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SMPTE STANDARD

SMPTE 297M
Revision of
SMPTE 297M-2000

for Television —
Serial Digital Fiber Transmission System for SMPTE 259M, SMPTE 344M, SMPTE 292M and SMPTE 424M Signals

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Foreword

SMPTE (the Society of Motion Picture and Television Engineers) is an internationally recognized standards developing organization. Headquartered and incorporated in the United States of America, SMPTE has members in over 80 countries on six continents. SMPTE's Engineering Documents, including Standards, Recommended Practices and Engineering Guidelines, are prepared by SMPTE's Technology Committees. Participation in these Committees is open to all with a bona fide interest in their work. SMPTE cooperates closely with other standards-developing organizations, including ISO, IEC and ITU.

SMPTE Engineering Documents are drafted in accordance with the rules given in Part XIII of its Administrative Practices.

SMPTE Standard SMPTE 297M-2006 was prepared by Technology Committee N26

1 Scope

This standard defines an optical fiber system for transmitting bit-serial digital signals. It is intended for transmitting SMPTE 259M signals (143 through 360 Mb/s), SMPTE 344M signals (540Mb/s), SMPTE 292M signals (1.485 Gb/s and 1.485/1.001 Gb/s) and SMPTE 424M signals (2.970 Gb/s and 2.970/1.001 Gb/s).

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of the standards indicated below.

SMPTE 259M-2006, Television — SDTV Digital Signal/Data — Serial Digital Interface

SMPTE 292M-1998, Television — Bit-Serial Digital Interface for High-Definition Television Systems

SMPTE 344M-2000, Television — 540 Mb/s Serial Digital Interface

SMPTE 424M-2006, Television — 3 Gb/s Signal/Data Serial Interface

SMPTE EG 34-1999, Pathological Conditions in Serial Digital Video Systems

ANSI/EIA/TIA-492AAAA-A (2002), Detail Specification for 62.5 µm Core Diameter/125 µm Cladding Diameter Class Ia, Graded-Index Multimode Optical Fibers

ITU-T G.651 (1998), Characteristics of a 50/125 µm Multimode Graded Index Optical Fibre Cable

ITU-T Rec. G.652 (2006), Characteristics of a single-mode Optical Fibre Cable

IEC 60793-2 (2003-10), Optical fibres — Part 2: Product Specifications — General

IEC 60825-1 (2001-08), including Amendment 1, Safety of Laser Products, Equipment Classification Requirements, and User's Guide

IEC 61754-20 (2002-08), Fibre Optic Connector Interfaces — Part 20: Type LC Connector Family

IEC 60793-1-40 (2001-07), Measurement methods and test procedures — Attenuation

3 Optical transmission system specification (see Annex A for definitions of fiber terms)

3.1 Physical packaging and connectors of transmitter and receiver units

3.1.1 The preferred Tx and Rx unit optical domain connectors and their mating input and output cable sections shall be LC/PC as per IEC 61754-20-1.

Other application-specific connector types such as SC, ST, FC, MU, etc. may optionally be specified. The Tx / Rx unit or its product documentation shall indicate the connector type. Furthermore, the product documentation shall include detailed mechanical and optical specifications for the specified connector.

3.1.2 The preferred Tx and Rx unit optical domain connector polish shall be PC.

Other application-specific connector polishes such as SPC, UPC and APC may optionally be specified, provided the polish is clearly labeled as described in section 3.3 and 3.5 below. The Tx / Rx unit product documentation shall include detailed specifications for the required optical connector polish.

NOTE – While angle-polish connectors (i.e. APC) and flat-polish connectors (i.e. PC, SPC, and UPC) of the same type (e.g. LC) can be mechanically mated, they are not optically compatible. System designers and system installers are therefore advised to ensure compatibility of cable, connector type and polish throughout the installation.

3.1.3 A short pigtail of single-mode fiber as specified in ITU-T G.652 shall be used to connect the Tx unit light source to its output optical connector if the light source is not physically installed and connected in a receptacle (see Annex A.1).

A short pigtail of multimode 50/125 micron fiber as specified in ITU-T G.651 is acceptable if the Tx unit is intended exclusively for multimode link applications.

The Tx unit or its product documentation shall indicate which type of pigtail, if any, is installed.

3.1.4 A short pigtail of 62.5/125 micron multimode fiber specified in ANSI/EIA/TIA-492AAAA-A (2002) shall be used to connect the Rx unit optical receiver to its input optical connector if the receiver is not physically installed and connected in a receptacle (see Annex A.1).

