



**International
Standard**

**ISO/IEC/IEEE
8802-3**

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

**Part 3:
Standard for Ethernet**

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

Partie 3: Norme pour Ethernet

**Fourth edition
2026-08**



COPYRIGHT PROTECTED DOCUMENT

© IEEE 2022

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from IEEE at the address below.

Institute of Electrical and Electronics Engineers, Inc
3 Park Avenue, New York
NY 10016-5997, USA

Email: stds.ipr@ieee.org
Website: www.ieee.org

Published in Switzerland

Foreword

ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission) form the specialized system for worldwide standardization. National bodies that are members of ISO or IEC participate in the development of International Standards through technical committees established by the respective organization to deal with particular fields of technical activity. ISO and IEC technical committees collaborate in fields of mutual interest. Other international organizations, governmental and non-governmental, in liaison with ISO and IEC, also take part in the work.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of document should be noted.

IEEE Standards documents are developed within IEEE Societies and subcommittees of IEEE Standards Association (IEEE SA) Board of Governors. IEEE develops its standards through an accredited consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE standards are documents developed by volunteers with scientific, academic, and industry-based expertise in technical working groups. Volunteers are not necessarily members of IEEE or IEEE SA and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

ISO and IEC draw attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO and IEC take no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO and IEC had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents and <https://patents.iec.ch>. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html. In the IEC, see www.iec.ch/understanding-standards.

ISO/IEC/IEEE 8802-3 was prepared by the LAN/MAN of the IEEE Computer Society (as IEEE Std 802.3-2022) and drafted in accordance with its editorial rules. It was adopted, under the “fast-track procedure” defined in the Partner Standards Development Organization cooperation agreement between ISO and IEEE, by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 6, *Telecommunications and information exchange between systems*.

This fourth edition cancels and replaces the third edition (ISO/IEC/IEEE 8802-3:2021), which has been technically revised. It also incorporates the Amendments ISO/IEC/IEEE 8802-3:2021/Amd 2:2021, ISO/IEC/IEEE 8802-3:2021/Amd 3:2021, ISO/IEC/IEEE 8802-3:2021/Amd 4:2021, ISO/IEC/IEEE 8802-3:2021/Amd 5:2021, ISO/IEC/IEEE 8802-3:2021/Amd 6:2021, ISO/IEC/IEEE 8802-3:2021/Amd 7:2021, ISO/IEC/IEEE 8802-3:2021/Amd 8:2021, ISO/IEC/IEEE 8802-3:2021/Amd 9:2021, ISO/IEC/IEEE 8802-3:2021/Amd 10:2021, ISO/IEC/IEEE 8802-3:2021/Amd 11:2021, ISO/IEC/IEEE 8802-3:2021/Amd 12:2021, ISO/IEC/IEEE 8802-3:2021/Amd 13:2021, ISO/IEC/IEEE 8802-3:2021/Amd 14:2021, ISO/IEC/IEEE 8802-3:2021/Amd 1:2021.

A list of all parts in the ISO/IEC/IEEE 8802 series can be found on the ISO and IEC websites.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html and www.iec.ch/national-committees.

**Important
Notice**

This document is a copyrighted IEEE Standard. IEEE hereby grants permission to ISO and IEC to reproduce this document for purposes of coordination and/or consideration for adoption. No further reproduction or distribution of this document is permitted without the express written permission of IEEE Standards Activities. Prior to any use of this standard, in part or in whole, by another standards development organization, permission must first be obtained from the IEEE Standards Activities Department (stds.ipr@ieee.org).

IEEE Standards Association
445 Hoes Lane
Piscataway, NJ 08854, USA

IEEE Standard for Ethernet

LAN/MAN Standards Committee
of the
IEEE Computer Society

Approved 13 May 2022

IEEE SA Standards Board

Abstract: Ethernet local area network operation is specified for selected speeds of operation from 1 Mb/s to 400 Gb/s using a common media access control (MAC) specification and management information base (MIB). The Carrier Sense Multiple Access with Collision Detection (CSMA/CD) MAC protocol specifies shared medium (half duplex) operation, as well as full duplex operation. Speed specific Media Independent Interfaces (MIIs) allow use of selected Physical Layer devices (PHYs) for operation over coaxial, twisted pair or fiber optic cables, or electrical backplanes. System considerations for multisegment shared access networks describe the use of Repeaters that are defined for operational speeds up to 1000 Mb/s. Local Area Network (LAN) operation is supported at all speeds. Other specified capabilities include: various PHY types for access networks, PHYs suitable for metropolitan area network applications, and the provision of power over selected twisted pair PHY types.

Keywords: 2.5 Gigabit Ethernet, 5 Gigabit Ethernet, 10 Gigabit Ethernet, 25 Gigabit Ethernet, 40 Gigabit Ethernet, 50 Gigabit Ethernet, 100 Gigabit Ethernet, 200 Gigabit Ethernet, 400 Gigabit Ethernet, AN, attachment unit interface, AUI, Auto-Negotiation, Backplane Ethernet, balanced cable, data processing, DTE Power via the MDI, EEE, Energy-Efficient Ethernet, EPoC, EPON, EPON protocol over coax, Ethernet, Ethernet in the first mile, Ethernet Passive Optical Network, express traffic, Fast Ethernet, FEC, forward error correction, Gigabit Ethernet, IEEE 802.3™, information exchange, isolation, LAN, local area network, management, MCRS, MDI, media independent interface, medium dependent interface, MIB, MII, MMF, MPCP, Multi-Channel Reconciliation Sublayer, multimode fiber, multipoint control protocol, P2MP, PCS, PD, PHY, physical coding sublayer, Physical Layer, Physical Layer Collision Avoidance, Physical Layer device, physical medium attachment, physical medium dependent, PLCA, PMA, PMD, PoDL, PoE, point to multipoint, Power over Data Lines, Power over Ethernet, Power Sourcing Equipment, Powered Device, PSE, reconciliation sublayer, repeater, RS, single-mode fiber, SMF, type field

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2022 by The Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 29 July 2022. Printed in the United States of America.

IEEE and 802 are registered trademarks in the U.S. Patent & Trademark Office, owned by The Institute of Electrical and Electronics Engineers, Incorporated.

PDF: ISBN 978-1-5044-8725-2 STD25431
Print: ISBN 978-1-5044-8726-9 STDPD25431

IEEE prohibits discrimination, harassment and bullying.

For more information, visit <http://www.ieee.org/web/aboutus/whatis/policies/p9-26.html>.

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE Standards documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page (<https://standards.ieee.org/ipr/disclaimers.html>), appear in all standards and may be found under the heading “Important Notices and Disclaimers Concerning IEEE Standards Documents.”

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE SA) Standards Board. IEEE develops its standards through an accredited consensus development process, which brings together volunteers representing varied viewpoints and interests to achieve the final product. IEEE Standards are documents developed by volunteers with scientific, academic, and industry-based expertise in technical working groups. Volunteers are not necessarily members of IEEE or IEEE SA, and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE makes no warranties or representations concerning its standards, and expressly disclaims all warranties, express or implied, concerning this standard, including but not limited to the warranties of merchantability, fitness for a particular purpose and non-infringement. In addition, IEEE does not warrant or represent that the use of the material contained in its standards is free from patent infringement. IEEE standards documents are supplied “AS IS” and “WITH ALL FAULTS.”

Use of an IEEE standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity, nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: THE NEED TO PROCURE SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE is the approved IEEE standard.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, nor be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that the presenter's views should be considered the personal views of that individual rather than the formal position of IEEE, IEEE SA, the Standards Committee, or the Working Group.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE or IEEE SA. However, **IEEE does not provide interpretations, consulting information, or advice pertaining to IEEE Standards documents.**

Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its Societies and Standards Coordinating Committees are not able to provide an instant response to comments, or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in evaluating comments or in revisions to an IEEE standard is welcome to join the relevant IEEE working group. You can indicate interest in a working group using the Interests tab in the Manage Profile & Interests area of the [IEEE SA myProject system](#).¹ An IEEE Account is needed to access the application.

Comments on standards should be submitted using the [Contact Us](#) form.²

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not constitute compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Data privacy

Users of IEEE Standards documents should evaluate the standards for considerations of data privacy and data ownership in the context of assessing and using the standards in compliance with applicable laws and regulations.

¹ Available at: <https://development.standards.ieee.org/myproject-web/public/view.html#landing>.

² Available at: <https://standards.ieee.org/content/ieee-standards/en/about/contact/index.html>.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under US and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate licensing fees, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400; <https://www.copyright.com/>. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every 10 years. When a document is more than 10 years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit [IEEE Xplore](#) or [contact IEEE](#).³ For more information about the IEEE SA or IEEE's standards development process, visit the IEEE SA Website.

Errata

Errata, if any, for all IEEE standards can be accessed on the [IEEE SA Website](#).⁴ Search for standard number and year of approval to access the web page of the published standard. Errata links are located under the Additional Resources Details section. Errata are also available in [IEEE Xplore](#). Users are encouraged to periodically check for errata.

Patents

IEEE Standards are developed in compliance with the [IEEE SA Patent Policy](#).⁵

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has

³ Available at: <https://ieeexplore.ieee.org/browse/standards/collection/ieee>.

⁴ Available at: <https://standards.ieee.org/standard/index.html>.

⁵ Available at: <https://standards.ieee.org/about/sasb/patcom/materials.html>.

filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE SA Website at <https://standards.ieee.org/about/sasb/patcom/patents.html>. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

IMPORTANT NOTICE

IEEE Standards do not guarantee or ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. IEEE Standards development activities consider research and information presented to the standards development group in developing any safety recommendations. Other information about safety practices, changes in technology or technology implementation, or impact by peripheral systems also may be pertinent to safety considerations during implementation of the standard. Implementers and users of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.

Participants

The following individuals were officers and members of the IEEE 802.3 working group at the beginning of the IEEE 802.3dc working group ballot.

David J. Law, *IEEE 802.3 Working Group Chair*
Adam Healey, *IEEE 802.3 Working Group Vice-Chair*
Jon Lewis, *IEEE 802.3 Working Group Secretary*
Steven B. Carlson, *IEEE 802.3 Working Group Executive Secretary*
Valerie Maguire, *IEEE 802.3 Working Group Treasurer*

Adam Healey, *IEEE P802.3 (IEEE 802.3dc) Task Force Chair and Editor-in-Chief*
Pete Anslow, *IEEE P802.3 (IEEE 802.3dc) Task Force Section Editor*
Marek Hajduczenia, *IEEE P802.3 (IEEE 802.3dc) Task Force Section Editor*
Jon Lewis, *IEEE P802.3 (IEEE 802.3dc) Task Force Section Editor*
Adee Ran, *IEEE P802.3 (IEEE 802.3dc) Task Force Section Editor*

Historical participants

The following individuals participated in the IEEE 802.3 working group during various stages of the standard's development. Since the initial publication, many IEEE standards have added functionality or provided updates to material included in this standard. Included is a historical list of participants who have dedicated their valuable time, energy, and knowledge to the creation of this material:

IEEE Std 802.3 document	Date approved by IEEE and ANSI	Officers at the time of working group ballot
IEEE Std 802.3-1985, Original 10 Mb/s standard, MAC, PLS, AUI, 10BASE5	23 June 1983 (IEEE) 31 December 1984 (ANSI)	Donald C. Loughry , <i>Working Group Chair</i>
IEEE Std 802.3a-1988 (Clause 10), 10 Mb/s MAU 10BASE2	15 November 1985 (IEEE) 28 December 1987 (ANSI)	Donald C. Loughry , <i>Working Group Chair</i> Alan Flatman , <i>Task Force Chair</i>
IEEE Std 802.3b-1985 (Clause 11), 10 Mb/s Broad-band MAU, 10BROAD36	19 September 1985 (IEEE) 28 February 1986 (ANSI)	Donald C. Loughry , <i>Working Group Chair</i> Menachem Abraham , <i>Task Force Chair</i>
IEEE Std 802.3c-1985 (9.1–9.8), 10 Mb/s Baseband Repeater	12 December 1985 (IEEE) 4 June 1986 (ANSI)	Donald C. Loughry , <i>Working Group Chair</i> Geoffrey O. Thompson , <i>Task Force Chair</i>
IEEE Std 802.3d-1987 (9.9), 10 Mb/s Fiber MAU, FOIRL	10 December 1987 (IEEE) 9 February 1989 (ANSI)	Donald C. Loughry , <i>Working Group Chair</i> Steven Moustakas , <i>Task Force Chair</i>
IEEE Std 802.3e-1987 (Clause 12), 1 Mb/s MAU and Hub 1BASE5	11 June 1987 (IEEE) 15 December 1987 (ANSI)	Donald C. Loughry , <i>Working Group Chair</i> Robert Galin , <i>Task Force Chair</i>
IEEE Std 802.3h-1990 (Clause 5), 10 Mb/s Layer Management, DTEs	28 September 1990 (IEEE) 11 March 1991 (ANSI)	Donald C. Loughry , <i>Working Group Chair</i> Andy J. Luque , <i>Task Force Chair</i>
IEEE Std 802.3i-1990 (Clauses 13 and 14), 10 Mb/s UTP MAU, 10 BASE-T	28 September 1990 (IEEE) 11 March 1991 (ANSI)	Donald C. Loughry , <i>Working Group Chair</i> Patricia Thaler , <i>Task Force Chair (initial)</i> Richard Anderson , <i>Task Force Chair (final)</i>

IEEE Std 802.3 document	Date approved by IEEE and ANSI	Officers at the time of working group ballot
IEEE Std 802.3j-1993 (Clauses 15–18), 10 Mb/s Fiber MAUs 10BASE-FP, 10BASE-FB, and 10BASE-FL	15 September 1993 (IEEE) 15 March 1994 (ANSI)	Patricia Thaler , <i>Working Group Chair</i> Keith Amundsen , <i>Task Force Chair (initial)</i> Frederick Scholl , <i>Task Force Chair (final)</i> Michael E. Lee , <i>Technical Editor</i>
IEEE Std 802.3k-1993 (Clause 19), 10 Mb/s Layer Management, Repeaters	17 September 1992 (IEEE) 8 March 1993 (ANSI)	Patricia Thaler , <i>Working Group Chair</i> Joseph S. Skorupa , <i>Task Force Chair</i> Geoffrey O. Thompson , <i>Vice Chair and Editor</i>
IEEE Std 802.3/-1992 (14.10), 10 Mb/s PICS Proforma 10BASE-T MAU	17 September 1992 (IEEE) 23 February 1993 (ANSI)	Patricia Thaler , <i>Working Group Chair</i> Mike Armstrong , <i>Task Force Chair and Editor</i> Paul Nikolich , <i>Vice Chair</i> William Randle , <i>Editorial Coordinator</i>
IEEE Std 802.3m-1995, Maintenance 2	21 September 1995 (IEEE) 16 July 1996 (ANSI)	Patricia Thaler , <i>Working Group Chair</i> Gary Robinson , <i>Maintenance Chair</i>
IEEE Std 802.3n-1995, Maintenance 3	21 September 1995 (IEEE) 4 April 1996 (ANSI)	Patricia Thaler , <i>Working Group Chair</i> Gary Robinson , <i>Maintenance Chair</i>
IEEE Std 802.3p-1993 (Clause 20), Management, 10 Mb/s Integrated MAUs	17 June 1993 (IEEE) 4 January 1994 (ANSI)	Patricia Thaler , <i>Working Group Chair</i> Joseph S. Skorupa , <i>Task Force Chair</i> Geoffrey O. Thompson , <i>Vice Chair and Editor</i>
IEEE Std 802.3q-1993 (Clause 5), 10 Mb/s Layer Management, GDMO Format	17 June 1993 (IEEE) 4 January 1994 (ANSI)	Patricia Thaler , <i>Working Group Chair</i> Joseph S. Skorupa , <i>Task Force Chair</i> Geoffrey O. Thompson , <i>Vice Chair and Editor</i>
IEEE Std 802.3r-1996 (8.8), Type 10BASE5 Medium Attachment Unit PICS proforma	29 July 1996 (IEEE) 6 January 1997 (ANSI)	Patricia Thaler , <i>Working Group Chair</i> Imre Juhász , <i>Task Force Chair</i> William Randle , <i>Task Force Editor</i>
IEEE Std 802.3s-1995, Maintenance 4	21 September 1995 (IEEE) 8 April 1996 (ANSI)	Geoffrey O. Thompson , <i>Working Group Chair</i> Gary Robinson , <i>Maintenance Chair</i>
IEEE Std 802.3t-1995, 120 Ω informative annex to 10BASE-T	14 June 1995 (IEEE) 12 January 1996 (ANSI)	Geoffrey O. Thompson , <i>Working Group Chair</i> Jacques Christ , <i>Task Force Chair</i>
IEEE Std 802.3u-1995 (Clauses 21–30), Type 100BASE-T MAC param- eters, Physical Layer, MAUs, and Repeater for 100 Mb/s Operation	14 June 1995 (IEEE) 4 April 1996 (ANSI)	Geoffrey O. Thompson , <i>Working Group Chair</i> Peter Tarrant , <i>Task Force Chair (Phase 1)</i> Howard Frazier , <i>Task Force Chair (Phase 2)</i> Paul Sherer , <i>Task Force Editor-in-Chief (Phase 1)</i> Howard Johnson , <i>Task Force Editor-in-Chief (Phase 2)</i> Colin Mick , <i>Task Force Comment Editor</i>
IEEE Std 802.3v-1995, 150 Ω informative annex to 10BASE-T	12 December 1995 (IEEE) 16 July 1996 (ANSI)	Geoffrey O. Thompson , <i>Working Group Chair</i> Larry Nicholson , <i>Task Force Chair</i>
IEEE Std 802.3x-1997 and IEEE Std 802.3y-1997 (Revi- sions to IEEE Std 802.3, Clauses 31 and 32), Full- Duplex Operation and Type 100BASE-T2	20 March 1997 (IEEE) 5 September 1997 (ANSI)	Geoffrey O. Thompson , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Rich Seifert , <i>Task Force Chair and Editor (802.3x)</i> J. Scott Carter , <i>Task Force Chair (802.3y)</i> Colin Mick , <i>Task Force Editor (802.3y)</i>
IEEE Std 802.3z-1998 (Clauses 34–39, 41–42), Type 1000BASE-X MAC Param- eters, Physical Layer, Repeater, and Management Parameters for 1000 Mb/s Operation	25 June 1998 (IEEE)	Geoffrey O. Thompson , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Howard M. Frazier, Jr. , <i>Task Force Chair</i> Howard W. Johnson , <i>Task Force Editor</i>
IEEE Std 802.3aa-1998, Maintenance 5	25 June 1998 (IEEE)	Geoffrey O. Thompson , <i>Working Group Chair</i> Colin Mick , <i>Task Force Editor</i>

IEEE Std 802.3 document	Date approved by IEEE and ANSI	Officers at the time of working group ballot
IEEE Std 802.3ab-1999 (Clause 40), Physical Layer Parameters and Specifications for 1000 Mb/s Operation Over 4 Pair of Category 5 Balanced Copper Cabling, Type 1000BASE-T	26 June 1999 (IEEE)	Geoffrey O. Thompson , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Robert M. Grow , <i>Working Group Secretary</i> George Eisler , <i>Task Force Chair</i> Colin Mick , <i>Task Force Editor</i>
IEEE Std 802.3ac-1998, Frame Extensions for Virtual Bridged Local Area Network (VLAN) Tagging on IEEE 802.3 Networks	16 September 1998 (IEEE)	Geoffrey O. Thompson , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Andy J. Luque , <i>Working Group Secretary</i> Ian Crayford , <i>Task Force Chair</i> Rich Seifert , <i>Task Force Editor</i>
IEEE Std 802.3ad-2000 (Clause 43), Aggregation of Multiple Link Segments	30 March 2000 (IEEE)	Geoffrey O. Thompson , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Robert M. Grow , <i>Working Group Secretary</i> Steven Haddock , <i>Task Force Chair</i> Tony Jeffree , <i>Task Force Co-Editor</i> Rich Seifert , <i>Task Force CoEditor</i>
IEEE Std 802.3-2002 (IEEE 802.3ag, Maintenance 6, Revision of the base), Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access method and Physical Layer specifications	14 January 2002 (IEEE)	Geoffrey O. Thompson , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Robert M. Grow , <i>Working Group Secretary</i>
IEEE Std 802.3ae-2002, (Clauses 44–53) Media Access Control (MAC) Parameters, Physical Layers, and Management Parameters for 10 Gb/s Operation	13 June 2002 (IEEE)	Geoffrey O. Thompson , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Robert M. Grow , <i>Working Group Secretary</i> R. Jonathan Thatcher , <i>Task Force Chair</i> Stephen Haddock , <i>Task Force Vice Chair</i> Bradley J. Booth , <i>Task Force Editor</i> Lacreshia Laningham , <i>Task Force Assistant Editor</i> Benjamin Brown , <i>Logic Track Chair</i> Walter Thirion , <i>Optical Track Chair</i>
IEEE Std 802.3af-2003, (Clause 33) Data Terminal Equipment (DTE) Power via Media Dependent Interface (MDI)	12 June 2003 (IEEE)	Geoffrey O. Thompson , <i>Working Group Chair (Phase 1)</i> Robert M. Grow , <i>Working Group Chair (Phase 2)</i> David J. Law , <i>Working Group Vice Chair</i> Robert M. Grow , <i>Working Group Secretary (Phase 1)</i> Steven B. Carlson , <i>Working Group Secretary (Phase 2)</i> Steven B. Carlson , <i>Task Force Chair</i> Michael S. McCormack , <i>Task Force Editor (Phase 1)</i> John J. Jetzt , <i>Task Force Editor (Phase 2)</i> Chad M. Jones , <i>Task Force Comment Editor</i>
IEEE Std 802.3ah-2004, Media Access Control Parameters, Physical Layers, and Management Parameters for Subscriber Access Networks	6 April 2005 (IEEE)	Robert M. Grow , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Steven B. Carlson , <i>Working Group Secretary</i> Howard Frazier , <i>Task Force Chair</i> Wael W. Diab , <i>Task Force Editor-in-Chief</i> Hugh Barrass , <i>Task Force Vice-Chair</i> Scott Simon , <i>Task Force Recording Secretary</i> Behrooz Rezvani , <i>Task Force Executive Secretary</i>
IEEE Std 802.3aj-2003, Maintenance 7	11 September 2003 (IEEE)	Robert M. Grow , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair, Task Force Chair</i> Steven B. Carlson , <i>Working Group Secretary</i> Catherine K. N. Berger , <i>Task Force Editor</i>
IEEE Std 802.3ak-2004, Physical Layer and Management Parameters for 10Gb/s Operation, Type 10GBASE-CX4	9 February 2004 (IEEE)	Robert M. Grow , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Steven B. Carlson , <i>Working Group Secretary</i> Daniel J. Dove , <i>Task Force Chair</i> Howard A. Baumer , <i>Task Force Editor</i>

IEEE Std 802.3 document	Date approved by IEEE and ANSI	Officers at the time of working group ballot
IEEE Std 802.3-2005 (IEEE 802.3REVam, Revision of the base), Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access method and Physical Layer specifications	9 June 2005 (IEEE)	Robert M. Grow , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Wael W. Diab , <i>Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Piers Dawe , <i>Review Editor</i>
IEEE Std 802.3an-2006, Physical Layer and Management Parameter for 10 Gb/s Operation, Type 10GBASE-T	8 June 2006 (IEEE)	Robert M. Grow , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Wael William Diab , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Bradley Booth , <i>Task Force Chair</i> Sanjay Kasturia , <i>Task Force Editor-in-Chief</i> George Eisler , <i>Task Force Recording Secretary</i>
IEEE Std 802.3ap-2007, Ethernet Operation over Electrical Backplanes	22 March 2007 (IEEE)	Robert M. Grow , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice-Chair</i> Wael W. Diab , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Bradley Booth , <i>Working Group Treasurer</i> Adam Healey , <i>Task Force Chair</i> John D'Ambrosia , <i>Task Force Secretary</i> Schelto vanDoorn , <i>Task Force Editor-in-Chief (Phase 1)</i> Ilango S. Ganga , <i>Task Force Editor-in-Chief (Phase 2)</i>
IEEE Std 802.3aq-2006, Physical Layer and Management Parameters for 10 Gb/s Operation, Type 10GBASE-LRM	15 September 2006 (IEEE)	Robert M. Grow , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Wael William Diab , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> David G. Cunningham , <i>Task Force Chair</i> Nick Weiner , <i>Task Force Editor</i> Piers Dawe , <i>Task Force Contributing Editor</i>
IEEE Std 802.3as-2006, Frame format extensions	15 September 2006 (IEEE)	Robert M. Grow , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair</i> Wael William Diab , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Kevin Q. Daines , <i>Task Force Chair</i> Glenn W. Parsons , <i>Task Force Editor</i>
IEEE Std 802.3-2005/Cor 1-2006 (IEEE 802.3au), DTE Power via MDI Isolation corrigendum	8 June 2006 (IEEE)	Robert M. Grow , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair; Task Force Editor</i> Wael W. Diab , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i>
IEEE Std 802.3-2005/Cor 2-2007 (IEEE 802.3aw), 10GBASE-T corrigendum	7 June 2007 (IEEE)	Robert M. Grow , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair; Task Force Editor</i> Wael W. Diab , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Bradley Booth , <i>Working Group Treasurer</i>
IEEE Std 802.3-2008 (IEEE 802.3ay), Maintenance #9 (Revision of the base), Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access method and Physical Layer specifications	26 September 2008 (IEEE)	Robert M. Grow , <i>Working Group Chair</i> David J. Law , <i>Working Group Vice Chair; Task Force Editor</i> Wael William Diab , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Bradley Booth , <i>Working Group Treasurer</i>
IEEE Std 802.3at-2009 Data Terminal Equipment (DTE) Power via the Media Dependent Interface (MDI) Enhancements	11 September 2009 (IEEE)	David J. Law , <i>Working Group Chair</i> Wael William Diab , <i>Working Group Vice Chair</i> Adam Healey , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Bradley Booth , <i>Working Group Treasurer</i> Mike McCormack , <i>Task Force Chair</i> D. Matthew Landry , <i>Task Force Chief Editor</i> Chad Jones , <i>Task Force Comment Editor</i>

IEEE Std 802.3 document	Date approved by IEEE and ANSI	Officers at the time of working group ballot
IEEE Std 802.3av-2009 Physical Layer Specifications and Management Parameters for 10 Gb/s Passive Optical Networks	11 September 2009 (IEEE)	David J. Law , <i>Working Group Chair</i> Wael William Diab , <i>Working Group Vice Chair</i> Adam Healey , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Bradley Booth , <i>Working Group Treasurer</i> Glen Kramer , <i>Task Force Chair</i> Duane Remein , <i>Task Force Chief Editor</i> Marek Hajduczenia , <i>Task Force Assistant Editor</i>
IEEE Std 802.3az-2010 Media Access Control Parameters, Physical Layers, and Management Parameters for Energy-Efficient Ethernet	30 September 2010 (IEEE)	David J. Law , <i>Working Group Chair</i> Wael William Diab , <i>Working Group Vice Chair</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Adam Healey , <i>Working Group Secretary</i> Bradley Booth , <i>Working Group Treasurer</i> Michael Bennett , <i>Task Force Chair</i> Sanjay Kasturia , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3ba Media Access Control Parameters, Physical Layers, and Management Parameters for 40 Gb/s and 100 Gb/s Operation	17 June 2010 (IEEE)	David J. Law , <i>Working Group Chair</i> Wael William Diab , <i>Working Group Vice-Chair</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Adam Healey , <i>Working Group Secretary</i> Bradley Booth , <i>Working Group Treasurer</i> John D'Ambrosia , <i>Task Force Chair</i> Ilango S. Ganga , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3-2008/Cor 1- 2009 (IEEE 802.3bb) Pause Reaction Delay Corrigendum.	9 December 2009 (IEEE)	David J. Law , <i>Working Group Chair</i> Wael William Diab , <i>Working Group Vice-Chair</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Adam Healey , <i>Working Group Secretary</i> Bradley Booth , <i>Working Group Treasurer</i>
IEEE Std 802.3bc-2009 Ether- net Organizationally Specific Type, Length, Value (TLVs)	11 September 2009 (IEEE)	David J. Law , <i>Working Group Chair and Task Force Editor</i> Wael W. Diab , <i>Working Group Vice Chair, Task Force Chair</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Adam Healey , <i>Working Group Secretary</i> Bradley Booth , <i>Working Group Treasurer</i>
IEEE Std 802.3bd-2011 MAC Control Frame for Priority- based Flow Control	16 June 2011 (IEEE)	Tony Jeffree , <i>IEEE 802.1 Working Group Chair</i> Paul Congdon , <i>IEEE 802.1 Working Group Vice Chair</i> David J. Law , <i>IEEE 802.3 Working Group Chair</i> Wael W. Diab , <i>IEEE 802.3 Working Group Vice Chair</i> Pat Thaler , <i>Data Center Bridging Task Group Chair</i>
IEEE Std 802.3bf-2011 Media Access Control (MAC) Service Interface and Management Parameters to Support Time Synchronization Protocols	16 May 2011 (IEEE)	David J. Law , <i>Working Group Chair</i> Wael William Diab , <i>Working Group Vice-Chair</i> Adam Healey , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Steven B. Carlson , <i>Task Force Chair</i> Marek Hajduczenia , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3bg-2011 Physical Layer and Management Parameters for Serial 40 Gb/s Ethernet Operation Over Single-Mode Fiber	31 March 2011 (IEEE)	David J. Law , <i>Working Group Chair</i> Wael William Diab , <i>Working Group Vice-Chair</i> Adam Healey , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Mark Nowell , <i>Task Force Chair</i> Pete Anslow , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3-2012 (IEEE 802.3ah), Maintenance #10 (Revision of the base), Standard for Ethernet	28 December 2012 (IEEE)	David J. Law , <i>Working Group Chair</i> Wael William Diab , <i>Working Group Vice-Chair, Task Force Chair and Editor-in-Chief</i> Adam Healey , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasure</i>
IEEE Std 802.3bk-2013 Physical Layer Specifications and Management Parameters for Extended Ethernet Passive Optical Networks	23 August 2013 (IEEE)	David J. Law , <i>Working Group Chair</i> Wael William Diab , <i>Working Group Vice-Chair</i> Adam Healey , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Marek Hajduczenia , <i>Task Force Chair</i> Susumu Nishihara , <i>Task Force Editor-in-Chief</i>

IEEE Std 802.3 document	Date approved by IEEE and ANSI	Officers at the time of working group ballot
IEEE Std 802.3bj-2014 Physical Layer Specifications and Management Parameters for 100 Gb/s Operation Over Backplanes and Copper Cables	12 June 2014 (IEEE)	David J. Law , <i>Working Group Chair</i> Wael William Diab , <i>Working Group Vice-Chair (initial)</i> Adam Healey , <i>Working Group Secretary (initial)</i> , <i>Task Force Editor-in-Chief (initial)</i> , <i>Working Group Vice-Chair (final)</i> , <i>Task Force Chair (final)</i> Pete Anslow , <i>Working Group Secretary (final)</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> John D'Ambrosia , <i>Task Force Chair (initial)</i> Matthew Brown , <i>Task Force Editor-in-Chief (final)</i>
IEEE Std 802.3bm-2015 Physical Layer Specifications and Management Parameters for 40 Gb/s and 100 Gb/s Operation Over Fiber Optic Cables	16 February 2015 (IEEE)	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary and Task Force Editor-in-Chief</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Dan Dove , <i>Task Force Chair</i> Kapil Shrikhande , <i>Task Force Vice-Chair</i>
IEEE Std 802.3-2015 (IEEE 802.3bx), Maintenance #11 (Revision of the base), Standard for Ethernet	3 September 2015	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair, Task Force Chair, and Task Force Editor-in-Chief</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i>
IEEE Std 802.3bw-2015 Physical Layer Specifications and Management Parameters for 100 Mb/s Operation over a Single Balanced Twisted Pair Cable (100BASE-T1)	26 October 2015	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary and Task Force Chair, Phase 2</i> Valerie Maguire , <i>Working Group Treasurer</i> Thomas Hogenmüller , <i>Task Force Chair, Phase 1</i> Mehmet Tazebay , <i>Task Force Vice-Chair</i> Curtis Donahue , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3by-2016 Media Access Control Parameters, Physical Layers, and Management Parameters for 25 Gb/s Operation	30 June 2016	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Mark Nowell , <i>Task Force Chair</i> Matthew Brown , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3bq-2016 Physical Layers and Management Parameters for 25 Gb/s and 40 Gb/s Operation, Types 25GBASE-T and 40GBASE-T	30 June 2016	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> David Chalupsky , <i>Task Force Chair</i> George Zimmerman , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3bp-2016 Physical Layer Specifications and Management Parameters for 1 Gb/s Operation over a Single Twisted-Pair Copper Cable	30 June 2016	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary and Task Force Chair</i> Valerie Maguire , <i>Working Group Treasurer</i> Marek Hajduczenia , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3br-2016 Specification and Management Parameters for Interspersing Express Traffic	30 June 2016	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Ludwig Winkel , <i>Task Force Chair</i> Patricia Thaler , <i>Task Force Editor-in-Chief</i>

IEEE Std 802.3 document	Date approved by IEEE and ANSI	Officers at the time of working group ballot
IEEE Std 802.3bn-2016 Physical Layer Specifications and Management Parameters for Ethernet Passive Optical Networks Protocol over Coax	22 September 2016	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Mark Laubach , <i>Task Force Chair</i> Duane Remein , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3bz-2016 Media Access Control Parameters, Physical Layers, and Management Parameters for 2.5 Gb/s and 5 Gb/s Operation, Types 2.5GBASE-T and 5GBASE-T	22 September 2016	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> David Chalupsky , <i>Task Force Chair</i> George Zimmerman , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3bu-2016 Physical Layer and Management Parameters for Power over Data Lines (PoDL) of Single Balanced Twisted-Pair Ethernet	7 December 2016	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Dave Dwelley , <i>Task Force Chair, Phase 1</i> Dan Dove , <i>Task Force Chair, Phase 2</i> Andy Gardner , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3bv-2017 Physical Layer Specifications and Management Parameters for 1000 Mb/s Operation Over Plastic Optical Fiber	14 February 2017	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Robert M. Grow , <i>Task Force Chair</i> Rubén Pérez-Aranda , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3-2015/Cor 1-2017 (IEEE Std 802.3ce) Multilane Timestamping	23 March 2017	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair, Task Force Chair, and Task Force Editor-in-Chief</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i>
IEEE Std 802.3bs-2017 Media Access Control Parameters, Physical Layers, and Management Parameters for 200 Gb/s and 400 Gb/s Operation	6 December 2017	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary and Task Force Editor-in-Chief</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> John D'Ambrosia , <i>Task Force Chair</i>
IEEE Std 802.3cc-2017 Physical Layer and Management Parameters for Serial 25 Gb/s Ethernet Operation Over Single-Mode Fiber	6 December 2017	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> David Lewis , <i>Task Force Chair</i> Kohichi R. Tamura , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3cb-2018 Physical Layer Specifications and Management Parameters for 2.5 Gb/s and 5 Gb/s Operation over Backplane	27 September 2018	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Yong Kim , <i>Task Force Chair, Phase 1</i> Daniel F. Smith , <i>Task Force Chair, Phase 2</i> William Lo , <i>Task Force Editor-in-Chief, Phase 1</i> Daniel F. Smith , <i>Task Force Editor-in-Chief, Phase 2</i>

IEEE Std 802.3 document	Date approved by IEEE and ANSI	Officers at the time of working group ballot
IEEE Std 802.3bt-2018 Physical Layer and Management Parameters for Power over Ethernet over 4 pairs	27 September 2018	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Chad Jones , <i>Task Force Chair</i> Koussalya Balasubramanian , <i>Task Force Editor-in-Chief, Phase 1</i> Lennart Yseboodt , <i>Task Force Editor-in-Chief, Phase 2</i>
IEEE Std 802.3cd-2018 Media Access Control Parameters for 50 Gb/s and Physical Layers and Management Parameters for 50 Gb/s, 100 Gb/s, and 200 Gb/s Operation	5 December 2018	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Mark Nowell , <i>Task Force Chair</i> Matt Brown , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3cn-2019 Physical Layers and Management Parameters for 50 Gb/s, 200 Gb/s, and 400 Gb/s Operation over Single-Mode Fiber	7 November 2019	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary and Task Force Editor-in-Chief</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> John D'Ambrosia , <i>Task Force Chair</i>
IEEE Std 802.3cg-2019 Physical Layers Specifications and Management Parameters for 10 Mb/s Operation and Associated Power Delivery over a Single Balanced Pair of Conductors	7 November 2019	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> George Zimmerman , <i>Task Force Chair</i> Valerie Maguire , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3cq-2020 Maintenance #13: Power over Ethernet over 2 pairs	30 January 2020	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Chad Jones , <i>Task Force Chair</i> Lennart Yseboodt , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3cm-2020 Physical Layer and Management Parameters for 400 Gb/s over Multimode Fiber	30 January 2020	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Robert Lingle, Jr. , <i>Task Force Chair</i> Jonathan P. King , <i>Task Force Editor-in-Chief, Phase 1</i> Jonathan D. Ingham , <i>Task Force Editor-in-Chief, Phase 2</i>
IEEE Std 802.3ch-2020 Physical Layer Specifications and Management Parameters for 2.5 Gb/s, 5 Gb/s, and 10 Gb/s Automotive Electrical Ethernet	4 June 2020	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary, Phase 1</i> Jon Lewis , <i>Working Group Secretary, Phase 2</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Steven B. Carlson , <i>Task Force Chair</i> Natalie Wienckowski , <i>Task Force Editor-in-Chief</i>
IEEE Std 802.3ca-2020 Physical Layer Specifications and Management Parameters for 25 Gb/s and 50 Gb/s Passive Optical Networks	4 June 2020	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Pete Anslow , <i>Working Group Secretary, Phase 1</i> Jon Lewis , <i>Working Group Secretary, Phase 2</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Curtis Knittle , <i>Task Force Chair</i> Glen Kramer , <i>Task Force Vice-Chair</i> Marek Hajduczenia , <i>Task Force Editor-in-Chief</i>

IEEE Std 802.3 document	Date approved by IEEE and ANSI	Officers at the time of working group ballot	
IEEE Std 802.3cr-2021 Maintenance #14: Isolation	9 February 2021	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Jon Lewis , <i>Working Group Secretary, Task Force Chair, and Task Force Editor</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i>	
IEEE Std 802.3cu-2021 Physical Layers and Management Parameters for 100 Gb/s and 400 Gb/s Operation over Single-Mode Fiber at 100 Gb/s per Wavelength	9 February 2021	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Jon Lewis , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Mark Nowell , <i>Task Force Chair</i> Gary Nicholl , <i>Editor-in-Chief</i>	
IEEE Std 802.3cv-2021 Maintenance #15: Power over Ethernet	9 May 2021	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Jon Lewis , <i>Working Group Secretary and Task Force Editor-in-Chief</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Chad Jones , <i>Task Force Chair</i>	
IEEE Std 802.3ct-2021 Physical Layers and Management Parameters for 100 Gb/s Operation over DWDM Systems	16 June 2021	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Jon Lewis , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> John D'Ambrosia , <i>Task Force Chair</i> Tom Issenhuth , <i>Task Force Editor-in-Chief</i>	
IEEE Std 802.3cp-2021 Bidirectional 10 Gb/s, 25 Gb/s, and 50 Gb/s Optical Access PHYs	16 June 2021	David J. Law , <i>Working Group Chair</i> Adam Healey , <i>Working Group Vice-Chair</i> Jon Lewis , <i>Working Group Secretary</i> Steven B. Carlson , <i>Working Group Executive Secretary</i> Valerie Maguire , <i>Working Group Treasurer</i> Frank Effenberger , <i>Task Force Chair</i> Duane Remein , <i>Task Force Editor-in-Chief, Phase 1</i> Yuanqiu Luo , <i>Task Force Editor-in-Chief, Phase 2</i>	
Abaye, Ali	Albrecht, Alan	Anderson, Paul	Astorg, Jean-Pierre
Abbas, Fazal	Albright, Keith	Anderson, Richard	Atace, Mehran
Abbas, Ghani	Alderrou, Don	Anderson, Stephen D.	Atias, Ilan
Abbott, John S.	Alexander, Jan	Anderson, Stephen J.	Augusta, Steve
Abbott, Justin	Alexander, Thomas	Anderson, Tony	Auld, Phil
Abedmamoore, Hamlet	Ali, Abe	Andersson, Ralph	Ayandeh, Siamack
Abler, Joe	Allard, Michel	Andrae, Stefan	Azadet, Kameran
Abraham, Menachem	Allen, Brad	Andresen, Jack S.	Babanezhad, Joseph N.
Abramson, David	Allen, David	Andrewartha, J. Michael	Babenko, Oleksandr
AbuGhazaleh, Shadi	Allen, John	Angha, Ali	Babla, Chet
Adams, Martin	Alon, Zehavit	Anslo, Peter	Baca, Richard
Adriaenssens, Luc	Alping, Arne	Antz, Ekkehard	Bachand, Gerard E.
Aekins, Rob	Altman, Michael	Aono, Michikazu	Baden, Eric
Aelmore, Don	Alush, Yehuda	Arai, Ken-ichi	Back, Kwang-Hyun
Agarwal, Puneet	Amason, Dale	Araki, Nobuyasu	Baggett, Tim
Agata, Akira	Amavisca, Karen	Armijo, Bert	Bains, Amrik
Agazzi, Oscar	Ambrose, Andrew	Armstrong, Mike	Bala, Guna
Agee, John R.	Amer, Khaled	Armstrong, Susie	Balakrishnam, R. V.
Aggarwal, Nand	Amin, Nitish	Arnold, Brian	Balasubramanian, Koussalya
Agnes, Andrea	Amleshi, Peerouz	Aronson, Joseph	Balasubramanian, Vittal
Ahmad, Faisal	Amundsen, Keith	Aronson, Lewis B.	Baldman, Andy
Ahmed, Mohammad	An, Hongming	Aronson, Simcha	Baldwin, Thananya
Ahrens, Paul	Andersen, Ole Christian	Arst, Phil L.	Balmer, Keith
Akasaka, Youichi	Anderson, Arlan J.	Artman, Doug	Balsby, Mogens Cash
Akella, Vish	Anderson, Eric	Arunarathi, Venkat	Bandali, Bruce
Alavi, Reza	Anderson, Jon	Asmussen, Jes	Bandyopadhyay, Jaya

Barazande-Pour, Majid	Bouzaglo, Sidney	Campbell, Bob	Cideciyan, Roy
Barbero, Fernando	Bovill, Kirk	Campbell, Peter	Claessen, Albert
Barkan, Ozdal	Bowerman, John	Campbell, Robert R.	Claessen, Guss
Barker, Ian	Bowers, Richard	Canavese, Luigi	Clancy, G. J.
Barnea, Eyal	Boyd, Edward	Carlo, James T.	Clark, Brice
Barnett, Barry	Boyer, Rich	Carlson, Craig	Clarke, Susan Roden
Barnette, Jim	Bradshaw, Peter	Carlson, Steven B.	Claseman, George
Barr, David	Braga, Al	Carnine, Dan	Cobb, Terry
Barrass, Hugh	Brand, Richard	Carroll, J. Martin	Coden, Michael
Barrett, Bob	Brandner, Rudolf	Carter, J. Scott	Coffey, Kelly B.
Barrick, Scott	Brandt, David	Carty, Clark	Cohen, Larry
Bartur, Meir	Braun, Ralf-Peter	Casher, Patrick	Cole, Christopher R.
Barzilai, Yoram	Brehove, Richard S.	Castellano, Andrew	Coleman, Doug
Bates, Stephen	Breuer, Dirk	Cates, Ron	Colla, Régis
Baumer, Howard	Brewer, Steve	Catlin, Jeffrey D.	Cone, Kevin
Baumgartner, Steven	Bridge, Robert F.	Chabot, Craig	Congdon, Herbert V.
Beaudoin, Denis	Bridgers, Vince	Chacon Simon, Geoffrey	Congdon, Paul
Beauregard, Francois	Brier, Dave	Chadha, Mandeep	Conlon, Patrick
Beck, Michaël	Brierley-Green, Andrew	Chalupsky, David	Connor, Don
Beckwith, Jonathan	Brikovskis, Rhett	Champion, Bruce	Conroy, Keith
Beia, Christian	Brill, Charles	Chang, Edward	Conte, Robert
Beili, Edward	Brillhart, Theodore	Chang, Edward G.	Cook, Charles I.
Beliaev, Alexei	Brink, Robert D.	Chang, Edward S.	Cooper, Ronald J.
Belknap, William	Brooks, Paul	Chang, Frank	Cooper, Stephen
Bello, Eran	Brooks, Rick	Chang, Fuhlim	Coote, Neil
Belopolsky, Yakov	Brophy, Timothy	Chang, Jacky	Cornejo, Edward
Below, Randy J.	Brown, Alan M.	Chang, Justin	Crane, Ronald
Bemmel, Vincent	Brown, Benjamin	Chang, Kiwon	Cravens, George
Ben-Artzi, Liav	Brown, Daniel J.	Chang, Luke	Crayford, Ian
Bennett, Michael	Brown, Dave	Chang, Samuel	Creigh, John
Bennett, Richard	Brown, David	Chang, Sun-Hyok	Crepin, J. Francois
Benson, Miles	Brown, Jack	Chang, Xin	Cronin, Bill
Bergey, Chris	Brown, Kevin	Chantrell, Thomas	Cross, Peter
Berglund, Sidney	Brown, Matthew	Charney, Howard	Cross, Richard
Bergmann, Ernest E.	Brown, Suzy	Chen, Chan	Cruikshank, Brian
Bergstrom, April	Brown, Thomas	Chen, Chung-Jue	Crupnicoff, Diego
Berman, David J.	Brownlee, Phillip	Chen, David	Cuesta, Emilio
Bernstein, Gary	Bruckman, Leon	Chen, Jian	Cui, Kai
Bertoldi, Roberto	Brunn, Brian	Chen, Xiaopeng	Cullerot, David
Beruto, Piergiorgio	Brunner, Robert	Chen, Zinan (Nan)	Cullin, Chris
Bestel, John L.	Brychta, Michal	Cheng, Linda	Cunningham, David G.
Bethune, Dave	Buck, Steve F.	Cheng, Weiying	Curcio, Joe
Bevilacqua, John	Buckman, Lisa	Cheng, Wheling	Curtis, Robert A.
Bhagwat, Gitesh	Bugg, Mark	Cheong, Kok-Wui	Cushin, Simon
Bhatt, Vipul	Bullock, Chris	Cherubini, Giovanni	Dabiri, Dariush
Bhoja, Sudeep	Bulnes, Juan	Cherukuri, Rao	Dahlgren, Robert
Bhugra, Harmmeet	Bunch, Bill	Chiang, Albert	Dahmouh, Saleem
Bialkowski, Jan	Burgess, James	Chin, David	Dai, Eugene
Binder, James	Burrell, Gary	Chin, Hon Wah	Dai, Shaoan
Birenbaum, Larry	Burton, Scott	Chini, Ahmad	Daido, Fumio
Bisberg, Jeff E.	Busse, Robert A.	Cho, Jae hun	Daines, Bernard
Bliss, William	Bustos Heredia, Jairo	Choi, Francis	Daines, Kevin Q.
Bo, Gao	Butler, Thomas T.	Choi, Jin-Seek	Dallesasse, John
Bohbot, Michel	Butter, Adrian	Chopra, Rahul	Dalmia, Kamal
Bohm, Mark	Bynum, Roy	Chou, Joseph	D'Ambrosia, John
Bohrer, Mark	Cady, Ed	Choudhury, Golam	Damouny, Nabil
Bonnamy, Jean-Michel	Cafiero, Luca	Chow, Jacky	Dance, Rupert S.
Booth, Bradley J.	Caggioni, Francesco	Chow, Kuen	Darby, Mark
Booth, Paul	Cagle, John	Choy, Henry	Darling, Mike
Bordogna, Mark	Cain, Jeffrey C.	Christ, Chris	Darshan, Yair
Bottorff, Paul	Calbone, Anthony	Christ, Jacques	Dartnell, Peter
Boucino, Thomas J.	Calderon, Juan-Carlos	Chu, George	Datta, Subrata
Bouda, Martin	Caldwell, Donald	Chuang, Keng Hua	Davidson, John
Bourche, Samuel	Caldwell, Maurice	Chung, Hwan-Seok	Davies, David
Bourque, David	Calvin, John	Chzh, Yue-Der	Davis, Edward

Dawe, Peter	Dupuis, Joseph E.	Figueira, Norival	Goergen, Joel
Dawe, Piers J. G.	Dupuis, Marc R.	Figueroa, Juan	Goetz, Franz
Dawson, Fred	Dwellely, David	Finch, Robert G.	Goetzfried, Volker
De Andrea, John	Easley, J. Craig	Finn, Norman	Golbert, Adi
de Graaf, Kathryn	Eastman, Paul	Firoozmand, Farzin	Golden, Glenn
de Grace, Gerald	Ebeling, Jeff	Fischer, David	Goldis, Moty
de la Garrigue, Michael	Ecclesine, Peter	Fischer, Thomas	Goldman, Matthew
De Leon, Moshe	Eckert, Edward J.	Fitzgerald, John	Gong, Zhigang
Deandrea, John	Eddings, Clay	Flatman, Alan	Goodman, Timothy D.
Dearing, Mark	Edholm, Phil	Flickinger, Steve	Goody, Steve
Debbasch, Bernard O.	Edsall, Tom	Folkens, Norbert	Gore, Brandon
deBie, Michael	Edwards, Dean	Folting, Christian G.	Gorshe, Steven
Debiec, Tom	Edwards, Gareth	Forbes, Harry	Goswami, Sanjay
DeCramer, John	Effenberger, Frank J.	Ford, Brian	Goto, Hideki
Dedic, Ian	Egan, John	Franchuk, Brian	Gottron, Jens
Dedrick, Joel	Eiliya, Herman	Fransen, Richard	Graba, James
Deffley, Steve	Eisler, George	Fraser, Roger	Graber, Steffen
Delaney, Dave	Eitel, Cornelia	Frazier, Howard M.	Graham, Rich
De-Leon, Moshe	Elbakoury, Hesham	Frazier, Robert	Granger, Russ
Delveaux, William	Elhøj, Martin	Freitag, Ladd	Grann, Eric B.
DeMent, Ralph	Elie-Dit-Cosaque, David	Friedenbach, Ken	Grasmehr, Tom
den Besten, Gerrit	Elliff, Kevin M.	Fritsche, Matthias	Grau, Olaf
DeNicholas, Joe	Elswick, Michael	Fritz, Scott	Gray, C. Thomas
DeNicolò, Tazio M.	Ely, Paul “Skip”	Frojd, Krister	Gray, Eric
Desai, Sanjay	Ely, Richard	Froke, Richard	Green, Larry
Desanti, Claudio	English, Kent	Fromm, Ingrid	Green, Martin
Desaulniers, Peter	Ennis, Gregory	Frosch, Richard	Greenlaw, Jonathan E.
Devon, Mark	Enrico, Gianfranco	Fu, Hongyan	Gregory, Bryan
Dhawan, Sanjay	Ensign, Brian S.	Fu, Shiyong	Grenier, Richard
Di Minico, Chris	Erba, Simone	Fuess, Judy	Grewal, Karanvir
Diab, Wael William	Erbacher, Norman	Fujimoto, Yukihiro	Grimwood, Michael R.
Diamond, Patrick	Esmailian, Tooraj	Fukuoka, Atsuhisa	Grivna, Edward
DiBiao, Eric	Esser, Nick	Fukuoka, Takashi	Grow, Robert M.
Dickens, Erik	Essig, Daniel	Fuller, John	Gubow, Martin
Dickinson, John	Estes, David	Furlong, Darrell	Gudz, Robert
Dietz, Bryan	Estrin, Judith	Furlong, Michael	Gulle, Andreas
Dillard, John	Everitt, Jim	Gable, Mel	Gulukota, Karunakar
Dillow, Daniel	Evitts, Steve	Gaglianella, Robert D.	Gummalla, Ajay
Diminico, Christopher	Ewen, John F.	Gaither, Justin	Gumpertz, Richard
Dineen, Thomas J.	Eyal, Massad	Galin, Robert	Gundubogula, Sudhakar
Ding, Zhemin	Fabbri, Richard	Gandhi, Sharad	Gunther, Craig
Dingman, Sean	Fallahi, Siavash	Gandy, Tom	Guo, Bin
Dinh, Thuyen	Faller, Josef	Ganga, Ilango S.	Guo, Yong
Dittler, Hans Peter	Fan, Dawei	Gangopadhy, Robin	Gupta, Sandeep
Djahanshahi, Hormoz	Fanoni, Sabina	Gao, Xiao Ming	Gupta, Sudhir
Dobson, Hamish	Farhoodfar, Arash	Garavaglia, Andrea	Gupta, Tanmay
Dolfi, David W.	Farjad, Ramin	Gardenhour, Clete	Gusat, Mitch
Donahue, Curtis	Farkas, Janos	Gardner, Andrew	Gustafsson, Jonas
Donhowe, Mark	Farley, Rebecca	Gardner, Mike	Gustlin, Mark
Dorris, Hank (H. N.)	Fathi Moghadam, Borhan	Garner, Geoffrey M.	Gyugyi, Paul J.
Dove, Daniel	Fedyk, Donald	Gauthier, Claude	Gyurek, Russ
Doyle, James	Feist, Eldon	Geng, Lemon	Haas, Steven
Draper, Daniel S.	Feldman, Daniel	Gentry, Denton	Hackert, Michael
Dredge, Scott	Feldman, Shahar	George, John	Haddad, Tariq
Drever, Brian	Feng, Dongning	Gerhardt, Floyd H.	Haddock, Stephen
Dreyer, Steve	Feng, Feifei (Felix)	Gerhardt, Keith	Haile-Mariam, Atikem
Dring, John	Ferdun, Severn	Gerhold, Mark	Hajduczenia, Marek
Du, Liang	Ferrant, Jean-Loup	Ghanwani, Anoop	Hakimi, Sharam
Dube, Kathryn	Ferretti, Vincent	Ghiassi, Ali	Hallatt, Clive
Dudek, Michael	Feuerstraeter, Mark	Ghoshal, Sajol	Hamano, Hiroshi
Duelk, Marcus	Feyh, German	Giannakopoulos, Dimitrios	Hamidy, Farid
Duer, Nick	Fiedler, Jens	Giaretta, Giorgio	Hamilton, Kevin
Dugan, Richard	Fiere, Julien	Gilliland, Pat	Hammond, Bernie
Duley, Raymond S.	Fife, James	Ginis, George	Hanigal, Benny
Dunbar, Linda	Fifield, Dave	Glanzner, Martin	Hankins, Greg

Hanna, Charaf	Hochstedler, Charlie	Jelatis, George D.	Katz, Harold W.
Hanna, G. Y.	Hoffner, Charles	Jensen, Ernie	Katzenberg, Boris
Hansen, Chris	Hoge, Jay	Jetzt, John	Kaufman, Dave
Hansen, Johannes	Hogenmueller, Thomas	Jewell, Jack L.	Kaul, Sumesh
Hansen, Mogens	Hoglund, David	Jha, Pankaj	Kawahara, Keisuke
Hanson, Del	Holden, Brian	Jiang, Hongtao	Kawatsu, Yasuaki
Haran, Onn	Hoover, Bryan	Jiang, Jessica Xin	Kayser, Kevin
Hariti, Hacene	Hopkins, Gregory	Jiang, Qiaofeng	Keasler, William
Harkins, Guy	Hopwood, Keith	Jiang, Wenbin	Keeley, James
Harper, Milton C.	Horner, Rita	Jie, Ni	Keen, Hal
Harshbarger, Doug	Horowitz, Steven E.	Jimenez, Andrew C.	Kellam, Paul
Hartley, G. R.	Hormmeyer, Bernd	Jin, Robert	Kelly, N. Patrick
Hartmann, Stephan	Horvat, Michael	Joh, Clarence	Kelsen, Michael
Haser, Alexandra	Hotta, Yoshifumi	Johas Teener, Michael D.	Kennedy, Joe
Hashimoto, Tomohiro	Hou, Victor	John, Richard	Kenny, John J.
Hasley, Lloyd	Hronik, Stanley	Johnson, Donald C.	Kesler, Scott
Hassoun, Marwan	Hsiaw, Henry	Johnson, Howard	Kesling, Dawson
Hatamian, Mehdi	Hsu, Jacob	Johnson, John	Khermosh, Lior
Hatfield, W. B.	Hua, Rui	Johnson, Mize	Khuu, Tuan
Hatley, Tom	Huang, Fred	Johnson, Scott	Kidwell, Gary
Haughey, Stephen	Huang, Liang-wei	Jolly, Cristopher	Kikuta, Tomohiro
Haung, Haw Ming	Huang, Xi	Jones, Chad	Kilcrease, Ket
Hayakawa, Akinori	Huang, Xingang	Jones, Nick	Kilgore, Bob
Hayashi, Takehiro	Huber, Thomas	Jones, Peter	Kim, Chan
Hayden, Kirk	Hudson, Charles	Jones, William W.	Kim, Dae Young
Hayek, Claude	Hudson, Chuck	Jonsson, Ragnar	Kim, Inho
Haynes, Hayden	Hudson, Todd	Jonsson, Ulf	Kim, Jin H.
Hays, Robert	Hughes, Michael	Joo, Bheom-Soon	Kim, Kihong (Joshua)
Hayssen, Carl G.	Hurwitz, Walter K.	Joo, Seong-Soon	Kim, Seung-Hwan
Hazarika, Asif	Huszk, Gergely	Jordan, Anthony	Kim, Su-Hyung
He, Xiang	Huumala, Dean	Jørgensen, Thomas K.	Kim, Yongbum
Healey, Adam	Huynh, Thong	Joseph, Antony	Kimber, Eric
Heath, Jeffrey	Hyakutake, Yasuhiro	Jover, Juan	Kimber, Mark
Hecht, Gaby	Hyer, David W.	Juhász, Imre	Kimmitt, Myles
Heck, Howard	Ichino, Haruhiko	Julyan, Jason	Kimpe, Marc
Heckroth, Jim	Ikeda, Hiroki	Jung, Kwi-Yung	Kimura, Mitsunobu
Heegard, Chris	Ilyadis, Nicholas	Junkers, Dieter W.	Kincaid, John
Hegde, Gopal	Ingham, Jonathan	Jury, Paul	Kind, Bill
Hegde, Rajmohan	Ingrassia, Alessandro	Kabal, David	King, Jonathan P.
Heidasch, Wolfgang	Innis, James	Kabra, Lokesh	King, Neal
Heldman, Ronen	Insler, Romain	Kadambi, Jayant	Kinnard, Brian
Helster, David	Irwin, Scott	Kadry, Haysam	Kinncingham, Alan
Hendel, Ariel	Ishibe, Kazuhiko	Kagami, Manabu	Kipp, Scott G.
Hendel, Itzik	Ishida, Osamu	Kairis, Vic	Kish, Paul
Hennenfent, Susan	Isono, Hideki	Kaku, Shinkyō	Kitayama, Tadayoshi
Herman, Carl	Issenhuth, Tom	Kal, Omer	Klaus, Andrew
Herrity, Ken	Ito, Hiroaki	Kalkunte, Mohan	Klein, Philippe
Herve, Pierre	Iwade, Hirotake	Kalla, Amrit	Klempa, Michael
Hess, David	Iwaoka, Mitsuru	Kalman, Joel S.	Kliger, Avi
Hesson, James H.	Jackson, Kenneth	Kaltenbach, Matt	Knight, Richard
Hickey, John	Jackson, Steve	Kamat, Puru	Knittle, Curtis
Hicks, Chip	Jacobsen, Krista S.	Kamino, John	Ko, Dylan
Hidaka, Yasuo	Jacobson, Michael R.	Kao, Ron	Ko, Mike
Higuchi, Tetsuya	Jacobson, Mike	Kaplan, Hadriel	Kobayashi, Hiroshi
Hiironen, Olli-Pekka	Jadeja, Ajit	Kaps, Rainer	Kobayashi, Shigeru
Hill, John	Jaeger, John M.	Karam, Roger	Kobayashi, Shoukei
Hill, Tricia	Jaffa, Brent	Karandikar, Abhay	Kochuparambil, Elizabeth
Hindi, Sammy	Jain, Raj	Kardontchik, Jaime	Kocsis, Sam
Hingston, William	Jain, Rajeev	Kareti, Upen	Koczwar, Wojciech
Hinrichs, Henry	James, David V.	Kasai, Yuji	Kodama, Satoshi
Hinzel, David	Jang, Eric	Kasapi, Athanasios	Koehler, Daniel
Hirai, Riu	Jang, Woo-Hyuk	Kasey, Allen	Koeman, Henricus
Hirano, Kengo	Janshego, Stephen	Kashyap, Prakash	Koenen, David J.
Hirase, Hidenari	Jedwab, Jonathan	Kasturia, Sanjay	Koenig, Christine
Hirth, Ryan	Jeffree, Tony	Kato, Toyoyuki	Koeppendoerfer, Erwin

