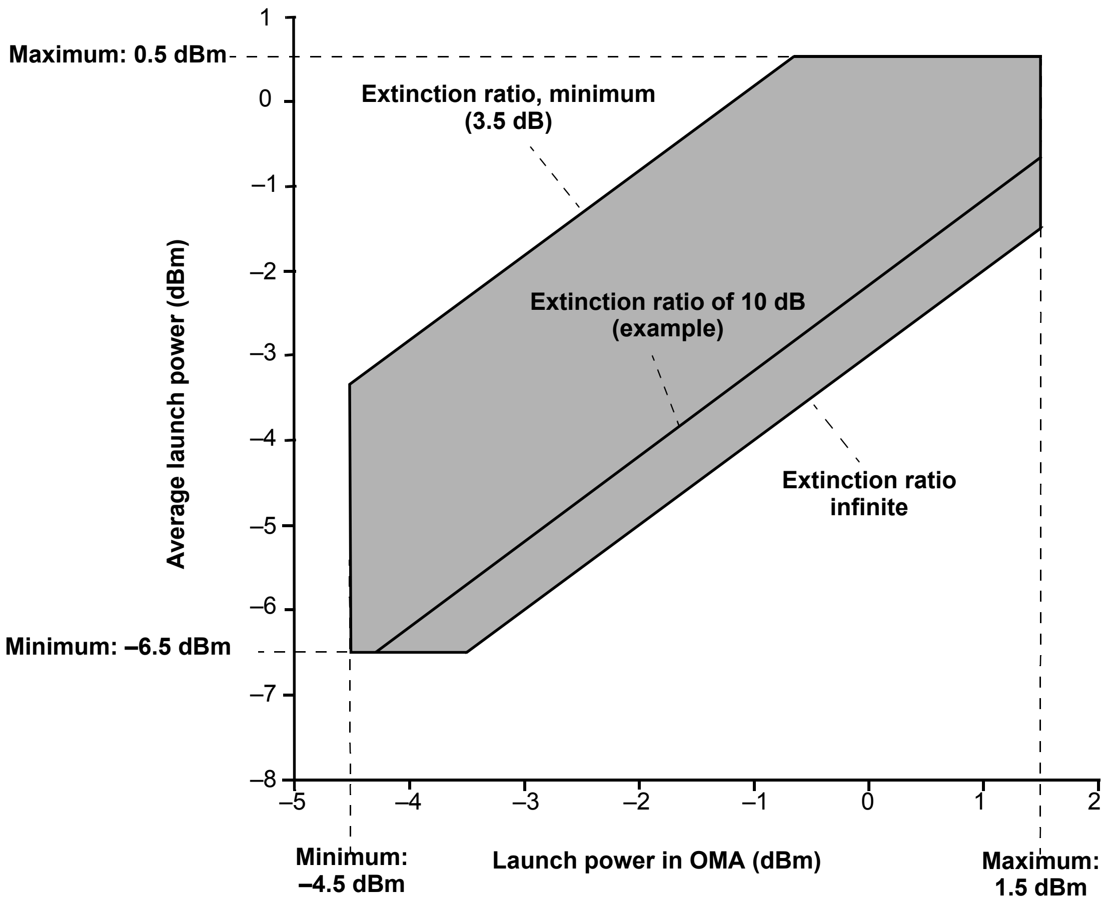

Figure 68–5—Graphical representation of approximate region of transmitter compliance (shown shaded) (informative)

68.6.5 Transmitter optical waveform—transmitter eye mask

The required transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram as shown in Figure 68–6. Compliance is to be assured with pattern 1 or 3 defined in 52.9.1. Measurements during system operation or with other patterns, such as a 2^{23}– 1 PRBS or a valid 10GBASE-R signal, are likely to give very similar results. The transmitter optical waveform of a port transmitting the test pattern specified in Table 68–6 shall meet specifications according to the methods specified below.

Normalized amplitudes of 0 and 1 represent the amplitudes of logic ZERO and ONE respectively. These are defined by the means of the lower and upper halves of the central 0.2 UI of the eye. Normalized times of 0 and 1 on the unit interval scale are determined by the eye crossing means measured at the average value of the optical eye pattern. A clock recovery unit (CRU) should be used to trigger the oscilloscope for mask measurements, as shown in Figure 52-9. It should have a high frequency corner bandwidth of 4 MHz and a slope of –20 dB/decade. The CRU tracks acceptable levels of low-frequency jitter and wander.

The eye is measured with respect to the mask using a receiver with the fourth-order Bessel-Thomson response with nominal f_r of 7.5 GHz as specified for STM-64 in ITU-T G.691, with the tolerances there specified. The Bessel-Thomson receiver is not intended to represent the noise filter used within a compliant optical receiver, but is intended to provide uniform measurement conditions at the transmitter. The nominal transfer function is given in Equation (52–2) and Equation (52–3).

The transmitter shall achieve a hit ratio lower than 5×10^{-5} hits per sample, where "hits" are the number of samples within the grey areas of Figure 68–6, and the sample count is the total number of samples from 0 UI to 1 UI. Some illustrative examples are provided in 68.6.5.1.

Further information on optical eye pattern measurement procedures may be found in IEC 61280-2-2.

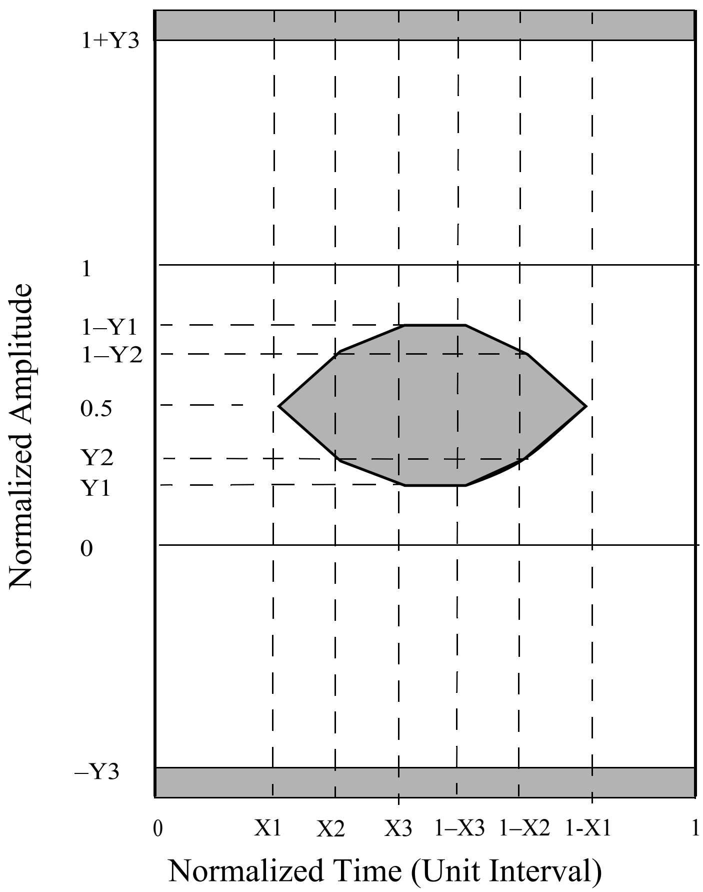

Figure 68–6—Transmitter eye mask definition

68.6.5.1 Transmitter eye mask acceptable hit count examples (informative)

If an oscilloscope records 1350 samples/screen, and the time-base is set to 0.2 UI per division with 10 divisions across the screen, and the measurement is continued for 200 waveforms, then a transmitter with an expectation of less than 6.75 hits is compliant. i.e.,

$$\frac{5 \times 10^{-5} \times 200 \times 1350}{0.2 \times 10} = 6.75 \tag{68–1}$$

Likewise, if a measurement is continued for 1000 waveforms, then an expectation of less than 33.75 hits is compliant. An extended measurement is expected to give a more accurate result, and a single reading of 6 hits in 200 waveforms would not give a statistically significant pass or fail. Measurements to "zero hits", which involve finding the position of the worst single sample in the measurement, have degraded reproducibility because random processes cause the position of such a single low-probability event to vary.

