

ISO/IEC 14776-151:2010-07 (E)

Information technology – Small computer system interface (SCSI) – Part 151: Serial attached SCSI-1.1 (SAS-1.1)

Contents

	Page
Foreword	28
Introduction	29
1 Scope	31
2 Normative references	33
3 Terms, definitions, symbols, abbreviations, keywords and conventions	34
3.1 Terms and definitions	34
3.2 Symbols and abbreviations	54
3.3 Keywords	57
3.4 Editorial conventions	58
3.5 Class diagram and object diagram conventions	59
3.6 State machine conventions	64
3.6.1 State machine conventions overview	64
3.6.2 Transitions	64
3.6.3 Messages, requests, indications, confirmations, responses and event notifications	65
3.6.4 State machine counters, timers and variables	65
3.6.5 State machine arguments	65
3.7 Bit and byte ordering	65
3.8 Notation for procedures and functions	66
4 General	67
4.1 Architecture	67
4.1.1 Architecture overview	67
4.1.2 Physical links and phys	68
4.1.3 Ports (narrow ports and wide ports)	71
4.1.4 SAS devices	74
4.1.5 Expander devices (edge expander devices and fanout expander devices)	75
4.1.6 Service delivery subsystem	77
4.1.7 Domains	78
4.1.8 Expander device topologies	80
4.1.8.1 Expander device topology overview	80
4.1.8.2 Edge expander device set	80
4.1.8.3 Expander device topologies	81
4.1.9 Pathways	84
4.1.10 Connections	85
4.2 Names and identifiers	87
4.2.1 Names and identifiers overview	87
4.2.2 SAS address	87
4.2.3 Hashed SAS address	88
4.2.4 Device names	88
4.2.5 Port names	88
4.2.6 Port identifiers	88
4.2.7 Phy identifiers	89
4.3 State machines	90
4.3.1 State machine overview	90
4.3.2 Transmit data path	92
4.3.3 Receive data path	96
4.3.4 State machines and SAS device, SAS port and SAS phy classes	99
4.4 Resets	100
4.4.1 Reset overview	100
4.4.2 Hard reset	102
4.4.2.1 Hard reset overview	102
4.4.2.2 Additional hard reset processing by SAS ports	102
4.4.2.3 Additional hard reset processing by expander ports	102

4.5 I_T nexus loss	102
4.6 Expander device model	102
4.6.1 Expander device model overview	102
4.6.2 Expander ports	103
4.6.3 Expander connection manager (ECM).....	104
4.6.4 Expander connection router (ECR).....	104
4.6.5 Broadcast primitive processor (BPP).....	104
4.6.6 Expander device interfaces	104
4.6.6.1 Expander device interface overview.....	104
4.6.6.2 Expander device interfaces detail	106
4.6.6.3 ECM interface.....	106
4.6.6.4 ECR interface.....	108
4.6.6.5 BPP interface	110
4.6.7 Expander device routing	110
4.6.7.1 Routing attributes and routing methods	110
4.6.7.2 Connection request routing.....	111
4.6.7.3 Expander route table.....	111
4.7 Discover process.....	112
4.7.1 Discover process overview	112
4.7.2 Allowed topologies	114
4.7.3 Discover process optimization	115
4.7.4 Expander route index order	116
4.8 Phy test functions	121
5 Physical layer.....	122
5.1 Physical layer overview	122
5.2 Passive interconnect	122
5.2.1 SATA connectors and cable assemblies	122
5.2.2 SAS connectors and cables.....	122
5.2.3 Connectors	126
5.2.3.1 Connectors overview.....	126
5.2.3.2 SAS internal connectors.....	127
5.2.3.2.1 SAS Drive connectors.....	127
5.2.3.2.1.1 SAS Drive plug connector	127
5.2.3.2.1.2 SAS Drive cable receptacle connector.....	127
5.2.3.2.1.3 SAS Drive backplane receptacle connector.....	128
5.2.3.2.1.4 SAS Drive connector pin assignments.....	128
5.2.3.2.2 SAS 4i connectors	130
5.2.3.2.2.1 SAS 4i cable receptacle connector	130
5.2.3.2.2.2 SAS 4i plug connector.....	130
5.2.3.2.2.3 SAS 4i connector pin assignments	131
5.2.3.2.3 Mini SAS 4i connectors.....	132
5.2.3.2.3.1 Mini SAS 4i cable plug connector	132
5.2.3.2.3.2 Mini SAS 4i receptacle connector	133
5.2.3.2.3.3 Mini SAS 4i connector pin assignments.....	134
5.2.3.3 SAS external connectors.....	136
5.2.3.3.1 SAS 4x connectors	136
5.2.3.3.1.1 SAS 4x cable plug connector.....	136
5.2.3.3.1.2 SAS 4x receptacle connector.....	136
5.2.3.3.1.3 SAS 4x connector pin assignments	138
5.2.3.3.2 Mini SAS 4x connectors.....	138
5.2.3.3.2.1 Mini SAS 4x cable plug connector	138
5.2.3.3.2.2 Mini SAS 4x receptacle connector	140
5.2.3.3.2.3 Mini SAS 4x connector pin assignments.....	143
5.2.4 Cable assemblies	143
5.2.4.1 SAS internal cable assemblies.....	143
5.2.4.1.1 SAS Drive cable assemblies.....	143
5.2.4.1.2 SAS internal symmetric cable assemblies.....	144
5.2.4.1.2.1 SAS internal symmetric cable assemblies overview	144
5.2.4.1.2.2 SAS internal symmetric cable assembly - SAS 4i.....	145

5.2.4.1.2.3 SAS internal symmetric cable assembly - Mini SAS 4i	146
5.2.4.1.2.4 SAS internal symmetric cable assembly - SAS 4i to Mini SAS 4i	147
5.2.4.1.3 SAS internal fanout cable assemblies	148
5.2.4.1.3.1 SAS internal fanout cable assemblies overview	148
5.2.4.1.3.2 SAS internal controller-based fanout cable assemblies	149
5.2.4.1.3.3 SAS internal backplane-based fanout cable assemblies	151
5.2.4.2 SAS external cable assemblies	152
5.2.4.2.1 SAS external cable assemblies overview	152
5.2.4.2.2 SAS external cable assembly - SAS 4x	153
5.2.4.2.3 SAS external cable assembly - Mini SAS 4x	154
5.2.4.2.4 SAS external cable assembly - SAS 4x to Mini SAS 4x	156
5.2.5 Backplanes	156
5.2.6 Cable assembly and backplane specifications	157
5.3 Transmitter and receiver device electrical characteristics	161
5.3.1 Compliance points	161
5.3.2 Test loads	169
5.3.2.1 Test loads overview	169
5.3.2.2 Zero-length test load	170
5.3.2.3 TCTF test load	171
5.3.2.4 Low-loss TCTF test load	173
5.3.3 General electrical characteristics	174
5.3.4 Transmitter and receiver device transients	177
5.3.5 Eye masks	177
5.3.5.1 Eye masks overview	177
5.3.5.2 Transmitter device eye mask	178
5.3.5.3 Receiver device eye mask	178
5.3.5.4 Receiver device jitter tolerance eye mask	179
5.3.6 Transmitter device characteristics	180
5.3.6.1 Transmitter device characteristics overview	180
5.3.6.2 Transmitter device signal output characteristics as measured with the zero-length test load	181
5.3.6.3 Transmitter device signal output characteristics as measured with each test load	181
5.3.6.4 Transmitter device maximum jitter	183
5.3.6.5 Transmitter device signal output levels for OOB signals	183
5.3.7 Receiver device characteristics	183
5.3.7.1 Receiver device characteristics overview	183
5.3.7.2 Delivered signal (receiver device signal tolerance) characteristics	184
5.3.7.3 Maximum delivered jitter	186
5.3.7.4 Receiver device jitter tolerance	186
5.3.8 Spread spectrum clocking	187
5.3.9 Non-tracking clock architecture	187
5.4 READY LED signal electrical characteristics	187
6 Phy layer	189
6.1 Phy layer overview	189
6.2 8b10b coding	189
6.2.1 8b10b coding overview	189
6.2.2 8b10b coding introduction	189
6.2.3 8b10b coding notation conventions	189
6.3 Character encoding and decoding	190
6.3.1 Introduction	190
6.3.2 Transmission order	190
6.3.3 Data and control characters	190
6.3.4 Encoding characters in the transmitter	197
6.3.5 Decoding characters in the receiver	197
6.4 Dwords, primitives, data dwords and invalid dwords	197
6.5 Bit order	198
6.6 Out of band (OOB) signals	199
6.6.1 OOB signals overview	199
6.6.2 Transmitting OOB signals	200
6.6.3 Receiving OOB signals	202

6.6.4 Transmitting the SATA port selection signal.....	204
6.7 Phy reset sequences.....	204
6.7.1 Phy reset sequences overview.....	204
6.7.2 SATA phy reset sequence.....	205
6.7.2.1 SATA OOB sequence.....	205
6.7.2.2 SATA speed negotiation sequence.....	205
6.7.3 SAS to SATA phy reset sequence.....	206
6.7.4 SAS to SAS phy reset sequence.....	207
6.7.4.1 SAS OOB sequence.....	207
6.7.4.2 SAS speed negotiation sequence.....	208
6.7.4.2.1 SAS speed negotiation sequence overview.....	208
6.7.4.2.2 Speed negotiation window.....	209
6.7.4.2.3 SAS speed negotiation sequence.....	210
6.7.5 Phy reset sequence after devices are attached.....	212
6.8 SP (phy layer) state machine.....	213
6.8.1 SP state machine overview.....	213
6.8.2 SP transmitter and receiver.....	215
6.8.3 OOB sequence states.....	216
6.8.3.1 OOB sequence states overview.....	216
6.8.3.2 SP0:OOB_COMINIT state.....	216
6.8.3.2.1 State description.....	216
6.8.3.2.2 Transition SP0:OOB_COMINIT to SP1:OOB_AwaitCOMX.....	217
6.8.3.2.3 Transition SP0:OOB_COMINIT to SP3:OOB_AwaitCOMINIT_Sent.....	217
6.8.3.2.4 Transition SP0:OOB_COMINIT to SP4:OOB_COMSAS.....	217
6.8.3.3 SP1:OOB_AwaitCOMX state.....	217
6.8.3.3.1 State description.....	217
6.8.3.3.2 Transition SP1:OOB_AwaitCOMX to SP0:OOB_COMINIT.....	217
6.8.3.3.3 Transition SP1:OOB_AwaitCOMX to SP4:OOB_COMSAS.....	217
6.8.3.4 SP2:OOB_NoCOMSASTimeout state.....	218
6.8.3.4.1 State description.....	218
6.8.3.4.2 Transition SP2:OOB_NoCOMSASTimeout to SP0:OOB_COMINIT.....	218
6.8.3.4.3 Transition SP2:OOB_NoCOMSASTimeout to SP4:OOB_COMSAS.....	218
6.8.3.5 SP3:OOB_AwaitCOMINIT_Sent state.....	218
6.8.3.5.1 State description.....	218
6.8.3.5.2 Transition SP3:OOB_AwaitCOMINIT_Sent to SP4:OOB_COMSAS.....	218
6.8.3.6 SP4:OOB_COMSAS state.....	218
6.8.3.6.1 State description.....	218
6.8.3.6.2 Transition SP4:OOB_COMSAS to SP5:OOB_AwaitCOMSAS_Sent.....	218
6.8.3.6.3 Transition SP4:OOB_COMSAS to SP6:OOB_AwaitNoCOMSAS.....	218
6.8.3.6.4 Transition SP4:OOB_COMSAS to SP7:OOB_AwaitCOMSAS.....	219
6.8.3.7 SP5:OOB_AwaitCOMSAS_Sent state.....	219
6.8.3.7.1 State description.....	219
6.8.3.7.2 Transition SP5:OOB_AwaitCOMSAS_Sent to SP6:OOB_AwaitNoCOMSAS.....	219
6.8.3.8 SP6:OOB_AwaitNoCOMSAS state.....	219
6.8.3.8.1 State description.....	219
6.8.3.8.2 Transition SP6:OOB_AwaitNoCOMSAS to SP0:OOB_COMINIT.....	219
6.8.3.8.3 Transition SP6:OOB_AwaitNoCOMSAS to SP8:SAS_Start.....	219
6.8.3.9 SP7:OOB_AwaitCOMSAS state.....	219
6.8.3.9.1 State description.....	219
6.8.3.9.2 Transition SP7:OOB_AwaitCOMSAS to SP2:OOB_NoCOMSASTimeout.....	219
6.8.3.9.3 Transition SP7:OOB_AwaitCOMSAS to SP6:OOB_AwaitNoCOMSAS.....	219
6.8.3.9.4 Transition SP7:OOB_AwaitCOMSAS to SP16:SATA_COMWAKE.....	219
6.8.3.9.5 Transition SP7:OOB_AwaitCOMSAS to SP26:SATA_SpinupHold.....	220
6.8.4 SAS speed negotiation states.....	220
6.8.4.1 SAS speed negotiation states overview.....	220
6.8.4.2 SP8:SAS_Start state.....	221
6.8.4.2.1 State description.....	221
6.8.4.2.2 Transition SP8:SAS_Start to SP0:OOB_COMINIT.....	222
6.8.4.2.3 Transition SP8:SAS_Start to SP9:SAS_RateNotSupported.....	222
6.8.4.2.4 Transition SP8:SAS_Start to SP10:SAS_AwaitALIGN.....	222

