

INTERNATIONAL STANDARD



**Information technology – Small computer system interface (SCSI) –
Part 154: Serial Attached SCSI - 3 (SAS-3)**

(standards.iteh.ai)

[ISO/IEC 14776-154:2017](https://standards.iteh.ai/catalog/standards/sist/3cc9c166-22ff-48a8-88d5-f3ec20f80bb4/iso-iec-14776-154-2017)

[https://standards.iteh.ai/catalog/standards/sist/3cc9c166-22ff-48a8-88d5-
f3ec20f80bb4/iso-iec-14776-154-2017](https://standards.iteh.ai/catalog/standards/sist/3cc9c166-22ff-48a8-88d5-f3ec20f80bb4/iso-iec-14776-154-2017)



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 Varembe
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 It also gives information on projects, replaced and withdrawn publications.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 14776-1:2017
<https://standards.iteh.ai/catalog/standards/sist/5c9206-22ff-48a8-88d5-3ec20f80bb4/iso-iec-14776-154-2017>



ISO/IEC 14776-154

Edition 1.0 2017-12

INTERNATIONAL STANDARD



Information technology – Small computer system interface (SCSI) –
Part 154: Serial Attached SCSI - 3 (SAS-3)
(standards.iteh.ai)

ISO/IEC 14776-154:2017
<https://standards.iteh.ai/catalog/standards/sist/3cc9c166-22ff-48a8-88d5-f3ec20f80bb4/iso-iec-14776-154-2017>

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 35.200

ISBN 978-2-8322-5168-3

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

CONTENTS

FOREWORD.....	14
INTRODUCTION.....	16
1 Scope.....	18
2 Normative references.....	18
3 Terms, definitions, symbols, abbreviations, keywords, and conventions.....	20
3.1 Terms and definitions.....	20
3.2 Symbols and abbreviations.....	33
3.2.1 Abbreviations.....	33
3.2.2 Symbols.....	36
3.2.2.1 Units.....	36
3.2.2.2 Mathematical operators.....	36
3.2.2.3 Other symbols.....	37
3.3 Keywords.....	38
3.4 Editorial conventions.....	39
3.5 Numeric and character conventions.....	40
3.5.1 Numeric conventions.....	40
3.5.2 Units of measure.....	40
3.5.3 Byte encoded character strings conventions.....	41
4 General.....	42
4.1 Physical links and phys.....	42
4.2 Phy test functions.....	42
5 Physical layer.....	43
5.1 Physical layer overview.....	43
5.2 Conventions for defining maximum limits for S-parameters.....	43
5.3 Compliance points.....	44
5.3.1 Compliance points overview.....	44
5.3.2 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s compliance points.....	45
5.3.3 12 Gbit/s compliance points.....	53
5.4 Interconnects.....	55
5.4.1 SATA connectors and cable assemblies.....	55
5.4.2 SAS connectors and cables.....	56
5.4.3 Connectors.....	60
5.4.3.1 Connectors overview.....	60
5.4.3.2 Connector categories.....	62
5.4.3.3 Recommended electrical performance limits for mated connector pairs supporting rates of 12 Gbit/s.....	63
5.4.3.4 SAS internal connectors.....	64
5.4.3.4.1 SAS Drive connectors.....	64
5.4.3.4.1.1 SAS Drive plug connector.....	64
5.4.3.4.1.2 SAS Drive cable receptacle connector.....	65
5.4.3.4.1.3 SAS Drive backplane receptacle connector.....	66
5.4.3.4.1.4 SAS Drive connector pin assignments.....	67
5.4.3.4.1.5 SAS MultiLink Drive plug connector.....	69
5.4.3.4.1.6 SAS MultiLink Drive cable receptacle connector.....	69
5.4.3.4.1.7 SAS MultiLink Drive backplane receptacle connector.....	70
5.4.3.4.1.8 SAS MultiLink Drive connector pin assignments.....	70
5.4.3.4.1.9 Micro SAS plug connector.....	74
5.4.3.4.1.10 Micro SAS receptacle connector.....	74
5.4.3.4.1.11 Micro SAS connector pin assignments.....	75
5.4.3.4.2 SAS 4i connectors.....	76
5.4.3.4.2.1 SAS 4i cable receptacle connector.....	76

ITeh STANDARD PREVIEW
(standards.iteh.ai)

ISO/IEC 14776-154:2017
finishing maximum limits for S-parameters
9c166-22ff-48a8-88d5-
3ec20f80bb4/iso-iec-14776-154-2017