The hit ratio limit has been chosen to avoid misleading results due to transmitter and oscilloscope noise.

68.6.6 Transmitter waveform and dispersion penalty (TWDP)

The transmitter waveform shall meet the transmitter waveform and dispersion penalty (TWDP) specification given in Table 68–3.

TWDP is a measure of the deterministic dispersion penalty due to a particular transmitter with reference emulated multimode fibers and receiver. Figure 68–7 shows the TWDP measurement configuration. A waveform from TP2 of the system under test is captured for analysis using an oscilloscope having a fourth-order, 7.5 GHz Bessel-Thomson response.

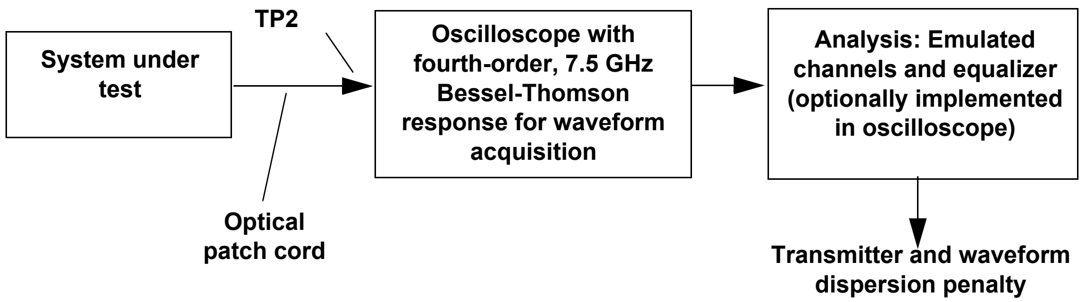

Figure 68–7—Transmitter waveform and dispersion penalty measurement configuration

68.6.6.1 TWDP measurement procedure

The system under test repetitively transmits a test pattern, as specified in Table 68–6. The waveform is captured using averaging to avoid a pessimistic estimate of TWDP. An effective sample rate of at least seven samples per unit interval is required. If test pattern 1 is transmitted, then the specified sub-pattern is to be captured. If PRBS9 is used, then the entire pattern is to be captured.

NOTE—The algorithm assumes 16 samples per unit interval. Interpolation is required for a waveform not captured with 16 samples per unit interval. Use of the sin(x)/x method or the cubic spline method is recommended. Linear interpolation is not recommended.

The captured waveform is analyzed using the algorithm given below, or equivalent. This algorithm analyses the waveform in combination with each of three emulated channels, equivalent to those given in Table 68–5 for the comprehensive stressed receiver specifications, and with an emulated reference receiver equalizer. A penalty is computed for each of the three emulated channels and the TWDP value is the largest of the three penalty results.

The reference equalizer is a decision feedback equalizer with defined tap number and spacing, as specified in 68.6.6.2. This is not intended to represent the equalizer used within an optical receiver, but is intended to provide uniform measurement conditions at the transmitter.

See Swenson, et al. [B45a] for a detailed explanation of the TWDP algorithm.

68.6.6.2 TWDP signal processing algorithm[1, 2]

```
%%%%%%% MATLAB (R) script to compute TWDP %%%%%%%%%%%%%%%%%%%%%%

%% TP2 test inputs
%% The values given below for TxDataFile and MeasuredWaveformFile are examples and should be
%% replaced by actual path\filenames for each waveform tested.
%% Transmit data file: The transmit data sequence is one of the TWDP test patterns defined in
%% Table 68–6. The file format is ASCII with a single column of chronological ones and zeros
%% with no headers or footers.
TxDataFile = 'prbs9_950.txt';
%% Measured waveform: The waveform consists of exactly N samples per unit interval T, where N is the
%% oversampling rate. The waveform must be circularly shifted to align with the data sequence. The file
%% format for the measured waveform is ASCII with a single column of chronological numerical samples,
%% in optical power, with no headers or footers.
MeasuredWaveformFile = 'preproc-1207-01.txt';
OverSampleRate = 16; % Oversampling rate, must be even
%% Simulated fiber responses, modeled as a set of ideal delta functions with specified amplitudes in optical
%% power and delays in nanoseconds, in rows. The three cases specified in Table 68–5 for the
%% comprehensive stressed receiver tests are used. The vector 'PCoefs' contains the amplitudes, and the
%% vector 'Delays' contains the delays.
FiberResp = [...
   0.000000 0.072727 0.145455 0.218182
   0.158 0.176 0.499 0.167
   0.000 0.513 0.000 0.487
   0.254 0.453 0.155 0.138];
Delays = FiberResp(1,:)';

%% Program constants %%
SymbolPeriod = 1/10.3125; % Symbol period (ns)
EqNf = 14; EqNb = 5; % 14 T/2-spaced feedforward equalizer taps; 5 T-spaced feedback equalizer taps
%% Set search range for equalizer delay, specified in symbol periods. Lower end of range is minimum
%% channel delay. Upper end of range is the sum of the lengths of the FFE and channel. Round up and add
%% 5 to account for the antialiasing filter.
EqDelMin = floor(min(Delays)/SymbolPeriod);
EqDelMax = ceil(EqNf/2 + max(Delays)/SymbolPeriod)+5;
EqDelVec = [EqDelMin:EqDelMax];
PAlloc = 6.5; % Total allocated dispersion penalty (dBo)
Q0 = 7.03; % BER = 10^(-12)
N0 = SymbolPeriod/2 / (Q0 * 10^(PAlloc/10))^2;

%% Load input waveform and data sequence, generate filter and other matrices
yout0 = load(MeasuredWaveformFile);
XmitData = load(TxDataFile);
PtrnLength = length(XmitData);
TotLen = PtrnLength*OverSampleRate;
Fgrid = [-TotLen/2:TotLen/2-1].'/(PtrnLength*SymbolPeriod);
%% Compute frequency response of 7.5 GHz 4th order Butterworth antialiasing filter
a = [1 123.1407 7581.811 273453.7 4931335]; % Denominator polynomial for frequency response
b = 4931335; % Numerator for frequency response
ExpArg = -j*2*pi*Fgrid;
```

[1]*Copyright release for MATLAB code:* Users of this standard may freely copy or reproduce the MATLAB code in this subclause so it can be used for its intended purpose. Users should be aware, however, that this copyright release does not cover any patent rights that a third party may have in the MATLAB code.

