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IEEE 1394 Single-mode Fiber PMD Specification

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Abstract

This document specifies an IEEE 1394 single-mode fiber PMD sublayer that supports baseband operation over single-mode optical fiber..

Keywords

IEEE 1394, Serial Bus, single-mode fiber, SMF PMD

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Contents

Annexes

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IEEE Std 1394-2008, Standard for a High Performance Serial Bus

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Foreword (This foreword is not part of 1394 Trade Association Specification 2008004)

This document specifies an IEEE 1394 single-mode fiber PMD sublayer that supports baseband operation over single-mode optical fiber.

There are 3 annexes in this specification. Annex B is normative and part of this specification. Annexes A and C are informative and are not considered part of this specification.
This specification was accepted by the Board of Directors of the 1394 Trade Association. Board of
Directors acceptance of this specification does not necessarily imply that all board members voted for acceptance. At the time it accepted this specification, the 1394 Trade Association. Board of Directors had the following members:

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Revision 0.5 (Oct. 22, 2008) – removed multimode fiber section and changed name from IEEE 1394 Enhanced Glass Optical Fiber PMD Specification to IEEE 1394 Single-mode Fiber PMD Specification

Revision 0.6 (Nov. 18, 2008) – incorporated comments from Si WG ballot.

Revision 0.7 (Jan. 16, 2009) – incorporated comments from SIG ballot

IEEE 1394 Single-mode Fiber PMD Specification

1 Scope and purpose

1.1 Scope

This document specifies an IEEE 1394 single-mode fiber PMD sublayer that supports baseband operation over single-mode optical fiber.

1.2 Purpose

IEEE 1394 supports a variety of transmission media, including multimode glass fiber (MMF). Single-mode fiber has a much higher bandwidth-distance product and is less expensive than multimode fiber. Recent developments in transceiver technology (such as CMOS photonics) have made single-mode transceivers much more cost-effective as well.

This document defines an IEEE 1394 single-mode fiber PMD sublayer which supports operation at data rates of S800 and greater on single-mode optical fiber over multi-kilometer distances.

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2 Normative references

2.1 Reference scope

The specifications and standards named in this section contain provisions, which, through reference in this text, constitute provisions of this 1394 Trade Association Specification. At the time of publication, the editions indicated were valid. All specifications and standards are subject to revision; parties to agreements based on this 1394 Trade Association Specification are encouraged to investigate the possibility of applying the most recent editions of the specifications and standards indicated below.

2.2 Approved references

The following approved specifications and standards may be obtained from the organizations that control them.

– IEEE Std 1394-2008, Standard for a High Performance Serial Bus

Throughout this document, the term “IEEE 1394" shall be understood to refer to IEEE Std 1394-2008.

2.3 References under development

At the time of publication, the following referenced specifications and standards were under development.

– N/A

2.4 Reference acquisition

The references cited may be obtained from the organizations that control them:

1394 Trade Association, 315 Lincoln, Suite E, Mukilteo, WA 98275 USA; (425) 514-8454 / (425) 710-9971 (FAX); http://www.1394ta.org/

American National Standards Institute (ANSI), 11 West 42nd Street, New York, NY 10036, USA; (212) 642-4900 / (212) 398-0023 (FAX); http://www.ansi.org/

Institute of Electrical and Electronic Engineers (IEEE), 445 Hoes Lane, PO Box 1331, Piscataway, NJ 08855-1331, USA; (732) 981-0060 / (732) 981-1721 (FAX); http://www.ieee.org/

In addition, many of the documents controlled by the above organizations may also be ordered through a third party:

Global Engineering Documents, 15 Inverness Way, Englewood, CO 80112-5776; (800) 624-3974 / (303) 792-2192; http://www.global.ihs.com/

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3 Definitions and notation

3.1 Definitions

3.1.1 Conformance

Several keywords are used to differentiate levels of requirements and optionality, as follows:

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

3.1.1.2 ignored: A keyword that describes bits, bytes, quadlets, octlets or fields whose values are not checked by the recipient.

3.1.1.3 may: A keyword that indicates flexibility of choice with no implied preference.

3.1.1.4 reserved: A keyword used to describe objects (bits, bytes, quadlets, octlets and fields) or the code values assigned to these objects in cases where either the object or the code value is set aside for future standardization. Usage and interpretation may be specified by future extensions to this or other specifications. A reserved object shall be zeroed or, upon development of a future specification, set to a value specified by such a specification. The recipient of a reserved object shall ignore its value. The recipient of an object defined by this specification as other than reserved shall inspect its value and reject reserved code values.