6.8.4.3 SP9:SAS_RateNotSupported state.....	222
6.8.4.3.1 State description.....	222
6.8.4.3.2 Transition SP9:SAS_RateNotSupported to SP14:SAS_Fail.....	222
6.8.4.4 SP10:SAS_AwaitALIGN state.....	222
6.8.4.4.1 State description.....	222
6.8.4.4.2 Transition SP10:SAS_AwaitALIGN to SP0:OOB_COMINIT.....	222
6.8.4.4.3 Transition SP10:SAS_AwaitALIGN to SP11:SAS_AwaitALIGN1.....	222
6.8.4.4.4 Transition SP10:SAS_AwaitALIGN to SP12:SAS_AwaitSNW.....	222
6.8.4.4.5 Transition SP10:SAS_AwaitALIGN to SP14:SAS_Fail.....	222
6.8.4.5 SP11:SAS_AwaitALIGN1 state.....	223
6.8.4.5.1 State description.....	223
6.8.4.5.2 Transition SP11:SAS_AwaitALIGN1 to SP0:OOB_COMINIT.....	223
6.8.4.5.3 Transition SP11:SAS_AwaitALIGN1 to SP12:SAS_AwaitSNW.....	223
6.8.4.5.4 Transition SP11:SAS_AwaitALIGN1 to SP14:SAS_Fail.....	223
6.8.4.6 SP12:SAS_AwaitSNW state.....	223
6.8.4.6.1 State description.....	223
6.8.4.6.2 Transition SP12:SAS_AwaitSNW to SP0:OOB_COMINIT.....	223
6.8.4.6.3 Transition SP12:SAS_AwaitSNW to SP13:SAS_Pass.....	223
6.8.4.7 SP13:SAS_Pass state.....	223
6.8.4.7.1 State description.....	223
6.8.4.7.2 Transition SP13:SAS_Pass to SP0:OOB_COMINIT.....	223
6.8.4.7.3 Transition SP13:SAS_Pass to SP8:SAS_Start.....	223
6.8.4.7.4 Transition SP13:SAS_Pass to SP15:SAS_PHY_Ready.....	224
6.8.4.8 SP14:SAS_Fail state.....	224
6.8.4.8.1 State description.....	224
6.8.4.8.2 Transition SP14:SAS_Fail to SP1:OOB_AwaitCOMX.....	224
6.8.4.8.3 Transition SP14:SAS_Fail to SP8:SAS_Start.....	224
6.8.4.9 SP15:SAS_PHY_Ready state.....	224
6.8.4.9.1 State description.....	224
6.8.4.9.2 Transition SP15:SAS_PHY_Ready to SP0:OOB_COMINIT.....	224
6.8.5 SATA host emulation states.....	225
6.8.5.1 SATA host emulation states overview.....	225
6.8.5.2 SP16:SATA_COMWAKE state.....	226
6.8.5.2.1 State description.....	226
6.8.5.2.2 Transition SP16:SATA_COMWAKE to SP17:SATA_AwaitCOMWAKE.....	227
6.8.5.3 SP17:SATA_AwaitCOMWAKE state.....	227
6.8.5.3.1 State description.....	227
6.8.5.3.2 Transition SP17:SATA_AwaitCOMWAKE to SP0:OOB_COMINIT.....	227
6.8.5.3.3 Transition SP17:SATA_AwaitCOMWAKE to SP18:SATA_AwaitNoCOMWAKE.....	227
6.8.5.4 SP18:SATA_AwaitNoCOMWAKE state.....	227
6.8.5.4.1 State description.....	227
6.8.5.4.2 Transition SP18:SATA_AwaitNoCOMWAKE to SP0:OOB_COMINIT.....	227
6.8.5.4.3 Transition SP18:SATA_AwaitNoCOMWAKE to SP19:SATA_AwaitALIGN.....	227
6.8.5.5 SP19:SATA_AwaitALIGN state.....	227
6.8.5.5.1 State description.....	227
6.8.5.5.2 Transition SP19:SATA_AwaitALIGN to SP0:OOB_COMINIT.....	227
6.8.5.5.3 Transition SP19:SATA_AwaitALIGN to SP20:SATA_AdjustSpeed.....	227
6.8.5.6 SP20:SATA_AdjustSpeed state.....	227
6.8.5.6.1 State description.....	227
6.8.5.6.2 Transition SP20:SATA_AdjustSpeed to SP0:OOB_COMINIT.....	228
6.8.5.6.3 Transition SP20:SATA_AdjustSpeed to SP21:SATA_TransmitALIGN.....	228
6.8.5.7 SP21:SATA_TransmitALIGN state.....	228
6.8.5.7.1 State description.....	228
6.8.5.7.2 Transition SP21:SATA_TransmitALIGN to SP0:OOB_COMINIT.....	228
6.8.5.7.3 Transition SP21:SATA_TransmitALIGN to SP22:SATA_PHY_Ready.....	228
6.8.5.8 SP22:SATA_PHY_Ready state.....	228
6.8.5.8.1 State description.....	228
6.8.5.8.2 Transition SP22:SATA_PHY_Ready to SP0:OOB_COMINIT.....	228
6.8.5.8.3 Transition SP22:SATA_PHY_Ready to SP23:SATA_PM_Partial.....	228
6.8.5.8.4 Transition SP22:SATA_PHY_Ready to SP24:SATA_PM_Slumber.....	228

6.8.5.9 SP23:SATA_PM_Partial state.....	228
6.8.5.9.1 State description.....	228
6.8.5.9.2 Transition SP23:SATA_PM_Partial to SP0:OOB_COMINIT.....	229
6.8.5.9.3 Transition SP23:SATA_PM_Partial to SP16:SATA_COMWAKE.....	229
6.8.5.9.4 Transition SP23:SATA_PM_Partial to SP18:SATA_AwaitNoCOMWAKE.....	229
6.8.5.10 SP24:SATA_PM_Slumber state.....	229
6.8.5.10.1 State description.....	229
6.8.5.10.2 Transition SP24:SATA_PM_Slumber to SP0:OOB_COMINIT.....	229
6.8.5.10.3 Transition SP24:SATA_PM_Slumber to SP16:SATA_COMWAKE.....	229
6.8.5.10.4 Transition SP24:SATA_PM_Slumber to SP18:SATA_AwaitNoCOMWAKE.....	229
6.8.6 SATA port selector state.....	229
6.8.6.1 State description.....	229
6.8.6.2 Transition SP25:SATA_PortSel to SP1:OOB_AwaitCOMX.....	229
6.8.7 SATA spinup hold state.....	230
6.8.7.1 State description.....	230
6.8.7.2 Transition SP26:SATA_SpinupHold to SP0:OOB_COMINIT.....	230
6.9 SP_DWS (phy layer dword synchronization) state machine.....	230
6.9.1 SP_DWS state machine overview.....	230
6.9.2 SP_DWS receiver.....	232
6.9.3 SP_DWS0:AcquireSync state.....	233
6.9.3.1 State description.....	233
6.9.3.2 Transition SP_DWS0:AcquireSync to SP_DWS1:Valid1.....	233
6.9.4 SP_DWS1:Valid1 state.....	233
6.9.4.1 State description.....	233
6.9.4.2 Transition SP_DWS1:Valid1 to SP_DWS0:AcquireSync.....	233
6.9.4.3 Transition SP_DWS1:Valid1 to SP_DWS2:Valid2.....	233
6.9.5 SP_DWS2:Valid2 state.....	233
6.9.5.1 State description.....	233
6.9.5.2 Transition SP_DWS2:Valid2 to SP_DWS0:AcquireSync.....	234
6.9.5.3 Transition SP_DWS2:Valid2 to SP_DWS3:SyncAcquired.....	234
6.9.6 SP_DWS3:SyncAcquired state.....	234
6.9.6.1 State description.....	234
6.9.6.2 Transition SP_DWS3:SyncAcquired to SP_DWS4:Lost1.....	234
6.9.7 SP_DWS4:Lost1 state.....	234
6.9.7.1 State description.....	234
6.9.7.2 Transition SP_DWS4:Lost1 to SP_DWS5:Lost1Recovered.....	234
6.9.7.3 Transition SP_DWS4:Lost1 to SP_DWS6:Lost2.....	234
6.9.8 SP_DWS5:Lost1Recovered state.....	234
6.9.8.1 State description.....	234
6.9.8.2 Transition SP_DWS5:Lost1Recovered to SP_DWS3:SyncAcquired.....	234
6.9.8.3 Transition SP_DWS5:Lost1Recovered to SP_DWS6:Lost2.....	234
6.9.9 SP_DWS6:Lost2 state.....	234
6.9.9.1 State description.....	234
6.9.9.2 Transition SP_DWS6:Lost2 to SP_DWS7:Lost2Recovered.....	234
6.9.9.3 Transition SP_DWS6:Lost2 to SP_DWS8:Lost3.....	235
6.9.10 SP_DWS7:Lost2Recovered state.....	235
6.9.10.1 State description.....	235
6.9.10.2 Transition SP_DWS7:Lost2Recovered to SP_DWS4:Lost1.....	235
6.9.10.3 Transition SP_DWS7:Lost2Recovered to SP_DWS8:Lost3.....	235
6.9.11 SP_DWS8:Lost3 state.....	235
6.9.11.1 State description.....	235
6.9.11.2 Transition SP_DWS8:Lost3 to SP_DWS9:Lost3Recovered.....	235
6.9.11.3 Transition SP_DWS8:Lost3 to SP_DWS0:AcquireSync.....	235
6.9.12 SP_DWS9:Lost3Recovered state.....	235
6.9.12.1 State description.....	235
6.9.12.2 Transition SP_DWS9:Lost3Recovered to SP_DWS6:Lost2.....	235
6.9.12.3 Transition SP_DWS9:Lost3Recovered to SP_DWS0:AcquireSync.....	235
6.10 Spin-up.....	235
7 Link layer.....	237