[2]The script and associated files are available at http://standards.ieee.org/downloads/802/802.3aq-2006/

```
H_r = b./polyval(a,-ExpArg); % Frequency response of Butterworth antialiasing filter

ONE=ones(PtrnLength,1);

%% Normalize the received OMA to 1. Estimate the OMA of the captured waveform by using a linear fit to
%% estimate a pulse response, synthesize a square wave, and calculate the OMA of the synthesized square
%% wave per 52.9.5
ant=4; mem=40; % Anticipation and memory parameters for linear fit
X=zeros(ant+mem+1,PtrnLength); % Size data matrix for linear fit
Y=zeros(OverSampleRate,PtrnLength); % Size observation matrix for linear fit
for ind=1:ant+mem+1
   X(ind,:)=circshift(XmitData,ind-ant-1)'; % Wrap appropriately for lin fit
end
X=[X;ones(1,PtrnLength)]; % The all-ones row is included to compute the bias
for ind=1:OverSampleRate
   Y(ind,:)=yout0([0:PtrnLength-1]*OverSampleRate+ind)'; % Each column is one bit period
end
Qmat=Y*X'*(X*X')^(-1); % Coefficient matrix resulting from linear fit. Each column (except
%% the last) is one bit period of the pulse response. The last column is the bias.
SqWvPer=16; % Even number; sets the period of the square wave used to compute the OMA
SqWv=[zeros(SqWvPer/2,1);ones(SqWvPer/2,1)]; % One period of square wave (column)
X=zeros(ant+mem+1,SqWvPer); % Size data matrix for synthesis
for ind=1:ant+mem+1
   X(ind,:)=circshift(SqWv,ind-ant-1)'; % Wrap appropriately for synthesis
end
X=[X;ones(1,SqWvPer)]; % Include the bias
Y=Qmat*X;Y=Y(:); % Synthesize the modulated square wave, put into one column
avgpos=[0.4*SqWvPer/2*OverSampleRate:0.6*SqWvPer/2*OverSampleRate]; % samples to average over
ZeroLevel=mean(Y(round(avgpos),:)); % Average over middle 20% of "zero" run
% Average over middle 20% of "one" run, compute OMA
MeasuredOMA=mean(Y(round(SqWvPer/2*OverSampleRate+avgpos),:))-ZeroLevel;
%% Subtract zero level and normalize OMA
yout0 = (yout0-ZeroLevel)/MeasuredOMA;

%% Compute the noise autocorrelation sequence at the output of the front-end antialiasing filter and
%% rate-2/T sampler.
Snn = N0/2 * fftshift(abs(H_r).^2) * 1/SymbolPeriod * OverSampleRate;
Rnn = real(ifft(Snn));
Corr = Rnn(1:OverSampleRate/2:end);
C = toeplitz(Corr(1:EqNf));

%% Compute the minimum slicer MSE and corresponding TWDP for the three stressor fibers
X = toeplitz(XmitData, [XmitData(1); XmitData(end:-1:2)]); % Used in MSE calculation
Rxx = X'*X; % Used in MSE calculation
TrialTWDP = [];
for ii=1:3 % index for stressor fiber
   %% Propagate the waveform through fiber ii.
   %% The DC response of each fiber is normalized to 1.
   PCoefs = FiberResp(ii+1,:)';
   Hsys = exp(ExpArg * Delays') * PCoefs; Hx = fftshift(Hsys/sum(PCoefs));
   yout = real(ifft(fft(yout0).*Hx));
   %% Process signal through front-end antialiasing filter %%%%%%%%%%%%%%%%%%%
   yout = real(ifft(fft(yout) .* fftshift(H_r)));
   %% Compute MMSE-DFE %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```



```
    %% The MMSE-DFE filter coefficients computed below minimize mean-squared error at the slicer input.
    %% The derivation follows from the fact that the slicer input over the period of the data sequence can be
    %% expressed as Z = (R+N)*W - X*[0 B]', where R and N are Toeplitz matrices constructed from the
    %% signal and noise components, respectively, at the sampled output of the antialiasing filter, W is the
    %% feedforward filter, X is a Toeplitz matrix constructed from the input data sequence, and B is the
    %% feedback filter. The computed W and B minimize the mean square error between the input to the
    %% slicer and the transmitted sequence due to residual ISI and Gaussian noise. Minimize MSE over 2/T
    %% sampling phase and FFE delay and determine BER
    MseOpt = Inf;
    for jj= [0:OverSampleRate-1]-OverSampleRate/2 % sampling phase
      %% Sample at rate 2/T with new phase (wrap around as required)
      yout_2overT = yout(mod([1:OverSampleRate/2:TotLen]+jj-1,TotLen)+1);
      Rout = toeplitz(yout_2overT, [yout_2overT(1); yout_2overT(end:-1:end-EqNf+2)]);
      R = Rout(1:2:end, :);
      RINV = inv([R'*R+PtrnLength*C R'*ONE;ONE'*R PtrnLength]);
      R=[R ONE]; % Add all-ones column to compute optimal offset
      Rxr = X'*R; Px_r = Rxx - Rxr*RINV*Rxr';
      %% Minimize MSE over equalizer delay
      for kk = 1:length(EqDelVec)
        EqDel = EqDelVec(kk);
        SubRange = [EqDel+1:EqDel+EqNb+1];
        SubRange = mod(SubRange-1,PtrnLength)+1;
        P = Px_r(SubRange,SubRange);
        P00 = P(1,1); P01 = P(1,2:end); P11 = P(2:end,2:end);
        Mse = P00 - P01*inv(P11)*P01';
        if (Mse<MseOpt)
          MseOpt = Mse;
          B = -inv(P11)*P01'; % Feedback filter
          XSel = X(:,SubRange);
          W = RINV*R'*XSel*[1;B]; % Feedforward filter
          Z = R*W - XSel*[0;B]; % Input to slicer
          %% STEP 6 - Compute BER using semi-analytic method %%%%%%%%%%%%%%%%%%
          MseGaussian = W(1:end-1)'*C*W(1:end-1);
          Ber = mean(0.5*erfc((abs(Z-0.5)/sqrt(MseGaussian))/sqrt(2)));
        end
      end
    end

    %% Compute equivalent SNR %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    %% This function computes the inverse of the Gaussian error probability function. The
    %% built-in function erfcinv() is not sensitive enough for low probability of error cases.
    if Ber>10^(-12) Q = sqrt(2)*erfinv(1-2*Ber);
    elseif Ber>10^(-323) Q = 2.1143*(-1.0658-log10(Ber)).^0.5024;
    else Q = inf;
    end

    %% Compute penalty %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    RefSNR = 10 * log10(Q0) + PAlloc;
    TrialTWDP(ii) = RefSNR-10*log10(Q);
end