3.1.1.5 shall: A keyword that indicates a mandatory requirement. Designers are required to implement all such mandatory requirements to assure interoperability with other products conforming to this specification.

3.1.1.6 should: A keyword that denotes flexibility of choice with a strongly preferred alternative. Equivalent to the phrase “is recommended.”

3.1.2 Glossary

The following terms are used in this specification:

3.1.2.1 Optical modulation amplitude: The difference in optical power between logic 1 and logic 0 levels.

3.1.2.2 Relative intensity noise: The ratio of the variance in the optical power to the average optical power.

3.1.3 Abbreviations

The following are abbreviations that are used in this specification:

CSR	Control and status register [B1]
DJ	Deterministic jitter
MDI	Medium dependent interface
MMF	Multimode fiber
OMA	Optical modulation amplitude
PMD	Physical media dependent

RIN	Relative intensity noise
RJ	Random jitter
SJ	Sinusoidal jitter
SMF	Single-mode fiber
TJ	Total jitter
VCSEL	Vertical cavity surface-emitting laser

4 Overview – Applications of single-mode fiber (SMF)

IEEE 1394 supports a wide variety of long-haul transmission media, including UTP, coaxial cable, multimode fiber (MMF) and plastic optical fiber (POF). However, it has never specified a physical layer for single-mode fiber (SMF).

SMF has a distance-bandwidth product that is unmatched by any other transmission media. Recent advances in transceiver technology (such as CMOS photonics, etc.) have made fiber optics much more cost-effective.

Data rates supported by IEEE 1394 have increased from the original S400 to S800 and S1600 with 1394b and soon to S3200 with 1394-2008. The ability to support these (and higher) data rates at long distances makes SMF an excellent addition to IEEE 1394 networks.

Applications which can benefit from the distance and bandwidth of SMF include:

- Security systems and high-resolution wide-area surveillance
- Medical imaging
- Broadcast content development, editing and transport
- Military
- Campus backbone
- Manufacturing – machine vision and control
- Digital signage
- Projection systems

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5 Single-mode optical fiber PMD specification

5.1 Introduction

This clause specifies the optical signaling properties for an alternate PHY. The focus is on long wavelength lasers and single-mode fibers for long-haul distances. The specification covers optical connections operating at S800, S1600, and S3200 data rates.

Figure 1 shows the relationship of this clause to the PHY master architecture. For system conformance, the PMD sublayer is standardized at the following points:

– The optical transmit signal is defined at the output end of a 5 m or less patch cord (i.e., TP2) connected to the transmitter receptacle defined in 5.9.

– The optical receive signal is defined at the output of the cable plant (i.e., TP3) connected to the receiver receptacle also defined in 5.9.