5.4.3.4.2.2 SAS 4i plug connector.....	76
5.4.3.4.2.3 SAS 4i connector pin assignments	77
5.4.3.4.3 Mini SAS 4i connectors.....	79
5.4.3.4.3.1 Mini SAS 4i cable plug connector	79
5.4.3.4.3.2 Mini SAS 4i receptacle connector	79
5.4.3.4.3.3 Mini SAS 4i connector pin assignments.....	80
5.4.3.4.4 Mini SAS HD internal connectors	82
5.4.3.4.4.1 Mini SAS HD 4i cable plug connector	82
5.4.3.4.4.2 Mini SAS HD 8i cable plug connector	83
5.4.3.4.4.3 Mini SAS HD 4i receptacle connector	84
5.4.3.4.4.4 Mini SAS HD 8i receptacle connector	85
5.4.3.4.4.5 Mini SAS HD 16i receptacle connector.....	86
5.4.3.4.4.6 Mini SAS HD 4i connector pin assignments.....	87
5.4.3.5 SAS external connectors.....	90
5.4.3.5.1 Mini SAS 4x connectors.....	90
5.4.3.5.1.1 Mini SAS 4x cable plug connector	90
5.4.3.5.1.2 Mini SAS 4x receptacle connector	97
5.4.3.5.1.3 Mini SAS 4x connector pin assignments.....	103
5.4.3.5.1.4 Mini SAS 4x active connector pin assignments	104
5.4.3.5.1.5 Mini SAS 4x active cable power requirements.....	105
5.4.3.5.2 Mini SAS HD external connectors	106
5.4.3.5.2.1 Mini SAS HD 4x cable plug connector	106
5.4.3.5.2.2 Mini SAS HD 8x cable plug connector	107
5.4.3.5.2.3 Mini SAS HD 4x receptacle connector.....	108
5.4.3.5.2.4 Mini SAS HD 8x receptacle connector.....	109
5.4.3.5.2.5 Mini SAS HD 16x receptacle connector.....	110
5.4.3.5.2.6 Mini SAS HD 4x connector pin assignments.....	111
5.4.3.5.2.7 Mini SAS HD external connector management interface.....	112
5.4.3.5.2.8 Mini SAS HD external connector memory map.....	113
5.4.3.5.3 QSFP+ connectors.....	113
5.4.3.5.3.1 QSFP+ cable plug.....	113
5.4.3.5.3.2 QSFP+ receptacle.....	114
5.4.3.5.3.3 QSFP+ connector pin assignments	115
5.4.3.5.3.4 QSFP+ memory map	116
5.4.4 Cable assemblies.....	117
5.4.4.1 SAS internal cable assemblies.....	117
5.4.4.1.1 SAS Drive cable assemblies.....	117
5.4.4.1.2 SAS internal symmetric cable assemblies.....	119
5.4.4.1.2.1 SAS internal symmetric cable assemblies overview	119
5.4.4.1.2.2 SAS internal symmetric cable assembly - SAS 4i.....	120
5.4.4.1.2.3 SAS internal symmetric cable assembly - Mini SAS 4i	121
5.4.4.1.2.4 SAS internal symmetric cable assembly - Mini SAS HD 4i.....	122
5.4.4.1.2.5 SAS internal symmetric cable assembly - Mini SAS HD 8i.....	123
5.4.4.1.2.6 SAS internal symmetric cable assembly - SAS 4i to Mini SAS 4i with vendor-specific sidebands.....	124
5.4.4.1.2.7 SAS internal symmetric cable assembly - SAS 4i controller to Mini SAS 4i backplane with SGPIO.....	125
5.4.4.1.2.8 SAS internal symmetric cable assembly - Mini SAS 4i controller to SAS 4i backplane with SGPIO.....	126
5.4.4.1.2.9 SAS internal symmetric cable assembly - Mini SAS 4i to Mini SAS HD 4i	127
5.4.4.1.3 SAS internal fanout cable assemblies	128
5.4.4.1.3.1 SAS internal fanout cable assemblies overview	128
5.4.4.1.3.2 SAS internal controller-based fanout cable assemblies.....	129
5.4.4.1.3.3 SAS internal backplane-based fanout cable assemblies	132
5.4.4.2 SAS external cable assemblies.....	135
5.4.4.2.1 SAS external cable assemblies overview	135
5.4.4.2.2 SAS external cable assembly - Mini SAS 4x.....	136
5.4.4.2.3 SAS external cable assembly - Mini SAS HD 4x.....	139

5.4.4.2.4 SAS external cable assembly - Mini SAS HD 8x	141
5.4.4.2.5 SAS external cable assembly - Mini SAS HD 8x to Mini SAS HD 4x	143
5.4.4.2.6 SAS external cable assembly - Mini SAS HD 4x to Mini SAS 4x	145
5.4.4.2.7 SAS external cable assembly - QSFP+	146
5.4.5 Backplanes	146
5.5 TxRx connection characteristics	147
5.5.1 TxRx connection characteristics overview	147
5.5.2 TxRx connection general characteristics	148
5.5.3 Passive TxRx connection S-parameter limits	149
5.5.4 Passive TxRx connection characteristics for untrained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	151
5.5.5 Passive TxRx connection characteristics for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	152
5.5.6 Passive TxRx connection characteristics for trained 12 Gbit/s	153
5.5.7 TxRx connection characteristics for active cable assemblies	157
5.5.7.1 Active cable assembly electrical characteristics for trained 6 Gbit/s overview	157
5.5.7.2 Active cable assembly output electrical characteristics for trained 6 Gbit/s	157
5.5.7.3 Active cable assembly S-parameter limits for trained 6 Gbit/s and trained 12 Gbit/s	158
5.5.7.4 Active cable assembly electrical characteristics overview for 12 Gbit/s	159
5.5.7.5 Active cable assembly electrical characteristics for 12 Gbit/s	160
5.6 Test loads	161
5.6.1 Test loads overview	161
5.6.2 Zero-length test load	162
5.6.3 TCTF test load	163
5.6.4 Low-loss TCTF test load	168
5.6.5 Trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s reference transmitter test load	169
5.7 End to end simulation for trained 12 Gbit/s	173
5.7.1 End to end simulation for trained 12 Gbit/s overview	173
5.7.2 Usage models for end to end simulation for trained 12 Gbit/s	174
5.7.3 Reference transmitter equalization for trained 12 Gbit/s	175
5.7.4 Crosstalk measurement for end to end simulations and 12 Gbit/s jitter tolerance	177
5.8 Transmitter device and receiver device electrical characteristics	178
5.8.1 General electrical characteristics	178
5.8.2 Transmitter device and receiver device transients	179
5.8.3 Eye masks and the JTF	180
5.8.3.1 Eye masks overview	180
5.8.3.2 JTF	180
5.8.3.3 Transmitter device eye mask for untrained 1.5 Gbit/s and 3 Gbit/s	181
5.8.3.4 Receiver device eye mask for untrained 1.5 Gbit/s and 3 Gbit/s	182
5.8.3.5 Receiver device jitter tolerance eye mask for untrained 1.5 Gbit/s and 3 Gbit/s	182
5.8.4 Transmitter device characteristics	184
5.8.4.1 Transmitter device characteristics overview	184
5.8.4.2 Transmitter device coupling requirements	184
5.8.4.3 Transmitter device general electrical characteristics	184
5.8.4.4 Transmitter device signal output characteristics for untrained 1.5 Gbit/s and 3 Gbit/s as measured with the zero-length test load	186
5.8.4.5 Transmitter device signal output characteristics for untrained 1.5 Gbit/s and 3 Gbit/s as measured with each test load	187
5.8.4.6 Transmitter device signal output characteristics for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s ..	189
5.8.4.6.1 Transmitter device signal output characteristics for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s overview	189
5.8.4.6.2 Trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s transmitter device test procedure	190
5.8.4.6.3 Trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s Transmitter device S-parameter limits	191
5.8.4.6.4 Recommended trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s transmitter device settings for interoperability	192
5.8.4.6.5 Trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s reference transmitter device characteristics	193
5.8.4.6.6 Trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s Transmitter equalization, VMA, and $V_{P,P}$ measurement	194
5.8.4.7 Transmitter device signal output characteristics for trained 12 Gbit/s	196
5.8.4.7.1 Transmitter device signal output characteristics for trained 12 Gbit/s overview	196