Kohl, David E.	Lapak, Jeffrey	Lidinsky, William P.	Maguire, Valerie
Kojima, Keisuke	Lare, Ed	Lim, Jane	Maislos, Ariel
Kola, Srinivas	Lari, Ferdinando	Lim, Seyoun	Makarem, Rabih
Kolesar, Paul F.	Larios, Efstathios	Limb, John O.	Maki, Jeffery J.
Koller, Steven	Larsen, Loren	Lin, Alex	Malicoat, David
Kolze, Tom	Larsen, Wayne	Lin, Chan-De	Malkemus, James
Konda, Kishan Rao	Larson, Donald C.	Lin, George	Malkiman, Yonatan
Kondo, Taiji	Latchman, Ryan	Lin, Ray	Mallette, Edwin
Kono, Masashi	Lau, Tony	Lin, Ru Jian	Malpass, Trey
Kooistra, David	Laubach, Mark	Linde, Yoseph L.	Maltbie, Daniel
Koonce, Derek	Lauck, Tony	Lindquist, Wayne	Mandin, Jeff
Kopera, Paul	LaVigne, Bruce	Lindsay, Thomas A.	Mangin, Jim
Koppermueller, Daniel	Law, David J.	Lindsey, Laurie	Maniloff, Eric
Kosanovich, Keith	Lawrence, Eric	Lingle, Robert	Marchetti, Bob
Koshevoy, Leonid	Lawton, Michael	Lipshteyn, Marina	Marchitto, Luciano
Kosilek, Josef	Laynor, John	Liu, Alexander	Mariotti, Carlo
Kota, Kishore	Le Cheminant, Greg	Liu, Cathy	Marques, Flavio
Kotas, Donald E.	Le Goff, Yannick	Liu, Chang-Chi	Marris, Arthur
Kous, William F.	Le, My	Liu, Dekun	Marsh, Charles
Koyama, Tetsu	Le, Quang	Liu, Fengkun	Marshall, Robert
Kozaki, Seiji	Lebar, Michael	Liu, Hai-Feng	Marsland, Robert A.
Kozilek, Josef	LeCheminant, Greg	Liu, James	Martin, Arlen
Koziuk, Glen	Lee, Arthur	Liu, Karen	Martin, Arlon
Kramer, Glen	Lee, Changoo	Liu, Zhenyu	Martin, David W.
Krent, Daniel	Lee, Chun-Tsung	Livingston, William D.	Martin, Jeff
Krieger, Olaf	Lee, Dong-Soo	Lo, William	Mash, Chris
Krishnamurthy, Subi	Lee, Eugene	Lobel, Martin	Mashiko, Koichiro
Krolner, Lars Paul	Lee, Fu-Ho	Lockyer, Terry	Mason, Scott
Kropp, Joerg-R	Lee, Han Hyub	Logan, Hugh	Masuda, Takeo
Kropveld, Simon	Lee, Hyeong Ho	Lokhandwala, Moiz	Matheus, Kirsten
Kubovcik, George	Lee, Jack	Lomelino, Larry	Mathey, Thomas
Kumada, Taketo	Lee, June Hee	Long, Leland	Matni, Ziad Albert
Kumar, C.	Lee, Kyusang	Lorei, Sherry J.	Matoglu, Erdem
Kumar, Pankaj	Lee, Michael	Lotfi, Jahan	Matola, Laurence
Kumar, Vinod	Lee, Sylvanus	Lott, James A.	Matsuda, Naoki
Kummert, Ted	Lee, Wesley	Lou, Dennis	Matsuda, Shougo
Kundu, Aniruddha	Lee, Ying	Loughry, Don	Matsuo, Hideyuki
Kung, David	Lefebvre, Vincent	Love, Bob	Matthys, Bob
Kuo, Albert	Lefkowitz, Richard	Loveless, Rick	Matz, Bret A.
Kuo, Jeffrey	Lehr, Amir	Lozano, Raul	Mayer, Bob
Kurcharczyk, David	Leizerovich, Hanan	Lu, Ken	Mazor, Joseph
Kurker, Christopher	Lemoff, Brian E.	Lu, Yuchun	Mazzini, Marco
Kuroda, Yasuyuki	Lemon, John	Lucas, Fred A.	McCallum, David S.
Kurokawa, Hidetsune	Lena, Richard	Lucas, James A.	McCammon, Kent
Kusano, Toshihiko	Lenkisch, Andreas	Lukacs, Miklos	McCarron, Philip L.
Kuyt, Gerard	Leo, Lisa	Lum, Meilissa R.	McCarthy, Frank
Kvist, Bengt	Leonowich, Robert H.	Luo, Yuanqiu	McCarthy, Mick
Kwan, Bruce	Lerer, Michael	Luque, Andy J.	McClay, C. Phillip
Kwentus, Alan	Lerniphonphun, Warayot	Lusted, Kent	McClellan, Brett
LaBarre, Lee	Leshem, Amir	Lutz, Sharon	McClellan, Kelly
Labib, Adel Henry	Lessard, Andre	Lynch, Jeffrey	McConnell, Mike
LaCerte, Richard	Leung, Raymond W. K.	Lynn, Mark	McCool, John
Lackner, Hans	Leung, Tommy	Lynskey, Eric R.	McCormack, Michael S.
Lahat, Gadi	Levin, Alex	Lyon, Ian	McCoy, Gary
Laihonen, Kari	Levy, Avinoam	Lysdal, Henning	Mcdermott, Thomas
Lakshmikantha, Ashvin	Lewing, Van	Lyubomirsky, Ilya	McDonald, Andy
Lamb, Lowell D.	Lewis, David	Mace, Gael	McDonough, John
Lambrecht, Frank	Lewis, Jon	Mack-Crane, Ben	McDowell, Jerry
Lamers, Lawrence J.	Lewis, Richard	MacLeod, Brian	McGrath, Jim
Lander, Erik	Li, David	MacLeod, Kenneth	McGugan, Chris
Landry, D. Matthew	Li, Lei	Madani, Sam	McGuire, Alan
Lane, Brett	Li, Mike-Peng	Madgar, Zahy	McIntosh, James
Lane, William	Li, Shaohua	Magee, Anthony	McKechnie, Keith
Langlands, Gordon	Liang, Sam	Maggiolino, Joseph	McMaster, Donna
Langston, Daun	Lichtenegger, Thomas	Magliozzi, Randall	McMillan, Larry

McNarney, Martin	Moustakas, Steven	Norton, Bob	Patel, Bhavesh
McShane, Tim	Mueller, Harald	Noseworthy, Bob	Patel, Dipak M.
McSorley, Greg	Mueller, Thomas	Nouri, Ahmad	Patel, Piyush
McVey, James D.	Mueller, Wayne A.	Nowell, Mark	Patel, Pravin
Measor, Grahame	Muir, Robert	Oakley, Ivan	Patel, Sandeep
Medina, Marcel	Muir, Ron	Obara, Satoshi	Patel, Shashi
Meghelli, Mounir	Mukherjee, Shankar	Oberstar, John	Pathak, Vijay
Mehta, Mukesh	Muller, Shimon	O'Connor, J. Michael	Patoka, Martin
Mei, Richard Y.	Multanen, Eric	Ofelt, David	Paul, Aidan
Meier, Wolfgang	Munson, Carrie	Oganessyan, Gourgen	Paul, Prasun K.
Melendy, Vince	Murakami, Ken	Ogura, Ichiro	Pavlovsky, Alex
Mellitz, Richard	Murphy, Denis	Oh, Stephen	Payne, John
Menachem, Avraham	Murphy, Sean	O'Hara, Steven	Peatfield, Tony
Menuchery, Menucher	Murphy, Thomas	Ohlén, Peter	Peck, Anthony
Merrill, Mark	Murray, Brian	Ohni, Josef	Peers, Neil
Messenger, John	Murray, Dale	Ojha, Raj	Peeters-Weem, Jan P.
Metzger, Jo Beth	Murthy, Narayan	Okabe, Ryo	Peker, Arkadiy
Metzger, Steve	Murthy, Samba	Okada, Mitsuji	Pelissier, Joseph
Meyer, Jeffrey	Murty, Ramana	Oksman, Vladimir	Pelster, Jim
Meyouhas, Yossi	Muscat, Angela	Oliveira, Guy P.	Peng, Wanquan
Mezer, Amir	Musk, Robert	Oliver, Chris	Peng, Y. Lisa
Mi, Guangcan	Muth, Jim	Oliver, Lloyd	Pepeljugoski, Petar
Miao, Tremont	Muyshondt, Henry	Olsen, David	Pepper, Gerald
Micallef, Joseph	Nachman, Yaron	Olsson, Bengt-Erik	Perez De Aranda Alonso, Rubén
Michaelis, Thomas	Nadeau, Gerard	Oltmanns, Mike	Perkins, Drew D.
Michalowski, Richard	Nadolny, James	O'Mahony, Barry	Perrie, Randy
Mick, Colin	Nagahori, Takeshi	OMathuna, Padraig	Pesavento, Gerry
Migueluez, Phil	Naganuma, Ken	Omori, Kumi	Peters, Michael
Milbury, Martin R.	Naidu, Hari	Onodera, Keith	Peters, William R.
Millar, Jim	Nakagawa, Hideki	Ooka, Toshio	Peterson, Brian
Miller, Bruce D.	Nakamine, Wendell	Orlik, Philip	Peterson, David
Miller, C. Kenneth	Nakamoto, Edward	O'Rourke, Aidan	Petrilla, John
Miller, Larry D.	Nakamura, Karl	Ossman, Valy	Pham, Phong
Miller, Martin	Nariya, Makoto	Otaka, Akihiro	Phanse, Abhijit
Misek, Brian	Nazari, Nersi	O'Toole, Michael	Phinney, Thomas L.
Mizrahi, Jacob (Kobi)	Neblett, W. P.	O'Toole, Tony	Picard, Jean
Mlinarsky, Fanny	Nedellec, Erwan	Ouellette, Michel	Piede, David
Moattar, Reza	Neer, Jay	Oughton, George	Piehler, David
Moeller, Merrick	Nelson, Darcy	Oulundsen, George	Pierce, Roy
Moffitt, Bryan	Nelson, James	Overs, Pat	Pieters, Robert
Mohamadi, Fred	Nelson, Kristian	Ozawa, Kazuyuki	Pietilainen, Antti
Mohammadian, Ardeshir	Nering, Raymond	Pace, Paul	Pietsch, Christian
Mohl, Dirk S.	Neulinger, Christian	Pace, Robert R.	Pillai, Velu C.
Molle, Mart L.	Neveux, Paul	Palanzo, Charles	Pimpinella, Rick
Mompoin, Ray	New, Anthony	Palkert, Thomas	Pischl, Neven
Monson, John	Nguyen, Trung	Pan, Hui	Pittala, Fabio
Montenegro, Gabriel	Nguyenphu, Thinh	Pandey, Sujan	Pitzer, Armin
Montojo, Juan	Nicholas, Henry T.	Panguluri, Sessa	Pivonka, Ed
Montreuil, Leo	Nicholl, Gary	Pannell, Donald	Plunkett, Timothy R.
Montstream, Cindy	Nicholl, Shawn	Panos, Bill	Poehmerer, Rainer
Mooney, Paul	Nicholson, Larry	Papandrea, Gabriel D.	Pohl, Christopher
Moore, Charles	Nielsen, Allan	Pardo, Carlos	Poisner, David
Moore, Paul B.	Nikolich, Paul	Parhi, Keshab K.	Pondillo, Peter
Moore, Robert	Nim, David	Park, Chul Soo	Popescu, Petre
Moorwood, Andy	Nishida, Glenn	Park, Jisang	Porat, Hayim
Mora, Matthew	Nishihara, Susumu	Park, Moon	Porter, Jeff
Morales, Octavio	Nishimura, Shinji	Parker, Jim	Posthuma, Carl R.
Mori, Kazuyuki	Noh, George	Parnaby, Gavin	Poston, Bill
Moritake, Toshiyuki	Nojima, Kazuhiro	Parruck, Bidyut	Potter, David
Moriwaki, Shohei	Nolan, John	Parsons, Earl	Potterf, Jason
Morrell, Robert L.	Nolish, Kevin	Parsons, Elwood T.	Pottratz, Kimberly
Morris, John	Noll, Kevin	Parsons, Glenn W.	Powell, Scott R.
Mortonson, Robert	Nomura, Takumi	Parthasarathy, Vasu	Powell, William
Moseley, Simon	Nootbaar, Michael	Paslaski, Joel	Pozzebon, Dino
Moses, Jack	Nordin, Ronald	Pate, Jerry	Prat, Gideon

Prediger, Bernd	Rizk, Ramez	Savara, Raj	Shiino, Masato
Preis, Roland	Rizzolo, Anthony	Savi, Olindo	Shin, Hyungsoo
Printis, Robert S.	Robertson, Iain	Sawano, Hiroshi	Shin, Jong-Yoon
Pritikin, Max	Robinson, Gary	Sawyer, T. Shannon	Shirani, Ramin
Prodan, Richard	Robinson, Steven	Say-Otun, Sabit	Shirao, Mizuki
Proffitt, John	Robinson, Stuart	Sayre, Edward	Shohet, Zion
Pryor, Steve	Rock, Timothy	Schell, J. David	Shorthill, Larry
Qian, Haoli	Rodensky, Michael	Schicketanz, Dieter W.	Shridhar, Avadhani
Quackenbush, William	Rodriguez, A.	Schindler, Frederick	Shrikhande, Kapil
Quast, Holger	Rodriguez, Carlos	Schmidt, Ronald	Shuai, Jialong
Quigley, Tomas J.	Roece, Josef	Schmitt, Matthew	Shukla, Priyank
Quilici, Jim	Rogers, Shawn	Schmitt, Tom	Siegmund, Martin
Quinn, Patrick W.	Rohde, Derek	Schneelee, Stefan	Sikdar, Som
Quirk, John	Romascanu, Dan	Schoenmaker, Peter	Silberman, Nathan
Rabinovich, Rick	Römer, Tume	Scholl, Frederick	Simmons, Tim
Radcliffe, Jerry K.	Rommel, Albrecht	Schramm, Thomas	Simon, Scott
Rado, Ted	Roos, David	Schrans, Thomas	Simsarian, Jesse
Raghavan, Sreen	Rosenthal, Robert	Schreuer, Walter	Singh, Bharat
Rahman, Saifur	Ross, Floyd	Schroeder, Ted	Singh, Charan J.
Rahman, Syed	Ross, Tam	Schube, Scott	Singh, Paramjeet (P. J.)
Rahn, Jurgén	Roszbach, Martin	Schuessler, James	Sirazi, Semir
Rajabzadeh, Mohammad	Roth, Christopher	Schultz, Benjamin	Sivakolundu, Ramesh
Rajkotia, Purva	Rothenberg, Michael	Schulz, Klaus	Skaar, Tom
Raju, Parthasarathy	Rotolo, Salvatore	Schwartz, David	Skorupa, Joseph
Rakib, Shlomo	Rouyer, Jessy	Schwartz, Peter	Skoutas, James P.
Raman, Naresh	Rowell, Tony	Scruton, Peter	Slavick, Jeff
Ramelson, Brian	Roy, Archana	Scull, Harvey R.	Sloan, Dinah
Ramsey, Brian J.	Rubin, Larry	Seaman, Anthony	Slykhouse, Tom
Ran, Adeé	Russo, Paul F.	Seaman, Michael	Smith, Andrew
Randall, Karen	Ryan, Bill	Searles, Shawn	Smith, Daniel
Randle, William	Rysin, Alexander	Sedarat, Hossein	Smith, David A.
Rannow, Randy K.	Ryu, Hyunsurk (Eric)	Sedio, Stephn	Smith, Eric
Rao, Ram	Sadeghi, Khosrow	Seely, Ted	Smith, Grant
Rao, Sailesh K.	Sadler, Jonathan	Seemann, Brian	Smith, Michael
Rasimas, Jennifer G.	Saeki, Naoto	Sefidvash, Khorvash (Kory)	Smith, Robert W.
Rausch, Dan	Sagi, Dalit	Seifert, Richard	Smith, Steve
Rautenberg, Peter	Sajassi, Ali	Seiger, Alexander	Snyder, Robert
Rawson, Eric	Sakaguchi, Ed	Sekel, Steve	Sofer, Dror
Rechtman, Zvi	Sakai, Toshiaki	Seki, Katsutoshi	Soffer, Ran
Reed, Robert	Sakamoto, Hisaya	Sela, Oren	Solomon, Joe
Reede, Ivan	Sala, Dolores	Selee, Steve	Somer, Gregory
Regev, Alon	Salehi, Hamid	Sendelbach, Lee	Sommers, Scott
Rehm, Dennis	Salinger, Jorge	Seno, Shoichiro	Sone, Yoshiaki
Reilly, Eugene	Sallaway, Peter	Serbay, Murat	Song, Jaeyeon
Reinhard, Michael	Salowey, Joseph	Serizawa, Naoshi	Song, Jian
Reinstedler, Jim	Saltsidis, Panagiotis	Seto, Koichiro	Song, Xiaolu
Reintjes, Maurice	Salunke, Vineet	Shafai, Farhad	Sorbara, Massimo
Remein, Duane	Salzman, Michael M.	Shafir, Haim	Sorensen, David
Ren, Hao	Samaan, Moni	Shah, Amit	Sørensen, Michel
Rendel, Andreas	Sambasivan, Sam	Shah, Sunil	Sotelo, Walter
Rennie, Lawrence	Sammartino, Fred	Shain, Vadim	Soto, Stephen
Renteria, Victor	Samueli, Henry	Shanbhag, Abhijit	Soto, Walt
Reshef, Tamir	Sanders, Anthony	Shanbhag, Megha	Souvignier, Tom
Ressler, Michael	Sanitá, Gianluca	Shani, Ron	Spagna, Fulvio
Rettig, Thomas	Sankey, Mark	Shariff, Masood	Sparrowhawk, Bryan
Reviriego, Pedro	Saracino, Concita	She, Qingya	Speiser, Ben
Reysen, Bill	Sarkar, Arindam	Shellhammer, Stephen	Spencer, Gary
Rezvani, Behrooz	Sarles, Bill	Shen, Bazhong	Sprague, Edward
Rhee, June-Koo (Kevin)	Sarles, F.	Shen, Sam	Spratt, Michael
Riani, Jamal	Sasaki, Akira	Sheppard, Ben	Sprecher, Nurit
Richkas, Dave	Sasaki, Yasuo	Sherer, Paul	Squire, Matthew B.
Rickert, Joseph	Sassower, Stan	Shergill, Robbie	Srivastava, Atul
Rimboim, Poldi (Pavlick)	Sastry, Ramesh	Sheth, Siddharth	Srodzinski, David
Ritger, John	Sathe, Satish	Shigematsu, Masayuki	St Peter, Matthew
Rivett, Paul	Sauer, John	Shih, Cheng-Chung	St. Amand, Joseph

Stacy, David N.	Takayama, Kazuya	Tsukamoto, Yoshihiro	Walker, Dylan
Stanford, Clayton	Takeda, Noriyuki	Tsumura, Eddie	Walker, Rick
Staniec, Thomas	Takefman, Michael	Tu, Mike	Wall, Bill
Stanley, Patrick H.	Takessian, Martin	Turlej, Zbigniew	Walter, Edward
Stanton, Kevin	Takizawa, Motoyuki	Turner, Brad	Wang, Chang Jung
Stapleton, Nick	Tamura, Kohichi	Turner, Edward	Wang, Chenxi
Starkins, Graham	Tan, Alexander	Turner, Wendell	Wang, Chiung Hung
Stassar, Peter	Tan, Kan	Tusiray, Bulent	Wang, Greg
Staub, Peter	Tanaka, Keiji	Twersky, Jacob	Wang, Haifei
Stearns, Margit	Tanaka, Toshiaki	Twu, Bor-long	Wang, Peter
Steenman, Henk	Tang, Wen-Tsung	Tzannes, Marcos	Wang, Robert
Stein, David E.	Tarana, Sandra	Uematsu, Kiyoshi	Wang, Roy
Stencel, Leonard	Tarassov, Victor J.	Ugolini, Alan	Wang, Tongtong
Stephens, Gary	Tarrant, Peter	Uhl, Herbert	Wang, Xiaofeng
Stetter, Claus	Tate, Mike	Ullal, Jayshree	Wang, Xinyuan
Staudler, Ronald	Tatsuta, Tsutomu	Ulm, John	Wang, Xuehuan
Stevens, Daniel	Tatum, Jim	Ulrich, Steven	Wang, Yun-Che
Stewart, Donald S.	Tavacoli, James M.	Ulrichs, Ed	Wang, Zhong Feng
Stewart, Heath	Tavana, Sadry	Umeda, Daisuke	Ward, Ken
Stoddart, Dean M.	Tawa, Katsuhisa	Umnov, Alexander	Warland, Tim
Stokesberry, Daniel P.	Taylor, Ken	Ungerboeck, Gottfried	Warren, David
Stoltz, Mario	Taylor, Mark	Unmehopa, Musa	Warren, Jeff
Stone, Robert	Tazebay, Mehmet	Vaden, Sterling A.	Warshaw, Marc
Stook, Christopher	Teckman, Tim	Vafiades, Todd	Washburn, Ted
Storaasli, Olaf	Teipen, Brian	Valle, Stefano	Watanabe, Yuji
Storozum, Steve	Teixeira, Antonio L.	Valliappan, Magesh	Watson, Bruce
Stover, David	Telang, Vivek	Van Bavel, Nicholas	Watson, Robert
Strohmayer, Rick	Tellado, José	Van Goor, David J.	Weaver, James
Strong, Stephen	Tellas, Ronald	Van Laanen, Peter	Weber, Markus
Stuart, Richard	Terada, Masaru	van Oosten, Erik	Wechsler, Christoph
Suermann, Thomas	Thaler, Patricia A.	Vanderlaan, Paul Z.	Wei, Dong
Sugawa, Jun	Thatcher, R. Jonathan	vanDoorn, Schelto J.	Wei, Yuehua
Sugg, Alan	Theodoras, James	Van-Mierop, Dono	Weil, Jason
Sultan, Robert	Thiagarajan, Sashisekaran	VanSchyndel, Andre	Weiman, Lyle
Sulyma, Ron	Thirion, Walter	Varanese, Nicola	Weiner, Nick
Summers, Robert	Thompson, Geoffrey O.	Vareljian, Albert	Weis, Brian
Sumner, Ken F.	Thomson, Douglas	Veerayah, Kumaran	Weissberger, Alan
Sun, Junqing	Thon, Lars E.	Venkatavaraton, V. Kumar	Weitzner, Andrew
Sun, Liyang	Thorne, David	Venugopal, Prasad	Weizman, Moti
Sun, Yi	Ting, Ao	Vepa, Ramakrishna	Welch, Brian
Sundaresan, Karthik	Tipper, Alan	Vergnaud, Gérard	Welch, Jim
Suzaki, Tetsuyuki	Tobol, Nathan	Verheggen, Bill	Wen, Yang
Suzuki, Hiroshi	Todd, John	Verigin, Iain	Wendt, Matthias
Suzuki, Ken-ichi	Tolley, Bruce	Verne, Robert	Weniger, Fred
Suzuki, Muneyoshi	Tomaszewski, Carlos A.	Vernickel, Ricky	Wertheim, Oded
Suzuki, Naoki	Tomaszewski, Peter	Vetteth, Anoop	Wertz, Jason
Suzuki, Yasuo	Tooyserkani, Pirooz	Vijeh, Nader	Wery, Willem
Svensson, Daniel	Torgerson, Paul	Vilozny, Ron	Wetzel, Alan
Swanson, Steve	Torres, Luis	Visser, John	White, David
Swenson, Norman L.	Townsend, Rick	Vitali, Marco	White, Hugh E.
Szczepanek, Andre	Toyoda, Hidehiro	Vittal, Balasubramanian	White, Lawrence
Sze, Daniel	Träber, Mario	Vladan, Ionel Marius	White, Martin
Szeto, William	Tracy, Nathan	Vlasov, Yurii	Whitlow, Tony
Szostak, Tad	Traeber, Mario	Vogel, David	Wiedemann, Bill
Taborek, Richard	Tran, Hiep	Voloshin, Moshe	Wiencko, Joseph A.
Taich, Dimitry	Tran, Viet	Von Herzen, Brian	Wienckowski, Natalie
Tailor, Bharat	Traverso, Matthew	Voros, John von	Wijnen, Bert
Tajima, Akio	Tremblay, David	Voss, Robert	Williams, Bruce
Tajima, Takayuki	Tremblay, Francois	Wadekar, Manoj	Williams, Richard
Takahara, Tomoo	Tretter, Albert	Wager, William	Williamson, Erica
Takahashi, Eiichi	Trowbridge, Stephen J.	Wagner, Martin	Williamson, Robert S.
Takahashi, Hidenori	Truman, Thomas E.	Wagner, Robert	Wilmarth, Roger
Takahashi, Satoshi	Tseng, Ta Chin	Wainwright, P. E.	Wils, Joris
Takahashi, Tadashi	Tseng, Wen-Cheng	Wakayama, Ikuro	Wilson, Izumi
Takahata, Kiyoto	Tsuji, Shinji	Walker, Clinton	Wincin, Mike

Wingrove, Mark	Wong, Leo	Xu, Yu	Yokomoto, Tetsuya
Winkel, Ludwig	Wong, Percy	Yagil, Ariel	Yokota, Nobushige
Winterton, Darin	Woodruff, Bill	Yam, Michael	Yoo, Tae-Whan
Withey, James	Woodruff, Paul	Yamada, Masaki	Yoon, Bin Yeong
Witkowski, Mike	Woodward, Ted K.	Yamamoto, Shuto	Yoon, Chong Ho
Witt, Kevin	Wu, Chien-Hsien	Yamashita, Hajime	Yorks, Jason
Witzner, Andrew	Wu, Choa-Ping	Yamazaki, Shuntaro	Yoshihara, Osamu
Wolcott, John	Wu, Dance	Yang, Howard	Yoshikawa, Takashi
Won, Jonghwa	Wu, Guangsheng	Yang, Steven	Young, Adrian
Won, King	Wu, Mau-Lin	Yang, Yinglin (Frank)	Young, George
Won, Shin-Hee	Wu, Peter	Yara, Ronald	Young, James
Wong, Ching	Wu, Robert	Yasukawa, Masaki	Young, Ken
Wong, David	Wucher, Markus	Yi, Jun	Yousefi, Nariman
Wong, Don	Wurster, Stefan M.	Yiu, Lee Chung	
Wong, Edward	Xu, Dayin	Yoder, Doug	

The following members of the individual balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

Iwan Adhicandra	Hideki Isono	Arumugam Paventhan
Thomas Alexander	Tom Issenhuth	David Piehler
Butch Anton	Raj Jain	Rick Pimpinella
Philippe Astier	SangKwon Jeong	Fabio Pittala
Liav Ben-Artsi	Peter Jones	Richard Pitwon
Rich Boyer	Lokesh Kabra	William Powell
Theodore Brillhart	Piotr Karocki	Adee Ran
Matthew Brown	Stuart Kerry	Randy K. Rannow
William Byrd	Evgeny Khorov	Alon Regev
John Calvin	Kihong/Joshua Kim	Maximilian Riegel
Steven B. Carlson	Yongbum Kim	Alexander Rysin
Juan Carreon	Sam Kocsis	Toshiaki Sakai
Clark Carty	Taiji Kondo	Frank Schewe
Pin Chang	Glen Kramer	Qingya She
Chan Chen	Gavin Lai	Priyank Shukla
Ritwik Chowdhury	Mark Laubach	William Simms
Piers J. G. Dawe	David J. Law	Jeff Slavick
John Deandrea	Pi-Cheng Law	Scott Sommers
Claudio DeSanti	Hyeong Ho Lee	Heath Stewart
Stephen Didde	Charles Lennon	Walter Struppler
Christopher Diminico	David Lewis	Mitsutoshi Sugawara
Michael Dudek	Jon Lewis	David Tepen
Andrew Fieldsend	Ru Lin	James Theodoras
Avraham Freedman	Kent Lusted	Geoffrey O. Thompson
Matthias Fritsche	Valerie Maguire	Michael Thompson
Devon Gayle	Jeffery Maki	Nathan Tracy
Ali Ghiasi	Roger Marks	David Tremblay
James Gilb	Arthur Marris	John Vergis
Joel Goergen	Michael Maytum	Lisa Ward
Brandon Gore	Brett McClellan	Keith Waters
James Graba	Jonathon McLendon	James Weaver
Robert M. Grow	Richard Mellitz	Stephen Webb
Marek Hajduczenia	John Messenger	Matthias Wendt
Xiang He	Michael Montemurro	Natalie Wienckowski
Adam Healey	Rick Murphy	Scott Willy
Howard Heck	Ramana Murty	Andreas Wolf
Marco Hernandez	N. Kishor Narang	Chun Yu Charles Wong
David Hess	Karim Nassiri Toussi	Mau-Lin Wu
Yasuo Hidaka	Raymond Nering	Yu Xu
Guido Hiertz	Shawn Nicholl	James Young
Werner Hoelzl	Satoshi Obara	Yu Yuan
Thomas Huber	Thomas Palkert	Oren Yuen
Woojung Huh	Carlos Pardo	Janusz Zalewski
Yasuhiro Hyakutake	Earl Parsons	Bo Zhang
Tetsushi Ikegami	Bansi Patel	George Zimmerman

When the IEEE SA Standards Board approved this standard on 13 May 2022, it had the following membership:

David J. Law, *Chair*
Ted Burse, *Vice Chair*
Gary Hoffman, *Past Chair*
Konstantinos Karachalios, *Secretary*

Edward A. Addy
Ramy Ahmed Fathy
J. Travis Griffith
Guido R. Hiertz
Yousef Kimiagar
Joseph L. Koepfinger*
Thomas Koshy
John D. Kulick

Johnny Daozhuang Lin
Kevin Lu
Daleep C. Mohla
Andrew Myles
Damir Novosel
Annette D. Reilly
Robby Robson
Jon Walter Rosdahl

Mark Siira
Dorothy V. Stanley
Lei Wang
F. Keith Waters
Karl Weber
Sha Wei
Philip B. Winston
Daidi Zhong

*Member Emeritus

Introduction

This introduction is not part of IEEE Std 802.3-2022, IEEE Standard for Ethernet.

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

The half duplex Media Access Control (MAC) protocol specified in IEEE Std 802.3-1985 is Carrier Sense Multiple Access with Collision Detection (CSMA/CD). This MAC protocol was key to the experimental Ethernet developed at Xerox Palo Alto Research Center, which had a 2.94 Mb/s data rate. Ethernet at 10 Mb/s was jointly released as a public specification by Digital Equipment Corporation (DEC), Intel and Xerox in 1980. “Local Area Networks: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications” was approved as an IEEE standard by the IEEE Standards Board in 1983 and subsequently published in 1985 as IEEE Std 802.3-1985. Since 1985, new media options, new speeds of operation, and new capabilities have been added to IEEE Std 802.3. A full duplex MAC protocol and the ability to use an EtherType to specify the MAC client protocol were added in 1997. The title was changed to Standard for Ethernet with the 2012 Revision.

Some of the major additions to IEEE Std 802.3 are identified in the marketplace with their project number. This is most common for projects adding higher speeds of operation or new protocols. For example, IEEE Std 802.3u™ added 100 Mb/s operation (also called Fast Ethernet), IEEE Std 802.3z™ added 1000 Mb/s operation (also called Gigabit Ethernet), IEEE Std 802.3ae™ added 10 Gb/s operation (also called 10 Gigabit Ethernet), IEEE Std 802.3ah™ specified access network Ethernet (also called Ethernet in the First Mile) and IEEE Std 802.3ba added 40 Gb/s operation (also called 40 Gigabit Ethernet) and 100 Gb/s operation (also called 100 Gigabit Ethernet). These major additions are all now included in and are superseded by IEEE Std 802.3-2022 and are not maintained as separate documents.

At the date of IEEE Std 802.3-2022 publication, IEEE Std 802.3 was composed of the following documents:

IEEE Std 802.3-2022

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

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

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

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

Section Five—Includes Clause 56 through Clause 77 and Annex 57A through Annex 76A. Clause 56 through Clause 67 and Clause 75 through Clause 77, as well as associated annexes, specify subscriber access and other Physical Layers and sublayers for operation from 512 kb/s to 10 Gb/s, and defines services and protocol elements that enable the exchange of IEEE Std 802.3 format frames between stations in a subscriber access network. Clause 68 specifies a 10 Gb/s Physical Layer specification. Clause 69 through Clause 74 and associated annexes specify Ethernet operation over electrical backplanes at speeds of 1000 Mb/s and 10 Gb/s.

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

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

Section Eight—Includes Clause 116 through Clause 140 and Annex 119A through Annex 136D. Clause 116 through Clause 124 and associated annexes include general information on 200 Gb/s and 400 Gb/s operation as well as 200 Gb/s and 400 Gb/s Physical Layer specifications. Clause 125 includes general information on 2.5 Gb/s and 5 Gb/s operation. Clause 126 through Clause 130 and associated annexes include 2.5 Gb/s and 5 Gb/s Physical Layer specifications. Clause 131 provides general information on 50 Gb/s operation. Clause 132 through Clause 140 and associated annexes include 50 Gb/s Physical Layer specifications and additional 100 Gb/s, 200 Gb/s, and 400 Gb/s Physical Layer specifications.

Section Nine—Includes Clause 141 through Clause 160 and Annex 142A through Annex 154A. Clause 141 through Clause 144 and associated annexes specify symmetric and asymmetric operation of Ethernet passive optical networks over multiple 25 Gb/s channels. Clause 145 and associated annexes specify increased power delivery using all four pairs in the structured wiring plant. Clause 146 through Clause 149 and associated annexes specify Physical Layers for 10 Mb/s, 2.5 Gb/s, 5 Gb/s, and 10 Gb/s operation over a single balanced pair of conductors. Clause 150 and Clause 151 include additional 400 Gb/s Physical Layer specifications. Clause 153 and Clause 154 specify 100 Gb/s operation over DWDM channels. Clause 157 through Clause 160 include 10 Gb/s, 25 Gb/s, and 50 Gb/s bidirectional Physical Layer specifications.

Two companion documents exist, IEEE Std 802.3.1 and IEEE Std 802.3.2. IEEE Std 802.3.1 describes Ethernet management information base (MIB) modules for use with the Simple Network Management Protocol (SNMP). IEEE Std 802.3.2 describes YANG data models for Ethernet. IEEE Std 802.3.1 and IEEE Std 802.3.2 are updated to add management capability for enhancements to IEEE Std 802.3 after approval of those enhancements.

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

Acknowledgments

Grateful acknowledgment is made for portions of this standard reprinted with permission from Broadcom Corporation, OPEN Alliance BroadR-Reach® (OABR) Physical Layer Transceiver Specification For Automotive Applications V3.2, June 24, 2014, © 2014.

Grateful acknowledgment is made for portions of this standard reprinted with permission from Data-Over-Cable Service Interface Specifications DOCSIS® 3.1 Physical Layer Specification CM-SP-PHYv3.1-I01-131029 (Cable Television Laboratories, Inc. 2013), © 2013.

Grateful acknowledgment is made for portions of this standard reprinted with permission from Maxim Integrated Products, Inc., DS18B20 “Programmable Resolution 1-Wire Digital Thermometer” Data Sheet, Rev. 042208, © 2008.

IEEE Standard for Ethernet

Contents

1. Introduction.....	167
1.1 Overview.....	167
1.1.1 Scope.....	167
1.1.2 Basic concepts.....	167
1.1.3 Architectural perspectives.....	168
1.1.4 Layer interfaces.....	172
1.1.5 Application areas	172
1.1.6 Word usage	172
1.2 Notation	173
1.2.1 State diagram conventions	173
1.2.2 Service specification method and notation	174
1.2.3 Physical Layer and media notation	175
1.2.4 Physical Layer message notation	175
1.2.5 Hexadecimal notation	175
1.2.6 Accuracy and resolution of numerical quantities	176
1.2.7 Qm.n number format.....	176
1.2.8 Em dash (—) in a table cell	176
1.3 Normative references	176
1.4 Definitions	187
1.5 Abbreviations.....	227
2. Media Access Control (MAC) service specification	235
2.1 Scope and field of application	235
2.2 Overview of the service	235
2.2.1 General description of services provided by the layer.....	235
2.2.2 Model used for the service specification	235
2.2.3 Overview of interactions.....	235
2.2.4 Basic services.....	236
2.3 Detailed service specification	236
2.3.1 MA_DATA.request	236
2.3.2 MA_DATA.indication.....	237
3. Media Access Control (MAC) frame and packet specifications	239

3.1	Overview.....	239
3.1.1	Packet format.....	239
3.1.2	Service interface mappings.....	240
3.2	Elements of the MAC frame and packet.....	240
3.2.1	Preamble field.....	240
3.2.2	Start Frame Delimiter (SFD) field.....	240
3.2.3	Address fields.....	240
3.2.4	Destination Address field.....	241
3.2.5	Source Address field.....	242
3.2.6	Length/Type field.....	242
3.2.7	MAC Client Data field.....	242
3.2.8	Pad field.....	243
3.2.9	Frame Check Sequence (FCS) field.....	243
3.2.10	Extension field.....	243
3.3	Order of bit transmission.....	244
3.4	Invalid MAC frame.....	244
4.	Media Access Control.....	245
4.1	Functional model of the MAC method.....	245
4.1.1	Overview.....	245
4.1.2	CSMA/CD operation.....	246
4.1.3	Relationships to the MAC client and Physical Layers.....	248
4.2	CSMA/CD Media Access Control (MAC) method: Precise specification.....	248
4.2.1	Introduction.....	248
4.2.2	Overview of the procedural model.....	248
4.2.3	Packet transmission model.....	251
4.2.4	Frame reception model.....	259
4.2.5	Preamble generation.....	261
4.2.6	Start frame sequence.....	261
4.2.7	Global declarations.....	261
4.2.8	Frame transmission.....	265
4.2.9	Frame reception.....	272
4.2.10	Common procedures.....	276
4.3	Interfaces to/from adjacent layers.....	276
4.3.1	Overview.....	276
4.3.2	MAC service.....	276
4.3.3	Services required from the Physical Layer.....	279
4.4	Specific implementations.....	281
4.4.1	Compatibility overview.....	281
4.4.2	MAC parameters.....	282
4.4.3	Configuration guidelines.....	283
5.	Layer Management.....	284
5.1	Introduction.....	284
5.1.1	Systems Management overview.....	284
5.1.2	Layer Management model.....	284
5.1.3	Packages.....	285
5.1.4	Conformance requirements.....	285
5.2	Management facilities.....	285
5.2.1	Introduction.....	285
5.2.2	DTE MAC Sublayer Management facilities.....	285
5.2.3	DTE Physical Sublayer Management facilities.....	295

5.2.4	DTE Management procedural model.....	296
6.	Physical Signaling (PLS) service specifications.....	301
6.1	Scope and field of application	301
6.2	Overview of the service	301
6.2.1	General description of services provided by the layer.....	301
6.2.2	Model used for the service specification	301
6.2.3	Overview of interactions.....	301
6.2.4	Basic services and options	302
6.3	Detailed service specification	302
6.3.1	Peer-to-peer service primitives	302
6.3.2	Sublayer-to-sublayer service primitives	303
7.	Physical Signaling (PLS) and Attachment Unit Interface (AUI) specifications	305
7.1	Scope.....	305
7.1.1	Definitions	305
7.1.2	Summary of major concepts	305
7.1.3	Application.....	306
7.1.4	Modes of operation	306
7.1.5	Allocation of function	306
7.2	Functional specification	306
7.2.1	PLS–PMA (DTE–MAU) Interface protocol.....	306
7.2.2	PLS interface to MAC and management entities.....	313
7.2.3	Frame structure	315
7.2.4	PLS functions.....	316
7.3	Signal characteristics	319
7.3.1	Signal encoding.....	319
7.3.2	Signaling rate	324
7.3.3	Signaling levels.....	324
7.4	Electrical characteristics	324
7.4.1	Driver characteristics	324
7.4.2	Receiver characteristics	327
7.4.3	AUI cable characteristics	329
7.5	Functional description of interchange circuits.....	331
7.5.1	General.....	331
7.5.2	Definition of interchange circuits	331
7.6	Mechanical characteristics.....	333
7.6.1	Definition of mechanical interface	333
7.6.2	Line interface connector	333
7.6.3	Contact assignments	334
8.	Medium Attachment Unit and baseband medium specifications, type 10BASE5	337
8.1	Scope.....	337
8.1.1	Overview.....	337
8.1.2	Definitions	338
8.1.3	Application perspective: MAU and MEDIUM objectives	338
8.2	MAU functional specifications	339
8.2.1	MAU Physical Layer functions	339
8.2.2	MAU interface messages	342
8.2.3	MAU state diagrams	344
8.3	MAU–medium electrical characteristics	344

8.3.1	MAU-to-coaxial cable interface	344
8.3.2	MAU electrical characteristics.....	351
8.3.3	MAU-DTE electrical characteristics.....	352
8.3.4	MAU-DTE mechanical connection.....	352
8.4	Characteristics of the coaxial cable	352
8.4.1	Coaxial cable electrical parameters	352
8.4.2	Coaxial cable properties.....	353
8.4.3	Total segment dc loop resistance	355
8.5	Coaxial trunk cable connectors.....	355
8.5.1	Inline coaxial extension connector	355
8.5.2	Coaxial cable terminator.....	356
8.5.3	MAU-to-coaxial cable connection.....	356
8.6	System considerations.....	358
8.6.1	Transmission system model.....	358
8.6.2	Transmission system requirements.....	359
8.6.3	Labeling	360
8.7	Environmental specifications.....	360
8.7.1	General safety requirements	360
8.7.2	Network safety requirements	360
8.7.3	Electromagnetic environment	362
8.7.4	Temperature and humidity	362
8.7.5	Regulatory requirements.....	362
8.8	Protocol implementation conformance statement (PICS) proforma for Clause 8, Medium Attachment Unit and baseband medium specifications, type 10BASE5	363
8.8.1	Overview.....	363
8.8.2	Abbreviations and special symbols.....	363
8.8.3	Instructions for completing the PICS proforma.....	363
8.8.4	Identification	365
8.8.5	Global statement of conformance	365
8.8.6	PICS proforma tables for MAU	366
8.8.7	PICS proforma tables for MAU AUI characteristics.....	373
8.8.8	PICS proforma tables for 10BASE5 coaxial cable	377
9.	Repeater unit for 10 Mb/s baseband networks.....	379
9.1	Overview.....	379
9.2	References.....	379
9.3	Definitions	379
9.4	Compatibility interface	379
9.4.1	AUI compatibility	379
9.4.2	Mixing segment compatibility	380
9.4.3	Link segment compatibility	381
9.5	Basic functions.....	381
9.5.1	Repeater set network properties.....	381
9.5.2	Signal amplification.....	381
9.5.3	Signal symmetry	382
9.5.4	Signal retiming.....	382
9.5.5	Data handling.....	382
9.5.6	Collision handling.....	383
9.5.7	Electrical isolation	385
9.6	Detailed repeater functions and state diagrams	385
9.6.1	State diagram notation	385
9.6.2	Data and collision handling	387
9.6.3	Preamble regeneration	387

9.6.4	Fragment extension	387
9.6.5	MAU Jabber Lockup Protection	387
9.6.6	Auto-Partitioning/Reconnection (optional)	389
9.7	Electrical isolation	391
9.7.1	Environment A requirements	391
9.7.2	Environment B requirements	391
9.8	Reliability	393
9.9	Medium attachment unit and baseband medium specification for a vendor-independent FOIRL	393
9.9.1	Scope	393
9.9.2	FOMAU functional specifications	395
9.9.3	FOMAU electrical characteristics	401
9.9.4	FOMAU/Optical medium interface	402
9.9.5	Characteristics of the optical fiber cable link segment	405
9.9.6	System requirements	406
9.9.7	Environmental specifications	408
10.	Medium attachment unit and baseband medium specifications, type 10BASE2	410
10.1	Scope	410
10.1.1	Overview	410
10.1.2	Definitions	411
10.1.3	Application perspective: MAU and medium objectives	411
10.2	References	412
10.3	MAU functional specifications	412
10.3.1	MAU Physical Layer functional requirements	413
10.3.2	MAU interface messages	415
10.3.3	MAU state diagrams	417
10.4	MAU–medium electrical characteristics	418
10.4.1	MAU-to-coaxial cable interface	418
10.4.2	MAU electrical characteristics	420
10.4.3	MAU–DTE electrical characteristics	421
10.5	Characteristics of coaxial cable system	421
10.5.1	Coaxial cable electrical parameters	421
10.5.2	Coaxial cable physical parameters	422
10.5.3	Total segment dc loop resistance	423
10.6	Coaxial trunk cable connectors	424
10.6.1	In-line coaxial extension connector	424
10.6.2	Coaxial cable terminator	425
10.6.3	MAU-to-coaxial cable connection	425
10.7	System considerations	425
10.7.1	Transmission system model	425
10.7.2	Transmission system requirements	427
10.8	Environmental specifications	428
10.8.1	Safety requirements	428
10.8.2	Electromagnetic environment	428
10.8.3	Regulatory requirements	428
11.	Broadband medium attachment unit and broadband medium specifications, type 10BROAD36	429
11.1	Scope	429
11.1.1	Overview	429
11.1.2	Definitions	431
11.1.3	MAU and medium objectives	431

11.1.4	Compatibility considerations	432
11.1.5	Relationship to PLS and AUI	432
11.1.6	Mode of operation.....	432
11.2	MAU functional specifications.....	432
11.2.1	MAU functional requirements	432
11.2.2	DTE PLS to MAU and MAU to DTE PLS messages	435
11.2.3	MAU state diagrams	436
11.3	MAU characteristics	439
11.3.1	MAU-to-coaxial cable interface	439
11.3.2	MAU frequency allocations.....	444
11.3.3	AUI electrical characteristics.....	445
11.3.4	MAU transfer characteristics	446
11.3.5	Reliability.....	452
11.4	System considerations.....	453
11.4.1	Delay budget and network diameter	453
11.4.2	MAU operation with packets shorter than 512 bits	453
11.5	Characteristics of the coaxial cable system	454
11.5.1	Electrical requirements	454
11.5.2	Mechanical requirements.....	454
11.5.3	Delay requirements	454
11.6	Frequency translator requirements for the single-cable version	455
11.6.1	Electrical requirements	455
11.6.2	Mechanical requirements.....	455
11.7	Environmental specifications.....	455
11.7.1	Safety requirements	455
11.7.2	Electromagnetic environment	456
11.7.3	Temperature and humidity	456
12.	Physical signaling, medium attachment, and baseband medium specifications, type 1BASE5	457
12.1	Introduction.....	457
12.1.1	Overview.....	457
12.1.2	Scope.....	457
12.1.3	Definitions	457
12.1.4	General characteristics	457
12.1.5	Compatibility	458
12.1.6	Objectives of type 1BASE5 specification	458
12.2	Architecture	458
12.2.1	Major concepts.....	458
12.2.2	Application perspective	459
12.2.3	Packet structure.....	459
12.3	DTE physical signaling (PLS) specification.....	462
12.3.1	Overview.....	462
12.3.2	Functional specification	463
12.4	Hub specification	469
12.4.1	Overview.....	469
12.4.2	Hub structure.....	470
12.4.3	Hub PLS functional specification	471
12.5	Physical medium attachment (PMA) specification	476
12.5.1	Overview.....	476
12.5.2	PLS–PMA interface.....	476
12.5.3	Signal characteristics	477
12.6	Medium Dependent Interface (MDI) specification	484
12.6.1	Line interface connector	484

12.6.2	Connector contact assignments.....	485
12.6.3	Labeling	485
12.7	Cable medium characteristics	486
12.7.1	Overview.....	486
12.7.2	Transmission parameters	486
12.7.3	Coupling parameters	487
12.7.4	Noise environment	488
12.8	Special link specification	489
12.8.1	Overview.....	489
12.8.2	Transmission characteristics	489
12.8.3	Permitted configurations.....	489
12.9	Timing.....	489
12.9.1	Overview.....	489
12.9.2	DTE timing	490
12.9.3	Medium timing	490
12.9.4	Special link timing	490
12.9.5	Hub timing	490
12.10	Safety	491
12.10.1	Isolation	491
12.10.2	Telephony voltages	492
13.	System considerations for multisegment 10 Mb/s baseband networks	493
13.1	Overview.....	493
13.1.1	Repeater usage	494
13.2	Definitions	494
13.3	Transmission System Model 1.....	494
13.4	Transmission System Model 2.....	501
13.4.1	Round-trip collision delay	501
13.4.2	Interpacket gap (IPG) shrinkage.....	502
13.5	Full duplex topology limitations.....	503
14.	Twisted-pair medium attachment unit (MAU) and baseband medium, type 10BASE-T including type 10BASE-Te.....	504
14.1	Scope.....	504
14.1.1	Overview.....	504
14.1.2	Definitions	505
14.1.3	Application perspective	506
14.1.4	Relationship to PLS and AUI	507
14.2	MAU functional specifications.....	507
14.2.1	MAU functions	508
14.2.2	PMA interface messages.....	512
14.2.3	MAU state diagrams	513
14.3	MAU electrical specifications	519
14.3.1	MAU-to-MDI interface characteristics.....	519
14.3.2	MAU-to-AUI specification.....	528
14.4	Characteristics of the simplex link segment	530
14.4.1	Overview.....	530
14.4.2	Transmission parameters	530
14.4.3	Coupling parameters	531
14.4.4	Noise environment.....	532
14.5	MDI specification	532
14.5.1	MDI connectors	532

14.5.2	Crossover function	533
14.6	System considerations.....	534
14.7	Environmental specifications.....	535
14.7.1	General safety	535
14.7.2	Network safety	535
14.7.3	Environment.....	536
14.8	MAU labeling	536
14.9	Timing summary	537
14.10	Protocol implementation conformance statement (PICS) proforma for Clause 14, Twisted-pair medium attachment unit (MAU) and baseband medium, type 10BASE-T and type 10BASE-Te.....	538
14.10.1	Introduction.....	538
14.10.2	Identification of implementation	539
14.10.3	Identification of the protocol	539
14.10.4	PICS proforma for 10BASE-T	540
15.	Fiber optic medium and common elements of medium attachment units and star, type 10BASE-F	555
15.1	Scope.....	555
15.1.1	Overview.....	555
15.1.2	Definitions	557
15.1.3	Applications perspective: MAUs, stars, and fiber optic medium	557
15.2	MDI optical characteristics	560
15.2.1	Transmit optical parameters.....	560
15.2.2	Receive optical parameters	567
15.3	Characteristics of the fiber optic medium.....	568
15.3.1	Optical fiber and cable	568
15.3.2	Optical medium connector plug and socket.....	568
15.3.3	Fiber optic medium insertion loss.....	569
15.3.4	Electrical isolation	570
15.4	MAU reliability.....	570
15.5	MAU–AUI specification.....	570
15.5.1	MAU–AUI electrical characteristics	570
15.5.2	MAU–AUI mechanical connections.....	570
15.5.3	Power consumption.....	570
15.5.4	MAU–AUI messages.....	571
15.6	Environmental specifications.....	572
15.6.1	Safety requirements	572
15.6.2	Electromagnetic environment	572
15.6.3	Other environmental requirements	572
15.7	MAU labeling	572
15.7.1	10BASE-FP star labeling.....	573
15.8	Protocol implementation conformance statement (PICS) proforma for Clause 15, Fiber optic medium and common elements of medium attachment units and star, type 10BASE-F.....	574
15.8.1	Introduction.....	574
15.8.2	Abbreviations and special symbols.....	574
15.8.3	Instructions for completing the PICS proforma.....	574
15.8.4	Identification	576
15.8.5	Major capabilities/options.....	577
15.8.6	PICS Proforma for the fiber optic medium.....	577
16.	Fiber optic passive star and medium attachment unit, type 10BASE-FP	579

16.1	Scope.....	579
16.1.1	Overview.....	579
16.2	PMA interface messages.....	580
16.2.1	PMA-to-MDI interface signal encodings	580
16.2.2	PMA-to-MDI OTD messages.....	580
16.2.3	MDI ORD-to-PMA messages.....	581
16.3	10BASE-FP MAU functional specifications.....	582
16.3.1	Transmit function requirements.....	582
16.3.2	Receive function requirements	584
16.3.3	Loopback function requirements	584
16.3.4	Collision presence function requirements.....	585
16.3.5	signal_quality_error Message (SQE) Test function requirements.....	586
16.3.6	Jabber function requirements.....	586
16.3.7	Link fault detection and low light function requirements.....	587
16.3.8	Interface message time references	588
16.3.9	MAU state diagram.....	588
16.4	Timing summary.....	596
16.5	10BASE-FP Star functional specifications.....	596
16.5.1	Star functions	596
16.5.2	Star optical characteristics	597
16.6	Protocol implementation conformance statement (PICS) proforma for Clause 16, Fiber optic passive star and medium attachment unit, type 10BASE-FP	598
16.6.1	Introduction.....	598
16.6.2	Abbreviations and special symbols.....	598
16.6.3	Instructions for completing the PICS proforma.....	598
16.6.4	Identification.....	600
16.6.5	Major capabilities/options.....	601
16.6.6	PICS proforma for the type 10BASE-FP MAU	601
16.6.7	PICS proforma tables for 10BASE-FP stars.....	613
17.	Fiber optic medium attachment unit, type 10BASE-FB.....	615
17.1	Scope.....	615
17.1.1	Overview.....	615
17.1.2	Relationship to AUI.....	615
17.2	PMA interface messages.....	616
17.2.1	PMA-to-MDI interface signal encodings	616
17.2.2	PMA-to-MDI OTD messages.....	616
17.2.3	MDI ORD-to-PMA messages.....	617
17.2.4	Transitions between signals.....	618
17.2.5	Signaling rate	618
17.3	MAU functional specifications.....	618
17.3.1	Transmit function requirements.....	618
17.3.2	Receive function requirements	619
17.3.3	Collision function requirements.....	619
17.3.4	Loopback function requirements	620
17.3.5	Fault-handling function requirements.....	620
17.3.6	Jabber function requirements.....	620
17.3.7	Low light level detection function requirements	621
17.3.8	Synchronous qualification function requirements	621
17.3.9	Interface message time references	622
17.3.10	MAU state diagrams	622
17.4	Timing summary.....	626

17.5	Protocol implementation conformance statement (PICS) proforma for Clause 17, Fiber optic medium attachment unit, type 10BASE-FB	627
17.5.1	Introduction.....	627
17.5.2	Abbreviations and special symbols.....	627
17.5.3	Instructions for completing the PICS proforma.....	627
17.5.4	Identification.....	629
17.5.5	PICS proforma for the type 10BASE-FB MAU.....	629
17.5.6	PICS proforma for the type 10BASE-FB MAU.....	630
18.	Fiber optic medium attachment unit, type 10BASE-FL	640
18.1	Scope.....	640
18.1.1	Overview.....	640
18.2	PMA interface messages.....	640
18.2.1	PMA to fiber optic link segment messages	641
18.2.2	Fiber optic link segment to PMA messages.....	641
18.2.3	Interface message time references	642
18.3	MAU functional specifications.....	642
18.3.1	MAU functions	642
18.3.2	MAU state diagrams	646
18.4	Timing summary.....	653
18.5	Protocol implementation conformance statement (PICS) proforma for Clause 18, Fiber optic medium attachment unit, type 10BASE-FL	654
18.5.1	Introduction.....	654
18.5.2	Abbreviations and special symbols.....	654
18.5.3	Instructions for completing the PICS proforma.....	655
18.5.4	Identification.....	656
18.5.5	Major capabilities/options.....	657
18.5.6	PICS proforma tables for the type 10BASE-FL MAU.....	657
19.	Layer Management for 10 Mb/s baseband repeaters	670
19.1	Introduction.....	670
19.1.1	Scope.....	670
19.1.2	Relationship to objects in IEEE Std 802.1F-1993	670
19.1.3	Definitions	670
19.1.4	Symbols and abbreviations	670
19.1.5	Management model.....	671
19.2	Managed objects	672
19.2.1	Introduction.....	672
19.2.2	Overview of managed objects.....	672
19.2.3	Repeater managed object class	677
19.2.4	ResourceTypeID Managed Object Class.....	680
19.2.5	Group managed object class	680
19.2.6	Port managed object class.....	681
20.	Layer Management for 10 Mb/s baseband medium attachment units	687
20.1	Introduction.....	687
20.1.1	Scope.....	687
20.1.2	Management model.....	687
20.2	Managed objects	687
20.2.1	Text description of managed objects	687
20.2.2	MAU Managed object class.....	689

21. Introduction to 100 Mb/s baseband networks, type 100BASE-T	693
21.1 Overview.....	693
21.1.1 Reconciliation Sublayer (RS) and Media Independent Interface (MII)	694
21.1.2 Physical Layer signaling systems	694
21.1.3 Repeater	694
21.1.4 Auto-Negotiation	694
21.1.5 Management.....	694
21.2 References.....	694
21.3 Definitions	694
21.4 Abbreviations.....	694
21.5 State diagrams.....	694
21.5.1 Actions inside state blocks.....	695
21.5.2 State diagram variables	695
21.5.3 State transitions	695
21.5.4 Operators.....	695
21.6 Protocol implementation conformance statement (PICS) proforma.....	697
21.6.1 Introduction.....	697
21.6.2 Abbreviations and special symbols.....	697
21.6.3 Instructions for completing the PICS proforma.....	697
21.6.4 Additional information	698
21.6.5 Exceptional information	698
21.6.6 Conditional items	698
21.7 MAC delay constraints (exposed MII)	699
22. Reconciliation Sublayer (RS) and Media Independent Interface (MII).....	700
22.1 Overview.....	700
22.1.1 Summary of major concepts	701
22.1.2 Application.....	701
22.1.3 Rates of operation	702
22.1.4 Allocation of functions	702
22.1.5 Relationship of MII and GMII.....	702
22.2 Functional specifications	702
22.2.1 Mapping of MII signals to PLS service primitives and Station Management.....	702
22.2.2 MII signal functional specifications	706
22.2.3 MII data stream	715
22.2.4 Management functions.....	717
22.3 Signal timing characteristics	732
22.3.1 Signals that are synchronous to TX_CLK	732
22.3.2 Signals that are synchronous to RX_CLK.....	733
22.3.3 Signals that have no required clock relationship	733
22.3.4 MDIO timing relationship to MDC	733
22.4 Electrical characteristics	734
22.4.1 Signal levels.....	734
22.4.2 Signal paths.....	735
22.4.3 Driver characteristics	735
22.4.4 Receiver characteristics	736
22.4.5 Cable characteristics	736
22.4.6 Hot insertion and removal.....	738
22.5 Power supply.....	738
22.5.1 Supply voltage	738
22.5.2 Load current	739
22.5.3 Short-circuit protection	739

22.6	Mechanical characteristics	739
22.6.1	Definition of mechanical interface	739
22.6.2	Shielding effectiveness and transfer impedance	739
22.6.3	Connector pin numbering	740
22.6.4	Clearance dimensions	740
22.6.5	Contact assignments	740
22.7	LPI assertion and detection	742
22.7.1	LPI messages	743
22.7.2	Transmit LPI state diagram	743
22.7.3	Considerations for transmit system behavior	744
22.8	Protocol implementation conformance statement (PICS) proforma for Clause 22, Reconciliation Sublayer (RS) and Media Independent Interface (MII)	745
22.8.1	Introduction	745
22.8.2	Identification	745
22.8.3	PICS proforma tables for reconciliation sublayer and media independent interface	746
23.	Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 100BASE-T4	757
23.1	Overview	757
23.1.1	Scope	757
23.1.2	Objectives	757
23.1.3	Relation of 100BASE-T4 to other standards	757
23.1.4	Summary	757
23.1.5	Application of 100BASE-T4	760
23.2	PCS functional specifications	761
23.2.1	PCS functions	761
23.2.2	PCS interfaces	766
23.2.3	Frame structure	766
23.2.4	PCS state diagrams	767
23.2.5	PCS electrical specifications	775
23.3	PMA service interface	775
23.3.1	PMA_TYPE.indication	776
23.3.2	PMA_UNITDATA.request	776
23.3.3	PMA_UNITDATA.indication	777
23.3.4	PMA_CARRIER.indication	778
23.3.5	PMA_LINK.indication	778
23.3.6	PMA_LINK.request	779
23.3.7	PMA_RXERROR.indication	780
23.4	PMA functional specifications	780
23.4.1	PMA functions	780
23.4.2	PMA interface messages	784
23.4.3	PMA state diagrams	785
23.5	PMA electrical specifications	787
23.5.1	PMA-to-MDI interface characteristics	787
23.5.2	Power consumption	801
23.6	Link segment characteristics	801
23.6.1	Cabling	801
23.6.2	Link transmission parameters	802
23.6.3	Noise	804
23.6.4	Installation practice	805
23.7	MDI specification	805
23.7.1	MDI connectors	805
23.7.2	Crossover function	806

23.8	System considerations.....	806
23.9	Environmental specifications.....	807
23.9.1	General safety	807
23.9.2	Network safety.....	807
23.9.3	Environment.....	809
23.10	PHY labeling.....	809
23.11	Timing summary.....	809
23.11.1	Timing references	809
23.11.2	Definitions of controlled parameters	810
23.11.3	Table of required timing values	812
23.12	Protocol implementation conformance statement (PICS) proforma for Clause 23, Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer, and baseband medium, type 100BASE-T4	820
23.12.1	Introduction.....	820
23.12.2	Identification	820
23.12.3	Major capabilities/options.....	821
23.12.4	PICS proforma tables for the Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 100BASE-T4	821
24.	Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA) sublayer, type 100BASE-X.....	834
24.1	Overview.....	834
24.1.1	Scope.....	834
24.1.2	Objectives	834
24.1.3	Relationship of 100BASE-X to other standards	835
24.1.4	Summary of 100BASE-X sublayers	835
24.1.5	Inter-sublayer interfaces	836
24.1.6	Functional block diagram	838
24.1.7	State diagram conventions	838
24.2	Physical Coding Sublayer (PCS).....	838
24.2.1	Service Interface (MII)	838
24.2.2	Functional requirements	838
24.2.3	State variables	844
24.2.4	State diagrams.....	849
24.3	Physical Medium Attachment (PMA) sublayer.....	856
24.3.1	Service interface	856
24.3.2	Functional requirements	860
24.3.3	State variables	862
24.3.4	Process specifications and state diagrams	864
24.4	Physical Medium Dependent (PMD) sublayer service interface.....	870
24.4.1	PMD service interface	870
24.4.2	Medium Dependent Interface (MDI).....	872
24.5	Compatibility considerations	872
24.6	Delay constraints.....	872
24.6.1	PHY delay constraints (exposed MII)	873
24.6.2	DTE delay constraints (unexposed MII).....	873
24.6.3	Carrier deassertion/assertion constraint (half duplex mode only)	874
24.7	Environmental specifications.....	874
24.8	Protocol implementation conformance statement (PICS) proforma for Clause 24, Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA) sublayer, type 100BASE-X.....	875
24.8.1	Introduction.....	875
24.8.2	Identification	875

24.8.3	PICS proforma tables for the Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA) sublayer, type 100BASE-X.....	876
25.	Physical Medium Dependent (PMD) sublayer and baseband medium, type 100BASE-TX.....	879
25.1	Overview.....	879
25.1.1	State diagram conventions.....	879
25.2	Functional specifications.....	879
25.3	General exceptions.....	879
25.4	Specific requirements and exceptions.....	881
25.4.1	Change to 7.2.3.1.1, “Line state patterns”.....	881
25.4.2	Change to 7.2.3.3, “Loss of synchronization”.....	881
25.4.3	Change to Table 8-1, “Contact assignments for twisted pair”.....	881
25.4.4	Deletion of 8.3, “Station labelling”.....	881
25.4.5	Change to 9.1.7, “Worst case droop of transformer”.....	881
25.4.6	Replacement of 8.4.1, “UTP isolation requirements”.....	883
25.4.7	Addition to 10.1, “Receiver”.....	883
25.4.8	Change to 9.1.9, “Jitter”.....	883
25.4.9	Cable plant.....	883
25.4.10	Replacement of 11.2, “Crossover function”.....	885
25.4.11	Change to A.2, “DDJ test pattern for baseline wander measurements”.....	885
25.4.12	Change to Annex G, “Stream cipher scrambling function”.....	885
25.4.13	Change to Annex I, “Common mode cable termination”.....	885
25.5	EEE capability.....	885
25.5.1	Change to TP-PMD 7.1.2 “Encoder”.....	886
25.5.2	Change to TP-PMD 7.2.2 “Decoder”.....	887
25.5.3	Changes to 10.1.1.1 “Signal_Detect assertion threshold”.....	888
25.5.4	Changes to 10.1.1.2 “Signal_Detect deassertion threshold”.....	888
25.5.5	Change to 10.1.2 “Signal_Detect timing requirements on assertion”.....	889
25.5.6	Change to 10.1.3 “Signal_Detect timing requirements on deassertion”.....	889
25.5.7	Changes to TP-PMD 10.2 “Transmitter”.....	889
25.5.8	Replace TP-PMD Table 4 “Signal_Detect summary” with Table 25–3.....	890
25.6	Protocol implementation conformance statement (PICS) proforma for Clause 25, Physical Medium Dependent (PMD) sublayer and baseband medium, type 100BASE-TX.....	891
25.6.1	Introduction.....	891
25.6.2	Identification.....	891
25.6.3	Major capabilities/options.....	892
25.6.4	PICS proforma tables for the Physical Medium Dependent (PMD) sublayer and baseband medium, type 100BASE-TX.....	892
26.	Physical Medium Dependent (PMD) sublayer and baseband medium, type 100BASE-FX.....	896
26.1	Overview.....	896
26.2	Functional specifications.....	896
26.3	General exceptions.....	896
26.4	Specific requirements and exceptions.....	897
26.4.1	Medium Dependent Interface (MDI).....	897
26.4.2	Crossover function.....	897
26.5	Protocol implementation conformance statement (PICS) proforma for Clause 26, Physical Medium Dependent (PMD) sublayer and baseband medium, type 100BASE-FX.....	898
26.5.1	Introduction.....	898
26.5.2	Identification.....	898
26.5.3	Protocol summary.....	898
26.5.4	Major capabilities/options.....	899