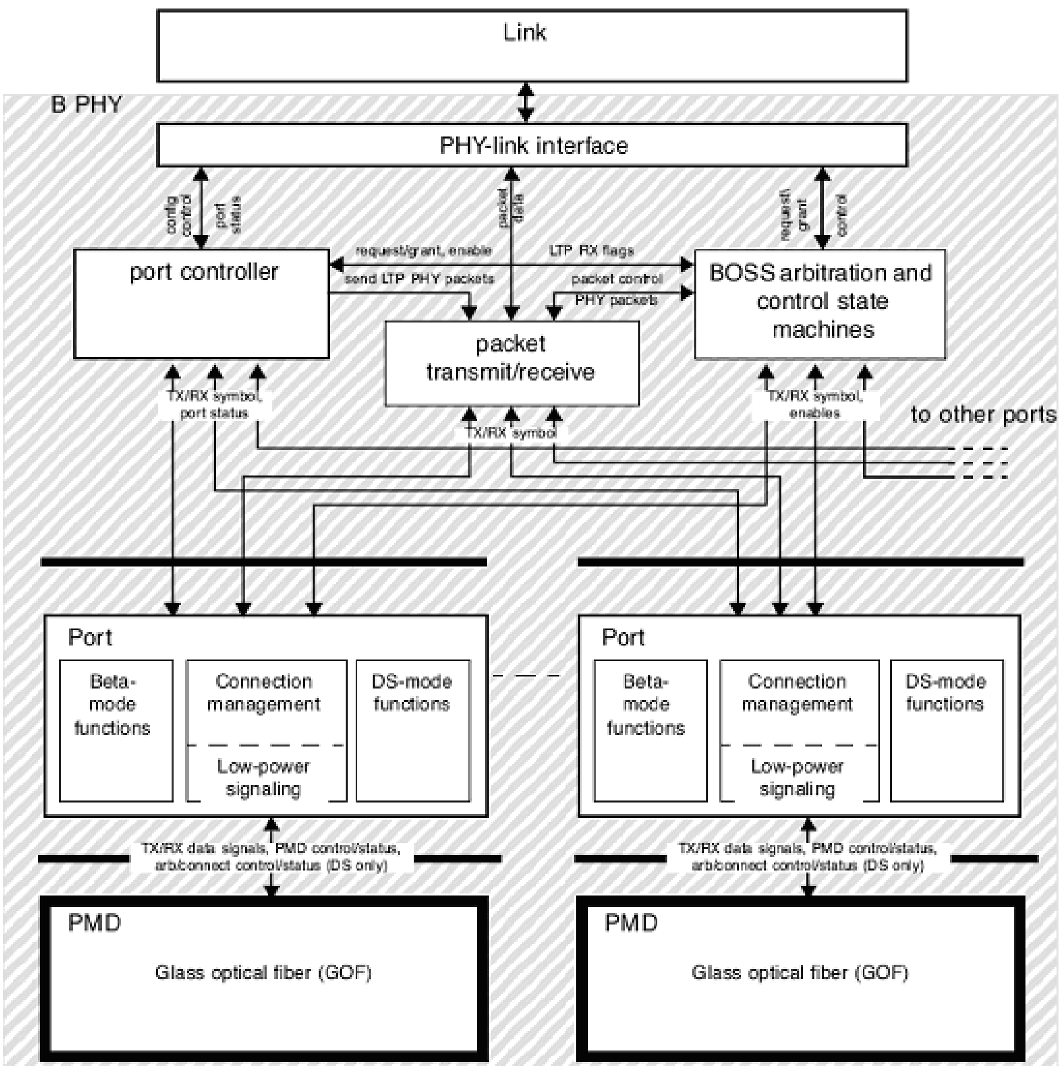

Figure 1 -- PHY master architecture (GOF PMD in context) (reprinted from [B2])

TP1 and TP4 are standardized reference points for use by implementers to certify component conformance, as illustrated in Figure 2. The electrical specifications of the PMD service interface (i.e., TP1 and TP4) are not system compliance points (as they may not be readily testable in a system implementation).

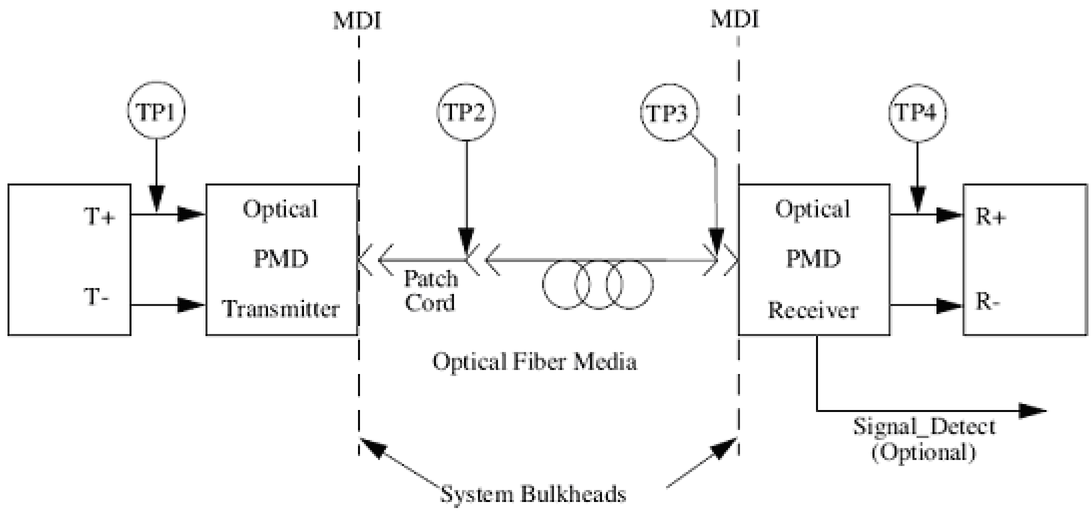

Figure 2 -- PMD block diagram (reprinted from [B2])

5.2 Operating range

The operating range is defined in Table 1. A compliant transceiver is capable of supporting the SMF media type listed in Table 1 according to the specifications defined in this subclause. A transceiver that exceeds the operational range requirement while meeting all other optical specifications is considered compliant.