%% Pick highest value due to the multiple fiber responses from TrialTWDP.
TWDP = max(TrialTWDP)
%% End of program
```


68.6.7 Transmitter signal to noise ratio

The system under test shall meet the RIN_xOMA specification, given in Table 68–3 as $RIN_{20}OMA$, when measured using the procedure given in 58.7.7. A different measurement procedure for the same quantity, giving approximately the same results, uses the setup shown in Figure 68–8 and proceeds as follows:

a) Measure OMA, using a square wave and following the method of 68.6.2
b) Using the same square wave, measure the rms noise over flat regions of the logic ONE and logic ZERO portions of the square wave, as indicated in Figure 68–4, compensating for noise in the measurement system. The optical path and detector combination are configured for a single dominant reflection with the reflector adjusted to produce an optical return loss, as seen by the system under test, equal to the optical return loss tolerance (min) specified in Table 68–3. The length of the single-mode fiber is not critical, but should be in excess of 2 m. The polarization rotator is capable of transforming an arbitrary orientation elliptically polarized wave into a fixed orientation linearly polarized wave, and should be adjusted to maximize the noise. The receiver of the system under test should be receiving a signal that is asynchronous to that being transmitted. If possible, means should be used to prevent noise of frequency less than 1 MHz from affecting the result. Q_{sq} is given by Equation 68–2:

$$Q_{sq} = \frac{\text{OMA}}{\text{logic ONE noise (rms)} + \text{logic ZERO noise (rms)}} \quad (68\text{–}2)$$

where OMA and rms noise are measured in the same linear units of optical power, for example mW.

c) RIN_xOMA is then computed using the relationship shown in Equation 68–3:

$$RIN_xOMA = -20 \times \log_{10}(Q_{sq}) - 10 \times \log_{10}(BW) \qquad \text{dB/Hz} \quad (68\text{–}3)$$

where BW is the low pass bandwidth of oscilloscope minus high pass bandwidth of the measurement system. For the specified measurement setup, BW is approximately 7.5×10^9 Hz.

Q_{sq} may be computed from the RIN_xOMA using the relationship shown in Equation 68–4:

$$Q_{sq} = 10^{-RINxOMA\ \ 20}\ \sqrt{BW} \quad (68\text{–}4)$$

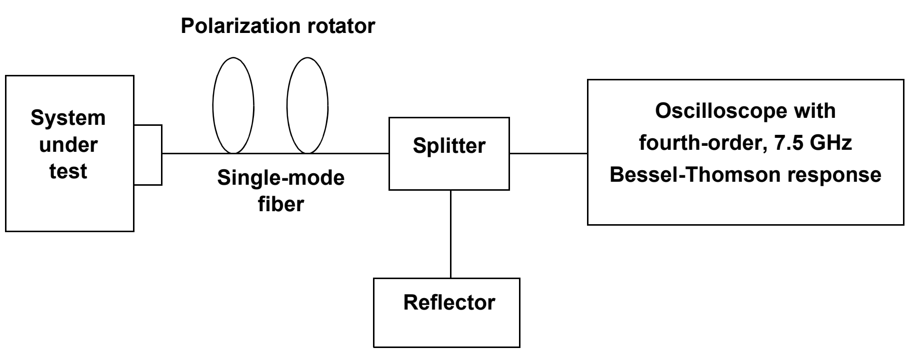

Figure 68–8—Transmitter signal to noise measurement setup

68.6.8 Transmitter uncorrelated jitter

Uncorrelated jitter refers to the component of jitter in the transmitted optical signal that is not correlated to the transmitter data.

The uncorrelated jitter specification of Table 68–3 shall be met when measured using an oscilloscope with a fourth-order, 7.5 GHz Bessel-Thomson response. The test pattern specified in Table 68–6 is used. A clock recovery unit (CRU) should be used to trigger the oscilloscope as shown in Figure 52–9. It should have a high frequency corner bandwidth of 4 MHz and a slope of –20 dB/decade. The CRU tracks acceptable levels of low-frequency jitter and wander. The oscilloscope is to be synchronized to the data pattern. The receiver of the system under test should be receiving a signal that is asynchronous to that being transmitted.

Figure 68–9 illustrates two measurement window positions, one on a rising edge, the other on a falling edge and both placed at the average power level of the pattern. The uncorrelated jitter (rms) is given by the RMS value of the standard deviations of the two distributions, as shown in Equation 68–5:

$$\text{Uncorrelated jitter (rms)} = \sqrt{(\sigma_r^2 + \sigma_f^2)\ \ 2} \tag{68–5}$$

where
σ_r is the standard deviation of the jitter on the rising edge
σ_f is the standard deviation of the jitter on the falling edge

Compensation for measurement system jitter is encouraged.

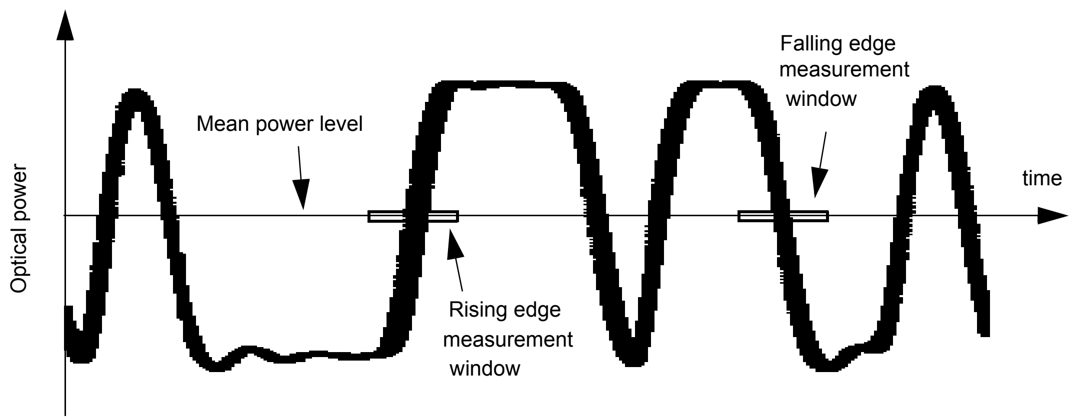

Figure 68–9—Measurement windows for transmitter uncorrelated jitter

68.6.9 Comprehensive stressed receiver sensitivity and overload

The PMD's receiver shall satisfy the comprehensive stressed receiver sensitivity and comprehensive stressed receiver overload specifications given in Table 68–5. These parameters are defined by reference to the procedures of 68.6.9.1 to 68.6.9.4. A BER of better than 10^{-12} shall be achieved with asynchronous transmission from the system under test. The received and transmitted patterns are the same, and as specified in Table 68–6 for the comprehensive stressed receiver sensitivity and the comprehensive stressed receiver overload.

68.6.9.1 Comprehensive stressed receiver sensitivity and overload test block diagram

Figure 68–10 shows the reference block diagram for the comprehensive stressed receiver test. As shown in the figure, an electrical signal is created using a pattern generator with pattern according to Table 68–6, and impaired by the following:

a) Gaussian low pass filter
b) Gaussian white noise source
c) Intersymbol interference (ISI)

NOTE—Gaussian noise that extends, positively and negatively, to at least seven times its rms value is adequate.

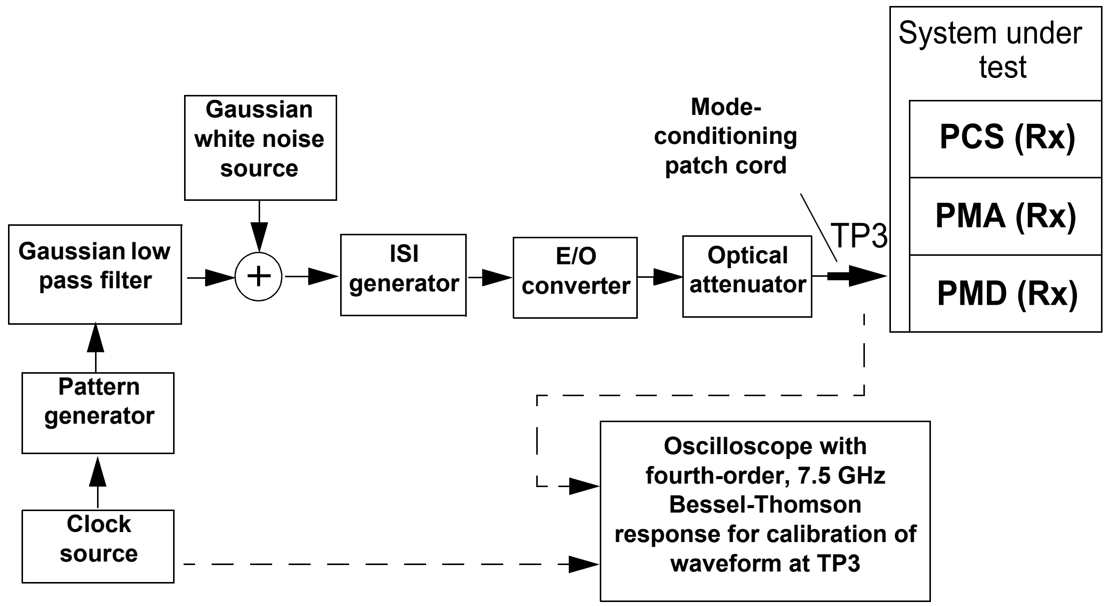