26.5.5	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and baseband medium, type 100BASE-FX.....	899
27.	Repeater for 100 Mb/s baseband networks.....	900
27.1	Overview.....	900
27.1.1	Scope.....	900
27.1.2	Application perspective	901
27.1.3	Relationship to PHY	902
27.2	PMA interface messages.....	902
27.3	Repeater functional specifications.....	902
27.3.1	Repeater functions	903
27.3.2	Detailed repeater functions and state diagrams	907
27.4	Repeater electrical specifications.....	921
27.4.1	Electrical isolation	921
27.5	Environmental specifications.....	921
27.5.1	General safety	921
27.5.2	Network safety	921
27.5.3	Electrical isolation	922
27.5.4	Reliability.....	922
27.5.5	Environment.....	923
27.6	Repeater labeling	923
27.7	Protocol implementation conformance statement (PICS) proforma for Clause 27, Repeater for 100 Mb/s baseband networks	924
27.7.1	Introduction.....	924
27.7.2	Identification.....	924
27.7.3	Major capabilities/options.....	925
27.7.4	PICS proforma tables for the repeater for 100 Mb/s baseband networks	925
28.	Physical Layer link signaling for Auto-Negotiation on twisted pair	933
28.1	Overview.....	933
28.1.1	Scope.....	933
28.1.2	Application perspective/objectives	934
28.1.3	Relationship to architectural layering	934
28.1.4	Compatibility considerations	935
28.2	Functional specifications	936
28.2.1	Transmit function requirements.....	937
28.2.2	Receive function requirements	941
28.2.3	Arbitration function requirements	943
28.2.4	Management function requirements	949
28.2.5	Absence of management function.....	955
28.2.6	Technology-Dependent Interface	955
28.3	State diagrams and variable definitions.....	957
28.3.1	State diagram variables	958
28.3.2	State diagram timers	964
28.3.3	State diagram counters.....	967
28.3.4	State diagrams.....	968
28.4	Electrical specifications	971
28.5	Protocol implementation conformance statement (PICS) proforma for Clause 28, Physical Layer link signaling for Auto-Negotiation on twisted pair.....	972
28.5.1	Introduction.....	972
28.5.2	Identification	972
28.5.3	Major capabilities/options.....	973

28.5.4	PICS proforma tables for Physical Layer link signaling for Auto-Negotiation on twisted pair.....	973
28.6	Auto-Negotiation expansion.....	987
29.	System considerations for multisegment 100BASE-T networks	988
29.1	Overview.....	988
29.1.1	Single collision domain multisegment networks.....	989
29.1.2	Repeater usage	990
29.2	Transmission System Model 1.....	990
29.3	Transmission System Model 2.....	990
29.3.1	Round-trip collision delay	992
29.4	Full duplex 100 Mb/s topology limitations.....	994
30.	Management.....	996
30.1	Overview.....	996
30.1.1	Scope.....	997
30.1.2	Relationship to objects in IEEE 802.1F.....	997
30.1.3	Systems management overview.....	997
30.1.4	Management model.....	998
30.2	Managed objects	999
30.2.1	Introduction.....	999
30.2.2	Overview of managed objects.....	999
30.2.3	Containment.....	1006
30.2.4	Naming.....	1009
30.2.5	Capabilities	1009
30.3	Layer management for DTEs.....	1040
30.3.1	MAC entity managed object class	1040
30.3.2	PHY device managed object class	1050
30.3.3	MAC control entity object class	1055
30.3.4	PAUSE entity managed object class.....	1057
30.3.5	MPCP managed object class.....	1058
30.3.6	OAM object class.....	1064
30.3.7	OMPEmulation managed object class	1079
30.3.8	EXTENSION entity managed object class.....	1081
30.4	Layer management for 10, 100, and 1000 Mb/s baseband repeaters.....	1081
30.4.1	Repeater managed object class	1081
30.4.2	Group managed object class	1085
30.4.3	Repeater port managed object class.....	1086
30.5	Layer management for medium attachment units (MAUs)	1093
30.5.1	MAU managed object class	1093
30.6	Management for link Auto-Negotiation	1113
30.6.1	Auto-Negotiation managed object class	1113
30.7	Management for Link Aggregation	1118
30.7.1	Aggregator managed object class	1118
30.7.2	Aggregation Port managed object class.....	1126
30.7.3	Aggregation Port Statistics managed object class	1132
30.7.4	Aggregation Port Debug Information managed object class	1134
30.8	Management for WAN Interface Sublayer (WIS).....	1137
30.8.1	WIS managed object class	1137
30.9	Management for Power over Ethernet	1144
30.9.1	PSE managed object class.....	1144
30.10	Layer management for Midspan	1151

30.10.1	Midspan managed object class	1151
30.10.2	PSE Group managed object class	1152
30.11	Layer Management for Physical Medium Entity (PME).....	1153
30.11.1	PAF managed object class	1153
30.11.2	PME managed object class	1157
30.12	Layer Management for Link Layer Discovery Protocol (LLDP).....	1160
30.12.1	LLDP Configuration managed object class	1160
30.12.2	LLDP Local System Group managed object class	1161
30.12.3	LLDP Remote System Group managed object class	1178
30.13	Management for oTimeSync entity	1193
30.13.1	TimeSync entity managed object class.....	1193
30.14	Management for MAC Merge Sublayer	1196
30.14.1	oMACMergeEntity managed object class	1196
30.15	Layer management for Power over Data Lines (PoDL) of Single Pair Ethernet	1199
30.15.1	PoDL PSE managed object class	1199
30.16	Management for PLCA Reconciliation Sublayer	1204
30.16.1	PLCA managed object class	1204
31.	MAC Control	1207
31.1	Overview.....	1207
31.2	Layer architecture	1207
31.3	Support by interlayer interfaces	1207
31.3.1	MA_CONTROL.request.....	1209
31.3.2	MA_CONTROL.indication	1209
31.4	MAC Control frames	1210
31.4.1	MAC Control frame format	1210
31.5	Opcode-independent MAC Control sublayer operation	1211
31.5.1	Frame parsing and data frame reception.....	1211
31.5.2	Control frame reception	1212
31.5.3	Opcode-independent MAC Control receive state diagram.....	1212
31.6	Compatibility requirements	1214
31.7	MAC Control client behavior	1214
31.8	Protocol implementation conformance statement (PICS) proforma for Clause 31, MAC Control	1215
31.8.1	Introduction.....	1215
31.8.2	Identification	1215
31.8.3	PICS proforma for MAC Control frames	1216
32.	Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 100BASE-T2	1217
32.1	Overview.....	1217
32.1.1	Relation of 100BASE-T2 to other standards	1217
32.1.2	Operation of 100BASE-T2	1217
32.1.3	Application of 100BASE-T2	1222
32.1.4	State diagram conventions	1222
32.2	PHY Control functional specifications and service interface	1222
32.2.1	PHY Control function.....	1222
32.2.2	PHY Control Service interface	1223
32.2.3	State diagram variables	1225
32.2.4	State diagram timers	1226
32.2.5	PHY Control state diagram.....	1227
32.3	PCS functional specifications	1227

32.3.1	PCS functions	1229
32.3.2	PCS interfaces.....	1235
32.3.3	Frame structure	1236
32.3.4	State variables	1236
32.3.5	State diagrams.....	1238
32.3.6	PCS electrical specifications.....	1239
32.4	PMA functional specifications and service interface	1242
32.4.1	PMA functional specifications.....	1242
32.4.2	PMA service interface	1246
32.5	Management functions.....	1249
32.5.1	100BASE-T2 Use of Auto-Negotiation and MII Registers 8, 9, and 10	1249
32.5.2	Management functions.....	1250
32.5.3	PHY specific registers for 100BASE-T2.....	1251
32.5.4	Changes and additions to Auto-Negotiation (Clause 28)	1253
32.6	PMA electrical specifications	1256
32.6.1	PMA-to-MDI interface characteristics	1256
32.6.2	Power consumption.....	1280
32.7	Link segment characteristics.....	1280
32.7.1	Cabling.....	1281
32.7.2	Link transmission parameters	1281
32.7.3	Noise	1283
32.7.4	Installation practice.....	1285
32.8	MDI specification	1286
32.8.1	MDI connectors	1286
32.8.2	Crossover function	1286
32.9	System considerations.....	1287
32.10	Environmental specifications.....	1287
32.10.1	General safety	1287
32.10.2	Network safety.....	1287
32.10.3	Environment.....	1289
32.10.4	Cabling specifications.....	1289
32.11	PHY labeling.....	1289
32.12	Delay constraints.....	1289
32.12.1	PHY delay constraints (exposed MII)	1289
32.12.2	DTE delay constraints (unexposed MII).....	1290
32.13	Protocol implementation conformance statement (PICS) proforma for Clause 32, Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 100BASE-T2	1291
32.13.1	Identification.....	1291
32.13.2	Major capabilities/options.....	1292
32.13.3	Compatibility considerations	1292
32.13.4	PHY control function.....	1293
32.13.5	Physical Coding Sublayer (PCS) or Physical Medium Attachment (PMA) sublayer	1294
33.	Power over Ethernet over 2 Pairs	1311
33.1	Overview.....	1311
33.1.1	Objectives	1311
33.1.2	Compatibility considerations	1312
33.1.3	Relationship of Power over Ethernet to the IEEE 802.3 Architecture	1312
33.1.4	Type 1 and Type 2 system parameters.....	1313
33.2	Power sourcing equipment (PSE).....	1314
33.2.1	PSE location.....	1315
33.2.2	Midspan PSE types	1315

33.2.3	PI pin assignments	1320
33.2.4	PSE state diagrams.....	1321
33.2.5	PSE detection of PDs.....	1329
33.2.6	PSE classification of PDs and mutual identification	1332
33.2.7	Power supply output	1337
33.2.8	Power supply allocation.....	1343
33.2.9	PSE power removal	1343
33.3	Powered devices (PDs)	1345
33.3.1	PD PI.....	1346
33.3.2	PD type descriptions	1346
33.3.3	PD state diagram.....	1347
33.3.4	PD valid and non-valid detection signatures	1350
33.3.5	PD classifications.....	1351
33.3.6	PSE Type identification	1353
33.3.7	PD power	1354
33.3.8	PD Maintain Power Signature	1359
33.4	Additional electrical specifications.....	1360
33.4.1	Electrical isolation	1360
33.4.2	Fault tolerance.....	1361
33.4.3	Impedance balance.....	1362
33.4.4	Common-mode output voltage	1363
33.4.5	Pair-to-pair output noise voltage.....	1365
33.4.6	Differential noise voltage.....	1366
33.4.7	Return loss	1366
33.4.8	100BASE-TX transformer droop.....	1367
33.4.9	Midspan PSE device additional requirements	1367
33.5	Management function requirements	1373
33.5.1	PSE registers	1373
33.6	Data Link Layer classification.....	1378
33.6.1	TLV frame definition.....	1378
33.6.2	Data Link Layer classification timing requirements.....	1378
33.6.3	Power control state diagrams.....	1379
33.6.4	State change procedure across a link	1384
33.7	Environmental.....	1386
33.7.1	General safety	1386
33.7.2	Network safety.....	1386
33.7.3	Installation and maintenance guidelines	1386
33.7.4	Patch panel considerations.....	1386
33.7.5	Telephony voltages.....	1386
33.7.6	Electromagnetic emissions	1387
33.7.7	Temperature and humidity.....	1387
33.7.8	Labeling	1387
33.8	Protocol implementation conformance statement (PICS) proforma for Clause 33, Power over Ethernet over 2 Pairs.....	1388
33.8.1	Introduction.....	1388
33.8.2	Identification	1388
33.8.3	PICS proforma tables for Power over Ethernet over 2 Pairs	1390
34.	Introduction to 1000 Mb/s baseband networks.....	1404
34.1	Overview.....	1404
34.1.1	Reconciliation Sublayer (RS) and Gigabit Media Independent Interface (GMII).....	1404
34.1.2	Physical Layer signaling systems	1405
34.1.3	Repeater	1405

34.1.4	Auto-Negotiation, type 1000BASE-X	1405
34.1.5	Auto-Negotiation, type 1000BASE-T	1405
34.1.6	Auto-Negotiation, type 1000BASE-T1	1405
34.1.7	Management	1405
34.2	State diagrams	1406
34.3	Protocol implementation conformance statement (PICS) proforma	1406
35.	Reconciliation Sublayer (RS) and Gigabit Media Independent Interface (GMII)	1407
35.1	Overview	1407
35.1.1	Summary of major concepts	1408
35.1.2	Application	1408
35.1.3	Rate of operation	1408
35.1.4	Allocation of functions	1408
35.2	Functional specifications	1409
35.2.1	Mapping of GMII signals to PLS service primitives and Station Management	1409
35.2.2	GMII signal functional specifications	1412
35.2.3	GMII data stream	1422
35.2.4	MAC delay constraints (with GMII)	1425
35.2.5	Management functions	1425
35.3	Signal mapping	1425
35.4	LPI Assertion and Detection	1426
35.4.1	LPI messages	1427
35.4.2	Transmit LPI state diagram	1427
35.4.3	Considerations for transmit system behavior	1428
35.5	Electrical characteristics	1428
35.5.1	DC characteristics	1429
35.5.2	AC characteristics	1429
35.6	Protocol implementation conformance statement (PICS) proforma for Clause 35, Reconciliation Sublayer (RS) and Gigabit Media Independent Interface (GMII)	1434
35.6.1	Introduction	1434
35.6.2	Identification	1434
35.6.3	PICS proforma tables for reconciliation sublayer and Gigabit Media Independent Interface	1435
36.	Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA) sublayer, type 1000BASE-X	1439
36.1	Overview	1439
36.1.1	Scope	1439
36.1.2	Objectives	1439
36.1.3	Relationship of 1000BASE-X to other standards	1439
36.1.4	Summary of 1000BASE-X sublayers	1440
36.1.5	Inter-sublayer interfaces	1440
36.1.6	Functional block diagram	1441
36.1.7	State diagram conventions	1441
36.2	Physical Coding Sublayer (PCS)	1442
36.2.1	PCS Interface (GMII)	1442
36.2.2	Functions within the PCS	1443
36.2.3	Use of code-groups	1443
36.2.4	8B/10B transmission code	1443
36.2.5	Detailed functions and state diagrams	1456
36.3	Physical Medium Attachment (PMA) sublayer	1475
36.3.1	Service Interface	1475

36.3.2	Functions within the PMA	1476
36.3.3	A physical instantiation of the PMA Service Interface	1477
36.3.4	General electrical characteristics of the TBI	1480
36.3.5	TBI transmit interface electrical characteristics	1482
36.3.6	TBI receive interface electrical characteristics	1483
36.3.7	Loopback mode	1483
36.3.8	Test functions	1484
36.4	Compatibility considerations	1484
36.5	Delay constraints	1485
36.5.1	MDI to GMII delay constraints	1485
36.5.2	DTE delay constraints (half duplex mode)	1486
36.5.3	Carrier deassertion/assertion constraint (half duplex mode)	1486
36.6	Environmental specifications	1486
36.7	Protocol implementation conformance statement (PICS) proforma for Clause 36, Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA) sublayer, type 1000BASE-X	1487
36.7.1	Introduction	1487
36.7.2	Identification	1487
36.7.3	Major capabilities/options	1488
36.7.4	PICS proforma tables for the PCS and PMA sublayer, type 1000BASE-X	1488
37.	Auto-Negotiation function, type 1000BASE-X	1492
37.1	Overview	1492
37.1.1	Scope	1492
37.1.2	Application perspective/objectives	1492
37.1.3	Relationship to architectural layering	1493
37.1.4	Compatibility considerations	1493
37.2	Functional specifications	1494
37.2.1	Config_Reg encoding	1494
37.2.2	Transmit function requirements	1497
37.2.3	Receive function requirements	1498
37.2.4	Arbitration process requirements	1498
37.2.5	Management function requirements	1502
37.2.6	Absence of management function	1505
37.3	Detailed functions and state diagrams	1505
37.3.1	State diagram variables	1506
37.4	Environmental specifications	1512
37.5	Protocol implementation conformance statement (PICS) proforma for Clause 37, Auto-Negotiation function, type 1000BASE-X	1513
37.5.1	Introduction	1513
37.5.2	Identification	1513
37.5.3	Major capabilities/options	1514
37.5.4	PICS proforma tables for the Auto-Negotiation function, type 1000BASE-X	1514
38.	Physical Medium Dependent (PMD) sublayer and baseband medium, type 1000BASE-LX (long wavelength laser) and 1000BASE-SX (short wavelength laser)	1517
38.1	Overview	1517
38.1.1	Physical Medium Dependent (PMD) sublayer service interface	1517
38.1.2	Medium Dependent Interface (MDI)	1518
38.2	PMD functional specifications	1519
38.2.1	PMD block diagram	1519
38.2.2	PMD transmit function	1519

38.2.3	PMD receive function	1519
38.2.4	PMD signal detect function	1520
38.3	PMD to MDI optical specifications for 1000BASE-SX	1520
38.3.1	Transmitter optical specifications	1521
38.3.2	Receive optical specifications	1522
38.3.3	Illustrative 1000BASE-SX link power budget and penalties	1522
38.4	PMD to MDI optical specifications for 1000BASE-LX	1523
38.4.1	Transmitter optical specifications	1523
38.4.2	Receive optical specifications	1524
38.4.3	Illustrative 1000BASE-LX link power budget and penalties	1525
38.5	Jitter specifications for 1000BASE-SX and 1000BASE-LX	1525
38.6	Optical measurement requirements	1526
38.6.1	Center wavelength and spectral width measurements	1526
38.6.2	Optical power measurements	1526
38.6.3	Extinction ratio measurements	1526
38.6.4	Relative Intensity Noise (RIN)	1526
38.6.5	Transmitter optical waveform (transmit eye)	1527
38.6.6	Transmit rise/fall characteristics	1527
38.6.7	Receive sensitivity measurements	1528
38.6.8	Total jitter measurements	1528
38.6.9	Deterministic jitter measurement (optional)	1529
38.6.10	Coupled Power Ratio (CPR) measurements	1529
38.6.11	Conformance test signal at TP3 for receiver testing	1529
38.6.12	Measurement of the receiver 3 dB electrical upper cutoff frequency	1531
38.7	Environmental specifications	1532
38.7.1	General safety	1532
38.7.2	Laser safety	1532
38.7.3	Installation	1532
38.8	Environment	1532
38.8.1	Electromagnetic emission	1532
38.8.2	Temperature, humidity, and handling	1533
38.9	PMD labeling requirements	1533
38.10	Fiber optic cabling model	1533
38.11	Characteristics of the fiber optic cabling	1533
38.11.1	Optical fiber and cable	1534
38.11.2	Optical fiber connection	1534
38.11.3	Medium Dependent Interface (MDI)	1535
38.11.4	Single-mode fiber offset-launch mode-conditioning patch cord for MMF operation of 1000BASE-LX	1536
38.12	Protocol implementation conformance statement (PICS) proforma for Clause 38, Physical Medium Dependent (PMD) sublayer and baseband medium, type 1000BASE-LX (Long Wavelength Laser) and 1000BASE-SX (Short Wavelength Laser)	1538
38.12.1	Introduction	1538
38.12.2	Identification	1538
38.12.3	Major capabilities/options	1539
38.12.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and baseband medium, type 1000BASE-LX (Long Wavelength Laser) and 1000BASE-SX (Short Wavelength Laser)	1540
39.	Physical Medium Dependent (PMD) sublayer and baseband medium, type 1000BASE-CX (short-haul copper)	1545
39.1	Overview	1545
39.2	Functional specifications	1545

39.2.1	PMD transmit function	1545
39.2.2	PMD receive function	1545
39.2.3	PMD signal detect function	1545
39.3	PMD to MDI electrical specifications	1546
39.3.1	Transmitter electrical specifications	1547
39.3.2	Receiver electrical specifications	1549
39.3.3	Jitter specifications for 1000BASE-CX	1550
39.4	Jumper cable assembly characteristics	1551
39.4.1	Compensation networks	1551
39.4.2	Shielding	1551
39.5	MDI specification	1551
39.5.1	MDI connectors	1552
39.5.2	Crossover function	1554
39.6	Electrical measurement requirements	1555
39.6.1	Transmit rise/fall time	1555
39.6.2	Transmit skew measurement	1555
39.6.3	Transmit eye (normalized and absolute)	1555
39.6.4	Through connection impedance	1555
39.6.5	Jumper cable intra-pair differential skew	1555
39.6.6	Receiver link signal	1556
39.6.7	Near-End Cross Talk (NEXT)	1556
39.6.8	Differential time-domain reflectometry (TDR) measurement procedure	1556
39.7	Environmental specifications	1557
39.8	Protocol implementation conformance statement (PICS) proforma for Clause 39, Physical Medium Dependent (PMD) sublayer and baseband medium, type 1000BASE-CX	1558
39.8.1	Introduction	1558
39.8.2	Identification	1558
39.8.3	Major capabilities/options	1559
39.8.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and baseband medium, type 1000BASE-CX (short-haul copper)	1559
40.	Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 1000BASE-T	1563
40.1	Overview	1563
40.1.1	Objectives	1563
40.1.2	Relationship of 1000BASE-T to other standards	1563
40.1.3	Operation of 1000BASE-T	1564
40.1.4	Signaling	1568
40.1.5	Inter-sublayer interfaces	1569
40.1.6	Conventions in this clause	1569
40.2	1000BASE-T Service Primitives and Interfaces	1569
40.2.1	Technology-Dependent Interface	1569
40.2.2	PMA Service Interface	1570
40.2.3	PMA_TXMODE.indication	1572
40.2.4	PMA_CONFIG.indication	1573
40.2.5	PMA_UNITDATA.request	1573
40.2.6	PMA_UNITDATA.indication	1574
40.2.7	PMA_SCRSTATUS.request	1575
40.2.8	PMA_RXSTATUS.indication	1575
40.2.9	PMA_REMRXSTATUS.request	1576
40.2.10	PMA_RESET.indication	1576
40.2.11	PMA_LPIMODE.indication	1576
40.2.12	PMA_LPIREQ.request	1577

40.2.13	PMA_REMLPIREQ.request.....	1577
40.2.14	PMA_UPDATE.indication.....	1578
40.2.15	PMA_REMUPDATE.request.....	1578
40.3	Physical Coding Sublayer (PCS).....	1579
40.3.1	PCS functions.....	1580
40.3.2	Stream structure.....	1596
40.3.3	State variables.....	1596
40.3.4	State diagrams.....	1601
40.4	Physical Medium Attachment (PMA) sublayer.....	1607
40.4.1	PMA functional specifications.....	1607
40.4.2	PMA functions.....	1608
40.4.3	MDI.....	1611
40.4.4	Automatic MDI/MDI-X Configuration.....	1611
40.4.5	State variables.....	1612
40.4.6	State Diagrams.....	1617
40.5	Management interface.....	1620
40.5.1	Support for Auto-Negotiation.....	1620
40.5.2	MASTER-SLAVE configuration resolution.....	1625
40.6	PMA electrical specifications.....	1627
40.6.1	PMA-to-MDI interface tests.....	1627
40.7	Link segment characteristics.....	1648
40.7.1	Cabling system characteristics.....	1648
40.7.2	Link transmission parameters.....	1649
40.7.3	Coupling parameters.....	1649
40.7.4	Delay.....	1651
40.7.5	Noise environment.....	1651
40.7.6	External coupled noise.....	1652
40.8	MDI specification.....	1652
40.8.1	MDI connectors.....	1652
40.8.2	Crossover function.....	1653
40.8.3	MDI electrical specifications.....	1654
40.9	Environmental specifications.....	1656
40.9.1	General safety.....	1656
40.9.2	Network safety.....	1656
40.9.3	Environment.....	1657
40.10	PHY labeling.....	1657
40.11	Delay constraints.....	1658
40.11.1	MDI to GMII delay constraints.....	1658
40.11.2	DTE delay constraints (half duplex only).....	1659
40.11.3	Carrier de-assertion/assertion constraint (half duplex mode).....	1659
40.12	Protocol implementation conformance statement (PICS) proforma for Clause 40—Physical coding sublayer (PCS), physical medium attachment (PMA) sublayer and baseband medium, type 1000BASE-T.....	1660
40.12.1	Identification.....	1660
40.12.2	Major capabilities/options.....	1660
40.12.3	Clause conventions.....	1661
40.12.4	Physical Coding Sublayer (PCS).....	1661
40.12.5	Physical Medium Attachment (PMA).....	1665
40.12.6	Management interface.....	1667
40.12.7	PMA Electrical Specifications.....	1669
40.12.8	Characteristics of the link segment.....	1675
40.12.9	MDI requirements.....	1676
40.12.10	General safety and environmental requirements.....	1678
40.12.11	Timing requirements.....	1679

41. Repeater for 1000 Mb/s baseband networks.....	1680
41.1 Overview.....	1680
41.1.1 Scope.....	1680
41.1.2 Application perspective	1681
41.1.3 Relationship to PHY	1681
41.2 Repeater functional specifications.....	1681
41.2.1 Repeater functions	1682
41.2.2 Detailed repeater functions and state diagrams	1686
41.3 Repeater electrical specifications.....	1694
41.3.1 Electrical isolation	1694
41.4 Environmental specifications.....	1694
41.4.1 General safety	1694
41.4.2 Network safety	1694
41.4.3 Electrical isolation	1695
41.4.4 Reliability.....	1695
41.4.5 Environment.....	1696
41.5 Repeater labeling	1696
41.6 Protocol implementation conformance statement (PICS) proforma for Clause 41, Repeater for 1000 Mb/s baseband networks	1696
41.6.1 Introduction.....	1696
41.6.2 Identification	1697
41.6.3 Major capabilities/options.....	1697
41.6.4 PICS proforma tables for the Repeater for 1000 Mb/s baseband networks.....	1698
42. System considerations for multisegment 1000 Mb/s networks	1705
42.1 Overview.....	1705
42.1.1 Single collision domain multisegment networks	1706
42.1.2 Repeater usage	1707
42.2 Transmission System Model 1.....	1707
42.3 Transmission System Model 2.....	1707
42.3.1 Round-trip collision delay	1708
42.4 Full duplex 1000 Mb/s topology limitations.....	1711
43. Content moved to IEEE Std 802.1AX-2008.....	1712
44. Introduction to 10 Gb/s baseband networks	1713
44.1 Overview.....	1713
44.1.1 Scope.....	1713
44.1.2 Objectives	1713
44.1.3 Relationship of 10 Gigabit Ethernet to the ISO OSI reference model.....	1713
44.1.4 Summary of 10 Gigabit Ethernet sublayers.....	1715
44.1.5 Management.....	1717
44.2 State diagrams.....	1717
44.3 Delay constraints.....	1717
44.4 Protocol implementation conformance statement (PICS) proforma.....	1719
45. Management Data Input/Output (MDIO) Interface.....	1720
45.1 Overview.....	1720
45.1.1 Summary of major concepts	1720
45.1.2 Application.....	1720

45.2	MDIO Interface registers	1721
45.2.1	PMA/PMD registers	1724
45.2.2	WIS registers.....	1949
45.2.3	PCS registers.....	1966
45.2.4	PHY XS registers.....	2044
45.2.5	DTE XS registers	2066
45.2.6	TC registers.....	2088
45.2.7	Auto-Negotiation registers.....	2097
45.2.8	OFDM PMA/PMD registers	2131
45.2.9	Power Unit registers.....	2137
45.2.10	Clause 22 extension registers.....	2142
45.2.11	Vendor specific MMD 1 registers	2144
45.2.12	Vendor specific MMD 2 registers	2145
45.3	Management frame structure	2147
45.3.1	IDLE (idle condition).....	2148
45.3.2	PRE (preamble).....	2148
45.3.3	ST (start of frame).....	2148
45.3.4	OP (operation code).....	2148
45.3.5	PRTAD (port address)	2148
45.3.6	DEVAD (device address)	2148
45.3.7	TA (turnaround).....	2148
45.3.8	ADDRESS / DATA	2148
45.4	Electrical interface	2149
45.4.1	Electrical specification.....	2149
45.4.2	Timing specification	2149
45.5	Protocol implementation conformance statement (PICS) proforma for Clause 45, Management Data Input/Output (MDIO) Interface	2151
45.5.1	Introduction.....	2151
45.5.2	Identification	2151
45.5.3	PICS proforma tables for the Management Data Input Output (MDIO) Interface.....	2152
46.	Reconciliation Sublayer (RS) and 10 Gigabit Media Independent Interface (XGMII).....	2204
46.1	Overview.....	2204
46.1.1	Summary of major concepts	2205
46.1.2	Application.....	2205
46.1.3	Rate of operation.....	2205
46.1.4	Delay constraints.....	2206
46.1.5	Allocation of functions	2206
46.1.6	XGMII structure	2206
46.1.7	Mapping of XGMII signals to PLS service primitives	2207
46.2	XGMII data stream	2210
46.2.1	Inter-frame <inter-frame>.....	2210
46.2.2	Preamble <preamble> and start of frame delimiter <sfd>.....	2210
46.2.3	Data <data>.....	2211
46.2.4	End of frame delimiter <efd>	2211
46.2.5	Definition of Start of Packet and End of Packet Delimiters	2211
46.3	XGMII functional specifications	2211
46.3.1	Transmit	2212
46.3.2	Receive.....	2216
46.3.3	Error and fault handling.....	2219
46.3.4	Link fault signaling.....	2220
46.4	LPI assertion and detection.....	2222
46.4.1	LPI messages	2223

46.4.2	Transmit LPI state diagram.....	2223
46.4.3	Considerations for transmit system behavior.....	2225
46.4.4	Considerations for receive system behavior	2225
46.5	XGMII electrical characteristics	2225
46.6	Protocol implementation conformance statement (PICS) proforma for Clause 46, Reconciliation Sublayer (RS) and 10 Gigabit Media Independent Interface (XGMII).....	2227
46.6.1	Introduction.....	2227
46.6.2	Identification	2227
46.6.3	PICS proforma tables for Reconciliation Sublayer and 10 Gigabit Media Independent Interface	2228
47.	XGMII Extender Sublayer (XGXS) and 10 Gigabit Attachment Unit Interface (XAUI).....	2233
47.1	Overview.....	2233
47.1.1	Summary of major concepts	2234
47.1.2	Application.....	2234
47.1.3	Rate of operation.....	2234
47.1.4	Allocation of functions	2235
47.1.5	Global signal detect function	2235
47.1.6	Global transmit disable function.....	2235
47.2	Functional specifications	2235
47.2.1	PCS and PMA functionality	2235
47.2.2	Delay constraints.....	2236
47.3	XAUI Electrical characteristics	2236
47.3.1	Signal levels	2236
47.3.2	Signal paths.....	2236
47.3.3	Driver characteristics	2237
47.3.4	Receiver characteristics	2239
47.3.5	Interconnect characteristics.....	2241
47.4	Electrical measurement requirements.....	2242
47.4.1	Compliance interconnect definition.....	2242
47.4.2	Eye template measurements.....	2243
47.4.3	Jitter test requirements	2244
47.5	Environmental specifications.....	2244
47.6	Protocol implementation conformance statement (PICS) proforma for Clause 47, XGMII Extender (XGMII) and 10 Gigabit Attachment Unit Interface (XAUI).....	2245
47.6.1	Introduction.....	2245
47.6.2	Identification	2245
47.6.3	Major capabilities/options.....	2246
47.6.4	PICS proforma tables for XGXS and XAUI	2246
48.	Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA) sublayer, type 10GBASE-X	2248
48.1	Overview.....	2248
48.1.1	Objectives	2248
48.1.2	Relationship of 10GBASE-X to other standards	2249
48.1.3	Summary of 10GBASE-X sublayers	2249
48.1.4	Rate of operation.....	2250
48.1.5	Allocation of functions	2250
48.1.6	Inter-sublayer interfaces	2251
48.1.7	Functional block diagram	2251
48.1.8	Special symbols	2252
48.2	Physical Coding Sublayer (PCS).....	2252

48.2.1	PCS service interface (XGMII)	2252
48.2.2	Functions within the PCS	2252
48.2.3	Use of code-groups	2253
48.2.4	Ordered sets and special code-groups	2255
48.2.5	Management function requirements	2261
48.2.6	Detailed functions and state diagrams	2262
48.2.7	Auto-Negotiation for Backplane Ethernet	2279
48.3	Physical Medium Attachment (PMA) sublayer	2279
48.3.1	Functions within the PMA	2280
48.3.2	Service interface	2281
48.3.3	Loopback mode	2282
48.3.4	Test functions	2282
48.4	Compatibility considerations	2282
48.5	Delay constraints	2282
48.6	Environmental specifications	2283
48.7	Protocol implementation conformance statement (PICS) proforma for Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA) sublayer, type 10GBASE-X	2284
48.7.1	Introduction	2284
48.7.2	Identification	2284
48.7.3	Major capabilities/options	2285
48.7.4	PICS proforma tables for the PCS and PMA sublayer, type 10GBASE-X	2285
49.	Physical Coding Sublayer (PCS) for 64B/66B, type 10GBASE-R	2288
49.1	Overview	2288
49.1.1	Scope	2288
49.1.2	Objectives	2288
49.1.3	Relationship of 10GBASE-R to other standards	2288
49.1.4	Summary of 10GBASE-R and 10GBASE-W sublayers	2289
49.1.5	Inter-sublayer interfaces	2291
49.1.6	Functional block diagram	2292
49.2	Physical Coding Sublayer (PCS)	2293
49.2.1	PCS service interface (XGMII)	2293
49.2.2	Functions within the PCS	2293
49.2.3	Use of blocks	2294
49.2.4	64B/66B transmission code	2294
49.2.5	Transmit process	2300
49.2.6	Scrambler	2300
49.2.7	Gearbox	2301
49.2.8	Test-pattern generators	2301
49.2.9	Block synchronization	2302
49.2.10	Descrambler	2302
49.2.11	Receive process	2302
49.2.12	Test-pattern checker	2303
49.2.13	Detailed functions and state diagrams	2304
49.2.14	PCS Management	2312
49.2.15	Delay constraints	2313
49.2.16	Auto-Negotiation for Backplane Ethernet	2314
49.3	Protocol implementation conformance statement (PICS) proforma for Clause 49, Physical Coding Sublayer (PCS) type 10GBASE-R	2318
49.3.1	Introduction	2318
49.3.2	Identification	2318
49.3.3	Major capabilities/options	2319
49.3.4	PICS Proforma Tables for PCS, type 10GBASE-R	2319

49.3.5	Test-pattern modes.....	2320
49.3.6	Management.....	2321
50.	WAN Interface Sublayer (WIS), type 10GBASE-W	2324
50.1	Overview.....	2324
50.1.1	Scope.....	2324
50.1.2	Objectives	2325
50.1.3	Relationship to other sublayers.....	2326
50.1.4	Summary of functions.....	2326
50.1.5	Sublayer interfaces.....	2327
50.1.6	Functional block diagram	2327
50.1.7	Notational conventions	2327
50.2	WIS Service Interface	2328
50.2.1	WIS_UNITDATA.request.....	2328
50.2.2	WIS_UNITDATA.indication	2329
50.2.3	WIS_SIGNAL.request.....	2329
50.2.4	WIS_SIGNAL.indication	2330
50.3	Functions within the WIS	2330
50.3.1	Payload mapping and data-unit delineation.....	2332
50.3.2	WIS frame generation	2334
50.3.3	Scrambling	2340
50.3.4	Octet and frame delineation.....	2341
50.3.5	Error propagation.....	2341
50.3.6	Mapping between WIS and PMA	2342
50.3.7	WIS data delay constraints	2343
50.3.8	WIS test-pattern generator and checker.....	2344
50.3.9	Loopback	2347
50.3.10	Link status.....	2347
50.3.11	Management interface.....	2347
50.4	Synchronization state diagram.....	2349
50.4.1	State diagram variables.....	2349
50.4.2	State diagram	2351
50.4.3	Parameter values	2353
50.5	Environmental specifications.....	2353
50.6	Protocol implementation conformance statement (PICS) proforma for Clause 50, WAN Interface Sublayer (WIS), type 10GBASE-W	2355
50.6.1	Introduction.....	2355
50.6.2	Identification.....	2355
50.6.3	Major capabilities/options.....	2356
50.6.4	PICS proforma tables for the WAN Interface Sublayer (WIS), type 10GBASE-W	2356
51.	Physical Medium Attachment (PMA) sublayer, type Serial.....	2361
51.1	Overview.....	2361
51.1.1	Scope.....	2361
51.1.2	Summary of functions.....	2361
51.2	PMA Service Interface.....	2362
51.2.1	PMA_UNITDATA.request.....	2362
51.2.2	PMA_UNITDATA.indication	2363
51.2.3	PMA_SIGNAL.indication	2363
51.2.4	PMA_RXMODE.request.....	2364
51.2.5	PMA_TXMODE.request.....	2364
51.2.6	PMA_ENERGY.indication.....	2364

51.3	Functions within the PMA	2365
51.3.1	PMA transmit function	2365
51.3.2	PMA receive function	2365
51.3.3	Delay Constraints	2365
51.4	Sixteen-Bit Interface (XSBI)	2366
51.4.1	Required signals	2367
51.4.2	Optional Signals	2369
51.5	General electrical characteristics of the XSBI	2370
51.5.1	DC characteristics	2370
51.5.2	Valid signal levels	2370
51.5.3	Rise and fall time definition	2371
51.5.4	Output load	2371
51.6	XSBI transmit interface electrical characteristics	2371
51.6.1	XSBI transmit interface timing	2371
51.6.2	XSBI PMA_TX_CLK and PMA_TXCLK_SRC Specification	2373
51.7	XSBI receive interface electrical characteristics	2374
51.7.1	XSBI receive interface timing	2374
51.7.2	XSBI PMA_RX_CLK specification	2376
51.8	PMA loopback mode (optional)	2376
51.9	Environmental specifications	2377
51.10	Protocol implementation conformance statement (PICS) proforma for Clause 51, Physical Medium Attachment (PMA) sublayer, type Serial	2378
51.10.1	Introduction	2378
51.10.2	Identification	2378
51.10.3	Major capabilities/options	2379
51.10.4	PICS proforma tables for the PMA Interface Sublayer, type Serial	2379
52.	Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-S (short wavelength serial), 10GBASE-L (long wavelength serial), and 10GBASE-E (extra long wavelength serial)	2381
52.1	Overview	2381
52.1.1	Physical Medium Dependent (PMD) sublayer service interface	2382
52.2	Delay constraints	2384
52.3	PMD MDIO function mapping	2384
52.4	PMD functional specifications	2385
52.4.1	PMD block diagram	2385
52.4.2	PMD Transmit function	2385
52.4.3	PMD Receive function	2385
52.4.4	PMD Signal Detect function	2385
52.4.5	PMD_reset function	2386
52.4.6	PMD_fault function	2386
52.4.7	PMD_global_transmit_disable function	2386
52.4.8	PMD_transmit_fault function	2387
52.4.9	PMD_receive_fault function	2387
52.5	PMD to MDI optical specifications for 10GBASE-S	2387
52.5.1	10GBASE-S transmitter optical specifications	2388
52.5.2	10GBASE-S receive optical specifications	2390
52.5.3	Illustrative 10GBASE-S link power budgets	2390
52.6	PMD to MDI optical specifications for 10GBASE-L	2390
52.6.1	10GBASE-L transmitter optical specifications	2391
52.6.2	10GBASE-L receive optical specifications	2393
52.6.3	Illustrative 10GBASE-L link power budgets	2393
52.7	PMD to MDI optical specifications for 10GBASE-E	2394

52.7.1	10GBASE-E transmitter optical specifications	2395
52.7.2	10GBASE-E receive optical specifications	2396
52.7.3	Illustrative 10GBASE-E link power budgets.....	2396
52.8	Jitter specifications for 10GBASE-R and 10GBASE-W	2396
52.8.1	Sinusoidal jitter for receiver conformance test	2397
52.9	Optical measurement requirements	2398
52.9.1	Test patterns	2398
52.9.2	Center wavelength, spectral width, and side mode suppression ratio (SMSR) measurements.....	2400
52.9.3	Average optical power measurements	2400
52.9.4	Extinction ratio measurements.....	2400
52.9.5	Optical modulation amplitude (OMA) test procedure	2400
52.9.6	Relative intensity noise optical modulation amplitude (RINxOMA) measuring procedure	2401
52.9.7	Transmitter optical waveform.....	2403
52.9.8	Receiver sensitivity measurements	2404
52.9.9	Stressed receiver conformance test.....	2405
52.9.10	Transmitter and dispersion penalty measurement	2410
52.9.11	Measurement of the receiver 3 dB electrical upper cutoff frequency.....	2412
52.10	Environmental specifications.....	2413
52.10.1	General safety	2413
52.10.2	Laser safety	2413
52.10.3	Installation	2413
52.11	Environment.....	2413
52.11.1	Electromagnetic emission	2413
52.11.2	Temperature, humidity, and handling	2414
52.12	PMD labeling requirements	2414
52.13	Fiber optic cabling model	2414
52.14	Characteristics of the fiber optic cabling (channel)	2415
52.14.1	Optical fiber and cable.....	2415
52.14.2	Optical fiber connection.....	2415
52.14.3	10GBASE-E attenuator management	2416
52.14.4	Medium Dependent Interface (MDI) requirements	2417
52.15	Protocol implementation conformance statement (PICS) proforma for Clause 52, Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-S (short wavelength serial), 10GBASE-L (long wavelength serial), and 10GBASE-E (extra long wavelength serial)	2418
52.15.1	Introduction.....	2418
52.15.2	Identification	2418
52.15.3	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and baseband medium, types 10GBASE-R and 10GBASE-W	2420
53.	Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-LX4.....	2425
53.1	Overview.....	2425
53.1.1	Physical Medium Dependent (PMD) service interface	2425
53.1.2	PMD_UNITDATA.request.....	2425
53.1.3	PMD_UNITDATA.indication	2426
53.1.4	PMD_SIGNAL.indication	2427
53.2	Delay constraints.....	2427
53.3	PMD MDIO function mapping.....	2427
53.4	PMD functional specifications.....	2428
53.4.1	PMD block diagram.....	2428
53.4.2	PMD transmit function	2429

53.4.3	PMD receive function	2430
53.4.4	Global PMD signal detect function	2430
53.4.5	PMD lane by lane signal detect function	2430
53.4.6	PMD reset function	2431
53.4.7	Global PMD transmit disable function	2431
53.4.8	PMD lane by lane transmit disable function	2431
53.4.9	PMD fault function	2431
53.4.10	PMD transmit fault function (optional)	2431
53.4.11	PMD receive fault function (optional)	2431
53.5	Wavelength-division multiplexed-lane assignments	2431
53.6	Operating ranges for 10GBASE-LX4 PMD	2431
53.7	PMD to MDI optical specifications for 10GBASE-LX4	2433
53.7.1	Transmitter optical specifications	2433
53.7.2	Receive optical specifications	2434
53.7.3	Illustrative 10GBASE-LX4 link power budget and penalties	2434
53.8	Jitter specifications for each lane of the 10GBASE-LX4 PMD	2434
53.8.1	Transmit jitter specification	2434
53.8.2	Receive jitter tolerance specification	2436
53.9	Optical measurement requirements	2438
53.9.1	Wavelength range measurements	2438
53.9.2	Optical power measurements	2439
53.9.3	Source spectral window measurements	2439
53.9.4	Extinction ratio measurements	2439
53.9.5	Optical Modulation Amplitude (OMA) measurements	2439
53.9.6	Relative Intensity Noise [RIN12(OMA)]	2439
53.9.7	Transmitter optical waveform (transmit eye)	2439
53.9.8	Transmit rise/fall characteristics	2441
53.9.9	Receive sensitivity measurements	2441
53.9.10	Transmitter jitter conformance (per lane)	2441
53.9.11	Receive sensitivity measurements	2443
53.9.12	Stressed receiver conformance test	2443
53.9.13	Measurement of the receiver 3 dB electrical upper cutoff frequency	2445
53.9.14	Conformance test signal at TP3 for receiver testing	2446
53.9.15	Receiver test suite for WDM conformance testing	2448
53.10	Environmental specifications	2450
53.10.1	General safety	2450
53.10.2	Laser safety	2450
53.10.3	Installation	2451
53.11	Environment	2451
53.11.1	Electromagnetic emission	2451
53.11.2	Temperature, humidity, and handling	2451
53.12	PMD labeling requirements	2451
53.13	Fiber optic cabling model	2452
53.14	Characteristics of the fiber optic cabling (channel)	2452
53.14.1	Optical fiber and cable	2452
53.14.2	Optical fiber connection	2453
53.14.3	Medium Dependent Interface (MDI)	2454
53.15	Protocol implementation conformance statement (PICS) proforma for Clause 53, Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-LX4	2455
53.15.1	Introduction	2455
53.15.2	Identification	2455
53.15.3	Major capabilities/options	2456
53.15.4	PICS proforma tables for 10GBASE-LX4 and baseband medium	2457

54. Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-CX4	2464
54.1 Overview.....	2464
54.2 Physical Medium Dependent (PMD) service interface	2465
54.3 Delay constraints.....	2465
54.4 PMD MDIO function mapping.....	2465
54.5 PMD functional specifications.....	2465
54.5.1 Link block diagram.....	2465
54.5.2 PMD Transmit function	2466
54.5.3 PMD Receive function.....	2466
54.5.4 Global PMD signal detect function	2466
54.5.5 PMD lane-by-lane signal detect function	2467
54.5.6 Global PMD transmit disable function	2467
54.5.7 PMD lane-by-lane transmit disable function	2467
54.5.8 Loopback mode.....	2468
54.5.9 PMD fault function	2468
54.5.10 PMD transmit fault function	2468
54.5.11 PMD receive fault function.....	2468
54.6 MDI Electrical specifications for 10GBASE-CX4.....	2468
54.6.1 Signal levels	2468
54.6.2 Signal paths.....	2469
54.6.3 Transmitter characteristics	2469
54.6.4 Receiver characteristics	2474
54.7 Cable assembly characteristics	2475
54.7.1 Characteristic impedance and reference impedance	2476
54.7.2 Cable assembly insertion loss	2476
54.7.3 Cable assembly return loss	2477
54.7.4 Near-End Crosstalk (NEXT)	2478
54.7.5 Far-End Crosstalk (FEXT).....	2479
54.7.6 Shielding	2481
54.7.7 Crossover function.....	2481
54.8 MDI specification	2482
54.8.1 MDI connectors	2482
54.8.2 Connector pin assignments	2483
54.9 Environmental specifications.....	2483
54.10 Protocol implementation conformance statement (PICS) proforma for Clause 54, Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-CX4	2484
54.10.1 Introduction.....	2484
54.10.2 Identification.....	2484
54.10.3 PICS proforma tables for 10GBASE-CX4 and baseband medium	2485
54.10.4 Major capabilities/options.....	2485
55. Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 10GBASE-T.....	2491
55.1 Overview.....	2491
55.1.1 Objectives	2491
55.1.2 Relationship of 10GBASE-T to other standards.....	2492
55.1.3 Operation of 10GBASE-T	2492
55.1.4 Signaling	2498
55.1.5 Interfaces.....	2498
55.1.6 Conventions in this clause	2499
55.2 10GBASE-T service primitives and interfaces.....	2499
55.2.1 Technology Dependent Interface.....	2499

55.2.2	PMA service interface	2500
55.3	Physical Coding Sublayer (PCS)	2508
55.3.1	PCS service interface (XGMII)	2508
55.3.2	PCS functions	2508
55.3.3	Test-pattern generators	2524
55.3.4	PMA training side-stream scrambler polynomials	2525
55.3.5	LPI signaling	2527
55.3.6	Detailed functions and state diagrams	2530
55.3.7	PCS management	2535
55.4	Physical Medium Attachment (PMA) sublayer	2543
55.4.1	PMA functional specifications	2543
55.4.2	PMA functions	2544
55.4.3	MDI	2557
55.4.4	Automatic MDI/MDI-X configuration	2558
55.4.5	State variables	2559
55.4.6	State diagrams	2564
55.5	PMA electrical specifications	2569
55.5.1	Electrical isolation	2569
55.5.2	Test modes	2569
55.5.3	Transmitter electrical specifications	2573
55.5.4	Receiver electrical specifications	2575
55.6	Management interfaces	2577
55.6.1	Support for Auto-Negotiation	2577
55.6.2	MASTER-SLAVE configuration resolution	2580
55.7	Link segment characteristics	2582
55.7.1	Cabling system characteristics	2583
55.7.2	Link segment transmission parameters	2583
55.7.3	Coupling parameters between link segments	2587
55.7.4	Noise environment	2598
55.8	MDI specification	2599
55.8.1	MDI connectors	2599
55.8.2	MDI electrical specifications	2599
55.9	Environmental specifications	2602
55.9.1	General safety	2602
55.9.2	Network safety	2602
55.9.3	Installation and maintenance guidelines	2602
55.9.4	Telephone voltages	2603
55.9.5	Electromagnetic compatibility	2603
55.9.6	Temperature and humidity	2603
55.10	PHY labeling	2603
55.11	Delay constraints	2603
55.12	Protocol implementation conformance statement (PICS) proforma for Clause 55—Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 10GBASE-T	2605
55.12.1	Identification	2605
55.12.2	Major capabilities/options	2606
55.12.3	Physical Coding Sublayer (PCS)	2606
55.12.4	Physical Medium Attachment (PMA)	2608
55.12.5	Management interface	2610
55.12.6	PMA electrical specifications	2611
55.12.7	Characteristics of the link segment	2612
55.12.8	MDI requirements	2613
55.12.9	General safety and environmental requirements	2614
55.12.10	Timing requirements	2614

56. Introduction to Ethernet for subscriber access networks	2615
56.1 Overview.....	2615
56.1.1 Summary of P2P sublayers	2622
56.1.2 Summary of P2MP sublayers	2622
56.1.3 Physical Layer signaling systems	2624
56.1.4 Management.....	2630
56.1.5 Unidirectional transmission	2633
56.2 State diagrams.....	2634
56.3 Protocol implementation conformance statement (PICS) proforma.....	2634
57. Operations, Administration, and Maintenance (OAM)	2635
57.1 Overview.....	2635
57.1.1 Scope.....	2635
57.1.2 Summary of objectives and major concepts	2635
57.1.3 Summary of non-objectives	2636
57.1.4 Positioning of OAM within the IEEE 802.3 architecture	2636
57.1.5 Compatibility considerations	2636
57.1.6 State diagram conventions	2637
57.2 Functional specifications	2637
57.2.1 Interlayer service interfaces	2637
57.2.2 Principles of operation	2638
57.2.3 Instances of the MAC data service interface	2638
57.2.4 Responsibilities of OAM client	2638
57.2.5 OAM client interactions.....	2639
57.2.6 Instances of the OAM internal service interface	2642
57.2.7 Internal block diagram	2642
57.2.8 OAM internal interactions	2643
57.2.9 Modes.....	2644
57.2.10 OAM events	2645
57.2.11 OAM remote loopback	2646
57.2.12 Unidirectional OAM operation.....	2648
57.3 Detailed functions and state diagrams	2648
57.3.1 State diagram variables	2649
57.3.2 Control	2653
57.3.3 Multiplexer.....	2657
57.3.4 Parser	2658
57.4 OAMPDUs.....	2659
57.4.1 Ordering and representation of octets	2659
57.4.2 Structure.....	2660
57.4.3 OAMPDU descriptions.....	2661
57.5 OAM TLVs.....	2665
57.5.1 Parsing	2665
57.5.2 Information TLVs	2666
57.5.3 Link Event TLVs	2669
57.6 Variables	2674
57.6.1 Variable Descriptors	2674
57.6.2 Variable Containers	2674
57.6.3 Parsing	2676
57.6.4 Variable Branch/Leaf examples.....	2677
57.6.5 Variable Indications.....	2677
57.7 Protocol implementation conformance statement (PICS) proforma for Clause 57, Operations, Administration, and Maintenance (OAM)	2679

57.7.1	Introduction.....	2679
57.7.2	Identification.....	2679
57.7.3	PICS proforma tables for Operation, Administration, and Maintenance (OAM)	2680
57.7.4	Link Event TLVs	2684
57.7.5	Variables Descriptors and Containers.....	2685
58.	Physical Medium Dependent (PMD) sublayer and medium, type 100BASE-LX10 (Long Wavelength) and 100BASE-BX10 (Bi-Directional Long Wavelength)	2686
58.1	Overview.....	2686
58.1.1	Goals and objectives	2686
58.1.2	Positioning of this PMD set within the IEEE 802.3 architecture	2687
58.1.3	Terminology and conventions	2687
58.1.4	Physical Medium Dependent (PMD) sublayer service interface.....	2687
58.2	PMD functional specifications.....	2688
58.2.1	PMD block diagram.....	2689
58.2.2	PMD transmit function	2689
58.2.3	PMD receive function	2689
58.2.4	100BASE-LX10 and 100BASE-BX10 signal detect function	2690
58.3	PMD to MDI optical specifications for 100BASE-LX10	2690
58.3.1	Transmitter optical specifications	2690
58.3.2	Receiver optical specifications	2691
58.4	PMD to MDI optical specifications for 100BASE-BX10	2692
58.4.1	Transmit optical specifications	2692
58.4.2	Receiver optical specifications	2693
58.5	Illustrative 100BASE-LX10 and 100BASE-BX10 channels and penalties	2694
58.6	Jitter at TP1 and TP4 for 100BASE-LX10 and 100BASE-BX10	2694
58.7	Optical measurement requirements	2695
58.7.1	Test patterns.....	2695
58.7.2	Wavelength and spectral width measurements.....	2698
58.7.3	Optical power measurements.....	2698
58.7.4	Extinction ratio measurements.....	2698
58.7.5	Optical modulation amplitude (OMA) measurements (optional).....	2698
58.7.6	OMA relationship to extinction ratio and power measurements	2699
58.7.7	Relative intensity noise optical modulation amplitude (RINxOMA) measuring procedure	2699
58.7.8	Transmitter optical waveform (transmit eye)	2700
58.7.9	Transmitter and dispersion penalty (TDP) measurement	2702
58.7.10	Receiver sensitivity measurements	2705
58.7.11	Stressed receiver conformance test.....	2706
58.7.12	Jitter measurements.....	2711
58.8	Environmental, safety, and labeling	2712
58.8.1	General safety	2712
58.8.2	Laser safety	2712
58.8.3	Installation	2712
58.8.4	Environment.....	2712
58.8.5	PMD labeling requirements.....	2712
58.9	Characteristics of the fiber optic cabling	2713
58.9.1	Fiber optic cabling model	2713
58.9.2	Optical fiber and cable.....	2713
58.9.3	Optical fiber connection.....	2714
58.9.4	Medium Dependent Interface (MDI).....	2714

58.10	Protocol implementation conformance statement (PICS) proforma for Clause 58, Physical Medium Dependent (PMD) sublayer and medium, type 100BASE-LX10 (Long Wavelength) and 100BASE-BX10 (Bi-Directional Long Wavelength)	2715
58.10.1	Introduction	2715
58.10.2	Identification	2715
58.10.3	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 100BASE-LX10 and 100BASE-BX10	2716
59.	Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-LX10 (Long Wavelength) and 1000BASE-BX10 (Bi-Directional Long Wavelength)	2720
59.1	Overview	2720
59.1.1	Goals and objectives	2721
59.1.2	Positioning of 1000BASE-LX10 and 1000BASE-BX10 PMDs within the IEEE 802.3 architecture	2721
59.1.3	Terminology and conventions	2721
59.1.4	Physical Medium Dependent (PMD) sublayer service interface	2722
59.1.5	Delay constraints	2722
59.2	PMD functional specifications	2723
59.2.1	PMD block diagram	2723
59.2.2	PMD transmit function	2723
59.2.3	PMD receive function	2723
59.2.4	PMD signal detect function	2724
59.3	PMD to MDI optical specifications for 1000BASE-LX10	2724
59.3.1	Transmitter optical specifications	2725
59.3.2	Receiver optical specifications	2726
59.4	PMD to MDI optical specifications for 1000BASE-BX10-D and 1000BASE-BX10-U	2728
59.4.1	Transmit optical specifications	2728
59.4.2	Receiver optical specifications	2729
59.5	Illustrative 1000BASE-LX10 and 1000BASE-BX10 channels and penalties	2729
59.6	Jitter specifications	2729
59.7	Optical measurement requirements	2729
59.7.1	Test patterns	2730
59.7.2	Wavelength and spectral width measurements	2733
59.7.3	Optical power measurements	2734
59.7.4	Extinction ratio measurements	2734
59.7.5	OMA measurements (optional)	2734
59.7.6	OMA relationship to extinction ratio and power measurements	2734
59.7.7	Relative intensity noise optical modulation amplitude (RIN12OMA)	2734
59.7.8	Transmitter optical waveform (transmit eye)	2734
59.7.9	Transmit rise/fall characteristics	2735
59.7.10	Transmitter and dispersion penalty (TDP)	2735
59.7.11	Receive sensitivity measurements	2735
59.7.12	Total jitter measurements	2736
59.7.13	Deterministic or high probability jitter measurement	2736
59.7.14	Stressed receiver conformance test	2736
59.7.15	Measurement of the receiver 3 dB electrical upper cutoff frequency	2736
59.8	Environmental, safety, and labeling specifications	2737
59.8.1	General safety	2737
59.8.2	Laser safety	2737
59.8.3	Installation	2737
59.8.4	Environment	2737
59.8.5	PMD labeling requirements	2737
59.9	Characteristics of the fiber optic cabling	2738

59.9.1	Fiber optic cabling model	2738
59.9.2	Optical fiber and cable	2739
59.9.3	Optical fiber connection	2739
59.9.4	Medium Dependent Interface (MDI)	2740
59.9.5	Single-mode fiber offset-launch mode-conditioning patch cord for MMF operation of 1000BASE-LX10	2740
59.10	Protocol implementation conformance statement (PICS) proforma for Clause 59, Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-LX10 (Long Wavelength) and 1000BASE-BX10 (Bi-Directional Long Wavelength)	2742
59.10.1	Introduction	2742
59.10.2	Identification	2742
59.10.3	Major capabilities/options	2743
60.	Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-PX (long wavelength passive optical networks)	2747
60.1	Overview	2747
60.1.1	Goals and objectives	2747
60.1.2	Positioning of this PMD set within the IEEE 802.3 architecture	2747
60.1.3	Terminology and conventions	2748
60.1.4	Physical Medium Dependent (PMD) sublayer service interface	2748
60.1.5	Delay constraints	2749
60.2	PMD functional specifications	2750
60.2.1	PMD block diagram	2750
60.2.2	PMD transmit function	2750
60.2.3	PMD receive function	2751
60.2.4	PMD signal detect function	2751
60.2.5	PMD transmit enable function for ONU	2752
60.3	PMD to MDI optical specifications for 1000BASE-PX10-D and 1000BASE-PX10-U	2752
60.3.1	Transmitter optical specifications	2752
60.3.2	Receiver optical specifications	2754
60.4	PMD to MDI optical specifications for 1000BASE-PX20-D and 1000BASE-PX20-U	2755
60.4.1	Transmitter optical specifications	2756
60.4.2	Receiver optical specifications	2756
60.5	PMD to MDI optical specifications for 1000BASE-PX30-D and 1000BASE-PX30-U	2758
60.5.1	Transmitter optical specifications	2759
60.5.2	Receiver optical specifications	2760
60.6	PMD to MDI optical specifications for 1000BASE-PX40-D and 1000BASE-PX40-U	2760
60.6.1	Transmitter optical specifications	2762
60.6.2	Receiver optical specifications	2763
60.7	Illustrative 1000BASE-PX channels and penalties	2764
60.8	Jitter at TP1 to TP4 for 1000BASE-PX	2764
60.9	Optical measurement requirements	2764
60.9.1	Frame-based test patterns	2765
60.9.2	Wavelength, spectral width, and side mode suppression ratio (SMSR) measurements	2765
60.9.3	Optical power measurements	2765
60.9.4	Extinction ratio measurements	2765
60.9.5	OMA measurements (optional)	2766
60.9.6	OMA relationship to extinction ratio and power measurements	2766
60.9.7	Relative intensity noise optical modulation amplitude (RIN15OMA)	2766
60.9.8	Transmitter optical waveform (transmit eye)	2766
60.9.9	Transmitter and dispersion penalty (TDP)	2766
60.9.10	Receive sensitivity measurement	2767
60.9.11	Stressed receive conformance test	2767

60.9.12	Jitter measurements.....	2767
60.9.13	Other measurements	2767
60.10	Environmental, safety, and labeling	2771
60.10.1	General safety	2771
60.10.2	Laser safety	2771
60.10.3	Installation	2771
60.10.4	Environment.....	2771
60.10.5	PMD labeling requirements	2771
60.11	Characteristics of the fiber optic cabling	2772
60.11.1	Fiber optic cabling model	2772
60.11.2	Optical fiber and cable	2772
60.11.3	Optical fiber connection.....	2773
60.11.4	Medium Dependent Interface (MDI)	2773
60.12	Protocol implementation conformance statement (PICS) proforma for Clause 60, Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-PX (long wavelength passive optical networks).....	2774
60.12.1	Introduction.....	2774
60.12.2	Identification	2774
60.12.3	Major capabilities/options	2775
60.12.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 1000BASE-PX (long wavelength passive optical networks)	2776
61.	Physical Coding Sublayer (PCS), Transmission Convergence (TC) sublayer, and common specifications, type 10PASS-TS and type 2BASE-TL	2782
61.1	Overview.....	2782
61.1.1	Scope.....	2782
61.1.2	Objectives	2783
61.1.3	Relation of 2BASE-TL and 10PASS-TS to other standards	2783
61.1.4	Summary	2784
61.1.5	Application of 2BASE-TL, 10PASS-TS	2786
61.2	PCS functional specifications	2791
61.2.1	MAC-PHY Rate Matching functional specifications	2791
61.2.2	PME Aggregation functional specifications	2794
61.2.3	PCS sublayer: Management entity signals.....	2803
61.3	TC sublayer functional specifications.....	2805
61.3.1	The g-interface.....	2806
61.3.2	The a(b)-interface	2807
61.3.3	TC functions	2808
61.4	Handshaking and PHY control specification for type 2BASE-TL and 10PASS-TS	2823
61.4.1	Overview.....	2823
61.4.2	Replacement of 1, “Scope”	2823
61.4.3	Changes to 6.1, “Description of signals”	2824
61.4.4	Changes to 9.4, “Standard information field (S)”	2824
61.4.5	Changes to 9.5, “Non-standard information field (NS)”	2825
61.4.6	Applicability of Annex A–B and Appendix I–VI.....	2825
61.4.7	PME Aggregation – remote access of PME Aggregation registers.....	2825
61.5	Link segment characteristics.....	2828
61.6	MDI specification	2829
61.7	System considerations.....	2829
61.8	Environmental specifications.....	2829
61.9	PHY labeling.....	2829

61.10	Protocol implementation conformance statement (PICS) proforma for Clause 61, Physical Coding Sublayer (PCS), Transmission Convergence (TC) sublayer, and common specifications type 10PASS-TS, 2BASE-TL.....	2830
61.10.1	Introduction.....	2830
61.10.2	Identification.....	2830
61.10.3	Major capabilities/options.....	2831
61.10.4	PICS proforma tables for the Physical Coding Sublayer (PCS), Transmission Convergence (TC) sublayer, and common specifications type 10PASS-TS, 2BASE-TL.....	2831
62.	Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 10PASS-TS.....	2839
62.1	Overview.....	2839
62.1.1	Scope.....	2839
62.1.2	Objectives	2839
62.1.3	Relation of 10PASS-TS to other standards.....	2839
62.1.4	Summary of Physical Medium Attachment (PMA) specification	2839
62.2	PMA functional specifications.....	2840
62.2.1	PMA functional diagram	2840
62.2.2	PMA functional specifications.....	2840
62.2.3	General exceptions.....	2841
62.2.4	Specific requirements and exceptions.....	2842
62.3	PMD functional specifications.....	2842
62.3.1	PMD Overview	2842
62.3.2	PMD functional specifications.....	2843
62.3.3	General exceptions.....	2843
62.3.4	Specific requirements and exceptions.....	2843
62.3.5	Transmission medium interface characteristics	2852
62.4	Protocol implementation conformance statement (PICS) proforma for Clause 62, Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 10PASS-TS... ..	2856
62.4.1	Introduction.....	2856
62.4.2	Identification	2856
62.4.3	Major capabilities/options.....	2857
62.4.4	PICS proforma tables for the Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 10PASS-TS.....	2857
63.	Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 2BASE-TL.....	2861
63.1	2BASE-TL Overview	2861
63.1.1	Scope.....	2861
63.1.2	Objectives	2861
63.1.3	Relation of 2BASE-TL to other standards.....	2861
63.1.4	Summary of Physical Medium Attachment (PMA) specification	2861
63.1.5	Summary of Physical Medium Dependent (PMD) specification	2863
63.2	2BASE-TL PMA functional specifications	2864
63.2.1	General exceptions.....	2864
63.2.2	Specific requirements and exceptions.....	2864
63.3	2BASE-TL PMD functional specifications	2866
63.3.1	General exceptions.....	2866
63.3.2	Specific requirements and exceptions.....	2867
63.4	Protocol implementation conformance statement (PICS) proforma for Clause 63, Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD), type 2BASE-TL	2871