Data Rate	Range	Units
S800B	2000	m
S1600B	2000	m
S3200B	2000	m

Table 1 -- Operating range for single-mode fiber (SMF)

5.3 Transmitter optical specifications

The optical transmitter shall meet the specifications defined in Table 2 per measurement techniques defined in IEEE 802.3 [B8] section 52.9 (Optical measurement requirements).

It shall also meet a transmit mask of the eye measurement as defined in 5.7.5.

Description	Min	Max	unit	Notes
Signaling speed (nominal)	1	10.8	GBd	
Center wavelength range	1485	1500	nm	
Side Mode Suppression Ratio	30		dB	
Average launch power	-5.5	-3	dBm	
Average launch power of off transmitter (max)		-30	dBm	
Optical Modulation Amplitude	-6	-3.5	dBm	
Extinction ratio (min)	3		dB	
RIN12 OMA (max)		-130	dB/Hz	
Optical Return Loss tolerance (max)		12	dB	
Transmitter eye mask definition, {X1, X2, X3, Y1, Y2, Y3}		{0.25, 0.40, 0.45, 0.25, 0.28, 0.40}		As per clause 52.9 of [B8].
Link distance		2000	m	

Table 2 -- Optical transmit characteristics

5.4 Receiver optical specifications

The optical receiver shall meet the specifications defined in Table 3 per measurement techniques defined in IEEE 802.3-2005 [B8] section 52.9 (Optical measurement requirements). (These specifications are defined at TP3 as shown in Figure 2.)

An interface receiver shall operate with a BER not to exceed 10^{-12} (1 bit error in 10^{12} bits) when presented with a transmitter signal as specified in Clause 5.3 transmitted via a fiber connection compliant with the system budget specified in this clause.

Note: These specifications are intended to be met over 0-70° C temperature range.

Description	Min	Max	unit	Notes
Signaling speed	1	10.8	GBd	
Center wavelength	1485	1500	Nm	
Received power	-9.5	-3	dBm	
Receiver reflectance		12	dB	
Stressed receiver sensitivity , OMA		-10	dBm	
Vertical eye closure penalty	3		dB	Condition for stressed RX sensitivity measurement. Measurement is done as per clause 52.9 of [B8].
Stressed eye jitter	0.3		UI	Condition for stressed Rx sensitivity measurement. Measurement is done as per as per clause 52.9 of [B8].

Table 3 -- Optical receive characteristics

Receive conditions	Signal_detect value
Input optical power < -18dBm	Negated
Input_optical_power > specified receiver sensivity	Asserted
All other conditions	Unspecified

Table 4 -- Optical signal_detect thresholds

5.5 Worst-case connection optical power budget and penalties

The recommended worst-case power budget and connection penalties for a connection are shown in Table 5.

Description	Min	Max	Units	Notes
Distance	.5	2000	M	
Channel insertion loss	0	4	dB	Measured at nominal operating wavelength
Fiber type		SM		Per IEC 60793-2

Table 5 – Recommended optical power budget

5.6 Optical jitter specifications

Numbers in Table 7 through Table 12 represent high-frequency jitter, i.e., jitter frequency components above the corner frequencies in Table 6, and do not include low-frequency jitter or wander. Transmitters and receivers shall meet the normative values highlighted in **red boldface underscored type**. All other values are recommended. Jitter shall be measured as defined in Annex N of [B2].

Speed	Corner Frequency	Units
S800B	590	KHz
S1600B	1.179	MHz
S3200B	2.3	MHz

Table 6 -- High frequency jitter corner frequency

Jitter output	ps				UI			
Compliance point	DJ Pk-pk	RJ rms	RJ Pk-pk	TJ Pk-pk	DJ Pk-pk	RJ rms	RJ Pk-pk	TJ Pk-pk
TP1	102	8.70	122	224	0.10	0.009	0.12	0.22
TP1 to TP2	112	13.40	118	300	0.11	0.013	0.18	0.29
TP2	**214**	15.97	224	**438**	**0.21**	0.016	0.22	**0.43**
TP2 to TP3	31	4.46	62	93	0.03	0.004	0.06	0.09
TP3	244	16.58	232	476	0.24	0.016	0.23	0.47
TP3 to TP4	173	5.09	71	244	0.17	0.005	0.07	0.24
TP4	417	17.29	242	659	0.41	0.017	0.24	0.65