Figure 68–10—Reference measurement configuration for comprehensive stressed receiver sensitivity and overload test

The resulting electrical signal is converted to an optical signal using a linear electrical/optical converter, and the optical waveform is connected to an optical attenuator, and to the receiver under test via a mode-conditioning patch cord of the type defined in 38.11.4 or 59.9.5 for use with 62.5/125 m fiber.

The characteristics of the stressed test signal are defined in 68.6.9.2 and are based upon the parameters in Table 68–5. These parameters and the definition in 68.6.9.2 describe an ISI generator as a tapped delay line with four weighted taps, having equally spaced delays and with impulse response as illustrated in Figure 68–11.

Any implementation of the measurement configuration may be used, provided that the resulting signal and noise in the optical domain match those defined here. This consideration includes the shaping of the noise by the ISI generator.

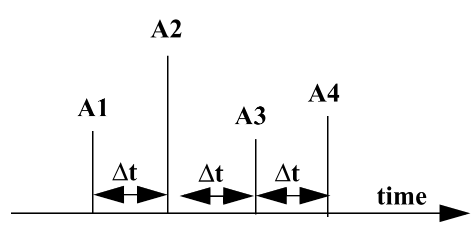

Figure 68–11—Illustration of parameters defining ISI generator impulse responses

68.6.9.2 Comprehensive stressed receiver test signal characteristics

The comprehensive stressed receiver test signal impairments are specified in Table 68–5 as the conditions of the comprehensive stressed receiver tests. These conditions include three sets of ISI parameters that are applied in turn. The ISI impaired test signal is defined by Equation 68–6:

$$S_{\text{ISI}}(t) = S(t) * G_{47}(t) * \left[\sum_{i=1}^{4} A_i \times \delta(t - i \times \Delta t) \right] \tag{68–6}$$

where
- $S(t)$ is an ideal NRZ test pattern signal specified in Table 68–6
- $G_{47}(t)$ is a Gaussian low pass filter with a 20% to 80% step response of 47 ps
- A_i are the amplitudes of the four impulses
- Δt is their spacing
- δ is the Dirac delta function
- * denotes convolution

The impulse spacing, and the amplitudes of the impulses for the three different test cases, are specified in Table 68–5.

The test signal is also impaired by broadband white Gaussian noise with a minimum bandwidth specified in Table 68–5 and with the amplitude adjusted such that Q_{sq} of the test signal, without ISI impairment, is as specified in Table 68–5.

Two different optical signal powers, in OMA, are used for the comprehensive stressed receiver sensitivity test. For the test with pre-cursor ISI tap weights, and the test with the post-cursor ISI tap weights, the OMA is set to the stressed sensitivity in OMA, given in Table 68–5. For the test with the symmetrical ISI tap weights, the OMA is set to the stressed sensitivity in OMA for symmetrical test, given in Table 68–5. For all three tests, the minimum extinction ratio specified in Table 68–3 is used.

For the comprehensive stressed receiver overload test, the OMA is set to the overload in OMA, given in Table 68–5, and with the maximum average power specified in Table 68–3.

68.6.9.3 Comprehensive stressed receiver test signal calibration

The test signal is calibrated as follows, using an optical reference receiver with a multimode compatible input and a 7.5 GHz fourth-order ideal Bessel-Thomson response.

The extinction ratio of the optical output is calibrated with the Gaussian low pass filter but without the ISI generator.

Without ISI impairment due to the ISI generator, the level of the Gaussian noise is adjusted such that Q_{sq} is as specified in Table 68–5. See 68.6.7 for the definition of signal to noise ratio Q_{sq}.

The ISI generator is configured and calibrated for each of the three ISI cases specified in Table 68–5. The calibration of the ISI may be done with any portion of a repeating test signal. One convenient example is an isolated ONE bit with at least ten ZERO bits before and after. The ISI generator is adjusted such that the signal, S_{meas}, recorded on the reference receiver is given by Equation 68–7:

$$S_{\mathrm{meas}}(t) = S_{\mathrm{cal}}(t) * G_{47}(t) * \left[\sum_{i=1}^{4} A_i \times \delta(t - i \times \Delta t) \right] * BT4_{7.5\,GHz}(t) \tag{68–7}$$

where

S_{cal} is an ideal NRZ calibration test signal

G_{47}, A_i , Δt, and * are defined as in 68.6.9.2

$BT4_{7.5GHz}(t)$ is the impulse response of an ideal 7.5 GHz fourth-order Bessel-Thomson filter representing the optical reference receiver response

In practice, the bandwidth of, or need for, the Gaussian low pass filter shown in block diagram of Figure 68–10 is determined by the characteristics of the signal source, ISI generator and E/O converter such that the final measured signal has the overall pulse response given by Equation 68–7.

Figure 68–12 illustrates the required measured test signals for the three cases specified in Table 68–5, where the test signal, S_{cal}, is a single ONE bit (rectangular pulse with 1 UI width) surrounded by ZEROs. Table 68–7 gives the tabulated amplitude vs. time for these curves.