5.8.4.7.2	12 Gbit/s Transmitter device S-parameter limits.....	203
5.8.4.7.3	12 Gbit/s reference transmitter device.....	205
5.8.4.7.4	Transmitter device end to end simulation characteristics for trained 12 Gbit/s	207
5.8.4.7.5	Transmitter device signal output characteristics at CTS for 12 Gbit/s when an active cable is connected.....	208
5.8.4.8	Transmitter device signal output characteristics for OOB signals	208
5.8.5	Receiver device characteristics	210
5.8.5.1	Receiver device characteristics overview.....	210
5.8.5.2	Receiver device coupling requirements	210
5.8.5.3	Receiver device general electrical characteristics.....	211
5.8.5.4	Delivered signal characteristics for untrained 1.5 Gbit/s and 3 Gbit/s.....	213
5.8.5.5	Maximum delivered jitter for untrained 1.5 Gbit/s and 3 Gbit/s	214
5.8.5.6	Receiver device jitter tolerance for untrained 1.5 Gbit/s and 3 Gbit/s	215
5.8.5.7	Receiver device and delivered signal characteristics for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, and 12 Gbit/s	216
5.8.5.7.1	Delivered signal characteristics for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, and 12 Gbit/s	216
5.8.5.7.2	Receiver device S-parameter limits	216
5.8.5.7.3	Reference receiver device characteristics	218
5.8.5.7.3.1	Reference receiver device overview	218
5.8.5.7.3.2	Reference receiver device DFE	219
5.8.5.7.3.3	Reference receiver device equalization for trained 12 Gbit/s.....	219
5.8.5.7.4	Reference receiver device termination characteristics for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	220
5.8.5.7.5	Reference receiver device termination characteristics for trained 12 Gbit/s.....	220
5.8.5.7.6	Stressed receiver device jitter tolerance test.....	221
5.8.5.7.6.1	Stressed receiver device jitter tolerance test overview for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	221
5.8.5.7.6.2	Stressed receiver device jitter tolerance test procedure for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	223
5.8.5.7.6.3	Test equipment calibration and ISI generator calibration for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	224
5.8.5.7.6.4	Crosstalk source calibration for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s.....	224
5.8.5.7.6.5	Stressed receiver device jitter tolerance test procedure for trained 12 Gbit/s.....	225
5.8.5.7.6.6	ISI generator calibration for trained 12 Gbit/s	225
5.8.5.7.6.7	Crosstalk calibration for the trained 12 Gbit/s stressed receiver device jitter tolerance test	228
5.8.5.7.6.8	Applied RJ for trained 12 Gbit/s stressed receiver device jitter tolerance test	228
5.8.5.7.6.9	Applied SJ.....	228
5.8.5.8	Delivered signal characteristics for OOB signals	230
5.8.6	Spread spectrum clocking (SSC).....	230
5.8.6.1	SSC overview.....	230
5.8.6.2	Transmitter SSC modulation	231
5.8.6.3	Receiver SSC modulation tolerance	232
5.8.6.4	Expander device center-spreading tolerance buffer.....	233
5.8.7	Non-tracking clock architecture.....	234
5.9	READY LED signal electrical characteristics.....	234
5.10	POWER DISABLE signal electrical characteristics	235
5.11	Out of band (OOB) signals	237
5.11.1	OOB signals overview.....	237
5.11.2	Transmitting OOB signals.....	238
5.11.3	Receiving OOB signals.....	240
5.11.4	Transmitting the SATA port selection signal.....	241
Annex A	(normative) Jitter tolerance pattern (JTPAT)	242
Annex B	(normative) SASWDP	244
B.1	SASWDP introduction	244
B.2	SASWDP.m.....	244