Table 7 -- S800B SMF jitter output

Jitter tolerance	ps					UI				
Compliance point	DJ Pk-pk	RJ rms	RJ Pk-pk	SJ Pk-pk	TJ Pk-pk	DJ Pk-pk	RJ rms	RJ Pk-pk	SJ Pk-pk	TJ Pk-pk
TP1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TP2	214	15.97	224	102	489	0.21	0.016	0.220	0.1	0.48
TP3	**244**	16.58	232	**102**	**527**	**0.24**	0.016	0.228	**0.1**	**0.52**
TP4	417	17.29	242	102	710	0.41	0.017	0.238	0.1	0.70

Table 8 -- S800B SMF jitter tolerance

The applied SJ shall be swept at a frequency of 637 KHz

Jitter output	ps				UI			
Compliance point	DJ Pk-pk	RJ rms	RJ Pk-pk	TJ Pk-pk	DJ Pk-pk	RJ rms	RJ Pk-pk	TJ Pk-pk
TP1	66	4.32	61	127	0.13	0.009	0.12	0.25
TP1 to TP2	66	5.09	71	137	0.13	0.010	0.14	0.27
TP2	**132**	6.68	92	**224**	**0.26**	0.013	0.18	**0.44**
TP2 to TP3	15	1.53	20	36	0.03	0.003	0.04	0.07
TP3	148	6.87	97	244	0.29	0.014	0.19	0.48
TP3 to TP4	56	6.10	86	142	0.11	0.012	0.17	0.28
TP4	203	9.16	127	331	0.40	0.018	0.25	0.65

Table 9 -- S1600B SMF jitter output

Jitter tolerance	ps					UI				
Compliance point	DJ Pk-pk	RJ rms	RJ Pk-pk	SJ Pk-pk	TJ Pk-pk	DJ Pk-pk	RJ rms	RJ Pk-pk	SJ Pk-pk	TJ Pk-pk
TP1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TP2	132	6.68	92	51	249	0.26	0.013	0.180	0.1	0.49
TP3	**148**	6.87	97	**51**	**270**	**0.29**	0.014	0.190	**0.1**	**0.53**
TP4	203	9.16	127	51	356	0.40	0.018	0.250	0.1	0.70

Table 10 -- S1600B SMF jitter tolerance

Jitter output	ps				UI			
Compliance point	DJ Pk-pk	RJ rms	RJ Pk-pk	TJ Pk-pk	DJ Pk-pk	RJ rms	RJ Pk-pk	TJ Pk-pk
TP1	33	2.2	30	63	0.16	0.08	0.11	0.27
TP1 to TP2	33	2.5	35.5	68.5	0.10	0.005	0.07	0.17
TP2	66	3.34	9.46	112	0.26	0.013	0.18	0.44
TP2 to TP3	7.5	.76	10	18	0.03	0.003	0.04	0.07
TP3	74	3.43	48	122	0.28	0.014	0.19	0.47
TP3 to TP4	28	3.05	43	71	0.10	0.007	0.10	0.20
TP4	102	4.58	63	165	0.42	0.018	0.25	0.67

Table 11 -- S3200B SMF jitter output

Jitter tolerance	ps					UI				
Compliance point	DJ Pk-pk	RJ rms	RJ Pk-pk	SJ Pk-pk	TJ Pk-pk	DJ Pk-pk	RJ rms	RJ Pk-pk	SJ Pk-pk	TJ Pk-pk
TP1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TP2	66	3.34	46	25	125	0.26	0.013	0.180	0.1	0.49
TP3	74	3.43	48	25	135	0.29	0.014	0.190	0.1	0.53
TP4	102	4.58	63	25	178	0.40	0.018	0.250	0.1	0.70

Table 12 -- S3200B SMF jitter tolerance

5.7 Optical measurement requirements

All optical measurements shall be made through a short patch cable, between 2 m and 5 m long.

5.7.1 Center wavelength and spectral width measurements

The center wavelength and spectral width (RMS) shall be measured using an optical spectrum analyzer per ANSI/TIA/EIA-455-127-91 [B4]. Spectral width shall be measured under modulated conditions using a valid encoded 8B/10B pattern under full power conditions across nominal operating temperatures.

