ISO/IEC 14165-151

Edition 1.0 2017-11

INTERNATIONAL STANDARD

colour inside

Information technology –Fibre channel – Part 151: Fibre Channel BaseT (FC-BaseT)



ISO/IEC 14165-151:2017-11(en)



THIS PUBLICATION IS COPYRIGHT PROTECTED
Copyright © 2017 ISO/IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about ISO/IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue
The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org
The world's leading online dictionary of electronic and electrical terms containing 20 000 terms and definitions in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary
65 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

ISO/IEC 14165-151

Edition 1.0 2017-11

INTERNATIONAL STANDARD

colour inside

Information technology –Fibre channel – Part 151: Fibre Channel BaseT (FC-BaseT)

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 35.200

ISBN 978-2-8322-5100-3

Warning! Make sure that you obtained this publication from an authorized distributor.

Information Technology — Fibre Channel — Part 151: BaseT

Technologies de l'information — Fibre Channel — Partie 151 (FC-BaseT)

Contents **Page**

FOREWORD 7
INTRODUCTION 9

1 Scope 10

2 Normative references 10

3 Terms, definitions, abbreviations, symbols, and conventions 11
3.1 Terms and definitions 11
3.2 Editorial conventions 14
3.3 Abbreviations, acronyms, and symbols 14
3.4 Keywords 15
3.5 State Diagram notation 16
3.5.1 State Diagram conventions 16
3.5.2 State Diagram variables 17
3.5.3 State Diagram timers 17
3.5.4 State transitions 17
3.5.5 Operators 18

4 Structure and concepts 19
4.1 Overview 19
4.2 Relationship with other standards 20
4.3 FC-BaseT PHY logical model 21
4.4 FC-BaseT usage of XGMII 22
4.5 Operation of FC-BaseT 23
4.5.1 Overview 23
4.5.2 PCS overview 24
4.5.3 PMA overview 25
4.6 FC-BaseT service primitives and interfaces 25
4.6.1 Overview 25
4.6.2 PMA service interface 25
4.6.3 Management function interface 30
4.7 FC-BaseT Nomenclature 31

5 Physical Coding Sublayer (PCS) 32
5.1 Overview 32
5.2 PCS reset function 32
5.3 PCS transmit function 33
5.3.1 Overview 33
5.3.2 36/33 transcoding 34
5.3.3 Error detecting code 36
5.3.4 PCS scrambling 37
5.3.5 Schläfli Lattice coding 39
5.3.6 Trellis coding 40
5.3.7 Generation of PMA training sequences 41
5.4 PCS receive function 42
5.4.1 Overview 42
5.4.2 Decoding 43
5.4.3 PCS descrambling 44
5.4.4 33/36 transcoding 45
5.4.5 PCS synchronization 46
5.5 State Diagrams 46

6 PMA Sublayer and Medium Dependent Interface 48
6.1 PMA Overview 48
6.2 PMA Functions 49
6.2.1 PMA Reset function 49
6.2.2 PMA Transmit function 49
6.2.3 PMA Receive Function 49
6.2.4 PHY Control Function 50
6.2.5 Link Monitor Function 53
6.2.6 Clock Recovery Function 53
6.2.7 State Diagrams 53
6.3 PMA Electrical Specification 56
6.3.1 Isolation and EMC Requirements 56
6.3.2 Test Modes 56
6.3.3 Transmitter Electrical Specifications 59
6.3.4 Receiver Electrical Specifications 64
6.4 MDI Specification 66
6.4.1 Overview 66
6.4.2 MDI Mechanical Specification 66
6.4.3 Automatic MDI/MDI-X Configuration 67
6.4.4 MDI Electrical Specification 67
6.4.5 MDI Fault tolerance 67
6.5 Link Segment Characteristics 67
6.5.1 Overview 67
6.5.2 FC-BaseT Link Topology 68
6.5.3 FC-BaseT Cable Plant Requirements 68

7 Elasticity FIFO 69
7.1 Overview 69
7.2 Ordered sets processing 70
7.3 Clock skew compensation 71

8 PHY startup procedure 73
8.1 Overview 73
8.2 Host speeds determination 73
8.3 Host synchronization 73
8.4 FC-BaseT auto-negotiation 74
8.4.1 Overview 74
8.4.2 FC-BaseT support 75
8.4.3 Master-Slave relationship 76
8.4.4 Cable length estimation 77
8.4.5 Tentative Operating Speed Determination 78
8.4.6 Configuration resolution 79
8.5 Speed downshift function 80
8.6 State diagrams 80