B.3 SASWDP_testcase.m	251
Annex C (informative) StatEye	253
C.1 StatEye introduction	253
C.2 analysis.py	253
C.3 cdr.py	254
C.4 extractJitter.py	255
C.5 penrose.py	257
C.6 portlocker.py	259
C.7 stateye.py	262
C.8 touchstone.py	277
C.9 testcase.py	285
C.10 testall.py	290
C.11 File StatEye_readme.pdf	293
C.11.1 How to install and run the SAS-2.1 StatEye	293
Annex D (normative) End to end simulation for trained 12 Gbit/s	294
D.1 Detailed end to end simulation procedure description for trained 12 Gbit/s	294
D.2 Trained 12 Gbit/s usage models, S-parameter files, and crosstalk amplitude	296
D.2.1 Transmitter device connected to a separable passive TxRx connection segment	296
D.2.2 Transmitter device connected to a non-separable passive TxRx connection segment	298
D.2.3 TxRx connection segment	301
D.2.4 Stressed Receiver device delivered signal calibration end to end simulation diagram	302
Annex E (informative) 12 Gbit/s S-parameters and end to end simulation	304
E.1 S-parameters for 12 Gbit/s simulation	304
E.1.1 Measurement procedure	304
E.1.2 Multiple channel segments	305
E.2 End to end simulation using SAS3_EYEOPENING	306
Annex F (informative) Signal performance measurements	307
F.1 Signal performance measurements overview	307
F.2 Glossary	307
F.3 Simple physical link	307
F.3.1 Simple physical link overview	307
F.3.2 Assumptions for the structure of the transmitter device and the receiver device	308
F.3.3 Definition of receiver sensitivity and receiver device sensitivity	309
F.4 Signal measurement architecture	310
F.4.1 General	310
F.4.2 Relationship between signal compliance measurements at interoperability points and operation in systems	310
F.5 De-embedding connectors in test fixtures	311
F.6 De-embedding test fixture for 12 Gbit/s transmitter compliance	311
F.7 Measurement conditions for signal output at the transmitter device	312
F.8 Measurement conditions for signal tolerance at the transmitter device	313
F.9 Measurement conditions for signal output at the receiver device	315
F.10 Measurement conditions for signal tolerance at the receiver device	315
F.11 S-parameter measurements	316
F.11.1 S-parameter overview	316
F.11.2 S-parameter naming conventions	316
F.11.3 Use of single ended instrumentation in differential applications	317
F.11.4 Measurement configurations for physical link elements	319
F.11.4.1 Measurement configuration overview	319
F.11.4.2 Transmitter device S_{22} measurements	319
F.11.4.3 Receiver device S_{11} measurements	320
F.11.4.4 TxRx connection S_{11} measurements at IT or CT	320
F.11.4.5 TxRx connection S_{22} measurements at IR or CR	321
F.12 Calibration of JMDs	322

ITC STANDARD PREVIEW
 (standards.iteh.ai)
 ISO/IEC 14776-154:2017
<https://standards.iteh.ai/catalog/standards/sist/3cc9c166-22ff-48a8-88d5-3ec2080bb4/iso-iec-14776-154-2017>

F.12.1 Calibration of JMDs overview	322
F.12.1.1 Purpose of JMD calibration	322
F.12.1.2 Overview of low frequency calibration for SSC configurations	322
F.12.1.3 Overview of low frequency calibration for non-SSC configurations	324
F.12.1.4 High frequency calibration	324
F.12.2 JMD calibration procedure	325
F.12.2.1 General characteristics and equipment	325
F.12.2.2 Calibration of the JMD for testing SSC configurations	326
F.12.2.3 Calibration of the JMD for testing non-SSC configurations	327
Annex G (informative) Description of the included Touchstone models for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	329
G.1 Description of included Touchstone models for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s overview ...	329
G.2 Reference transmitter device termination model for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	329
G.3 Reference receiver device termination model for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	330
G.4 Generic return loss circuit model for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	331
G.5 Reference transmitter test load for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	332
Annex H (informative) Mini SAS 4x active cable assembly power supply and voltage detection circuitry	335
Annex I (informative) SAS icons	336
Annex J (informative) Standards bodies contact information	338
Bibliography	339

iTeh STANDARD PREVIEW
(standards.iteh.ai)

[ISO/IEC 14776-154:2017](https://standards.iteh.ai/catalog/standards/sist/3cc9c166-22ff-48a8-88d5-f3ec20f80bb4/iso-iec-14776-154-2017)

<https://standards.iteh.ai/catalog/standards/sist/3cc9c166-22ff-48a8-88d5-f3ec20f80bb4/iso-iec-14776-154-2017>

Figure 1 – SCSI document relationships 16

Figure 2 – ATA document relationships 17

Figure 3 – Physical links and phys 42

Figure 4 – Maximum limits for S-parameters definitions 44

Figure 5 – 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s External cable assembly CT compliance points and CR compliance points 46

Figure 6 – Backplane with SAS Drive connector 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s IT compliance points and IR compliance points 47

Figure 7 – Backplane with SAS Drive connector 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s compliance points with SATA phy attached 48

Figure 8 – SAS multilane internal cable assembly 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s IT compliance points and IR compliance points 49

Figure 9 – SAS multilane internal cable assembly and backplane 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s IT compliance points and IR compliance points 50

Figure 10 – SAS multilane internal cable assembly and backplane 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s IT compliance points and IR compliance points with SATA device attached 51

Figure 11 – SAS Drive cable assembly 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s IT compliance points and IR compliance points 52