7.1 Link layer overview	237
7.2 Primitives	237
7.2.1 Primitives overview	237
7.2.2 Primitive summary	237
7.2.3 Primitive encodings	241
7.2.4 Primitive sequences	245
7.2.4.1 Primitive sequences overview	245
7.2.4.2 Single primitive sequence	245
7.2.4.3 Repeated primitive sequence	245
7.2.4.4 Continued primitive sequence	246
7.2.4.5 Triple primitive sequence	246
7.2.4.6 Redundant primitive sequence	247
7.2.5 Primitives not specific to type of connections	248
7.2.5.1 AIP (Arbitration in progress)	248
7.2.5.2 ALIGN	249
7.2.5.3 BREAK	250
7.2.5.4 BROADCAST	250
7.2.5.5 CLOSE	251
7.2.5.6 EOAF (End of address frame)	251
7.2.5.7 ERROR	251
7.2.5.8 HARD_RESET	251
7.2.5.9 NOTIFY	251
7.2.5.10 OPEN_ACCEPT	252
7.2.5.11 OPEN_REJECT	252
7.2.5.12 SOAF (Start of address frame)	254
7.2.6 Primitives used only inside SSP and SMP connections	255
7.2.6.1 ACK (Acknowledge)	255
7.2.6.2 CREDIT_BLOCKED	255
7.2.6.3 DONE	255
7.2.6.4 EOF (End of frame)	255
7.2.6.5 NAK (Negative acknowledgement)	255
7.2.6.6 RRDY (Receiver ready)	256
7.2.6.7 SOF (Start of frame)	256
7.2.7 Primitives used only inside STP connections and on SATA physical links	256
7.2.7.1 SATA_ERROR	256
7.2.7.2 SATA_PMACK, SATA_PMNAK, SATA_PMREQ_P and SATA_PMREQ_S (Power management acknowledgements and requests)	256
7.2.7.3 SATA_HOLD and SATA_HOLD_A (Hold and hold acknowledge)	257
7.2.7.4 SATA_R_RDY and SATA_X_RDY (Receiver ready and transmitter ready)	257
7.2.7.5 Other primitives used inside STP connections and on SATA physical links	257
7.3 Clock skew management	257
7.4 Idle physical links	258
7.5 CRC	258
7.5.1 CRC overview	258
7.5.2 CRC generation	259
7.5.3 CRC checking	261
7.6 Scrambling	261
7.7 Bit order of CRC and scrambler	263
7.8 Address frames	266
7.8.1 Address frames overview	266
7.8.2 IDENTIFY address frame	268
7.8.3 OPEN address frame	270
7.9 Identification and hard reset sequence	272
7.9.1 Identification and hard reset sequence overview	272
7.9.2 SAS initiator device rules	272
7.9.3 Fanout expander device rules	273
7.9.4 Edge expander device rules	273
7.9.5 SL_IR (link layer identification and hard reset) state machines	273
7.9.5.1 SL_IR state machines overview	273
7.9.5.2 SL_IR transmitter and receiver	274

7.9.5.3 SL_IR_TIR (transmit IDENTIFY or HARD_RESET) state machine	275
7.9.5.3.1 SL_IR_TIR state machine overview	275
7.9.5.3.2 SL_IR_TIR1:Idle state	275
7.9.5.3.2.1 State description	275
7.9.5.3.2.2 Transition SL_IR_TIR1:Idle to SL_IR_TIR2:Transmit_Identify	275
7.9.5.3.2.3 Transition SL_IR_TIR1:Idle to SL_IR_TIR3:Transmit_Hard_Reset.....	275
7.9.5.3.3 SL_IR_TIR2:Transmit_Identify state.....	275
7.9.5.3.3.1 State description	275
7.9.5.3.3.2 Transition SL_IR_TIR2:Transmit_Identify to SL_IR_TIR4:Completed.....	275
7.9.5.3.4 SL_IR_TIR3:Transmit_Hard_Reset state	276
7.9.5.3.4.1 State description	276
7.9.5.3.4.2 Transition SL_IR_TIR3:Transmit_Hard_Reset to SL_IR_TIR4:Completed	276
7.9.5.3.5 SL_IR_TIR4:Completed state.....	276
7.9.5.4 SL_IR_RIF (receive IDENTIFY address frame) state machine.....	276
7.9.5.4.1 SL_IR_RIF state machine overview	276
7.9.5.4.2 SL_IR_RIF1:Idle state	276
7.9.5.4.2.1 State description	276
7.9.5.4.2.2 Transition SL_IR_RIF1:Idle to SL_IR_RIF2:Receive_Identify_Frame	276
7.9.5.4.3 SL_IR_RIF2:Receive_Identify_Frame state	276
7.9.5.4.3.1 State description	276
7.9.5.4.3.2 Transition SL_IR_RIF2:Receive_Identify_Frame to SL_IR_RIF3:Completed	277
7.9.5.4.4 SL_IR_RIF3:Completed state.....	277
7.9.5.5 SL_IR_IRC (identification and hard reset control) state machine	277
7.9.5.5.1 SL_IR_IRC state machine overview	277
7.9.5.5.2 SL_IR_IRC1:Idle state	277
7.9.5.5.2.1 State description	277
7.9.5.5.2.2 Transition SL_IR_IRC1:Idle to SL_IR_IRC2:Wait.....	277
7.9.5.5.3 SL_IR_IRC2:Wait state.....	277
7.9.5.5.3.1 State description	277
7.9.5.5.3.2 Transition SL_IR_IRC2:Wait to SL_IR_IRC3:Completed	278
7.9.5.5.4 SL_IR_IRC3:Completed state	278
7.10 Power management	278
7.11 SAS domain changes.....	278
7.12 Connections	279
7.12.1 Connections overview.....	279
7.12.2 Opening a connection	280
7.12.2.1 Connection request	280
7.12.2.2 Results of a connection request.....	280
7.12.3 Arbitration fairness.....	281
7.12.4 Arbitration and resource management in an expander device	282
7.12.4.1 Arbitration and resource management in an expander device overview.....	282
7.12.4.2 Arbitration status	283
7.12.4.3 Edge expander devices.....	283
7.12.4.4 Fanout expander devices.....	284
7.12.4.5 Partial Pathway Timeout timer	284
7.12.4.6 Pathway recovery.....	284
7.12.5 Aborting a connection request	285
7.12.6 Closing a connection	287
7.12.7 Breaking a connection	288
7.13 Rate matching	288
7.14 SL (link layer for SAS phys) state machines	291
7.14.1 SL state machines overview	291
7.14.2 SL transmitter and receiver.....	293
7.14.3 SL_RA (receive OPEN address frame) state machine.....	294
7.14.4 SL_CC (connection control) state machine	295
7.14.4.1 SL_CC state machine overview	295
7.14.4.2 SL_CC0:Idle state	296
7.14.4.2.1 State description	296
7.14.4.2.2 Transition SL_CC0:Idle to SL_CC1:ArbSel	296
7.14.4.2.3 Transition SL_CC0:Idle to SL_CC2:Selected	296

7.14.4.3 SL_CC1:ArbSel state	296
7.14.4.3.1 State description	296
7.14.4.3.2 Transition SL_CC1:ArbSel to SL_CC0:Idle	297
7.14.4.3.3 Transition SL_CC1:ArbSel to SL_CC2:Selected	297
7.14.4.3.4 Transition SL_CC1:ArbSel to SL_CC3:Connected	297
7.14.4.3.5 Transition SL_CC1:ArbSel to SL_CC5:BreakWait	298
7.14.4.3.6 Transition SL_CC1:ArbSel to SL_CC6:Break	298
7.14.4.4 SL_CC2:Selected state	298
7.14.4.4.1 State description	298
7.14.4.4.2 Transition SL_CC2:Selected to SL_CC0:Idle	298
7.14.4.4.3 Transition SL_CC2:Selected to SL_CC3:Connected	299
7.14.4.4.4 Transition SL_CC2:Selected to SL_CC6:Break	299
7.14.4.5 SL_CC3:Connected state	299
7.14.4.5.1 State description	299
7.14.4.5.2 Transition SL_CC3:Connected to SL_CC4:DisconnectWait	299
7.14.4.5.3 Transition SL_CC3:Connected to SL_CC5:BreakWait	299
7.14.4.5.4 Transition SL_CC3:Connected to SL_CC6:Break	299
7.14.4.5.5 Transition SL_CC3:Connected to SL_CC7:CloseSTP	299
7.14.4.6 SL_CC4:DisconnectWait state	299
7.14.4.6.1 State description	299
7.14.4.6.2 Transition SL_CC4:DisconnectWait to SL_CC0:Idle	300
7.14.4.6.3 Transition SL_CC4:DisconnectWait to SL_CC5:BreakWait	300
7.14.4.6.4 Transition SL_CC4:DisconnectWait to SL_CC6:Break	300
7.14.4.7 SL_CC5:BreakWait state	300
7.14.4.7.1 State description	300
7.14.4.7.2 Transition SL_CC5:BreakWait to SL_CC0:Idle	300
7.14.4.8 SL_CC6:Break state	300
7.14.4.8.1 State description	300
7.14.4.8.2 Transition SL_CC6:Break to SL_CC0:Idle	300
7.14.4.9 SL_CC7:CloseSTP state	300
7.14.4.9.1 State description	300
7.14.4.9.2 Transition SL_CC7:CloseSTP to SL_CC0:Idle	301
7.15 XL (link layer for expander phys) state machine	301
7.15.1 XL state machine overview	301
7.15.2 XL transmitter and receiver	304
7.15.3 XL0:Idle state	306
7.15.3.1 State description	306
7.15.3.2 Transition XL0:Idle to XL1:Request_Path	306
7.15.3.3 Transition XL0:Idle to XL5:Forward_Open	306
7.15.4 XL1:Request_Path state	306
7.15.4.1 State description	306
7.15.4.2 Transition XL1:Request_Path to XL0:Idle	307
7.15.4.3 Transition XL1:Request_Path to XL2:Request_Open	307
7.15.4.4 Transition XL1:Request_Path to XL4:Open_Reject	307
7.15.4.5 Transition XL1:Request_Path to XL5:Forward_Open	308
7.15.4.6 Transition XL1:Request_Path to XL9:Break	308
7.15.5 XL2:Request_Open state	308
7.15.5.1 State description	308
7.15.5.2 Transition XL2:Request_Open to XL3:Open_Confirm_Wait	308
7.15.6 XL3:Open_Confirm_Wait state	308
7.15.6.1 State description	308
7.15.6.2 Transition XL3:Open_Confirm_Wait to XL0:Idle	309
7.15.6.3 Transition XL3:Open_Confirm_Wait to XL1:Request_Path	309
7.15.6.4 Transition XL3:Open_Confirm_Wait to XL5:Forward_Open	309
7.15.6.5 Transition XL3:Open_Confirm_Wait to XL7:Connected	309
7.15.6.6 Transition XL3:Open_Confirm_Wait to XL9:Break	309
7.15.6.7 Transition XL3:Open_Confirm_Wait to XL10:Break_Wait	309
7.15.7 XL4:Open_Reject state	309
7.15.7.1 State description	309
7.15.7.2 Transition XL4:Open_Reject to XL0:Idle	310