NOTE—The TWDP values without simulated channels, which are measured using the same method as TWDP except that the simulated fiber stressors are set to (0,1,0,0), are 4.1 dB, 3.9 dB, and 4.2 dB for the pre-cursor, symmetrical and post-cursor tests, respectively. Significant differences from these values indicate problems with the test equipment (possibly nonlinearities) and that the test will not provide valid results. For small differences, the ISI generator should be adjusted to obtain the expected values. Also, one should ensure that the test system has adequate low-frequency response to avoid baseline wander problems with the longer test patterns used for the test.

With the ISI generator present, the Q_{sq} values are as follows for the three different ISI impairments—pre-cursor: 45.6; symmetrical: 37.2; post-cursor: 47.0. Significant differences from these values indicate problems with the test equipment (possibly noise sources within the ISI generator), and the test will not provide valid results. For small differences, the amplitude of the added Gaussian white noise should be adjusted to obtain the expected values.

The attenuator setting is determined by measuring the OMA of the impaired test signal according to 68.6.2.

68.6.9.4 Comprehensive stressed receiver test procedure

The three ISI impairments defined in Table 68–5 and 68.6.9.2, together with the appropriate OMA values, also as specified in Table 68–5, define six discrete signal conditions.

With the test system setup as described in 68.6.9.2 and 68.6.9.3, for each case, select the required ISI impairment and set the attenuator and Gaussian white noise source to obtain either the stressed sensitivity in OMA, stressed sensitivity in OMA for symmetrical test or overload in OMA, with the appropriate noise, as specified in Table 68–5. Set the pattern generator to one of the patterns specified in Table 68–6 for these measurements. Connect the test signal to the system receiver TP3 and a BER of better than 10^{-12} shall be achieved for each case.

68.6.10 Simple stressed receiver sensitivity and overload (informative)

The simple stressed receiver sensitivity and simple stressed receiver overload are informative and compliance is not required. If measured, the receiver under test will be expected to satisfy the simple stressed receiver sensitivity and simple stressed receiver overload specifications in Table 68–5.

Figure 68–13 gives the block diagram for the simple stressed receiver test. A pattern generator output is impaired by a low pass filter and the resulting electrical signal is converted to an optical signal using a linear electrical/optical converter. Other signal impairments, such as jitter and RIN, should be negligible. The optical waveform is connected to an optical attenuator, and to the receiver under test via a mode-conditioning patch cord of the type defined in 38.11.4 or 59.9.5 for use with 62.5/125 µm fiber.

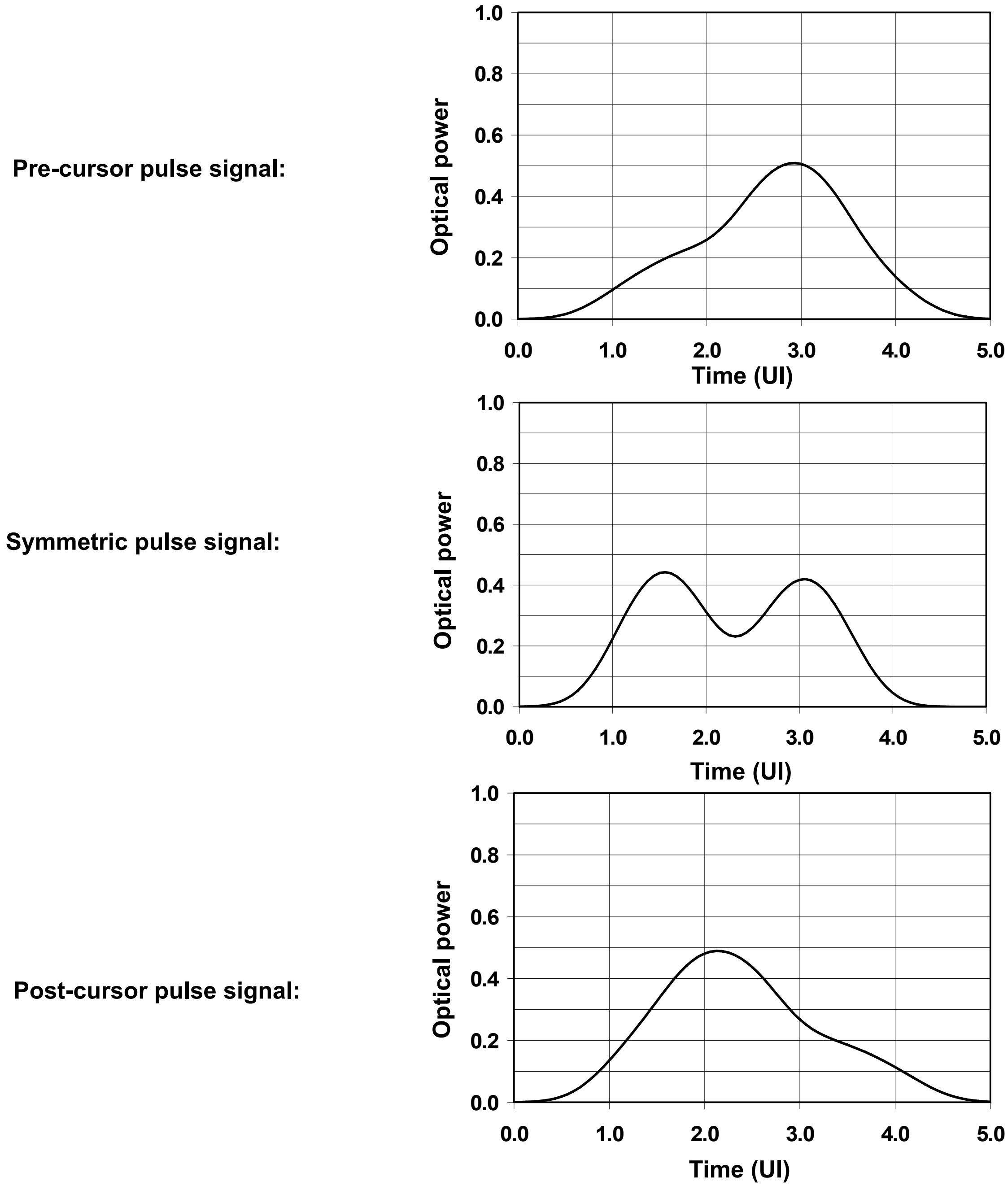

Figure 68–12—Comprehensive stressed receiver test pulse signals (i.e., signals corresponding to an isolated ONE bit)

NOTE—The optical powers have been normalized to correspond to waveforms with OMA of one.

The filter should be chosen so as to produce an optical output with the rise and fall times given in Table 68–5, and dominated by a fourth-order Bessel-Thomson response. The rise and fall times of the test signal are defined as measured with a 7.5 GHz Bessel-Thomson reference receiver and with the square wave pattern used for calibrating OMA for the comprehensive stressed receiver test of 68.6.9.

Table 68–7—Tabulated amplitude vs. time values for test signals of Figure 68–13

Time (UI)	Pre-cursor	Symmetrical	Post-cursor
0.000	0.000	0.000	0.000
0.125	0.001	0.001	0.001
0.250	0.003	0.004	0.003
0.375	0.008	0.011	0.009
0.500	0.016	0.026	0.019
0.625	0.029	0.053	0.036
0.750	0.048	0.095	0.061
0.875	0.071	0.154	0.095
1.000	0.096	0.224	0.136
1.125	0.121	0.298	0.180
1.250	0.146	0.364	0.227
1.375	0.168	0.413	0.276
1.500	0.189	0.439	0.327
1.625	0.207	0.439	0.378
1.750	0.223	0.413	0.423
1.875	0.239	0.367	0.459
2.000	0.259	0.312	0.481
2.125	0.288	0.264	0.489
2.250	0.327	0.235	0.484
2.375	0.374	0.234	0.467
2.500	0.422	0.261	0.437
2.625	0.464	0.305	0.398
2.750	0.494	0.355	0.352
2.875	0.508	0.395	0.307
3.000	0.506	0.417	0.268
3.125	0.487	0.415	0.238
3.250	0.451	0.388	0.216
3.375	0.402	0.338	0.200
3.500	0.344	0.273	0.186
3.625	0.284	0.203	0.171
3.750	0.228	0.137	0.154
3.875	0.180	0.084	0.135
4.000	0.138	0.046	0.114
4.125	0.103	0.022	0.091
4.250	0.072	0.009	0.069
4.375	0.048	0.003	0.048
4.500	0.029	0.001	0.031
4.625	0.016	0.000	0.018
4.750	0.007	0.000	0.009
4.875	0.003	0.000	0.004
5.000	0.001	0.000	0.001

Other implementations may be used provided that the resulting signal in the optical domain matches that created using the implementation described.

NOTE—The TWDP without simulated channels, which is measured using the same method as TWDP except that the simulated fiber stressors are set to (0, 1, 0, 0), for this test signal is 4 dB.

For the two OMA values (i.e., the stressed sensitivity in OMA, and the overload in OMA, both specified in Table 68–5), a BER of better than 10^{-12} should be achieved. For the simple stressed receiver sensitivity test, the minimum extinction ratio specified in Table 68–3 is used. For the simple stressed receiver overload test, the maximum average power specified in Table 68–3 is used.