Figure 12 – 12 Gbit/s TxRx connection and compliance points 53

Figure 13 – Simulated 12 Gbit/s TxRx connection and compliance points 53

Figure 14 – 12 Gbit/s CTS and CR compliance points 54

Figure 15 – SATA connectors and cables 55

Figure 16 – SAS Drive cable environments 56

Figure 17 – SAS Drive backplane environment 57

Figure 18 – SAS external cable environment 57

Figure 19 – SAS internal symmetric cable environment - controller to backplane 58

Figure 20 – SAS internal symmetric cable environment - controller to controller 58

Figure 21 – SAS internal controller-based fanout cable environment 59

Figure 22 – SAS internal backplane-based fanout cable environment 59

Figure 23 – Recommended |S_{DD21}|, |S_{CC22}|, |S_{DD22}|, NEXT, and FEXT limits for connector mated pairs supporting rates of 12 Gbit/s 64

Figure 24 – SAS Drive plug connector 65

Figure 25 – Single-port SAS Drive cable receptacle connector 65

Figure 26 – Dual-port SAS Drive cable receptacle connector 66

Figure 27 – SAS Drive backplane receptacle connector 66

Figure 28 – SAS MultiLink Drive plug connector 69

Figure 29 – SAS MultiLink Drive cable receptacle connector 69

Figure 30 – SAS MultiLink Drive backplane receptacle connector 70

Figure 31 – Micro SAS plug connector 74

Figure 32 – Micro SAS receptacle connector 74

Figure 33 – SAS 4i cable receptacle connector 76

Figure 34 – SAS 4i plug connector 76

Figure 35 – Mini SAS 4i cable plug connector 79

Figure 36 – Mini SAS 4i receptacle connector 79

Figure 37 – Mini SAS HD 4i cable plug connector 82

Figure 38 – Mini SAS HD 8i cable plug connector 83

Figure 39 – Mini SAS HD 4i receptacle connector 84

Figure 40 – Mini SAS HD 8i receptacle connector 85

Figure 41 – Mini SAS HD 16i receptacle connector 86

Figure 42 – Mini SAS 4x cable plug connector 90

Figure 43 – Mini SAS 4x cable plug connector for untrained 1.5 Gbit/s and 3 Gbit/s that attaches to an enclosure out port or an enclosure in port 92

Figure 44 – Mini SAS 4x cable plug connector for untrained 1.5 Gbit/s and 3 Gbit/s that attaches to an enclosure out port 92

Figure 45 – Mini SAS 4x cable plug connector for untrained 1.5 Gbit/s and 3 Gbit/s that attaches to an enclosure in port 93

Figure 46 – Mini SAS 4x cable plug connector for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s that attaches to an enclosure out port or an enclosure in port 93

Figure 47 – Mini SAS 4x cable plug connector for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s that attaches to an enclosure out port	94
Figure 48 – Mini SAS 4x cable plug connector for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s that attaches to an enclosure in port	94
Figure 49 – Mini SAS 4x active cable plug connector for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s that attaches to an enclosure out port or an enclosure in port	95
Figure 50 – Mini SAS 4x active cable plug connector for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s that attaches to an enclosure out port	95
Figure 51 – Mini SAS 4x active cable plug connector for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s that attaches to an enclosure in port	96
Figure 52 – Mini SAS 4x receptacle connector	97
Figure 53 – Mini SAS 4x receptacle connector - end device or enclosure universal port for untrained 1.5 Gbit/s and 3 Gbit/s	98
Figure 54 – Mini SAS 4x receptacle connector - enclosure out port for untrained 1.5 Gbit/s and 3 Gbit/s	99
Figure 55 – Mini SAS 4x receptacle connector - enclosure in port for untrained 1.5 Gbit/s and 3 Gbit/s	99
Figure 56 – Mini SAS 4x receptacle connector - end device or enclosure universal port for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s and for untrained 1.5 Gbit/s and 3 Gbit/s	100
Figure 57 – Mini SAS 4x receptacle connector - enclosure out port for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s and for untrained 1.5 Gbit/s and 3 Gbit/s	100
Figure 58 – Mini SAS 4x receptacle connector - enclosure in port for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s and for untrained 1.5 Gbit/s and 3 Gbit/s	101
Figure 59 – Mini SAS 4x active receptacle connector - end device or enclosure universal port	101
Figure 60 – Mini SAS 4x active receptacle connector - enclosure out port	102
Figure 61 – Mini SAS 4x active receptacle connector - enclosure in port	102
Figure 62 – Mini SAS HD 4x cable plug connector	106
Figure 63 – Mini SAS HD 8x cable plug connector	107
Figure 64 – Mini SAS HD 4x receptacle connector	108
Figure 65 – Mini SAS HD 8x receptacle connector	109
Figure 66 – Mini SAS HD 16x receptacle connector	110
Figure 67 – QSFP+ cable plug connector	113
Figure 68 – QSFP+ receptacle connector	114
Figure 69 – Single-port SAS Drive cable assembly	117
Figure 70 – Dual-port SAS Drive cable assembly	118
Figure 71 – MultiLink SAS Drive cable assembly	119
Figure 72 – SAS internal symmetric cable assembly - SAS 4i	120
Figure 73 – SAS internal symmetric cable assembly - Mini SAS 4i	121
Figure 74 – SAS internal symmetric cable assembly - Mini SAS HD 4i	122
Figure 75 – SAS internal symmetric cable assembly - Mini SAS HD 8i	123
Figure 76 – SAS internal symmetric cable assembly - SAS 4i to Mini SAS 4i with vendor-specific sideband signals	124
Figure 77 – SAS internal symmetric cable assembly - SAS 4i controller to Mini SAS 4i backplane with SGPIO connections	125
Figure 78 – SAS internal symmetric cable assembly - Mini SAS 4i controller to SAS 4i backplane with SGPIO connections	126
Figure 79 – SAS internal symmetric cable assembly - Mini SAS 4i to Mini SAS HD 4i	127
Figure 80 – SAS internal controller-based fanout cable assembly - SAS 4i	129
Figure 81 – SAS internal controller-based fanout cable assembly - Mini SAS 4i	130
Figure 82 – SAS internal controller-based fanout cable assembly - Mini SAS HD 4i	131
Figure 83 – SAS internal backplane-based fanout cable assembly - SAS 4i	132
Figure 84 – SAS internal backplane-based fanout cable assembly - Mini SAS 4i	133
Figure 85 – SAS internal backplane-based fanout cable assembly - Mini SAS HD 4i	134
Figure 86 – Mini SAS 4x external cable assembly	136
Figure 87 – Mini SAS 4x active external cable assembly	137
Figure 88 – SAS external cable assembly with Mini SAS 4x cable plug connectors	138
Figure 89 – SAS external cable assembly - Mini SAS HD 4x	139
Figure 90 – SAS external cable assembly with Mini SAS HD 4x cable plug connectors	140
Figure 91 – SAS external cable assembly - Mini SAS HD 8x	141
Figure 92 – SAS external cable assembly with Mini SAS HD 8x cable plug connectors	142