63.4.1	Introduction.....	2871
63.4.2	Identification.....	2871
63.4.3	Major capabilities/options.....	2872
63.4.4	PICS proforma tables for the Physical Medium Attachment (PMA) and Physical Medium Dependent (PMD) sublayers, type 2BASE-TL.....	2872
64.	Multipoint MAC Control.....	2874
64.1	Overview.....	2874
64.1.1	Goals and objectives.....	2875
64.1.2	Position of Multipoint MAC Control within the IEEE 802.3 hierarchy.....	2875
64.1.3	Functional block diagram.....	2877
64.1.4	Service interfaces.....	2878
64.1.5	State diagram conventions.....	2878
64.2	Multipoint MAC Control operation.....	2878
64.2.1	Principles of Multipoint MAC Control.....	2879
64.2.2	Multipoint transmission control, Control Parser, and Control Multiplexer.....	2881
64.3	Multipoint Control Protocol (MPCP).....	2893
64.3.1	Principles of Multipoint Control Protocol.....	2893
64.3.2	Compatibility considerations.....	2893
64.3.3	Discovery Processing.....	2894
64.3.4	Report Processing.....	2907
64.3.5	Gate Processing.....	2911
64.3.6	MPCPDU structure and encoding.....	2919
64.4	Protocol implementation conformance statement (PICS) proforma for Clause 64, Multipoint MAC Control.....	2928
64.4.1	Introduction.....	2928
64.4.2	Identification.....	2928
64.4.3	Major capabilities/options.....	2929
64.4.4	PICS proforma tables for Multipoint MAC Control.....	2929
65.	Extensions of the Reconciliation Sublayer (RS) and Physical Coding Sublayer (PCS)/Physical Media Attachment (PMA) for 1000BASE-X for multipoint links and forward error correction.....	2932
65.1	Extensions of the Reconciliation Sublayer (RS) for point-to-point emulation.....	2932
65.1.1	Overview.....	2932
65.1.2	Principle of operation.....	2932
65.1.3	Functional specifications.....	2933
65.2	Extensions of the physical coding sublayer for data detection and forward error correction.....	2936
65.2.1	Overview.....	2936
65.2.2	Burst-mode operation.....	2937
65.2.3	Forward error correction.....	2941
65.3	Extensions to PMA for 1000BASE-PX.....	2954
65.3.1	Extensions for 1000BASE-PX-U.....	2954
65.3.2	Extensions for 1000BASE-PX-D.....	2955
65.3.3	Delay variation requirements.....	2955
65.4	Protocol implementation conformance statement (PICS) proforma for Clause 65, Extensions of the Reconciliation Sublayer (RS) and Physical Coding Sublayer (PCS)/Physical Media Attachment (PMA) for 1000BASE-X for multipoint links and forward error correction.....	2956
65.4.1	Introduction.....	2956
65.4.2	Identification.....	2956
65.4.3	Major capabilities/options.....	2957

65.4.4	PICS proforma tables for Extensions of Reconciliation Sublayer (RS) and Physical Coding Sublayer (PCS)/Physical Media Attachment (PMA) for 1000BASE-X for multipoint links and forward error correction.....	2957
66.	Extensions of the 10 Gb/s Reconciliation Sublayer (RS), 100BASE-X PHY, and 1000BASE-X PHY for unidirectional transport	2960
66.1	Modifications to the physical coding sublayer (PCS) and physical medium attachment (PMA) sublayer, type 100BASE-X	2960
66.1.1	Overview.....	2960
66.1.2	Functional specifications	2960
66.2	Modifications to the physical coding sublayer (PCS) and physical medium attachment (PMA) sublayer, type 1000BASE-X	2962
66.2.1	Overview.....	2962
66.2.2	Functional specifications	2962
66.3	Modifications to the reconciliation sublayer (RS) for P2P 10 Gb/s operation	2964
66.3.1	Overview.....	2964
66.3.2	Functional specifications	2964
66.4	Modifications to the RS for P2MP 10 Gb/s operation.....	2965
66.4.1	Overview.....	2965
66.4.2	Functional specifications	2965
66.5	Protocol implementation conformance statement (PICS) proforma for Clause 66, Extensions of the 10 Gb/s Reconciliation Sublayer (RS), 100BASE-X PHY, and 1000BASE-X PHY for unidirectional transport.....	2967
66.5.1	Introduction.....	2967
66.5.2	Identification.....	2967
66.5.3	Major capabilities/options.....	2968
66.5.4	PICS proforma tables for Extensions of the 10 Gb/s Reconciliation Sublayer (RS), 100BASE-X PHY, and 1000BASE-X PHY for unidirectional transport.....	2968
67.	System considerations for Ethernet subscriber access networks	2971
67.1	Overview.....	2971
67.2	Discussion and examples of EFM P2MP topologies.....	2973
67.2.1	Trade off between link span and split ratio for P2MP PON architecture	2973
67.2.2	Single splitter topology for P2MP PON architecture	2973
67.2.3	Tree-and-branch topology for P2MP PON architecture	2974
67.2.4	Interoperability between certain 1000BASE-PX10 and 1000BASE-PX20	2974
67.3	Hybrid media topologies.....	2975
67.4	Topology limitations.....	2975
67.5	Deployment restrictions for subscriber access copper.....	2975
67.6	Operations, Administration, and Maintenance	2975
67.6.1	Unidirectional links.....	2976
67.6.2	Active and Passive modes.....	2976
67.6.3	Link status signaling in P2MP networks	2976
68.	Physical medium dependent (PMD) sublayer type 10GBASE-LRM	2977
68.1	Overview.....	2977
68.1.1	Physical Medium Dependent (PMD) sublayer service interface.....	2977
68.2	Delay constraints.....	2977
68.3	PMD MDIO function mapping.....	2978
68.4	PMD functional specifications.....	2978
68.4.1	PMD block diagram.....	2978

68.4.2	PMD transmit function	2978
68.4.3	PMD receive function	2978
68.4.4	PMD signal detect function	2979
68.4.5	PMD_reset function	2979
68.4.6	PMD_fault function	2979
68.4.7	PMD_global_transmit_disable function	2979
68.4.8	PMD_transmit_fault function	2980
68.4.9	PMD_receive_fault function	2980
68.5	PMD to MDI optical specifications	2980
68.5.1	Transmitter optical specifications	2980
68.5.2	Characteristics of signal within, and at the receiving end of, a compliant 10GBASE-LRM channel	2980
68.5.3	Receiver optical specifications	2981
68.6	Definitions of optical parameters and measurement methods	2981
68.6.1	Test patterns and related subclauses for optical parameters	2981
68.6.2	Optical modulation amplitude (OMA)	2981
68.6.3	Extinction ratio measurement	2982
68.6.4	Relationship between OMA, extinction ratio and average power	2982
68.6.5	Transmitter optical waveform—transmitter eye mask	2982
68.6.6	Transmitter waveform and dispersion penalty (TWDP)	2984
68.6.7	Transmitter signal to noise ratio	2992
68.6.8	Transmitter uncorrelated jitter	2993
68.6.9	Comprehensive stressed receiver sensitivity and overload	2994
68.6.10	Simple stressed receiver sensitivity and overload (optional)	2999
68.6.11	Receiver jitter tolerance	2999
68.7	Safety, installation, environment, and labeling	3000
68.7.1	Safety	3000
68.7.2	Installation	3001
68.7.3	Environment	3001
68.7.4	PMD labeling	3001
68.8	Fiber optic cabling model	3001
68.9	Characteristics of the fiber optic cabling (channel)	3001
68.9.1	Optical fiber and cable	3001
68.9.2	Optical fiber connections	3001
68.9.3	Single-mode fiber offset-launch mode-conditioning patch cord	3002
68.10	Protocol implementation conformance statement (PICS) proforma for Clause 68, Physical medium dependent (PMD) sublayer type 10GBASE-LRM	3003
68.10.1	Introduction	3003
68.10.2	Identification	3003
68.10.3	PICS proforma tables for physical medium dependent (PMD) sublayer type 10GBASE-LRM	3004
69.	Introduction to Ethernet operation over electrical backplanes	3008
69.1	Overview	3008
69.1.1	Scope	3008
69.1.2	Relationship of Backplane Ethernet to the ISO OSI reference model	3008
69.2	Summary of Backplane Ethernet Sublayers	3013
69.2.1	Reconciliation sublayer and media independent interfaces	3013
69.2.2	Management interface	3013
69.2.3	Physical Layer signaling systems	3014
69.2.4	Auto-Negotiation	3015
69.2.5	Management	3016
69.2.6	Low-Power Idle	3016

69.3	Delay constraints.....	3016
69.4	State diagrams.....	3017
69.5	Protocol implementation conformance statement (PICS) proforma.....	3017
70.	Physical Medium Dependent sublayer and baseband medium, type 1000BASE-KX	3019
70.1	Overview.....	3019
70.2	Physical Medium Dependent (PMD) service interface	3019
70.2.1	PMD_RXQUIET.request.....	3020
70.2.2	PMD_TXQUIET.request.....	3020
70.3	PCS requirements for Auto-Negotiation (AN) service interface.....	3020
70.4	Delay constraints.....	3020
70.5	PMD MDIO function mapping.....	3021
70.6	PMD functional specifications.....	3021
70.6.1	Link block diagram.....	3022
70.6.2	PMD transmit function	3022
70.6.3	PMD receive function.....	3022
70.6.4	PMD signal detect function	3022
70.6.5	PMD transmit disable function.....	3023
70.6.6	Loopback mode.....	3023
70.6.7	PMD fault function	3023
70.6.8	PMD transmit fault function.....	3023
70.6.9	PMD receive fault function.....	3023
70.6.10	PMD LPI function	3023
70.7	1000BASE-KX electrical characteristics.....	3024
70.7.1	Transmitter characteristics	3024
70.7.2	Receiver characteristics	3028
70.8	Interconnect characteristics.....	3030
70.9	Environmental specifications.....	3030
70.9.1	General safety	3030
70.9.2	Network safety.....	3030
70.9.3	Installation and maintenance guidelines	3030
70.9.4	Electromagnetic compatibility	3030
70.9.5	Temperature and humidity	3030
70.10	Protocol implementation conformance statement (PICS) proforma for Clause 70, Physical Medium Dependent (PMD) sublayer and baseband medium, type 1000BASE-KX.....	3031
70.10.1	Introduction.....	3031
70.10.2	Identification	3031
70.10.3	Major capabilities/options.....	3032
70.10.4	PICS proforma tables for Clause 70, Physical Medium Dependent (PMD) sublayer and baseband medium, type 1000BASE-KX	3033
71.	Physical Medium Dependent sublayer and baseband medium, type 10GBASE-KX4.....	3036
71.1	Overview.....	3036
71.2	Physical Medium Dependent (PMD) service interface	3036
71.2.1	PMD_RXQUIET.request.....	3037
71.2.2	PMD_TXQUIET.request.....	3037
71.3	PCS requirements for Auto-Negotiation (AN) service interface.....	3037
71.4	Delay constraints.....	3038
71.5	PMD MDIO function mapping.....	3038
71.6	PMD functional specifications.....	3038
71.6.1	Link block diagram.....	3038
71.6.2	PMD Transmit function	3039

71.6.3	PMD Receive function.....	3040
71.6.4	Global PMD signal detect function	3040
71.6.5	PMD lane-by-lane signal detect function	3040
71.6.6	Global PMD transmit disable function	3040
71.6.7	PMD lane-by-lane transmit disable function	3040
71.6.8	Loopback mode.....	3041
71.6.9	PMD fault function	3041
71.6.10	PMD transmit fault function	3041
71.6.11	PMD receive fault function.....	3041
71.6.12	PMD LPI function	3041
71.7	Electrical characteristics for 10GBASE-KX4	3042
71.7.1	Transmitter characteristics	3042
71.7.2	Receiver characteristics	3047
71.8	Interconnect characteristics.....	3049
71.9	Environmental specifications.....	3049
71.9.1	General safety	3049
71.9.2	Network safety	3049
71.9.3	Installation and maintenance guidelines	3049
71.9.4	Electromagnetic compatibility	3049
71.9.5	Temperature and humidity	3049
71.10	Protocol implementation conformance statement (PICS) proforma for Clause 71, Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-KX4	3050
71.10.1	Introduction.....	3050
71.10.2	Identification.....	3050
71.10.3	Major capabilities/options.....	3051
71.10.4	PICS proforma tables for Clause 71, Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-KX4.....	3051
72.	Physical Medium Dependent sublayer and baseband medium, type 10GBASE-KR.....	3057
72.1	Overview.....	3057
72.2	Physical Medium Dependent (PMD) service interface	3057
72.2.1	PMD_RX_MODE.request.....	3058
72.2.2	PMD_TX_MODE.request	3058
72.3	PCS requirements for Auto-Negotiation (AN) service interface	3059
72.4	Delay constraints.....	3059
72.5	PMD MDIO function mapping.....	3059
72.6	PMD functional specifications.....	3059
72.6.1	Link block diagram	3059
72.6.2	PMD transmit function	3060
72.6.3	PMD receive function	3060
72.6.4	PMD signal detect function	3061
72.6.5	PMD transmit disable function	3061
72.6.6	Loopback mode.....	3061
72.6.7	PMD_fault function	3062
72.6.8	PMD transmit fault function	3062
72.6.9	PMD receive fault function.....	3062
72.6.10	PMD control function	3062
72.6.11	PMD LPI function	3074
72.7	10GBASE-KR electrical characteristics	3075
72.7.1	Transmitter characteristics	3075
72.7.2	Receiver characteristics	3083
72.8	Interconnect characteristics.....	3085
72.9	Environmental specifications.....	3085

72.9.1	General safety	3085
72.9.2	Network safety	3085
72.9.3	Installation and maintenance guidelines	3085
72.9.4	Electromagnetic compatibility	3085
72.9.5	Temperature and humidity	3085
72.10	Protocol implementation conformance statement (PICS) proforma for Clause 72, Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-KR	3086
72.10.1	Introduction	3086
72.10.2	Identification	3086
72.10.3	Major capabilities/options	3087
72.10.4	PICS proforma tables for Clause 72, Physical Medium Dependent (PMD) sublayer and baseband medium, type 10GBASE-KR	3087
73.	Auto-Negotiation for backplane and copper cable assembly	3094
73.1	Auto-Negotiation introduction	3094
73.2	Relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model	3095
73.3	Functional specifications	3095
73.4	Transmit function requirements	3096
73.5	DME transmission	3096
73.5.1	DME electrical specifications	3096
73.5.2	DME page encoding	3096
73.5.3	DME page timing	3097
73.6	Link codeword encoding	3098
73.6.1	Selector Field	3099
73.6.2	Echoed Nonce Field	3099
73.6.3	Transmitted Nonce Field	3099
73.6.4	Technology Ability Field	3100
73.6.5	FEC capability	3100
73.6.6	Pause Ability	3101
73.6.7	Remote Fault	3102
73.6.8	Acknowledge	3102
73.6.9	Next Page	3102
73.6.10	Transmit Switch function	3102
73.7	Receive function requirements	3103
73.7.1	DME page reception	3103
73.7.2	Receive Switch function	3103
73.7.3	Link codeword matching	3103
73.7.4	Arbitration function requirements	3103
73.7.5	Renegotiation function	3104
73.7.6	Priority Resolution function	3104
73.7.7	Next Page function	3105
73.8	Management register requirements	3107
73.9	Technology-Dependent interface	3108
73.9.1	AN_LINK.indication	3108
73.10	State diagrams and variable definitions	3109
73.10.1	State diagram variables	3109
73.10.2	State diagram timers	3116
73.10.3	State diagram counters	3118
73.10.4	State diagrams	3119
73.11	Protocol implementation conformance statement (PICS) proforma for Clause 73, Auto-Negotiation for backplane and copper cable assembly	3122
73.11.1	Introduction	3122
73.11.2	Identification	3122

73.11.3	Major capabilities/options.....	3123
73.11.4	PICS proforma tables for Auto-Negotiation for backplane and copper cable assembly	3123
74.	Forward error correction (FEC) sublayer for BASE-R PHYs.....	3130
74.1	Overview.....	3130
74.2	Objectives	3130
74.3	Relationship to other sublayers.....	3130
74.4	Inter-sublayer interfaces	3131
74.4.1	Functional Block Diagram for 10GBASE-R PHYs	3132
74.4.2	Functional block diagram for 25GBASE-R PHYs	3133
74.4.3	Functional block diagram for 40GBASE-R PHYs	3134
74.4.4	Functional block diagram for 100GBASE-R PHYs	3134
74.5	FEC service interface.....	3135
74.5.1	10GBASE-R service primitives.....	3136
74.5.2	25GBASE-R service primitives.....	3139
74.5.3	40GBASE-R and 100GBASE-R service primitives	3140
74.6	Delay constraints.....	3141
74.7	FEC principle of operation	3141
74.7.1	FEC code.....	3141
74.7.2	FEC block format.....	3142
74.7.3	Composition of the FEC block	3142
74.7.4	Functions within FEC sublayer.....	3143
74.8	FEC MDIO function mapping	3151
74.8.1	FEC capability	3151
74.8.2	FEC Enable	3151
74.8.3	FEC Enable Error Indication	3152
74.8.4	FEC Error monitoring capability	3152
74.9	BASE-R PHY test-pattern mode	3153
74.10	Detailed functions and state diagrams	3153
74.10.1	State diagram conventions	3153
74.10.2	State variables	3153
74.10.3	State diagrams	3154
74.11	Protocol implementation conformance statement (PICS) proforma for Clause 74, forward error correction (FEC) sublayer for BASE-R PHYs	3156
74.11.1	Introduction.....	3156
74.11.2	Identification	3156
74.11.3	Major capabilities/options.....	3157
74.11.4	Management.....	3158
74.11.5	FEC requirements	3159
74.11.6	FEC Error Monitoring	3160
75.	Physical Medium Dependent (PMD) sublayer and medium for passive optical networks, type 10GBASE-PR and 10/1GBASE-PRX.....	3161
75.1	Overview.....	3161
75.1.1	Terminology and conventions	3161
75.1.2	Goals and objectives	3161
75.1.3	Power budget classes	3161
75.1.4	Power budgets.....	3162
75.1.5	Positioning of PMD sublayer within the IEEE 802.3 architecture.....	3163
75.2	PMD types	3163
75.2.1	Mapping of PMDs to power budgets.....	3166
75.3	PMD functional specifications.....	3167

75.3.1	PMD service interface	3167
75.3.2	PMD block diagram.....	3169
75.3.3	PMD transmit function	3169
75.3.4	PMD receive function	3169
75.3.5	PMD signal detect function	3169
75.3.6	PMD transmit enable function for ONU.....	3171
75.4	PMD to MDI optical specifications for 10/10G–EPON and 10/1G–EPON OLT PMDs.....	3171
75.4.1	Transmitter optical specifications.....	3171
75.4.2	Receiver optical specifications	3172
75.5	PMD to MDI optical specifications for 10/10G–EPON and 10/1G–EPON ONU PMDs.....	3174
75.5.1	Transmitter optical specifications	3175
75.5.2	Receiver optical specifications	3176
75.6	Dual-rate (coexistence) mode	3177
75.6.1	Downstream dual-rate operation.....	3178
75.6.2	Upstream dual-rate operation.....	3178
75.7	Definitions of optical parameters and measurement methods	3178
75.7.1	Insertion loss	3178
75.7.2	Allocation for penalties in 10G–EPON PMDs	3178
75.7.3	Test patterns	3179
75.7.4	Wavelength, spectral width, and side mode suppression ratio (SMSR) measurement...	3179
75.7.5	Optical power measurements.....	3180
75.7.6	Extinction ratio measurements.....	3180
75.7.7	Optical modulation amplitude (OMA) test procedure	3180
75.7.8	Relative intensity noise optical modulation amplitude (RINxOMA) measuring procedure	3180
75.7.9	Transmit optical waveform (transmit eye).....	3180
75.7.10	Transmitter and dispersion penalty (TDP).....	3181
75.7.11	Receive sensitivity	3181
75.7.12	Stressed receiver conformance test.....	3181
75.7.13	Jitter measurements.....	3182
75.7.14	Laser on/off timing measurement	3182
75.7.15	Receiver settling timing measurement.....	3182
75.8	Environmental, safety, and labeling	3184
75.8.1	General safety	3184
75.8.2	Laser safety	3184
75.8.3	Installation	3184
75.8.4	Environment.....	3184
75.8.5	PMD labeling.....	3184
75.9	Characteristics of the fiber optic cabling.....	3185
75.9.1	Fiber optic cabling model	3185
75.9.2	Optical fiber and cable	3185
75.9.3	Optical fiber connection.....	3186
75.9.4	Medium Dependent Interface (MDI).....	3186
75.10	Protocol implementation conformance statement (PICS) proforma for Clause 75, Physical Medium Dependent (PMD) sublayer and medium for passive optical networks, type 10GBASE–PR and 10/1GBASE–PRX.....	3187
75.10.1	Introduction.....	3187
75.10.2	Identification	3187
75.10.3	Major capabilities/options.....	3188
75.10.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium for passive optical networks, type 10GBASE–PR and 10/1GBASE–PRX.....	3189
76.	Reconciliation Sublayer, Physical Coding Sublayer, and Physical Media Attachment for 10G- EPON	3197

76.1	Overview.....	3197
76.1.1	Conventions	3197
76.1.2	Delay constraints.....	3197
76.2	Reconciliation Sublayer (RS) for 10G-EPON	3197
76.2.1	Overview.....	3197
76.2.2	Dual-speed Media Independent Interface	3200
76.2.3	Summary of major concepts	3202
76.2.4	GMII structure	3202
76.2.5	XGMII structure	3202
76.2.6	Mapping of XGMII and GMII signals to PLS service primitives	3203
76.3	Physical Coding Sublayer (PCS) for 10G-EPON.....	3205
76.3.1	Overview.....	3205
76.3.2	PCS transmit function.....	3207
76.3.3	PCS receive Function.....	3224
76.4	10GBASE-PR and 10/1GBASE-PRX PMA	3238
76.4.1	Extensions for 10GBASE-PR-U and 10/1GBASE-PRX-U	3240
76.4.2	Extensions for 10GBASE-PR-D and 10/1GBASE-PRX-D	3240
76.5	Protocol implementation conformance statement (PICS) proforma for Clause 76, Reconciliation Sublayer, Physical Coding Sublayer, and Physical Media Attachment for 10G-EPON.....	3241
76.5.1	Introduction.....	3241
76.5.2	Identification	3241
76.5.3	Major capabilities/options	3242
76.5.4	PICS proforma tables for Reconciliation Sublayer (RS), Physical Coding Sublayer (PCS), and Physical Media Attachment (PMA) for point-to-multipoint media, types 10GBASE-PR and 10/1GBASE-PRX.....	3243
77.	Multipoint MAC Control for 10G-EPON.....	3247
77.1	Overview.....	3247
77.1.1	Goals and objectives	3248
77.1.2	Position of Multipoint MAC Control within the IEEE 802.3 hierarchy.....	3248
77.1.3	Functional block diagram	3252
77.1.4	Service interfaces	3253
77.1.5	State diagram conventions	3253
77.2	Multipoint MAC Control operation.....	3253
77.2.1	Principles of Multipoint MAC Control.....	3254
77.2.2	Multipoint transmission control, Control Parser, and Control Multiplexer.....	3256
77.3	Multipoint Control Protocol (MPCP)	3269
77.3.1	Principles of Multipoint Control Protocol	3269
77.3.2	Compatibility considerations	3269
77.3.3	Discovery processing.....	3270
77.3.4	Report Processing	3284
77.3.5	Gate Processing.....	3287
77.3.6	MPCPDU structure and encoding.....	3296
77.4	Discovery Process in dual-rate systems.....	3305
77.4.1	OLT speed-specific discovery	3305
77.4.2	ONU speed-specific registration.....	3306
77.5	Protocol implementation conformance statement (PICS) proforma for Clause 77, Multipoint MAC Control.....	3309
77.5.1	Introduction.....	3309
77.5.2	Identification	3309
77.5.3	Major capabilities/options	3310
77.5.4	PICS proforma tables for Multipoint MAC Control.....	3310

78. Energy-Efficient Ethernet (EEE)	3313
78.1 Overview.....	3313
78.1.1 LPI Signaling.....	3313
78.1.2 LPI Client service interface	3314
78.1.3 Reconciliation sublayer operation	3316
78.1.4 PHY types optionally supporting EEE	3319
78.2 LPI mode timing parameters description.....	3321
78.3 Capabilities Negotiation	3323
78.4 Data Link Layer capabilities.....	3324
78.4.1 Data Link Layer capabilities timing requirements	3325
78.4.2 Control state diagrams	3325
78.4.3 State change procedure across a link	3334
78.5 Communication link access latency.....	3337
78.5.1 PHY extension using extender sublayers.....	3340
78.5.2 25 Gb/s 40 Gb/s, and 100 Gb/s PHY extension using 25GAUI, XLAUI, or CAUI-n ...	3341
78.6 Protocol implementation conformance statement (PICS) proforma for EEE Data Link Layer Capabilities	3342
78.6.1 Introduction.....	3342
78.6.2 Identification	3342
78.6.3 Major capabilities/options.....	3343
78.6.4 DLL requirements.....	3343
79. IEEE 802.3 Organizationally Specific Link Layer Discovery Protocol (LLDP) type, length, and value (TLV) information elements	3344
79.1 Overview.....	3344
79.1.1 IEEE 802.3 LLDP frame format.....	3344
79.2 Requirements of the IEEE 802.3 Organizationally Specific TLV set	3345
79.3 IEEE 802.3 Organizationally Specific TLVs	3346
79.3.1 MAC/PHY Configuration/Status TLV	3346
79.3.2 Power Via MDI TLV	3347
79.3.3 Link Aggregation TLV (deprecated)	3357
79.3.4 Maximum Frame Size TLV	3358
79.3.5 EEE TLV	3360
79.3.6 EEE Fast Wake TLV	3361
79.3.7 Additional Ethernet Capabilities TLV	3362
79.3.8 Power via MDI Measurements TLV	3363
79.4 IEEE 802.3 Organizationally Specific TLV selection management	3366
79.4.1 IEEE 802.3 Organizationally Specific TLV selection variable/LLDP Configuration managed object class cross reference	3366
79.4.2 IEEE 802.3 Organizationally Specific TLV/LLDP Local and Remote System group managed object class cross references.....	3366
79.5 Protocol implementation conformance statement (PICS) proforma for IEEE 802.3 Organizationally Specific Link Layer Discovery Protocol (LLDP) type, length, and value (TLV) information elements.....	3372
79.5.1 Introduction.....	3372
79.5.2 Identification	3372
79.5.3 Major capabilities/options.....	3373
79.5.4 IEEE 802.3 Organizationally Specific TLV	3373
79.5.5 MAC/PHY Configuration/Status TLV	3374
79.5.6 EEE TLV	3374
79.5.7 EEE Fast Wake TLV	3375
79.5.8 Power Via MDI TLV	3375

79.5.9	Link Aggregation TLV	3379
79.5.10	Maximum Frame Size TLV	3379
79.5.11	Additional Ethernet Capabilities TLV	3380
79.5.12	Power via MDI Measurements TLV	3380
80.	Introduction to 40 Gb/s and 100 Gb/s networks	3381
80.1	Overview	3381
80.1.1	Scope	3381
80.1.2	Objectives	3381
80.1.3	Relationship of 40 Gigabit and 100 Gigabit Ethernet to the ISO OSI reference model	3381
80.1.4	Nomenclature	3382
80.1.5	Physical Layer signaling systems	3385
80.2	Summary of 40 Gigabit and 100 Gigabit Ethernet sublayers	3388
80.2.1	Reconciliation Sublayer (RS) and Media Independent Interface	3388
80.2.2	Physical Coding Sublayer (PCS)	3388
80.2.3	Forward error correction (FEC) sublayers	3388
80.2.4	Physical Medium Attachment (PMA) sublayer	3388
80.2.5	Physical Medium Dependent (PMD) sublayer	3389
80.2.6	Auto-Negotiation	3389
80.2.7	Management interface (MDIO/MDC)	3389
80.2.8	Management	3389
80.3	Service interface specification method and notation	3389
80.3.1	Inter-sublayer service interface	3389
80.3.2	Instances of the Inter-sublayer service interface	3390
80.3.3	Semantics of inter-sublayer service interface primitives	3396
80.4	Delay constraints	3399
80.5	Skew constraints	3401
80.6	State diagrams	3406
80.7	Protocol implementation conformance statement (PICS) proforma	3407
81.	Reconciliation Sublayer (RS) and Media Independent Interface for 40 Gb/s and 100 Gb/s operation (XLGMII and CGMII)	3408
81.1	Overview	3408
81.1.1	Summary of major concepts	3409
81.1.2	Application	3409
81.1.3	Rate of operation	3409
81.1.4	Delay constraints	3409
81.1.5	Allocation of functions	3409
81.1.6	XLGMII/CGMII structure	3410
81.1.7	Mapping of XLGMII/CGMII signals to PLS service primitives	3410
81.2	XLGMII/CGMII data stream	3413
81.2.1	Inter-frame <inter-frame>	3414
81.2.2	Preamble <preamble> and start of frame delimiter <sfd>	3414
81.2.3	Data <data>	3415
81.2.4	End of frame delimiter <efd>	3415
81.2.5	Definition of Start of Packet and End of Packet Delimiters	3415
81.3	XLGMII/CGMII functional specifications	3415
81.3.1	Transmit	3415
81.3.2	Receive	3419
81.3.3	Error and fault handling	3423
81.3.4	Link fault signaling	3424

81.4	LPI assertion and detection.....	3426
81.4.1	LPI messages	3427
81.4.2	Transmit LPI state diagram.....	3428
81.4.3	Considerations for transmit system behavior.....	3428
81.4.4	Considerations for receive system behavior	3428
81.5	Protocol implementation conformance statement (PICS) proforma for Clause 81, Reconciliation Sublayer (RS) and Media Independent Interface for 40 Gb/s and 100 Gb/s operation	3430
81.5.1	Introduction.....	3430
81.5.2	Identification.....	3430
81.5.3	PICS proforma tables for Reconciliation Sublayer and Media Independent Interface for 40 Gb/s and 100 Gb/s operation.....	3431
82.	Physical Coding Sublayer (PCS) for 64B/66B, type 40GBASE-R and 100GBASE-R	3436
82.1	Overview.....	3436
82.1.1	Scope.....	3436
82.1.2	Relationship of 40GBASE-R and 100GBASE-R to other standards	3436
82.1.3	Summary of 40GBASE-R and 100GBASE-R sublayers	3437
82.1.4	Inter-sublayer interfaces	3438
82.1.5	Functional block diagram	3439
82.2	Physical Coding Sublayer (PCS).....	3440
82.2.1	Functions within the PCS	3440
82.2.2	Use of blocks	3441
82.2.3	64B/66B transmission code	3441
82.2.4	Transmit process.....	3447
82.2.5	Scrambler	3447
82.2.6	Block distribution	3448
82.2.7	Alignment marker insertion.....	3448
82.2.8	BIP calculations	3451
82.2.9	Rapid alignment marker insertion.....	3451
82.2.10	PMA or FEC Interface.....	3453
82.2.11	Test-pattern generators	3454
82.2.12	Block synchronization	3454
82.2.13	PCS lane deskew.....	3454
82.2.14	PCS lane reorder	3455
82.2.15	Alignment marker removal.....	3455
82.2.16	Descrambler	3455
82.2.17	Receive process.....	3455
82.2.18	Test-pattern checker.....	3456
82.2.19	Detailed functions and state diagrams	3456
82.3	PCS Management	3473
82.3.1	PCS MDIO function mapping	3473
82.4	Loopback	3474
82.5	Delay constraints.....	3474
82.6	Auto-Negotiation	3474
82.7	Protocol implementation conformance statement (PICS) proforma for Clause 82, Physical Coding Sublayer (PCS) for 64B/66B, type 40GBASE-R and 100GBASE-R.....	3475
82.7.1	Introduction.....	3475
82.7.2	Identification	3475
82.7.3	Major capabilities/options.....	3476
82.7.4	PICS proforma tables for PCS, type 40GBASE-R and 100GBASE-R	3477
83.	Physical Medium Attachment (PMA) sublayer, type 40GBASE-R and 100GBASE-R.....	3482

83.1	Overview.....	3482
83.1.1	Scope.....	3482
83.1.2	Position of the PMA in the 40GBASE-R or 100GBASE-R sublayers.....	3482
83.1.3	Summary of functions.....	3482
83.1.4	PMA sublayer positioning.....	3482
83.2	PMA interfaces.....	3485
83.3	PMA service interface.....	3485
83.4	Service interface below PMA.....	3488
83.5	Functions within the PMA.....	3489
83.5.1	Per input-lane clock and data recovery.....	3489
83.5.2	Bit-level multiplexing.....	3489
83.5.3	Skew and Skew Variation.....	3491
83.5.4	Delay constraints.....	3492
83.5.5	Clocking architecture.....	3492
83.5.6	Signal drivers.....	3493
83.5.7	Link status.....	3493
83.5.8	PMA local loopback mode.....	3493
83.5.9	PMA remote loopback mode (optional).....	3493
83.5.10	PMA test patterns (optional).....	3494
83.5.11	Energy Efficient Ethernet.....	3496
83.6	PMA MDIO function mapping.....	3499
83.7	Protocol implementation conformance statement (PICS) proforma for Clause 83, Physical Medium Attachment (PMA) sublayer, type 40GBASE-R and 100GBASE-R.....	3503
83.7.1	Introduction.....	3503
83.7.2	Identification.....	3503
83.7.3	Major capabilities/options.....	3504
83.7.4	Skew generation and tolerance.....	3506
83.7.5	Test patterns.....	3506
83.7.6	Loopback modes.....	3507
83.7.7	EEE deep sleep with XLAUI/CAUI.....	3507
84.	Physical Medium Dependent sublayer and baseband medium, type 40GBASE-KR4.....	3508
84.1	Overview.....	3508
84.2	Physical Medium Dependent (PMD) service interface.....	3508
84.3	PCS requirements for Auto-Negotiation (AN) service interface.....	3510
84.4	Delay constraints.....	3510
84.5	Skew constraints.....	3510
84.6	PMD MDIO function mapping.....	3511
84.7	PMD functional specifications.....	3512
84.7.1	Link block diagram.....	3512
84.7.2	PMD transmit function.....	3512
84.7.3	PMD receive function.....	3512
84.7.4	Global PMD signal detect function.....	3513
84.7.5	PMD lane-by-lane signal detect function.....	3513
84.7.6	Global PMD transmit disable function.....	3513
84.7.7	PMD lane-by-lane transmit disable function.....	3514
84.7.8	Loopback mode.....	3514
84.7.9	PMD_fault function.....	3514
84.7.10	PMD transmit fault function.....	3514
84.7.11	PMD receive fault function.....	3514
84.7.12	PMD control function.....	3515
84.8	40GBASE-KR4 electrical characteristics.....	3515
84.8.1	Transmitter characteristics.....	3515

84.8.2	Receiver characteristics	3515
84.9	Interconnect characteristics.....	3515
84.10	Environmental specifications.....	3515
84.10.1	General safety	3515
84.10.2	Network safety	3516
84.10.3	Installation and maintenance guidelines	3516
84.10.4	Electromagnetic compatibility	3516
84.10.5	Temperature and humidity	3516
84.11	Protocol implementation conformance statement (PICS) proforma for Clause 84, Physical Medium Dependent sublayer and baseband medium, type 40GBASE-KR4	3517
84.11.1	Introduction.....	3517
84.11.2	Identification	3517
84.11.3	Major capabilities/options.....	3518
84.11.4	PICS proforma tables for Clause 84, Physical Medium Dependent (PMD) sublayer and baseband medium, type 40GBASE-KR4.....	3519
85.	Physical Medium Dependent sublayer and baseband medium, type 40GBASE-CR4 and 100GBASE-CR10.....	3522
85.1	Overview.....	3522
85.2	Physical Medium Dependent (PMD) service interface	3523
85.3	PCS requirements for Auto-Negotiation (AN) service interface	3524
85.4	Delay constraints.....	3524
85.5	Skew constraints	3525
85.6	PMD MDIO function mapping.....	3525
85.7	PMD functional specifications.....	3527
85.7.1	Link block diagram.....	3527
85.7.2	PMD Transmit function	3529
85.7.3	PMD Receive function.....	3529
85.7.4	Global PMD signal detect function	3529
85.7.5	PMD lane-by-lane signal detect function	3530
85.7.6	Global PMD transmit disable function	3530
85.7.7	PMD lane-by-lane transmit disable function	3530
85.7.8	Loopback mode.....	3530
85.7.9	PMD_fault function	3531
85.7.10	PMD transmit fault function	3531
85.7.11	PMD receive fault function.....	3531
85.7.12	PMD control function	3531
85.8	MDI Electrical specifications for 40GBASE-CR4 and 100GBASE-CR10	3531
85.8.1	Signal levels	3531
85.8.2	Signal paths.....	3531
85.8.3	Transmitter characteristics	3532
85.8.4	Receiver characteristics at TP3 summary	3542
85.9	Channel characteristics	3545
85.10	Cable assembly characteristics	3545
85.10.1	Characteristic impedance and reference impedance.....	3546
85.10.2	Cable assembly insertion loss	3546
85.10.3	Cable assembly insertion loss deviation (ILD).....	3548
85.10.4	Cable assembly return loss	3549
85.10.5	Cable assembly multiple disturber near-end crosstalk (MDNEXT) loss	3550
85.10.6	Cable assembly multiple disturber far-end crosstalk (MDFEXT) loss.....	3550
85.10.7	Cable assembly integrated crosstalk noise (ICN)	3551
85.10.8	Cable assembly test fixture	3553
85.10.9	Mated test fixtures	3553

85.10.10	Shielding	3556
85.10.11	Crossover function	3556
85.11	MDI specification	3557
85.11.1	40GBASE-CR4 MDI connectors	3557
85.11.2	100GBASE-CR10 MDI connectors	3560
85.11.3	Electronic keying	3562
85.12	Environmental specifications	3562
85.13	Protocol implementation conformance statement (PICS) proforma for Clause 85, Physical Medium Dependent (PMD) sublayer and baseband medium, type 40GBASE-CR4 and 100GBASE-CR10	3563
85.13.1	Introduction	3563
85.13.2	Identification	3563
85.13.3	Major capabilities/options	3564
85.13.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and baseband medium, type 40GBASE-CR4 and 100GBASE-CR10	3565
86.	Physical Medium Dependent (PMD) sublayer and medium, type 40GBASE-SR4 and 100GBASE-SR10	3570
86.1	Overview	3570
86.2	Physical Medium Dependent (PMD) service interface	3572
86.3	Delay and Skew	3573
86.3.1	Delay constraints	3573
86.3.2	Skew and Skew Variation constraints	3573
86.4	PMD MDIO function mapping	3573
86.5	PMD functional specifications	3574
86.5.1	PMD block diagram	3574
86.5.2	PMD transmit function	3575
86.5.3	PMD receive function	3575
86.5.4	PMD global signal detect function	3575
86.5.5	PMD lane-by-lane signal detect function	3576
86.5.6	PMD reset function	3576
86.5.7	PMD global transmit disable function (optional)	3576
86.5.8	PMD lane-by-lane transmit disable function (optional)	3577
86.5.9	PMD fault function (optional)	3577
86.5.10	PMD transmit fault function (optional)	3577
86.5.11	PMD receive fault function (optional)	3577
86.6	Lane assignments	3577
86.7	PMD to MDI specifications for 40GBASE-SR4 or 100GBASE-SR10	3577
86.7.1	Transmitter optical specifications	3578
86.7.2	Characteristics of signal within, and at the receiving end of, a compliant optical channel	3579
86.7.3	40GBASE-SR4 or 100GBASE-SR10 receiver optical specifications	3580
86.7.4	40GBASE-SR4 or 100GBASE-SR10 illustrative link power budget	3581
86.8	Definitions of optical and dual-use parameters and measurement methods	3581
86.8.1	Test points and compliance boards	3581
86.8.2	Test patterns and related subclauses	3581
86.8.3	Parameters applicable to both electrical and optical signals	3584
86.8.4	Optical parameter definitions	3586
86.9	Safety, installation, environment, and labeling	3589
86.9.1	General safety	3589
86.9.2	Laser safety	3589
86.9.3	Installation	3589
86.9.4	Environment	3589

86.9.5	PMD labeling.....	3589
86.10	Optical channel.....	3589
86.10.1	Fiber optic cabling model.....	3590
86.10.2	Characteristics of the fiber optic cabling (channel).....	3590
86.10.3	Medium Dependent Interface (MDI).....	3591
86.11	Protocol implementation conformance statement (PICS) proforma for Clause 86, Physical Medium Dependent (PMD) sublayer and medium, type 40GBASE-SR4 and 100GBASE-SR10.....	3595
86.11.1	Introduction.....	3595
86.11.2	Identification.....	3595
86.11.3	Major capabilities/options.....	3596
86.11.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, types 40GBASE-SR4 and 100GBASE-SR10.....	3597
87.	Physical Medium Dependent (PMD) sublayer and medium, type 40GBASE-LR4 and 40GBASE-ER4.....	3601
87.1	Overview.....	3601
87.2	Physical Medium Dependent (PMD) service interface.....	3601
87.3	Delay and Skew.....	3603
87.3.1	Delay constraints.....	3603
87.3.2	Skew constraints.....	3603
87.4	PMD MDIO function mapping.....	3603
87.5	PMD functional specifications.....	3603
87.5.1	PMD block diagram.....	3603
87.5.2	PMD transmit function.....	3604
87.5.3	PMD receive function.....	3605
87.5.4	PMD global signal detect function.....	3605
87.5.5	PMD lane-by-lane signal detect function.....	3606
87.5.6	PMD reset function.....	3606
87.5.7	PMD global transmit disable function (optional).....	3606
87.5.8	PMD lane-by-lane transmit disable function.....	3606
87.5.9	PMD fault function (optional).....	3607
87.5.10	PMD transmit fault function (optional).....	3607
87.5.11	PMD receive fault function (optional).....	3607
87.6	Wavelength-division-multiplexed lane assignments.....	3607
87.7	PMD to MDI optical specifications for 40GBASE-LR4 and 40GBASE-ER4.....	3607
87.7.1	40GBASE-LR4 and 40GBASE-ER4 transmitter optical specifications.....	3608
87.7.2	40GBASE-LR4 and 40GBASE-ER4 receive optical specifications.....	3609
87.7.3	40GBASE-LR4 and 40GBASE-ER4 illustrative link power budgets.....	3610
87.8	Definition of optical parameters and measurement methods.....	3610
87.8.1	Test patterns for optical parameters.....	3611
87.8.2	Skew and Skew Variation.....	3612
87.8.3	Wavelength and side mode suppression ratio (SMSR).....	3612
87.8.4	Average optical power.....	3612
87.8.5	Optical Modulation Amplitude (OMA).....	3612
87.8.6	Transmitter and dispersion penalty.....	3612
87.8.7	Extinction ratio.....	3614
87.8.8	Relative Intensity Noise (RIN20OMA).....	3614
87.8.9	Transmitter optical waveform (transmit eye).....	3614
87.8.10	Receiver sensitivity.....	3614
87.8.11	Stressed receiver sensitivity.....	3614
87.8.12	Receiver 3 dB electrical upper cutoff frequency.....	3620
87.9	Safety, installation, environment, and labeling.....	3620

87.9.1	General safety	3620
87.9.2	Laser safety	3620
87.9.3	Installation	3621
87.9.4	Environment.....	3621
87.9.5	PMD labeling requirements.....	3621
87.10	Fiber optic cabling model	3621
87.11	Characteristics of the fiber optic cabling (channel)	3622
87.11.1	Optical fiber cable.....	3622
87.11.2	Optical fiber connection.....	3623
87.11.3	Medium Dependent Interface (MDI) requirements	3623
87.12	Requirements for interoperation between 40GBASE-LR4 and 40GBASE-ER4.....	3623
87.13	Protocol implementation conformance statement (PICS) proforma for Clause 87, Physical Medium Dependent (PMD) sublayer and medium, type 40GBASE-LR4 and 40GBASE-ER4.....	3624
87.13.1	Introduction.....	3624
87.13.2	Identification	3624
87.13.3	Major capabilities/options.....	3625
87.13.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 40GBASE-LR4 and 40GBASE-ER4.....	3626
88.	Physical Medium Dependent (PMD) sublayer and medium, type 100GBASE-LR4 and 100GBASE-ER4	3629
88.1	Overview.....	3629
88.2	Physical Medium Dependent (PMD) service interface	3629
88.3	Delay and Skew	3631
88.3.1	Delay constraints.....	3631
88.3.2	Skew constraints	3631
88.4	PMD MDIO function mapping.....	3631
88.5	PMD functional specifications.....	3631
88.5.1	PMD block diagram.....	3631
88.5.2	PMD transmit function	3633
88.5.3	PMD receive function	3633
88.5.4	PMD global signal detect function	3633
88.5.5	PMD lane-by-lane signal detect function	3634
88.5.6	PMD reset function	3634
88.5.7	PMD global transmit disable function (optional)	3634
88.5.8	PMD lane-by-lane transmit disable function	3634
88.5.9	PMD fault function (optional)	3635
88.5.10	PMD transmit fault function (optional)	3635
88.5.11	PMD receive fault function (optional).....	3635
88.6	Wavelength-division-multiplexed lane assignments	3635
88.7	PMD to MDI optical specifications for 100GBASE-LR4 and 100GBASE-ER4	3635
88.7.1	100GBASE-LR4 and 100GBASE-ER4 transmitter optical specifications	3636
88.7.2	100GBASE-LR4 and 100GBASE-ER4 receive optical specifications	3638
88.7.3	100GBASE-LR4 and 100GBASE-ER4 illustrative link power budgets.....	3639
88.8	Definition of optical parameters and measurement methods.....	3639
88.8.1	Test patterns for optical parameters.....	3639
88.8.2	Wavelength and side mode suppression ratio (SMSR)	3639
88.8.3	Average optical power	3639
88.8.4	Optical Modulation Amplitude (OMA).....	3640
88.8.5	Transmitter and dispersion penalty (TDP).....	3640
88.8.6	Extinction ratio	3642
88.8.7	Relative Intensity Noise (RIN20OMA).....	3642

88.8.8	Transmitter optical waveform (transmit eye)	3642
88.8.9	Receiver sensitivity	3643
88.8.10	Stressed receiver sensitivity	3643
88.8.11	Receiver 3 dB electrical upper cutoff frequency	3643
88.9	Safety, installation, environment, and labeling	3643
88.9.1	General safety	3643
88.9.2	Laser safety	3643
88.9.3	Installation	3644
88.9.4	Environment	3644
88.9.5	Electromagnetic emission	3644
88.9.6	Temperature, humidity, and handling	3644
88.9.7	PMD labeling requirements	3644
88.10	Fiber optic cabling model	3645
88.11	Characteristics of the fiber optic cabling (channel)	3645
88.11.1	Optical fiber cable	3646
88.11.2	Optical fiber connection	3646
88.11.3	Medium Dependent Interface (MDI) requirements	3646
88.12	Protocol implementation conformance statement (PICS) proforma for Clause 88, Physical Medium Dependent (PMD) sublayer and medium, type 100GBASE-LR4 and 100GBASE-ER4	3647
88.12.1	Introduction	3647
88.12.2	Identification	3647
88.12.3	Major capabilities/options	3648
88.12.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, types 100GBASE-LR4 and 100GBASE-ER4	3649
89.	Physical Medium Dependent (PMD) sublayer and medium, type 40GBASE-FR	3652
89.1	Overview	3652
89.2	Physical Medium Dependent (PMD) service interface	3653
89.3	Delay and skew	3654
89.3.1	Delay constraints	3654
89.3.2	Skew constraints	3654
89.4	PMD MDIO function mapping	3654
89.5	PMD functional specifications	3655
89.5.1	PMD block diagram	3655
89.5.2	PMD transmit function	3655
89.5.3	PMD receive function	3655
89.5.4	PMD global signal detect function	3656
89.5.5	PMD reset function	3657
89.5.6	PMD global transmit disable function (optional)	3657
89.5.7	PMD fault function (optional)	3657
89.5.8	PMD transmit fault function (optional)	3657
89.5.9	PMD receive fault function (optional)	3657
89.6	PMD to MDI optical specifications for 40GBASE-FR	3657
89.6.1	40GBASE-FR transmitter optical specifications	3658
89.6.2	40GBASE-FR receive optical specifications	3658
89.6.3	40GBASE-FR illustrative link power budget	3659
89.6.4	Comparison of power budget methodology	3659
89.7	Definition of optical parameters and measurement methods	3660
89.7.1	Test patterns for optical parameters	3660
89.7.2	Skew and Skew Variation	3661
89.7.3	Wavelength and side mode suppression ratio (SMSR)	3661
89.7.4	Average optical power	3661

89.7.5	Dispersion penalty	3661
89.7.6	Extinction ratio	3662
89.7.7	Relative Intensity Noise (RIN20OMA)	3663
89.7.8	Transmitter optical waveform (transmit eye)	3663
89.7.9	Receiver sensitivity	3663
89.7.10	Receiver jitter tolerance	3663
89.7.11	Receiver 3 dB electrical upper cutoff frequency	3663
89.8	Safety, installation, environment, and labeling	3664
89.8.1	General safety	3664
89.8.2	Laser safety	3664
89.8.3	Installation	3664
89.8.4	Environment	3664
89.8.5	PMD labeling requirements	3665
89.9	Fiber optic cabling model	3665
89.10	Characteristics of the fiber optic cabling (channel)	3665
89.10.1	Optical fiber cable	3665
89.10.2	Optical fiber connection	3666
89.10.3	Medium Dependent Interface (MDI) requirements	3667
89.11	Protocol implementation conformance statement (PICS) proforma for Clause 89, Physical Medium Dependent (PMD) sublayer and medium, type 40GBASE-FR	3668
89.11.1	Introduction	3668
89.11.2	Identification	3668
89.11.3	Major capabilities/options	3669
89.11.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 40GBASE-FR	3669
90.	Ethernet support for time synchronization protocols	3672
90.1	Introduction	3672
90.2	Overview	3672
90.3	Relationship with other IEEE standards	3672
90.4	Time Synchronization Service Interface (TSSI)	3672
90.4.1	Introduction	3672
90.4.2	TSSI	3674
90.4.3	Detailed service specification	3674
90.5	generic Reconciliation Sublayer (gRS)	3675
90.5.1	TS_SFD_Detect_TX function	3675
90.5.2	TS_SFD_Detect_RX function	3675
90.6	Overview of management features	3676
90.7	Data delay measurement	3677
90.8	Protocol implementation conformance statement (PICS) proforma for Clause 90, Ethernet support for time synchronization protocols	3679
90.8.1	Introduction	3679
90.8.2	Identification	3679
90.8.3	TSSI indication	3680
90.8.4	Data delay reporting	3680
91.	Reed-Solomon forward error correction (RS-FEC) sublayer for 100GBASE-R PHYs	3681
91.1	Overview	3681
91.1.1	Scope	3681
91.1.2	Position of RS-FEC in the 100GBASE-R sublayers	3681
91.2	FEC service interface	3681
91.3	PMA compatibility	3683

91.4	Delay constraints.....	3683
91.5	Functions within the RS-FEC sublayer	3683
91.5.1	Functional block diagram	3683
91.5.2	Transmit function.....	3683
91.5.3	Receive function	3691
91.5.4	Detailed functions and state diagrams	3697
91.6	RS-FEC MDIO function mapping.....	3706
91.6.1	FEC_bypass_correction_enable.....	3708
91.6.2	FEC_bypass_indication_enable.....	3708
91.6.3	four_lane_pmd.....	3708
91.6.4	FEC_degraded_SER_enable.....	3708
91.6.5	FEC_degraded_SER_activate_threshold.....	3709
91.6.6	FEC_degraded_SER_deactivate_threshold.....	3709
91.6.7	FEC_degraded_SER_interval.....	3709
91.6.8	FEC_bypass_correction_ability.....	3709
91.6.9	FEC_bypass_indication_ability.....	3709
91.6.10	hi_ser.....	3709
91.6.11	FEC_degraded_SER_ability.....	3709
91.6.12	FEC_degraded_SER.....	3709
91.6.13	FEC_optional_states	3709
91.6.14	amps_lock<x>.....	3710
91.6.15	fec_align_status	3710
91.6.16	FEC_corrected_cw_counter.....	3710
91.6.17	FEC_uncorrected_cw_counter.....	3710
91.6.18	FEC_lane_mapping<x>.....	3710
91.6.19	FEC_symbol_error_counter_i.....	3710
91.6.20	align_status	3710
91.6.21	BIP_error_counter_i.....	3710
91.6.22	lane_mapping<x>.....	3711
91.6.23	block_lock<x>.....	3711
91.6.24	am_lock<x>.....	3711
91.7	Protocol implementation conformance statement (PICS) proforma for Clause 91, Reed-Solomon forward error correction (RS-FEC) sublayer for 100GBASE-R PHYs.....	3712
91.7.1	Introduction.....	3712
91.7.2	Identification.....	3712
91.7.3	Major capabilities/options.....	3713
91.7.4	PICS proforma tables for Reed-Solomon forward error correction (RS-FEC) sublayer for 100GBASE-R PHYs	3713
92.	Physical Medium Dependent (PMD) sublayer and baseband medium, type 100GBASE-CR4.....	3718
92.1	Overview.....	3718
92.2	Physical Medium Dependent (PMD) service interface	3719
92.3	PCS requirements for Auto-Negotiation (AN) service interface.....	3720
92.4	Delay constraints.....	3720
92.5	Skew constraints	3720
92.6	PMD MDIO function mapping.....	3721
92.7	PMD functional specifications.....	3722
92.7.1	Link block diagram	3722
92.7.2	PMD Transmit function	3724
92.7.3	PMD Receive function.....	3724
92.7.4	Global PMD signal detect function	3724
92.7.5	PMD lane-by-lane signal detect function	3724
92.7.6	Global PMD transmit disable function	3725

92.7.7	PMD lane-by-lane transmit disable function	3725
92.7.8	Loopback mode.....	3725
92.7.9	PMD fault function	3725
92.7.10	PMD transmit fault function.....	3725
92.7.11	PMD receive fault function.....	3726
92.7.12	PMD control function	3726
92.8	100GBASE-CR4 electrical characteristics	3727
92.8.1	Signal levels.....	3727
92.8.2	Signal paths.....	3727
92.8.3	Transmitter characteristics	3727
92.8.4	Receiver characteristics	3736
92.9	Channel characteristics	3740
92.10	Cable assembly characteristics	3741
92.10.1	Characteristic impedance and reference impedance	3741
92.10.2	Cable assembly insertion loss	3741
92.10.3	Cable assembly differential return loss.....	3743
92.10.4	Differential to common-mode return loss.....	3743
92.10.5	Differential to common-mode conversion loss.....	3745
92.10.6	Common-mode to common-mode return loss	3745
92.10.7	Cable assembly Channel Operating Margin	3745
92.11	Test fixtures	3747
92.11.1	TP2 or TP3 test fixture.....	3747
92.11.2	Cable assembly test fixture	3749
92.11.3	Mated test fixtures	3749
92.12	MDI specification	3755
92.12.1	100GBASE-CR4 MDI connectors.....	3756
92.13	Environmental specifications.....	3758
92.14	Protocol implementation conformance statement (PICS) proforma for Clause 92, Physical Medium Dependent (PMD) sublayer and baseband medium, type 100GBASE-CR4	3759
92.14.1	Introduction.....	3759
92.14.2	Identification	3759
92.14.3	Major capabilities/options.....	3760
92.14.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and baseband medium, type 100GBASE-CR4.....	3761
93.	Physical Medium Dependent (PMD) sublayer and baseband medium, type 100GBASE-KR4	3767
93.1	Overview.....	3767
93.2	Physical Medium Dependent (PMD) service interface	3768
93.3	PCS requirements for Auto-Negotiation (AN) service interface.....	3769
93.4	Delay constraints.....	3769
93.5	Skew constraints	3769
93.6	PMD MDIO function mapping.....	3770
93.7	PMD functional specifications.....	3771
93.7.1	Link block diagram.....	3771
93.7.2	PMD Transmit function	3771
93.7.3	PMD Receive function.....	3772
93.7.4	Global PMD signal detect function	3772
93.7.5	PMD lane-by-lane signal detect function	3772
93.7.6	Global PMD transmit disable function	3773
93.7.7	PMD lane-by-lane transmit disable function	3773
93.7.8	Loopback mode.....	3773
93.7.9	PMD fault function	3774
93.7.10	PMD transmit fault function	3774

93.7.11	PMD receive fault function.....	3774
93.7.12	PMD control function	3774
93.8	100GBASE-KR4 electrical characteristics	3775
93.8.1	Transmitter characteristics	3775
93.8.2	Receiver characteristics	3781
93.9	Channel characteristics	3785
93.9.1	Channel Operating Margin	3785
93.9.2	Insertion loss	3785
93.9.3	Return loss	3787
93.9.4	AC-coupling.....	3787
93.10	Environmental specifications.....	3787
93.10.1	General safety	3787
93.10.2	Network safety.....	3788
93.10.3	Installation and maintenance guidelines	3788
93.10.4	Electromagnetic compatibility	3788
93.10.5	Temperature and humidity	3788
93.11	Protocol implementation conformance statement (PICS) proforma for Clause 93, Physical Medium Dependent (PMD) sublayer and baseband medium, type 100GBASE-KR4.....	3789
93.11.1	Introduction.....	3789
93.11.2	Identification	3789
93.11.3	Major capabilities/options.....	3790
93.11.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and baseband medium, type 100GBASE-KR4.....	3791
94.	Physical Medium Attachment (PMA) sublayer, Physical Medium Dependent (PMD) sublayer, and baseband medium, type 100GBASE-KP4	3796
94.1	Overview.....	3796
94.2	Physical Medium Attachment (PMA) Sublayer	3797
94.2.1	PMA Service Interface.....	3797
94.2.2	PMA Transmit Functional Specifications.....	3801
94.2.3	PMA Receive Functional Specifications	3805
94.2.4	Skew constraints	3806
94.2.5	Delay constraints.....	3806
94.2.6	Link status.....	3806
94.2.7	PMA local loopback mode	3806
94.2.8	PMA remote loopback mode (optional)	3807
94.2.9	PMA test patterns.....	3807
94.2.10	PMA MDIO function mapping.....	3808
94.3	Physical Medium Dependent (PMD) Sublayer	3809
94.3.1	Physical Medium Dependent (PMD) service interface	3809
94.3.2	PCS requirements for Auto-Negotiation (AN) service interface.....	3811
94.3.3	Delay constraints.....	3811
94.3.4	Skew constraints	3811
94.3.5	PMD MDIO function mapping.....	3812
94.3.6	PMD functional specifications.....	3813
94.3.7	PMD fault function	3815
94.3.8	PMD transmit fault function	3815
94.3.9	PMD receive fault function.....	3816
94.3.10	PMD control function	3816
94.3.11	PMD LPI function	3824
94.3.12	PMD Transmitter electrical characteristics.....	3826
94.3.13	PMD Receiver electrical characteristics	3836
94.4	Channel characteristics	3840

94.4.1	Channel Operating Margin	3840
94.4.2	Channel insertion loss	3840
94.4.3	Channel return loss	3842
94.4.4	Channel AC-coupling	3843
94.5	Environmental specifications.....	3843
94.5.1	General safety	3843
94.5.2	Network safety	3843
94.5.3	Installation and maintenance guidelines	3844
94.5.4	Electromagnetic compatibility	3844
94.5.5	Temperature and humidity	3844
94.6	Protocol implementation conformance statement (PICS) proforma for Clause 94, Physical Medium Attachment (PMA) sublayer, Physical Medium Dependent (PMD) sublayer, and baseband medium, type 100GBASE-KP4	3845
94.6.1	Introduction.....	3845
94.6.2	Identification	3845
94.6.3	Major capabilities/options.....	3846
94.6.4	PICS proforma tables for Physical Medium Attachment (PMA) sublayer, Physical Medium Dependent (PMD) sublayer, and baseband medium, type 100GBASE-KP4 ..	3846
95.	Physical Medium Dependent (PMD) sublayer and medium, type 100GBASE-SR4	3854
95.1	Overview.....	3854
95.1.1	Bit error ratio	3855
95.2	Physical Medium Dependent (PMD) service interface	3855
95.3	Delay and Skew	3856
95.3.1	Delay constraints.....	3856
95.3.2	Skew constraints	3856
95.4	PMD MDIO function mapping.....	3857
95.5	PMD functional specifications.....	3857
95.5.1	PMD block diagram.....	3858
95.5.2	PMD transmit function	3858
95.5.3	PMD receive function	3858
95.5.4	PMD global signal detect function	3859
95.5.5	PMD lane-by-lane signal detect function	3859
95.5.6	PMD reset function	3859
95.5.7	PMD global transmit disable function (optional)	3860
95.5.8	PMD lane-by-lane transmit disable function (optional)	3860
95.5.9	PMD fault function (optional)	3860
95.5.10	PMD transmit fault function (optional)	3860
95.5.11	PMD receive fault function (optional).....	3860
95.6	Lane assignments	3860
95.7	PMD to MDI optical specifications for 100GBASE-SR4	3861
95.7.1	100GBASE-SR4 transmitter optical specifications	3861
95.7.2	100GBASE-SR4 receive optical specifications.....	3862
95.7.3	100GBASE-SR4 illustrative link power budget.....	3863
95.8	Definition of optical parameters and measurement methods.....	3863
95.8.1	Test patterns for optical parameters.....	3863
95.8.2	Center wavelength and spectral width	3864
95.8.3	Average optical power	3864
95.8.4	Optical Modulation Amplitude (OMA)	3865
95.8.5	Transmitter and dispersion eye closure (TDEC)	3865
95.8.6	Extinction ratio	3868
95.8.7	Transmitter optical waveform (transmit eye)	3868
95.8.8	Stressed receiver sensitivity.....	3868

95.9	Safety, installation, environment, and labeling.....	3872
95.9.1	General safety	3872
95.9.2	Laser safety	3872
95.9.3	Installation	3872
95.9.4	Environment.....	3872
95.9.5	Electromagnetic emission	3872
95.9.6	Temperature, humidity, and handling	3872
95.9.7	PMD labeling requirements	3873
95.10	Fiber optic cabling model	3873
95.11	Characteristics of the fiber optic cabling (channel)	3874
95.11.1	Optical fiber cable.....	3874
95.11.2	Optical fiber connection.....	3874
95.11.3	Medium Dependent Interface (MDI)	3874
95.12	Protocol implementation conformance statement (PICS) proforma for Clause 95, Physical Medium Dependent (PMD) sublayer and medium, type 100GBASE-SR4.....	3876
95.12.1	Introduction.....	3876
95.12.2	Identification	3876
95.12.3	Major capabilities/options.....	3877
95.12.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 100GBASE-SR4	3878
96.	Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 100BASE-T1	3882
96.1	Overview.....	3882
96.1.1	100BASE-T1 architecture.....	3883
96.1.2	Conventions in this clause	3884
96.2	100BASE-T1 service primitives and interfaces.....	3885
96.2.1	PMA service interface	3885
96.2.2	PMA_LINK.indication	3887
96.2.3	PMA_TXMODE.indication.....	3887
96.2.4	PMA_UNITDATA.request.....	3888
96.2.5	PMA_UNITDATA.indication	3888
96.2.6	PMA_SCRSTATUS.request.....	3889
96.2.7	PMA_RXSTATUS.indication	3889
96.2.8	PMA_REMRXSTATUS.request.....	3890
96.2.9	PMA_RESET.indication.....	3890
96.2.10	PMA_TXEN.request.....	3890
96.3	100BASE-T1 Physical Coding Sublayer (PCS) functions	3891
96.3.1	PCS Reset function	3892
96.3.2	PCS data transmission enabling.....	3893
96.3.3	PCS Transmit.....	3894
96.3.4	PCS Receive	3903
96.3.5	PCS Loopback	3909
96.4	Physical Medium Attachment (PMA) Sublayer	3910
96.4.1	PMA Reset function.....	3910
96.4.2	PMA Transmit function	3911
96.4.3	PMA Receive function.....	3912
96.4.4	PHY Control function	3913
96.4.5	Link Monitor function	3913
96.4.6	PMA clock recovery	3913
96.4.7	State variables	3913
96.5	PMA electrical specifications	3916
96.5.1	EMC tests.....	3916