7.15.8 XL5:Forward_Open state.....	310
7.15.8.1 State description	310
7.15.8.2 Transition XL5:Forward_Open to XL6:Open_Response_Wait.....	310
7.15.9 XL6:Open_Response_Wait state	310
7.15.9.1 State description	310
7.15.9.2 Transition XL6:Open_Response_Wait to XL0:Idle.....	311
7.15.9.3 Transition XL6:Open_Response_Wait to XL1:Request_Path.....	311
7.15.9.4 Transition XL6:Open_Response_Wait to XL2:Request_Open	311
7.15.9.5 Transition XL6:Open_Response_Wait to XL7:Connected	311
7.15.9.6 Transition XL6:Open_Response_Wait to XL9:Break	312
7.15.9.7 Transition XL6:Open_Response_Wait to XL10:Break_Wait.....	312
7.15.10 XL7:Connected state	312
7.15.10.1 State description	312
7.15.10.2 Transition XL7:Connected to XL8:Close_Wait.....	312
7.15.10.3 Transition XL7:Connected to XL9:Break.....	312
7.15.10.4 Transition XL7:Connected to XL10:Break_Wait.....	312
7.15.11 XL8:Close_Wait state	313
7.15.11.1 State description	313
7.15.11.2 Transition XL8:Close_Wait to XL0:Idle.....	313
7.15.11.3 Transition XL8:Close_Wait to XL9:Break.....	313
7.15.11.4 Transition XL8:Close_Wait to XL10:Break_Wait.....	313
7.15.12 XL9:Break state	313
7.15.12.1 State description	313
7.15.12.2 Transition XL9:Break to XL0:Idle.....	313
7.15.13 XL10:Break_Wait state	314
7.15.13.1 State description	314
7.15.13.2 Transition XL10:Break_Wait to XL0:Idle	314
7.16 SSP link layer	314
7.16.1 Opening an SSP connection.....	314
7.16.2 Full duplex	314
7.16.3 SSP frame transmission and reception.....	314
7.16.4 SSP flow control	315
7.16.5 Interlocked frames	315
7.16.6 Breaking an SSP connection	317
7.16.7 Closing an SSP connection	317
7.16.8 SSP (link layer for SSP phys) state machines.....	318
7.16.8.1 SSP state machines overview.....	318
7.16.8.2 SSP transmitter and receiver	321
7.16.8.3 SSP_TIM (transmit interlocked frame monitor) state machine.....	322
7.16.8.4 SSP_TCM (transmit frame credit monitor) state machine.....	323
7.16.8.5 SSP_D (DONE control) state machine.....	323
7.16.8.6 SSP_TF (transmit frame control) state machine	324
7.16.8.6.1 SSP_TF state machine overview.....	324
7.16.8.6.2 SSP_TF1:Connected_Idle state	324
7.16.8.6.2.1 State description	324
7.16.8.6.2.2 Transition SSP_TF1:Connected_Idle to SSP_TF2:Tx_Wait.....	324
7.16.8.6.2.3 Transition SSP_TF1:Connected_Idle to SSP_TF4:Transmit_DONE.....	325
7.16.8.6.3 SSP_TF2:Tx_Wait state	325
7.16.8.6.3.1 State description	325
7.16.8.6.3.2 Transition SSP_TF2:Tx_Wait to SSP_TF3:Transmit_Frame.....	325
7.16.8.6.3.3 Transition SSP_TF2:Tx_Wait to SSP_TF4:Transmit_DONE.....	325
7.16.8.6.4 SSP_TF3:Transmit_Frame state	325
7.16.8.6.4.1 State description	325
7.16.8.6.4.2 Transition SSP_TF3:Transmit_Frame to SSP_TF1:Connected_Idle.....	326
7.16.8.6.5 SSP_TF4:Transmit_DONE state	326
7.16.8.7 SSP_RF (receive frame control) state machine.....	326
7.16.8.8 SSP_RCM (receive frame credit monitor) state machine.....	327
7.16.8.9 SSP_RIM (receive interlocked frame monitor) state machine.....	327
7.16.8.10 SSP_TC (transmit credit control) state machine	328
7.16.8.11 SSP_TAN (transmit ACK/NAK control) state machine.....	328

7.17 STP link layer	328
7.17.1 STP frame transmission and reception.....	328
7.17.2 STP initiator phy throttling.....	329
7.17.3 STP flow control.....	329
7.17.4 Continued primitive sequence.....	332
7.17.5 Affiliations	332
7.17.6 Opening an STP connection	333
7.17.7 Closing an STP connection	334
7.17.8 STP connection management examples	334
7.17.9 STP (link layer for STP phys) state machines	336
7.17.10 SMP target port support.....	337
7.18 SMP link layer	337
7.18.1 SMP frame transmission and reception.....	337
7.18.2 SMP flow control.....	337
7.18.3 Closing an SMP connection.....	337
7.18.4 SMP (link layer for SMP phys) state machines.....	337
7.18.4.1 SMP state machines overview	337
7.18.4.2 SMP transmitter and receiver.....	337
7.18.4.3 SMP_IP (link layer for SMP initiator phys) state machine	338
7.18.4.3.1 SMP_IP state machine overview	338
7.18.4.3.2 SMP_IP1:Idle state	339
7.18.4.3.2.1 State description	339
7.18.4.3.2.2 Transition SMP_IP1:Idle to SMP_IP2:Transmit_Frame.....	339
7.18.4.3.3 SMP_IP2:Transmit_Frame state	339
7.18.4.3.3.1 State description	339
7.18.4.3.3.2 Transition SMP_IP2:Transmit_Frame to SMP_IP3:Receive_Frame	340
7.18.4.3.4 SMP_IP3:Receive_Frame state	340
7.18.4.4 SMP_TP (link layer for SMP target phys) state machine	340
7.18.4.4.1 SMP_TP state machine overview.....	340
7.18.4.4.2 SMP_TP1:Receive_Frame state	341
7.18.4.4.2.1 State description	341
7.18.4.4.2.2 Transition SMP_TP1:Receive_Frame to SMP_TP2:Transmit_Frame.....	342
7.18.4.4.3 SMP_TP2:Transmit_Frame state	342
8 Port layer.....	343
8.1 Port layer overview	343
8.2 PL (port layer) state machines	343
8.2.1 PL state machines overview	343
8.2.2 PL_OC (port layer overall control) state machine	345
8.2.2.1 PL_OC state machine overview	345
8.2.2.2 PL_OC1:Idle state	346
8.2.2.2.1 PL_OC1:Idle state description.....	346
8.2.2.2.2 Transition PL_OC1:Idle to PL_OC2:Overall_Control.....	347
8.2.2.3 PL_OC2:Overall_Control state	347
8.2.2.3.1 PL_OC2:Overall_Control state overview	347
8.2.2.3.2 PL_OC2:Overall_Control state establishing connections	347
8.2.2.3.3 PL_OC2:Overall_Control state connection established.....	350
8.2.2.3.4 PL_OC2:Overall_Control state unable to establish a connection.....	350
8.2.2.3.5 PL_OC2:Overall_Control state connection management.....	351
8.2.2.3.6 PL_OC2:Overall_Control state frame transmission.....	352
8.2.2.3.7 PL_OC2:Overall_Control state frame transmission cancellations	353
8.2.2.3.8 Transition PL_OC2:Overall_Control to PL_OC1:Idle.....	353
8.2.3 PL_PM (port layer phy manager) state machine	354
8.2.3.1 PL_PM state machine overview	354
8.2.3.2 PL_PM1:Idle state	356
8.2.3.2.1 PL_PM1:Idle state description.....	356
8.2.3.2.2 Transition PL_PM1:Idle to PL_PM2:Req_Wait.....	357
8.2.3.2.3 Transition PL_PM1:Idle to PL_PM3:Connected	357
8.2.3.3 PL_PM2:Req_Wait state	357
8.2.3.3.1 PL_PM2:Req_Wait state overview	357

8.2.3.3.2	PL_PM2:Req_Wait establishing a connection.....	357
8.2.3.3.3	PL_PM2:Req_Wait connection established.....	357
8.2.3.3.4	PL_PM2:Req_Wait unable to establish a connection.....	358
8.2.3.3.5	PL_PM2:Req_Wait connection management.....	358
8.2.3.3.6	Transition PL_PM2:Req_Wait to PL_PM1:Idle.....	358
8.2.3.3.7	Transition PL_PM2:Req_Wait to PL_PM3:Connected.....	358
8.2.3.3.8	Transition PL_PM2:Req_Wait to PL_PM4:Wait_For_Close.....	359
8.2.3.4	PL_PM3:Connected state.....	359
8.2.3.4.1	PL_PM3:Connected state description.....	359
8.2.3.4.2	Transition PL_PM3:Connected to PL_PM1:Idle.....	361
8.2.3.5	PL_PM4:Wait_For_Close state.....	361
8.2.3.5.1	PL_PM4:Wait_For_Close state description.....	361
8.2.3.5.2	Transition PL_PM4:Wait_For_Close to PL_PM1:Idle.....	361
9	Transport layer.....	362
9.1	Transport layer overview.....	362
9.2	SSP transport layer.....	362
9.2.1	SSP frame format.....	362
9.2.2	Information units.....	364
9.2.2.1	COMMAND frame - Command information unit.....	364
9.2.2.2	TASK frame - Task Management Function information unit.....	366
9.2.2.3	XFER_RDY frame - Transfer Ready information unit.....	367
9.2.2.4	DATA frame - Data information unit.....	368
9.2.2.5	RESPONSE frame - Response information unit.....	369
9.2.2.5.1	RESPONSE frame - Response information unit overview.....	369
9.2.2.5.2	Response information unit - NO_DATA format.....	371
9.2.2.5.3	Response information unit - RESPONSE_DATA format.....	371
9.2.2.5.4	Response information unit - SENSE_DATA format.....	372
9.2.3	Sequences of SSP frames.....	372
9.2.3.1	Sequences of SSP frames overview.....	372
9.2.3.2	Task management function sequence of SSP frames.....	372
9.2.3.3	Non-data command sequence of SSP frames.....	373
9.2.3.4	Write command sequence of SSP frames.....	373
9.2.3.5	Read command sequence of SSP frames.....	374
9.2.3.6	Bidirectional command sequence of SSP frames.....	374
9.2.4	SSP transport layer handling of link layer errors.....	375
9.2.4.1	SSP transport layer handling of link layer errors overview.....	375
9.2.4.2	COMMAND frame - handling of link layer errors.....	375
9.2.4.3	TASK frame - handling of link layer errors.....	376
9.2.4.4	XFER_RDY frame - handling of link layer errors.....	376
9.2.4.4.1	XFER_RDY frame overview.....	376
9.2.4.4.2	XFER_RDY frame with transport layer retries enabled.....	376
9.2.4.4.3	XFER_RDY frame with transport layer retries disabled.....	377
9.2.4.5	DATA frame - handling of link layer errors.....	377
9.2.4.5.1	DATA frame overview.....	377
9.2.4.5.2	DATA frame with transport layer retries enabled.....	377
9.2.4.5.3	DATA frame with transport layer retries disabled.....	378
9.2.4.6	RESPONSE frame - handling of link layer errors.....	378
9.2.5	SSP transport layer error handling summary.....	378
9.2.5.1	SSP transport layer error handling summary introduction.....	378
9.2.5.2	SSP initiator port transport layer error handling summary.....	378
9.2.5.3	SSP target port transport layer error handling summary.....	379
9.2.6	ST (transport layer for SSP ports) state machines.....	380
9.2.6.1	ST state machines overview.....	380
9.2.6.2	ST_I (transport layer for SSP initiator ports) state machines.....	381
9.2.6.2.1	ST_I state machines overview.....	381
9.2.6.2.2	ST_IFR (initiator frame router) state machine.....	383
9.2.6.2.2.1	ST_IFR state machine overview.....	383
9.2.6.2.2.2	Processing transport protocol service requests.....	383
9.2.6.2.2.3	Processing Frame Received confirmations.....	384