9 Port management 86
9.1 Overview 86
9.2 FC-BaseT management registers 86
9.3 Control Register 88
9.4 Status Register 91
9.5 Speed Downshift Register 93
9.6 Test Register 94
9.7 SNR Margin Registers 94
9.8 Auto-Negotiation Pages Registers 95

Annex A (informative) Additional 36/33 Mappings 98
A.1 Overview. 98
A.2 Notation 98
A.3 Additional mappings 98

Annex B (informative) Schläfli Lattice coding 100

Annex C (informative) Recommended 4GFC-BaseT power schedule 102

Bibliography 103

Figure **Page**

Figure 1 State diagram notation example. . . . 16
Figure 2 FC-BaseT topology 19
Figure 3 FC-BaseT relationship to the OSI Reference Model, the Fibre Channel Levels, and the IEEE 802.3 LAN Model. . . . 20
Figure 4 An FC-BaseT PHY logical model 21
Figure 5 PCS and PMA functional block diagram 24
Figure 6 PCS and PMA service interfaces 26
Figure 7 FC-BaseT nomenclature 31
Figure 8 PCS reference diagram 32
Figure 9 PCS transmit bit ordering 33
Figure 10 Side-stream scrambler for the Master PHY 37
Figure 11 Side-stream scrambler for the Slave PHY 38
Figure 12 4D PAM-8 Schläfli Lattice encoder. . . . 39
Figure 13 4D PAM-8 Trellis encoder 40
Figure 14 Generation of PMA training PAM-2 sequences 41
Figure 15 PCS receive bit ordering 42
Figure 16 4D PAM-8 Schläfli Lattice decoder. . . . 43
Figure 17 Side-stream descrambler for the Master PHY 44
Figure 18 Side-stream descrambler for the Slave PHY 44
Figure 19 PCS synchronization state diagram 47
Figure 20 PMA Reference Diagram 48
Figure 21 Example of Link Establishment 52
Figure 22 PHY Control State Diagram 55
Figure 23 Link Monitor State Diagram 56
Figure 24 Transmitter Test Fixture A 58
Figure 25 Transmitter Test Fixture B 58
Figure 26 Test Mode 1 Output (not to scale) 59
Figure 27 4GFC-BaseT Transmitter PSD at 5dBm 61
Figure 28 2GFC-BaseT Transmitter PSD at 5dBm 62
Figure 29 1GFC-BaseT Transmitter PSD at 5dBm 63
Figure 30 MDI Jack Connector. . . . 66
Figure 31 Balanced Cabling Plug Connector 66
Figure 32 FC-BaseT Link Topology 68
Figure 33 FC-BaseT elasticity FIFO 69
Figure 34 Example of E-FIFO implementation 70
Figure 35 FC-BaseT clock skew compensation 71
Figure 36 Base page encoding. . . . 75
Figure 37 Unformatted page encoding 76
Figure 38 Clock detect state diagram. . . . 84
Figure 39 Clock loopback state diagram 85
Figure B.1 4D symbol error rate in function of SNR 100