96.5.2	Test modes	3917
96.5.3	Test fixtures	3918
96.5.4	Transmitter electrical specifications	3919
96.5.5	Receiver electrical specifications	3923
96.5.6	Transmitter peak differential output	3924
96.5.7	PMA Local Loopback	3924
96.6	Management interface	3925
96.6.1	MASTER-SLAVE configuration	3925
96.6.2	PHY-initialization	3925
96.6.3	PMA and PCS MDIO function mapping	3925
96.7	Link segment characteristics	3926
96.7.1	Cabling system characteristics	3926
96.7.2	Noise environment	3928
96.8	MDI specification	3929
96.8.1	MDI connectors	3929
96.8.2	MDI electrical specification	3929
96.8.3	MDI fault tolerance	3930
96.9	Environmental specifications	3930
96.9.1	General safety	3930
96.9.2	Network safety	3930
96.10	Delay constraints	3931
96.11	Protocol implementation conformance statement (PICS) proforma for Clause 96, Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 100BASE-T1	3932
96.11.1	Introduction	3932
96.11.2	Identification	3932
96.11.3	Major capabilities/options	3933
96.11.4	PICS proforma tables for Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 100BASE-T1	3933
97.	Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer, and baseband medium, type 1000BASE-T1	3943
97.1	Overview	3943
97.1.1	Relationship of 1000BASE-T1 to other standards	3943
97.1.2	Operation of 1000BASE-T1	3943
97.1.3	Signaling	3948
97.1.4	Interfaces	3948
97.1.5	Conventions in this clause	3948
97.2	1000BASE-T1 Service Primitives and Interfaces	3948
97.2.1	Technology Dependent Interface	3949
97.2.2	PMA service interface	3950
97.3	Physical Coding Sublayer (PCS)	3957
97.3.1	PCS service interface (GMII)	3957
97.3.2	PCS functions	3957
97.3.3	Test-pattern generators	3968
97.3.4	PMA training side-stream scrambler polynomials	3968
97.3.5	LPI signaling	3970
97.3.6	Detailed functions and state diagrams	3971
97.3.7	PCS management	3979
97.3.8	BASE-T1 Operations, Administration, and Maintenance (OAM)	3980
97.4	Physical Medium Attachment (PMA) sublayer	3995
97.4.1	PMA functional specifications	3995
97.4.2	PMA functions	3995

97.4.3	MDI.....	4007
97.4.4	State variables.....	4007
97.4.5	State diagrams.....	4011
97.5	PMA electrical specifications.....	4012
97.5.1	EMC Requirements.....	4012
97.5.2	Test modes.....	4012
97.5.3	Transmitter electrical specifications.....	4016
97.5.4	Receiver electrical specifications.....	4020
97.6	Link segment characteristics.....	4020
97.6.1	Link transmission parameters for link segment type A.....	4021
97.6.2	Link transmission parameters for link segment type B.....	4024
97.6.3	Coupling parameters between type A link segments.....	4026
97.6.4	Coupling parameters between type B link segments.....	4028
97.7	Media Dependent Interface (MDI).....	4030
97.7.1	MDI connectors.....	4030
97.7.2	MDI electrical specification.....	4030
97.7.3	MDI fault tolerance.....	4031
97.8	Management Interfaces.....	4031
97.8.1	Optional Support for Auto-Negotiation.....	4031
97.9	Environmental specifications.....	4032
97.9.1	General safety.....	4032
97.9.2	Network safety.....	4032
97.10	Delay constraints.....	4032
97.11	Protocol implementation conformance statement (PICS) proforma for Clause 97, Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer, and baseband medium, type 1000BASE-T1.....	4034
97.11.1	Introduction.....	4034
97.11.2	Identification.....	4034
97.11.3	Major capabilities/options.....	4035
97.11.4	General.....	4035
97.11.5	Physical Coding Sublayer (PCS).....	4036
97.11.6	PCS Receive functions.....	4037
97.11.7	PCS loopback.....	4038
97.11.8	OAM.....	4039
97.11.9	Physical Medium Attachment (PMA).....	4040
97.11.10	PMA electrical specifications.....	4042
97.11.11	MDI electrical requirements.....	4045
97.11.12	MDI Requirements.....	4047
97.11.13	EEE capability requirements.....	4047
97.11.14	Environmental specifications.....	4048
98.	Auto-Negotiation for single differential-pair media.....	4049
98.1	Overview.....	4049
98.1.1	Scope.....	4049
98.1.2	Relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model....	4049
98.2	Functional specifications.....	4049
98.2.1	Transmit function requirements.....	4050
98.2.2	Receive function requirements.....	4058
98.2.3	AN half-duplex function requirements.....	4058
98.2.4	Arbitration function requirements.....	4059
98.3	State diagram variable to Auto-Negotiation register mapping.....	4061
98.4	Technology-Dependent Interface.....	4061
98.4.1	PMA_LINK.indication.....	4062

98.4.2	PMA_LINK.request.....	4062
98.5	Detailed functions and state diagrams	4062
98.5.1	State diagram variables	4063
98.5.2	State diagram timers	4069
98.5.3	State diagram counters.....	4072
98.5.4	Function	4073
98.5.5	State diagrams.....	4073
98.5.6	High-speed and low-speed Auto-Negotiation modes	4076
98.6	Protocol implementation conformance statement (PICS) proforma for Clause 98, Auto-Negotiation for Single Differential-Pair Media	4079
98.6.1	Introduction.....	4079
98.6.2	Identification	4079
98.6.3	Major capabilities/options.....	4080
98.6.4	General.....	4080
98.6.5	DME transmission	4080
98.6.6	Link codeword encoding	4081
98.6.7	Arbitration function requirements	4082
98.6.8	Service primitives	4083
98.6.9	State diagram and variable definitions.....	4084
98.6.10	High-speed and low-speed Auto-Negotiation modes	4086
99.	MAC Merge sublayer	4087
99.1	Introduction.....	4087
99.1.1	Relationship to other IEEE standards	4088
99.1.2	Functional Block Diagram.....	4090
99.2	MAC Merge Service Interface (MMSI)	4090
99.2.1	MM_CTL.request	4090
99.3	MAC Merge Packet (mPacket).....	4091
99.3.1	mPacket format	4091
99.3.2	Preamble	4091
99.3.3	Start mPacket Delimiter (SMD)	4092
99.3.4	frag_count.....	4092
99.3.5	mData.....	4093
99.3.6	CRC	4093
99.4	MAC Merge sublayer operation	4094
99.4.1	MAC Merge sublayer transmit behavior when preemption is disabled	4094
99.4.2	Determining that the link partner supports preemption	4094
99.4.3	Verifying preemption operation.....	4094
99.4.4	Transmit processing	4095
99.4.5	Receive processing	4095
99.4.6	Express filter	4096
99.4.7	Detailed functions and state diagrams	4097
99.4.8	Delay Constraints.....	4104
99.5	Protocol implementation conformance statement (PICS) proforma for Clause 99, MAC Merge sublayer	4106
99.5.1	Introduction.....	4106
99.5.2	Identification	4106
99.5.3	PICS proforma tables for MAC Merge sublayer.....	4107
100.	Physical Medium Dependent (PMD) sublayer, and medium for coaxial distribution networks, type 10GPASS-XR	4109
100.1	Overview.....	4109

100.1.1	Terminology and conventions	4109
100.1.2	Positioning of the PMD sublayer within the IEEE 802.3 architecture	4109
100.1.3	PMD types	4109
100.1.4	Mapping of PMD variables.....	4109
100.2	PMD functional specification	4113
100.2.1	PMD service interface	4113
100.2.2	Delay constraints.....	4114
100.2.3	PMD transmit function	4114
100.2.4	PMD receive function.....	4115
100.2.5	PMD transmit enable function.....	4115
100.3	PMD operational requirements	4115
100.3.1	CLT and CNU modulation formats	4115
100.3.2	Data rates	4116
100.3.3	CLT transmitter requirements.....	4118
100.3.4	CNU transmitter requirements.....	4127
100.3.5	CLT receiver requirements	4138
100.3.6	CNU receiver requirements	4141
100.3.7	Channel band rules.....	4144
100.4	Test requirements and measurement methods	4145
100.4.1	CLT RF output muting requirement	4145
100.4.2	CNU receive modulation error ratio testing	4146
100.4.3	Upstream channel power	4146
100.4.4	Guidelines for verifying compliance with downstream phase noise requirements	4147
100.5	Environmental, safety, and labeling	4149
100.5.1	General safety	4149
100.5.2	Installation	4149
100.5.3	Environment.....	4149
100.5.4	PMD labeling.....	4149
100.6	EEE capability	4149
100.7	Protocol implementation conformance statement (PICS) proforma for Clause 100, Physical Medium Dependent (PMD) sublayer and medium for coaxial cable distribution networks, type 10GPASS-XR	4150
100.7.1	Identification	4150
100.7.2	Major capabilities/options	4151
100.7.3	PICS proforma tables for Physical Medium Dependent (PMD) sublayer for coax cable distribution networks, type 10GPASS-XR.....	4152
101.	Reconciliation Sublayer, Physical Coding Sublayer, and Physical Media Attachment for EPoC ...	4156
101.1	Overview.....	4156
101.1.1	Conventions	4156
101.1.2	Constraints for delay through RS, PCS, and PMA	4156
101.1.3	Mapping of PCS, and PMA variables.....	4156
101.1.4	Functional blocks supporting 10GPASS-XR PCS, PMA, and PMD sublayers	4156
101.2	Reconciliation Sublayer (RS) for EPoC	4164
101.3	Physical Coding Sublayer (PCS) for EPoC	4164
101.3.1	Overview.....	4164
101.3.2	PCS transmit function.....	4166
101.3.3	PCS receive function	4185
101.4	10GPASS-XR PMA	4196
101.4.1	Overview.....	4196
101.4.2	PMA Service Interface.....	4197
101.4.3	Downstream PMA transmit function.....	4198
101.4.4	Upstream PMA transmit function.....	4224

101.4.5	Constellation structure and mapping	4246
101.4.6	PMA testing	4251
101.5	Applicability of Clause 90 and IEEE Std 802.1AS, Clause 13 for EPoC time transport	4252
101.5.1	CLT PHY asymmetry correction of future time transmitted by the CLT to CNU _i	4252
101.5.2	CNU PHY asymmetry correction of future time received by CNU _i	4252
101.6	Protocol implementation conformance statement (PICS) proforma for Clause 101, Reconciliation Sublayer, Physical Coding Sublayer, and Physical Media Attachment for EPoC	4254
101.6.1	Introduction	4254
101.6.2	Identification	4254
101.6.3	Major capabilities/options	4255
101.6.4	PICS proforma tables for Reconciliation Sublayer, Physical Coding Sublayer, and Physical Media Attachment for EPoC	4255
102.	EPoC PHY Link	4262
102.1	PHY Link overview and architecture	4262
102.1.1	PHY Link frame structure and protocol	4262
102.1.2	PHY Link block diagram	4264
102.1.3	PHY Link Message Engine	4265
102.1.4	PHY Link FEC encoder	4266
102.1.5	PHY Link scrambler	4268
102.1.6	PHY Link symbol map and constellation mapping	4268
102.1.7	Interleaving	4269
102.1.8	Mapping of PHY Link variables	4269
102.2	Downstream PHY Link	4273
102.2.1	Downstream PHY Link Physical Layer	4273
102.2.2	Downstream preamble	4276
102.2.3	Downstream frame	4277
102.2.4	Downstream PHY Link FEC	4283
102.2.5	Downstream PHY Link response time.	4283
102.2.6	PHY Link managed variables	4283
102.2.7	Downstream state diagrams	4284
102.3	Upstream PHY Link	4289
102.3.1	Upstream PHY Link Physical Layer	4289
102.3.2	Upstream PHY Link frame	4289
102.3.3	Upstream PHY Link FEC	4291
102.3.4	Upstream PHY Link pilot pattern	4291
102.3.5	Upstream state diagrams	4291
102.4	PHY Link applications	4294
102.4.1	PHY Discovery	4295
102.4.2	Upstream Wideband Probing	4303
102.4.3	Link-up declaration	4310
102.4.4	Link-down declaration	4311
102.4.5	OFDM Profile descriptors	4312
102.5	Protocol implementation conformance statement (PICS) proforma for Clause 102, EPoC PHY Link	4314
102.5.1	Introduction	4314
102.5.2	Identification	4314
102.5.3	Major capabilities/options	4315
102.5.4	PICS proforma tables for EPoC PHY Link	4315
103.	Multipoint MAC Control for EPoC	4322

103.1	Overview.....	4322
103.1.1	Position of Multipoint MAC Control within the IEEE 802.3 hierarchy.....	4324
103.1.2	Functional block diagram	4326
103.1.3	Service interfaces	4327
103.1.4	State diagram conventions	4327
103.1.5	Other conventions.....	4327
103.2	Multipoint MAC Control operation.....	4327
103.2.1	Principles of Multipoint MAC Control.....	4327
103.2.2	Multipoint transmission control, Control Parser, and Control Multiplexer.....	4328
103.3	Multipoint Control Protocol (MPCP)	4342
103.3.1	Principles of Multipoint Control Protocol	4342
103.3.2	Compatibility considerations	4342
103.3.3	Discovery processing.....	4342
103.3.4	Report Processing	4353
103.3.5	Gate Processing.....	4353
103.3.6	MPCPDU structure and encoding.....	4361
103.4	Protocol implementation conformance statement (PICS) proforma for Clause 103, Multipoint MAC Control for EPoC	4364
103.4.1	Introduction.....	4364
103.4.2	Identification	4364
103.4.3	Major capabilities/options	4365
103.4.4	PICS proforma tables for Multipoint MAC Control.....	4365
104.	Power over Data Lines (PoDL) of Single-Pair Ethernet.....	4370
104.1	Overview.....	4370
104.1.1	Compatibility considerations	4370
104.1.2	Relationship of PoDL to the IEEE 802.3 architecture.....	4370
104.1.3	PoDL system types	4371
104.2	Link segment.....	4372
104.3	Class power requirements.....	4372
104.4	Power Sourcing Equipment (PSE).....	4373
104.4.1	PSE types	4374
104.4.2	PI pin assignments	4374
104.4.3	PSE classes	4374
104.4.4	PSE state diagram	4374
104.4.5	PSE detection of a PD.....	4381
104.4.6	PSE classification of a PD	4382
104.4.7	PSE output requirements	4382
104.4.8	PSE power removal	4387
104.5	Powered Device (PD)	4387
104.5.1	PD types.....	4387
104.5.2	PD PI.....	4387
104.5.3	PD classes	4388
104.5.4	PD state diagram.....	4388
104.5.5	PD signature.....	4391
104.5.6	PD classification and mutual identification between the PSE and PD	4392
104.5.7	PD power	4392
104.5.8	PD Maintain full voltage.....	4396
104.6	Additional electrical specifications.....	4396
104.6.1	Isolation	4396
104.6.2	Fault tolerance.....	4397
104.7	Serial communication classification protocol (SCCP)	4397
104.7.1	SCCP signaling	4397

104.7.2	Serial communication classification protocols	4403
104.8	Environmental.....	4407
104.8.1	General safety	4407
104.8.2	Network safety	4407
104.8.3	Installation and maintenance guidelines	4407
104.8.4	Patch panel considerations	4408
104.8.5	Telephony voltages	4408
104.8.6	Electromagnetic emissions	4408
104.8.7	Temperature and humidity	4408
104.9	Protocol implementation conformance statement (PICS) proforma for Clause 104, Power over Data Lines (PoDL) of Single-Pair Ethernet.....	4409
104.9.1	Introduction.....	4409
104.9.2	Identification	4409
104.9.3	Major capabilities/options.....	4410
104.9.4	PICS proforma tables for Clause 104, Power over Data Lines (PoDL) of Single-Pair Ethernet	4411
105.	Introduction to 25 Gb/s networks	4421
105.1	Overview.....	4421
105.1.1	Scope.....	4421
105.1.2	Relationship of 25 Gigabit Ethernet to the ISO OSI reference model.....	4421
105.1.3	Nomenclature.....	4422
105.2	Physical Layer signaling systems	4423
105.3	Summary of 25 Gigabit Ethernet sublayers.....	4424
105.3.1	Reconciliation Sublayer (RS) and 25 Gigabit Media Independent Interface (25GMII).....	4424
105.3.2	Physical Coding Sublayer (PCS)	4425
105.3.3	Forward error correction (FEC) sublayer	4425
105.3.4	Physical Medium Attachment (PMA) sublayer	4425
105.3.5	Physical Medium Dependent (PMD) sublayer	4425
105.3.6	Auto-Negotiation (AN).....	4425
105.3.7	Management interface (MDIO/MDC)	4425
105.3.8	Management.....	4426
105.4	Service interface specification method and notation	4426
105.4.1	Inter-sublayer service interface.....	4426
105.4.2	Instances of the Inter-sublayer service interface.....	4427
105.4.3	Semantics of inter-sublayer service interface primitives.....	4427
105.5	Delay constraints.....	4432
105.6	State diagrams.....	4433
105.7	Protocol implementation conformance statement (PICS) proforma.....	4434
106.	Reconciliation Sublayer (RS) and Media Independent Interface (25GMII) for 25 Gb/s operation .	4435
106.1	Overview.....	4435
106.1.1	Summary of major concepts	4436
106.1.2	Application.....	4436
106.1.3	Rate of operation.....	4436
106.1.4	Delay constraints.....	4436
106.1.5	Allocation of functions	4437
106.1.6	25GMII structure	4437
106.1.7	Mapping of 25GMII signals to PLS service primitives	4437
106.2	25GMII data stream	4438
106.3	25GMII functional specifications	4438
106.4	LPI Assertion and Detection.....	4438

106.5	Protocol implementation conformance statement (PICS) proforma for Clause 106 Reconciliation Sublayer (RS) and Media Independent Interface (25GMII) for 25 Gb/s operation	4439
106.5.1	Introduction.....	4439
106.5.2	Identification.....	4439
106.5.3	PICS proforma Tables for Reconciliation Sublayer and 25 Gigabit Media Independent Interface	4440
107.	Physical Coding Sublayer (PCS) for 64B/66B, type 25GBASE-R	4441
107.1	Overview.....	4441
107.1.1	Scope.....	4441
107.1.2	Relationship of 25GBASE-R to other standards	4441
107.1.3	Summary of 25GBASE-R sublayers	4441
107.1.4	Inter-sublayer interfaces	4441
107.2	Functions within the PCS	4442
107.2.1	Notation conventions	4443
107.2.2	Transmission order	4443
107.2.3	Test-pattern generator	4444
107.3	LPI	4444
107.4	Delay constraints.....	4445
107.5	Support for Auto-Negotiation.....	4445
107.6	Protocol implementation conformance statement (PICS) proforma for Clause 107, Physical Coding Sublayer (PCS) for 64B/66B, type 25GBASE-R.....	4446
107.6.1	Introduction.....	4446
107.6.2	Identification.....	4446
107.6.3	Major capabilities/options.....	4447
107.6.4	25G PCS	4447
108.	Reed-Solomon forward error correction (RS-FEC) sublayer for 10GBASE-R and 25GBASE-R PHYs.....	4449
108.1	Overview.....	4449
108.1.1	Scope.....	4449
108.1.2	Position of RS-FEC in the 10GBASE-R and 25GBASE-R PHY sublayers	4449
108.1.3	Inter-sublayer interfaces	4450
108.2	FEC service interface.....	4452
108.2.1	10GBASE-R service primitives.....	4453
108.2.2	25GBASE-R service primitives.....	4454
108.3	PMA compatibility	4455
108.4	Delay constraints.....	4455
108.5	Functions within the RS-FEC sublayer	4456
108.5.1	Functional block diagram	4456
108.5.2	Transmit function.....	4457
108.5.3	Receive function	4461
108.5.4	Detailed functions and state diagrams	4464
108.6	RS-FEC MDIO function mapping.....	4469
108.6.1	FEC_bypass_correction_enable.....	4470
108.6.2	FEC_bypass_indication_enable.....	4470
108.6.3	RS-FEC Enable.....	4471
108.6.4	FEC_bypass_correction_ability.....	4471
108.6.5	FEC_bypass_indication_ability.....	4471
108.6.6	FEC_high_ser	4471
108.6.7	FEC_corrected_cw_counter.....	4471

108.6.8 FEC_uncorrected_cw_counter.....	4471
108.6.9 FEC_symbol_error_counter_0.....	4472
108.6.10 align_status	4472
108.7 Protocol implementation conformance statement (PICS) proforma for Clause 108, Reed-Solomon forward error correction (RS-FEC) sublayer for 10GBASE-R and 25GBASE-R PHYs	4473
108.7.1 Introduction.....	4473
108.7.2 Identification.....	4473
108.7.3 Major capabilities/options.....	4474
108.7.4 PICS proforma tables for Reed-Solomon forward error correction (RS-FEC) sublayer for 10GBASE-R and 25GBASE-R PHYs	4474
109. Physical Medium Attachment (PMA) sublayer, type 25GBASE-R.....	4477
109.1 Overview.....	4477
109.1.1 Scope.....	4477
109.1.2 Position of the PMA in the 25GBASE-R sublayers	4477
109.1.3 Summary of functions.....	4478
109.1.4 PMA sublayer positioning	4479
109.2 PMA service interface	4480
109.3 Service interface below PMA	4481
109.4 Functions within the PMA	4482
109.4.1 Signal drivers	4482
109.4.2 PMA local loopback mode	4482
109.4.3 PMA remote loopback mode	4482
109.4.4 PMA test patterns.....	4482
109.4.5 Energy Efficient Ethernet for 25GAUI.....	4485
109.5 Delay constraints.....	4485
109.6 PMA MDIO function mapping.....	4485
109.7 Protocol implementation conformance statement (PICS) proforma for Clause 109, Physical Medium Attachment (PMA) sublayer, type 25GBASE-R	4488
109.7.1 Introduction.....	4488
109.7.2 Identification	4488
109.7.3 PICS proforma tables for the 25GBASE-R PMA Sublayer	4489
109.7.4 Major capabilities/options.....	4489
110. Physical Medium Dependent (PMD) sublayer and baseband medium, type 25GBASE-CR and 25GBASE-CR-S	4491
110.1 Overview.....	4491
110.2 PMD service interface	4492
110.3 PCS requirements for Auto-Negotiation (AN) service interface.....	4493
110.4 Delay constraints.....	4493
110.5 PMD MDIO function mapping.....	4494
110.6 FEC modes.....	4494
110.7 PMD functional specifications.....	4495
110.7.1 Link block diagram.....	4495
110.7.2 PMD transmit function	4496
110.7.3 PMD receive function	4497
110.7.4 Global PMD signal detect function	4497
110.7.5 Global PMD transmit disable function	4497
110.7.6 Loopback mode.....	4498
110.7.7 PMD fault function	4498
110.7.8 PMD transmit fault function	4498

110.7.9 PMD receive fault function.....	4498
110.7.10PMD control function	4498
110.8 Electrical characteristics	4498
110.8.1 Signal levels	4498
110.8.2 Signal paths.....	4499
110.8.3 Transmitter characteristics	4499
110.8.4 Receiver characteristics	4499
110.9 Channel characteristics	4504
110.10 Cable assembly characteristics	4504
110.10.1Characteristic impedance and reference impedance	4505
110.10.2Cable assembly insertion loss	4505
110.10.3Cable assembly differential return loss.....	4505
110.10.4Differential to common-mode return loss.....	4506
110.10.5Differential to common-mode conversion loss.....	4506
110.10.6Common-mode to common-mode return loss	4506
110.10.7Cable assembly Channel Operating Margin	4506
110.11 MDI specification	4510
110.11.1Single-lane MDI connectors	4510
110.12 Environmental specifications.....	4511
110.13 Protocol implementation conformance statement (PICS) proforma for Clause 110, Physical Medium Dependent (PMD) sublayer and baseband medium, type 25GBASE-CR and 25GBASE-CR-S	4512
110.13.1Introduction.....	4512
110.13.2Identification.....	4512
110.13.3Major capabilities/options.....	4513
110.13.4PICS proforma tables for Physical Medium Dependent (PMD) sublayer and baseband medium, type 25GBASE-CR and 25GBASE-CR-S.....	4514
111. Physical Medium Dependent (PMD) sublayer and baseband medium, type 25GBASE-KR and 25GBASE-KR-S	4520
111.1 Overview.....	4520
111.2 PMD service interface	4521
111.3 PCS requirements for Auto-Negotiation (AN) service interface.....	4522
111.4 Delay constraints.....	4522
111.5 PMD MDIO function mapping.....	4522
111.6 FEC modes.....	4523
111.7 PMD functional specifications.....	4524
111.7.1 Link block diagram.....	4524
111.7.2 PMD transmit function	4524
111.7.3 PMD receive function	4525
111.7.4 Global PMD signal detect function	4525
111.7.5 Global PMD transmit disable function	4525
111.7.6 Loopback mode.....	4525
111.7.7 PMD fault function	4526
111.7.8 PMD transmit fault function	4526
111.7.9 PMD receive fault function.....	4526
111.7.10PMD control function	4526
111.8 Electrical characteristics	4526
111.8.1 MDI.....	4526
111.8.2 Transmitter characteristics	4527
111.8.3 Receiver characteristics	4527
111.9 Channel characteristics	4530
111.9.1 25GBASE-KR channel	4530

111.9.2 25GBASE-KR-S channel	4530
111.10 Environmental specifications.....	4531
111.11 Protocol implementation conformance statement (PICS) proforma for Clause 111, Physical Medium Dependent (PMD) sublayer and baseband medium, type 25GBASE-KR and 25GBASE-KR-S	4532
111.11.1 Introduction.....	4532
111.11.2 Identification.....	4532
111.11.3 Major capabilities/options.....	4533
111.11.4 PICS proforma tables for Physical Medium Dependent (PMD) sublayer and baseband medium, type 25GBASE-KR and 25GBASE-KR-S	4533
112. Physical Medium Dependent (PMD) sublayer and medium, type 25GBASE-SR	4539
112.1 Overview.....	4539
112.1.1 Bit error ratio	4540
112.2 Physical Medium Dependent (PMD) service interface	4540
112.3 Delay constraints.....	4541
112.4 PMD MDIO function mapping.....	4541
112.5 PMD functional specifications.....	4542
112.5.1 PMD block diagram.....	4542
112.5.2 PMD transmit function	4543
112.5.3 PMD receive function.....	4543
112.5.4 PMD global signal detect function	4543
112.5.5 PMD reset function.....	4544
112.5.6 PMD global transmit disable function (optional)	4544
112.5.7 PMD fault function (optional)	4544
112.5.8 PMD transmit fault function (optional)	4544
112.5.9 PMD receive fault function (optional).....	4544
112.6 PMD to MDI optical specifications for 25GBASE-SR	4544
112.6.1 25GBASE-SR transmitter optical specifications.....	4545
112.6.2 25GBASE-SR receive optical specifications.....	4545
112.6.3 25GBASE-SR illustrative link power budget.....	4545
112.7 Definition of optical parameters and measurement methods.....	4545
112.7.1 Test patterns for optical parameters.....	4545
112.7.2 Center wavelength and spectral width	4546
112.7.3 Average optical power	4546
112.7.4 Optical Modulation Amplitude (OMA).....	4546
112.7.5 Transmitter and dispersion eye closure (TDEC)	4546
112.7.6 Extinction ratio	4546
112.7.7 Transmitter optical waveform (transmit eye)	4546
112.7.8 Stressed receiver sensitivity.....	4546
112.8 Safety, installation, environment, and labeling.....	4546
112.8.1 General safety	4546
112.8.2 Laser safety	4547
112.8.3 Installation	4547
112.8.4 Environment.....	4547
112.8.5 Electromagnetic emission	4547
112.8.6 Temperature, humidity, and handling	4547
112.8.7 PMD labeling requirements	4547
112.9 Fiber optic cabling model	4548
112.10 Characteristics of the fiber optic cabling (channel).....	4548
112.10.1 Optical fiber cable.....	4548
112.10.2 Optical fiber connection.....	4548
112.10.3 Medium Dependent Interface (MDI)	4549

112.11 Protocol implementation conformance statement (PICS) proforma for Clause 112, Physical Medium Dependent (PMD) sublayer and medium, type 25GBASE-SR	4550
112.11.1 Introduction	4550
112.11.2 Identification	4550
112.11.3 Major capabilities/options	4551
112.11.4 PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 25GBASE-SR	4551
113. Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer, and baseband medium, types 25GBASE-T and 40GBASE-T	4554
113.1 Overview	4554
113.1.1 Nomenclature	4554
113.1.2 Relationship of 25GBASE-T and 40GBASE-T to other standards	4555
113.1.3 Operation of 25GBASE-T and 40GBASE-T	4555
113.1.4 Signaling	4561
113.1.5 Interfaces	4562
113.1.6 Conventions in this clause	4562
113.2 25GBASE-T and 40GBASE-T service primitives and interfaces	4562
113.2.1 Technology Dependent Interface	4563
113.2.2 PMA service interface	4564
113.3 Physical Coding Sublayer (PCS)	4571
113.3.1 PCS service interface (25GMII/XLGMII)	4571
113.3.2 PCS functions	4572
113.3.3 Test-pattern generators	4594
113.3.4 PMA training side-stream scrambler polynomials	4595
113.3.5 LPI signaling	4596
113.3.6 Detailed functions and state diagrams	4599
113.3.7 PCS management	4605
113.4 Physical Medium Attachment (PMA) sublayer	4612
113.4.1 PMA functional specifications	4612
113.4.2 PMA functions	4613
113.4.3 MDI	4626
113.4.4 Automatic MDI/MDI-X configuration	4628
113.4.5 State variables	4628
113.4.6 State diagrams	4633
113.5 PMA electrical specifications	4636
113.5.1 Electrical isolation	4636
113.5.2 Test modes	4636
113.5.3 Transmitter electrical specifications	4641
113.5.4 Receiver electrical specifications	4643
113.6 Management interfaces	4645
113.6.1 Support for Auto-Negotiation	4645
113.6.2 MASTER-SLAVE configuration resolution	4648
113.7 Link segment characteristics	4650
113.7.1 Cabling system characteristics	4651
113.7.2 Link segment transmission parameters	4651
113.7.3 Coupling parameters between link segments	4656
113.7.4 Direct attach cable assembly—Short Reach Mode	4658
113.7.5 Noise environment	4662
113.8 MDI specification	4663
113.8.1 MDI connectors	4663
113.8.2 MDI electrical specifications	4664
113.9 Environmental specifications	4666

113.9.1 General safety	4666
113.9.2 Network safety	4666
113.9.3 Installation and maintenance guidelines	4666
113.9.4 Telephone voltages	4667
113.9.5 Electromagnetic compatibility	4667
113.9.6 Temperature and humidity	4667
113.10 PHY labeling.....	4667
113.11 Delay constraints.....	4667
113.12 Protocol implementation conformance statement (PICS) proforma for Clause 113, Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer, and baseband medium, types 25GBASE-T and 40GBASE-T	4669
113.12.1 Identification	4669
113.12.2 Major capabilities/options.....	4670
113.12.3 Physical Coding Sublayer (PCS)	4670
113.12.4 Physical Medium Attachment (PMA)	4672
113.12.5 Management interface.....	4675
113.12.6 PMA Electrical Specifications.....	4676
113.12.7 Characteristics of the link segment	4677
113.12.8 Characteristics of the direct attach cable assembly	4678
113.12.9 MDI requirements.....	4678
113.12.10 General safety and environmental requirements	4679
113.12.11 Timing requirements	4679
114. Physical Medium Dependent (PMD) sublayer and medium, types 25GBASE-LR and 25GBASE-ER.....	4680
114.1 Overview.....	4680
114.1.1 Bit error ratio	4681
114.2 Physical Medium Dependent (PMD) service interface	4681
114.3 Delay constraints.....	4681
114.4 PMD MDIO function mapping.....	4682
114.5 PMD functional specifications.....	4682
114.5.1 PMD block diagram.....	4682
114.5.2 PMD transmit function	4683
114.5.3 PMD receive function	4683
114.5.4 PMD global signal detect function	4683
114.5.5 PMD reset function	4684
114.5.6 PMD global transmit disable function (optional)	4684
114.5.7 PMD fault function (optional)	4684
114.5.8 PMD transmit fault function (optional)	4684
114.5.9 PMD receive fault function (optional).....	4684
114.6 PMD to MDI optical specifications for 25GBASE-LR and 25GBASE-ER	4685
114.6.1 25GBASE-LR and 25GBASE-ER transmitter optical specifications	4686
114.6.2 25GBASE-LR and 25GBASE-ER receive optical specifications	4687
114.6.3 25GBASE-LR and 25GBASE-ER illustrative link power budgets.....	4688
114.7 Definition of optical parameters and measurement methods.....	4688
114.7.1 Test patterns for optical parameters.....	4688
114.7.2 Wavelength and side mode suppression ratio (SMSR)	4688
114.7.3 Average optical power	4689
114.7.4 Optical Modulation Amplitude (OMA).....	4689
114.7.5 Transmitter and dispersion penalty (TDP).....	4689
114.7.6 Extinction ratio	4690
114.7.7 Relative Intensity Noise (RIN _{20OMA}).....	4690
114.7.8 Transmitter optical waveform (transmit eye)	4690

114.7.9 Receiver sensitivity	4691
114.7.10 Stressed receiver sensitivity	4691
114.8 Safety, installation, environment, and labeling	4691
114.9 Fiber optic cabling model	4691
114.10 Characteristics of the fiber optic cabling (channel)	4692
114.11 Requirements for interoperation between 25GBASE-LR and 25GBASE-ER	4693
114.12 Protocol implementation conformance statement (PICS) proforma for Clause 114, Physical Medium Dependent (PMD) sublayer and medium, types 25GBASE-LR and 25GBASE-ER	4694
114.12.1 Introduction	4694
114.12.2 Identification	4694
114.12.3 Major capabilities/options	4695
114.12.4 PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, types 25GBASE-LR and 25GBASE-ER	4696
115. Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer, and Physical Medium Dependent (PMD) sublayer, types 1000BASE-RHA, 1000BASE-RHB, and 1000BASE- RHC	4699
115.1 Overview	4699
115.1.1 Features	4699
115.1.2 Conventions	4699
115.1.3 Relationship of 1000BASE-RHx to other standards	4699
115.1.4 Relationship to other Gigabit Ethernet PHY types	4700
115.1.5 Operation of 1000BASE-RHx	4700
115.1.6 Functional block diagram	4702
115.2 Physical Coding Sublayer (PCS)	4703
115.2.1 Transmit Block	4703
115.2.2 Pilots data path	4705
115.2.3 Physical header encoding and scrambling	4707
115.2.4 Payload data encoding and scrambling	4709
115.2.5 PCS receive function	4719
115.3 Physical Medium Attachment (PMA) sublayer	4721
115.3.1 PMA transmit function	4721
115.3.2 PMA receive function	4722
115.3.3 Interface to the PMD	4723
115.3.4 Physical Header Data (PHD)	4724
115.3.5 PHY control	4727
115.3.6 Adaptive THP protocol	4734
115.3.7 PHY quality monitor	4738
115.3.8 Fixed-point format formal definition	4742
115.4 Energy-Efficient Ethernet (EEE)	4742
115.4.1 LPI mode transmit operation	4744
115.4.2 LPI mode receive operation	4744
115.4.3 PMD power control state variables	4745
115.4.4 PMD power control state diagrams	4745
115.5 Test modes	4747
115.5.1 Test mode 1	4748
115.5.2 Test mode 2	4748
115.5.3 Test mode 3	4748
115.5.4 Test mode 4	4748
115.5.5 Test mode 5	4748
115.5.6 Test mode 6	4748
115.6 Physical Medium Dependent (PMD) sublayer	4750

115.6.1	PMD service interface	4750
115.6.2	PMD functional specifications.....	4753
115.6.3	PMD to MDI optical specifications	4755
115.6.4	Optical measurement requirements	4759
115.7	Characteristics of the fiber optic cabling (channel).....	4765
115.7.1	Transfer function of fiber optic channel type I	4767
115.7.2	Transfer function of fiber optic channel type II.....	4768
115.7.3	Transfer function of fiber optic channel type III	4769
115.7.4	Fiber optic channel insertion loss measurement	4770
115.7.5	Fiber optic channel transfer function measurement.....	4770
115.7.6	Worst-case 1000BASE-RHx link power budget	4770
115.8	Medium Dependent Interface (MDI).....	4770
115.8.1	MDI mechanical interface for 1000BASE-RHA.....	4770
115.9	1000BASE-H Operations, Administration, and Maintenance (1000BASE-H OAM) channel	4772
115.9.1	1000BASE-H OAM message transmission protocol.....	4772
115.9.2	1000BASE-H OAM channel status	4773
115.9.3	1000BASE-H OAM message reception protocol	4774
115.9.4	1000BASE-H OAM channel state diagrams descriptions	4775
115.10	Loopback modes	4780
115.11	Management interface.....	4780
115.12	Environmental specifications.....	4780
115.12.1	Temperature classes	4780
115.12.2	General safety	4781
115.12.3	Environmental safety	4781
115.12.4	Electromagnetic compatibility.....	4782
115.12.5	Optical safety	4782
115.13	Delay constraints.....	4782
115.14	Protocol implementation conformance statement (PICS) proforma for Clause 115, Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer, and Physical Medium Dependent (PMD) sublayer, types 1000BASE-RHA, 1000BASE-RHB, and 1000BASE-RHC.....	4783
115.14.1	Introduction	4783
115.14.2	Identification.....	4783
115.14.3	Major capabilities/options	4784
115.14.4	Physical Coding Sublayer (PCS).....	4785
115.14.5	Physical Medium Attachment (PMA)	4787
115.14.6	Energy-Efficient Ethernet (EEE).....	4789
115.14.7	Test modes	4790
115.14.8	Physical Medium Dependent (PMD)	4791
115.14.9	PMD to MDI optical specifications	4792
115.14.10	Optical measurement requirements	4793
115.14.11	Characteristics of the fiber optic cabling (channel).....	4794
115.14.12	Medium dependent interface (MDI).....	4794
115.14.13	1000BASE-H Operations, Administration, and Maintenance (1000BASE-H OAM) channel	4795
115.14.14	Loopback modes.....	4796
115.14.15	Management Interface	4796
115.14.16	Environmental specifications	4796
115.14.17	Delay constraints	4797
116.	Introduction to 200 Gb/s and 400 Gb/s networks	4798
116.1	Overview.....	4798

116.1.1	Scope.....	4798
116.1.2	Relationship of 200 Gigabit and 400 Gigabit Ethernet to the ISO OSI reference model	4798
116.1.3	Nomenclature.....	4799
116.1.4	Physical Layer signaling systems	4801
116.2	Summary of 200 Gigabit and 400 Gigabit Ethernet sublayers	4802
116.2.1	Reconciliation Sublayer (RS) and Media Independent Interface	4802
116.2.2	200GMII and 400GMII Extender Sublayers (200GXS and 400GXS).....	4802
116.2.3	Physical Coding Sublayer (PCS)	4803
116.2.4	Physical Medium Attachment (PMA) sublayer.....	4803
116.2.5	Physical Medium Dependent (PMD) sublayer	4803
116.2.6	Management interface (MDIO/MDC)	4803
116.2.7	Management.....	4803
116.3	Service interface specification method and notation	4803
116.3.1	Inter-sublayer service interface.....	4804
116.3.2	Instances of the Inter-sublayer service interface.....	4804
116.3.3	Semantics of inter-sublayer service interface primitives.....	4804
116.4	Delay constraints.....	4807
116.5	Skew constraints	4809
116.6	FEC Degrade.....	4813
116.7	State diagrams.....	4814
116.8	Protocol implementation conformance statement (PICS) proforma.....	4815
117.	Reconciliation Sublayer (RS) and Media Independent Interface for 200 Gb/s and 400 Gb/s operation (200GMII and 400GMII).....	4816
117.1	Overview.....	4816
117.1.1	Summary of major concepts	4817
117.1.2	Application.....	4817
117.1.3	Rate of operation.....	4817
117.1.4	Delay constraints.....	4817
117.1.5	Allocation of functions	4818
117.1.6	200GMII/400GMII structure	4818
117.1.7	Mapping of 200GMII/400GMII signals to PLS service primitives.....	4818
117.2	200GMII/400GMII data stream.....	4818
117.3	200GMII/400GMII functional specifications	4818
117.4	LPI Assertion and Detection.....	4818
117.5	Protocol implementation conformance statement (PICS) proforma for Clause 117, Reconciliation Sublayer (RS) and Media Independent Interface for 200 Gb/s and 400 Gb/s operation (200GMII and 400GMII).....	4819
117.5.1	Introduction.....	4819
117.5.2	Identification.....	4819
117.5.3	Major capabilities/options.....	4820
117.5.4	PICS proforma tables for Reconciliation Sublayer (RS) and Media Independent Interface for 200 Gb/s and 400 Gb/s operation (200GMII and 400GMII).....	4820
118.	200GMII Extender, 400GMII Extender, 200GMII Extender Sublayer (200GXS), and 400GMII Extender Sublayer (400GXS).....	4823
118.1	Overview.....	4823
118.1.1	Summary of major concepts	4824
118.1.2	200GXS/400GXS Sublayer.....	4824
118.1.3	200GAUI-n/400GAUI-n.....	4824
118.2	FEC Degrade.....	4824

118.2.1 DTE XS FEC Degrade signaling	4824
118.2.2 PHY XS FEC Degrade signaling	4825
118.3 200GXS and 400GXS partitioning example	4825
118.4 200GXS and 400GXS MDIO function mapping.....	4825
118.5 Protocol implementation conformance statement (PICS) proforma for Clause 118, 200GMII Extender, 400GMII Extender, 200GMII Extender Sublayer (200GXS), and 400GMII Extender Sublayer (400GXS)	4829
118.5.1 Introduction.....	4829
118.5.2 Identification.....	4829
118.5.3 Major capabilities/options.....	4830
118.5.4 PICS proforma tables for 200GMII Extender, 400GMII Extender, 200GMII Extender Sublayer (200GXS), and 400GMII Extender Sublayer (400GXS)	4830
118.5.5 Test-pattern modes.....	4832
118.5.6 Bit order	4832
118.5.7 Management.....	4833
119. Physical Coding Sublayer (PCS) for 64B/66B, type 200GBASE-R and 400GBASE-R	4835
119.1 Overview.....	4835
119.1.1 Scope.....	4835
119.1.2 Relationship of 200GBASE-R and 400GBASE-R to other standards	4835
119.1.3 Physical Coding Sublayer (PCS)	4835
119.1.4 Inter-sublayer interfaces	4836
119.1.5 Functional block diagram	4837
119.2 Physical Coding Sublayer (PCS)	4838
119.2.1 Functions within the PCS	4838
119.2.2 Use of blocks	4838
119.2.3 64B/66B code	4839
119.2.4 Transmit	4840
119.2.5 Receive function	4853
119.2.6 Detailed functions and state diagrams	4856
119.3 PCS management.....	4865
119.3.1 PCS MDIO function mapping	4865
119.3.2 FEC_corrected_cw_counter.....	4866
119.3.3 FEC_uncorrected_cw_counter.....	4866
119.3.4 FEC_symbol_error_counter_i	4866
119.4 Loopback	4866
119.5 Delay constraints.....	4867
119.6 Auto-Negotiation	4867
119.7 Protocol implementation conformance statement (PICS) proforma for Clause 119, Physical Coding Sublayer (PCS) for 64B/66B, type 200GBASE-R and 400GBASE-R.....	4868
119.7.1 Introduction.....	4868
119.7.2 Identification.....	4868
119.7.3 Major capabilities/options.....	4869
119.7.4 PICS proforma tables for Physical Coding Sublayer (PCS) 64B/66B, type 200GBASE-R and 400GBASE-R.....	4869
120. Physical Medium Attachment (PMA) sublayer, type 200GBASE-R and 400GBASE-R.....	4874
120.1 Overview.....	4874
120.1.1 Scope.....	4874
120.1.2 Position of the PMA in the 200GBASE-R and 400GBASE-R sublayers	4874
120.1.3 Summary of functions.....	4874
120.1.4 PMA sublayer positioning	4875

120.2	PMA interfaces	4877
120.3	PMA service interface	4877
120.4	Service interface below PMA	4880
120.5	Functions within the PMA	4881
120.5.1	Per input-lane clock and data recovery	4881
120.5.2	Bit-level multiplexing	4881
120.5.3	Skew and Skew Variation	4882
120.5.4	Delay constraints	4884
120.5.5	Clocking architecture	4884
120.5.6	Signal drivers	4885
120.5.7	PAM4 Encoding	4885
120.5.8	Link status	4886
120.5.9	PMA local loopback mode (optional)	4886
120.5.10	PMA remote loopback mode (optional)	4887
120.5.11	PMA test patterns (optional)	4887
120.6	PMA MDIO function mapping	4893
120.7	Protocol implementation conformance statement (PICS) proforma for Clause 120, Physical Medium Attachment (PMA) sublayer, type 200GBASE-R and 400GBASE-R	4898
120.7.1	Introduction	4898
120.7.2	Identification	4898
120.7.3	Major capabilities/options	4899
120.7.4	Skew generation and tolerance	4901
120.7.5	Test patterns	4901
120.7.6	Loopback modes	4902
120.7.7	Encoding	4903
121.	Physical Medium Dependent (PMD) sublayer and medium, type 200GBASE-DR4	4904
121.1	Overview	4904
121.1.1	Bit error ratio	4904
121.2	Physical Medium Dependent (PMD) service interface	4905
121.3	Delay and Skew	4906
121.3.1	Delay constraints	4906
121.3.2	Skew constraints	4906
121.4	PMD MDIO function mapping	4907
121.5	PMD functional specifications	4907
121.5.1	PMD block diagram	4907
121.5.2	PMD transmit function	4908
121.5.3	PMD receive function	4908
121.5.4	PMD global signal detect function	4908
121.5.5	PMD lane-by-lane signal detect function	4909
121.5.6	PMD reset function	4909
121.5.7	PMD global transmit disable function (optional)	4909
121.5.8	PMD lane-by-lane transmit disable function (optional)	4910
121.5.9	PMD fault function (optional)	4910
121.5.10	PMD transmit fault function (optional)	4910
121.5.11	PMD receive fault function (optional)	4910
121.6	Lane assignments	4910
121.7	PMD to MDI optical specifications for 200GBASE-DR4	4910
121.7.1	200GBASE-DR4 transmitter optical specifications	4911
121.7.2	200GBASE-DR4 receive optical specifications	4911
121.7.3	200GBASE-DR4 illustrative link power budget	4912
121.8	Definition of optical parameters and measurement methods	4913
121.8.1	Test patterns for optical parameters	4913

121.8.2	Wavelength and side mode suppression ratio (SMSR)	4914
121.8.3	Average optical power	4914
121.8.4	Outer Optical Modulation Amplitude (OMA _{outer})	4914
121.8.5	Transmitter and dispersion eye closure for PAM4 (TDECQ)	4914
121.8.6	Extinction ratio	4920
121.8.7	Transmitter transition time	4920
121.8.8	Relative intensity noise (RIN _{21.4OMA})	4920
121.8.9	Receiver sensitivity	4921
121.8.10	Stressed receiver sensitivity	4921
121.9	Safety, installation, environment, and labeling	4925
121.9.1	General safety	4925
121.9.2	Laser safety	4925
121.9.3	Installation	4925
121.9.4	Environment	4925
121.9.5	Electromagnetic emission	4925
121.9.6	Temperature, humidity, and handling	4925
121.9.7	PMD labeling requirements	4926
121.10	Fiber optic cabling model	4926
121.11	Characteristics of the fiber optic cabling (channel)	4927
121.11.1	Optical fiber cable	4927
121.11.2	Optical fiber connection	4927
121.11.3	Medium Dependent Interface (MDI)	4927
121.12	Protocol implementation conformance statement (PICS) proforma for Clause 121, Physical Medium Dependent (PMD) sublayer and medium, type 200GBASE-DR4	4930
121.12.1	Introduction	4930
121.12.2	Identification	4930
121.12.3	Major capabilities/options	4931
121.12.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 200GBASE-DR4	4931
122.	Physical Medium Dependent (PMD) sublayer and medium, type 200GBASE-FR4, 200GBASE- LR4, 200GBASE-ER4, 400GBASE-FR8, 400GBASE-LR8, and 400GBASE-ER8	4934
122.1	Overview	4934
122.1.1	Bit error ratio	4935
122.2	Physical Medium Dependent (PMD) service interface	4936
122.3	Delay and Skew	4936
122.3.1	Delay constraints	4936
122.3.2	Skew constraints	4937
122.4	PMD MDIO function mapping	4937
122.5	PMD functional specifications	4937
122.5.1	PMD block diagram	4937
122.5.2	PMD transmit function	4939
122.5.3	PMD receive function	4939
122.5.4	PMD global signal detect function	4939
122.5.5	PMD lane-by-lane signal detect function	4940
122.5.6	PMD reset function	4940
122.5.7	PMD global transmit disable function (optional)	4940
122.5.8	PMD lane-by-lane transmit disable function	4940
122.5.9	PMD fault function (optional)	4940
122.5.10	PMD transmit fault function (optional)	4940
122.5.11	PMD receive fault function (optional)	4941
122.6	Wavelength-division-multiplexed lane assignments	4941

122.7	PMD to MDI optical specifications for 200GBASE-FR4, 200GBASE-LR4, 200GBASE-ER4, 400GBASE-FR8, 400GBASE-LR8, and 400GBASE-ER8.....	4942
122.7.1	200GBASE-FR4, 200GBASE-LR4, 200GBASE-ER4, 400GBASE-FR8, 400GBASE-LR8, and 400GBASE-ER8 transmitter optical specifications	4943
122.7.2	200GBASE-FR4, 200GBASE-LR4, 200GBASE-ER4, 400GBASE-FR8, 400GBASE-LR8, and 400GBASE-ER8 receive optical specifications	4946
122.7.3	200GBASE-FR4, 200GBASE-LR4, 200GBASE-ER4, 400GBASE-FR8, 400GBASE-LR8, and 400GBASE-ER8 illustrative link power budgets.....	4948
122.8	Definition of optical parameters and measurement methods.....	4948
122.8.1	Test patterns for optical parameters.....	4948
122.8.2	Wavelength and side mode suppression ratio (SMSR)	4949
122.8.3	Average optical power	4949
122.8.4	Outer Optical Modulation Amplitude (OMA _{outer}).....	4950
122.8.5	Transmitter and dispersion eye closure for PAM4 (TDECQ)	4950
122.8.6	Extinction ratio	4952
122.8.7	Transmitter transition time.....	4953
122.8.8	Relative intensity noise (RIN _{17.1OMA} , RIN _{15.6OMA} , and RIN _{15OMA}).....	4953
122.8.9	Receiver sensitivity	4953
122.8.10	Stressed receiver sensitivity	4955
122.9	Safety, installation, environment, and labeling.....	4957
122.9.1	General safety	4957
122.9.2	Laser safety	4957
122.9.3	Installation	4958
122.9.4	Environment.....	4958
122.9.5	Electromagnetic emission	4958
122.9.6	Temperature, humidity, and handling	4958
122.9.7	PMD labeling requirements.....	4958
122.10	Fiber optic cabling model	4958
122.11	Characteristics of the fiber optic cabling (channel)	4959
122.11.1	Optical fiber cable.....	4959
122.11.2	Optical fiber connection.....	4959
122.11.3	Medium Dependent Interface (MDI) requirements	4961
122.12	Requirements for interoperation between 200GBASE-ER4 and 200GBASE-LR4	4961
122.13	Requirements for interoperation between 400GBASE-ER8 and 400GBASE-FR8	4961
122.14	Requirements for interoperation between 400GBASE-ER8 and 400GBASE-LR8	4962
122.15	Protocol implementation conformance statement (PICS) proforma for Clause 122, Physical Medium Dependent (PMD) sublayer and medium, type 200GBASE-FR4, 200GBASE-LR4, 200GBASE-ER4, 400GBASE-FR8, 400GBASE-LR8, and 400GBASE-ER8.....	4963
122.15.1	Introduction.....	4963
122.15.2	Identification.....	4963
122.15.3	Major capabilities/options.....	4964
122.15.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 200GBASE-FR4, 200GBASE-LR4, 200GBASE-ER4, 400GBASE-FR8, 400GBASE-LR8, and 400GBASE-ER8	4965
123.	Physical Medium Dependent (PMD) sublayer and medium, type 400GBASE-SR16	4969
123.1	Overview.....	4969
123.1.1	Bit error ratio	4970
123.2	Physical Medium Dependent (PMD) service interface	4970
123.3	Delay and Skew	4971
123.3.1	Delay constraints.....	4971
123.3.2	Skew constraints	4971
123.4	PMD MDIO function mapping.....	4972

123.5	PMD functional specifications.....	4972
123.5.1	PMD block diagram.....	4972
123.5.2	PMD transmit function	4973
123.5.3	PMD receive function.....	4973
123.5.4	PMD global signal detect function	4974
123.5.5	PMD lane-by-lane signal detect function	4974
123.5.6	PMD reset function.....	4974
123.5.7	PMD global transmit disable function (optional)	4975
123.5.8	PMD lane-by-lane transmit disable function (optional)	4975
123.5.9	PMD fault function (optional)	4975
123.5.10	PMD transmit fault function (optional)	4975
123.5.11	PMD receive fault function (optional).....	4975
123.6	Lane assignments.....	4975
123.7	PMD to MDI optical specifications for 400GBASE-SR16	4976
123.7.1	400GBASE-SR16 transmitter optical specifications	4976
123.7.2	400GBASE-SR16 receive optical specifications.....	4976
123.7.3	400GBASE-SR16 illustrative link power budget.....	4976
123.8	Definition of optical parameters and measurement methods.....	4976
123.8.1	Test patterns for optical parameters.....	4976
123.8.2	Center wavelength and spectral width.....	4977
123.8.3	Average optical power.....	4977
123.8.4	Optical Modulation Amplitude (OMA).....	4977
123.8.5	Transmitter and dispersion eye closure (TDEC)	4977
123.8.6	Extinction ratio	4977
123.8.7	Transmitter optical waveform (transmit eye)	4977
123.8.8	Stressed receiver sensitivity.....	4977
123.9	Safety, installation, environment, and labeling.....	4978
123.9.1	General safety	4978
123.9.2	Laser safety	4978
123.9.3	Installation	4978
123.9.4	Environment.....	4978
123.9.5	Electromagnetic emission	4978
123.9.6	Temperature, humidity, and handling.....	4978
123.9.7	PMD labeling requirements.....	4979
123.10	Fiber optic cabling model	4979
123.11	Characteristics of the fiber optic cabling (channel)	4979
123.11.1	Optical fiber cable.....	4980
123.11.2	Optical fiber connection.....	4980
123.11.3	Medium Dependent Interface (MDI).....	4980
123.12	Protocol implementation conformance statement (PICS) proforma for Clause 123, Physical Medium Dependent (PMD) sublayer and medium, type 400GBASE-SR16.....	4982
123.12.1	Introduction.....	4982
123.12.2	Identification.....	4982
123.12.3	Major capabilities/options.....	4983
123.12.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 400GBASE-SR16.....	4983
124.	Physical Medium Dependent (PMD) sublayer and medium, type 400GBASE-DR4	4987
124.1	Overview.....	4987
124.1.1	Bit error ratio	4987
124.2	Physical Medium Dependent (PMD) service interface	4988
124.3	Delay and Skew	4989
124.3.1	Delay constraints.....	4989

124.3.2 Skew constraints	4989
124.4 PMD MDIO function mapping.....	4989
124.5 PMD functional specifications.....	4990
124.5.1 PMD block diagram.....	4990
124.5.2 PMD transmit function	4991
124.5.3 PMD receive function	4991
124.5.4 PMD global signal detect function	4991
124.5.5 PMD lane-by-lane signal detect function	4992
124.5.6 PMD reset function.....	4992
124.5.7 PMD global transmit disable function (optional)	4992
124.5.8 PMD lane-by-lane transmit disable function (optional)	4993
124.5.9 PMD fault function (optional)	4993
124.5.10 PMD transmit fault function (optional)	4993
124.5.11 PMD receive fault function (optional).....	4993
124.6 Lane assignments	4993
124.7 PMD to MDI optical specifications for 400GBASE-DR4	4993
124.7.1 400GBASE-DR4 transmitter optical specifications	4994
124.7.2 400GBASE-DR4 receive optical specifications	4994
124.7.3 400GBASE-DR4 illustrative link power budget	4995
124.8 Definition of optical parameters and measurement methods.....	4996
124.8.1 Test patterns for optical parameters.....	4996
124.8.2 Wavelength and side mode suppression ratio (SMSR)	4997
124.8.3 Average optical power.....	4997
124.8.4 Outer Optical Modulation Amplitude (OMA _{outer}).....	4997
124.8.5 Transmitter and dispersion eye closure for PAM4 (TDECQ)	4997
124.8.6 Extinction ratio	4997
124.8.7 Transmitter transition time.....	4998
124.8.8 Relative intensity noise (RIN _{21.4OMA})	4998
124.8.9 Receiver sensitivity.....	4998
124.8.10 Stressed receiver sensitivity.....	4999
124.9 Safety, installation, environment, and labeling.....	4999
124.9.1 General safety	4999
124.9.2 Laser safety	5000
124.9.3 Installation	5000
124.9.4 Environment.....	5000
124.9.5 Electromagnetic emission	5001
124.9.6 Temperature, humidity, and handling.....	5001
124.9.7 PMD labeling requirements.....	5001
124.10 Fiber optic cabling model	5001
124.11 Characteristics of the fiber optic cabling (channel)	5001
124.11.1 Optical fiber cable.....	5001
124.11.2 Optical fiber connection.....	5002
124.11.3 Medium Dependent Interface (MDI).....	5003
124.12 Protocol implementation conformance statement (PICS) proforma for Clause 124, Physical Medium Dependent (PMD) sublayer and medium, type 400GBASE-DR4	5005
124.12.1 Introduction.....	5005
124.12.2 Identification.....	5005
124.12.3 Major capabilities/options.....	5006
124.12.4 PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 400GBASE-DR4	5006
125. Introduction to 2.5 Gb/s and 5 Gb/s networks	5009
125.1 Overview.....	5009

125.1.1	Scope.....	5009
125.1.2	Relationship of 2.5 Gigabit and 5 Gigabit Ethernet to the ISO OSI reference model....	5009
125.1.3	Nomenclature.....	5009
125.1.4	Physical Layer signaling systems	5011
125.2	Summary of 2.5 Gigabit and 5 Gigabit Ethernet sublayers	5012
125.2.1	Reconciliation Sublayer (RS) and Media Independent Interface	5012
125.2.2	Physical Coding Sublayer (PCS)	5012
125.2.3	Physical Medium Attachment sublayer (PMA).....	5013
125.2.4	Auto-Negotiation	5013
125.2.5	Management interface (MDIO/MDC)	5013
125.2.6	Management.....	5013
125.3	Delay Constraints.....	5014
126.	Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer, and baseband medium, types 2.5GBASE-T and 5GBASE-T	5015
126.1	Overview.....	5015
126.1.1	Nomenclature.....	5015
126.1.2	Relationship of 2.5GBASE-T and 5GBASE-T to other standards.....	5015
126.1.3	Operation of 2.5GBASE-T and 5GBASE-T.....	5016
126.1.4	Signaling	5022
126.1.5	Interfaces.....	5022
126.1.6	Conventions in this clause	5023
126.2	2.5GBASE-T and 5GBASE-T service primitives and interfaces	5023
126.2.1	Technology Dependent Interface	5023
126.2.2	PMA service interface	5024
126.3	Physical Coding Sublayer (PCS)	5032
126.3.1	PCS service interface (XGMII)	5032
126.3.2	PCS functions	5032
126.3.3	Test-pattern generators	5047
126.3.4	PMA training side-stream scrambler polynomials	5047
126.3.5	LPI signaling.....	5049
126.3.6	Detailed functions and state diagrams	5051
126.3.7	PCS management	5057
126.4	Physical Medium Attachment (PMA) sublayer.....	5065
126.4.1	PMA functional specifications.....	5065
126.4.2	PMA functions.....	5066
126.4.3	MDI.....	5079
126.4.4	Automatic MDI/MDI-X configuration	5081
126.4.5	State variables	5082
126.4.6	State diagrams.....	5087
126.5	PMA electrical specifications	5092
126.5.1	Electrical isolation	5092
126.5.2	Test modes	5092
126.5.3	Transmitter electrical specifications	5096
126.5.4	Receiver electrical specifications.....	5099
126.6	Management interfaces	5101
126.6.1	Support for Auto-Negotiation.....	5101
126.6.2	MASTER-SLAVE configuration resolution	5104
126.7	Link segment characteristics.....	5106
126.7.1	Cabling system characteristics.....	5107
126.7.2	Link segment transmission parameters.....	5107
126.7.3	Coupling parameters between link segments.....	5112
126.8	MDI specification	5118

126.8.1 MDI connectors	5118
126.8.2 MDI electrical specifications	5119
126.9 Environmental specifications	5120
126.9.1 General safety	5120
126.9.2 Network safety	5121
126.9.3 Installation and maintenance guidelines	5121
126.9.4 Telephone voltages	5121
126.9.5 Electromagnetic compatibility	5121
126.9.6 Temperature and humidity	5122
126.10 PHY labeling	5122
126.11 Delay constraints	5122
126.12 Protocol implementation conformance statement (PICS) proforma for Clause 126— Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer, and baseband medium, types 2.5GBASE-T and 5GBASE-T	5123
126.12.1 Identification	5123
126.12.2 Major capabilities/options	5124
126.12.3 Physical Coding Sublayer (PCS)	5124
126.12.4 Physical Medium Attachment (PMA)	5127
126.12.5 PMA Electrical Specifications	5129
126.12.6 PMA Management Interface	5130
126.12.7 Characteristics of the link segment	5131
126.12.8 MDI requirements	5132
126.12.9 General safety and environmental requirements	5133
126.12.10 Timing requirements	5133
127. Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA) sublayer for 2.5 Gb/s 8B/10B 2.5GBASE-X	5134
127.1 Overview	5134
127.1.1 Scope	5134
127.1.2 Relationship of 2.5GBASE-X to other standards	5134
127.1.3 Summary of 2.5GBASE-X sublayers	5134
127.1.4 Inter-sublayer interfaces	5135
127.1.5 Functional block diagram	5136
127.2 Physical Coding Sublayer (PCS)	5136
127.2.1 PCS Interface (XGMII)	5136
127.2.2 Functions within the PCS	5137
127.2.3 PCS used with 2.5GBASE-KX PMD	5137
127.2.4 Use of code-groups	5138
127.2.5 XGMII to 2.5GPII mapping	5138
127.2.6 8B/10B transmission code	5142
127.2.7 Detailed functions and state diagrams	5146
127.3 Physical Medium Attachment (PMA) sublayer	5167
127.3.1 Service Interface	5167
127.3.2 Functions within the PMA	5168
127.3.3 Loopback mode	5169
127.3.4 Test functions	5169
127.4 Compatibility considerations	5170
127.5 Delay constraints	5170
127.6 Environmental specifications	5170
127.7 Protocol implementation conformance statement (PICS) proforma for Clause 127, Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA) sublayer for 2.5 Gb/s 8B/10B 2.5GBASE-X	5171
127.7.1 Introduction	5171