9.2.6.2.2.4	Processing Transmission Complete and Reception Complete messages.....	385
9.2.6.2.2.5	Processing miscellaneous requests.....	386
9.2.6.2.3	ST_ITS (initiator transport server) state machine.....	386
9.2.6.2.3.1	ST_ITS state machine overview.....	386
9.2.6.2.3.2	ST_ITS1:Initiator_Start state.....	387
9.2.6.2.3.2.1	State description.....	387
9.2.6.2.3.2.2	Transition ST_ITS1:Initiator_Start to ST_ITS3:Prepare_Command.....	387
9.2.6.2.3.2.3	Transition ST_ITS1:Initiator_Start to ST_ITS4:Prepare_Task.....	387
9.2.6.2.3.3	ST_ITS2:Initiator_Send_Frame state.....	388
9.2.6.2.3.3.3	Transition ST_ITS2:Initiator_Send_Frame to ST_ITS1:Initiator_Start.....	391
9.2.6.2.3.3.4	Transition ST_ITS2:Initiator_Send_Frame to ST_ITS5:Prepare_Data_Out.....	391
9.2.6.2.3.3.5	Transition ST_ITS2:Initiator_Send_Frame to ST_ITS6:Process_Data_In.....	391
9.2.6.2.3.4	ST_ITS3:Prepare_Command state.....	392
9.2.6.2.3.4.1	State description.....	392
9.2.6.2.3.4.2	Transition ST_ITS3:Prepare_Command to ST_ITS2:Initiator_Send_Frame.....	392
9.2.6.2.3.5	ST_ITS4:Prepare_Task state.....	392
9.2.6.2.3.5.1	State description.....	392
9.2.6.2.3.5.2	Transition ST_ITS4:Prepare_Task to ST_ITS2:Initiator_Send_Frame.....	393
9.2.6.2.3.6	ST_ITS5:Prepare_Data_Out state.....	393
9.2.6.2.3.6.1	State description.....	393
9.2.6.2.3.6.2	Transition ST_ITS5:Prepare_Data_Out to ST_ITS2:Initiator_Send_Frame.....	393
9.2.6.2.3.7	ST_ITS6:Receive_Data_In state.....	394
9.2.6.2.3.7.1	State description.....	394
9.2.6.2.3.7.2	Transition ST_ITS6:Receive_Data_In to ST_ITS1:Initiator_Start.....	395
9.2.6.2.3.7.3	Transition ST_ITS6:Receive_Data_In to ST_ITS2:Initiator_Send_Frame.....	395
9.2.6.3	ST_T (transport layer for SSP target ports) state machines.....	395
9.2.6.3.1	ST_T state machines overview.....	395
9.2.6.3.2	ST_TFR (target frame router) state machine.....	397
9.2.6.3.2.1	ST_TFR state machine overview.....	397
9.2.6.3.2.2	Processing Frame Received confirmations.....	397
9.2.6.3.2.3	Processing transport protocol service requests and responses.....	399
9.2.6.3.2.4	Processing miscellaneous requests and confirmations.....	401
9.2.6.3.3	ST_TTS (target transport server) state machine.....	402
9.2.6.3.3.1	ST_TTS state machine overview.....	402
9.2.6.3.3.2	ST_TTS1:Target_Start state.....	402
9.2.6.3.3.2.1	State description.....	402
9.2.6.3.3.2.2	Transition ST_TTS1:Target_Start to ST_TTS3:Prepare_Data_In.....	403
9.2.6.3.3.2.3	Transition ST_TTS1:Target_Start to ST_TTS4:Prepare_Xfer_Rdy.....	403
9.2.6.3.3.2.4	Transition ST_TTS1:Target_Start to ST_TTS5:Receive_Data_Out.....	403
9.2.6.3.3.2.5	Transition ST_TTS1:Target_Start to ST_TTS7:Prepare_Response.....	403
9.2.6.3.3.3	ST_TTS2:Target_Send_Frame state.....	403
9.2.6.3.3.3.1	Transition ST_TTS2:Target_Send_Frame to ST_TTS1:Target_Start.....	406
9.2.6.3.3.3.2	Transition ST_TTS2:Target_Send_Frame to ST_TTS3:Prepare_Data_In.....	406
9.2.6.3.3.3.3	Transition ST_TTS2:Target_Send_Frame to ST_TTS5:Receive_Data_Out.....	406
9.2.6.3.3.4	ST_TTS3:Prepare_Data_In state.....	406
9.2.6.3.3.4.1	State description.....	406
9.2.6.3.3.4.2	Transition ST_TTS3:Prepare_Data_In to ST_TTS2:Target_Send_Frame.....	407
9.2.6.3.3.5	ST_TTS4:Prepare_Xfer_Rdy state.....	407
9.2.6.3.3.5.1	State description.....	407
9.2.6.3.3.5.2	Transition ST_TTS4:Prepare_Xfer_Rdy to ST_TTS2:Target_Send_Frame.....	408
9.2.6.3.3.6	ST_TTS5:Receive_Data_Out state.....	408
9.2.6.3.3.6.1	State description.....	408
9.2.6.3.3.6.2	Transition ST_TTS5:Receive_Data_Out to ST_TTS1:Target_Start.....	409
9.2.6.3.3.6.3	Transition ST_TTS5:Receive_Data_Out to ST_TTS4:Prepare_Xfer_Rdy.....	409
9.2.6.3.3.7	ST_TTS6:Prepare_Response state.....	409
9.2.6.3.3.7.1	State description.....	409
9.2.6.3.3.7.2	Transition ST_TTS6:Prepare_Response to ST_TTS2:Target_Send_Frame.....	410
9.3	STP transport layer.....	410
9.3.1	Initial FIS.....	410
9.3.2	BIST Activate FIS.....	411

9.3.3 TT (transport layer for STP ports) state machines.....	411
9.4 SMP transport layer.....	411
9.4.1 SMP transport layer overview.....	411
9.4.2 SMP_REQUEST frame.....	412
9.4.3 SMP_RESPONSE frame.....	412
9.4.4 Sequence of SMP frames.....	413
9.4.5 MT (transport layer for SMP ports) state machines.....	413
9.4.5.1 SMP transport layer state machines overview.....	413
9.4.5.2 MT_IP (transport layer for SMP initiator ports) state machine.....	413
9.4.5.2.1 MT_IP state machine overview.....	413
9.4.5.2.2 MT_IP1:Idle state.....	414
9.4.5.2.2.1 State description.....	414
9.4.5.2.2.2 Transition MT_IP1:Idle to MT_IP2:Send.....	414
9.4.5.2.3 MT_IP2:Send state.....	415
9.4.5.2.3.1 State description.....	415
9.4.5.2.3.2 Transition MT_IP2:Send to MT_IP1:Idle.....	415
9.4.5.2.3.3 Transition MT_IP2:Send to MT_IP3:Receive.....	415
9.4.5.2.4 MT_IP3:Receive state.....	415
9.4.5.2.4.1 State description.....	415
9.4.5.2.4.2 Transition MT_IP3:Receive to MT_IP1:Idle.....	415
9.4.5.3 MT_TP (transport layer for SMP target ports) state machine.....	415
9.4.5.3.1 MT_TP state machine overview.....	415
9.4.5.3.2 MT_TP1:Idle state.....	416
9.4.5.3.2.1 State description.....	416
9.4.5.3.2.2 Transition MT_TP1:Idle to MT_TP2:Respond.....	416
9.4.5.3.3 MT_TP2:Respond state.....	416
9.4.5.3.3.1 State description.....	416
9.4.5.3.3.2 Transition MT_TP2:Respond to MT_TP1:Idle.....	417
10 Application layer.....	418
10.1 Application layer overview.....	418
10.2 SCSI application layer.....	418
10.2.1 SCSI transport protocol services.....	418
10.2.1.1 SCSI transport protocol services overview.....	418
10.2.1.2 Send SCSI Command transport protocol service.....	419
10.2.1.3 SCSI Command Received transport protocol service.....	420
10.2.1.4 Send Command Complete transport protocol service.....	421
10.2.1.5 Command Complete Received transport protocol service.....	421
10.2.1.6 Send Data-In transport protocol service.....	422
10.2.1.7 Data-In Delivered transport protocol service.....	423
10.2.1.8 Receive Data-Out transport protocol service.....	423
10.2.1.9 Data-Out Received transport protocol service.....	424
10.2.1.10 Terminate Data Transfer transport protocol service.....	424
10.2.1.11 Data Transfer Terminated transport protocol service.....	424
10.2.1.12 Send Task Management Request transport protocol service.....	425
10.2.1.13 Task Management Request Received transport protocol service.....	425
10.2.1.14 Task Management Function Executed transport protocol service.....	426
10.2.1.15 Received Task Management Function Executed transport protocol service.....	427
10.2.2 Application client error handling.....	428
10.2.3 Device server error handling.....	429
10.2.4 Task router and task manager error handling.....	429
10.2.5 SCSI transport protocol event notifications.....	430
10.2.6 SCSI commands.....	430
10.2.6.1 INQUIRY command.....	430
10.2.6.2 LOG SELECT and LOG SENSE commands.....	430
10.2.6.3 MODE SELECT and MODE SENSE commands.....	430
10.2.6.4 START STOP UNIT command.....	430
10.2.7 SCSI mode parameters.....	430
10.2.7.1 Disconnect-Reconnect mode page.....	430
10.2.7.1.1 Disconnect-Reconnect mode page overview.....	430

10.2.7.1.2	BUS INACTIVITY TIME LIMIT field	431
10.2.7.1.3	MAXIMUM CONNECT TIME LIMIT field.....	432
10.2.7.1.4	MAXIMUM BURST SIZE field.....	432
10.2.7.1.5	FIRST BURST SIZE field.....	432
10.2.7.2	Protocol-Specific Port mode page.....	433
10.2.7.2.1	Protocol-Specific Port mode page overview	433
10.2.7.2.2	Protocol-Specific Port mode page - short format.....	433
10.2.7.2.3	Protocol-Specific Port mode page - Phy Control And Discover subpage	434
10.2.7.3	Protocol-Specific Logical Unit mode page.....	437
10.2.7.3.1	Protocol-Specific Logical Unit mode page overview	437
10.2.7.3.2	Protocol-Specific Logical Unit mode page - short format.....	437
10.2.8	SCSI log parameters	438
10.2.8.1	Protocol-Specific Port log page	438
10.2.9	SCSI diagnostic parameters	441
10.2.9.1	Protocol-Specific diagnostic page	441
10.2.10	SCSI power conditions	443
10.2.10.1	SCSI power conditions overview.....	443
10.2.10.2	SA_PC (SCSI application layer power condition) state machine	443
10.2.10.2.1	SA_PC state machine overview	443
10.2.10.2.2	SA_PC_0:Powered_On state	444
10.2.10.2.2.1	State description	444
10.2.10.2.2.2	Transition SA_PC_0:Powered_On to SA_PC_4:Stopped	444
10.2.10.2.2.3	Transition SA_PC_0:Powered_On to SA_PC_5:Active_Wait.....	444
10.2.10.2.3	SA_PC_1:Active state	445
10.2.10.2.3.1	State description	445
10.2.10.2.3.2	Transition SA_PC_1:Active to SA_PC_2:Idle	445
10.2.10.2.3.3	Transition SA_PC_1:Active to SA_PC_3:Standby.....	445
10.2.10.2.3.4	Transition SA_PC_1:Active to SA_PC_4:Stopped.....	445
10.2.10.2.4	SA_PC_2:Idle state	445
10.2.10.2.4.1	State description	445
10.2.10.2.4.2	Transition SA_PC_2:Idle to SA_PC_1:Active	445
10.2.10.2.4.3	Transition SA_PC_2:Idle to SA_PC_3:Standby.....	445
10.2.10.2.4.4	Transition SA_PC_2:Idle to SA_PC_4:Stopped.....	445
10.2.10.2.5	SA_PC_3:Standby state	445
10.2.10.2.5.1	State description	445
10.2.10.2.5.2	Transition SA_PC_3:Standby to SA_PC_4:Stopped	446
10.2.10.2.5.3	Transition SA_PC_3:Standby to SA_PC_5:Active_Wait.....	446
10.2.10.2.5.4	Transition SA_PC_3:Standby to SA_PC_6:Idle_Wait.....	446
10.2.10.2.6	SA_PC_4:Stopped state.....	446
10.2.10.2.6.1	State description	446
10.2.10.2.6.2	Transition SA_PC_4:Stopped to SA_PC_3:Standby	446
10.2.10.2.6.3	Transition SA_PC_4:Stopped to SA_PC_5:Active_Wait	446
10.2.10.2.6.4	Transition SA_PC_4:Stopped to SA_PC_6:Idle_Wait	446
10.2.10.2.7	SA_PC_5:Active_Wait state	446
10.2.10.2.7.1	State description	446
10.2.10.2.7.2	Transition SA_PC_5:Active_Wait to SA_PC_1:Active	447
10.2.10.2.7.3	Transition SA_PC_5:Active_Wait to SA_PC_3:Standby.....	447
10.2.10.2.7.4	Transition SA_PC_5:Active_Wait to SA_PC_4:Stopped	447
10.2.10.2.7.5	Transition SA_PC_5:Active_Wait to SA_PC_6:Idle_Wait.....	447
10.2.10.2.8	SA_PC_6:Idle_Wait state	447
10.2.10.2.8.1	State description	447
10.2.10.2.8.2	Transition SA_PC_6:Idle_Wait to SA_PC_2:Idle	447
10.2.10.2.8.3	Transition SA_PC_6:Idle_Wait to SA_PC_3:Standby.....	447
10.2.10.2.8.4	Transition SA_PC_6:Idle_Wait to SA_PC_4:Stopped	447
10.2.10.2.8.5	Transition SA_PC_6:Idle_Wait to SA_PC_5:Active_Wait.....	448
10.2.11	SCSI vital product data (VPD)	448
10.3	ATA application layer	449
10.4	Management application layer	449
10.4.1	READY LED signal behavior	449
10.4.2	Management protocol services.....	450