Figure 93 – SAS external cable assembly - Mini SAS HD 8x to Mini SAS HD 4x	143
Figure 94 – SAS external cable assembly with a Mini SAS HD 8x cable plug connector and two Mini SAS HD 4x cable plug connectors	144
Figure 95 – SAS external cable assembly - Mini SAS HD 4x to Mini SAS 4x	145
Figure 96 – SAS external cable assembly with a Mini SAS HD 4x cable plug connector and a Mini SAS 4x cable plug connector	146
Figure 97 – Passive TxRx connection $ S_{DD22} $, $ S_{CD22} $, $ S_{CD21} $, and NEXT limits	151
Figure 98 – Example of a passive TxRx connection compliance testing for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	152
Figure 99 – Example passive TxRx connection compliance testing for trained 12 Gbit/s	154
Figure 100 – Passive TxRx connection segment between CTS and CR or ITS and IR end to end simulation diagram for trained 12 Gbit/s	155
Figure 101 – Active cable S-parameter limits	159
Figure 102 – Active cable eye mask for 12 Gbit/s	160
Figure 103 – Zero-length test load for transmitter device compliance point	162
Figure 104 – Zero-length test load for receiver device compliance point	162
Figure 105 – Zero-length test load $ S_{DD21}(f) $ requirements	163
Figure 106 – TCTF test load	163
Figure 107 – TCTF test load $ S_{DD21}(f) $ and ISI loss requirements at IT for untrained 3 Gbit/s	164
Figure 108 – TCTF test load $ S_{DD21}(f) $ and ISI loss requirements at CT for untrained 3 Gbit/s	165
Figure 109 – TCTF test load $ S_{DD21}(f) $ and ISI loss requirements at IT for untrained 1.5 Gbit/s	166
Figure 110 – TCTF test load $ S_{DD21}(f) $ and ISI loss requirements at CT for untrained 1.5 Gbit/s	167
Figure 111 – Low-loss TCTF test load	168
Figure 112 – Low-loss TCTF test load $ S_{DD21}(f) $ and ISI loss requirements	169
Figure 113 – Trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s reference transmitter with a test load $ S_{DD21}(f) $ up to 6 GHz	170
Figure 114 – Trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s reference transmitter test load pulse response	171
Figure 115 – Trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s reference transmitter test load impulse response for 6 Gbit/s	172
Figure 116 – Trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s reference transmitter test load D24.3 response	173
Figure 117 – NEXT and FEXT measurement definition	174
Figure 118 – Reference sampling point and reference pulse response cursor	175
Figure 119 – Reference transmitter coefficient error computation	176
Figure 120 – Convergence of reference transmitter equalization	177
Figure 121 – Transmitter device transient test circuit	179
Figure 122 – Receiver device transient test circuit	179
Figure 123 – Transmitter device eye mask	181
Figure 124 – Receiver device eye mask	182
Figure 125 – Deriving a receiver device jitter tolerance eye mask for untrained 1.5 Gbit/s and 3 Gbit/s	183
Figure 126 – Transmitter device common mode voltage limit	190
Figure 127 – Transmitter device $ S_{CC22} $, $ S_{DD22} $, and $ S_{CD22} $ limits	192
Figure 128 – Trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s reference transmitter device	193
Figure 129 – Trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s reference transmitter device termination S-parameters model	194
Figure 130 – Transmitter equalization measurement	195
Figure 131 – Minimum and maximum coefficient ranges at maximum peak to peak voltage	198
Figure 132 – 12 Gbit/s transmitter device common mode voltage limit	199
Figure 133 – Transmitter circuit compliance test configuration	201
Figure 134 – 12 Gbit/s transmitter circuit output waveform	202
Figure 135 – 12 Gbit/s transmitter device $ S_{CC22} $, $ S_{DD22} $, and $ S_{CD22} $ limits	204
Figure 136 – 12 Gbit/s reference transmitter device	205
Figure 137 – 12 Gbit/s reference transmitter	205
Figure 138 – Simulation of the reference transmitter from a captured signal	208
Figure 139 – Applied SJ for untrained 1.5 Gbit/s and 3 Gbit/s	215
Figure 140 – Receiver device $ S_{CC11} $, $ S_{DD11} $, and $ S_{CD11} $ limits	217
Figure 141 – Reference receiver device for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	218
Figure 142 – Reference receiver device for trained 12 Gbit/s	218