5.7.2 Optical power measurements

Optical power shall be measured using the methods specified in ANSI/TIA/EIA-455-95A-00 [B3]. This measurement may be made with the node transmitting any valid 8B/10B data stream.

5.7.3 Extinction ratio measurements

Extinction ratio shall be measured using the methods specified in ANSI/TIA/EIA-526-14A-98 [B5]. This measurement may be made with the node transmitting a repeating K28.7 data pattern. The extinction ratio is measured under fully modulated conditions with worst-case reflections.

NOTE—K28.7 generates a 100 MHZ, 200 MHz or 400 MHz square wave, depending on whether connection is operating at S800B, S1600B or S3200B.

5.7.4 Relative intensity noise (RIN)

RIN shall be measured according to A.5 of ANSI X3.230-1994 [B6]. According to that subclause, “this procedure describes a component test which may not be appropriate for a system level test depending on the implementation.”

5.7.5 Transmitter optical waveform (transmit eye)

The required transmitter pulse shape characteristics are specified in the form of a mask of the transmitter eye diagram as shown in Figure 3. The transmit mask is not used for response time and jitter specification.

Normalized amplitudes of 0.0 and 1.0 represent the amplitudes of logic 0 and 1, respectively.

The eye shall be measured with respect to the mask of the eye using a fourth-order Bessel-Thompson filter with a transfer function given by:

$$Hp = \frac{105}{105 + 105y + 45y^2 + 10y^3 + y^4}$$

Where:

$$y = 2.114p$$

$$p = \frac{j\omega}{\omega_r}$$

$$\omega_r = 2\pi f_r$$

$$f_r = 1.500GHz$$

and where the filter response versus frequency range for this fourth-order Bessel-Thompson filter is defined in ITU-T G.957 [B1]9, along with the allowed tolerances for its physical implementation.

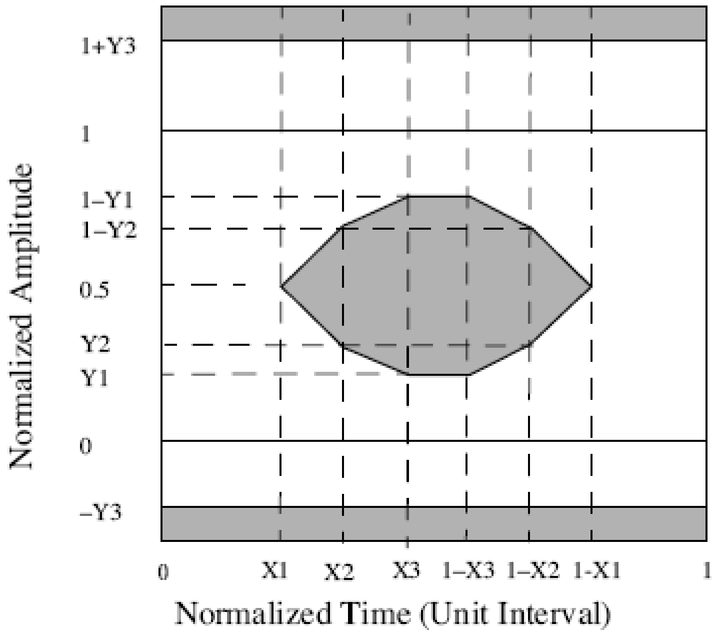

Figure 3 -- Transmitter eye mask diagram

NOTES

1—This Bessel-Thompson filter is not intended to represent the noise filter used within an optical receiver, but is intended to provide uniform measurement conditions at the transmitter.

2—The fourth-order Bessel-Thompson filter is reactive. To suppress reflections, a 6 dB attenuator may be required at the filter output.

5.7.6 Transmit rise and fall characteristics

Optical response time specifications are based on unfiltered waveforms. Some lasers have overshoot and ringing on the optical waveforms that, if unfiltered, compromise the accuracy of the measured 20%–80% response times. For standardizing the measurement method, measured waveforms shall conform to the mask defined in Figure 3. If a filter is needed to conform to the mask, the filter response should be removed using the equation:

$$T_{rise,\,fall} = \sqrt{\left(T_{rise,\,fall\_measured}\right)^2 - \left(T_{rise,\,fall\_filter}\right)^2}$$

where the filter may be different for rise and fall. Any filter should have an impulse response equivalent to a fourth-order Bessel-Thompson filter. The fourth-order Bessel-Thompson filter defined in 5.7.5 may be a convenient filter for this measurement; however, its low bandwidth adversely impacts the accuracy of the $T_{rise,fall}$ measurements.