The Rx unit or its product documentation shall indicate which type of pigtail, if any, is installed.

3.2 Transmitter unit

3.2.1 The transmitter unit shall produce an intensity-varying optical output signal in accordance with the relevant low-power (short-haul), medium-power (medium-haul) or high-power (long-haul) link parameters in table 1, when modulated by an electrical signal with specifications per SMPTE 259M, modulated by an electrical signal with specifications per SMPTE 344M, modulated by an electrical signal with specifications per SMPTE 292M or modulated by an electrical signal with specifications per SMPTE 424M.

NOTE – Devices compliant with this standard may be designed to accept one, all, or any combination of SMPTE 259M, SMPTE 344M, SMPTE 292M and SMPTE 424M input signals.

Refer to Informative Annex D for examples of maximum transmission distance performance for low-power (short-haul), medium-power (medium-haul) and high-power (long-haul) link applications compliant with this revision of SMPTE 297M.

Table 1 – Transmitter unit output signal specifications

	High-power (Long-haul) link	Medium-power (medium-haul) link	Low-power (short-haul) link	
Transmission circuit fiber [10]	SM (9.0/125 µm)	SM (9.0/125 µm)	SM (9.0/125 µm)	MM [1] (50.0/125 µm, 62.5/125 µm)
Light source type [8] [9]	Laser	Laser	Laser	Laser or LED [2] [3]
Optical wavelength	1310 nm ± 40 nm	1310 nm ± 40 nm	1310 nm ± 40 nm	1310 nm ± 40 nm
	1550 nm ± 40 nm	1550 nm ± 40 nm	1550 nm ± 40 nm	850 nm ± 30 nm
Maximum spectral line width between half-power points	<=1 nm	<=4 nm	<=10 nm	<=30 nm
Maximum Optical Power [4]	+10 dBm	0 dBm	-3 dBm	
Minimum Optical Power [4]	0 dBm	-3 dBm	-12 dBm	
Minimum Extinction ratio [5]	5:1 (10:1 preferred)			
Rise and fall times for SMPTE 259M [6]	As specified in SMPTE 259M for the electrical signal < 1.5 ns (20% to 80%)			
Rise and fall times for SMPTE 344M [6]	As specified in SMPTE 344M for the electrical signal < 0.80 ns (20% to 80%)			
Rise and fall times for SMPTE 292M [6]	As specified in SMPTE 292M for the electrical signal < 270 ps (20% to 80%)			
Rise and fall times for SMPTE 424M [6]	As specified in SMPTE 424M for the electrical signal < 135 ps (20% to 80%)			
Maximum Intrinsic jitter (optical)	As specified in SMPTE 259M, SMPTE 344M, SMPTE 292M or SMPTE 424M for the corresponding electrical signal			
Maximum Reflected power	-14 dB			
Electrical / optical transfer function	Logic "1" maximum intensity / Logic "0" minimum intensity			

NOTES:

[1] See ITU-T G.651 and ANSI/EIA/TIA-492AAAA-A for optional MM fiber type.

[2] LEDs may not function reliably at higher bit rates specified in SMPTE 259M, SMPTE 344M, SMPTE 292M or SMPTE 344M.

[3] Tx units intended solely for multimode transmission link applications shall be so marked.

[4] Power is average power measured with an average-reading power meter.

[5] Is the ratio between the maximum and minimum output power of the transmitter.

[6] Rise/fall times are measured following a fourth-order Bessel-Thompson filter with a 3 dB point at 0.75 x data rate in MHz; i.e., 0.75 x 270 Mb/s = 203 MHz.

[8] Lasers are all class 1 as defined in IEC 60825-1 (2001-08).

[9] A laser warning label that is clearly visible during maintenance, operations, and servicing shall be present on equipment. Text borders and symbols must be black on a yellow background. The laser warning label shall be as illustrated:

Refer to Annex C for further information.

[10] Optical fiber specification defined by IEC 60793-2 (2003-10).

3.3 Transmitter unit labeling

3.3.1 Transmitter units shall be labeled to indicate the application (low-power, medium-power or high-power), the polish of the connector, the payload types they support and the wavelength they use. The labeling shall have the format <application>-<polish>-<signal type>-<wavelength>.