Figure 143 – Reference receiver device termination S-parameters for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	220
Figure 144 – Stressed receiver device jitter tolerance test block diagram for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	221
Figure 145 – Stressed receiver device jitter tolerance test D24.3 eye opening for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	223
Figure 146 – Stressed receiver transmitter equalization adjustment for 12 Gbit/s	225
Figure 147 – Simulation of the reference transmitter from a captured signal	226
Figure 148 – Applied SJ for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, and 12 Gbit/s without SSC support	228
Figure 149 – Applied SJ for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s and 12 Gbit/s with SSC support	229
Figure 150 – Center-spreading tolerance buffer	234
Figure 151 – OOB signal transmission	239
Figure 152 – SATA port selection signal	241
Figure C.1 – Reference channel eye opening	293
Figure D.1 – Trained 12 Gbit/s die to die insertion loss model	294
Figure D.2 – Transmitter device end to end simulation diagram that includes a separable TxRx connection segment	297
Figure D.3 – End to end simulation diagram from target device usage model for a transmitter device connected to a non-separable TxRx connection segment	299
Figure D.4 – End to end simulation diagram of the target device usage model for a transmitter device connected to a non-separable TxRx connection segment	300
Figure D.5 – Stressed receiver device delivered signal calibration end to end simulation diagram	302
Figure E.1 – S-parameter measurement connections for a four port VNA	304
Figure E.2 – Example of a SAS three TxRx connection segment	305
Figure F.1 – A simple physical link	307
Figure F.2 – Transmitter device details	308
Figure F.3 – Receiver device details	309
Figure F.4 – De-embedding of connectors in test fixtures	311
Figure F.5 – De-embedding to ET for 12 Gbit/s transmitter compliance	312
Figure F.6 – De-embedding calibration test structure	312
Figure F.7 – Measurement conditions for signal output at the transmitter device	313
Figure F.8 – Transmitter device signal output measurement test fixture details	313
Figure F.9 – Measurement conditions for signal tolerance at the transmitter device	314
Figure F.10 – Calibration of test fixture for signal tolerance at the transmitter device	314
Figure F.11 – Measurement conditions for signal output at the receiver device	315
Figure F.12 – Measurement conditions for signal tolerance at the receiver device	315
Figure F.13 – Calibration of test fixture for signal tolerance at the receiver device	316
Figure F.14 – S-parameter port naming conventions	317
Figure F.15 – Four single ended port or two differential port element	318
Figure F.16 – S-parameters for single ended and differential systems	318
Figure F.17 – Measurement conditions for S_{22} at the transmitter device connector	319
Figure F.18 – Measurement conditions for S_{11} at the receiver device connector	320
Figure F.19 – Measurement conditions for S_{11} at IT or CT	321
Figure F.20 – Measurement conditions for S_{22} at IR or CR	322
Figure G.1 – Reference transmitter device and reference receiver device termination circuit model	329
Figure G.2 – Generic return loss circuit model	331
Figure G.3 – Generic return loss model $ S_{11} $	332
Figure G.4 – Reference transmitter test load measurement setup	333
Figure G.5 – Reference transmitter test load $ S_{DD21}(f) $ up to 20 GHz	334
Figure H.1 – Dual comparator design for active cable assembly detection	335
Figure I.1 – SAS primary icon	336
Figure I.2 – SAS alternate icon	336
Figure I.3 – MultiLink SAS icon	337