5.7.7 Receiver sensitivity measurements

The receive sensitivity (minimum) is measured using a laser with a particular extinction ratio while sampling at the eye center. The sensitivity penalty due to the laser extinction ratio is removed before reporting receiver sensitivity.

5.7.8 Jitter measurements

Jitter shall be measured according to the methods in Annex 48B of [B8].

5.8 Optical connection cabling model

5.8.1 Characteristics of the fiber optic medium

The fiber cable plant shall meet the specifications defined in Table 13. The fiber optic medium consists of one or more sections of fiber optic cable, with any intermediate connectors required to connect sections together, terminated at each end in the optical connector plug. The fiber optic medium spans from one MDI to another MDI.

Description	Value	Units
Nominal fiber wavelength (Note a)	1550	nm
Recommended maximum fiber cable attenuation (Note b)	0.35	dB/km
Dispersion slope (Note c)	0.093	ps/nm^2km

Table 13 -- SMF Characteristics

Notes for Table 13:

a) The wavelength specified is the nominal fiber specification which is the typical measurement wavelength.
b) Attenuation is defined in ITU-T G.652 [B12].
c) See G.652 [B12] for correct use of dispersion slope

5.8.2 Single-mode connector insertion loss

The maximum connection distances for single-mode fiber (SMF) are calculated based on an allocation of 1.5 dB total connection loss. This allocation supports a minimum of three connections with an average insertion loss equal to 0.5 dB (or less) per connection or two connections (as shown in Figure 4) with a maximum insertion loss of 0.75 dB.

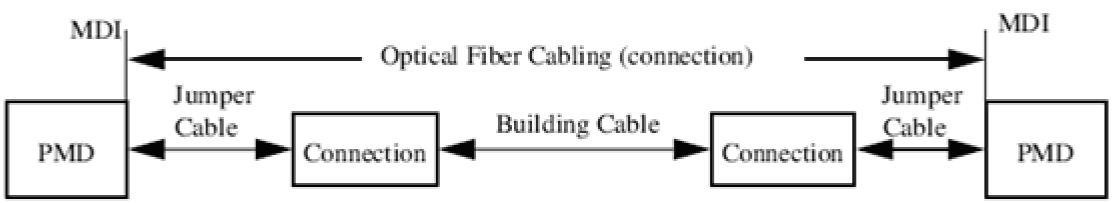

Figure 4 -- Optical fiber cabling model (reprinted from [B2])

5.8.3 Optical connection return loss

The return loss for single-mode connections shall be greater than 26 dB as measured by the methods of IEC 61300-2-6 [B13].

5.9 Optical connection

The optical connection (i.e., plug and receptacle) shall be the duplex LC, meeting the following requirements:

– Performance complies with ANSI/TIA/EIA-568B.3 [B10].

– The dimension and interface meet the specifications of TIA/EIA-604-10B FOCIS 10 [B11].
– Polarity shall be maintained.

Sample drawings of a duplex LC connection (receptacle and plug) are provided in Figure 5 and Figure 6, respectively.

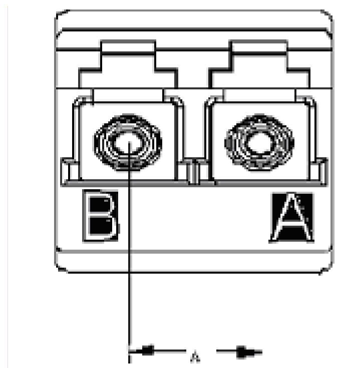

Figure 5 -- Duplex receptacle interface (reprinted from [B2])

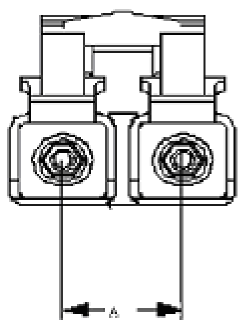

Figure 6 -- Duplex plug interface (reprinted from [B2])

NOTE – The LC connector is also specified by Clause 10 of IEEE 1394 [B2] for use with multimode fiber. To prevent inadvertent interconnection of single-mode and multimode equipment, it is recommended that the color code specified in Clause 6.2.3 of TIA-568C.3 [B10] be followed (black for 50-micron multimode plugs and receptacles and blue for single-mode plugs and receptacles.)

Annex A
(informative)

Link budget example

The losses in a typical optical link are shown in Figure 7.