– The element <application> shall have the value:

- H for high-power (long-haul) link applications
- M for medium-power (medium-haul) link applications
- L for low-power (short-haul) link applications

– The element <polish> shall have the value:

- PC for Physical Contact (flat polished) Connectors - preferred
- SPC for Super Physical Contact (flat polished) Connectors - optional
- UPC for Ultra Physical Contact (flat polished) Connectors - optional
- APC for Angle Physical Contact (angle polished) Connectors - optional

– For each supported signal type, the element <signal type> shall have the value:

- A to indicate support of SMPTE 259M signals
- B to indicate support of SMPTE 344M signals
- C to indicate support of SMPTE 292M signals
- D to indicate support for SMPTE 424M signals

– The element <wavelength> shall have the value:

- 850 for 850 nm transmitters,
- 1310 for 1310 nm transmitters
- 1550 for 1550 nm transmitters.

EXAMPLE: An angle polished low-power (short-haul) transmitter that supports SMPTE 259M and SMPTE 292M signals at an optical wavelength of 1310 nm is labeled L-APC-AC-1310.

NOTE – Equipment designed in compliance with previous revisions of this standard may not conform to this label requirement.

3.4 Receiver unit

A receiver unit shall output an electrical signal per SMPTE 259M, SMPTE 344M, SMPTE 292M or SMPTE 424M when receiving an optical signal per table 2.

NOTE – Devices compliant with this standard may be designed to produce one, all, or any combination of SMPTE 259M, SMPTE 344M, SMPTE 292M and SMPTE 424M electrical signals.

Table 2 – Optical receiver input signal specifications

Transmission circuit fiber	Single-mode	Multimode[2]
Minimum input overload power [1,3]	- 7.5 dBm, 0 dBm preferred	
Minimum input power for SMPTE 259M, SMPTE 344M and SMPTE 292M [1]	- 20 dBm	
Minimum input power for SMPTE 424M[1]	- 17 dBm	
Detector damage threshold [3]	+ 1 dBm (minimum)	

NOTES

1) Within the receiver input range, a BER $< 10^{-12}$ shall be achieved with the SDI Matrix Checkfield signal. A BER $< 10^{-14}$ is recommended.

2) Multimode fiber is not recommended for high-power (long-haul), or medium-power (medium-haul), link applications at SMPTE 344M, SMPTE 292M or SMPTE 424M signal rates.

3) Depending on product implementation, optical attenuators may need to be used to meet specified overload and detector damage performance. See informative annex E and F for further information.

3.5 Receiver unit labeling

Receivers shall be labeled to indicate the polish of the connector and the payload types they support. The labeling shall have the format <polish>-<signal type>-<wavelength range>.

– The element <polish> shall have the value:

- PC for Physical Contact (flat polished) Connectors - preferred
- SPC for Super Physical Contact (flat polished) Connectors - optional
- UPC for Ultra Physical Contact (flat polished) Connectors - optional
- APC for Angle Physical Contact (angle polished) Connectors – optional

– For each support signal type, the element <signal type> shall have the value:

- A to indicate support of SMPTE 259M signals
- B to indicate support of SMPTE 344M signals
- C to indicate support of SMPTE 292M signals
- D to indicate support for SMPTE 424M signals

– The element <wavelength range> shall have the value:

- 850 to indicate support of 850 nm only
- 850-1310 to indicate support of 850 nm through 1310 nm
- 1310 to indicate support for 1310 nm only
- 1550 to indicate support for 1550 nm only
- 1310-1550 to indicate support for 1310 nm through 1550 nm

EXAMPLE: A PC polished receiver that supports SMPTE 424M signals at a wavelength of 850 nm only is labeled PC-D-850.

NOTE – Equipment designed in compliance with previous revisions of this standard may not conform to this label requirement.

3.6 Optical fiber circuit and connector specification

3.6.1 Optical fiber type options

The user may use single-mode fiber for medium-power / medium-haul applications and either single-mode or multimode fiber for low-power / short-haul link applications, to establish a point-to-point optical circuit between the transmitter and receiver optical connectors. A point-to-point circuit may consist of one or multiple serially interconnected sections of the selected type of optical fiber in cables, jumpers, and/or patch cords. Mixing fiber types in the multiple sections of a point-to-point circuit is physically possible, but technically unacceptable and would not be in compliance with this standard.

Single-mode optical fiber shall comply with ITU-T Rec. G.652 (2006), and have a maximum attenuation of 0.35dB per kilometer at 1310 nm, and 0.25dB per kilometer at 1550 nm.