Table **Page**

Table 1 ISO and American Conventions 14
Table 2 State Diagram Operators. 18
Table 3 FC-BaseT design goals for data rates and cable reaches
for the cabling channels specified by ISO/IEC 11801:2002/AMD2:2010 20
Table 4 XGMII frequencies for FC-BaseT 22
Table 5 XGMII characters. 22
Table 6 FC-BaseT symbol and data rates 23
Table 7 Fibre Channel words 34
Table 8 XGMII representation of Fibre Channel words 35
Table 9 36/33 transcoding 35
Table 10 36/33 transcoding examples 35
Table 11 Bit to symbols mapping 40
Table 12 PMA training sequences 41
Table 13 PCS synchronization state variables. 46
Table 14 Idle2 and Idle3 Ordered Sets. 51
Table 15 PHY Control and Link Monitor State Variables 53
Table 16 PHY Control and Link Monitor Timers. 54
Table 17 Management Register Settings for Test Modes 57
Table 18 Disturbing Signal Frequency 59
Table 19 Droop Requirements 59
Table 20 Transmitter Power Schedule 64
Table 21 Transmitter Frequency Requirements. 64
Table 22 Receiver Frequency Requirements. 65
Table 23 Alien Noise Requirements. 65
Table 24 Assignment of PMA Signals to MDI and MDI-X Contacts. 67
Table 25 FC-BaseT MDI Electrical Requirements 67
Table 26 FC-BaseT Cable Plant Requirements. 68
Table 27 Extended Fill Words 70
Table 28 Technology Ability Field. 75
Table 29 Unformatted code field of the first unformatted page 76
Table 30 Master-Slave seed assignment. 77
Table 31 Unformatted code field of the second unformatted page. 78
Table 32 Unformatted code field of the third unformatted page. 79
Table 33 Cable length estimation state variables. 81
Table 34 Cable length estimation timers 83
Table 35 FC-BaseT registers 86
Table 36 FC-BaseT control register bits. 88
Table 37 FC-BaseT status register bits 91
Table 38 FC-BaseT speed downshift register bits 93
Table 39 FC-BaseT test register bits 94
Table 40 FC-BaseT SNR margin registers bits 94
Table 41 FC-BaseT auto-negotiation pages registers bits. 96
Table A.1 Additional 36/33 mappings. 98
Table A.2 6-bit encoding of XGMII control characters 99
Table C.1 Recommended transmitter power schedule 102

INFORMATION TECHNOLOGY – FIBRE CHANNEL –

Part 151: Fibre Channel BaseT (FC-BaseT)

FOREWORD

1) ISO (International Organization for Standardization) and IEC (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. Their preparation is entrusted to technical committees; any ISO and IEC member body interested in the subject dealt with may participate in this preparatory work. International governmental and non-governmental organizations liaising with ISO and IEC also participate in this preparation.

2) In the field of information technology, ISO and IEC have established a joint technical committee, ISO/IEC JTC 1. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

3) The formal decisions or agreements of IEC and ISO on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC and ISO member bodies.

4) IEC, ISO and ISO/IEC publications have the form of recommendations for international use and are accepted by IEC and ISO member bodies in that sense. While all reasonable efforts are made to ensure that the technical content of IEC, ISO and ISO/IEC publications is accurate, IEC or ISO cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.

5) In order to promote international uniformity, IEC and ISO member bodies undertake to apply IEC, ISO and ISO/IEC publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any ISO/IECpublication and the corresponding national or regional publication should be clearly indicated in the latter.

6) ISO and IEC provide no marking procedure to indicate their approval and cannot be rendered responsible for any equipment declared to be in conformity with an ISO/IEC publication.

7) All users should ensure that they have the latest edition of this publication.

8) No liability shall attach to IEC or ISO or its directors, employees, servants or agents including individual experts and members of their technical committees and IEC or ISO member bodies for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication of, use of, or reliance upon, this ISO/IEC publication or any other IEC, ISO or ISO/IEC publications.

9) Attention is drawn to the normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

10) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

International Standard ISO/IEC 14165-151 was prepared by subcommittee 25: Interconnection of information technology equipment, of ISO/IEC joint technical committee 1: Information technology.

The list of all currently available parts of the ISO/IEC 14165 series, under the general title *Information technology – Fibre Channel,* can be found on the IEC web site.

This International Standard has been approved by vote of the member bodies and the voting results may

be obtained from the address given on the second title page.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

IMPORTANT - The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This part of ISO/IEC 14165 describes extensions to the Fibre Channel signaling and physical layer requirements defined in ANSI INCITS 404-2005, Fibre Channel - Physical Interfaces 2, to transport Fibre Channel over the commonly available 4-pair balanced copper cablings specified in ISO/IEC 11801:2002 and TIA/EIA-568-B.2-2001. This document is one of the Fibre Channel family of standards.

INFORMATION TECHNOLOGY — FIBRE CHANNEL —

Part 151: Fibre Channel BaseT (FC-BaseT)

1 Scope

This part of ISO/IEC 14165 describes extensions to the Fibre Channel signaling and physical layer requirements defined in ISO/IEC 14165-142, Fibre Channel - Physical Interfaces 2, to transport Fibre Channel over the commonly available 4-pair balanced copper cablings specified in ISO/IEC 11801:2002 and TIA/EIA-568-B.2-2001. This standard is one of the Fibre Channel family of standards.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60603-7-2, *Connectors for electronic equipment – Part 7-2: Detail specification for 8-way, unshielded, free and fixed connectors, for data transmissions with frequencies up to 100 MHz*