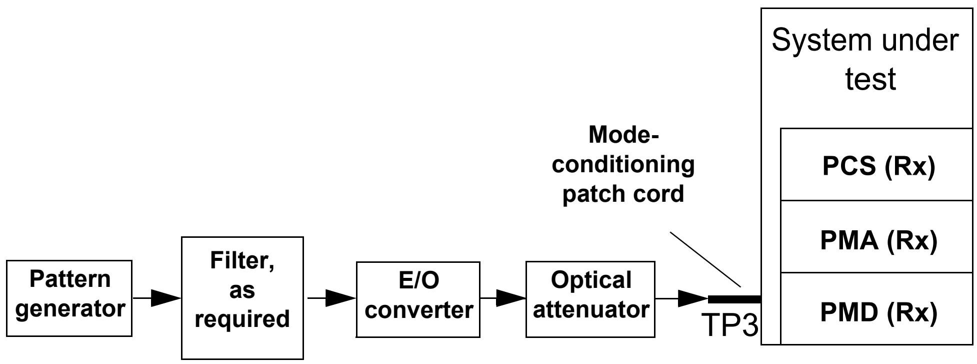

Figure 68–13—Measurement configuration for simple stressed receiver sensitivity test (informative)

68.6.11 Receiver jitter tolerance

The receiver jitter tolerance specification given in Table 68–5 shall be met when measured as described here. This specification addresses the need for the receiver to track low-frequency jitter without the occurrence of errors.

Figure 68–14 gives the measurement configuration for the receiver jitter tolerance test. An optical pattern generator output is impaired by frequency modulation of the generating clock. The optical waveform is connected to the receiver under test via an optical attenuator and mode-conditioning patch cord suitable for 62.5/125 m fiber.

Two jitter frequency and amplitude combinations are specified in Table 68–5. These are applied as the conditions of two separate receiver jitter tolerance tests. For each, the power in OMA at the receiver is adjusted, using the optical attenuator, to be equal to the stressed sensitivity in OMA, also given in Table 68–5, and a BER of better than 10^{-12} shall be achieved.

Various implementations may be used, provided that the resulting jitter in the optical domain matches that specified. Phase or frequency modulation may be applied to induce the sinusoidal jitter, and the modulation may be applied to the clock source or to the data stream itself.

68.7 Safety, installation, environment, and labeling

68.7.1 Safety

The 10GBASE-LRM environmental specifications are as defined in 52.10.1 for general safety, and as defined in 52.10.2 for laser safety.

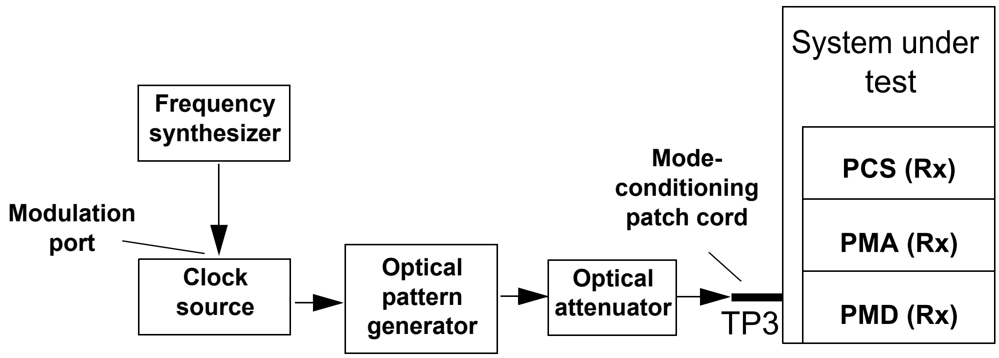

Figure 68–14—Measurement configuration for receiver jitter tolerance test

68.7.2 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.

NOTE—The preferred launch (as specified in Table 68–3) is expected to provide more stable operation. It is recommended that link stability be confirmed by physical manipulation of the transmitter patch cord.

68.7.3 Environment

The 10GBASE-LRM operating environment specifications are as defined in 52.11, as defined in 52.11.1 for electromagnetic emission, and as defined in 52.11.2 for temperature, humidity, and handling.

68.7.4 PMD labeling

The 10GBASE-LRM labeling recommendations and requirements are as defined in 52.12.

68.8 Fiber optic cabling model

The fiber optic cabling model is shown in Figure 38-7.

A channel may contain additional connectors or other optical elements as long as the optical characteristics of the channel such as attenuation, dispersion, reflections, modal bandwidth and total connector loss meet the specifications. Insertion loss measurements of installed multimode fiber cables are made in accordance with IEC 61280-4-1/Method 2. 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.

68.9 Characteristics of the fiber optic cabling (channel)

The channel consists of one or more sections of fiber optic cable and any intermediate connections required to connect sections together. The fiber optic cabling shall meet the requirements of Table 68–8.

68.9.1 Optical fiber and cable

The optical fiber shall meet the requirements of IEC 60793-2-10 and the requirements given in Table 68–9, where they differ. Multimode cables chosen from IEC 60794-2-11 or IEC 60794-3-12 may be suitable.

Table 68–8—Fiber optic cabling (channel)

Description	Type	Value	Unit
Fiber insertion loss at 1300 nm	max	0.4	dB
Losses of all connectors and splices	max	1.5	dB

Table 68–9—Optical fiber and cable

Description	Type	Value	Unit
Cable attenuation at 1300 nm	max	1.5	dB/km
Modal bandwidth at 1300 nm	min	Value used as 1300 nm modal bandwidth portion of fiber identifier in Table 68–2	MHz · km
Zero dispersion wavelength (λ_0) for 62.5 μm MMF	range	$1320 \le \lambda_0 \le 1365$	nm
Chromatic dispersion slope for 62.5 μm MMF	max	0.11 for $1320 \le \lambda_0 \le 1348$ and $0.001(1458 - \lambda_0)$ for $1348 \le \lambda_0 \le 1365$	$ps/nm^2 \cdot km$
Zero dispersion wavelength (λ_0) for 50 μm MMF	range	$1295 \le \lambda_0 \le 1320$	nm
Chromatic dispersion slope for 50 μm MMF	max	0.11 for $1300 \le \lambda_0 \le 1320$ and $0.001(\lambda_0 - 1190)$ for $1295 \le \lambda_0 \le 1300$	$ps/nm^2 \cdot km$

68.9.2 Optical fiber connections

An optical fiber connection, as shown in Figure 38–7, consists of a mated pair of optical connectors.

68.9.2.1 Connection insertion loss

The insertion loss is specified for a connection, which consists of a mated pair of optical connectors.

The maximum link distances for multimode fiber are calculated based on an allocation of 1.5 dB total connector and splice loss. For example, this allocation supports three connections with an insertion loss equal to 0.5 dB (or less) per connection, or two connections (as shown in Figure 38-7) with an insertion loss equal to 0.75 dB per connection. Connections with different loss characteristics may be used provided the requirements of Table 68–8 are met.

68.9.2.2 Maximum discrete reflectance

The maximum discrete reflectance shall be less than –20 dB.