127.7.2	Identification	5171
127.7.3	Major capabilities/options.....	5172
127.7.4	PICS proforma tables for the PCS and PMA sublayer, type 2.5GBASE-X.....	5172
128.	Physical Medium Dependent sublayer and baseband medium, type 2.5GBASE-KX.....	5175
128.1	Overview.....	5175
128.2	Physical Medium Dependent (PMD) service interface	5175
128.2.1	PMD_UNITDATA.request.....	5176
128.2.2	PMD_UNITDATA.indication	5176
128.2.3	PMD_SIGNAL.indication	5176
128.2.4	PMD_RXQUIET.request.....	5177
128.2.5	PMD_TXQUIET.request.....	5177
128.3	PCS requirements for Auto-Negotiation (AN) service interface.....	5178
128.4	Delay constraints.....	5178
128.5	PMD MDIO function mapping.....	5178
128.6	PMD functional specifications.....	5179
128.6.1	Link block diagram	5179
128.6.2	PMD transmit function	5180
128.6.3	PMD receive function	5180
128.6.4	PMD signal detect function	5180
128.6.5	PMD transmit disable function.....	5180
128.6.6	Loopback mode.....	5180
128.6.7	PMD fault function	5181
128.6.8	PMD transmit fault function	5181
128.6.9	PMD receive fault function.....	5181
128.6.10	PMD LPI function	5181
128.7	2.5GBASE-KX electrical characteristics.....	5182
128.7.1	Transmitter characteristics	5182
128.7.2	Receiver characteristics	5186
128.8	Interconnect characteristics.....	5187
128.9	Environmental specifications.....	5187
128.9.1	General safety	5187
128.9.2	Network safety	5187
128.9.3	Installation and maintenance guidelines	5187
128.9.4	Electromagnetic compatibility	5187
128.9.5	Temperature and humidity	5187
128.10	Protocol implementation conformance statement (PICS) proforma for Clause 128, Physical Medium Dependent sublayer and baseband medium, type 2.5GBASE-KX	5188
128.10.1	Introduction.....	5188
128.10.2	Identification.....	5188
128.10.3	Major capabilities/options.....	5189
128.10.4	PICS proforma tables for Clause 128, Physical Medium Dependent (PMD) sublayer and baseband medium, type 2.5GBASE-KX.	5189
129.	Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA) sublayer for 5 Gb/s 64B/66B, type 5GBASE-R	5193
129.1	Overview.....	5193
129.1.1	Scope.....	5193
129.1.2	Relationship of 5GBASE-R to other standards	5193
129.1.3	Summary of 5GBASE-R sublayers	5194
129.1.4	Inter-sublayer interfaces	5195
129.2	Physical Coding Sublayer (PCS).....	5195

129.2.1 Functions within the PCS	5195
129.2.2 Notation conventions	5196
129.2.3 Transmission order	5196
129.2.4 Low Power Idle	5197
129.2.5 PCS used with 5GBASE-KR PMD	5198
129.3 Physical Medium Attachment (PMA) sublayer	5198
129.3.1 Service Interface	5198
129.3.2 Functions within the PMA	5198
129.3.3 PMA loopback mode (optional)	5199
129.4 Compatibility considerations	5199
129.5 Delay constraints	5199
129.6 Environmental specifications	5199
129.7 Protocol implementation conformance statement (PICS) proforma for Clause 129, Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA) sublayer for 5 Gb/s 64B/66B, type 5GBASE-R	5200
129.7.1 Introduction	5200
129.7.2 Identification	5200
129.7.3 Major capabilities/options	5201
129.7.4 PICS Proforma Tables for PCS, type 5GBASE-R	5201
129.7.5 Test-pattern modes	5202
129.7.6 Management	5202
130. Physical Medium Dependent sublayer and baseband medium, type 5GBASE-KR	5205
130.1 Overview	5205
130.2 Physical Medium Dependent (PMD) service interface	5205
130.2.1 PMD_UNITDATA.request	5206
130.2.2 PMD_UNITDATA.indication	5206
130.2.3 PMD_SIGNAL.indication	5206
130.2.4 PMD_RX_MODE.request	5207
130.2.5 PMD_TX_MODE.request	5207
130.3 PCS requirements for Auto-Negotiation (AN) service interface	5208
130.4 Delay constraints	5208
130.5 PMD MDIO function mapping	5208
130.6 PMD functional specifications	5209
130.6.1 Link block diagram	5209
130.6.2 PMD transmit function	5209
130.6.3 PMD receive function	5209
130.6.4 PMD signal detect function	5209
130.6.5 PMD transmit disable function	5210
130.6.6 Loopback mode	5210
130.6.7 PMD_fault function	5211
130.6.8 PMD transmit fault function	5211
130.6.9 PMD receive fault function	5211
130.6.10 PMD LPI function	5211
130.7 5GBASE-KR electrical characteristics	5212
130.7.1 Transmitter characteristics	5212
130.7.2 Receiver characteristics	5217
130.8 Interconnect characteristics	5219
130.9 Environmental specifications	5219
130.9.1 General safety	5219
130.9.2 Network safety	5219
130.9.3 Installation and maintenance guidelines	5219
130.9.4 Electromagnetic compatibility	5219

130.9.5 Temperature and humidity	5219
130.10 Protocol implementation conformance statement (PICS) proforma for Clause 130, Physical Medium Dependent (PMD) sublayer and baseband medium, type 5GBASE-KR	5220
130.10.1 Introduction	5220
130.10.2 Identification	5220
130.10.3 Major capabilities/options	5221
130.10.4 PICS proforma tables for Clause 130, Physical Medium Dependent (PMD) sublayer and baseband medium, type 5GBASE-KR	5221
131. Introduction to 50 Gb/s networks	5225
131.1 Overview	5225
131.1.1 Scope	5225
131.1.2 Relationship of 50 Gigabit Ethernet to the ISO OSI reference model	5225
131.1.3 Nomenclature	5226
131.1.4 Physical Layer signaling systems	5227
131.2 Summary of 50 Gigabit Ethernet sublayers	5228
131.2.1 Reconciliation Sublayer (RS) and Media Independent Interface (50GMII)	5228
131.2.2 Physical Coding Sublayer (PCS)	5228
131.2.3 Forward error correction (FEC) sublayer	5228
131.2.4 Physical Medium Attachment (PMA) sublayer	5228
131.2.5 Physical Medium Dependent (PMD) sublayer	5228
131.2.6 Management interface (MDIO/MDC)	5228
131.2.7 Management	5229
131.3 Service interface specification method and notation	5229
131.3.1 Inter-sublayer service interface	5229
131.3.2 Instances of the inter-sublayer service interface	5229
131.3.3 Semantics of inter-sublayer service interface primitives	5229
131.4 Delay constraints	5231
131.5 Skew constraints	5232
131.6 State diagrams	5234
131.7 Protocol implementation conformance statement (PICS) proforma	5234
132. Reconciliation Sublayer (RS) and Media Independent Interface (50GMII) for 50 Gb/s operation .	5235
132.1 Overview	5235
132.1.1 Summary of major concepts	5235
132.1.2 Application	5235
132.1.3 Rate of operation	5235
132.1.4 Delay constraints	5236
132.1.5 Allocation of functions	5237
132.1.6 50GMII structure	5237
132.1.7 Mapping of 50GMII signals to PLS service primitives	5237
132.2 50GMII data stream	5237
132.3 50GMII functional specifications	5237
132.4 LPI assertion and detection	5237
132.5 Protocol implementation conformance statement (PICS) proforma for Clause 132, Reconciliation Sublayer (RS) and Media Independent Interface (50GMII) for 50 Gb/s operation	5238
132.5.1 Introduction	5238
132.5.2 Identification	5238
132.5.3 PICS proforma tables for Reconciliation Sublayer (RS) and Media Independent Interface (50GMII) for 50 Gb/s operation	5239

133. Physical Coding Sublayer (PCS) for 64B/66B, type 50GBASE-R	5240
133.1 Overview.....	5240
133.1.1 Scope.....	5240
133.1.2 Relationship of 50GBASE-R to other standards	5240
133.1.3 Summary of 50GBASE-R sublayers	5240
133.1.4 Inter-sublayer interfaces	5240
133.1.5 Functional block diagram	5242
133.2 Physical Coding Sublayer (PCS)	5243
133.2.1 Functions within the PCS	5243
133.2.2 Alignment marker insertion	5243
133.2.3 PCS lane deskew.....	5244
133.2.4 Detailed functions and state diagrams	5244
133.3 Delay constraints.....	5244
133.4 Auto-Negotiation	5244
133.5 Protocol implementation conformance statement (PICS) proforma for Clause 133, Physical Coding Sublayer (PCS) for 64B/66B, type 50GBASE-R.....	5245
133.5.1 Introduction.....	5245
133.5.2 Identification	5245
133.5.3 Major capabilities/options.....	5246
133.5.4 PICS proforma tables for Physical Coding Sublayer (PCS) for 64B/66B, type 50GBASE-R	5246
134. Reed-Solomon forward error correction (RS-FEC) sublayer for 50GBASE-R PHYs.....	5250
134.1 Overview.....	5250
134.1.1 Scope.....	5250
134.1.2 Position of RS-FEC in the 50GBASE-R sublayers	5250
134.2 FEC service interface.....	5250
134.3 PMA compatibility	5251
134.4 Delay constraints.....	5252
134.5 Functions within the RS-FEC sublayer	5252
134.5.1 Functional block diagram	5252
134.5.2 Transmit function.....	5252
134.5.3 Receive function	5257
134.5.4 Detailed functions and state diagrams	5259
134.6 RS-FEC MDIO function mapping.....	5262
134.6.1 FEC_bypass_indication_enable.....	5263
134.6.2 FEC_degraded_SER_enable.....	5263
134.6.3 FEC_degraded_SER_activate_threshold.....	5263
134.6.4 FEC_degraded_SER_deactivate_threshold.....	5263
134.6.5 FEC_degraded_SER_interval.....	5263
134.6.6 FEC_bypass_indication_ability	5263
134.6.7 hi_ser.....	5264
134.6.8 FEC_degraded_SER_ability	5264
134.6.9 FEC_degraded_SER	5264
134.6.10 fec_optional_states.....	5264
134.6.11 amps_lock<x>.....	5264
134.6.12 fec_align_status	5264
134.6.13 FEC_corrected_cw_counter.....	5264
134.6.14 FEC_uncorrected_cw_counter.....	5264
134.6.15 FEC_lane_mapping<x>	5265
134.6.16 FEC_symbol_error_counter_i	5265
134.6.17 align_status	5265

134.6.18 BIP_error_counter_i	5265
134.6.19 lane_mapping<x>.....	5265
134.6.20 block_lock<x>	5265
134.6.21 am_lock<x>	5265
134.7 Protocol implementation conformance statement (PICS) proforma for Clause 134, Reed-Solomon forward error correction (RS-FEC) sublayer for 50GBASE-R PHYs	5266
134.7.1 Introduction.....	5266
134.7.2 Identification.....	5266
134.7.3 Major capabilities/options.....	5267
134.7.4 PICS proforma tables for Reed-Solomon forward error correction (RS-FEC) sublayer for 50GBASE-R PHYs	5267
135. Physical Medium Attachment (PMA) sublayer, type 50GBASE-R and 100GBASE-P	5270
135.1 Overview.....	5270
135.1.1 Scope.....	5270
135.1.2 Position of the PMA in the 50GBASE-R and 100GBASE-P sublayers	5270
135.1.3 Summary of functions.....	5270
135.1.4 PMA sublayer positioning	5271
135.2 PMA interfaces	5273
135.3 PMA service interface	5274
135.4 Service interface below PMA	5275
135.5 Functions within the PMA	5276
135.5.1 Per input-lane clock and data recovery.....	5277
135.5.2 Bit-level multiplexing	5278
135.5.3 Skew and Skew Variation.....	5278
135.5.4 Delay constraints.....	5281
135.5.5 Clocking architecture.....	5281
135.5.6 Signal drivers	5281
135.5.7 PAM4 encoding	5282
135.5.8 PMA local loopback mode (optional).....	5283
135.5.9 PMA remote loopback mode (optional)	5284
135.5.10 PMA test patterns (optional).....	5284
135.6 PMA MDIO function mapping.....	5285
135.7 Protocol implementation conformance statement (PICS) proforma for Clause 135, Physical Medium Attachment (PMA) sublayer, type 50GBASE-R and 100GBASE-P	5289
135.7.1 Introduction.....	5289
135.7.2 Identification	5289
135.7.3 Major capabilities/options.....	5290
135.7.4 PICS proforma tables for Physical Medium Attachment (PMA) sublayer, type 50GBASE-R and 100GBASE-P	5291
135.7.7 Encoding	5295
136. Physical Medium Dependent (PMD) sublayer and baseband medium, type 50GBASE-CR, 100GBASE-CR2, and 200GBASE-CR4	5296
136.1 Overview.....	5296
136.2 Conventions	5298
136.3 PMD service interfaces.....	5298
136.4 PCS requirements for Auto-Negotiation (AN) service interface.....	5300
136.5 Delay constraints.....	5300
136.6 Skew constraints	5301
136.6.1 Skew Constraints for 50GBASE-CR.....	5301
136.6.2 Skew Constraints for 100GBASE-CR2 and 200GBASE-CR4	5301

136.7	PMD MDIO function mapping.....	5301
136.8	PMD functional specifications.....	5305
136.8.1	Link block diagram.....	5305
136.8.2	PMD transmit function.....	5306
136.8.3	PMD receive function.....	5307
136.8.4	PMD global signal detect function.....	5307
136.8.5	PMD lane-by-lane signal detect function.....	5307
136.8.6	PMD global transmit disable function (optional).....	5307
136.8.7	PMD lane-by-lane transmit disable function (optional).....	5308
136.8.8	PMD fault function.....	5308
136.8.9	PMD transmit fault function (optional).....	5308
136.8.10	PMD receive fault function (optional).....	5308
136.8.11	PMD control function.....	5308
136.9	PMD electrical characteristics.....	5325
136.9.1	AC-coupling.....	5325
136.9.2	Signal paths.....	5325
136.9.3	Transmitter characteristics.....	5325
136.9.4	Receiver characteristics.....	5330
136.10	Channel characteristics.....	5334
136.11	Cable assembly characteristics.....	5334
136.11.1	Characteristic impedance and reference impedance.....	5335
136.11.2	Cable assembly insertion loss.....	5335
136.11.3	Cable assembly ERL.....	5335
136.11.4	Differential to common-mode return loss.....	5336
136.11.5	Differential to common-mode conversion loss.....	5336
136.11.6	Common-mode to common-mode return loss.....	5336
136.11.7	Cable assembly Channel Operating Margin.....	5336
136.12	MDI specifications.....	5340
136.13	Environmental specifications.....	5340
136.14	Protocol implementation conformance statement (PICS) proforma for Clause 136, Physical Medium Dependent (PMD) sublayer and baseband medium, type 50GBASE-CR, 100GBASE-CR2, and 200GBASE-CR4.....	5341
136.14.1	Introduction.....	5341
136.14.2	Identification.....	5341
136.14.3	Major capabilities/options.....	5342
136.14.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and baseband medium, type 50GBASE-CR, 100GBASE-CR2, and 200GBASE-CR4.....	5343
137.	Physical Medium Dependent (PMD) sublayer and baseband medium, type 50GBASE-KR, 100GBASE-KR2, and 200GBASE-KR4.....	5347
137.1	Overview.....	5347
137.2	Conventions.....	5350
137.3	PMD service interfaces.....	5350
137.4	PCS requirements for Auto-Negotiation (AN) service interface.....	5350
137.5	Delay constraints.....	5350
137.6	Skew constraints.....	5351
137.6.1	Skew Constraints for 50GBASE-KR.....	5351
137.6.2	Skew Constraints for 100GBASE-KR2 and 200GBASE-KR4.....	5351
137.7	PMD MDIO function mapping.....	5351
137.8	PMD functional specifications.....	5352
137.8.1	Link block diagram.....	5352
137.8.2	PMD transmit function.....	5352
137.8.3	PMD receive function.....	5352

137.8.4	PMD global signal detect function	5352
137.8.5	PMD lane-by-lane signal detect function	5352
137.8.6	PMD global transmit disable function (optional)	5352
137.8.7	PMD lane-by-lane transmit disable function (optional)	5352
137.8.8	PMD fault function	5353
137.8.9	PMD transmit fault function (optional)	5353
137.8.10	PMD receive fault function (optional)	5353
137.8.11	PMD control function	5353
137.9	Electrical characteristics	5353
137.9.1	MDI	5353
137.9.2	Transmitter characteristics	5353
137.9.3	Receiver characteristics	5354
137.10	Channel characteristics	5354
137.10.1	Channel insertion loss	5356
137.10.2	Channel ERL	5356
137.11	Environmental specifications	5356
137.12	Protocol implementation conformance statement (PICS) proforma for Clause 137, Physical Medium Dependent (PMD) sublayer and baseband medium, type 50GBASE-KR, 100GBASE-KR2, and 200GBASE-KR4	5358
137.12.1	Introduction	5358
137.12.2	Identification	5358
137.12.3	Major capabilities/options	5359
137.12.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and baseband medium, type 50GBASE-KR, 100GBASE-KR2, and 200GBASE-KR4	5360
138.	Physical Medium Dependent (PMD) sublayer and medium, type 50GBASE-SR, 100GBASE-SR2, 200GBASE-SR4, 400GBASE-SR8	5363
138.1	Overview	5363
138.1.1	Bit error ratio	5366
138.2	Physical Medium Dependent (PMD) service interface	5367
138.3	Delay and Skew	5368
138.3.1	Delay constraints	5368
138.3.2	Skew constraints	5368
138.4	PMD MDIO function mapping	5369
138.5	PMD functional specifications	5370
138.5.1	PMD block diagram	5370
138.5.2	PMD transmit function	5371
138.5.3	PMD receive function	5371
138.5.4	PMD global signal detect function	5371
138.5.5	PMD lane-by-lane signal detect function	5372
138.5.6	PMD reset function	5372
138.5.7	PMD global transmit disable function (optional)	5372
138.5.8	PMD lane-by-lane transmit disable function (optional)	5372
138.5.9	PMD fault function (optional)	5372
138.5.10	PMD transmit fault function (optional)	5373
138.5.11	PMD receive fault function (optional)	5373
138.6	Lane assignments	5373
138.7	PMD to MDI optical specifications for 50GBASE-SR, 100GBASE-SR2, 200GBASE-SR4, and 400GBASE-SR8	5373
138.7.1	Transmitter optical specifications	5374
138.7.2	Receiver optical specifications	5374
138.7.3	Illustrative link power budget	5375
138.8	Definition of optical parameters and measurement methods	5376

138.8.1	Test patterns for optical parameters.....	5376
138.8.2	Center wavelength and spectral width.....	5377
138.8.3	Average optical power.....	5377
138.8.4	Outer Optical Modulation Amplitude (OMA _{outer}).....	5377
138.8.5	Transmitter and dispersion eye closure for PAM4 (TDECQ).....	5377
138.8.6	Extinction ratio.....	5378
138.8.7	Transmitter transition time.....	5378
138.8.8	Relative intensity noise (RIN _{12OMA}).....	5378
138.8.9	Receiver sensitivity.....	5379
138.8.10	Stressed receiver sensitivity.....	5379
138.9	Safety, installation, environment, and labeling.....	5380
138.9.1	General safety.....	5380
138.9.2	Laser safety.....	5380
138.9.3	Installation.....	5381
138.9.4	Environment.....	5381
138.9.5	Electromagnetic emission.....	5381
138.9.6	Temperature, humidity, and handling.....	5381
138.9.7	PMD labeling requirements.....	5381
138.10	Fiber optic cabling model.....	5381
138.10.1	Fiber optic cabling model.....	5382
138.10.2	Characteristics of the fiber optic cabling (channel).....	5383
138.10.3	Medium Dependent Interface (MDI).....	5384
138.11	Protocol implementation conformance statement (PICS) proforma for Clause 138, Physical Medium Dependent (PMD) sublayer and medium, type 50GBASE-SR, 100GBASE-SR2, 200GBASE-SR4, 400GBASE-SR8.....	5387
138.11.1	Introduction.....	5387
138.11.2	Identification.....	5387
138.11.3	Major capabilities/options.....	5388
138.11.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 50GBASE-SR, 100GBASE-SR2, 200GBASE-SR4, 400GBASE-SR8..	5389
139.	Physical Medium Dependent (PMD) sublayer and medium, type 50GBASE-FR, 50GBASE-LR, and 50GBASE-ER.....	5393
139.1	Overview.....	5393
139.1.1	Bit error ratio.....	5394
139.2	Physical Medium Dependent (PMD) service interface.....	5394
139.3	Delay and Skew.....	5395
139.3.1	Delay constraints.....	5395
139.3.2	Skew constraints.....	5395
139.4	PMD MDIO function mapping.....	5396
139.5	PMD functional specifications.....	5396
139.5.1	PMD block diagram.....	5396
139.5.2	PMD transmit function.....	5397
139.5.3	PMD receive function.....	5397
139.5.4	PMD global signal detect function.....	5397
139.5.5	PMD reset function.....	5398
139.5.6	PMD global transmit disable function (optional).....	5398
139.5.7	PMD fault function (optional).....	5398
139.5.8	PMD transmit fault function (optional).....	5398
139.5.9	PMD receive fault function (optional).....	5398
139.6	PMD to MDI optical specifications for 50GBASE-FR, 50GBASE-LR, and 50GBASE-ER.....	5399
139.6.1	50GBASE-FR, 50GBASE-LR, and 50GBASE-ER transmitter optical specifications..	5399
139.6.2	50GBASE-FR, 50GBASE-LR, and 50GBASE-ER receive optical specifications.....	5400

139.6.3	50GBASE-FR, 50GBASE-LR, and 50GBASE-ER illustrative link power budgets	5402
139.7	Definition of optical parameters and measurement methods.....	5402
139.7.1	Test patterns for optical parameters.....	5402
139.7.2	Wavelength and side-mode suppression ratio (SMSR).....	5403
139.7.3	Average optical power.....	5403
139.7.4	Outer Optical Modulation Amplitude (OMA _{outer}).....	5403
139.7.5	Transmitter and dispersion eye closure for PAM4 (TDECQ).....	5404
139.7.6	Extinction ratio	5406
139.7.7	Transmitter transition time.....	5406
139.7.8	Relative intensity noise (RIN _{17.1} OMA, RIN _{15.6} OMA, and RIN ₁₅ OMA)	5406
139.7.9	Receiver sensitivity.....	5407
139.7.10	Stressed receiver sensitivity.....	5407
139.8	Safety, installation, environment, and labeling.....	5409
139.8.1	General safety	5409
139.8.2	Laser safety	5410
139.8.3	Installation	5410
139.8.4	Environment.....	5410
139.8.5	Electromagnetic emission.....	5410
139.8.6	Temperature, humidity, and handling.....	5410
139.8.7	PMD labeling requirements.....	5410
139.9	Fiber optic cabling model	5411
139.10	Characteristics of the fiber optic cabling (channel).....	5411
139.10.1	Optical fiber cable.....	5412
139.10.2	Optical fiber connection.....	5412
139.10.3	Medium Dependent Interface (MDI) requirements	5412
139.11	Requirements for interoperation between 50GBASE-ER and 50GBASE-FR	5413
139.12	Requirements for interoperation between 50GBASE-ER and 50GBASE-LR.....	5413
139.13	Protocol implementation conformance statement (PICS) proforma for Clause 139, Physical Medium Dependent (PMD) sublayer and medium, type 50GBASE-FR, 50GBASE-LR, and 50GBASE-ER	5414
139.13.1	Introduction.....	5414
139.13.2	Identification.....	5414
139.13.3	Major capabilities/options.....	5415
139.13.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 50GBASE-FR, 50GBASE-LR, and 50GBASE-ER	5415
140.	Physical Medium Dependent (PMD) sublayer and medium, type 100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1	5419
140.1	Overview.....	5419
140.1.1	Bit error ratio	5420
140.2	Physical Medium Dependent (PMD) service interface	5420
140.3	Delay and Skew	5421
140.3.1	Delay constraints.....	5421
140.3.2	Skew constraints	5421
140.4	PMD MDIO function mapping.....	5422
140.5	PMD functional specifications.....	5422
140.5.1	PMD block diagram.....	5422
140.5.2	PMD transmit function	5423
140.5.3	PMD receive function	5423
140.5.4	PMD global signal detect function	5423
140.5.5	PMD reset function	5424
140.5.6	PMD global transmit disable function (optional)	5424
140.5.7	PMD fault function (optional)	5424

140.5.8	PMD transmit fault function (optional)	5424
140.5.9	PMD receive fault function (optional)	5424
140.6	PMD to MDI optical specifications for 100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1	5425
140.6.1	100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1 transmitter optical specifications	5425
140.6.2	100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1 receive optical specifications	5427
140.6.3	100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1 illustrative link power budgets	5429
140.7	Definition of optical parameters and measurement methods	5431
140.7.1	Test patterns for optical parameters	5431
140.7.2	Wavelength and side-mode suppression ratio (SMSR)	5432
140.7.3	Average optical power	5432
140.7.4	Outer Optical Modulation Amplitude (OMA _{outer})	5432
140.7.5	Transmitter and dispersion eye closure for PAM4 (TDECQ)	5432
140.7.6	Transmitter eye closure for PAM4 (TECQ)	5434
140.7.7	Over/under-shoot	5434
140.7.8	Transmitter power excursion	5434
140.7.9	Extinction ratio	5435
140.7.10	Transmitter transition time	5435
140.7.11	Relative intensity noise (RIN _{xOMA})	5435
140.7.12	Receiver sensitivity	5435
140.7.13	Stressed receiver sensitivity	5436
140.8	Safety, installation, environment, and labeling	5437
140.8.1	General safety	5437
140.8.2	Laser safety	5437
140.8.3	Installation	5437
140.8.4	Environment	5437
140.8.5	Electromagnetic emission	5437
140.8.6	Temperature, humidity, and handling	5438
140.8.7	PMD labeling requirements	5438
140.9	Fiber optic cabling model	5438
140.10	Characteristics of the fiber optic cabling (channel)	5439
140.10.1	Optical fiber cable	5439
140.10.2	Optical fiber connection	5440
140.10.3	Medium Dependent Interface (MDI)	5441
140.11	Interoperation between 100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1	5441
140.11.1	Interoperation between 100GBASE-FR1 and 100GBASE-DR	5441
140.11.2	Interoperation between 100GBASE-LR1 and 100GBASE-DR	5441
140.11.3	Interoperation between 100GBASE-LR1 and 100GBASE-FR1	5441
140.12	Protocol implementation conformance statement (PICS) proforma for Clause 140, Physical Medium Dependent (PMD) sublayer and medium, type 100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1	5443
140.12.1	Introduction	5443
140.12.2	Identification	5443
140.12.3	Major capabilities/options	5444
140.12.4	PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 100GBASE-DR, 100GBASE-FR1, and 100GBASE-LR1, 100GBASE-FR1, and 100GBASE-LR1	5445
141.	Physical Medium Dependent (PMD) sublayer and medium for Nx25G-EPON passive optical networks	5449

141.1	Overview.....	5449
141.1.1	Terminology.....	5449
141.1.2	Positioning of the PMD sublayer within the IEEE 802.3 architecture	5449
141.1.3	PHY link types.....	5449
141.2	PMD nomenclature	5452
141.2.1	Introduction.....	5452
141.2.2	PMD rate classes.....	5452
141.2.3	PMD coexistence classes	5452
141.2.4	PMD transmission direction classes	5452
141.2.5	PMD power classes.....	5452
141.2.6	PMD naming.....	5453
141.2.7	Supported combinations of OLT and ONU PMDs.....	5453
141.3	PMD functional specifications.....	5455
141.3.1	PMD service interface	5455
141.3.2	PMD block diagram.....	5457
141.3.3	PMD transmit function	5458
141.3.4	PMD receive function	5458
141.3.5	PMD signal detect function	5458
141.4	Wavelength allocation	5459
141.5	PMD to MDI optical specifications for OLT PMDs	5460
141.5.1	Transmitter optical specifications	5460
141.5.2	Receiver optical specifications	5460
141.6	PMD to MDI optical specifications for ONU PMDs	5465
141.6.1	Transmitter optical specifications	5465
141.6.2	Receiver optical specifications	5468
141.7	Definitions of optical parameters and measurement methods	5470
141.7.1	Insertion loss	5470
141.7.2	Test patterns	5470
141.7.3	Wavelength and spectral width measurement	5470
141.7.4	Optical power measurements.....	5470
141.7.5	Extinction ratio measurements.....	5470
141.7.6	Optical Modulation Amplitude (OMA) test procedure	5470
141.7.7	Relative intensity noise optical modulation amplitude (RINxOMA) measuring procedure	5470
141.7.8	Transmit optical waveform (transmit eye).....	5471
141.7.9	Transmitter and dispersion penalty (TDP) for 25G	5471
141.7.10	Receive sensitivity	5472
141.7.11	Stressed receiver conformance test.....	5472
141.7.12	Jitter measurements.....	5472
141.7.13	Laser on/off timing measurement	5472
141.7.14	Receiver settling timing measurement.....	5474
141.8	Environmental, safety, and labeling	5475
141.8.1	General safety	5475
141.8.2	Laser safety	5475
141.8.3	Installation	5475
141.8.4	Environment.....	5475
141.8.5	PMD labeling.....	5475
141.9	Characteristics of the fiber optic cabling	5476
141.9.1	Fiber optic cabling model	5476
141.9.2	Optical fiber and cable.....	5476
141.9.3	Optical fiber connection.....	5476
141.9.4	Medium Dependent Interface (MDI).....	5477

141.10 Protocol implementation conformance statement (PICS) proforma for Clause 141, Physical Medium Dependent (PMD) sublayer and medium for Nx25G-EPON passive optical networks	5478
141.10.1 Introduction.....	5478
141.10.2 Identification.....	5478
141.10.3 Major capabilities/options.....	5479
141.10.4 PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium for passive optical networks, type 25/10GBASE-PQ, 25GBASE-PQ, 50/10GBASE-PQ, 50/25GBASE-PQ, and 50GBASE-PQ.....	5482
142. Physical Coding Sublayer and Physical Media Attachment for Nx25G-EPON	5495
142.1 Overview.....	5495
142.1.1 Conventions	5495
142.1.2 Delay constraints.....	5500
142.1.3 Burst transmission.....	5500
142.2 PCS transmit data path.....	5502
142.2.1 64B/66B line encoder	5502
142.2.2 Scrambler	5504
142.2.3 64B/66B to 256B/257B transcoder.....	5504
142.2.4 FEC encoder	5504
142.2.5 Transmit data path state diagrams	5514
142.3 PCS receive data path	5521
142.3.1 FEC decoder	5521
142.3.2 256B/257B to 64B/66B transcoder.....	5522
142.3.3 Descrambler	5522
142.3.4 64B/66B decoder	5523
142.3.5 Receive data path state diagrams	5524
142.4 Nx25G-EPON PMA	5530
142.4.1 Service Interface	5530
142.4.2 Differential encoder	5532
142.4.3 Differential decoder	5533
142.4.4 PMA transmit clock	5533
142.4.5 TCDR measurement	5533
142.5 Protocol implementation conformance statement (PICS) proforma for Clause 142, Physical Coding Sublayer and Physical Media Attachment for Nx25G-EPON	5535
142.5.1 Introduction.....	5535
142.5.2 Identification	5535
142.5.3 PCS capabilities/options	5536
142.5.4 PCS processes	5536
142.5.5 PMA processes	5537
143. Multi-Channel Reconciliation Sublayer	5538
143.1 Overview.....	5538
143.2 Summary of major concepts	5538
143.2.1 Concept of a logical link and LLID.....	5539
143.2.2 Concept of an MCRS channel	5539
143.2.3 Binding of multiple MACs to multiple xMII instances.....	5539
143.2.4 Transmission and reception over multiple MCRS channels.....	5540
143.2.5 Dynamic channel bonding	5542
143.2.6 MDIO addressing model for multi-channel architecture.....	5546
143.3 MCRS functional specifications	5548
143.3.1 MCRS interfaces.....	5548

143.3.2	Envelope header format	5551
143.3.3	Transmit functional specifications	5553
143.3.4	Receive functional specifications	5561
143.4	Nx25G-EPON MCRS requirements	5566
143.4.1	Nx25G-EPON architecture	5566
143.4.2	MCRS time synchronization	5569
143.4.3	Delay variability constraints	5570
143.4.4	Asymmetric rate operation	5570
143.5	Protocol implementation conformance statement (PICS) proforma for Clause 143, Multi-Channel Reconciliation Sublayer	5573
143.5.1	Introduction	5573
143.5.2	Identification	5573
143.5.3	Generic MCRS	5574
143.5.4	MCRS in Nx25G-EPON	5574
144.	Multipoint MAC Control for Nx25G-EPON	5576
144.1	Overview	5576
144.1.1	Principles of point-to-multipoint operation	5576
144.1.2	Position of Multipoint MAC Control (MPMC) within the IEEE 802.3 hierarchy	5579
144.1.3	Functional block diagram	5579
144.1.4	Service interfaces	5579
144.1.5	Conventions	5582
144.2	Protocol-independent operation	5582
144.2.1	Control Parser and Control Multiplexer	5583
144.3	Multipoint Control Protocol (MPCP)	5586
144.3.1	Principles of Multipoint Control Protocol (MPCP)	5586
144.3.2	MPCP block diagram	5590
144.3.3	Delay variability requirements	5592
144.3.4	Logical link identifier (LLID) types	5592
144.3.5	Allocation of LLID values	5593
144.3.6	MPCPDU structure and encoding	5594
144.3.7	Discovery process	5608
144.3.8	Granting process	5618
144.3.9	Discovery process in dual-rate systems	5623
144.4	Channel Control Protocol (CCP)	5625
144.4.1	CCP block diagram	5625
144.4.2	Principles of Channel Control Protocol	5626
144.4.3	CCPDU structure and encoding	5628
144.4.4	Channel Control operation	5632
144.5	Protocol implementation conformance statement (PICS) proforma for Clause 144, Multipoint MAC Control for Nx25G-EPON	5637
144.5.1	Introduction	5637
144.5.2	Identification	5637
144.5.3	Major capabilities/options	5638
144.5.4	PICS proforma tables for Multipoint MAC Control	5638
145.	Power over Ethernet	5643
145.1	Overview	5643
145.1.1	Compatibility considerations	5644
145.1.2	Relationship of Power over Ethernet to the IEEE 802.3 Architecture	5644
145.1.3	System parameters	5645
145.1.4	Cabling requirements	5646

145.2	Power sourcing equipment (PSE)	5647
145.2.1	PSE Type descriptions	5647
145.2.2	PSE location	5648
145.2.3	Midspan PSE variants	5648
145.2.4	PSE PI	5655
145.2.5	PSE state diagrams	5656
145.2.6	PSE detection of PDs	5692
145.2.7	Connection check	5695
145.2.8	PSE classification of PDs and mutual identification	5695
145.2.9	4PID requirements	5703
145.2.10	Power supply output	5703
145.2.11	Power supply allocation	5718
145.2.12	PSE Maintain Power Signature (MPS) requirements	5718
145.3	Powered devices (PDs)	5719
145.3.1	PD Type descriptions	5720
145.3.2	PD PI	5720
145.3.3	PD state diagrams	5722
145.3.4	PD valid and non-valid detection signatures	5735
145.3.5	PD signature configurations	5737
145.3.6	PD classification	5738
145.3.7	PSE Type identification	5742
145.3.8	PD power	5742
145.3.9	PD Maintain Power Signature	5752
145.4	Additional electrical specifications	5754
145.4.1	Electrical isolation	5754
145.4.2	Fault tolerance	5755
145.4.3	Impedance balance	5756
145.4.4	Common-mode output voltage	5757
145.4.5	Pair-to-pair output noise voltage	5759
145.4.6	Differential noise voltage	5759
145.4.7	Return loss	5760
145.4.8	100BASE-TX transformer droop	5760
145.4.9	Midspan PSE device additional requirements	5760
145.5	Data Link Layer classification	5766
145.5.1	TLV frame definition	5766
145.5.2	Data Link Layer classification timing requirements	5766
145.5.3	Power control state diagrams	5766
145.5.4	Power requests and allocations	5789
145.5.5	State change procedure across a link (single-signature)	5789
145.5.6	State change procedure across a link (dual-signature)	5791
145.5.7	Autoclass	5792
145.6	Environmental	5793
145.6.1	General safety	5793
145.6.2	Network safety	5793
145.6.3	Installation and maintenance guidelines	5793
145.6.4	Patch panel considerations	5794
145.6.5	Electromagnetic emissions	5794
145.6.6	Temperature and humidity	5794
145.6.7	Labeling	5794
145.7	Protocol implementation conformance statement (PICS) proforma for Clause 145, Power over Ethernet	5795
145.7.1	Introduction	5795
145.7.2	Identification	5795
145.7.3	PICS proforma tables for Power over Ethernet	5798

146. Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 10BASE-T1L	5814
146.1 Overview.....	5814
146.1.1 Relationship of 10BASE-T1L to other standards	5814
146.1.2 Operation of 10BASE-T1L.....	5814
146.1.3 Conventions in this clause	5816
146.2 Service primitives and interfaces.....	5817
146.2.1 PMA_LINK.request.....	5817
146.2.2 PMA_LINK.indication	5819
146.2.3 PMA_TXMODE.indication.....	5819
146.2.4 PMA_UNITDATA.indication	5820
146.2.5 PMA_UNITDATA.request.....	5820
146.2.6 PMA_RXSTATUS.indication	5820
146.2.7 PMA_REMRXSTATUS.request.....	5821
146.2.8 PMA_SCRSTATUS.request.....	5821
146.2.9 PMA_TXEN.request (tx_enable_mii).....	5822
146.2.10 PMA_RX_LPI_STATUS.request (rx_lpi_active).....	5822
146.2.11 PMA_TX_LPI_STATUS.request (tx_lpi_active)	5823
146.2.12 PMA_TX_LPI_STATUS.indication	5823
146.3 Physical Coding Sublayer (PCS) functions	5824
146.3.1 PCS Reset function	5824
146.3.2 PCS Data Transmission Enable	5824
146.3.3 PCS Transmit.....	5826
146.3.4 PCS Receive	5837
146.3.5 PCS loopback.....	5844
146.4 Physical Medium Attachment (PMA) sublayer.....	5844
146.4.1 PMA Reset function.....	5846
146.4.2 PMA Transmit function.....	5846
146.4.3 PMA Receive function.....	5846
146.4.4 PHY Control function.....	5847
146.4.5 Link Monitor function	5854
146.4.6 PMA clock recovery	5854
146.4.7 LPI quiet-refresh cycling	5854
146.5 PMA electrical specifications	5857
146.5.1 EMC tests.....	5857
146.5.2 Test modes	5857
146.5.3 Test fixture	5858
146.5.4 Transmitter electrical specifications	5858
146.5.5 Receiver electrical specifications.....	5861
146.5.6 PMA local loopback	5862
146.6 Management interface.....	5862
146.6.1 Support for Auto-Negotiation	5862
146.6.2 MASTER-SLAVE configuration	5862
146.6.3 PHY initialization	5863
146.6.4 Increased transmit level configuration.....	5863
146.6.5 EEE configuration.....	5863
146.6.6 PMA and PCS MDIO function mapping	5863
146.7 Link segment characteristics.....	5864
146.7.1 Link transmission parameters for 10BASE-T1L	5864
146.7.2 Coupling parameters between 10BASE-T1L link segments	5868
146.8 MDI specification	5869
146.8.1 MDI connectors	5869
146.8.2 MDI electrical specification.....	5872

146.8.3 MDI return loss	5872
146.8.4 MDI mode conversion loss	5872
146.8.5 MDI DC power voltage tolerance.....	5872
146.8.6 MDI fault tolerance.....	5872
146.9 Environmental specifications.....	5873
146.9.1 General safety	5873
146.9.2 Network safety	5873
146.10 Delay constraints.....	5873
146.11 Protocol implementation conformance statement (PICS) proforma for Clause 146, Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 10BASE-T1L	5875
146.11.1 Introduction.....	5875
146.11.2 Identification.....	5875
146.11.3 Major capabilities/options.....	5876
146.11.4 PICS proforma tables for Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 10BASE-T1L.....	5876
147. Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 10BASE-T1S	5884
147.1 Overview.....	5884
147.1.1 Relationship of 10BASE-T1S to other standards	5884
147.1.2 Operation of 10BASE-T1S	5884
147.1.3 Conventions in this clause	5885
147.2 Service primitives and interfaces.....	5886
147.2.1 PMA_UNITDATA.indication	5887
147.2.2 PMA_UNITDATA.request.....	5887
147.2.3 Mapping of PMA_CARRIER.indication.....	5888
147.2.4 PMA_LINK.request.....	5888
147.2.5 PMA_LINK.indication	5888
147.2.6 PCS_STATUS.indication	5889
147.3 Physical Coding Sublayer (PCS) functions	5889
147.3.1 PCS Reset function	5889
147.3.2 PCS Transmit.....	5890
147.3.3 PCS Receive	5897
147.3.4 PCS loopback.....	5902
147.3.5 Collision detection	5902
147.3.6 Carrier sense	5903
147.3.7 Support for PCS status generation.....	5903
147.4 Physical Medium Attachment (PMA) sublayer.....	5908
147.4.1 PMA Reset function.....	5908
147.4.2 PMA Transmit function.....	5908
147.4.3 PMA Receive function.....	5909
147.4.4 Link Monitor function	5910
147.5 PMA electrical specifications	5911
147.5.1 EMC tests.....	5911
147.5.2 Test modes	5911
147.5.3 Test fixtures	5912
147.5.4 Transmitter electrical specification.....	5913
147.5.5 Receiver electrical specifications.....	5915
147.5.6 PMA local loopback	5915
147.6 Management interface.....	5916
147.6.1 Support for Auto-Negotiation.....	5916
147.7 Point-to-point link segment characteristics.....	5916

147.7.1	Insertion loss	5916
147.7.2	Return loss	5916
147.7.3	Mode conversion loss	5917
147.7.4	Power sum alien near-end crosstalk (PSANEXT).....	5917
147.7.5	Power sum alien attenuation to crosstalk ratio far-end (PSAACRF)	5917
147.8	Mixing segment characteristics	5917
147.8.1	Insertion loss	5918
147.8.2	Return loss	5918
147.8.3	Mode conversion loss	5918
147.9	MDI specification	5918
147.9.1	MDI connectors	5918
147.9.2	MDI electrical specification.....	5921
147.9.3	MDI line powering voltage tolerance	5921
147.9.4	MDI fault tolerance.....	5921
147.10	Environmental specifications.....	5922
147.10.1	General safety	5922
147.10.2	Network safety	5922
147.11	Delay constraints.....	5923
147.12	Protocol implementation conformance statement (PICS) proforma for Clause 147, Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 10BASE-T1S	5924
147.12.1	Introduction.....	5924
147.12.2	Identification.....	5924
147.12.3	Major capabilities/options.....	5925
147.12.4	PICS proforma tables for Physical Medium Attachment (PMA) sublayer and baseband medium, type 10BASE-T1S	5925
148.	PLCA Reconciliation Sublayer (RS)	5932
148.1	Introduction.....	5932
148.1.1	Conventions in this clause	5932
148.2	Overview.....	5932
148.3	Relationship with other IEEE standards	5933
148.4	PLCA Reconciliation Sublayer operation.....	5934
148.4.1	General.....	5934
148.4.2	Mapping of MII signals to PLS service primitives and PLCA functions	5934
148.4.3	Requirements for the PHY	5936
148.4.4	PLCA Control	5937
148.4.5	PLCA Data.....	5944
148.4.6	PLCA Status	5949
148.5	Protocol implementation conformance statement (PICS) proforma for Clause 148, PLCA Reconciliation Sublayer (RS)	5951
148.5.1	Introduction.....	5951
148.5.2	Identification.....	5951
148.5.3	PICS proforma tables for PLCA Reconciliation Sublayer (RS).....	5952
149.	Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer, and baseband medium, type 2.5GBASE-T1, 5GBASE-T1, and 10GBASE-T1	5954
149.1	Overview.....	5954
149.1.1	Nomenclature.....	5954
149.1.2	Relationship of 2.5GBASE-T1, 5GBASE-T1, and 10GBASE-T1 to other standards ...	5954
149.1.3	Operation of 2.5GBASE-T1, 5GBASE-T1, and 10GBASE-T1	5955
149.1.4	Signaling	5959

149.1.5 Interfaces.....	5960
149.1.6 Conventions in this clause	5960
149.2 2.5GBASE-T1, 5GBASE-T1, and 10GBASE-T1 service primitives and interfaces	5960
149.2.1 Technology Dependent Interface	5961
149.2.2 PMA service interface	5962
149.3 Physical Coding Sublayer (PCS) functions	5969
149.3.1 PCS service interface (XGMII)	5969
149.3.2 PCS functions	5969
149.3.3 Test-pattern generators	5985
149.3.4 Side-stream scrambler polynomials.....	5986
149.3.5 PMA training frame	5987
149.3.6 LPI signaling.....	5987
149.3.7 Detailed functions and state diagrams	5990
149.3.8 PCS management	6003
149.3.9 MultiGBASE-T1 operations, administration, and maintenance (OAM)	6004
149.4 Physical Medium Attachment (PMA) sublayer.....	6019
149.4.1 PMA functional specifications.....	6019
149.4.2 PMA functions	6019
149.4.3 MDI.....	6030
149.4.4 State variables	6030
149.4.5 State diagrams	6033
149.5 PMA electrical specifications	6035
149.5.1 Test modes	6035
149.5.2 Transmitter electrical specifications	6037
149.5.3 Receiver electrical specifications.....	6040
149.6 Management interface.....	6041
149.6.1 Optional Support for Auto-Negotiation	6041
149.7 Link segment characteristics.....	6041
149.7.1 Link transmission parameters	6041
149.7.2 Coupling parameters between link segments.....	6046
149.8 MDI specification	6048
149.8.1 MDI connectors	6048
149.8.2 MDI electrical specification.....	6048
149.8.3 MDI fault tolerance.....	6049
149.9 Environmental specifications.....	6049
149.9.1 General safety	6049
149.9.2 Network safety	6050
149.10 Delay constraints.....	6050
149.11 Protocol implementation conformance statement (PICS) proforma for Clause 149, Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer, and baseband medium, type 2.5GBASE-T1, 5GBASE-T1, and 10GBASE-T1	6052
149.11.1 Introduction.....	6052
149.11.2 Identification.....	6052
149.11.3 Major capabilities/options.....	6053
149.11.4 PICS proforma tables for Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer, and baseband medium, type 2.5GBASE-T1, 5GBASE-T1, and 10GBASE-T1	6053
150. Physical Medium Dependent (PMD) sublayer and medium, type 400GBASE-SR4.2	6068
150.1 Overview.....	6068
150.1.1 Bit error ratio	6069
150.2 Physical Medium Dependent (PMD) service interface	6069
150.3 Delay and Skew	6070

150.3.1 Delay constraints.....	6070
150.3.2 Skew constraints	6070
150.4 PMD MDIO function mapping.....	6071
150.5 PMD functional specifications.....	6071
150.5.1 PMD block diagram.....	6072
150.5.2 PMD transmit function	6072
150.5.3 PMD receive function	6072
150.5.4 PMD global signal detect function	6073
150.5.5 PMD lane-by-lane signal detect function	6074
150.5.6 PMD reset function.....	6074
150.5.7 PMD global transmit disable function (optional)	6074
150.5.8 PMD lane-by-lane transmit disable function (optional)	6074
150.5.9 PMD fault function (optional)	6074
150.5.10 PMD transmit fault function (optional)	6074
150.5.11 PMD receive fault function (optional).....	6075
150.6 Wavelength ranges.....	6075
150.7 PMD to MDI optical specifications for 400GBASE-SR4.2	6075
150.7.1 Transmitter optical specifications	6076
150.7.2 Receiver optical specifications	6076
150.7.3 Illustrative link power budget	6078
150.8 Definition of optical parameters and measurement methods.....	6078
150.8.1 Test patterns for optical parameters.....	6078
150.8.2 Center wavelength and spectral width	6079
150.8.3 Average optical power.....	6079
150.8.4 Outer Optical Modulation Amplitude (OMA _{outer}).....	6079
150.8.5 Transmitter and dispersion eye closure for PAM4 (TDECQ)	6080
150.8.6 Extinction ratio	6080
150.8.7 Transmitter transition time.....	6080
150.8.8 Relative intensity noise (RIN _{2OMA})	6081
150.8.9 Receiver sensitivity.....	6081
150.8.10 Stressed receiver sensitivity	6082
150.9 Safety, installation, environment, and labeling.....	6083
150.9.1 General safety	6083
150.9.2 Laser safety	6083
150.9.3 Installation	6083
150.9.4 Environment.....	6084
150.9.5 Electromagnetic emission	6084
150.9.6 Temperature, humidity, and handling	6084
150.9.7 PMD labeling requirements	6084
150.10 Fiber optic cabling model	6084
150.10.1 Fiber optic cabling model	6085
150.10.2 Characteristics of the fiber optic cabling (channel).....	6085
150.10.3 Medium Dependent Interface (MDI).....	6086
150.11 Protocol implementation conformance statement (PICS) proforma for Clause 150, Physical Medium Dependent (PMD) sublayer and medium, type 400GBASE-SR4.2.....	6088
150.11.1 Introduction.....	6088
150.11.2 Identification.....	6088
150.11.3 Major capabilities/options.....	6089
150.11.4 PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 400GBASE-SR4.2	6089
151. Physical Medium Dependent (PMD) sublayer and medium, type 400GBASE-FR4 and 400GBASE-LR4-6.....	6093

151.1	Overview.....	6093
151.1.1	Bit error ratio	6093
151.2	Physical Medium Dependent (PMD) service interface	6094
151.3	Delay and Skew	6095
151.3.1	Delay constraints.....	6095
151.3.2	Skew constraints	6095
151.4	PMD MDIO function mapping.....	6095
151.5	PMD functional specifications.....	6096
151.5.1	PMD block diagram.....	6096
151.5.2	PMD transmit function	6096
151.5.3	PMD receive function.....	6097
151.5.4	PMD global signal detect function	6097
151.5.5	PMD lane-by-lane signal detect function	6098
151.5.6	PMD reset function.....	6098
151.5.7	PMD global transmit disable function (optional)	6098
151.5.8	PMD lane-by-lane transmit disable function	6099
151.5.9	PMD fault function (optional)	6099
151.5.10	PMD transmit fault function (optional)	6099
151.5.11	PMD receive fault function (optional).....	6099
151.6	Wavelength-division-multiplexed lane assignments	6100
151.7	PMD to MDI optical specifications for 400GBASE-FR4 and 400GBASE-LR4-6	6100
151.7.1	400GBASE-FR4 and 400GBASE-LR4-6 transmitter optical specifications	6100
151.7.2	400GBASE-FR4 and 400GBASE-LR4-6 receive optical specifications	6102
151.7.3	400GBASE-FR4 and 400GBASE-LR4-6 illustrative link power budgets.....	6104
151.8	Definition of optical parameters and measurement methods.....	6106
151.8.1	Test patterns for optical parameters.....	6106
151.8.2	Wavelength and side mode suppression ratio (SMSR)	6107
151.8.3	Average optical power	6107
151.8.4	Outer Optical Modulation Amplitude (OMA _{outer}).....	6107
151.8.5	Transmitter and dispersion eye closure for PAM4 (TDECQ)	6107
151.8.6	Transmitter eye closure for PAM4 (TECQ)	6108
151.8.7	Over/under-shoot	6108
151.8.8	Transmitter power excursion	6108
151.8.9	Extinction ratio	6108
151.8.10	Transmitter transition time.....	6108
151.8.11	Relative intensity noise (RIN _{17.1OMA} and RIN _{15.6OMA}).....	6109
151.8.12	Receiver sensitivity.....	6109
151.8.13	Stressed receiver sensitivity.....	6110
151.9	Safety, installation, environment, and labeling.....	6110
151.9.1	General safety	6110
151.9.2	Laser safety	6110
151.9.3	Installation	6110
151.9.4	Environment.....	6111
151.9.5	Electromagnetic emission.....	6111
151.9.6	Temperature, humidity, and handling.....	6111
151.9.7	PMD labeling requirements	6111
151.10	Fiber optic cabling model	6111
151.11	Characteristics of the fiber optic cabling (channel)	6112
151.11.1	Optical fiber cable.....	6112
151.11.2	Optical fiber connection.....	6112
151.11.3	Medium Dependent Interface (MDI) requirements	6113
151.12	Interoperation between 400GBASE-LR4-6 and 400GBASE-FR4	6113

151.13 Protocol implementation conformance statement (PICS) proforma for Clause 151, Physical Medium Dependent (PMD) sublayer and medium, type 400GBASE-FR4 and 400GBASE-LR4-6.....	6115
151.13.1 Introduction.....	6115
151.13.2 Identification.....	6115
151.13.3 Major capabilities/options.....	6116
151.13.4 PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 400GBASE-FR4 and 400GBASE-LR4-6	6116
152. Inverse RS-FEC sublayer.....	6120
152.1 Overview.....	6120
152.1.1 Scope.....	6120
152.1.2 Position of Inverse RS-FEC in the 100GBASE-R sublayers	6120
152.2 Inverse RS-FEC service interface.....	6121
152.3 PMA or FEC sublayer compatibility	6121
152.4 Delay constraints.....	6121
152.5 Functions within the Inverse RS-FEC sublayer.....	6121
152.5.1 Functional block diagram	6121
152.5.2 Transmit function.....	6122
152.5.3 Receive function	6127
152.5.4 Detailed functions and state diagrams	6132
152.6 Inverse RS-FEC MDIO function mapping	6134
152.6.1 IFEC_bypass_correction_enable	6134
152.6.2 IFEC_bypass_indication_enable	6135
152.6.3 IFEC_bypass_correction_ability	6135
152.6.4 IFEC_bypass_indication_ability.....	6136
152.6.5 hi_ser.....	6136
152.6.6 amps_lock<x>.....	6136
152.6.7 IFEC_align_status.....	6136
152.6.8 IFEC_corrected_cw_counter	6136
152.6.9 IFEC_uncorrected_cw_counter	6136
152.6.10 IFEC_lane_mapping<x>.....	6136
152.6.11 IFEC_symbol_error_counter_i.....	6137
152.6.12 align_status	6137
152.6.13 BIP_error_counter_i.....	6137
152.6.14 lane_mapping<x>.....	6137
152.6.15 block_lock<x>	6137
152.6.16 am_lock<x>	6137
152.7 Protocol implementation conformance statement (PICS) proforma for Clause 152, Inverse RS-FEC sublayer.....	6138
152.7.1 Introduction.....	6138
152.7.2 Identification.....	6138
152.7.3 Major capabilities/options.....	6139
152.7.4 PICS proforma tables for Inverse RS-FEC sublayer	6139
153. SC-FEC and 100GBASE-ZR Physical Medium Attachment (PMA) sublayer for 100GBASE-ZR PHYs.....	6142
153.1 Overview.....	6142
153.1.1 Scope.....	6142
153.1.2 Position of SC-FEC and 100GBASE-ZR PMA in the 100GBASE-R sublayers	6142
153.2 SC-FEC sublayer	6142
153.2.1 FEC service interface.....	6142

153.2.2	Delay constraints.....	6143
153.2.3	Functions within the SC-FEC sublayer	6144
153.2.4	Detailed functions and state diagrams	6151
153.2.5	SC-FEC MDIO function mapping.....	6155
153.3	100GBASE-ZR PMA sublayer.....	6156
153.3.1	100GBASE-ZR PMA service interface	6156
153.3.2	Functions within the 100GBASE-ZR PMA sublayer.....	6157
153.4	Protocol implementation conformance statement (PICS) proforma for Clause 153, SC-FEC and 100GBASE-ZR Physical Medium Attachment (PMA) sublayer for 100GBASE-ZR PHYs	6159
153.4.1	Introduction.....	6159
153.4.2	Identification	6159
153.4.3	Major capabilities/options.....	6160
153.4.4	PICS proforma tables for SC-FEC sublayer for 100GBASE-ZR PHYs	6160
154.	Physical Medium Dependent (PMD) sublayer and medium, type 100GBASE-ZR.....	6162
154.1	Overview.....	6162
154.1.1	Bit error ratio	6163
154.2	Physical Medium Dependent (PMD) service interface	6164
154.3	Delay and Skew	6164
154.3.1	Delay constraints.....	6164
154.3.2	Skew constraints	6164
154.4	PMD MDIO function mapping.....	6165
154.5	PMD functional specifications.....	6166
154.5.1	PMD block diagram.....	6166
154.5.2	PMD transmit function	6166
154.5.3	PMD receive function.....	6167
154.5.4	PMD global signal detect function	6167
154.5.5	PMD reset function.....	6167
154.5.6	PMD global transmit disable function (optional)	6167
154.5.7	PMD fault function (optional)	6167
154.5.8	PMD transmit fault function (optional)	6168
154.5.9	PMD receive fault function (optional).....	6168
154.6	DWDM channel over a DWDM black link	6168
154.7	PMD to MDI optical specifications for 100GBASE-ZR.....	6170
154.7.1	100GBASE-ZR transmitter optical specifications.....	6171
154.7.2	100GBASE-ZR receive optical specifications	6172
154.8	100GBASE-ZR DWDM black link transfer characteristics.....	6172
154.9	Definition of optical parameters and measurement methods.....	6172
154.9.1	Test patterns for optical parameters.....	6172
154.9.2	Optical center frequency (wavelength) and side-mode suppression ratio (SMSR).....	6174
154.9.3	Average channel output power	6174
154.9.4	Spectral excursion.....	6174
154.9.5	Laser linewidth	6174
154.9.6	Offset between the carrier and the nominal center frequency	6175
154.9.7	Power difference between X and Y polarizations	6175
154.9.8	Skew between X and Y polarizations	6175
154.9.9	Error vector magnitude	6175
154.9.10	I-Q offset.....	6175
154.9.11	Optical signal-to-noise ratio (OSNR)	6175
154.9.12	Transmitter in-band OSNR.....	6175
154.9.13	Average receive power	6175
154.9.14	Receiver sensitivity.....	6176

154.9.15 Receiver OSNR.....	6176
154.9.16 Receiver OSNR tolerance	6176
154.9.17 Ripple.....	6176
154.9.18 Optical path OSNR penalty	6176
154.9.19 Optical path power penalty	6176
154.9.20 Polarization dependent loss	6176
154.9.21 Polarization rotation speed.....	6177
154.9.22 Inter-channel crosstalk at TP3	6177
154.9.23 Interferometric crosstalk at TP3	6177
154.10 Safety, installation, environment, and labeling.....	6177
154.10.1 General safety	6177
154.10.2 Laser safety	6177
154.10.3 Installation	6177
154.10.4 Environment.....	6177
154.10.5 Electromagnetic emission	6178
154.10.6 Temperature, humidity, and handling.....	6178
154.10.7 PMD labeling requirements	6178
154.11 Medium Dependent Interface (MDI).....	6178
154.12 Protocol implementation conformance statement (PICS) proforma for Clause 154, Physical Medium Dependent (PMD) sublayer and medium, type 100GBASE-ZR	6179
154.12.1 Introduction.....	6179
154.12.2 Identification.....	6179
154.12.3 Major capabilities/options.....	6180
154.12.4 PICS proforma tables for Physical Medium Dependent (PMD) sublayer and medium, type 100GBASE-ZR.....	6180
155. Clause 155 is reserved for future use.....	6183
156. Clause 156 is reserved for future use.....	6184
157. Introduction to 10 Gb/s, 25 Gb/s, and 50 Gb/s BiDi PHYs.....	6185
157.1 Overview.....	6185
157.1.1 Scope.....	6185
157.1.2 Relationship of Multi-Gigabit Ethernet BiDi PHYs to the ISO OSI reference model ...	6185
157.1.3 Nomenclature.....	6185
157.1.4 Physical Layer signaling systems	6187
157.2 Summary of Multi-Gigabit Ethernet BiDi sublayers.....	6189
157.2.1 Reconciliation Sublayer (RS) and Media Independent Interface (XGMII, 25GMII, and 50GMII)	6189
157.2.2 Physical Coding Sublayer (PCS)	6189
157.2.3 Forward error correction (FEC) sublayer	6189
157.2.4 Physical Medium Attachment (PMA) sublayer.....	6190
157.2.5 Physical Medium Dependent (PMD) sublayer	6190
157.2.6 Management interface (MDIO/MDC)	6190
157.2.7 Management.....	6190
157.3 Service interface specification method and notation	6190
157.4 Delay constraints.....	6190
157.5 ONU silent start	6191
157.6 Protocol implementation conformance statement (PICS) proforma.....	6191
158. Physical Medium Dependent (PMD) sublayer and medium, types 10GBASE-BR10, 10GBASE- BR20, and 10GBASE-BR40.....	6192

158.1	Overview.....	6192
158.1.1	Bit error ratio	6192
158.2	PMD sublayer service interface.....	6193
158.3	Delay constraints.....	6193
158.4	PMD MDIO function mapping.....	6193
158.5	PMD functional specifications.....	6194
158.5.1	PMD block diagram.....	6194
158.5.2	PMD transmit function	6194
158.5.3	PMD receive function.....	6194
158.5.4	PMD signal detect function	6195
158.5.5	PMD reset function.....	6196
158.5.6	PMD global transmit disable function.....	6196
158.5.7	PMD fault function	6196
158.5.8	PMD transmit fault function	6196
158.5.9	PMD receive fault function.....	6196
158.5.10	ONU silent start	6196
158.6	PMD to MDI optical specifications for 10GBASE-BRx.....	6196
158.6.1	10GBASE-BRx transmitter optical specifications	6197
158.6.2	10GBASE-BRx receive optical specifications	6198
158.6.3	10GBASE-BRx illustrative link power budgets	6199
158.7	Jitter specifications for 10GBASE-BRx	6199
158.8	Definition of optical parameters and measurement methods.....	6199
158.8.1	Test patterns	6199
158.8.2	Wavelength and side-mode suppression ratio (SMSR)	6200
158.8.3	Average optical power.....	6201
158.8.4	Extinction ratio	6201
158.8.5	Optical Modulation Amplitude (OMA).....	6201
158.8.6	Relative Intensity Noise (RINxOMA).....	6201
158.8.7	Transmitter optical waveform (transmitter eye)	6201
158.8.8	Receiver sensitivity.....	6202
158.8.9	Stressed receiver sensitivity.....	6202
158.8.10	Transmitter and dispersion penalty (TDP).....	6207
158.9	Safety, installation, environment, and labeling.....	6209
158.9.1	General safety	6209
158.9.2	Laser safety	6209
158.9.3	Installation	6209
158.9.4	Environment.....	6209
158.9.5	Electromagnetic emission.....	6209
158.9.6	Temperature, humidity, and handling.....	6210
158.9.7	PMD labeling requirements.....	6210
158.10	Fiber optic cabling model	6210
158.11	Characteristics of the fiber optic cabling (channel)	6211
158.11.1	Optical fiber and cable.....	6211
158.11.2	Optical fiber connection.....	6211
158.11.3	Medium Dependent Interface (MDI) requirements	6212
158.12	Requirements for interoperation between 10GBASE-BRx PMDs.....	6212
158.13	Protocol implementation conformance statement (PICS) proforma for Clause 158, Physical Medium Dependent (PMD) sublayer and medium, types 10GBASE-BR10, 10GBASE- BR20, and 10GBASE-BR40.....	6213
158.13.1	Introduction.....	6213
158.13.2	Identification.....	6213
158.13.3	Major capabilities/options.....	6214
158.13.4	PICS proforma tables for PMD sublayer and medium, types 10GBASE-BR10, 10GBASE-BR20, and 10GBASE-BR40	6214