IEC 60603-7-3, *Connectors for electronic equipment – Part 7-3: Detail specification for 8-way, shielded, free and fixed connectors, for data transmission with frequencies up to 100 MHz*

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*

ISO/IEC 14165-122, *Information technology - Fibre Channel - Part 122: Arbitrated Loop - 2 (FC-AL-2)* [ANSI INCITS 332-1999 including ANSI INCITS 332-1999/AM1-2003 and ANSI INCITS 332-1999/AM2-2006]

ISO/IEC 11801:2002, *Information technology - Generic cabling for customer premises*

ISO/IEC 11801:2002/AMD1:2008

ISO/IEC 11801:2002/AMD2:2010

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

ANSI INCITS 404-2006, *Information technology - Fibre Channel - Part 142: Physical Interfaces - 2 (FC-PI-2)*

ANSI INCITS 424-2007, *Information technology - Fibre Channel - Framing and Signaling - 2 (FC-FS-2)*

IEEE Std 802.3-2005, *Standard for information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements - Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications*

IEEE Std 802.3an-2006, *Physical Layer and Management Parameters for 10 Gb/s Operation, Type 10GBASE-T*

3 Terms, definitions, abbreviations, symbols, and conventions

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/

- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
10 Gigabit Media Independent Interface
XGMII
interface defined in IEEE 802.3-2005 for 10 Gbit/s operations but used in this standard for lower speeds operations (see 4.4)

3.1.2
Auto-Negotiation
algorithm that allows two devices at either end of a link segment to negotiate common data service functions

3.1.3
balanced cable
cable consisting of one or more metallic symmetrical cable elements (e.g., twisted pairs)

3.1.4
bit error rate
BER
ratio of the number of bits received in error to the total number of bits received

3.1.5
dimension
component of the PHY that generates locally and recovers from the link partner a logical sequence of symbols

Note 1 to entry: A transmit or receive dimension is a logical reference for a wire pair, independent from the specific wire pair where symbols are sent or received.

Note 2 to entry: Dimensions A, B, C, and D are respectively associated with sequences A_n, B_n, C_n, and D_n (see 4.3).

3.1.6
jitter
variations of signal transitions from their ideal positions in time. Jitter may be characterized by its spectral properties and its distribution in time

3.1.7
link
transmission path between any two interfaces of generic cabling

3.1.8
link segment
point-to-point full-duplex medium connection between two and only two Medium Dependent Interfaces (MDIs)

3.1.9
Master PHY
PHY that uses an external clock for generating its clock signals to determine the timing of transmitter and receiver operations

Note 1 to entry: It also uses the Master transmit scrambler generator polynomial for side-stream scrambling.

3.1.10
Medium Dependent Interface
MDI
mechanical and electrical interface between the transmission medium and the Physical Layer device

3.1.11
Ordered Set
word composed of a special character in its first (left-most) position and data characters in its remaining positions (see FC-FS-2)

3.1.12
Physical Coding Sublayer
PCS
portion of the Physical Layer that couples the XGMII and the Physical Medium Attachment (PMA)

Note 1 to entry: The PCS contains the functions to encode data bits for transmission via the PMA and to decode the received conditioned signal from the PMA.

3.1.13
Physical Layer device
PHY
portion of the Physical Layer between the Medium Dependent Interface (MDI) and the XGMII, consisting of the Physical Coding Sublayer (PCS) and the Physical Medium Attachment (PMA)

Note 1 to entry: The PHY contains the functions that transmit, receive, and manage the encoded signals that are impressed on and recovered from the physical medium.

3.1.14
Physical Medium Attachment sublayer
PMA sublayer
portion of the Physical Layer that contains the functions for transmission, reception, clock recovery and skew alignment

3.1.15
Scrambler
randomizing mechanism that is used to eliminate long strings of consecutive identical transmitted symbols and avoid the presence of spectral lines in the signal spectrum without changing the signaling rate

3.1.16
Side-stream scrambler
scrambler in which the state of the scrambler is dependent only on the prior state of the scrambler and not on the transmitted data

3.1.17
Slave PHY
PHY that recovers its clock from the received signal and uses it to determine the timing of transmitter operations

Note 1 to entry: It also uses the Slave transmit scrambler generator polynomial for side-stream scrambling.