68.9.3 Single-mode fiber offset-launch mode-conditioning patch cord

Single-mode fiber offset-launch mode-conditioning patch cords shall satisfy the requirements of 38.11.4 or 59.9.5. Any discrete reflectance within the patch cord shall be less than –20 dB.

68.10 Protocol implementation conformance statement (PICS) proforma for Clause 68, Physical medium dependent (PMD) sublayer type 10GBASE-LRM[2]

68.10.1 Introduction

The supplier of a protocol implementation that is claimed to conform to IEEE Std 802.3aq-2006, Physical medium dependent (PMD) sublayer type 10GBASE-LRM, 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.

68.10.2 Identification

68.10.2.1 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]	
NOTES 1—Required for all implementations. 2—May be completed as appropriate in meeting the requirements for the identification. 3—The terms Name and Version should be interpreted appropriately to correspond with a supplier's terminology (e.g., Type, Series, Model).	

68.10.2.2 Protocol summary

Identification of protocol standard	IEEE Std 802.3aq-2006, physical medium dependent (PMD) sublayer type 10GBASE-LRM
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 802.3aq-2006.)	

Date of Statement	

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

68.10.2.3 Major capabilities/options

Item	Feature	Subclause	Value/Comment	Status	Support
*MD	MDIO capability	68.3	Registers and interface supported	O	Yes [ ] No [ ]
*INS	Installation / Cable	68.9	Items marked with INS include installation practices and cable specifications not applicable to a PHY manufacturer	O	Yes [ ] No [ ]
DLY	Delay constraints	68.2	Device conforms to delay constraints	M	Yes [ ]

68.10.3 PICS proforma tables for physical medium dependent (PMD) sublayer type 10GBASE-LRM

68.10.3.1 PMD functional specifications

Item	Feature	Subclause	Value/Comment	Status	Support
FS1	Optical launch	68.4.1, 68.5.1	PMD supports both preferred and alternative launches	M	Yes [ ]
FS2	Transmit function	68.4.2	Conveys bits from PMD service interface to MDI	M	Yes [ ]
FS3	Transmitter optical signal	68.4.2	Higher optical power transmitted is a logic 1	M	Yes [ ]
FS4	Receive function	68.4.3	Conveys bits from MDI to PMD service interface	M	Yes [ ]
FS5	Receiver optical signal	68.4.3	Higher optical power received is a logic 1	M	Yes [ ]
FS6	Signal detect function	68.4.4	Mapping to PMD service interface	M	Yes [ ]
FS7	Signal detect parameter	68.4.4	Generated according to Table 68–1	M	Yes [ ]

68.10.3.2 Management functions

Item	Feature	Subclause	Value/Comment	Status	Support
MD1	Management register set	68.3	Mapped as per Table 52-3 and Table 52-4	MD:M	Yes [ ] N/A [ ]
MD2	PMD_reset bit	68.4.5, 45.2.1.1.1		MD:M	Yes [ ] N/A[ ]
MD3	PMD_global_transmit_disable bit	68.4.7, 45.2.1.8.5		MD:O	Yes [ ] No [ ] N/A [ ]
MD4	PMD_transmit_fault bit	68.4.8, 45.2.1.7.4		MD:O	Yes [ ] No [ ] N/A [ ]
MD5	PMD receive fault bit	68.4.9, 45.2.1.7.5		MD:O	Yes [ ] No [ ] N/A [ ]
MD6	PMD fault bit	68.4.6		MD:O	Yes [ ] No [ ] N/A [ ]
MD7	PMD_signal_detect bit	68.4.4, 45.2.1.9.5		MD:M	Yes [ ] N/A [ ]

68.10.3.3 PMD to MDI optical specifications

Item	Feature	Subclause	Value/Comment	Status	Support
LRM1	10GBASE-LRM transmitter	68.5.1	Meets specifications in Table 68–3	M	Yes [ ]
LRM2	10GBASE-LRM receiver	68.5.3	Meets specifications in Table 68–5	M	Yes [ ]

68.10.3.4 Definitions of optical parameters and measurement methods

Item	Feature	Subclause	Value/Comment	Status	Support
OM1	Optical modulation amplitude	68.6.2		M	Yes [ ]
OM2	Extinction ratio	68.6.3		M	Yes [ ]
OM3	Transmitter optical wave-form— transmitter eye mask	68.6.5		M	Yes [ ]
OM4	Transmitter optical wave-form— transmitter waveform and dispersion penalty (TWDP)	68.6.6		M	Yes [ ]
OM5	Transmitter signal to noise ratio	68.6.7		M	Yes [ ]
OM6	Transmitter uncorrelated jitter	68.6.8		M	Yes [ ]
OM7	Comprehensive stressed receiver sensitivity	68.6.9		M	Yes [ ]
OM8	Comprehensive stressed receiver overload	68.6.9		M	Yes [ ]
OM9	Simple stressed receiver sensitivity	68.6.10		O	Yes [ ] No [ ]
OM10	Simple stressed receiver overload	68.6.10		O	Yes [ ] No [ ]
OM11	Receiver jitter tolerance	68.6.11		M	Yes [ ]

68.10.3.5 Safety, installation, environment, and labeling

Item	Feature	Subclause	Value/Comment	Status	Support
SE1	General safety	68.7.1	As 52.10.1. Conforms to IEC-60950: 1991	M	Yes [ ]
SE2	Laser safety — IEC Class 1	68.7.1	As 52.10.2. Conform to Class 1 laser requirements defined in IEC 60825-1	M	Yes [ ]
SE3	Electromagnetic interference	68.7.3	As 52.11.1. Comply with applicable local and national codes for the limitation of electromagnetic interference	M	Yes [ ]
SE4	PMD labeling	68.7.4	As 52.12	M	Yes [ ]

68.10.3.6 Characteristics of the fiber optic cabling (channel)

Item	Feature	Subclause	Value/Comment	Status	Support
FO1	Characteristics of fiber optic cabling (channel)	68.9	Meet the requirements of	INS:M	Yes [ ] N/A [ ]
FO2	Optical fiber characteristics	68.9.1	Meet the requirements given, including those of Table 68–9	INS:M	Yes [ ] N/A [ ]
FO3	Optical fiber connections	68.9.2	Insertion loss within specification of 68.9.2.1	INS:M	Yes [ ] N/A [ ]
FO4	Patch cords	68.9.3		INS:M	Yes [ ] N/A [ ]