10.4.3 SMP functions.....	451
10.4.3.1 SMP function request frame format.....	451
10.4.3.2 SMP function response frame format.....	453
10.4.3.3 REPORT GENERAL function.....	455
10.4.3.4 REPORT MANUFACTURER INFORMATION function	458
10.4.3.5 DISCOVER function.....	460
10.4.3.6 REPORT PHY ERROR LOG function.....	467
10.4.3.7 REPORT PHY SATA function.....	469
10.4.3.8 REPORT ROUTE INFORMATION function	471
10.4.3.9 CONFIGURE ROUTE INFORMATION function	473
10.4.3.10 PHY CONTROL function.....	474
10.4.3.11 PHY TEST FUNCTION function.....	478
Annex A (normative) Jitter tolerance patterns.....	482
A.1 Jitter tolerance pattern (JTPAT).....	482
A.2 Compliant jitter tolerance pattern (CJTPAT)	484
Annex B (normative) Signal performance measurements	489
B.1 Signal performance measurements overview	489
B.2 Simple physical link.....	489
B.2.1 Simple physical link overview	489
B.2.2 Assumptions for the structure of the transmitter device and the receiver device	490
B.2.3 Definition of receiver sensitivity and receiver device sensitivity	491
B.3 Measurement architecture requirements	492
B.3.1 General.....	492
B.3.2 Relationship between signal compliance measurements at interoperability points and operation in systems.....	492
B.4 De-embedding connectors in test fixtures.....	493
B.5 Measurement conditions for signal output at the transmitter device	493
B.6 Measurement conditions for signal tolerance at the transmitter device	494
B.7 Measurement conditions for signal output at the receiver device	495
B.8 Measurement conditions for signal tolerance at the receiver device	496
B.9 S-parameter measurements	496
B.9.1 S-parameter overview	496
B.9.2 S-parameter naming conventions.....	497
B.9.3 Use of single-ended instrumentation in differential applications.....	497
B.9.4 Measurement configurations for physical link elements	498
B.9.4.1 Measurement configuration overview	498
B.9.4.2 Transmitter device return loss.....	499
B.9.4.3 Receiver device return loss.....	500
B.9.4.4 Return loss (S_{11}) at IT or CT.....	500
B.9.4.5 Upstream return loss (S_{22}) at IR or CR.....	501
B.9.5 Summary for S-parameter measurements	502
Annex C (informative) SAS to SAS phy reset sequence examples	503
Annex D (informative) CRC	508
D.1 CRC generator and checker implementation examples	508
D.2 CRC implementation in C	508
D.3 CRC implementation with XORs.....	509
D.4 CRC examples.....	511
Annex E (informative) SAS address hashing.....	512
E.1 SAS address hashing overview	512
E.2 Hash collision probability	512
E.3 Hash generation.....	512
E.4 Hash implementation in C.....	513
E.5 Hash implementation with XORs	513
E.6 Hash examples	514

Annex F (informative) Scrambling.....	518
F.1 Scrambler implementation example.....	518
F.2 Scrambler implementation in C.....	518
F.3 Scrambler implementation with XORs.....	519
F.4 Scrambler examples.....	520
Annex G (informative) ATA architectural notes.....	521
G.1 STP differences from Serial ATA (SATA).....	521
G.2 STP differences from Serial ATA II.....	521
G.3 Affiliation policies.....	521
G.3.1 Affiliation policies overview.....	521
G.3.2 Affiliation policy for static STP initiator port to STP target port mapping.....	522
G.3.3 Affiliation policy with SATA queued commands and multiple STP initiator ports.....	522
G.3.4 Applicability of affiliation for STP target ports.....	522
G.4 SATA port selector considerations.....	522
G.5 SATA device not transmitting initial Register Device-to-Host FIS.....	522
Annex H (informative) ALIGN and/or NOTIFY insertion rate summary.....	523
Annex I (informative) Expander device handling of connections.....	524
I.1 Expander device handling of connections overview.....	524
I.2 Connection request - OPEN_ACCEPT.....	526
I.3 Connection request - OPEN_REJECT by end device.....	527
I.4 Connection request - OPEN_REJECT by expander device.....	528
I.5 Connection request - arbitration lost.....	529
I.6 Connection request - backoff and retry.....	530
I.7 Connection request - backoff and reverse path.....	531
I.8 Connection close - single step.....	532
I.9 Connection close - simultaneous.....	533
I.10 BREAK handling during path arbitration.....	534
I.11 BREAK handling during connection.....	535
I.12 STP connection - originated by STP initiator port.....	536
I.13 STP connection - originated by STP target port in an STP/SATA bridge.....	537
I.14 STP connection close - originated by STP initiator port.....	538
I.15 STP connection close - originated by STP target port in an STP/SATA bridge.....	539
I.16 Connection request - XL1:Request_Path to XL5:Forward_Open transition.....	540
I.17 Pathway blocked and pathway recovery example.....	541
Annex J (informative) Primitive encoding.....	542
Annex K (informative) Messages between state machines.....	545
K.1 Messages between phy layer and other layers.....	545
K.2 Messages between link layer, port layer, and management application layer for all protocols.....	545
K.3 Messages between link layer, port layer, and transport layer for SSP.....	547
K.4 Messages between link layer, port layer, and transport layer for SMP.....	549
K.5 Messages from transport layer to application layer for SSP.....	550
K.6 Messages from transport layer to application layer for SMP.....	551
Annex (informative) L Discover process example implementation.....	552
L.1 Discover process example implementation overview.....	552
L.2 Header file.....	552
L.3 Source file.....	568
Annex M SAS icon.....	588
Bibliography.....	589

Tables

	Page
Table 1 — ISO and American numbering conventions	59
Table 2 — Multiplicity notation in class diagrams	60
Table 3 — Data dword containing a value	66
Table 4 — Data dword containing four one-byte fields	66
Table 5 — Names and identifiers	87
Table 6 — SAM-3 attribute mapping	87
Table 7 — SAS address format	87
Table 8 — Hashed SAS address code parameter	88
Table 9 — Expander phy to ECM requests	106
Table 10 — Expander phy to ECM responses	107
Table 11 — ECM to expander phy confirmations	107
Table 12 — Expander phy to ECR to expander phy requests and indications	108
Table 13 — Expander phy to ECR to expander phy responses and confirmations	109
Table 14 — Expander phy to BPP requests	110
Table 15 — BPP to expander phy indications	110
Table 16 — Routing attributes and routing methods	111
Table 17 — Expander route table levels for edge expander device R or fanout expander device R	119
Table 18 — Expander route table levels for edge expander device N	119
Table 19 — Expander route entries for edge expander E0 phy 1	120
Table 20 — Expander route entries for fanout expander device F phy 0	121
Table 21 — Connectors	126
Table 22 — SAS Drive connector pin assignments	129
Table 23 — Controller SAS 4i connector pin assignments and physical link usage	131
Table 24 — Backplane SAS 4i connector pin assignments and physical link usage	132
Table 25 — Controller Mini SAS 4i connector pin assignments and physical link usage	134
Table 26 — Backplane Mini SAS 4i connector pin assignments and physical link usage	135
Table 27 — SAS 4x cable plug connector icons	136
Table 28 — SAS 4x receptacle connector icons	137
Table 29 — SAS 4x connector pin assignments and physical link usage	138
Table 30 — Mini SAS 4x cable plug connector icons and key slot positions	139
Table 31 — Mini SAS 4x receptacle connector icons and key positions	141
Table 32 — Mini SAS 4x connector pin assignments and physical link usage	143
Table 33 — Requirements for internal cable assemblies using SAS Drive connectors and backplanes	157
Table 34 — Requirements for SAS internal cable assemblies using SAS 4i or Mini SAS 4i	158
Table 35 — Additional requirements for cable assemblies using SAS 4i	159
Table 36 — Additional requirements for cable assemblies using Mini SAS 4i	159
Table 37 — Requirements for external cable assemblies	160
Table 38 — Additional requirements for external cable assemblies using SAS 4x	161
Table 39 — Additional requirements for external cable assemblies using Mini SAS 4x	161
Table 40 — Compliance points	162
Table 41 — General electrical characteristics	175
Table 42 — General transmitter device electrical characteristics	175
Table 43 — Receiver device general electrical characteristics	176
Table 44 — Transmitter device signal output characteristics as measured with the zero-length test load at transmitter device compliance points IT and CT	181
Table 45 — Transmitter device signal output characteristics as measured with each test load at transmitter device compliance points IT and CT	182
Table 46 — Transmitter device maximum jitter as measured with each test load at transmitter device compliance points IT and CT	183
Table 47 — Delivered signal characteristics as measured with the zero length test load at receiver device compliance points IR and CR	184
Table 48 — Maximum delivered jitter at receiver device compliance points IR and CR	186
Table 49 — Receiver device jitter tolerance at receiver device compliance points IR and CR	187
Table 50 — Output characteristics of the READY LED signal	188
Table 51 — Bit designations	189
Table 52 — Conversion from byte notation to character name example	190
Table 53 — Data characters	191
Table 54 — Control characters	196

Table 55 —	Control character usage	197
Table 56 —	Delayed code violation example	197
Table 57 —	OOB signal timing specifications	200
Table 58 —	OOB signal transmitter device requirements	200
Table 59 —	OOB signal receiver device burst time detection requirements	202
Table 60 —	OOB signal receiver device idle time detection requirements	202
Table 61 —	OOB signal receiver device negation time detection requirements	202
Table 62 —	SATA port selection signal transmitter device requirements	204
Table 63 —	Phy reset sequence timing specifications	205
Table 64 —	SATA speed negotiation sequence timing specifications	206
Table 65 —	SAS speed negotiation sequence timing specifications	209
Table 66 —	SP state machine timers	215
Table 67 —	SP_DWS timers	231
Table 68 —	Primitive format	237
Table 69 —	Primitives not specific to type of connection	237
Table 70 —	Primitives used only inside SSP and SMP connections	239
Table 71 —	Primitives used only inside STP connections and on SATA physical links	240
Table 72 —	Primitive encoding for primitives not specific to type of connection	241
Table 73 —	Primitive encoding for primitives used only inside SSP and SMP connections	243
Table 74 —	Primitive encoding for primitives used only inside STP connections and on SATA physical links	244
Table 75 —	Primitive sequences	245
Table 76 —	AIP primitives	249
Table 77 —	ALIGN primitives	249
Table 78 —	BROADCAST primitives	250
Table 79 —	CLOSE primitives	251
Table 80 —	NOTIFY primitives	252
Table 81 —	OPEN_REJECT abandon primitives	253
Table 82 —	OPEN_REJECT retry primitives	254
Table 83 —	DONE primitives	255
Table 84 —	NAK primitives	256
Table 85 —	RRDY primitives	256
Table 86 —	Clock skew management ALIGN insertion requirement	257
Table 87 —	CRC polynomials	259
Table 88 —	Scrambling for different data dword types	262
Table 89 —	Address frame format	267
Table 90 —	ADDRESS FRAME TYPE field	267
Table 91 —	IDENTIFY address frame format	268
Table 92 —	DEVICE TYPE field	268
Table 93 —	OPEN address frame format	270
Table 94 —	PROTOCOL field	270
Table 95 —	CONNECTION RATE field	271
Table 96 —	ARBITRATION WAIT TIME field	272
Table 97 —	SL_IR_IRC timers	273
Table 98 —	Connection Results of a connection request	280
Table 99 —	Arbitration priority for OPEN address frames passing on a physical link	281
Table 100 —	Arbitration priority for contending Request Path requests in the ECM when all requests have Retry Priority Status arguments of NORMAL	282
Table 101 —	Arbitration priority for contending Request Path requests in the ECM among requests with Retry Priority Status arguments of IGNORE AWT	282
Table 102 —	Pathway recovery priority	285
Table 103 —	Results of aborting a connection request	285
Table 104 —	Results of closing a connection	287
Table 105 —	Results of breaking a connection	288
Table 106 —	Rate matching ALIGN and/or NOTIFY insertion requirements	289
Table 107 —	SL_CC timers	295
Table 108 —	XL timers	301
Table 109 —	SSP frame interlock requirements	315
Table 110 —	SSP link layer timers	319
Table 111 —	STP link layer differences from SATA link layer during an STP connection	329