3.1.18
Symbol
smallest unit of data transmission on the medium

3.1.19
Symbol period
time interval for transmission of one symbol

3.1.20
Symbol rate
total number of symbols per second transferred to or from the Medium Dependent Interface (MDI) on a single wire pair

3.1.21
twisted-pair cable
bundle of multiple twisted pairs within a single protective sheath

3.1.22
word
<when used to indicate a size> 32 contiguous bits

3.2 Editorial conventions

In this standard, a number of conditions, mechanisms, sequences, parameters, events, states, or similar terms are printed with the first letter of each word in uppercase and the rest lowercase (e.g., Exchange, Class). Any lowercase uses of these words have the normal technical English meanings.

Lists sequenced by letters (e.g., a-red, b-blue, c-green) show no ordering relationship between the listed items. Numbered lists (e.g., 1-red, 2-blue, 3-green) show an ordering relationship between the listed items.

The ISO convention of numbering is used (i.e., the thousands and higher multiples are separated by a space and a comma is used as the decimal point.) A comparison of the American and ISO conventions are shown in table 1.

Table 1 – ISO and American Conventions

ISO	American
0,6	0.6
1 000	1,000
1 323 462,9	1,323,462.9

In case of any conflict between figure, table, and text, the text, then tables, and finally figures take precedence.

In all of the figures, tables, and text of this document, the most significant bit of a binary quantity is shown on the left side.

When the value of a bit or field is not relevant, x or xx appears in place of a specific value.

Unless stated otherwise, numbers that are not immediately followed by lower-case b or h are decimal values, numbers immediately followed by lower-case b (xxb) are binary values, and numbers or upper case letters immediately followed by lower-case h (xxh) are hexadecimal values.

A numeric range is indicated by listing the two extremes separated by ".." (e.g., "1 .. 6" indicates the range from 1 to 6, including 1 and 6).

3.3 Abbreviations, acronyms, and symbols

Abbreviations, acronyms, and symbols applicable to this standard are listed. Definitions of several of these items are included in 3.1.

⊕ The XOR operator
|| concatenation symbol (e.g., A || B represents the concatenation of A and B)
4D 4-dimensional
BER bit error rate
dB Decibel
E-FIFO Elasticity FIFO
EDC Error Detecting Code
EIA Electronic Industries Association
EMC Electromagnetic Compatibility
EMI Electromagnetic Interference
FEXT Far-end crosstalk
FLP Fast Link Pulse
I2C Inter-Integrated Circuit bus

IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
LAN	Local Area Network
MDI	Medium Dependent Interface
MDIO	Management Data Input/Output Interface
MII	Media Independent Interface
NEXT	Near-end crosstalk
NLP	Normal Link Pulse
OSI	Open Systems Interconnection
PAM	Pulse Amplitude Modulation
PAM-2	2-level Pulse Amplitude Modulation
PAM-8	8-level Pulse Amplitude Modulation
PCS	Physical Coding Sublayer
PHY	Physical Layer device
PMA	Physical Medium Attachment
ppm	Parts per million
PSD	Power Spectral Density
RF	Remote Fault
RX	Receiver
SNR	Signal to Noise Ratio
TIA	Telecommunication Industries Association
TX	Transmitter
XGMII	10 Gigabit Media Independent Interface

3.4 Keywords

3.4.1 expected: A keyword used to describe the behavior of the hardware or software in the design models assumed by this standard. Other hardware and software design models may also be implemented.

3.4.2 ignored: A keyword used to describe an unused bit, byte, word, field or code value. The contents or value of an ignored bit, byte, word, field or code value shall not be examined by the receiving device and may be set to any value by the transmitting device.

3.4.3 invalid: A keyword used to describe an illegal or unsupported bit, byte, word, field or code value. Receipt of an invalid bit, byte, word, field or code value shall be reported as an error.

3.4.4 mandatory: A keyword indicating an item that is required to be implemented as defined in this standard.

3.4.5 may: A keyword that indicates flexibility of choice with no implied preference (equivalent to “may or may not”).

3.4.6 may not: A keyword that indicates flexibility of choice with no implied preference (equivalent to “may or may not”).

3.4.7 obsolete: A keyword indicating that an item was defined in prior Fibre Channel standards but has been removed from this standard.

3.4.8 optional: A keyword that describes features that are not required to be implemented by this standard. However, if any optional feature defined by this standard is implemented, then it shall be implemented as defined in this standard.