Multimode optical fiber shall comply with ANSI/EIA/TIA-492AAAA-A (62.5/125 micron graded-index [GI] fiber) or ITU-T G.651 (50/125 micron graded-index [GI] fiber), and have a maximum attenuation of 1.5 dB per kilometer at 1310 nm and 3.75 dB per kilometer at 850 nm.

NOTE – For multimode fibers, the maximum distance may be limited by the signal dispersion, which can be expressed as a bitrate-length product. For 50/125 micron fiber, typical bitrate-length product values are in the range of 500MHz*km to 2 GHz*km, and for 62.5/125 micron fiber typical values are in the range of 200 MHz*km to 400 MHz*km respectively. These values may vary with wavelength. As a consequence, the dispersion of specific multimode fibers may be optimized for specific wavelengths.

3.6.2 Optical connector return loss

Optical connectors shall have optical return losses as follows, with measurements performed at 23°C +/- 5°C, in accordance with IEC 60793-1-40 (2001-07) Measurement methods and test procedures – Attenuation.

Table 3 – Optical connector return loss

Fiber Type	Minimum return loss
62.5/125 or 50/125 micron multimode	20 dB
8-10/125 micron single-mode	26 dB

NOTE – The minimum return loss figures are specified to accommodate multiple in-line reflections.

Annex A (informative)
Definitions of optical domain transmission media and connector terms

A.1 Optical fiber and cable assemblies

Cables contain one or more sheathing-encased individual optical fibers, arranged in a bundle or flat ribbon configuration. Fiber counts selected for high-density cables will be the designer's choice between the need for conduit space conservation and the need for convenient optical fiber cable management.

Jumpers, patch cords, and fiber circuit extenders are special-purpose optical fiber cables containing one or more fibers, each enclosed in a protective sheath.

Hybrid optical/copper cables are assemblies of one or more multimode and/or single-mode sheathed fibers, and two or more electrically-insulated copper wires or braids. They are fabricated for use in special applications such as interconnection of camera heads and base stations. Their specifications are to be defined in a separate SMPTE standard.

Pigtails are single fibers encased in a plastic material, but not including a protective sheath. They are fabricated for installation within terminal equipment to extend a fiber circuit from an interconnection panel receptacle to an optical device located within the equipment. They are terminated at the interconnection panel end in an appropriate connector interface (see Section 0.3 and 3.1.4).

A.2 Optical connectorization components

Connectors are installed at both ends of all fibers in single, duplex, or multiple fiber patch cords, and sheath- protected multi-fiber cables. Connectors are also installed at one end of pigtails whose other end is physically affixed to optical Tx and Rx devices located within user equipment.

Adapters are installed in rack- and wall-mounted patch panels in telecommunications closets and equipment rooms to intermate connector-terminated fibers. They are the optical equivalent of double-ended BNC barrels or panel-mounted adapters used to interconnect tandem lengths of coaxial cable. Adapters provide mechanical means for precisely butting together projecting fiber connector ferrules. They are used to physically establish circuits consisting of serially connected lengths of multimode and single-mode cable fibers or pigtails.

Adapters also accommodate the intermating of a single-mode light source output pigtail to a multimode transmission circuit input, and the intermating of a single-mode transmission circuit output to a multimode optical receiver input pigtail. Telecommunications industry practice allows the use of single-mode pigtails in a Tx unit to interface multimode fiber circuits. In an Rx unit, multimode pigtails may be used to receive optical signals from single-mode fiber circuits.

Receptacles are installed in terminal equipment to provide the interface between internally installed optical Tx and Rx devices and premises (plant) cabling circuits. A receptacle may physically comprise half of an adapter, with light sources or photo diodes physically installed in the other half. Such receptacles may be physically mounted on Tx or Rx unit PC boards. When a multimode or single-mode E/O or O/E transducer is mounted on a printed circuit board, which cannot be physically located at the interface panel, interconnection to the panel receptacle is established by a pigtail (see § 3.1.3 and § 3.1.4).

Annex B (informative)
Optical transmission circuit design and performance options

B.1 Tx and Rx unit selection criteria

The power budget of a fiber optic transmission link is the arithmetic difference between the Table 1 optical source minimum output power and the table 2 optical receiver maximum input power. The minimum power budget required for transmission of a signal between source and destination equipment is the fiber's attenuation at the desired transmission wavelength, plus the sum of the measured or specified losses at all splice points and in connectors, which may be as high as 0.5 dB per splice or connection. The system designer is advised to include a 3 dB to 6 dB "contingency" loss in setting up the loss budget of a long multi-section circuit.