Table 112	—	PL_OC state machine timers	345
Table 113	—	Confirmations from Unable To Connect or Retry Open messages	351
Table 114	—	PL_PM state machine timers	354
Table 115	—	Messages from Open Failed confirmations	358
Table 116	—	SSP frame format	362
Table 117	—	FRAME TYPE field	363
Table 118	—	COMMAND frame - Command information unit	365
Table 119	—	TASK ATTRIBUTE field	365
Table 120	—	TASK frame - Task Management Function information unit	366
Table 121	—	TASK MANAGEMENT FUNCTION field	367
Table 122	—	XFER_RDY frame - Transfer Ready information unit	368
Table 123	—	DATA frame - Data information unit	368
Table 124	—	RESPONSE frame - Response information unit	370
Table 125	—	DATAPRES field	370
Table 126	—	RESPONSE DATA field	371
Table 127	—	RESPONSE CODE field	371
Table 128	—	Sequences of SSP frames	372
Table 129	—	Confirmations sent to the SCSI application layer if a frame transmission or reception error occurs	386
Table 130	—	ST_ITS state machine variables	387
Table 131	—	ST_ITS state machine arguments	387
Table 132	—	Messages sent to the ST_IFR state machine	389
Table 133	—	Transmission Complete messages for XFER_RDY frame verification failures	390
Table 134	—	Reception Complete messages for read DATA frame verification failures	394
Table 135	—	ST_T state machine timers	395
Table 136	—	Task Management Function Executed Service Response argument mapping to Service Response argument	400
Table 137	—	Confirmations sent to the SCSI application layer	401
Table 138	—	ST_TTS state machine variables	402
Table 139	—	ST_TTS state machine arguments	402
Table 140	—	Messages sent to the ST_TFR state machine	405
Table 141	—	Reception Complete message for write DATA frame verification failures	408
Table 142	—	Request argument to RESPONSE frame RESPONSE DATA field mapping	410
Table 143	—	SMP frame format	411
Table 144	—	SMP FRAME TYPE field	411
Table 145	—	SMP_REQUEST frame format	412
Table 146	—	SMP_RESPONSE frame format	412
Table 147	—	MT_IP timers	413
Table 148	—	SCSI architecture mapping	419
Table 149	—	Send SCSI Command transport protocol service arguments	420
Table 150	—	SCSI Command Received transport protocol service arguments	420
Table 151	—	Send Command Complete transport protocol service arguments	421
Table 152	—	Command Complete Received transport protocol service arguments	422
Table 153	—	Send Data-In transport protocol service arguments	423
Table 154	—	Data-In Delivered transport protocol service arguments	423
Table 155	—	Receive Data-Out transport protocol service arguments	424
Table 156	—	Data-Out Received transport protocol service arguments	424
Table 157	—	Terminate Data Transfer transport protocol service arguments	424
Table 158	—	Data Transfer Terminated transport protocol service arguments	425
Table 159	—	Send Task Management Request transport protocol service arguments	425
Table 160	—	Task Management Request Received transport protocol service arguments	426
Table 161	—	Task Management Function Executed transport protocol service arguments	427
Table 162	—	Received Task Management Function Executed transport protocol service arguments	428
Table 163	—	Delivery Result to additional sense code mapping	429
Table 164	—	SCSI transport protocol events	430
Table 165	—	Disconnect-Reconnect mode page for SSP	431
Table 166	—	Protocol-Specific Port mode page subpages	433
Table 167	—	Protocol-Specific Port mode page for SAS SSP - short format	433
Table 168	—	I_T NEXUS LOSS TIME field	434
Table 169	—	Protocol-Specific Port mode page for SAS SSP - Phy Control And Discover subpage	435

Table 170 —	SAS phy mode descriptor	436
Table 171 —	Protocol-Specific Logical Unit mode page subpages	437
Table 172 —	Protocol-Specific Logical Unit mode page for SAS SSP - short format	437
Table 173 —	Protocol-Specific Port log page for SAS	438
Table 174 —	Protocol-Specific Port log parameter for SAS	439
Table 175 —	Parameter control byte in the Protocol-Specific Port log parameter for SAS	439
Table 176 —	SAS phy log descriptor	440
Table 177 —	Protocol-Specific diagnostic page for SAS	441
Table 178 —	PHY TEST FUNCTION field	442
Table 179 —	PHY TEST PATTERN field	442
Table 180 —	PHY TEST PATTERN PHYSICAL LINK RATE field	443
Table 181 —	Device Identification VPD page identification descriptors for the SAS target port	448
Table 182 —	Device Identification VPD page identification descriptors for the SAS target device	449
Table 183 —	READY LED signal behavior	450
Table 184 —	SMP request frame format	451
Table 185 —	SMP functions (FUNCTION field)	452
Table 186 —	SMP response frame format	453
Table 187 —	FUNCTION RESULT field	454
Table 188 —	REPORT GENERAL request	456
Table 189 —	REPORT GENERAL response	457
Table 190 —	REPORT MANUFACTURER INFORMATION request	458
Table 191 —	REPORT MANUFACTURER INFORMATION response	459
Table 192 —	DISCOVER request	461
Table 193 —	DISCOVER response	461
Table 194 —	ATTACHED DEVICE TYPE field	462
Table 195 —	NEGOTIATED PHYSICAL LINK RATE field	463
Table 196 —	ATTACHED SATA PORT SELECTOR and ATTACHED SATA DEVICE bits	464
Table 197 —	PROGRAMMED MINIMUM PHYSICAL LINK RATE and PROGRAMMED MAXIMUM PHYSICAL LINK rate fields	466
Table 198 —	HARDWARE MINIMUM PHYSICAL LINK RATE and HARDWARE MAXIMUM PHYSICAL LINK RATE fields ..	466
Table 199 —	ROUTING ATTRIBUTE field	467
Table 200 —	REPORT PHY ERROR LOG request	467
Table 201 —	REPORT PHY ERROR LOG response	468
Table 202 —	REPORT PHY SATA request	469
Table 203 —	REPORT PHY SATA response	470
Table 204 —	REPORT ROUTE INFORMATION request	471
Table 205 —	REPORT ROUTE INFORMATION response	472
Table 206 —	CONFIGURE ROUTE INFORMATION request	473
Table 207 —	CONFIGURE ROUTE INFORMATION response	474
Table 208 —	PHY CONTROL request	475
Table 209 —	PHY OPERATION field	476
Table 210 —	PROGRAMMED MINIMUM PHYSICAL LINK RATE and PROGRAMMED MAXIMUM PHYSICAL LINK RATE fields	477
Table 211 —	PHY CONTROL response	478
Table 212 —	PHY TEST FUNCTION request	479
Table 213 —	PHY TEST FUNCTION field	480
Table 214 —	PHY TEST PATTERN PHYSICAL LINK RATE field	480
Table 215 —	PHY TEST FUNCTION response	481
Table A.1 —	JTPAT for RD+	482
Table A.2 —	JTPAT for RD-	483
Table A.3 —	JTPAT for RD+ and RD-	484
Table A.4 —	CJTPAT scrambled in an SSP DATA frame	485
Table D.1 —	CRC examples	511
Table E.1 —	Monte-Carlo simulation results	512
Table E.2 —	Hash results for simple SAS addresses	514
Table E.3 —	Hash results for realistic SAS addresses	515
Table E.4 —	Hash results for a walking ones pattern	516
Table E.5 —	Hash results for a walking zeros pattern	517
Table F.1 —	Scrambler examples	520
Table H.1 —	ALIGN and/or NOTIFY insertion rate examples	523

Table I.1 — Column descriptions for connection examples	525
Table J.1 — Primitives with Hamming distance of 8	542
Table K.1 — Requests from management application layer or link layer to phy layer	545
Table K.2 — Confirmations from phy layer to link layer	545
Table K.3 — Requests between link layer and port layer	545
Table K.4 — Confirmations between link layer and port layer	546
Table K.5 — Requests from management application layer to link layer	546
Table K.6 — Confirmations between link layer and port layer, link layer, or application layer	547
Table K.7 — Requests between link layer, port layer, and transport layer for SSP	547
Table K.8 — Confirmations from port layer to transport layer for SSP	547
Table K.9 — Confirmations between SL link layer, port layer, and SSP transport layer	548
Table K.10 — Confirmations between SSP link layer, port layer, and SSP transport layer	549
Table K.11 — Requests between SL/SMP link layer, port layer, and SMP transport layer	549
Table K.12 — Confirmations between link layer, port layer, and SMP transport layer	550
Table K.13 — Requests and responses from SCSI application layer to SSP transport layer	550
Table K.14 — Confirmations and indications from SSP transport layer to SCSI application layer	551
Table K.15 — Requests from management application layer to SMP transport layer	551
Table K.16 — Confirmations from SMP transport layer to management application layer	551
Table L.1 — C program files	552

Figures

	Page
Figure 1 — SCSI document relationships	31
Figure 2 — ATA document relationships	32
Figure 3 — Classes in class diagrams	60
Figure 4 — Association relationships in class diagrams	61
Figure 5 — Aggregation relationships in class diagrams	61
Figure 6 — Generalization relationships in class diagrams	62
Figure 7 — Dependency relationships in class diagrams	62
Figure 8 — Objects in object diagrams	63
Figure 9 — State machine conventions	64
Figure 10 — SAS domain class diagram	68
Figure 11 — Physical links and phys	69
Figure 12 — Phy class diagram	70
Figure 13 — Phy object diagram	71
Figure 14 — Ports (narrow ports and wide ports)	72
Figure 15 — Port class diagram	73
Figure 16 — Port object diagram	74
Figure 17 — SAS devices	75
Figure 18 — Expander device	76
Figure 19 — Expander device class diagram	77
Figure 20 — Domains	78
Figure 21 — SAS domain bridging to ATA domains	78
Figure 22 — SAS domains bridging to ATA domains with SATA port selectors	79
Figure 23 — Devices spanning SAS domains	80
Figure 24 — Edge expander device set	81
Figure 25 — Maximum expander device set topology	82
Figure 26 — Fanout expander device topology	83
Figure 27 — Edge expander device set to edge expander device set topology	84
Figure 28 — Potential pathways	85
Figure 29 — Multiple connections on wide ports	86
Figure 30 — State machines for SAS devices	90
Figure 31 — State machines for expander devices	91
Figure 32 — Transmit data path in a SAS phy	92
Figure 33 — SSP link, port, SSP transport and SCSI application layer state machines	93
Figure 34 — SMP link, port, SMP transport and management application layer state machines	94
Figure 35 — STP link, port, STP transport and ATA application layer state machines	95
Figure 36 — Transmit data path and state machines in an expander phy	96
Figure 37 — Receive data path in a SAS phy	97
Figure 38 — Receive data path in an expander phy	98
Figure 39 — State machines and SAS device, SAS port and SAS phy classes	99
Figure 40 — State machine and expander device, expander port and expander phy classes	100
Figure 41 — Reset terminology	101
Figure 42 — Expander device model	103
Figure 43 — Expander device interfaces	105
Figure 44 — Expander device interface detail	106
Figure 45 — Expander route table example	112
Figure 46 — Level-order traversal example	113
Figure 47 — Examples of invalid topologies	115
Figure 48 — Expander route index levels example	117
Figure 49 — Expander route index levels example with fanout expander device	118
Figure 50 — Expander route index order example	120
Figure 51 — SATA connectors and cables	122
Figure 52 — SAS Drive cable environments	123
Figure 53 — SAS Drive backplane environment	123
Figure 54 — SAS external cable environment	124
Figure 55 — SAS internal symmetric cable environment - controller to backplane	124
Figure 56 — SAS internal symmetric cable environment - controller to controller	124
Figure 57 — SAS internal controller-based fanout cable environment	125
Figure 58 — SAS internal backplane-based fanout cable environment	125