3.4.9 reserved: A keyword referring to bits, bytes, words, fields and code values that are set aside for future standardization. A reserved bit, byte, word or field shall be set to zero, or in accordance with a future extension to this standard. Recipients are not required to check reserved bits, bytes, words or fields for zero values.

3.4.10 restricted: A keyword referring to bits, bytes, words, and fields that are set aside for use in other Fibre Channel standards. A restricted bit, byte, word, or field shall be treated as a reserved bit, byte, word or field for the purposes of the requirements defined in this standard.

3.4.11 shall: A keyword indicating a mandatory requirement. Designers are required to implement all such mandatory requirements to ensure interoperability with other products that conform to this standard.

3.4.12 should: A keyword indicating flexibility of choice with a strongly preferred alternative; equivalent to the phrase “it is strongly recommended”.

3.4.13 x or **xx:** The value of the bit or field is not relevant.

3.5 State Diagram notation

3.5.1 State Diagram conventions

The operation of a protocol may be described by subdividing the protocol into a number of interrelated functions.The operation of the functions may 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).

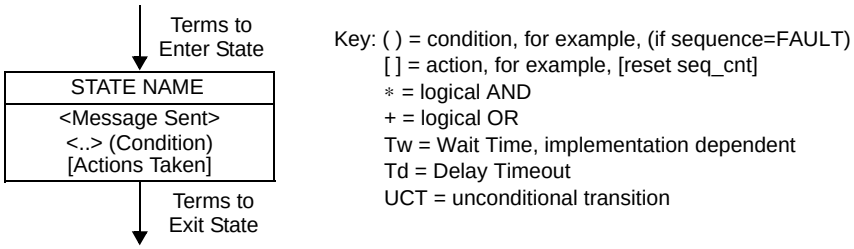


Figure 1 – State diagram notation example

Each state that the function is able to 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 (e.g., an exit condition from all states to the IDLE or RESET state) is indicated by an open arrow. Labels on transitions are qualifiers that shall be fulfilled before the transition is 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. The actions inside a state block execute instantaneously. Actions inside state blocks are atomic (i.e., uninterruptible). When a state is entered and after performing all the actions listed in a state block one time, the state block then continuously evaluates its exit conditions until one is satisfied, at which point control passes through a transition arrow to

the next block. While the state awaits fulfillment of one of its exit conditions, the actions inside do not implicitly repeat.

Valid state actions may include .indication and .request messages. No actions are taken outside of any state block.

The following convention is 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; and

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. However, such precedence does not override 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. However, it is important to distinguish 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 shall 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.

3.5.2 State Diagram variables

State variables are of two types, variables with no default value and variables with a default value. Variables with no default value, once set retain their value as long as succeeding blocks contain no references to them. Variables with default value evaluate to the variable default value in each state where the variable value is not explicitly set.

3.5.3 State Diagram timers

All timers operate in the same fashion. A timer is reset and starts counting upon entering a state where "start x_timer" is asserted. Time "x" after the timer has been started, "x_timer_done" is asserted and remains asserted until the timer is reset. At all other times, "x_timer_not_done" is asserted. When explicitly entering a state where "start x_timer" is asserted, the timer is reset and restarted even if the entered state is the same as the exited state. In addition, a timer is reset and stops counting upon entering a state where "stop timer" is asserted.

3.5.4 State transitions

The following terms are valid transition qualifiers:

a) Boolean expressions;

b) An event such as the expiration of a timer: timer_done;

c) An event such as the reception of a message: PMA_UNITDATA.indication;

d) An unconditional transition: UCT;

e) A branch taken when other exit conditions are not satisfied: ELSE.

Any open arrow (an arrow with no source block) represents a global transition. Global transitions are evaluated continuously whenever any state is evaluating its exit conditions. When a global transition becomes true, it supersedes all other transitions, including UCT, returning control to the block pointed to by the open arrow.

3.5.5 Operators

The state diagram operators are shown in table 2.

Table 2 – State Diagram Operators

Character	Meaning
*	Boolean AND
+	Boolean OR
^	Boolean XOR
!	Boolean NOT
<	Less than
≤	Less than or equal to
=	Equals (a test of equality)
≠	Not equals
≥	Greater than or equal to
>	Greater than
( )	Indicates precedence
⇐	Assignment operator
∈	Indicates membership
∉	Indicates nonmembership
|	Catenate
ELSE	No other state condition is satisfied