Table 1 – Numbering conventions	40
Table 2 – Comparison of decimal prefixes and binary prefixes	41
Table 3 – Compliance points.....	45
Table 4 – Connectors.....	60
Table 5 – Connector categories.....	62
Table 6 – Recommended electrical performance limits for the mated connector pairs that support rates of 12 Gbit/s.....	63
Table 7 – SAS Drive connector pin assignments.....	67
Table 8 – SAS MultiLink connector pin assignments.....	71
Table 9 – Micro SAS connector pin assignments	75
Table 10 – Controller SAS 4i connector pin assignments and physical link usage.....	77
Table 11 – Backplane SAS 4i connector pin assignments and physical link usage	78
Table 12 – Controller Mini SAS 4i connector pin assignments and physical link usage	80
Table 13 – Backplane Mini SAS 4i connector pin assignments and physical link usage.....	81
Table 14 – Controller Mini SAS HD 4i connector pin assignments and physical link usage.....	87
Table 15 – Backplane Mini SAS HD 4i connector pin assignments and physical link usage.....	88
Table 16 – Mini SAS 4x cable plug connector and Mini SAS 4x active cable plug connector icons, key slot positions, and key positions	91
Table 17 – Mini SAS 4x receptacle connector icons, key positions, and key slot positions.....	98
Table 18 – Mini SAS 4x connector pin assignments and physical link usage.....	103
Table 19 – Mini SAS 4x active connector pin assignments and physical link usage	104
Table 20 – Mini SAS 4x active cable supplied power requirements	105
Table 21 – Mini SAS HD 4x connector pin assignments and physical link usage	111
Table 22 – Management interface connection requirements.....	112
Table 23 – QSFP+ connector pin assignments.....	115
Table 24 – TxRx connection general characteristics	148
Table 25 – Maximum limits for S-parameters of the passive TxRx connection between ITS and IR or CTS and CR.....	150
Table 26 – Passive TxRx connection characteristics for trained 6 Gbit/s	152
Table 27 – Passive TxRx connection characteristics for trained 12 Gbit/s at ET and ER.....	156
Table 28 – Active cable assembly output electrical characteristics for trained 6 Gbit/s.....	157
Table 29 – Maximum limits for S-parameters for active cable assemblies	158
Table 30 – Active cable assembly electrical characteristics for 12 Gbit/s.....	160
Table 31 – General electrical characteristics	178
Table 32 – JTF parameters.....	181
Table 33 – Transmitter device general electrical characteristics	184
Table 34 – Transmitter device termination characteristics.....	185
Table 35 – Transmitter device signal output characteristics for untrained 1.5 Gbit/s and 3 Gbit/s as measured with the zero-length test load at IT and CT.....	186
Table 36 – Transmitter device signal output characteristics for untrained 1.5 Gbit/s and 3 Gbit/s as measured with each test load at IT and CT	188
Table 37 – Transmitter device signal output characteristics for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s at IT and CT.....	189
Table 38 – Transmitter device common mode voltage limit characteristics.....	190
Table 39 – Maximum limits for S-parameters at IT _S or CT _S	191
Table 40 – Recommended trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s transmitter device settings at IT and CT compliance point	192
Table 41 – Trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s reference transmitter device characteristics at IT and CT compliance point	193
Table 42 – Transmitter device signal output characteristics for trained 12 Gbit/s at ET, IT, and CT.....	196
Table 43 – 12 Gbit/s transmitter device common mode voltage limit characteristics.....	199
Table 44 – Transmitter coefficient requests and corresponding transmitter circuit response	200
Table 45 – Transmitter circuit coefficient presets at ET.....	203
Table 46 – 12 Gbit/s maximum limits for S-parameters at IT _S or CT _S	204
Table 47 – 12 Gbit/s reference transmitter device characteristics at ET.....	206
Table 48 – Transmitter device characteristics for trained 12 Gbit/s at ET and ER	207
Table 49 – Transmitter device signal output characteristics for 12 Gbit/s at CTS when an active cable is connected.....	208

Table 50 – Transmitter device signal output characteristics for OOB signals	209
Table 51 – Receiver device general electrical characteristics	211
Table 52 – Recommended receiver device common mode tolerance for 6 Gbit/s, and 12 Gbit/s	211
Table 53 – Receiver device termination characteristics	212
Table 54 – Delivered signal characteristics for untrained 1.5 Gbit/s and 3 Gbit/s as measured with the zero-length test load at IR and CR	213
Table 55 – Maximum delivered jitter for untrained 1.5 Gbit/s and 3 Gbit/s at IR and CR	214
Table 56 – Receiver device jitter tolerance for untrained 1.5 Gbit/s and 3 Gbit/s at IR and CR	215
Table 57 – f_{\min} , f_c , and f_{\max} for untrained 1.5 Gbit/s and 3 Gbit/s	216
Table 58 – Delivered signal characteristics for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, and 12 Gbit/s at IR and CR compliance point	216
Table 59 – Maximum limits for S-parameters at IR or CR	217
Table 60 – Reference receiver equalization stage characteristics for trained 12 Gbit/s	219
Table 61 – Stressed receiver device jitter tolerance test characteristics for trained 1.5 Gbit/s, 3 Gbit/s, and 6 Gbit/s	222
Table 62 – Number of bits received per number of errors for desired BER	224
Table 63 – ISI generator characteristics for trained 12 Gbit/s at ET and ER	227
Table 64 – RJ characteristics for trained 12 Gbit/s stressed receiver device tolerance test	228
Table 65 – f_{\min} , f_c , and f_{\max} for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, and 12 Gbit/s without SSC support	229
Table 66 – f_{\min} , f_c , f_{\max} , and SJ_{lf} for trained 1.5 Gbit/s, 3 Gbit/s, 6 Gbit/s, and 12 Gbit/s with SSC support	229
Table 67 – Delivered signal characteristics for OOB signals	230
Table 68 – SSC modulation types	230
Table 69 – SAS phy transmitter SSC modulation types	231
Table 70 – Expander phy transmitter SSC modulation types	232
Table 71 – Receiver SSC modulation types tolerance	232
Table 72 – Expander device center-spreading tolerance buffer	233
Table 73 – Output characteristics of the READY LED signal	235
Table 74 – Characteristics of the POWER DISABLE signal applied to the SAS target device	236
Table 75 – OOB signal timing specifications	237
Table 76 – OOB signal transmitter device requirements	238
Table 77 – OOB signal receiver device burst time detection requirements	240
Table 78 – OOB signal receiver device idle time detection requirements	240
Table 79 – OOB signal receiver device negation time detection requirements	240
Table 80 – SATA port selection signal transmitter device requirements	241
Table A.1 – JTPAT for RD+	242
Table A.2 – JTPAT for RD-	243
Table D.1 – Crosstalk transmitter characteristics	295
Table D.2 – S-parameter files for transmitter devices connected to separable TxRx connection segment ..	296
Table D.3 – The S-parameter files for a transmitter device connected to a non-separable TxRx connection segment	298
Table D.4 – S-parameter files for a TxRx connection segment	301
Table D.5 – S-parameter files for stressed receiver device delivered signal calibration	303
Table F.1 – High frequency jitter source amplitudes	325
Table F.2 – Low frequency jitter source calibration amplitudes	327
Table F.3 – Low frequency jitter attenuation targets	328
Table J.1 – Standards bodies	338