159. Physical Medium Dependent (PMD) sublayer and medium, types 25GBASE-BR10, 25GBASE-BR20, and 25GBASE-BR40.....	6218
159.1 Overview.....	6218
159.1.1 Bit error ratio	6219
159.2 Physical Medium Dependent (PMD) service interface	6219
159.3 Delay constraints.....	6219
159.4 PMD MDIO function mapping.....	6220
159.5 PMD functional specifications.....	6220
159.5.1 PMD block diagram.....	6220
159.5.2 PMD transmit function	6221
159.5.3 PMD receive function.....	6221
159.5.4 PMD global signal detect function	6221
159.5.5 PMD reset function.....	6222
159.5.6 PMD global transmit disable function	6222
159.5.7 PMD fault function (optional)	6222
159.5.8 PMD transmit fault function (optional)	6222
159.5.9 PMD receive fault function.....	6223
159.5.10 ONU silent start	6223
159.6 PMD to MDI optical specifications for 25GBASE-BRx.....	6223
159.6.1 25GBASE-BRx transmitter optical specifications	6224
159.6.2 25GBASE-BRx receiver optical specifications	6224
159.6.3 25GBASE-BRx illustrative link power budgets.....	6226
159.7 Definition of optical parameters and measurement methods.....	6226
159.7.1 Test patterns for optical parameters.....	6226
159.7.2 Wavelength and side-mode suppression ratio (SMSR)	6226
159.7.3 Average optical power.....	6226
159.7.4 Optical Modulation Amplitude (OMA).....	6227
159.7.5 Transmitter and dispersion penalty (TDP).....	6227
159.7.6 Extinction ratio	6228
159.7.7 Relative Intensity Noise (RIN _{20OMA}).....	6228
159.7.8 Transmitter optical waveform (transmit eye)	6228
159.7.9 Receiver sensitivity.....	6228
159.7.10 Stressed receiver sensitivity.....	6229
159.8 Safety, installation, environment, and labeling.....	6229
159.8.1 General safety	6229
159.8.2 Laser safety	6229
159.8.3 Installation	6230
159.8.4 Environment.....	6230
159.8.5 Electromagnetic emission	6230
159.8.6 Temperature, humidity, and handling	6230
159.8.7 PMD labeling requirements.....	6230
159.9 Fiber optic cabling model	6230
159.10 Characteristics of the fiber optic cabling (channel)	6231
159.10.1 Optical fiber cable.....	6232
159.10.2 Optical fiber connection.....	6232
159.10.3 Medium Dependent Interface (MDI) requirements	6232
159.11 Requirements for interoperation between 25GBASE-BRx PMDs.....	6233
159.12 Protocol implementation conformance statement (PICS) proforma for Clause 159, Physical Medium Dependent (PMD) sublayer and medium, types 25GBASE-BR10, 25GBASE-BR20, and 25GBASE-BR40.....	6234
159.12.1 Introduction.....	6234
159.12.2 Identification.....	6234
159.12.3 Major capabilities/options.....	6235

159.12.4PICS proforma tables for PMD sublayer and medium, types 25GBASE-BR10, 25GBASE-BR20, and 25GBASE-BR40	6235
160. Physical Medium Dependent (PMD) sublayer and medium, types 50GBASE-BR10, 50GBASE-BR20, and 50GBASE-BR40.....	6239
160.1 Overview.....	6239
160.1.1 Bit error ratio	6240
160.2 Physical Medium Dependent (PMD) service interface	6240
160.3 Delay and Skew	6241
160.3.1 Delay constraints.....	6241
160.3.2 Skew constraints	6241
160.4 PMD MDIO function mapping.....	6242
160.5 PMD functional specifications.....	6242
160.5.1 PMD block diagram.....	6242
160.5.2 PMD transmit function	6243
160.5.3 PMD receive function	6243
160.5.4 PMD global signal detect function	6243
160.5.5 PMD reset function	6244
160.5.6 PMD global transmit disable function	6244
160.5.7 PMD fault function (optional)	6244
160.5.8 PMD transmit fault function (optional)	6244
160.5.9 PMD receive fault function.....	6245
160.5.10 ONU silent start	6245
160.6 PMD to MDI optical specifications for 50GBASE-BRx.....	6245
160.6.1 50GBASE-BRx transmitter optical specifications	6245
160.6.2 50GBASE-BRx receive optical specifications	6246
160.6.3 50GBASE-BRx illustrative link power budgets.....	6248
160.7 Definition of optical parameters and measurement methods.....	6248
160.7.1 Test patterns for optical parameters.....	6248
160.7.2 Wavelength and side-mode suppression ratio (SMSR)	6249
160.7.3 Average optical power	6249
160.7.4 Outer Optical Modulation Amplitude (OMA _{outer}).....	6249
160.7.5 Transmitter and dispersion eye closure for PAM4 (TDECQ)	6250
160.7.6 Transmitter eye closure for PAM4 (TECQ)	6252
160.7.7 Extinction ratio	6252
160.7.8 Transmitter transition time.....	6252
160.7.9 Relative intensity noise (RIN _x OMA)	6252
160.7.10 Receiver sensitivity.....	6253
160.7.11 Stressed receiver sensitivity.....	6254
160.8 Safety, installation, environment, and labeling.....	6255
160.8.1 General safety	6255
160.8.2 Laser safety	6256
160.8.3 Installation	6256
160.8.4 Environment.....	6256
160.8.5 Electromagnetic emission	6256
160.8.6 Temperature, humidity, and handling	6256
160.8.7 PMD labeling requirements.....	6256
160.9 Fiber optic cabling model	6257
160.10 Characteristics of the fiber optic cabling (channel)	6257
160.10.1 Optical fiber cable.....	6258
160.10.2 Optical fiber connection.....	6258
160.10.3 Medium Dependent Interface (MDI) requirements	6258
160.11 Requirements for interoperation between 50GBASE-BRx PMDs.....	6259

160.12 Protocol implementation conformance statement (PICS) proforma for Clause 160, Physical Medium Dependent (PMD) sublayer and medium, types 50GBASE-BR10, 50GBASE-BR20, and 50GBASE-BR40.....	6260
160.12.1 Introduction.....	6260
160.12.2 Identification.....	6260
160.12.3 Major capabilities/options.....	6261
160.12.4 PICS proforma tables for PMD sublayer and medium, types 50GBASE-BR10, 50GBASE-BR20, and 50GBASE-BR40	6261
Annex A (informative) Bibliography	6265
Annex B (informative) System guidelines.....	6269
B.1 Baseband system guidelines and concepts, 10 Mb/s.....	6269
B.1.1 Overall system objectives	6269
B.1.2 Analog system components and parameter values	6269
B.1.3 Minimum frame length determination	6271
B.1.4 System jitter budgets.....	6272
B.1.5 Systems consideration calculations	6274
B.2 System parameters and budgets for 1BASE5	6281
B.2.1 Delay budget.....	6281
B.2.2 Minimum frame length determination	6282
B.2.3 Jitter budget.....	6283
B.3 Example crosstalk computation for multiple disturbers, balanced-pair cable	6284
B.4 10BASE-T guidelines	6286
B.4.1 System jitter budget	6286
B.4.2 Filter characteristics.....	6286
B.4.3 Notes for conformance testing	6286
B.5 10BASE-F	6289
B.5.1 System jitter budget	6289
B.5.2 10BASE-FP fiber optic segment loss budget	6289
Annex C (informative) State diagram, MAC sublayer	6292
Annex D (informative) Application context, selected medium specifications	6293
D.1 Introduction.....	6293
D.2 Type 10BASE5 applications.....	6293
D.3 Type 10BASE2 applications.....	6293
D.4 Type FOIRL and 10BASE-F applications; alternative fiber optic medium applications.....	6294
D.4.1 Alternative fiber types	6294
D.4.2 Type 10BASE-FP applications using 50/125 μm fiber	6296
D.5 10BASE-T use of cabling systems with a nominal differential characteristic impedance of 120 Ω	6297
D.6 10BASE-T use of cabling systems with a nominal differential characteristic impedance of 150 Ω	6298
Annex E (informative) Receiver wavelength design considerations (FOIRL).....	6300
Annex F (normative) Additional attributes required for systems	6301
F.1 Introduction.....	6301
F.1.1 Scope.....	6301
F.2 Objects/Attributes/Actions/Notifications	6301

F.2.1	TimeSinceSystemReset attribute	6301
F.2.2	RepeaterResetTimeStamp attribute	6302
F.2.3	ResetSystemAction action	6302
Annex G (normative) Additional material required for conformance testing		6303
G.1	Introduction	6303
G.1.1	Material in support of the aDataRateMismatches attribute	6303
Annex H (normative) GDMO specifications for CSMA/CD managed objects		6304
Annex J (normative) Electrical isolation and general safety		6305
J.1	Electrical isolation	6305
J.2	General safety	6305
J.3	Protocol implementation conformance statement (PICS) proforma for Annex J, Electrical isolation and general safety	6306
J.3.1	Introduction	6306
J.3.2	Identification	6306
J.3.3	Major capabilities/options	6307
J.3.4	PICS proforma tables for electrical isolation and general safety	6307
Annex K (informative) Optional alternative terminology for “master” and “slave”		6308
Annex 4A (normative) Simplified full duplex media access control		6309
4A.1	Functional model of the MAC method	6309
4A.1.1	Overview	6309
4A.1.2	Full duplex operation	6310
4A.1.3	Relationships to the MAC client and Physical Layers	6311
4A.2	Media access control (MAC) method: precise specification	6311
4A.2.1	Introduction	6311
4A.2.2	Overview of the procedural model	6311
4A.2.3	Packet transmission model	6317
4A.2.4	Frame reception model	6318
4A.2.5	Preamble generation	6319
4A.2.6	Start frame sequence	6319
4A.2.7	Global declarations	6320
4A.2.8	Frame transmission	6322
4A.2.9	Frame reception	6325
4A.2.10	Common procedures	6328
4A.3	Interfaces to/from adjacent layers	6328
4A.3.1	Overview	6328
4A.3.2	MAC service	6328
4A.3.3	Services required from the Physical Layer	6331
4A.4	Specific implementations	6332
4A.4.1	Compatibility overview	6332
4A.4.2	MAC parameters	6333
Annex 22A (informative) MII output delay, setup, and hold time budget		6334
22A.1	System model	6334
22A.2	Signal transmission path characteristics	6335
22A.3	Budget calculation	6336

Annex 22B (informative) MII driver ac characteristics.....	6338
22B.1 Implications of CMOS ASIC processes.....	6338
22B.2 $R_o(\text{min})$ and V, I values for operation from $5\text{ V} \pm 10\%$ supply.....	6339
22B.3 $R_o(\text{min})$ and V, I values for operation from $3.3\text{ V} \pm 0.3\text{ V}$ supply	6339
Annex 22C (informative) Measurement techniques for MII signal timing characteristics	6340
22C.1 Measuring timing characteristics of source terminated signals	6340
22C.2 Measuring timing characteristics of transmit signals at the MII.....	6340
22C.3 Measuring timing characteristics of receive signals at the MII	6340
22C.4 Measuring timing characteristics of MDIO	6341
Annex 22D (informative) Clause 22 access to Clause 45 MMD registers	6342
22D.1 Write operation	6342
22D.2 Read operation	6342
22D.3 MMD address operations	6342
22D.3.1 Address	6342
22D.3.2 Data, no post increment	6343
22D.3.3 Data, post increment on reads and writes	6343
22D.3.4 Data, post increment on writes only	6343
22D.4 PHY Coexistence and bus conflict avoidance	6343
Annex 23A (normative) 6T codewords	6344
Annex 23B (informative) Noise budget.....	6346
Annex 23C (informative) Use of cabling systems with a nominal differential characteristic impedance of 120 W	6347
Annex 27A (normative) Repeater delay consistency requirements.....	6348
Annex 28A (normative) Selector Field definitions.....	6349
Annex 28B (normative) IEEE 802.3 Selector Base Page definition	6350
28B.1 Selector field value.....	6350
28B.2 Technology Ability Field bit assignments	6350
28B.3 Priority resolution	6351
28B.4 Message Page transmission convention.....	6352
Annex 28C (normative) Next Page Message Code field definitions.....	6353
28C.1 Message code 0—Auto-Negotiation reserved code 1	6354
28C.2 Message code 1—Null Message code	6354
28C.3 Message code 2—Technology Ability extension code 1	6354
28C.4 Message code 3—Technology Ability extension code 2	6354
28C.5 Message code 4—Remote fault number code.....	6355
28C.6 Message code 5—Organizationally Unique Identifier (OUI) tag code	6355
28C.7 Message code 6—PHY identifier tag code	6356
28C.8 Message code 2047—Auto-Negotiation reserved code 2	6356
28C.9 Message code 7—100BASE-T2 technology message code	6356
28C.10 Message code 8—1000BASE-T technology message code	6356

28C.11 Message code 9—MultiGBASE-T and 1000BASE-T technology message code.....	6356
28C.12 Message code 10—EEE technology message code.....	6357
28C.13 Message code 11—Organizationally Unique Identifier Tagged Message (Extended Next Page).....	6357
Annex 28D (normative) Description of extensions to Clause 28 and associated annexes	6358
28D.1 Introduction.....	6358
28D.2 Extensions to Clause 28	6358
28D.2.1 Extensions required for Clause 31 (full duplex).....	6358
28D.2.2 Extensions required for Clause 32 (100BASE-T2)	6358
28D.3 Extensions for Clause 31.....	6358
28D.4 Extensions for Clause 32 (100BASE-T2).....	6359
28D.5 Extensions required for Clause 40 (1000BASE-T).....	6359
28D.6 Extensions required for Clause 55 (10GBASE-T).....	6360
28D.7 Extensions required for Energy-Efficient Ethernet (Clause 78)	6360
28D.8 Extensions required for Clause 113 (25GBASE-T and 40GBASE-T)	6360
28D.9 Extensions required for Clause 126 (2.5G/5GBASE-T).....	6361
Annex 29A (informative) DTE and repeater delay components	6362
29A.1 DTE delay	6362
29A.2 Repeater delay.....	6362
Annex 29B (informative) Recommended topology documentation.....	6363
Annex 30A (normative) GDMO specification for IEEE 802.3 managed object classes.....	6364
Annex 30B (normative) GDMO and ASN.1 definitions for management	6365
Annex 30C (normative) SNMP MIB definitions for Link Aggregation	6366
Annex 31A (normative) MAC Control opcode assignments.....	6367
Annex 31B (normative) MAC Control PAUSE operation	6373
31B.1 PAUSE description	6373
31B.2 Parameter semantics.....	6373
31B.3 Detailed specification of PAUSE operation.....	6374
31B.3.1 Transmit operation.....	6374
31B.3.2 Transmit state diagram for PAUSE operation	6374
31B.3.3 Receive operation	6375
31B.3.4 Receive state diagram for PAUSE operation.....	6377
31B.3.5 Status indication operation.....	6378
31B.3.6 Indication state diagram for pause operation	6378
31B.3.7 Timing considerations for PAUSE operation	6379
31B.4 Protocol implementation conformance statement (PICS) proforma for MAC Control PAUSE operation	6382
31B.4.1 Introduction.....	6382
31B.4.2 Identification.....	6382
31B.4.3 Major capabilities/options	6383
31B.4.4 PAUSE command requirements	6384
31B.4.5 PAUSE command state diagram requirements.....	6384
31B.4.6 PAUSE command MAC timing considerations	6384

Annex 31C (normative) MAC Control organization specific extension operation	6386
31C.1 Organization specific extension description	6386
31C.2 Transmission of Extension MAC Control frame	6386
31C.3 Receive operation.....	6386
31C.3.1 Receive state diagram (INITIATE MAC CONTROL FUNCTION) for EXTENSION operation	6387
31C.4 Protocol implementation conformance statement (PICS) proforma for MAC Control organization specific extension operation.....	6388
31C.4.1 Introduction.....	6388
31C.4.2 Identification.....	6388
31C.4.3 EXTENSION command state diagram requirements.....	6388
Annex 31D (normative) MAC Control PFC operation	6389
31D.1 PFC description.....	6389
31D.2 Parameter semantics.....	6389
31D.3 PFC transmit	6390
31D.4 Transmit state diagram for PFC operation.....	6391
31D.4.1 Constants.....	6391
31D.4.2 Variables	6392
31D.4.3 Messages.....	6392
31D.4.4 Transmit state diagram for PFC operation.....	6392
31D.5 PFC receive.....	6392
31D.6 Receive state diagram for PFC operation	6392
31D.6.1 Constants.....	6393
31D.6.2 Variables	6393
31D.6.3 Receive state diagram (INITIATE MAC CONTROL FUNCTION) for PFC operation	6394
31D.7 Protocol implementation conformance statement (PICS) proforma for MAC Control PFC operation.....	6395
31D.7.1 Introduction.....	6395
31D.7.2 Identification.....	6395
31D.7.3 Major capabilities/options	6396
31D.7.4 PFC command requirements.....	6396
31D.7.5 PFC command state diagram requirements	6396
Annex 32A (informative) Use of cabling systems with nominal differential characteristic impedance of 120 Ω or 150 Ω	6397
Annex 33A (informative) PSE-PD stability	6398
33A.1 Recommended PSE design guidelines and test setup.....	6398
33A.2 Recommended PD design guidelines.....	6400
Annex 36A (informative) Jitter test patterns	6401
36A.1 High-frequency test pattern.....	6401
36A.2 Low-frequency test pattern	6401
36A.3 Mixed frequency test pattern.....	6401
36A.4 Long continuous random test pattern.....	6401
36A.5 Short continuous random test pattern.....	6402
Annex 36B (informative) 8B/10B transmission code running disparity calculation examples	6404

Annex 38A (informative) Fiber launch conditions	6406
38A.1 Overfilled Launch	6406
38A.2 Radial Overfilled Launch (ROFL)	6406
Annex 40A (informative) Additional cabling design guidelines	6407
40A.1 Alien crosstalk	6407
40A.1.1 Multipair cabling (i.e., greater than 4-pair)	6407
40A.1.2 Bundled or hybrid cable configurations	6407
40A.2 Cabling configurations	6407
Annex 40B (informative) Description of cable clamp	6409
40B.1 Cable clamp validation	6411
Annex 40C (informative) Add-on interface for additional Next Pages	6413
40C.1 State variables	6415
40C.2 State diagrams	6415
40C.2.1 Auto-Negotiation Transmit state diagram add-on for 1000BASE-T	6415
40C.2.2 Auto-Negotiation Receive state diagram add-on for 1000BASE-T	6418
Annex 43A (informative) Annex 43A is no longer in use	6420
Annex 43B (informative) Annex 43B is no longer in use.	6421
Annex 43C (informative) Annex 43C is no longer in use.	6422
Annex 44A (informative) Diagram of Data Flow	6423
44A.1 10GBASE-R bit ordering	6423
44A.2 10GBASE-W serial bit ordering	6423
44A.3 10GBASE-LX4 bit ordering	6423
44A.4 Loopback locations	6429
Annex 45A (informative) Clause 45 MDIO electrical interface	6430
45A.1 MDIO driver	6430
45A.2 Single Clause 45 electrical interface	6430
45A.3 Clause 45 electrical interface for STA with Clause 22 electrical interface to PHYs	6431
45A.4 Clause 22 electrical interface for STA with Clause 45 electrical interface to MMDs	6431
Annex 48A (normative) Jitter test patterns	6433
48A.1 High-frequency test pattern	6433
48A.2 Low-frequency test pattern	6433
48A.3 Mixed-frequency test pattern	6433
48A.4 Continuous random test pattern (CRPAT)	6434
48A.5 Continuous jitter test pattern (CJPAT)	6435
48A.5.1 Continuous jitter test pattern (CJPAT) 10 bit values	6436
Annex 48B (informative) Jitter test methods	6440

48B.1	BER and jitter model.....	6440
48B.1.1	Description of dual Dirac mathematical model.....	6440
48B.1.2	Random Jitter.....	6442
48B.1.3	Addition of Deterministic Jitter.....	6442
48B.1.4	Effects of jitter high-pass filtering and CJPAT on deterministic jitter.....	6442
48B.2	Jitter tolerance test methodologies.....	6443
48B.2.1	Calibration of a signal source using the BERT scan technique.....	6443
48B.3	Jitter output test methodologies.....	6444
48B.3.1	Time domain measurement—Scope and BERT scan.....	6444
48B.3.2	Time Interval Analysis.....	6446
Annex 50A	(informative) Thresholds for Severely Errored Second calculations.....	6450
50A.1	Section SES threshold.....	6450
50A.2	Line SES threshold.....	6450
50A.3	Path SES threshold.....	6450
50A.4	Definition of Path Block Error.....	6451
50A.5	Definition of Far End Path Block Error.....	6451
Annex 55A	(normative) LDPC details.....	6452
55A.1	Generator matrix.....	6452
55A.2	Sparse parity check matrix H.....	6452
Annex 55B	(informative) Additional cabling design guidelines for 10GBASE-T.....	6453
55B.1	Alien crosstalk considerations.....	6453
55B.1.1	Alien crosstalk mitigation.....	6454
55B.1.2	Alien crosstalk mitigation procedure.....	6455
Annex 57A	(normative) Requirements for support of Slow Protocols.....	6456
57A.1	Introduction and rationale.....	6456
57A.2	Slow Protocol transmission characteristics.....	6456
57A.3	Addressing.....	6456
57A.4	Protocol identification.....	6457
57A.5	Handling of Slow Protocol frames.....	6458
57A.6	Protocol implementation conformance statement (PICS) proforma for Annex 57A, Requirements for support of Slow Protocols.....	6459
57A.6.1	Introduction.....	6459
57A.6.2	Identification.....	6459
Annex 57B	(normative) Organization specific slow protocol (OSSP).....	6461
57B.1	Transmission and representation of octets.....	6461
57B.1.1	OSSPDU frame structure.....	6461
57B.2	Protocol implementation conformance statement (PICS) proforma for Annex 57B, Organization specific slow protocol (OSSP).....	6463
57B.2.1	Introduction.....	6463
57B.2.2	Identification.....	6463
Annex 58A	(informative) Frame-based testing.....	6465
Annex 58B	(informative) Jitter, OMA, and TDP.....	6467

58B.1	Jitter at TP1 and TP4 for 100BASE-LX10 and 100BASE-BX10	6467
58B.2	OMA relationship to extinction ratio and power measurements	6467
58B.3	Approximate measures of TDP	6468
58B.4	Jitter measurements.....	6469
Annex 59A	(informative) Jitter budget and measurements	6471
59A.1	Jitter specifications.....	6471
59A.2	Total jitter measurements.....	6472
59A.3	Deterministic or high probability jitter measurement.....	6472
Annex 60A	(informative) Jitter at TP1 to TP4 for 1000BASE-PX.....	6473
Annex 61A	(informative) EFM Copper examples	6475
61A.1	Purpose and scope.....	6475
61A.2	Aggregation Discovery example.....	6475
61A.3	Example of 64/65-octet encapsulation	6479
Annex 61B	(informative) Handshake codepoints for 2BASE-TL and 10PASS-TS	6483
61B.1	Purpose and scope.....	6483
61B.2	Level-1 S field codepoints for 2BASE-TL and 10PASS-TS	6483
61B.3	Codepoints for 2BASE-TL	6483
61B.3.1	Level-2 S field codepoints for 2BASE-TL	6483
61B.3.2	Level-3 S field codepoints for 2BASE-TL	6485
61B.4	Codepoints for 10PASS-TS	6504
61B.4.1	Level-2 S field codepoints for 10PASS-TS	6504
61B.4.2	Level-3 S field codepoints for 10PASS-TS	6505
61B.5	Protocol implementation conformance statement (PICS) proforma for Annex 61B, Handshake codepoints for 2BASE-TL and 10PASS-TS	6510
61B.5.1	Introduction.....	6510
61B.5.2	Identification.....	6510
61B.5.3	Major capabilities/options.....	6510
61B.5.4	2BASE-TL handshake coding rules	6511
Annex 62A	(normative) PMD profiles for 10PASS-TS.....	6512
62A.1	Introduction and rationale	6512
62A.2	Relationship to other clauses.....	6512
62A.3	Profile definitions.....	6512
62A.3.1	Bandplan and PSD mask profiles	6512
62A.3.2	Bandplan definitions	6514
62A.3.3	PSD mask definitions.....	6514
62A.3.4	UPBO Reference PSD Profiles.....	6514
62A.3.5	Band Notch Profiles.....	6515
62A.3.6	Payload rate profiles	6517
62A.3.7	Complete profiles.....	6517
62A.3.8	Default profile.....	6517
62A.4	Register settings	6518
62A.5	Protocol implementation conformance statement (PICS) proforma for Annex 62A, PMD profiles for 10PASS-TS	6520
62A.5.1	Introduction.....	6520
62A.5.2	Identification.....	6520

62A.5.3 Major capabilities/options.....	6521
62A.5.4 PICS proforma tables for PMD profiles for 10PASS-TS	6521
Annex 62B (normative) Performance guidelines for 10PASS-TS PMD profiles	6525
62B.1 Introduction and rationale	6525
62B.2 Relationship to other clauses.....	6525
62B.3 Performance test cases	6525
62B.3.1 Additional tests	6527
62B.4 Deployment guidelines	6527
62B.5 Protocol implementation conformance statement (PICS) proforma for Annex 62B, Performance guidelines for 10PASS-TS PMD profiles.....	6528
62B.5.1 Introduction.....	6528
62B.5.2 Identification	6528
62B.5.3 Major capabilities/options.....	6529
62B.5.4 PICS proforma tables for Performance guidelines for 10PASS-TS PMD profiles	6529
Annex 62C (informative) 10PASS-TS Examples	6530
62C.1 Introduction.....	6530
62C.2 Bandplan configuration.....	6530
62C.2.1 Plan A with variable LF region.....	6533
62C.3 PSD mask configuration	6534
62C.3.1 General procedure.....	6534
62C.3.2 PSD Masks for Plan A with variable LF region	6534
Annex 63A (normative) PMD Profiles for 2BASE-TL.....	6535
63A.1 Introduction and rationale	6535
63A.2 Relationship to other clauses.....	6535
63A.3 Profile definitions.....	6535
63A.4 Register settings	6536
63A.5 Protocol implementation conformance statement (PICS) proforma Annex 63A, PMD Profiles for 2BASE-TL	6537
63A.5.1 Introduction.....	6537
63A.5.2 Identification	6537
63A.5.3 Major capabilities/options.....	6538
63A.5.4 PICS proforma tables for Performance guidelines for 2BASE-TL PMD profiles	6538
Annex 63B (normative) Performance guidelines for 2BASE-TL PMD profiles	6539
63B.1 Introduction and rationale	6539
63B.2 Relationship to other clauses.....	6539
63B.3 Performance test cases.	6539
63B.4 Deployment Guidelines.....	6541
63B.5 Protocol implementation conformance statement (PICS) proforma for Annex 63B, Performance guidelines for 2BASE-TL PMD profiles.....	6542
63B.5.1 Introduction.....	6542
63B.5.2 Identification	6542
63B.5.3 Major capabilities/options.....	6543
63B.5.4 PICS proforma tables for Performance guidelines for 2BASE-TL PMD profiles	6543
Annex 67A (informative) Environmental characteristics for Ethernet subscriber access networks	6544

67A.1	Introduction.....	6544
67A.1.1	Terminal deployment scenarios	6544
67A.2	Temperature	6545
67A.3	Temperature impact on optical components	6547
67A.3.1	Component case temperature recommendations	6547
Annex 69A	(normative) Interference tolerance testing	6549
69A.1	Introduction.....	6549
69A.2	Test setup	6549
69A.2.1	Pattern generator.....	6550
69A.2.2	Test channel.....	6550
69A.2.3	Interference generator.....	6551
69A.2.4	Transmitter control	6551
69A.3	Test methodology.....	6552
Annex 69B	(informative) Interconnect characteristics	6553
69B.1	Overview.....	6553
69B.2	Reference model	6553
69B.3	Characteristic impedance	6553
69B.4	Channel parameters.....	6554
69B.4.1	Overview.....	6554
69B.4.2	Fitted attenuation	6555
69B.4.3	Insertion loss	6557
69B.4.4	Insertion loss deviation	6560
69B.4.5	Return loss	6562
69B.4.6	Crosstalk	6563
Annex 73A	(normative) Next page message code field definitions	6566
73A.1	Message code 1—Null Message code	6566
73A.2	Message code 5—Organizationally Unique Identifier (OUI) tag code	6566
73A.3	Message code 6—AN device identifier tag code.....	6567
73A.4	Message code 10—EEE technology message code.....	6568
Annex 74A	(informative) FEC block encoding examples.....	6569
74A.1	Input to the FEC (2112,2080) Encoder.....	6569
74A.2	Output of the FEC (2112,2080) Encoder	6569
74A.3	Output of the FEC (2112,2080) Encoder after scrambling with PN-2112 sequence.....	6570
74A.4	Output of the PN-2112 sequence generator	6571
74A.5	Output of the FEC (2112,2080) Encoder to Support Rapid Block during the wake state in EEE (optional)	6571
74A.6	Output of the FEC (2112,2080) Encoder to Support Rapid Block during the refresh state in EEE (optional)	6571
Annex 75A	(informative) Dual-rate receiver implementation.....	6573
75A.1	Overview	6573
Annex 75B	(informative) Illustrative channels and penalties for 10GBASE-PR and 10/1GBASE-PRX power budget classes.....	6576

75B.1 Overview	6576
75B.2 Wavelength allocation.....	6576
75B.2.1 Downstream wavelength allocation.....	6576
75B.2.2 Upstream wavelength allocation.....	6578
Annex 75C (informative) Jitter at TP1 to TP8 for 10GBASE-PR and 10/1GBASE-PRX	6579
75C.1 Overview	6579
Annex 76A (informative) FEC Encoding example	6581
76A.1 Introduction and rationale	6581
76A.2 64B/66B block input	6581
76A.3 66 bit block input in binary format	6583
76A.4 RS(255,223) input buffer in Binary Format.....	6583
76A.5 RS(255,223) input buffer	6584
76A.6 Parity symbol output	6585
76A.7 Parity symbols in binary format.....	6585
76A.8 64B/66B Parity Blocks for Transmit	6586
76A.9 Parity 66 bit blocks in binary format	6586
Annex 83A (normative) 40 Gb/s Attachment Unit Interface (XLAUI) and 100 Gb/s ten-lane Attachment Unit Interface (CAUI-10).....	6587
83A.1 Overview	6587
83A.1.1 Summary of major concepts	6588
83A.1.2 Rate of operation.....	6588
83A.2 XLAUI/CAUI-10 link block diagram.....	6588
83A.2.1 Transmitter compliance points.....	6589
83A.2.2 Receiver compliance points	6590
83A.3 XLAUI/CAUI-10 electrical characteristics	6590
83A.3.1 Signal levels.....	6590
83A.3.2 Signal paths.....	6591
83A.3.3 EEE operation	6591
83A.3.4 Transmitter characteristics.....	6591
83A.3.5 Receiver characteristics	6596
83A.4 Interconnect characteristics.....	6600
83A.4.1 Characteristic impedance	6601
83A.5 Electrical parameter measurement methods	6602
83A.5.1 Transmit jitter	6602
83A.5.2 Receiver tolerance.....	6602
83A.6 Environmental specifications.....	6603
83A.6.1 General safety	6603
83A.6.2 Network safety	6603
83A.6.3 Installation and maintenance guidelines	6603
83A.6.4 Electromagnetic compatibility	6603
83A.6.5 Temperature and humidity.....	6603
83A.7 Protocol implementation conformance statement (PICS) proforma for Annex 83A, 40 Gb/s Attachment Unit Interface (XLAUI) and 100 Gb/s ten-lane Attachment Unit Interface (CAUI-10).....	6604
83A.7.1 Introduction.....	6604
83A.7.2 Identification	6604
83A.7.3 Major capabilities/options.....	6605
83A.7.4 XLAUI/CAUI-10 transmitter requirements.....	6605

83A.7.5	XLAUI/CAUI-10 receiver requirements	6606
83A.7.6	Electrical measurement methods	6606
83A.7.7	Environmental specifications.....	6606
Annex 83B (normative) Chip-to-module 40 Gb/s Attachment Unit Interface (XLAUI) and 100 Gb/s ten-lane Attachment Unit Interface (CAUI-10).....		6607
83B.1	Overview	6607
83B.2	Compliance point specifications for chip-to-module XLAUI/CAUI-10	6609
83B.2.1	Module specifications	6611
83B.2.2	Host specifications.....	6614
83B.2.3	Host input signal tolerance	6615
83B.3	Environmental specifications.....	6616
83B.3.1	General safety	6616
83B.3.2	Network safety	6616
83B.3.3	Installation and maintenance guidelines	6616
83B.3.4	Electromagnetic compatibility	6616
83B.3.5	Temperature and humidity.....	6617
83B.4	Protocol implementation conformance statement (PICS) proforma for Annex 83B, Chip-to-module 40 Gb/s Attachment Unit Interface (XLAUI) and 100 Gb/s ten-lane Attachment Unit Interface (CAUI-10)	6618
83B.4.1	Introduction.....	6618
83B.4.2	Identification	6618
83B.4.3	Major capabilities/options.....	6619
83B.4.4	Module requirements	6619
83B.4.5	Host requirements	6619
83B.4.6	Environmental specifications.....	6620
Annex 83C (informative) PMA sublayer partitioning examples.....		6621
83C.1	Partitioning examples with FEC	6621
83C.1.1	FEC implemented with PCS	6621
83C.1.2	FEC implemented with PMD	6622
83C.2	Partitioning examples with RS-FEC	6623
83C.2.1	Single PMA sublayer with RS-FEC	6623
83C.2.2	Single CAUI-10 with RS-FEC	6624
83C.3	Partitioning examples without FEC	6625
83C.3.1	Single PMA sublayer without FEC	6625
83C.3.2	Single XLAUI/CAUI-4 without FEC	6626
83C.3.3	Separate SERDES for optical module interface	6627
83C.4	Partitioning examples with SC-FEC	6628
83C.4.1	CAUI-4 with SC-FEC.....	6628
Annex 83D (normative) Chip-to-chip 100 Gb/s four-lane Attachment Unit Interface (CAUI-4).....		6629
83D.1	Overview	6629
83D.2	CAUI-4 chip-to-chip compliance point definition.....	6631
83D.3	CAUI-4 chip-to-chip electrical characteristics	6631
83D.3.1	CAUI-4 transmitter characteristics	6631
83D.3.2	Optional EEE operation	6633
83D.3.3	CAUI-4 receiver characteristics.....	6634
83D.3.4	Global energy detect function for optional EEE operation.....	6636
83D.4	CAUI-4 chip-to-chip channel characteristics.....	6636
83D.5	Example usage of the optional transmitter equalization feedback.....	6637

83D.5.1 Overview.....	6637
83D.5.2 Tuning equalization settings on lane 0 in the transmit direction	6638
83D.5.3 Tuning equalization settings on lane 0 in the receive direction.....	6639
83D.6 Protocol implementation conformance statement (PICS) proforma for Annex 83D, Chip-to-chip 100 Gb/s four-lane Attachment Unit Interface (CAUI-4)	6640
83D.6.1 Introduction.....	6640
83D.6.2 Identification	6640
83D.6.3 Major capabilities/options.....	6641
83D.6.4 PICS proforma tables for chip-to-chip 100 Gb/s four-lane Attachment Unit Interface (CAUI-4).....	6641
Annex 83E (normative) Chip-to-module 100 Gb/s four-lane Attachment Unit Interface (CAUI-4)	6643
83E.1 Overview	6643
83E.1.1 Bit error ratio	6644
83E.2 CAUI-4 chip-to-module compliance point definitions	6645
83E.3 CAUI-4 chip-to-module electrical characteristics	6645
83E.3.1 CAUI-4 host output characteristics.....	6645
83E.3.2 CAUI-4 module output characteristics	6651
83E.3.3 CAUI-4 host input characteristics.....	6652
83E.3.4 CAUI-4 module input characteristics	6656
83E.4 CAUI-4 measurement methodology	6659
83E.4.1 HCB/MCB characteristics	6659
83E.4.2 Eye width and eye height measurement method	6659
83E.5 Protocol implementation conformance statement (PICS) proforma for Annex 83E, Chip-to-module 100 Gb/s four-lane Attachment Unit Interface (CAUI-4)	6661
83E.5.1 Introduction.....	6661
83E.5.2 Identification	6661
83E.5.3 Major capabilities/options.....	6662
83E.5.4 PICS proforma tables for chip-to-module 100 Gb/s four-lane Attachment Unit Interface (CAUI-4)	6662
Annex 85A (informative) 40GBASE-CR4 and 100GBASE-CR10 TP0 and TP5 test point parameters.	6664
85A.1 Overview	6664
85A.2 Transmitter characteristics at TP0.....	6664
85A.3 Receiver characteristics at TP5	6665
85A.4 Transmitter and receiver differential printed circuit board trace loss.....	6665
85A.5 Channel insertion loss	6666
85A.6 Channel return loss.....	6667
85A.7 Channel insertion loss deviation (ILD).....	6667
85A.8 Channel integrated crosstalk noise (ICN)	6668
Annex 86A (normative) Parallel Physical Interface (nPPI) for 40GBASE-SR4 and 40GBASE-LR4 (XLPPI) and 100GBASE-SR10 (CPPI)	6670
86A.1 Overview	6670
86A.2 Block diagram and test points	6670
86A.3 Lane assignments	6670
86A.4 Electrical specifications for nPPI.....	6671
86A.4.1 nPPI host to module electrical specifications	6671
86A.4.2 nPPI module to host electrical specifications	6674
86A.5 Definitions of electrical parameters and measurement methods	6675
86A.5.1 Test points and compliance boards	6675

86A.5.2	Test patterns and related subclauses	6680
86A.5.3	Parameter definitions	6680
86A.6	Recommended electrical channel.....	6687
86A.7	Safety, installation, environment, and labeling.....	6688
86A.7.1	General safety	6688
86A.7.2	Installation	6688
86A.7.3	Environment.....	6688
86A.7.4	PMD labeling.....	6688
86A.8	Protocol implementation conformance statement (PICS) proforma for Annex 86A, Parallel Physical Interface (nPPI) for 40GBASE-SR4 and 40GBASE-LR4 (XLPPi) and 100GBASE-SR10 (CPPI)	6689
86A.8.1	Introduction.....	6689
86A.8.2	Identification	6689
86A.8.3	Major capabilities/options.....	6690
86A.8.4	PICS proforma tables for Parallel Physical Interface (nPPI) for 40GBASE-SR4 and 40GBASE-LR4 (XLPPi) and 100GBASE-SR10 (CPPI)	6690
Annex 91A	(informative) RS-FEC codeword examples	6693
91A.1	Input to the 64B/66B to 256B/257B transcoder.....	6693
91A.2	Output of the RS(528,514) encoder	6694
91A.3	Output of the RS(544,514) encoder	6694
91A.4	Reed-Solomon encoder model	6695
91A.4.1	Global variable declarations for RS(528,514)	6695
91A.4.2	Global variable declarations for RS(544,514)	6696
91A.4.3	Other global variable declarations	6696
91A.4.4	$GF(2^{10})$ multiplier function	6696
91A.4.5	Reed-Solomon encoder function	6696
91A.4.6	Main function.....	6697
Annex 92A	(informative) 100GBASE-CR4 TP0 and TP5 test point parameters and channel characteristics.....	6698
92A.1	Overview	6698
92A.2	Transmitter characteristics at TP0.....	6698
92A.3	Receiver characteristics at TP5	6698
92A.4	Transmitter and receiver differential printed circuit board trace loss	6698
92A.5	Channel insertion loss	6699
92A.6	Channel return loss.....	6701
92A.7	Channel Operating Margin (COM).....	6701
Annex 93A	(normative) Specification methods for electrical channels	6702
93A.1	Channel Operating Margin.....	6702
93A.1.1	Measurement of the channel	6705
93A.1.2	Transmitter and receiver device package models	6705
93A.1.3	Path terminations	6708
93A.1.4	Filters	6708
93A.1.5	Pulse response.....	6709
93A.1.6	Determination of variable equalizer parameters	6709
93A.1.7	Interference and noise amplitude.....	6711
93A.2	Test channel calibration using COM	6713
93A.3	Fitted insertion loss	6714
93A.4	Insertion loss deviation	6715

93A.5 Effective Return Loss.....	6715
93A.5.1 Pulse time-domain reflection signal	6715
93A.5.2 Effective reflection waveform	6716
93A.5.3 Sampled effective reflection	6717
93A.5.4 x-quantile of the reflection distribution	6718
93A.5.5 ERL	6718
Annex 93B (informative) Electrical backplane reference model	6719
Annex 93C (normative) Receiver interference tolerance	6720
93C.1 Test setup	6720
93C.2 Test method.....	6723
Annex 97A (normative) Common-mode conversion test methodology.....	6725
97A.1 Introduction.....	6725
97A.2 Test configuration and measurement	6725
97A.3 Protocol implementation conformance statement (PICS) proforma for Annex 97A, Common-mode conversion test methodology	6727
97A.3.1 Introduction.....	6727
97A.3.2 Identification.....	6727
97A.3.3 Major capabilities/options.....	6728
Annex 97B (normative) Alien Crosstalk Test Procedure	6729
97B.1 Introduction.....	6729
97B.1.1 Alien crosstalk test configurations.....	6729
97B.2 Alien crosstalk coupled between type A link segments.....	6729
97B.3 Cable bundling	6730
97B.4 Protocol implementation conformance statement (PICS) proforma for Annex 97B, Alien Crosstalk Test Procedure	6732
97B.4.1 Introduction.....	6732
97B.4.2 Identification.....	6732
97B.4.3 Major capabilities/options.....	6733
Annex 98A (normative) Selector Field definitions.....	6734
98A.1 Introduction.....	6734
Annex 98B (normative) IEEE 802.3 Selector Base Page definition	6735
98B.1 Introduction.....	6735
98B.2 Selector field value.....	6735
98B.3 Technology Ability Field bit assignments	6735
98B.3.1 10BASE-T1L-specific bit assignments	6736
98B.4 Priority Resolution	6736
98B.5 Message Page transmission convention.....	6736
Annex 98C (normative) Next Page Message Code Field definitions.....	6737
98C.1 Introduction.....	6737
98C.2 Message code 1—Null Message code	6737
98C.3 Message code 5—Organizationally Unique Identifier (OUI) tag code	6737

98C.4 Message code 6—AN device identifier tag code	6738
Annex 100A (normative) EPoC OFDM channel model.....	6739
100A.1 Topology	6739
100A.2 Downstream channel parameters	6739
100A.3 Upstream channel parameters	6742
100A.4 Protocol implementation conformance statement (PICS) proforma for Annex 100A, EPoC OFDM channel model.....	6745
100A.4.1 Introduction.....	6745
100A.4.2 Identification.....	6745
100A.4.3 Major capabilities/options.....	6746
Annex 109A (normative) Chip-to-chip 25 Gigabit Attachment Unit Interface (25GAUI C2C).....	6747
109A.1 Overview	6747
109A.2 25GAUI C2C compliance point definition	6748
109A.3 25GAUI C2C electrical characteristics.....	6748
109A.3.1 25GAUI C2C transmitter characteristics.....	6748
109A.3.2 25GAUI C2C receiver characteristics	6748
109A.3.3 Optional EEE operation	6748
109A.4 25GAUI C2C channel characteristics	6748
109A.5 Protocol implementation conformance statement (PICS) proforma for Annex 109A, Chip- to-chip 25 Gigabit Attachment Unit Interface (25GAUI C2C)	6749
109A.5.1 Introduction.....	6749
109A.5.2 Identification	6749
109A.5.3 Major capabilities/options.....	6750
109A.5.4 PICS proforma tables for chip-to-chip 25 Gigabit Attachment Unit Interface (25GAUI C2C)	6750
Annex 109B (normative) Chip-to-module 25 Gigabit Attachment Unit Interface (25GAUI C2M).....	6752
109B.1 Overview	6752
109B.1.1 Bit error ratio	6753
109B.2 25GAUI C2M compliance point definitions.....	6753
109B.3 25GAUI C2M electrical characteristics.....	6753
109B.3.1 25GAUI C2M host output characteristics	6753
109B.3.2 25GAUI C2M module output characteristics	6753
109B.3.3 25GAUI C2M host input characteristics	6754
109B.3.4 25GAUI C2M module input characteristics	6754
109B.4 25GAUI C2M measurement methodology	6755
109B.4.1 Eye width, eye height, and eye closure measurement method B.....	6755
109B.5 Protocol implementation conformance statement (PICS) proforma for Annex 109B, Chip- to-module 25 Gigabit Attachment Unit Interface (25GAUI C2M)	6757
109B.5.1 Introduction.....	6757
109B.5.2 Identification.....	6757
109B.5.3 Major capabilities/options.....	6758
109B.5.4 PICS proforma tables for chip-to-module 25 Gigabit Attachment Unit Interface (25GAUI C2M).....	6758
Annex 109C (informative) 25GBASE-R PMA sublayer partitioning examples.....	6761
Annex 110A (informative) TP0 and TP5 test point parameters and channel characteristics for 25GBASE-CR and 25GBASE-CR-S.....	6765

110A.1 Overview	6765
110A.2 Transmitter characteristics at TP0.....	6765
110A.3 Receiver characteristics at TP5	6765
110A.4 Transmitter and receiver differential printed circuit board trace loss	6765
110A.5 Channel insertion loss	6765
110A.6 Channel return loss.....	6767
110A.7 Channel Operating Margin (COM).....	6767
Annex 110B (normative) Test fixtures for 25GBASE-CR, 25GBASE-CR-S, and 25GAUI C2M	6768
110B.1 Test fixtures.....	6768
110B.1.1 SFP28 TP2 or TP3 test fixture	6768
110B.1.2 SFP28 Cable assembly test fixture	6768
110B.1.3 SFP28 Mated test fixtures.....	6769
110B.2 Protocol implementation conformance statement (PICS) proforma for Annex 110B, Test fixtures for 25GBASE-CR, 25GBASE-CR-S, and 25GAUI C2M.....	6771
110B.2.1 Introduction.....	6771
110B.2.2 Identification.....	6771
110B.2.3 Major capabilities/options.....	6772
110B.2.4 PICS proforma tables for test fixtures for 25GBASE-CR, 25GBASE-CR-S, and 25GAUI C2M	6772
Annex 110C (normative) Host and cable assembly form factors for 25GBASE-CR and 25GBASE-CR-S PHYs	6773
110C.1 Overview	6773
110C.2 Host form factors	6774
110C.2.1 SFP28 host form factor	6774
110C.2.2 QSFP28 host form factor	6774
110C.3 Cable assembly form factors.....	6775
110C.3.1 SFP28 to SFP28 cable assembly form factor.....	6775
110C.3.2 QSFP28 to QSFP28 cable assembly form factor.....	6775
110C.3.3 QSFP28 to 4×SFP28 cable assembly form factor	6775
Annex 113A (informative) Description of cable clamp and test setup.....	6777
113A.1 Overview	6777
113A.2 Description of cable clamp	6777
113A.3 Cable clamp measurement, calibration, and validation	6779
113A.4 Test setup	6782
Annex 115A (informative) BCH codeword examples	6783
115A.1 Output of the BCH(896, 720) encoder.....	6783
115A.2 Output of the BCH(1976, 1668) encoder.....	6783
Annex 119A (informative) 200GBASE-R and 400GBASE-R PCS FEC codeword examples	6785
Annex 120A (informative) 200 Gb/s and 400 Gb/s PMA sublayer partitioning examples.....	6791
120A.1 Partitioning example supporting 400GBASE-SR16.....	6791
120A.2 Partitioning examples supporting 200GBASE-DR4/FR4/LR4 and 400GBASE-FR8/LR8 ..	6792
120A.3 Partitioning examples supporting 400GBASE-DR4.....	6795
120A.4 Partitioning example using 200GXS and 400GXS.....	6797

Annex 120B (normative) Chip-to-chip 200 Gb/s eight-lane Attachment Unit Interface (200GAUI-8 C2C) and 400 Gb/s sixteen-lane Attachment Unit Interface (400GAUI-16 C2C).....	6798
120B.1 Overview	6798
120B.2 200GAUI-8 and 400GAUI-16 chip-to-chip compliance point definition	6800
120B.3 200GAUI-8 and 400GAUI-16 chip-to-chip electrical characteristics	6801
120B.3.1 200GAUI-8 and 400GAUI-16 C2C transmitter characteristics	6801
120B.3.2 200GAUI-8 and 400GAUI-16 C2C receiver characteristics	6801
120B.4 200GAUI-8 and 400GAUI-16 chip-to-chip channel characteristics	6802
120B.5 Protocol implementation conformance statement (PICS) proforma for Annex 120B, Chip-to-chip 200 Gb/s eight-lane Attachment Unit Interface (200GAUI-8 C2C) and 400 Gb/s sixteen-lane Attachment Unit Interface (400GAUI-16 C2C)	6803
120B.5.1 Introduction.....	6803
120B.5.2 Identification.....	6803
120B.5.3 Major capabilities/options.....	6804
120B.5.4 PICS proforma tables for Chip-to-chip 200 Gb/s eight-lane Attachment Unit Interface (200GAUI-8 C2C) and 400 Gb/s sixteen-lane Attachment Unit Interface (400GAUI-16 C2C)	6804
Annex 120C (normative) Chip-to-module 200 Gb/s eight-lane Attachment Unit Interface (200GAUI-8 C2M) and 400 Gb/s sixteen-lane Attachment Unit Interface (400GAUI-16 C2M)	6806
120C.1 Overview	6806
120C.1.1 Bit error ratio	6808
120C.2 200GAUI-8 and 400GAUI-16 chip-to-module compliance point definitions.....	6808
120C.3 200GAUI-8 and 400GAUI-16 chip-to-module electrical characteristics	6808
120C.3.1 200GAUI-8 and 400GAUI-16 C2M host output characteristics	6808
120C.3.2 200GAUI-8 and 400GAUI-16 C2M module output characteristics.....	6808
120C.3.3 200GAUI-8 and 400GAUI-16 C2M host input characteristics	6808
120C.3.4 200GAUI-8 and 400GAUI-16 C2M module input characteristics.....	6809
120C.4 200GAUI-8 and 400GAUI-16 C2M measurement methodology.....	6809
120C.5 Protocol implementation conformance statement (PICS) proforma for Annex 120C, Chip-to-module 200 Gb/s eight-lane Attachment Unit Interface (200GAUI-8 C2M) and 400 Gb/s sixteen-lane Attachment Unit Interface (400GAUI-16 C2M).....	6810
120C.5.1 Introduction.....	6810
120C.5.2 Identification.....	6810
120C.5.3 Major capabilities/options.....	6811
120C.5.4 PICS proforma tables for Chip-to-module 200 Gb/s eight-lane Attachment Unit Interface (200GAUI-8 C2M) and 400 Gb/s sixteen-lane Attachment Unit Interface (400GAUI-16 C2M)	6811
Annex 120D (normative) Chip-to-chip 200 Gb/s four-lane Attachment Unit Interface (200GAUI-4 C2C) and 400 Gb/s eight-lane Attachment Unit Interface (400GAUI-8 C2C)	6813
120D.1 Overview	6813
120D.2 200GAUI-4 and 400GAUI-8 chip-to-chip compliance point definition	6816
120D.3 200GAUI-4 and 400GAUI-8 chip-to-chip electrical characteristics	6816
120D.3.1 200GAUI-4 and 400GAUI-8 C2C transmitter characteristics	6816
120D.3.2 200GAUI-4 and 400GAUI-8 C2C receiver characteristics	6823
120D.4 200GAUI-4 and 400GAUI-8 chip-to-chip channel characteristics	6826
120D.4.1 Channel Operating Margin	6826
120D.4.2 Channel return loss	6827

120D.5 Protocol implementation conformance statement (PICS) proforma for Annex 120D, Chip-to-chip 200 Gb/s four-lane Attachment Unit Interface (200GAUI-4 C2C) and 400 Gb/s eight-lane Attachment Unit Interface (400GAUI-8 C2C)	6829
120D.5.1 Introduction.....	6829
120D.5.2 Identification.....	6829
120D.5.3 Major capabilities/options.....	6830
120D.5.4 PICS proforma tables for Chip-to-chip 200 Gb/s four-lane Attachment Unit Interface (200GAUI-4 C2C) and 400 Gb/s eight-lane Attachment Unit Interface (400GAUI-8 C2C)	6830
Annex 120E (normative) Chip-to-module 200 Gb/s four-lane Attachment Unit Interface (200GAUI-4 C2M) and 400 Gb/s eight-lane Attachment Unit Interface (400GAUI-8 C2M)	6832
120E.1 Overview	6832
120E.1.1 Bit error ratio	6834
120E.2 200GAUI-4 and 400GAUI-8 chip-to-module compliance point definitions.....	6834
120E.3 200GAUI-4 and 400GAUI-8 chip-to-module electrical characteristics	6835
120E.3.1 200GAUI-4 and 400GAUI-8 C2M host output characteristics	6835
120E.3.2 200GAUI-4 and 400GAUI-8 C2M module output characteristics.....	6840
120E.3.3 200GAUI-4 and 400GAUI-8 C2M host input characteristics	6842
120E.3.4 200GAUI-4 and 400GAUI-8 C2M module input characteristics.....	6845
120E.4 200GAUI-4 and 400GAUI-8 C2M measurement methodology.....	6847
120E.4.1 HCB/MCB characteristics	6847
120E.4.2 Eye width and eye height measurement method	6848
120E.4.3 Vertical eye closure	6850
120E.5 Protocol implementation conformance statement (PICS) proforma for Annex 120E, Chip-to-module 200 Gb/s four-lane Attachment Unit Interface (200GAUI-4 C2M) and 400 Gb/s eight-lane Attachment Unit Interface (400GAUI-8 C2M).....	6852
120E.5.1 Introduction.....	6852
120E.5.2 Identification.....	6852
120E.5.3 Major capabilities/options.....	6853
120E.5.4 PICS proforma tables for Chip-to-module 200 Gb/s four-lane Attachment Unit Interface (200GAUI-4 C2M) and 400 Gb/s eight-lane Attachment Unit Interface (400GAUI-8 C2M)	6853
Annex 127A (informative) Compatibility of 2.5GBASE-X PCS/PMA with 1000BASE-X PCS/PMA running 2.5 times faster	6855
Annex 128A (normative) 2.5 Gb/s Storage Enclosure Interface (2.5GSEI).....	6856
128A.1 Overview	6856
128A.1.1 Bit error ratio	6858
128A.2 2.5GSEI compliance point definitions.....	6858
128A.3 2.5GSEI electrical characteristics	6861
128A.3.1 2.5GSEI host output characteristics	6861
128A.3.2 2.5GSEI host input characteristics.....	6864
128A.3.3 2.5GSEI drive output characteristics	6867
128A.3.4 2.5GSEI drive input characteristics	6868
128A.4 Protocol implementation conformance statement (PICS) proforma for Annex 128A, 2.5 Gb/s Storage Enclosure Interface (2.5GSEI)	6871
128A.4.1 Introduction.....	6871
128A.4.2 Identification.....	6871
128A.4.3 Major capabilities/options.....	6872
128A.4.4 PICS proforma tables for 2.5 Gb/s Storage Enclosure Interface (2.5GSEI).....	6872

Annex 128B (normative) Test fixtures for 2.5 Gb/s and 5 Gb/s Storage Enclosure Interfaces.....	6874
128B.1 Host and drive compliance boards	6874
128B.1.1 Test fixture return loss	6874
128B.1.2 Test fixture insertion loss.....	6874
128B.2 Mated test fixtures.....	6875
128B.2.1 Mated test fixtures insertion loss	6876
128B.2.2 Mated test fixtures return loss.....	6876
128B.2.3 Mated test fixtures integrated crosstalk noise.....	6877
128B.3 Protocol implementation conformance statement (PICS) proforma for Annex 128B, Test fixtures for 2.5 Gb/s and 5 Gb/s Storage Enclosure Interfaces	6879
128B.3.1 Introduction.....	6879
128B.3.2 Identification	6879
128B.3.3 Major capabilities/options.....	6880
128B.3.4 PICS proforma tables for test fixtures	6880
Annex 130A (normative) 5 Gb/s Storage Enclosure Interface (5GSEI).....	6881
130A.1 Overview	6881
130A.1.1 Bit error ratio	6883
130A.2 5GSEI compliance point definitions	6883
130A.3 5GSEI electrical characteristics	6886
130A.3.1 5GSEI host output characteristics.....	6886
130A.3.2 5GSEI host input characteristics	6890
130A.3.3 5GSEI drive output characteristics	6893
130A.3.4 5GSEI drive input characteristics	6895
130A.4 Protocol implementation conformance statement (PICS) proforma for Annex 130A, 5 Gb/s Storage Enclosure Interface (5GSEI).....	6899
130A.4.1 Introduction.....	6899
130A.4.2 Identification	6899
130A.4.3 Major capabilities/options.....	6900
130A.4.4 PICS proforma tables for 5 Gb/s Storage Enclosure Interface (5GSEI).....	6900
Annex 135A (informative) 50 Gb/s and 100 Gb/s PMA sublayer partitioning examples.....	6902
135A.1 Partitioning examples of 50GBASE-R PHYs.....	6902
135A.2 Partitioning examples of 100GBASE-P PHYs	6907
135A.3 Partitioning examples of 100GAUI-n with Inverse RS-FEC.....	6908
135A.3.1 100GAUI-n with Inverse RS-FEC.....	6908
135A.3.2 CAUI-4 chip-to-chip and 100GAUI-n chip-to-module with Inverse RS-FEC.....	6909
Annex 135B (normative) Chip-to-Chip 50 Gb/s two-lane Attachment Unit Interface (LAUI-2 C2C)....	6910
135B.1 Overview	6910
135B.2 LAUI-2 C2C compliance point definition	6911
135B.3 LAUI-2 C2C electrical characteristics	6911
135B.3.1 LAUI-2 C2C transmitter characteristics	6911
135B.3.2 LAUI-2 C2C receiver characteristics	6912
135B.4 LAUI-2 C2C channel characteristics	6912
135B.5 Protocol implementation conformance statement (PICS) proforma for Annex 135B, Chip- to-Chip 50 Gb/s two-lane Attachment Unit Interface (LAUI-2 C2C)	6913
135B.5.1 Introduction.....	6913
135B.5.2 Identification	6913
135B.5.3 Major capabilities/options.....	6914

135B.5.4 PICS proforma tables for chip-to-chip 50 Gb/s two-lane Attachment Unit Interface (LAUI-2 C2C).....	6914
Annex 135C (normative) Chip-to-module 50 Gb/s two-lane Attachment Unit Interface (LAUI-2 C2M).....	6916
135C.1 Overview	6916
135C.1.1 Bit error ratio	6917
135C.2 LAUI-2 C2M compliance point definitions.....	6917
135C.3 LAUI-2 C2M electrical characteristics.....	6917
135C.3.1 LAUI-2 C2M host output characteristics.....	6917
135C.3.2 LAUI-2 C2M module output characteristics	6917
135C.3.3 LAUI-2 C2M host input characteristics.....	6918
135C.3.4 LAUI-2 C2M module input characteristics	6918
135C.4 LAUI-2 C2M measurement methodology	6918
135C.5 Protocol implementation conformance statement (PICS) proforma for Annex 135C, Chip-to-module 50 Gb/s two-lane Attachment Unit Interface (LAUI-2 C2M)	6919
135C.5.1 Introduction.....	6919
135C.5.2 Identification.....	6919
135C.5.3 Major capabilities/options.....	6920
135C.5.4 PICS proforma tables for chip-to-module 50 Gb/s two-lane Attachment Unit Interface (LAUI-2 C2M)	6920
Annex 135D (normative) Chip-to-chip 50 Gb/s two-lane Attachment Unit Interface (50GAUI-2 C2C) and 100 Gb/s four-lane Attachment Unit Interface (100GAUI-4 C2C)	6922
135D.1 Overview	6922
135D.2 50GAUI-2 C2C and 100GAUI-4 C2C compliance point definition	6924
135D.3 50GAUI-2 C2C and 100GAUI-4 C2C electrical characteristics.....	6924
135D.3.1 50GAUI-2 C2C and 100GAUI-4 C2C transmitter characteristics	6924
135D.3.2 50GAUI-2 C2C and 100GAUI-4 C2C receiver characteristics.....	6924
135D.4 50GAUI-2 C2C and 100GAUI-4 C2C channel characteristics	6924
135D.5 Protocol implementation conformance statement (PICS) proforma for Annex 135D, Chip-to-chip 50 Gb/s two-lane Attachment Unit Interface (50GAUI-2 C2C) and 100 Gb/s four-lane Attachment Unit Interface (100GAUI-4 C2C).....	6925
135D.5.1 Introduction.....	6925
135D.5.2 Identification.....	6925
135D.5.3 Major capabilities/options.....	6926
135D.5.4 PICS proforma tables for chip-to-chip 50 Gb/s two-lane Attachment Unit Interface (50GAUI-2 C2C) and 100 Gb/s four-lane Attachment Unit Interface (100GAUI-4 C2C).....	6926
Annex 135E (normative) Chip-to-module 50 Gb/s two-lane Attachment Unit Interface (50GAUI-2 C2M) and 100 Gb/s four-lane Attachment Unit Interface (100GAUI-4 C2M)	6928
135E.1 Overview	6928
135E.1.1 Bit error ratio	6930
135E.2 50GAUI-2 C2M and 100GAUI-4 C2M compliance point definitions	6930
135E.3 50GAUI-2 C2M and 100GAUI-4 C2M electrical characteristics	6930
135E.3.1 50GAUI-2 C2M and 100GAUI-4 C2M host output characteristics.....	6930
135E.3.2 50GAUI-2 C2M and 100GAUI-4 C2M module output characteristics	6930
135E.3.3 50GAUI-2 C2M and 100GAUI-4 C2M host input characteristics.....	6930
135E.3.4 50GAUI-2 C2M and 100GAUI-4 C2M module input characteristics	6930
135E.4 50GAUI-2 C2M and 100GAUI-4 C2M measurement methodology	6930

135E.5 Protocol implementation conformance statement (PICS) proforma for Annex 135E, Chip-to-module 50 Gb/s two-lane Attachment Unit Interface (50GAUI-2 C2M) and 100 Gb/s four-lane Attachment Unit Interface (100GAUI-4 C2M)	6931
135E.5.1 Introduction	6931
135E.5.2 Identification	6931
135E.5.3 Major capabilities/options	6932
135E.5.4 PICS proforma tables for chip-to-module 50 Gb/s two-lane Attachment Unit Interface (50GAUI-2 C2M) and 100 Gb/s four-lane Attachment Unit Interface (100GAUI-4 C2M)	6932
Annex 135F (normative) Chip-to-chip 50 Gb/s one-lane Attachment Unit Interface (50GAUI-1 C2C) and 100 Gb/s two-lane Attachment Unit Interface (100GAUI-2 C2C)	6935
135F.1 Overview	6935
135F.2 50GAUI-1 C2C and 100GAUI-2 C2C compliance point definition	6937
135F.3 50GAUI-1 C2C and 100GAUI-2 C2C electrical characteristics	6937
135F.3.1 50GAUI-1 C2C and 100GAUI-2 C2C transmitter characteristics	6937
135F.3.2 50GAUI-1 C2C and 100GAUI-2 C2C receiver characteristics	6937
135F.4 50GAUI-1 C2C and 100GAUI-2 C2C channel characteristics	6938
135F.5 Example usage of the optional transmitter precoder request	6938
135F.5.1 Overview	6938
135F.5.2 Configuring precoder setting in the transmit direction	6938
135F.5.3 Configuring precoder setting in the receive direction	6939
135F.6 Protocol implementation conformance statement (PICS) proforma for Annex 135F, Chip-to-chip 50 Gb/s one-lane Attachment Unit Interface (50GAUI-1 C2C) and 100 Gb/s two-lane Attachment Unit Interface (100GAUI-2 C2C)	6940
135F.6.1 Introduction	6940
135F.6.2 Identification	6940
135F.6.3 Major capabilities/options	6941
135F.6.4 PICS proforma tables for chip-to-chip 50 Gb/s one-lane Attachment Unit Interface (50GAUI-1 C2C) and 100 Gb/s two-lane Attachment Unit Interface (100GAUI-2 C2C)	6941
Annex 135G (normative) Chip-to-module 50 Gb/s one-lane Attachment Unit Interface (50GAUI-1 C2M) and 100 Gb/s two-lane Attachment Unit Interface (100GAUI-2 C2M)	6943
135G.1 Overview	6943
135G.1.1 Bit error ratio	6945
135G.2 50GAUI-1 C2M and 100GAUI-2 C2M compliance point definitions	6945
135G.3 50GAUI-1 C2M and 100GAUI-2 C2M electrical characteristics	6945
135G.3.1 50GAUI-1 C2M and 100GAUI-2 C2M host output characteristics	6945
135G.3.2 50GAUI-1 C2M and 100GAUI-2 C2M module output characteristics	6945
135G.3.3 50GAUI-1 C2M and 100GAUI-2 C2M host input characteristics	6945
135G.3.4 50GAUI-1 C2M and 100GAUI-2 C2M module input characteristics	6945
135G.4 50GAUI-1 C2M and 100GAUI-2 C2M measurement methodology	6945
135G.5 Protocol implementation conformance statement (PICS) proforma for Annex 135G, Chip-to-module 50 Gb/s one-lane Attachment Unit Interface (50GAUI-1 C2M) and 100 Gb/s two-lane Attachment Unit Interface (100GAUI-2 C2M)	6946
135G.5.1 Introduction	6946
135G.5.2 Identification	6946
135G.5.3 Major capabilities/options	6947
135G.5.4 PICS proforma tables for chip-to-module 50 Gb/s one-lane Attachment Unit Interface (50GAUI-1 C2M) and 100 Gb/s two-lane Attachment Unit Interface (100GAUI-2 C2M)	6947

Annex 136A (informative) TP0 and TP5 test point parameters and channel characteristics for 50GBASE-CR, 100GBASE-CR2, and 200GBASE-CR4	6950
136A.1 Overview	6950
136A.2 Transmitter characteristics at TP0.....	6950
136A.3 Receiver characteristics at TP5	6950
136A.4 Transmitter and receiver differential printed circuit board trace loss	6950
136A.5 Channel insertion loss	6950
136A.6 Channel effective return loss.....	6952
136A.7 Channel Operating Margin (COM).....	6952
Annex 136B (normative) Test fixtures for 50GBASE-CR, 100GBASE-CR2, 200GBASE-CR4, 50GAUI-1 C2M, and 100GAUI-2 C2M.....	6953
136B.1 Test fixtures.....	6953
136B.1.1 Mated test fixtures	6953
136B.2 Protocol implementation conformance statement (PICS) proforma for Annex 136B, Test fixtures for 50GBASE-CR, 100GBASE-CR2, 200GBASE-CR4, 50GAUI-1 C2M, and 100GAUI-2 C2M	6956
136B.2.1 Introduction.....	6956
136B.2.2 Identification	6956
136B.2.3 Major capabilities/options.....	6957
136B.2.4 PICS proforma tables for test fixtures for 50GBASE-CR, 100GBASE-CR2, 200GBASE-CR4, 50GAUI-1 C2M, and 100GAUI-2 C2M.....	6957
Annex 136C (normative) MDIs for 50GBASE-CR, 100GBASE-CR2, and 200GBASE-CR4	6958
136C.1 Overview	6958
136C.2 MDI connector types.....	6961
136C.2.1 SFP28.....	6961
136C.2.2 QSFP28	6962
136C.2.3 MicroQSFP	6962
136C.2.4 QSFP-DD	6963
136C.2.5 OSFP	6964
136C.3 Protocol implementation conformance statement (PICS) proforma for Annex 136C, MDIs for 50GBASE-CR, 100GBASE-CR2, and 200GBASE-CR4.....	6965
136C.3.1 Introduction.....	6965
136C.3.2 Identification	6965
136C.3.3 Major capabilities/options.....	6966
136C.3.4 PICS proforma tables for MDIs for 50GBASE-CR, 100GBASE-CR2, and 200GBASE-CR4.....	6966
Annex 136D (informative) Host and cable assembly form factors for 50GBASE-CR, 100GBASE-CR2, and 200GBASE-CR4	6967
136D.1 Overview	6967
136D.2 Host form factors	6967
136D.2.1 SFP28 host form factor	6967
136D.2.2 QSFP28 host form factor	6967
136D.2.3 microQSFP host form factor	6968
136D.2.4 QSFP-DD host form factor	6968
136D.2.5 OSFP host form factor	6968
136D.3 Cable assembly form factors.....	6969
136D.3.1 One-plug to one-plug cable assembly form factor.....	6969

136D.3.2 One-plug to two-plug cable assembly form factor	6970
136D.3.3 One-plug to four-plug cable assembly form factor	6971
136D.3.4 One-plug to eight-plug cable assembly form factor	6972
Annex 142A (informative) Encoding example for QC-LDPC(16952,14392) FEC and interleaving	6973
142A.1 Example of initial control seed sequence.....	6973
142A.2 QC-LDPC FEC encoder test vectors	6973
Annex 145A (informative) Resistance and current unbalance	6981
145A.1 Intra pair resistance unbalance	6981
145A.2 Pair-to-pair unbalance overview	6981
145A.3 Pair-to-pair link section resistance unbalance requirements for 4-pair operation	6983
145A.4 PSE resistance and current unbalance.....	6983
145A.4.1 Direct RPSE measurement.....	6984
145A.5 PD resistance and current unbalance	6985
Annex 145B (informative) Timing diagrams	6986
145B.1 CC_DET_SEQ timing diagrams.....	6986
145B.1.1 CC_DET_SEQ=0 timing diagrams	6986
145B.1.2 CC_DET_SEQ=1 timing diagrams	6987
145B.1.3 CC_DET_SEQ=2 timing diagrams	6988
145B.1.4 CC_DET_SEQ=3 timing diagrams	6989
145B.2 PSE Single-Event Physical Layer classification timing diagram	6990
145B.3 PSE Multiple-Event Physical Layer classification timing diagram.....	6990
Annex 145C (informative) Power system and parameters	6992
145C.1 Constant power	6992
145C.2 Current	6994
145C.3 Direct current resistance (DCR).....	6995
145C.4 Bundled cabling applications	6996
Annex 146A (informative) Guidelines for implementation of the 10BASE-T1L PHY in an intrinsically safe application	6997
Annex 146B (informative) Optional power distribution	7000
146B.1 Overview	7000
146B.2 Point-to-point powering topologies	7000
146B.3 Powered trunk cable topologies	7001
Annex 149A (normative) Coupling and screening attenuation test methodology.....	7002
149A.1 Introduction.....	7002
149A.2 General test conditions.....	7002
149A.3 Reference cable assembly	7002
149A.4 Measurement setup	7003
149A.5 Protocol implementation conformance statement (PICS) proforma for Annex 149A, Coupling and screening attenuation test methodology	7005
149A.5.1 Introduction.....	7005
149A.5.2 Identification	7005

149A.5.3 Major capabilities/options.....	7006
149A.5.4 PICS proforma tables for Coupling and screening attenuation test methodology	7006
Annex 149B (informative) OAM status	7008
149B.1 Purpose.....	7008
149B.2 MultiGBASE-T1 OAM status structure	7008
149B.3 MultiGBASE-T1 status message data.....	7008
149B.3.1 MultiGBASE-T1 status valid.....	7009
149B.3.2 Power supply warning	7009
149B.3.3 Internal temperature warning.....	7009
149B.3.4 No MAC messages warning	7009
149B.3.5 Degraded link segment	7009
149B.3.6 Polarity inversion	7009
149B.3.7 Vendor-specific field	7010
149B.3.8 Clear REC	7010
149B.3.9 REC cleared	7010
149B.3.10Receive error counter (REC).....	7010
149B.4 Detailed functions and state diagrams	7010
149B.4.1 State diagram conventions	7010
149B.4.2 State diagram parameters	7010
Annex 149C (informative) Tx Function to Rx function channel characteristics.....	7013
149C.1 Overview	7013
149C.2 Differential printed circuit board trace loss	7013
149C.3 Channel insertion loss	7014
149C.4 Channel return loss.....	7014
149C.4.1 Tx/Rx function to MDI return loss	7014
149C.4.2 Link segment return loss.....	7016
149C.4.3 Channel return loss concatenation	7017
149C.5 Coupling between ports on multiport designs.....	7017
Annex 154A (informative) Examples of 100GBASE-ZR compliant DWDM black links	7018
154A.1 Introduction.....	7018
154A.2 Relationship between OSNR and average optical power	7019
154A.3 Examples of DWDM black link applications with OSNR at TP3 between 19.5 dB (12.5 GHz) and 35 dB (12.5 GHz)	7020
154A.4 Example of DWDM black link applications with OSNR at TP3 greater than or equal to 35 dB (12.5 GHz).....	7021

IEEE Standard for Ethernet

1. Introduction

1.1 Overview

This is an international standard for Local and Metropolitan Area Networks (LANs and MANs), employing CSMA/CD as the shared media access method and the IEEE 802.3 (Ethernet) protocol and frame format for data communication. This international standard is intended to encompass several media types and techniques for a variety of MAC data rates as shown in Figure 1–1 and in 4.4.2.