Figure 59 —	SAS Drive plug connector	127
Figure 60 —	Single-port SAS Drive cable receptacle connector	127
Figure 61 —	Dual-port SAS Drive cable receptacle connector	128
Figure 62 —	SAS Drive backplane receptacle connector	128
Figure 63 —	SAS 4i cable receptacle connector	130
Figure 64 —	SAS 4i plug connector	130
Figure 65 —	Mini SAS 4i cable plug connector	133
Figure 66 —	Mini SAS 4i receptacle connector	133
Figure 67 —	SAS 4x cable plug connector	136
Figure 68 —	SAS 4x receptacle connector	137
Figure 69 —	Mini SAS 4x cable plug connector	139
Figure 70 —	Mini SAS 4x cable plug connector that attaches to an enclosure out port	140
Figure 71 —	Mini SAS 4x cable plug connector that attaches to an enclosure in port	140
Figure 72 —	Mini SAS 4x receptacle connector	141
Figure 73 —	Mini SAS 4x receptacle connector - end device	142
Figure 74 —	Mini SAS 4x receptacle connector - enclosure out port	142
Figure 75 —	Mini SAS 4x receptacle connector - enclosure in port	142
Figure 76 —	Single-port SAS Drive cable assembly	144
Figure 77 —	Dual-port SAS Drive cable assembly	144
Figure 78 —	SAS internal symmetric cable assembly - SAS 4i	145
Figure 79 —	SAS internal symmetric cable assembly - Mini SAS 4i	146
Figure 80 —	SAS internal symmetric cable assembly - SAS 4i to Mini SAS 4i	147
Figure 81 —	SAS internal controller-based fanout cable assembly - SAS 4i	149
Figure 82 —	SAS internal controller-based fanout cable assembly - Mini SAS 4i	150
Figure 83 —	SAS internal backplane-based fanout cable assembly - SAS 4i	151
Figure 84 —	SAS internal backplane-based fanout cable assembly - Mini SAS 4i	152
Figure 85 —	SAS external cable assembly - SAS 4x	153
Figure 86 —	SAS external cable assembly - Mini SAS 4x	154
Figure 87 —	SAS external cable assembly with Mini SAS 4x cable plug connectors	155
Figure 88 —	SAS external cable assembly - SAS 4x to Mini SAS 4x	156
Figure 89 —	SAS 4x and Mini SAS 4x cable assembly CT and CR compliance points	163
Figure 90 —	Backplane IT and IR compliance points	164
Figure 91 —	Backplane compliance points with SATA phy attached	165
Figure 92 —	SAS 4i and Mini SAS 4i cable assembly IT and IR compliance points	166
Figure 93 —	SAS 4i and Mini SAS 4i cable and backplane IT and IR compliance points	167
Figure 94 —	Internal cable and backplane IT and IR compliance points with SATA device attached	168
Figure 95 —	Internal cable IT and IR compliance points	169
Figure 96 —	Zero-length test load for transmitter device compliance point	170
Figure 97 —	Zero-length test load for receiver device compliance point	170
Figure 98 —	TCTF test load	171
Figure 99 —	TCTF test load S_{DD21} and ISI loss requirements at 3,0 Gbit/s	172
Figure 100 —	TCTF test load S_{DD21} and ISI loss requirements at 1,5 Gbit/s	173
Figure 101 —	Low-loss TCTF test load	173
Figure 102 —	Low-loss TCTF test load S_{DD21} and ISI loss requirements at 3,0 Gbit/s	174
Figure 103 —	Transmitter device transient test circuit	177
Figure 104 —	Receiver device transient test circuit	177
Figure 105 —	Transmitter device eye mask	178
Figure 106 —	Receiver device eye mask	178
Figure 107 —	Deriving a receiver device jitter tolerance eye mask	179
Figure 108 —	Applied sinusoidal jitter	180
Figure 109 —	SAS bit transmission logic	198
Figure 110 —	SAS bit reception logic	199
Figure 111 —	OOB signal transmission	201
Figure 112 —	OOB signal detection	203
Figure 113 —	SATA port selection signal	204
Figure 114 —	SATA OOB sequence	205
Figure 115 —	SATA speed negotiation sequence	205
Figure 116 —	SAS to SATA OOB sequence	207
Figure 117 —	SAS to SAS OOB sequence	208
Figure 118 —	SAS speed negotiation window	209

Figure 119	— SAS speed negotiation sequence (phy A: G1, G2, G3, phy B: G2 only)	211
Figure 120	— SAS speed negotiation sequence - phy reset problem	212
Figure 121	— Hot-plug and the phy reset sequence	213
Figure 122	— SP (phy layer) state machine - OOB sequence states	216
Figure 123	— SP (phy layer) state machine - SAS speed negotiation states	221
Figure 124	— SP (phy layer) state machine - SATA host emulation states	226
Figure 125	— SP (phy layer) state machine – SATA port selector state	229
Figure 126	— SP (phy layer) state machine - SATA spinup hold state	230
Figure 127	— SP_DWS (phy layer dword synchronization) state machine	232
Figure 128	— Transmitting a repeated primitive sequence	245
Figure 129	— Receiving a repeated primitive sequence	246
Figure 130	— Triple primitive sequence	247
Figure 131	— Redundant primitive sequence	248
Figure 132	— Elasticity buffers	257
Figure 133	— Address frame, SSP frame and SMP frame CRC bit ordering	260
Figure 134	— STP frame CRC bit ordering	261
Figure 135	— Transmit path bit ordering	263
Figure 136	— Receive path bit ordering	264
Figure 137	— STP transmit path bit ordering	265
Figure 138	— STP receive path bit ordering	266
Figure 139	— Address frame transmission	266
Figure 140	— SL_IR (link layer identification and hard reset) state machines	274
Figure 141	— Aborting a connection request with BREAK	286
Figure 142	— Connection request timeout example	287
Figure 143	— Closing a connection example	288
Figure 144	— Rate matching example	290
Figure 145	— SL (link layer for SAS phys) state machines (part 1)	292
Figure 146	— SL (link layer for SAS phys) state machines (part 2)	293
Figure 147	— XL (link layer for expander phys) state machine (part 1)	302
Figure 148	— XL (link layer for expander phys) state machine (part 2)	303
Figure 149	— XL (link layer for expander phys) state machine (part 3)	304
Figure 150	— SSP frame transmission	314
Figure 151	— Interlocked frames	316
Figure 152	— Non-interlocked frames with the same tag	316
Figure 153	— Non-interlocked frames with different tags	317
Figure 154	— Closing an SSP connection example	318
Figure 155	— SSP (link layer for SSP phys) state machines (part 1 - frame transmission)	320
Figure 156	— SSP (link layer for SSP phys) state machines (part 2 - frame reception)	321
Figure 157	— STP frame transmission	328
Figure 158	— STP flow control	331
Figure 159	— Transmitting a continued primitive sequence	332
Figure 160	— Receiving a continued primitive sequence	332
Figure 161	— STP initiator port opening an STP connection	335
Figure 162	— STP target port opening an STP connection	336
Figure 163	— SMP frame transmission	337
Figure 164	— SMP_IP (link layer for SMP initiator phys) state machine	339
Figure 165	— SMP_TP (link layer for SMP target phys) state machine	341
Figure 166	— Port layer examples	344
Figure 167	— PL_OC (port layer overall control) state machine	346
Figure 168	— PL_PM (port layer phy manager) state machine (part 1)	355
Figure 169	— PL_PM (port layer phy manager) state machine (part 2)	356
Figure 170	— Task management function sequence of SSP frames	372
Figure 171	— Non-data command sequence of SSP frames	373
Figure 172	— Write command sequence of SSP frames	373
Figure 173	— Read command sequence of SSP frames	374
Figure 174	— Bidirectional command sequence of SSP frames	374
Figure 175	— ST_I (transport layer for SSP initiator ports) state machines	382
Figure 176	— ST_T (transport layer for SSP target ports) state machines	396
Figure 177	— Sequence of SMP frames	413
Figure 178	— MT_IP (transport layer for SMP initiator ports) state machine	414

Figure 179 — MT_TP (transport layer for SMP target ports) state machine	416
Figure 180 — SA_PC (SCSI application layer power condition) state machine for SAS	444
Figure B.1 — A simple physical link	489
Figure B.2 — Transmitter device details	490
Figure B.3 — Receiver device details	491
Figure B.4 — De-embedding of connectors in test fixtures	493
Figure B.5 — Measurement conditions for signal output at the transmitter device	494
Figure B.6 — Transmitter device signal output measurement test fixture details	494
Figure B.7 — Measurement conditions for signal tolerance at the transmitter device	495
Figure B.8 — Calibration of test fixture for signal tolerance at the transmitter device	495
Figure B.9 — Measurement conditions for signal output at the receiver device	495
Figure B.10 — Measurement conditions for signal tolerance at the receiver device	496
Figure B.11 — Calibration of test fixture for signal tolerance at the receiver device	496
Figure B.12 — S-parameter port naming conventions	497
Figure B.13 — Four single-ended port or two differential port element	498
Figure B.14 — S-parameters for single-ended and differential systems	498
Figure B.15 — Measurement conditions for upstream return loss at the transmitter device connector	499
Figure B.16 — Measurement conditions for downstream return loss at the receiver device connector	500
Figure B.17 — Measurement conditions for downstream return loss at IT or CT	501
Figure B.18 — Measurement conditions for upstream return loss at IR or CR	502
Figure C.1 — SAS speed negotiation sequence (phy A: G1 only, phy B: G1 only)	503
Figure C.2 — SAS speed negotiation sequence (phy A: G1, G2, phy B: G1, G2)	504
Figure C.3 — SAS speed negotiation sequence (phy A: G1, G2, G3, phy B: G1, G2)	505
Figure C.4 — SAS speed negotiation sequence (phy A: G2, G3, phy B: G1, G2)	506
Figure C.5 — SAS speed negotiation sequence (phy A: G1 only, phy B: G2 only)	507
Figure D.1 — CRC generator example	508
Figure D.2 — CRC checker example	508
Figure E.1 — BCH(69, 39, 9) code generator	513
Figure F.1 — Scrambler	518
Figure I.1 — Example topology	524
Figure I.2 — Connection request - OPEN_ACCEPT	526
Figure I.3 — Connection request - OPEN_REJECT by end device	527
Figure I.4 — Connection request - OPEN_REJECT by expander device	528
Figure I.5 — Connection request - arbitration lost	529
Figure I.6 — Connection request - backoff and retry	530
Figure I.7 — Connection request - backoff and reverse path	531
Figure I.8 — Connection close - single step	532
Figure I.9 — Connection close - simultaneous	533
Figure I.10 — BREAK handling during path arbitration	534
Figure I.11 — BREAK handling during a connection	535
Figure I.12 — STP connection - originated by STP initiator port	536
Figure I.13 — STP connection - originated by STP target port in an STP/SATA bridge	537
Figure I.14 — STP connection close - originated by STP initiator port	538
Figure I.15 — STP connection close - originated by STP target port in an STP/SATA bridge	539
Figure I.16 — XL1:Request_Path to XL5:Forward_Open transition	540
Figure I.17 — Partial pathway recovery	541
Figure M.1 — SAS icon	588