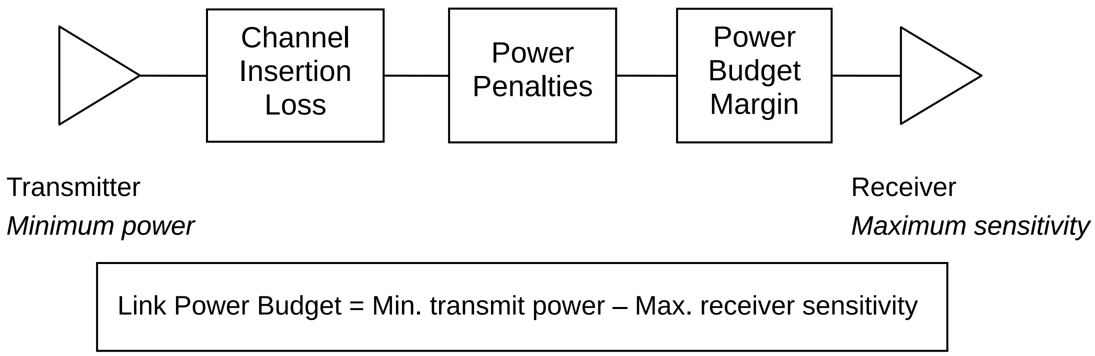

Figure 7 -- Losses in a typical fiber optic link

The channel insertion loss consists of cable loss and connector loss. The power penalty accounts for degradation in the signal due to dispersion properties of the channel.

A typical application of a 1394 fiber optic link consists of the connections shown in Figure 8.

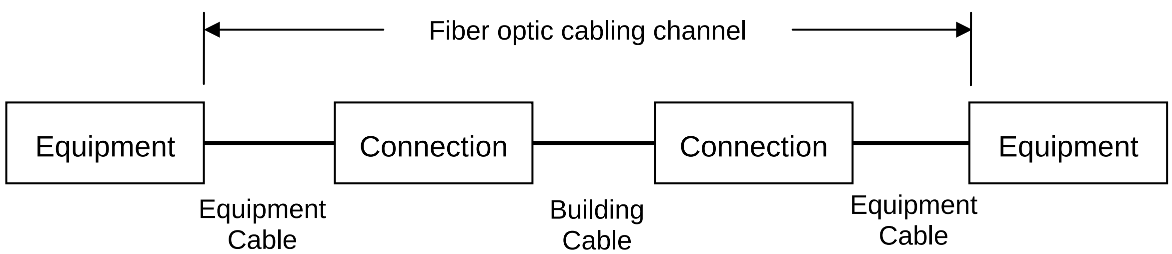

Figure 8 -- Typical connections and cabling for a 1394 optical link

The loss of each of these components of the typical fiber optic link is shown in Table 14.

Channel Loss element	Distance	Loss
Equipment Cable	300m	<.1 dB
Connector	NA	.2 to .5dB
Building Cable	1000m	.2 dB
Total	1600 m	.6 to 1.4 dB

Table 14 -- Typical loss budget of a 1394 optical link

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Annex B
(normative)

Compliance Requirements

This annex is intended to assist designers, implementers, and conformance test developers; it provides a concise summary of mandatory and optional features and, for each feature, reference to the governing normative clauses.

The conformance requirements for the SMF PMD are divided into two parts. The SMF cabling media shall comply with the requirements of Table 15.

Number	Description	Implementation	Reference
OF-1	Fiber attenuation	Mandatory	5.8.1
OF-2	Fiber dispersion slope	Mandatory	5.8.1
OF-3	Connector insertion loss	Mandatory	5.8.2
OF-4	Connector return loss	Mandatory	5.8.3

Table 15 -- SMF media requirements

The SMF PMD implementation shall comply with the requirements of Table 16. Note that clause 5.7 provides optical measurement requirements.

Number	Description	Implementation	Reference
SMF-1	Operating range	Mandatory	5.2
SMF-2	Transmitter optical specifications	Mandatory	5.3
SMF-3	Optical receive characteristics	Mandatory	5.4
SMF-4	Optical signal_detect thresholds	Mandatory	5.4
SMF-5	Optical power budget	Optional	5.5
SMF-6	Optical jitter specifications	Mandatory	5.6
SMF-7	Transmitter eye mask	Mandatory	5.7.5

Table 16 -- SMF PMD conformance requirements

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Annex C
(informative)

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