1.1.1 Scope

This standard defines Ethernet local area, access and metropolitan area networks. Ethernet is specified at selected speeds of operation; and uses a common media access control (MAC) specification and management information base (MIB). The Carrier Sense Multiple Access with Collision Detection (CSMA/CD) MAC protocol specifies shared medium (half duplex) operation, as well as full duplex operation. Speed specific Media Independent Interfaces (MIIs) provide an architectural and optional implementation interface to selected Physical Layer devices (PHYs). The Physical Layer encodes frames for transmission and decodes received frames with the modulation specified for the speed of operation, transmission medium and supported link length. Other specified capabilities include: control and management protocols, and the provision of power over selected twisted pair PHY types.

1.1.2 Basic concepts

This standard provides for two distinct modes of operation: half duplex and full duplex. A given IEEE 802.3 instantiation operates in either half or full duplex mode at any one time. The term “CSMA/CD MAC” is used throughout this standard synonymously with “802.3 MAC,” and may represent an instance of either a half duplex or full duplex mode data terminal equipment (DTE), even though full duplex mode DTEs do not implement the CSMA/CD algorithms traditionally used to arbitrate access to shared-media LANs.

1.1.2.1 Half duplex operation

In half duplex mode, the CSMA/CD media access method is the means by which two or more stations share a common transmission medium. To transmit, a station waits (defers) for a quiet period on the medium (that is, no other station is transmitting) and then sends the intended message in bit-serial form. If, after initiating a transmission, the message collides with that of another station, then each transmitting station intentionally transmits for an additional predefined period to ensure propagation of the collision throughout the system. The station remains silent for a random amount of time (backoff) before attempting to transmit again. Each aspect of this access method process is specified in detail in subsequent clauses of this standard.

Half duplex operation can be used with certain media types and configurations as defined by this standard. For allowable configurations, see 4.4.2.

1.1.2.2 Full duplex operation

Full duplex operation allows simultaneous communication between a pair of stations using point-to-point media (dedicated channel). Full duplex operation does not require that transmitters defer, nor do they monitor or react to receive activity, as there is no contention for a shared medium in this mode. Full duplex mode can only be used when all of the following are true:

- a) The physical medium is capable of supporting simultaneous transmission and reception without interference.
- b) There are exactly two stations connected with a full duplex point-to-point link. Since there is no contention for use of a shared medium, the multiple access (i.e., CSMA/CD) algorithms are unnecessary.
- c) Both stations on the LAN are capable of, and have been configured to use, full duplex operation.

The most common configuration envisioned for full duplex operation consists of a central bridge (also known as a switch) with a dedicated LAN connecting each bridge port to a single device. Repeaters as defined in this standard are outside the scope of full duplex operation.

Full duplex operation constitutes a proper subset of the MAC functionality required for half duplex operation.

1.1.3 Architectural perspectives

There are two important ways to view network design corresponding to the following:

- a) *Architecture*. Emphasizing the logical divisions of the system and how they fit together.
- b) *Implementation*. Emphasizing actual components, their packaging, and interconnection.

This standard is organized along architectural lines, emphasizing the large-scale separation of the system into two parts: the Media Access Control (MAC) sublayer of the Data Link Layer and the Physical Layer. These layers are intended to correspond closely to the lowest layers of the ISO/IEC Model for Open Systems Interconnection (see Figure 1–1). (See ISO/IEC 7498-1:1994.⁶) The Logical Link Control (LLC) sublayer, or other MAC client, and MAC sublayer together encompass the functions intended for the Data Link Layer as defined in the OSI model.

1.1.3.1 Architectural rationale

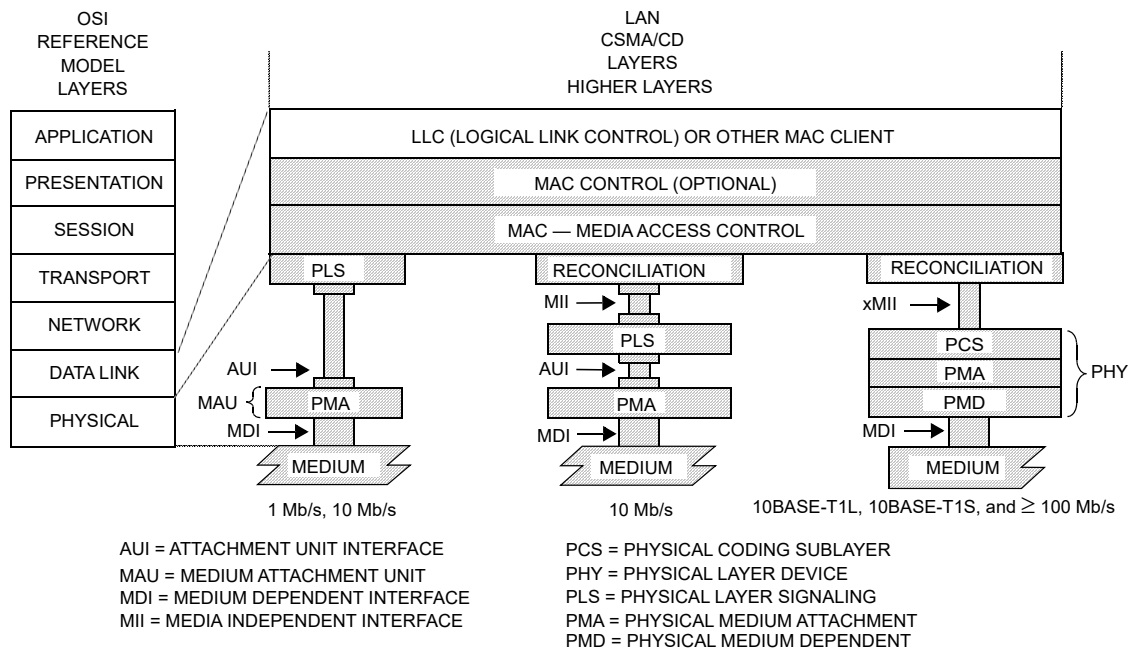
An architectural organization of the standard has two main advantages:

- a) *Clarity*. A clean overall division of the design along architectural lines makes the standard clearer.
- b) *Flexibility*. Segregation of medium-dependent aspects in the Physical Layer allows the LLC and MAC or equivalent sublayers to apply to a family of transmission media.

Partitioning the Data Link Layer allows various media access methods within the family of LAN standards.

The architectural model is based on a set of interfaces that may be different from those emphasized in implementations. One critical aspect of the design, however, shall be addressed largely in terms of the implementation interfaces: compatibility.

⁶For information about references, see 1.3.



NOTE—In this figure, the xMII is used as a generic term for the Media Independent Interfaces for implementations of 10BASE-T1L, 10BASE-T1S, and 100 Mb/s and above. For example: for 100 Mb/s implementations this interface is called MII; for 1 Gb/s implementations it is called GMII; for 10 Gb/s implementations it is called XGMII; etc.

Figure 1-1—IEEE 802.3 standard relationship to the ISO/IEC Open Systems Interconnection (OSI) reference model

1.1.3.2 Compatibility interfaces

The following important compatibility interfaces are defined within what is architecturally the Physical Layer.

- Medium Dependent Interfaces (MDI).** To communicate in a compatible manner, all stations shall adhere rigidly to the exact specification of physical media signals defined in the appropriate clauses in this standard, and to the procedures that define correct behavior of a station. The medium-independent aspects of the LLC sublayer and the MAC sublayer or equivalent should not be taken as detracting from this point; communication in an Ethernet Local Area Network requires complete compatibility at the Physical Medium interface (that is, the physical cable interface).
- Attachment Unit Interface (AUI).** Some DTEs are located some distance from their connection to the physical cable. A small amount of circuitry will exist in the Medium Attachment Unit (MAU) directly adjacent to the physical cable, while the majority of the hardware and all of the software will be placed within the DTE. The AUI is defined as a second compatibility interface. While conformance with this interface is not strictly necessary to ensure communication, it is recommended, since it allows maximum flexibility in intermixing MAUs and DTEs. The AUI may be optional or not specified for some implementations of this standard that are expected to be connected directly to the medium and so do not use a separate MAU or its interconnecting AUI cable. The PLS and PMA are then part of a single unit, and no explicit AUI implementation is required.
- Media Independent Interface (MII).** It is anticipated that some DTEs will be connected to a remote PHY, and/or to different medium dependent PHYs. The MII is defined as a third compatibility interface. While conformance with implementation of this interface is not strictly necessary to ensure

communication, it is recommended, since it allows maximum flexibility in intermixing PHYs and DTEs. The MII is optional.

- d) *Gigabit Media Independent Interface (GMII)*. The GMII is designed to connect a 1 Gb/s capable MAC or repeater unit to a 1 Gb/s PHY. While conformance with implementation of this interface is not strictly necessary to ensure communication, it is recommended, since it allows maximum flexibility in intermixing PHYs and DTEs at 1 Gb/s speeds. The GMII is intended for use as a chip-to-chip interface. No mechanical connector is specified for use with the GMII. The GMII is optional.
- e) *Ten-bit Interface (TBI)*. The TBI is provided by the 1000BASE-X PMA sublayer as a physical instantiation of the PMA service interface. The TBI is recommended for 1000BASE-X systems, since it provides a convenient partition between the high-frequency circuitry associated with the PMA sublayer and the logic functions associated with the PCS and MAC sublayers. The TBI is intended for use as a chip-to-chip interface. No mechanical connector is specified for use with the TBI. The TBI is optional.
- f) *10 Gigabit Media Independent Interface (XGMII)*. The XGMII is designed to connect a 2.5 Gb/s, 5 Gb/s, or 10 Gb/s capable MAC to a PHY of the same rate. While conformance with implementation of this interface is not necessary to ensure communication, it allows maximum flexibility in intermixing PHYs and DTEs at 2.5 Gb/s, 5 Gb/s, and 10 Gb/s speeds. The XGMII is intended for use as a chip-to-chip interface. No mechanical connector is specified for use with the XGMII. The XGMII is optional.
- g) *10 Gigabit Attachment Unit Interface (XAUI)*. The XAUI is designed to extend the connection between a 10 Gb/s capable MAC and a 10 Gb/s PHY. While conformance with implementation of this interface is not necessary to ensure communication, it is recommended, since it allows maximum flexibility in intermixing PHYs and DTEs at 10 Gb/s speeds. The XAUI is intended for use as a chip-to-chip interface. No mechanical connector is specified for use with the XAUI. The XAUI is optional.
- h) *10 Gigabit Sixteen-Bit Interface (XSBI)*. The XSBI is provided as a physical instantiation of the PMA service interface for 10GBASE-R and 10GBASE-W PHYs. While conformance with implementation of this interface is not necessary to ensure communication, it provides a convenient partition between the high-frequency circuitry associated with the PMA sublayer and the logic functions associated with the PCS and MAC sublayers. No mechanical connector is specified for use with the XSBI. The XSBI is optional.
- i) *25 Gigabit Media Independent Interface (25GMII)*. The 25GMII is designed to connect a 25 Gb/s capable MAC to a 25 Gb/s PHY. While conformance with implementation of this interface is not necessary to ensure communication, it allows flexibility in intermixing PHYs and DTEs at 25 Gb/s speeds. The 25GMII is a logical interconnection intended for use as an intra-chip interface. No mechanical connector is specified for use with the 25GMII. The 25GMII is optional.
- j) *25 Gigabit Attachment Unit Interface (25GAUI)*. The 25GAUI is a physical instantiation of the PMA service interface to extend the connection between 25 Gb/s capable PMAs. While conformance with implementation of this interface is not necessary to ensure communication, it is recommended, since it allows maximum flexibility in intermixing PHYs and DTEs at 25 Gb/s speeds. The 25GAUI is intended for use as a chip-to-chip or a chip-to-module interface. No mechanical connector is specified for use with the 25GAUI. The 25GAUI is optional.
- k) *40 Gb/s Media Independent Interface (XLGMII)*. The XLGMII is designed to connect a 40 Gb/s capable MAC to a 40 Gb/s PHY. While conformance with implementation of this interface is not necessary to ensure communication, it allows flexibility in intermixing PHYs and DTEs at 40 Gb/s speeds. The XLGMII is a logical interconnection intended for use as an intra-chip interface. No mechanical connector is specified for use with the XLGMII. The XLGMII is optional.
- l) *40 Gb/s Attachment Unit Interface (XLAUI)*. The XLAUI is a physical instantiation of the PMA service interface to extend the connection between 40 Gb/s capable PMAs. While conformance with implementation of this interface is not necessary to ensure communication, it is recommended, since it allows maximum flexibility in intermixing PHYs and DTEs at 40 Gb/s speeds. The XLAUI is

intended for use as a chip-to-chip or a chip-to-module interface. No mechanical connector is specified for use with the XLAUI. The XLAUI is optional.

- m) *40 Gb/s Parallel Physical Interface (XLPPPI)*. The XLPPPI is provided as a physical instantiation of the PMD service interface for 40GBASE-SR4 and 40GBASE-LR4 PMDs. The XLPPPI has four lanes. While conformance with implementation of this interface is not necessary to ensure communication, it allows flexibility in connecting the 40GBASE-SR4 or 40GBASE-LR4 PMDs. The XLPPPI is intended for use as a chip-to-module interface. No mechanical connector is specified for use with the XLPPPI. The XLPPPI is optional.
- n) *50 Gb/s Media Independent Interface (50GMII)*. The 50GMII is designed to connect a 50 Gb/s capable MAC to a 50 Gb/s PHY. While conformance with implementation of this interface is not necessary to ensure communication, it allows flexibility in intermixing PHYs and DTEs at 50 Gb/s speeds. The 50GMII is a logical interconnection intended for use as an intra-chip interface. No mechanical connector is specified for use with the 50GMII. The 50GMII is optional.
- o) *50 Gb/s Attachment Unit Interface (LAUI-2/50GAUI-n)*. The LAUI-2/50GAUI-n is a physical instantiation of the PMA service interface to extend the connection between 50 Gb/s capable PMAs. While conformance with implementation of this interface is not necessary to ensure communication, it is recommended, since it allows maximum flexibility in intermixing PHYs and DTEs at 50 Gb/s speeds. The LAUI-2/50GAUI-n is intended for use as a chip-to-chip or a chip-to-module interface. Two widths of 50GAUI-n are defined: a two-lane version (50GAUI-2) in Annex 135D and Annex 135E, and a one-lane version (50GAUI-1) in Annex 135F and Annex 135G. No mechanical connector is specified for use with the LAUI-2/50GAUI-n. The LAUI-2/50GAUI-n is optional.
- p) *100 Gb/s Media Independent Interface (CGMII)*. The CGMII is designed to connect a 100 Gb/s capable MAC to a 100 Gb/s PHY. While conformance with implementation of this interface is not necessary to ensure communication, it allows flexibility in intermixing PHYs and DTEs at 100 Gb/s speeds. The CGMII is a logical interconnection intended for use as an intra-chip interface. No mechanical connector is specified for use with the CGMII. The CGMII is optional.
- q) *100 Gb/s Attachment Unit Interface (CAUI-n/100GAUI-n)*. The CAUI-n/100GAUI-n is a physical instantiation of the PMA service interface to extend the connection between 100 Gb/s capable PMAs. While conformance with implementation of this interface is not necessary to ensure communication, it is recommended, since it allows maximum flexibility in intermixing PHYs and DTEs at 100 Gb/s speeds. The CAUI-n is intended for use as a chip-to-chip or a chip-to-module interface. Three widths of CAUI-n are defined: a ten-lane version (CAUI-10) in Annex 83A and Annex 83B, a four-lane version (CAUI-4/100GAUI-4) in Annex 83D, Annex 83E, Annex 135D, and Annex 135E, and a two-lane version (100GAUI-2) in Annex 135F and Annex 135G. No mechanical connector is specified for use with the CAUI-n/100GAUI-n. The CAUI-n/100GAUI-n is optional.
- r) *100 Gb/s Parallel Physical Interface (CPPI)*. The CPPI is provided as a physical instantiation of the PMD service interface for 100GBASE-SR10 PMDs. The CPPI has ten lanes. While conformance with implementation of this interface is not necessary to ensure communication, it allows flexibility in connecting the 100GBASE-SR10 PMDs. The CPPI is intended for use as a chip-to-module interface. No mechanical connector is specified for use with the CPPI. The CPPI is optional.
- s) *200 Gb/s Media Independent Interface (200GMII)*. The 200GMII is designed to connect a 200 Gb/s capable MAC to a 200 Gb/s PHY. While conformance with implementation of this interface is not necessary to ensure communication, it allows flexibility in intermixing PHYs and DTEs at 200 Gb/s speeds. The 200GMII is a logical interconnection intended for use as an intra-chip interface. No mechanical connector is specified for use with the 200GMII. The 200GMII is optional.
- t) *200 Gb/s Attachment Unit Interface (200GAUI-n)*. The 200GAUI-n is a physical instantiation of the PMA service interface to extend the connection between 200 Gb/s capable PMAs. While conformance with implementation of this interface is not necessary to ensure communication, it is recommended, since it allows maximum flexibility in intermixing PHYs and DTEs at 200 Gb/s speeds. The 200GAUI-n is intended for use as a chip-to-chip or a chip-to-module interface. Two widths of 200GAUI-n are defined: an eight-lane version (200GAUI-8) in Annex 120B and

Annex 120C, and a four-lane version (200GAUI-4) in Annex 120D and Annex 120E. No mechanical connector is specified for use with the 200GAUI-n. The 200GAUI-n is optional.

- u) *400 Gb/s Media Independent Interface (400GMII)*. The 400GMII is designed to connect a 400 Gb/s capable MAC to a 400 Gb/s PHY. While conformance with implementation of this interface is not necessary to ensure communication, it allows flexibility in intermixing PHYs and DTEs at 400 Gb/s speeds. The 400GMII is a logical interconnection intended for use as an intra-chip interface. No mechanical connector is specified for use with the 400GMII. The 400GMII is optional.
- v) *400 Gb/s Attachment Unit Interface (400GAUI-n)*. The 400GAUI-n is a physical instantiation of the PMA service interface to extend the connection between 400 Gb/s capable PMAs. While conformance with implementation of this interface is not necessary to ensure communication, it is recommended, since it allows maximum flexibility in intermixing PHYs and DTEs at 400 Gb/s speeds. The 400GAUI-n is intended for use as a chip-to-chip or a chip-to-module interface. Two widths of 400GAUI-n are defined: a sixteen-lane version (400GAUI-16) in Annex 120B and Annex 120C, and an eight-lane version (400GAUI-8) in Annex 120D and Annex 120E. No mechanical connector is specified for use with the 400GAUI-n. The 400GAUI-n is optional.

1.1.4 Layer interfaces

In the architectural model used here, the layers interact by way of well-defined interfaces, providing services as specified in Clause 2 and Clause 6. In general, the interface requirements are as follows:

- a) The interface between the MAC sublayer and its client includes facilities for transmitting and receiving frames, and provides per-operation status information for use by higher-layer error recovery procedures.
- b) The interface between the MAC sublayer and the Physical Layer includes signals for framing (carrier sense, receive data valid, transmit initiation) and contention resolution (collision detect), facilities for passing a pair of serial bit streams (transmit, receive) between the two layers, and a wait function for timing.

These interfaces are described more precisely in 4.3. Additional interfaces are necessary to provide for MAC Control services, and to allow higher level network management facilities to interact with these layers to perform operation, maintenance, and planning functions. Network management functions are described in Clause 30.

1.1.5 Application areas

Use of this standard is not restricted to any specific environments or applications.

In the context of this standard, the term “LAN” is used to indicate all networks that utilize the IEEE 802.3 (Ethernet) protocol for communication. These may include (but are not limited to) LANs and MANs.

1.1.6 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall equals is required to*).^{7 8}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should equals is recommended that*).

⁷The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

⁸The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

1.2 Notation

1.2.1 State diagram conventions

The operation of a protocol can be described by subdividing the protocol into a number of interrelated functions. The operation of the functions can be described by state diagrams. Each diagram represents the domain of a function and consists of a group of connected, mutually exclusive states. Only one state of a function is active at any given time (see Figure 1–1).

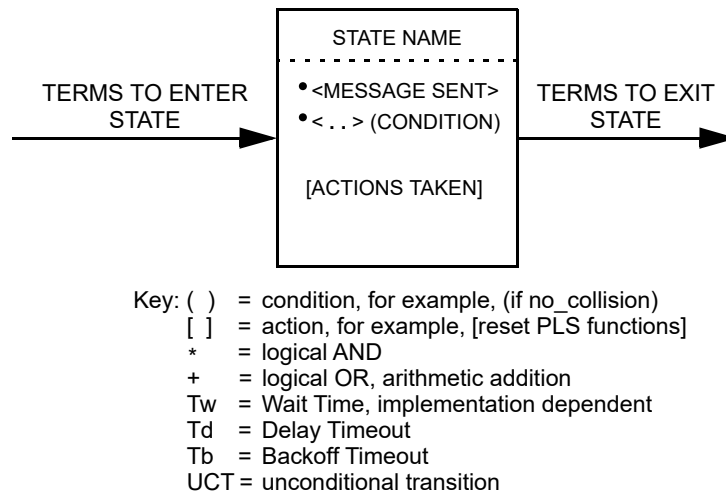


Figure 1–1—State diagram notation example

Each state that the function can assume is represented by a rectangle. These are divided into two parts by a horizontal line. In the upper part the state is identified by a name in capital letters. The lower part contains the name of any ON signal that is generated by the function. Actions are described by short phrases and enclosed in brackets.

All permissible transitions between the states of a function are represented graphically by arrows between them. A transition that is global in nature (for example, an exit condition from all states to the IDLE or RESET state) is indicated by an open arrow. Labels on transitions are qualifiers that have to be fulfilled before the transition will be taken. The label UCT designates an unconditional transition. Qualifiers described by short phrases are enclosed in parentheses.

State transitions and sending and receiving of messages occur instantaneously. When a state is entered and the condition to leave that state is not immediately fulfilled, the state executes continuously, sending the messages and executing the actions contained in the state in a continuous manner.

Some devices described in this standard (e.g., repeaters) are allowed to have two or more ports. State diagrams that are capable of describing the operation of devices with an unspecified number of ports require a qualifier notation that allows testing for conditions at multiple ports. The notation used is a term that

includes a description in parentheses of which ports have to meet the term for the qualifier to be satisfied (e.g., ANY and ALL). It is also necessary to provide for term-assignment statements that assign a name to a port that satisfies a qualifier. The following conventions are used to describe a term-assignment statement that is associated with a transition:

- a) The character “:” (colon) is a delimiter used to denote that a term assignment statement follows.
- b) The character “←” (left arrow) denotes assignment of the value following the arrow to the term preceding the arrow.

The state diagrams contain the authoritative statement of the functions they depict; when apparent conflicts between descriptive text and state diagrams arise, the state diagrams are to take precedence. This does not override, however, any explicit description in the text that has no parallel in the state diagrams.

The models presented by state diagrams are intended as the primary specifications of the functions to be provided. It is important to distinguish, however, between a model and a real implementation. The models are optimized for simplicity and clarity of presentation, while any realistic implementation may place heavier emphasis on efficiency and suitability to a particular implementation technology. It is the functional behavior of any unit that has to match the standard, not its internal structure. The internal details of the model are useful only to the extent that they specify the external behavior clearly and precisely.

1.2.2 Service specification method and notation

The service of a layer or sublayer is the set of capabilities that it offers to a user in the next higher (sub)layer. Abstract services are specified here by describing the service primitives and parameters that characterize each service. This definition of service is independent of any particular implementation (see Figure 1–2).

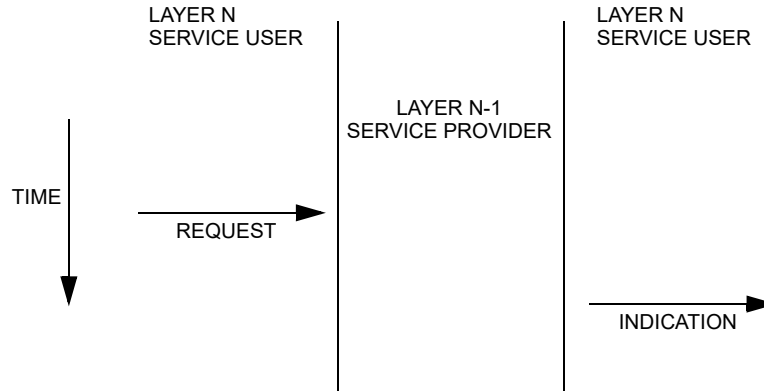


Figure 1–2—Service primitive notation

Specific implementations may also include provisions for interface interactions that have no direct end-to-end effects. Examples of such local interactions include interface flow control, status requests and indications, error notifications, and layer management. Specific implementation details are omitted from this service specification both because they will differ from implementation to implementation and because they do not impact the peer-to-peer protocols.

1.2.2.1 Classification of service primitives

Primitives are of two generic types:

- a) REQUEST. The request primitive is passed from layer N to layer N-1 to request that a service be initiated.
- b) INDICATION. The indication primitive is passed from layer N-1 to layer N to indicate an internal layer N-1 event that is significant to layer N. This event may be logically related to a remote service request, or may be caused by an event internal to layer N-1.

The service primitives are an abstraction of the functional specification and the user-layer interaction. The abstract definition does not contain local detail of the user/provider interaction. For instance, it does not indicate the local mechanism that allows a user to indicate that it is awaiting an incoming call. Each primitive has a set of zero or more parameters, representing data elements that shall be passed to qualify the functions invoked by the primitive. Parameters indicate information available in a user/provider interaction; in any particular interface, some parameters may be explicitly stated (even though not explicitly defined in the primitive) or implicitly associated with the service access point. Similarly, in any particular protocol specification, functions corresponding to a service primitive may be explicitly defined or implicitly available.

1.2.3 Physical Layer and media notation

Users of this standard need to reference which particular implementation is being used or identified. Therefore, a means of identifying each implementation is given by a simple, three-field, type notation that is explicitly stated at the beginning of each relevant clause. In general, the Physical Layer type is specified by these fields:

<data rate> <modulation type> <additional distinction>

The data rate, if only a number, is in Mb/s, and if suffixed by a “G”, is in Gb/s. The modulation type (e.g., BASE) indicates how encoded data is transmitted on the medium. The additional distinction may identify characteristics of transmission or medium and, in some cases, the type of PCS encoding used (examples of additional distinctions are “T” for twisted pair, “B” for bidirectional optics, and “X” for a block PCS coding used for that speed of operation). Expansions for defined Physical Layer types are included in 1.4.

1.2.4 Physical Layer message notation

Messages generated within the Physical Layer, either within or between PLS and the MAU (that is, PMA circuitry), are designated by an italic type to designate either form of physical or logical message used to execute the Physical Layer signaling process (for example, *input_idle* or *mau_available*).

1.2.5 Hexadecimal notation

Numerical values designated by the 0x prefix indicate a hexadecimal interpretation of the corresponding number. For example: 0x0F represents an 8-bit hexadecimal value of the decimal number 15 and 0x00000000 represents a 32-bit hexadecimal value of the decimal number 0.

Numerical values designated with a 16 subscript indicate a hexadecimal interpretation of the corresponding number. For example: 0F₁₆ represents an 8-bit hexadecimal value of the decimal number 15.

Hexadecimal values may also be indicated in text as hexadecimal or hex.

Hexadecimal numbers and values use upper case for hexadecimal digits A through F.

Separators may be used to improve readability of numbers—typically after every two or four hex digits counting from right to left. When hexadecimal is used for a fixed length value, protocol field, etc., where the value is not a multiple of 4 bits, the leftmost hexadecimal digit is truncated to fit the value's length (e.g., an 11 bit value of 0x25F is 010 0101 1111 in binary).

1.2.6 Accuracy and resolution of numerical quantities

Unless otherwise stated, numerical limits in this standard are to be taken as exact, with the number of significant digits and trailing zeros having no significance.

1.2.7 Qm.n number format

The Qm.n number format is a fixed-point number format where the number of fractional bits is specified by n and optionally the number of integer bits is specified by m. For example, a Q14 number has 14 fractional bits; a Q2.14 number has 2 integer bits and 14 fractional bits. Preceding the “Q” with a “U” indicates an unsigned number.

1.2.8 Em dash (—) in a table cell

A table cell containing an em-dash (—) indicates a lack of data for that cell, or:

- For a units cell, that there is no unit for that parameter
- For a maximum cell, that there is no requirement on the maximum value of that parameter
- For a minimum cell, that there is no requirement on the minimum value of that parameter

1.3 Normative references

The following standards contain provisions that, through reference in this text, constitute provisions of this standard. Standards may be subject to revision, and parties subject to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid international standards. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI INCITS 230-1994 (R1999), Information Technology—Fibre Channel—Physical and Signaling Interface (FC-PH) [formerly ANSI X3.230-1994 (R1999)].⁹

ANSI INCITS 263-1995 (S2010), Fibre Distributed Data Interface (FDDI)—Token Ring Twisted Pair Physical Layer Medium Dependent (TP-PMD) [formerly INCITS 263-1995 (R2005)].

ANSI/TIA-568-C.0 (February 2009), Generic Telecommunications Cabling for Customer Premises.¹⁰

ANSI/TIA-568-C.2-1 (July 2016), Balanced Twisted-Pair Telecommunications Cabling and Components Standard, Addendum 1: Specifications for 100 Ω Next Generation Cabling.

ANSI/TIA-568-C.2 (August 2009), Commercial Building Telecommunications Cabling Standard Part 2: Balanced Twisted-Pair Cabling Components.

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

ANSI/TIA-568.0-D, Generic Telecommunications Cabling for Customer Premises.

ANSI/TIA-604-18:2015, FOCIS 18—Fiber Optic Connector Intermateability Standard—Type MPO-16.

ANSI/TIA-604-18-A:2018, FOCIS 18—Fiber Optic Connector Intermateability Standard—Type MPO-16.

⁹ANSI publications are available from the American National Standards Institute (<https://www.ansi.org/>).

¹⁰ANSI/TIA publications are available from the IHS Standards Store (<https://global.ihs.com/>) or from the Telecommunications Industry Association (<https://www.tiaonline.org/>).

ANSI/TIA/EIA-455-95-2019, Absolute Optical Power Test for Optical Fibers and Cables.

ANSI/TIA/EIA-455-204-2013, Measurement of Bandwidth on Multimode Fiber..

ANSI/TIA/EIA-568-A-1995, Commercial Building Telecommunications Cabling Standard.

ASTM D4728, Standard Test Method for Random Vibration Testing of Shipping Containers.¹¹

ATIS-0300269.2006(S2016), Structure and Representation of Trace Message Formats for Information Exchange.¹²

ATIS-0600416.1999(R2010), Network to Customer Installation Interfaces—Synchronous Optical NETWORK (SONET)—Physical Layer Specification: Common Criteria.

ATIS-0600417.2003(S2015), Spectrum Management for Loop Transmission Systems.

ATIS-0600424.2004(S2015), Interface Between Networks and Customer Installation Very-high-bit-rate Digital Subscriber Lines (VDSL) Metallic Interface (DMT based).

ATIS-0600601.1999(S2015), Integrated Services Digital Network (ISDN)—Basic Access Interface for Use on Metallic Loops for Application on the Network Side of the NT (Layer 1 Specification).

ATIS-0600605.1991(S2015), Integrated Services Digital Network (ISDN)—Basic Access Interface for S and T Reference Points (Layer 1 Specification).

ATIS-0900105.2008, Synchronous Optical Network (SONET)—Basic Description including Multiplex Structure, Rates, and Formats.

CFR 76, Code of Federal Regulations, Title 47, Part 76, October 2005.

CISPR 22: 1993, Limits and Methods of Measurement of Radio Interference Characteristics of Information Technology Equipment.¹³

CISPR 25: Vehicles, boats and internal combustion engines—Radio disturbance characteristics—Limits and methods of measurement for the protection of on-board receivers.

EIA/JEDEC Standard EIA/JESD8-6, High Speed Transceiver Logic (HSTL), August 1995.¹⁴

ETSI TS 101 270-1 (1999), Transmission and Multiplexing (TM); Access transmission systems on metallic access cables; Very high speed Digital Subscriber Line (VDSL); Part 1: Functional requirements.¹⁵

IEC 60060 (all parts), High-voltage test techniques.¹⁶

IEC 60068, Basic environmental testing procedures.

¹¹ASTM publications are available from the American Society for Testing and Materials (<https://www.astm.org/>).

¹²ATIS publications are available from the Alliance for Telecommunications Industry Solutions (<https://atis.org/>).

¹³CISPR documents are available from the International Electrotechnical Commission (<https://www.iec.ch/>). CISPR documents are also available in the United States from the American National Standards Institute (<https://www.ansi.org/>).

¹⁴EIA publications are available from the IHS Standards Store (<https://global.ihs.com/>). JEDEC publications are available from the JEDEC Solid State Technology Association (<https://www.jedec.org/>).

¹⁵ETSI publications are available from the European Telecommunications Standards Institute (<https://www.etsi.org/>).

¹⁶IEC publications are available from the International Electrotechnical Commission (<https://www.iec.ch/>). IEC publications are also available in the United States from the American National Standards Institute (<https://www.ansi.org/>).

IEC 60068-2-1:2007, Environmental testing—Part 2-1: Tests—Test A: Cold.

IEC 60068-2-2:2007, Environmental testing—Part 2-2: Tests—Test B: Dry heat.

IEC 60068-2-6:2007, Environmental testing—Part 2-6: Tests—Test Fc: Vibration (sinusoidal).

IEC 60068-2-14:2009, Environmental testing—Part 2-14: Tests—Test N: Change of temperature.

IEC 60068-2-27:2008, Environmental testing—Part 2-27: Tests—Test Ea and guidance: Shock.

IEC 60068-2-30:2005, Environmental testing—Part 2-30: Tests—Test Db: Damp heat, cyclic (12 h + 12 h cycle).

IEC 60068-2-31:2008, Environmental testing—Part 2-31: Tests—Test Ec: Rough handling shocks, primarily for equipment-type specimens.

IEC 60068-2-38:2009, Environmental testing—Part 2-38: Tests—Test Z/AD: Composite temperature/humidity cyclic test.

IEC 60068-2-52:2017, Environmental testing—Part 2-52: Tests—Test Kb: Salt mist, cyclic (sodium chloride solution).

IEC 60068-2-64:2008, Environmental testing—Part 2-64: Tests—Test Fh: Vibration, broadband random and guidance.

IEC 60068-2-78:2012, Environmental testing—Part 2-78: Tests—Test Cab: Damp heat, steady state.

IEC 60079-0:2017, Explosive atmospheres—Part 0: Equipment—General requirements.

IEC 60079-11:2011, Explosive Atmospheres—Part 11: Equipment protection by intrinsic safety.

IEC 60096-1:1986, Radio-frequency cables, Part 1: General requirements and measuring methods and Amd. 2:1993.

IEC 60169-16:1982, Radio-frequency connectors, Part 16: R.F. coaxial connectors with inner diameter of outer conductor 7 mm (0.276 in) with screw coupling—Characteristic impedance 50 ohms (75 ohms) (Type N).

IEC 60529:2013, Degrees of Protection Provided by Enclosures (IP Code).

IEC 60603-7, Connectors for electronic equipment—Part 7: Detail specification for 8-way, unshielded, free and fixed connectors.

IEC 60603-7-4, Connectors for electronic equipment—Part 7-4: Detail specification for 8-way, unshielded, free and fixed connectors, for data transmissions with frequencies up to 250 MHz.

IEC 60603-7-5, Connectors for electronic equipment—Part 7-5: Detail specification for 8-way, shielded, free and fixed connectors, for data transmissions with frequencies up to 250 MHz.

IEC 60603-7-51, Connectors for electronic equipment—Part 7-51: Detail specification for 8-way, shielded, free and fixed connectors, for data transmissions with frequencies up to 500 MHz.

IEC 60603-7-81, Connectors for electronic equipment—Part 7-81: Detail specification for 8-way, shielded, free and fixed connectors, for data transmissions with frequencies up to 2 000 MHz.

IEC 60793-1:1992, Optical fibres—Part 1: Generic specification.

IEC 60793-1:1995, Optical fibres—Part 1: Generic specification.

IEC 60793-1-41:2001, Optical fibres—Part 1-41: Measurement methods and test procedures—Bandwidth.

IEC 60793-1-41:2010, Optical fibres—Part 1-41: Measurement methods and test procedures—Bandwidth.

IEC 60793-1-42, Optical fibres—Part 1-42: Measurement methods and test procedures—Chromatic dispersion.

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

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

IEC 60793-2:1992, Optical fibres—Part 2: Product specifications.

IEC 60793-2-40:2009, Optical fibres—Part 2-40: Product specifications—Sectional specification for category A4 multimode fibres.

IEC 60793-2-50:2008, Optical fibres—Part 2-50: Product specifications—Sectional specification for class B single-mode fibres.

IEC 60794-1:1993, Optical fibre cables—Part 1: Generic specification.

IEC 60794-1:1996, Optical fibre cables—Part 1: Generic specification.

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 60794-2:1989, Optical fibre cables—Part 2: Product specifications.

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 60807-2:1992, Rectangular connectors for frequencies below 3 MHz, Part 2: Detail specification for a range of connectors with assessed quality, with trapezoidal shaped metal shells and round contacts—Fixed solder contact types.

IEC 60807-3:1990, Rectangular connectors for frequencies below 3 MHz, Part 3: Detail specification for a range of connectors with trapezoidal shaped metal shells and round contacts—Removable crimp contact types with closed crimp barrels, rear insertion/rear extraction.

IEC 60825-1, Safety of laser products—Part 1: Equipment classification and requirements.

IEC 60825-2, Safety of laser products—Part 2: Safety of optical fibre communication systems (OFCS).

IEC 60874-10:1992, Connectors for optical fibres and cables—Part 10: Sectional specification, Fibre optic connector type BFOC/2,5.

IEC 60874-1:1993, Connectors for optical fibres and cables—Part 1: Generic specification.

IEC 60874-2:1993, Connectors for optical fibres and cables—Part 2: Sectional specification for fibre optic connector, Type F-SMA.

IEC 60950-1, Information technology equipment—Safety—Part 1: General requirements.

IEC 60950:1991, Safety of information technology equipment.

IEC 61000-4-2, Electromagnetic compatibility (EMC)—Part 4-2: Testing and measurement techniques—Electrostatic discharge immunity test.

IEC 61000-4-21, Electromagnetic compatibility (EMC)—Part 4-21: Testing and measurement techniques—Reverberation chamber test methods.

IEC 61000-4-3, Electromagnetic compatibility (EMC)—Part 4-3: Testing and measurement techniques—Radiated, radio-frequency, electromagnetic field immunity test.

IEC 61000-4-4:2012, Electromagnetic compatibility (EMC)—Part 4-4: Testing and measurement techniques—Electrical fast transient/burst immunity test.

IEC 61000-4-5:2017, Electromagnetic compatibility (EMC)—Part 4-5: Testing and measurement techniques—Surge immunity test.

IEC 61000-4-6:2013, Electromagnetic compatibility (EMC)—Part 4-6: Testing and measurement techniques—Immunity to conducted disturbances, induced by radio-frequency fields.

IEC 61000-6-4:2018, Electromagnetic compatibility (EMC)—Part 6-4: Generic standards—Emission standard for industrial environments.

IEC 61010-1:2017, Safety requirements for electrical equipment for measurement, control, and laboratory use—Part 1: General requirements.

IEC 61076-3-101:1997, Connectors with assessed quality, for use in d.c., low-frequency analogue and in digital high-speed data applications—Part 3: Rectangular connectors—Section 101: Detail specification for a range of shielded connectors with trapezoidal shaped shells and non-removable rectangular contacts on a 1.27 mm × 2.54 mm centre-line.

IEC 61076-3-103 (48B/574/NP), Detail specification for rectangular connectors, with assessed quality, 6 and 8 way, fixed and free shielded connectors with ribbon contacts for high speed data applications.

IEC 61169-24:2009, Radio-frequency connectors—Part 24: Sectional specification—Radio frequency coaxial connectors with screw coupling, typically for use in 75 Ω cable networks (type F).

IEC 61196-1:1995, Radio-frequency cables—Part 1: Generic specification—General, definitions, requirements and test methods.

IEC 61280-1-1:1998, Fibre optic communication subsystem basic test procedures—Part 1-1: Test procedures for general communication subsystems—Transmitter output optical power measurement for single-mode optical fibre cable.

IEC 61280-1-3:2010, Fibre optic communication subsystem test procedures—Part 1-3: General communication subsystems—Central wavelength and spectral width measurement.

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 61280-1-4:2009, Fibre optic communication subsystem test procedures—Part 1-4: General communication subsystems—Light source encircled flux measurement method.

IEC 61280-2-2:2008, Fiber optic communication sub-system basic test procedures—Part 2-2: Test procedures for digital systems—Optical eye pattern, waveform, and extinction ratio.

IEC 61280-4-1:2019+AMD1:2021, Fibre-optic communication subsystem test procedures—Part 4-1: Installed cable plant —Multimode attenuation measurement.

IEC 61280-4-2:2000, Fibre optic communication subsystem basic test procedures—Fibre optic cable plant—Single-mode fibre optic cable plant attenuation.

IEC 61300-2-4, Fibre optic interconnecting devices and passive components—Basic test and measurement procedures—Part 2-4: Tests—Fibre/cable retention.

IEC 61300-3-53, Fibre optic interconnecting devices and passive components—Basic test and measurement procedures—Part 3-53: Examinations and measurements—Encircled angular flux (EAF) measurement method based on two-dimensional far field data from step index multimode waveguide (including fibre).

IEC 61326-1:2012, Electrical equipment for measurement, control and laboratory use—EMC requirements—Part 1: General requirements.

IEC 61753-021-2:2002, Fibre optic passive component performance standard—Part 021-2: Fibre optic connectors terminated on single-mode fibre to category C Controlled environment.

IEC 61753-021-2:2007, Fibre optic interconnecting devices and passive components performance standard—Part 021-2: Grade C/3 single-mode fibre optic connectors for category C—Controlled environment.

IEC 61753-022-2:2012, Fibre optic interconnecting devices and passive components—Performance standard—Part 022-2: Fibre optic connectors terminated on multimode fibre for Category C—Controlled environment.

IEC 61753-1-1:2000, Fibre optic interconnecting devices and passive components performance standard—Part 1-1: General and guidance—Interconnecting devices (connectors).

IEC 61753-1:2007, Fibre optic interconnecting devices and passive components performance standard—Part 1: General and guidance for performance standards.

IEC 61754-1:1996, Fibre optic interfaces —Part 1: General and guidance.

IEC 61754-4:1997, Fibre optic connector interfaces—Part 4: Type SC connector family.

IEC 61754-7, Fibre optic connector interfaces—Part 7: Type MPO connector family.

IEC 61754-7-1:2014, Fibre optic interconnecting devices and passive components—Fibre optic connector interfaces—Part 7-1: Type MPO connector family—One fibre row.

IEC 61754-7-2:2017, Fibre optic interconnecting devices and passive components—Fibre optic connector interfaces—Part 7-2: Type MPO connector family—Two fibre rows.

IEC 61967-1, Integrated circuits—Measurement of electromagnetic emissions, 150 kHz to 1 GHz—Part 1: General conditions and definitions.

IEC 61967-4, Integrated circuits—Measurement of electromagnetic emissions, 150 kHz to 1 GHz—Part 4: Measurement of conducted emissions—1 Ω /150 Ω direct coupling method.

IEC 62132-1, Integrated circuits—Measurement of electromagnetic immunity, 150 kHz to 1 GHz—Part 1: General conditions and definitions.

IEC 62132-4, Integrated circuits—Measurements of electromagnetic immunity 150 kHz to 1 GHz—Part 4: Direct RF power injection method.

IEC 62153-4-14:2012, Metallic communication cable test methods—Part 4-14: Electromagnetic compatibility (EMC)—Coupling attenuation of cable assemblies (Field conditions) absorbing clamp method.

IEC 62153-4-7, Metallic communication cable test methods—Part 4-7: Electromagnetic compatibility (EMC)—Test method for measuring of transfer impedance Z_T and screening attenuation a_S or coupling attenuation a_C of connectors and assemblies up to and above 3 GHz—Triaxial tube in tube method.

IEC 62215-3, Integrated circuits—Measurement of impulse immunity—Part 3: Non-synchronous transient injection method.

IEC 62368-1:2018, Audio/video, information and communication technology equipment—Part 1: Safety requirements.

IEEE Std 1394TM-1995 IEEE Standard for a High Performance Serial Bus.^{17, 18}

IEEE Std 802[®], IEEE Standard for Local and Metropolitan Area Networks—Overview and Architecture.

IEEE Std 802.1ABTM-2009, IEEE Standard for Local and metropolitan area networks—Station and Media Access Control Connectivity Discovery.

IEEE Std 802.1ACTM, IEEE Standard for Local and metropolitan area networks—Media Access Control (MAC) Service Definition.

IEEE Std 802.1ASTM-2011, IEEE Standard for Local and metropolitan area networks—Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks.

IEEE Std 802.1FTM-1993, IEEE Standard for Local and Metropolitan Area Networks—Common Definitions and Procedures for IEEE 802 Management Information.¹⁹

IEEE Std 802.1QTM, Standard for Local and Metropolitan Area Networks—Bridges and Bridged Networks.

IEEE Std 802.3.1TM, IEEE Standard for Management Information Base (MIB) Module Definitions for Ethernet.

IEEE Std 802.5vTM-2001, IEEE Standard for Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Network—Specific Requirements.

¹⁷IEEE publications are available from The Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

¹⁸The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.

¹⁹IEEE Std 802.1F-1993 has been withdrawn; however, copies can be obtained from The Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

Part 5: Token Ring Access Method and Physical Layer Specifications. Amendment 5: Gigabit Token Ring Operation.²⁰

IEEE Std 802.9a™-1995, Local and Metropolitan Area Networks—802.9 Supplement—IEEE Standard Specification of ISLAN 16-T (supplement to 802.9-1994).²¹

IETF RFC 3621 (December 2003), *Power Ethernet MIB*, Berger, A., and Romascanu, D.²²

IETF RFC 4836 (April 2007), *Definitions of Managed Objects for IEEE 802.3 Medium Attachment Units (MAUs)*, Beili, E.

ISO 10605:2008, Road vehicles—Test methods for electrical disturbances from electrostatic discharge.

ISO 11452, Road vehicles—Component test methods for electrical disturbances from narrowband radiated electromagnetic energy.

ISO 12103-1:1997, Road vehicles—Test dust for filter evaluation—Part 1: Arizona test dust.

ISO 16750-1:2006, Road vehicles—Environmental conditions and testing for electrical and electronic equipment—Part 1: General.

ISO 16750-2:2012, Road vehicles—Environmental conditions and testing for electrical and electronic equipment—Part 2: Electrical loads.

ISO 16750-3:2012, Road vehicles—Environmental conditions and testing for electrical and electronic equipment—Part 3: Mechanical loads.

ISO 16750-4:2010, Road vehicles—Environmental conditions and testing for electrical and electronic equipment—Part 4: Climatic loads.

ISO 16750-5: 2010, Road vehicles—Environmental conditions and testing for electrical and electronic equipment - Part 5: Chemical loads.

ISO 20653:2013, Road vehicles—Degrees of protection (IP code)—Protection of electrical equipment against foreign objects, water and access.

ISO 26262, Road vehicles—Functional safety.

ISO 4892:1982, Plastics—Methods of exposure to laboratory light.

ISO 7637-2:2008, Road vehicles—Electrical disturbances from conduction and coupling—Part 2: Electrical transient conduction along supply lines only.

ISO 7637-3:2007, Road vehicles—Electrical disturbances from conduction and coupling—Part 3: Electrical transient transmission by capacitive and inductive coupling via lines other than supply lines.

ISO 8820-1:2014, Road vehicles—Fuse-links—Part 1: Definitions and general test requirements.

²⁰IEEE Std 802.5v-2001 has been withdrawn; however, copies can be obtained from The Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

²¹IEEE Std 802.9a-1995 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<https://global.ihs.com/>).

²²IETF RFCs are available from the Internet Engineering Task Force (<https://www.ietf.org/rfc.html>).

ISO/IEC 10040:1992, Information technology—Open Systems Interconnection—Systems management overview.²³

ISO/IEC 10165-2:1992, Information technology—Open Systems Interconnection—Structure of management information: Definition of management information.

ISO/IEC 10165-4:1992, Information technology—Open Systems Interconnection—Management information services—Structure of management information—Part 4: Guidelines for the definition of managed objects.

ISO/IEC 11801:1995, Information technology—Generic cabling for customer premises.²⁴

ISO/IEC 11801:2002, Information technology—Generic cabling for customer premises.

ISO/IEC 11801:2002 Amendment 1:2008, Information technology—Generic cabling for customer premises.

ISO/IEC 11801:2002 Amendment 2:2010, Information technology—Generic cabling for customer premises.

ISO/IEC 14763-3:2014, Information technology—Implementation and operation of customer premises cabling—Part 3: Testing of optical fibre cabling.

ISO/IEC 7498-1:1994, Information technology—Open Systems Interconnection—Basic Reference Model: The Basic Model.

ISO/IEC 7498-4:1989, Information processing systems—Open Systems Interconnection—Basic Reference Model—Part 4: Management Framework.

ISO/IEC 8802-2:1998, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 2: Logical link control.

ISO/IEC 8824:1990, Information technology—Open Systems Interconnection—Specification of Abstract Syntax Notation One (ASN.1).

ISO/IEC 9314-1:1989, Information processing systems—Fibre Distributed Data Interface (FDDI)—Part 1: Token Ring Physical Layer Protocol (PHY).

ISO/IEC 9314-2:1989, Information processing systems—Fibre Distributed Data Interface (FDDI)—Part 2: Token Ring Media Access Control (MAC).

ISO/IEC 9314-3:1990, Information processing systems—Fibre Distributed Data Interface (FDDI)—Part 3: Physical Layer Medium Dependent (PMD).

ISO/IEC 9646-1:1994, Information technology—Open Systems Interconnection—Conformance testing methodology and framework—Part 1: General concepts.

ISO/IEC 9646-2:1994, Information technology—Open Systems Interconnection—Conformance testing methodology and framework—Part 2: Abstract test suite specification.

²³ISO/IEC publications are available from the International Organization for Standardization (<https://www.iso.org/>) and the International Electrotechnical Commission (<https://www.iec.ch/>). ISO/IEC publications are also available in the United States from the American National Standards Institute (<https://www.ansi.org/>).

²⁴Previous editions of ISO/IEC standards are available from Deutsches Institut für Normung (<https://www.din.de/>).

ISO/IEC DIS 11801-1:2016, Information technology—Generic cabling for customer premises—Part 1: General Requirements.

ISO/IEC TR 24750:2007, Information technology—Assessment and mitigation of installed balanced cabling channels in order to support of 10GBASE-T.

ITU-T Recommendation G.650.1, 2010—Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable.²⁵

ITU-T Recommendation G.652, 2016—Characteristics of a single-mode optical fibre and cable.

ITU-T Recommendation G.657, 2016—Characteristics of a bending-loss insensitive single-mode optical fibre and cable.

ITU-T Recommendation G.671, 2009—Transmission characteristics of optical components and subsystems.

ITU-T Recommendation G.691, 2006—Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers.

ITU-T Recommendation G.694.1—Spectral grids for WDM applications: DWDM frequency grid.

ITU-T Recommendation G.694.2—Spectral grids for WDM applications: CWDM wavelength grid.

ITU-T Recommendation G.695, 2010—Optical interfaces for coarse wavelength division multiplexing applications.

ITU-T Recommendation G.698.2—Amplified multichannel dense wavelength division multiplexing applications with single channel optical interfaces.

ITU-T Recommendation G.709—Interfaces for the optical transport network.

ITU-T Recommendation G.709.2—OTU4 long-reach interface.

ITU-T Recommendation G.957, 2006—Optical interfaces for equipments and systems relating to the synchronous digital hierarchy.

ITU-T Recommendation G.959.1, 2009—Optical transport network physical layer interfaces.

ITU-T Recommendation G.975—Forward error correction for submarine systems.

ITU-T Recommendation G.991.2, 2001—Amendment 1.

ITU-T Recommendation G.991.2, 2001—Single-pair high-speed digital subscriber line (SHDSL) transceivers.

ITU-T Recommendation G.993.1, 2001—Very high speed digital subscriber line foundation.

ITU-T Recommendation G.993.1, 2003—Amendment 1.

ITU-T Recommendation G.994.1, 2004—Handshake procedures for digital subscriber line (DSL) transceivers.

²⁵ITU-T publications are available from the International Telecommunications Union (<https://www.itu.int/>).

ITU-T Recommendation I.430, 1995—Basic user-network interface—Layer 1 specification.

ITU-T Recommendation K.44, 2019—Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents—Basic Recommendation.

ITU-T Recommendation O.150, 1996—General requirements for instrumentation for performance measurements on digital transmission equipment.

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

ITU-T Recommendation O.172, 2005—Jitter and wander measuring equipment for digital systems which are based on the synchronous digital hierarchy (SDH).

MATLAB Matrix Laboratory Software.²⁶

NAMUR NE 021:2017, Electromagnetic Compatibility of Equipment for Industrial Processes and Laboratory.²⁷

SAE J1292, Automobile and Motor Coach Wiring.

SCTE 02 2006, Specification for “F” Port, Female, Indoor.

SFF-8402, Rev 1.1, September 13, 2014, Specification for SFP+ 1X 28 Gb/s Pluggable Transceiver Solution (SFP28).²⁸

SFF-8432, Rev 5.1, August 8, 2012, Specification for SFP+ Module and Cage.

SFF-8436, Rev 4.8, October 31, 2013, Specification for QSFP+ 10 Gb/s 4X Pluggable Transceiver.

SFF-8470, Rev 3.3, April 3, 2006, Specification for Shielded High Speed Serial Multilane Copper Connector.

SFF-8482, Specification for Serial Attachment 2X Unshielded Connector.

SFF-8642, Rev 3.2, January 26, 2017, Specification for Mini Multilane 12X 10 Gb/s Shielded Connector (CXP10).

SFF-8665, Rev 1.9, June 29, 2015, Specification for QSFP+ 28 Gb/s 4X Pluggable Transceiver Solution (QSFP28).

TIA TSB-155-A-2010, Guidelines for the Assessment and Mitigation of Installed Category 6 Cabling to Support 10GBASE-T.²⁹

TIA TSB-5021, Guidelines for the Assessment and Mitigation of Installed Cabling to Support 2.5GBASE-T and 5GBASE-T.

NOTE—Local and national standards such as those supported by ANSI, EIA, MIL, NFPA, and UL are not a formal part of this standard except where no international standard equivalent exists. A number of local and national standards are

²⁶For information on MATLAB, contact The MathWorks (<https://www.mathworks.com/>).

²⁷NAMUR publications are available from the User Association of Automation Technology in Process Industries (<https://www.namur.net/>).

²⁸SFF specifications are available from the Storage Networking Industry Association (<https://www.snia.org/sff/specifications/>).

²⁹TIA publications are available from the IHS Standards Store (<https://global.ihs.com/>) or from the Telecommunications Industry Association (<https://www.tiaonline.org/>).

referenced as resource material; these bibliographical references are located in the bibliography in Annex A.³⁰

³⁰Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement this standard.

³¹The *IEEE Standards Dictionary Online* is available at <https://dictionary.ieee.org/>.