Higher costs for single-mode Tx and Rx units needed to meet a specific loss budget may be offset by the use of lower cost multimode fiber throughout the circuit. However, the "minimum fiber bandwidth" of multimode fibers (expressed as a maximum "bandwidth-kilometer" value in the fiber specification) forces the use of single-mode fiber in any medium-power / medium-haul link that may eventually be required to transport 540 Mb/s SMPTE 344M-compatible signals, 1.485 or 1.485/1.001 Gb/s SMPTE 292M-compatible signals or 2.970 or 2.970/1.001 Gb/s SMPTE 424M compatible signals. This fiber type choice requirement has no equivalent in coaxial transmission circuit loss calculations.

The use of multimode fiber within low-power (short-haul) link circuits will also result in lower performance than single-mode fiber at these rates.

B.2 Multimode and single-mode fiber transmission characteristics

The distances over which digital signals can be transmitted on multimode and single-mode fibers without errors have "cliff effect" circuit length limits caused by "modal" and "chromatic" dispersion phenomena, respectively. Multimode fibers accept multiple input light rays (modes) from the light source at maximum angles of incidence defined by the "acceptance cone" (numerical aperture – NA) of the fiber. Propagation delays of the pulse-carrying rays reflected from boundary to boundary in the core increase with distance. The "cliff effect" distance of multimode fiber, calculated from its "bandwidth-kilometer" rating (see above), is that distance at which the signal is no longer recoverable, because the time of arrival of pulses transported by many rays masks signal transition points or overlaps pulses from adjacent signal unit intervals.

Contrary to popular conception, even the most expensive semiconductor laser light source does not emit light at a single wavelength. The single ray transmitted down the 8.0 to 10.0 micron core experiences different propagation delay at each wavelength within the 10-nm maximum spectral line width output of the laser (Table 1). The "cliff effect" point of single-mode fiber, many kilometers further down the fiber, is that distance at which the time of arrival of pulses transported at the spectral wavelength extremes mask signal transition points, or overlap pulses from adjacent signal unit intervals.

B.3 E/O transducer digital signal processing limitation

Designers should be aware that SMPTE 259M serial signals can contain substantial low-frequency energy.

Transducers used in SMPTE 259M signal transmission must therefore employ appropriate coupling time constants, clamping, and power-control loops. Proper performance can be verified by test transmission of the SDI checkfield signals specified in SMPTE RP 178. Designers may refer to SMPTE EG 34 for further guidance.

Annex C (informative)
Laser safety information

Visible and invisible radiation from laser diodes and LEDs used in optical fiber communications systems is considered to be a safe application of laser technology. Light output is entirely confined to the core of the interconnected fiber, and does not leak through the cladding and outer sheath. If the pigtail of an active light source is disconnected, damage to the eye is remotely possible under the most unlikely possibility that a person would look directly into the fiber at close range for an extended period of time.

Publications of the U.S. Government Food and Drug Administration's Center for Devices and Radiological Health, ANSI, and IEC provide guidance on practices to be followed in working with optical fiber communications systems. They also contain information on labeling requirements for modules containing a laser/LED light source coupled to the outside via a pigtail or optical connector. Users are further encouraged to check any local regulations that may exist.

Annex D (informative)
Maximum transmission distance range

The maximum transmission distance ranges for low-power (short-haul), medium-power (medium-haul) and high-power (long-haul), link applications can be computed by subtracting the transmitter output power levels from the minimum receiver input power levels. The power difference is then multiplied by the fiber loss factor at the specific wavelength (see tables D.1, D.2 and D.3).

This loss analysis does not account for splice losses or connector losses, which are typically 0.1dB each for single-mode fiber and 0.5dB each for multimode fiber. Other loss factors beyond fiber loss are not included; therefore these calculations only provide a guideline for applications.

Table D.1 – Low-power (short-haul) link applications — maximum transmission distance

	Single mode fiber				Multimode fiber			
	At minimum output power		At maximum output power		At minimum output power		At maximum output power	
Wavelength	1310nm	1550nm	1310nm	1550nm	850nm	1310nm	850nm	1310nm
Fiber loss (dB/km)	0.35	0.25	0.35	0.25	3.75	1.5	3.75	1.5
Output power (dBm)	-12		-3		-12		-3	
Minimum input power (dBm) [143Mb/s ~ 1.5Gb/s]	-20		-20		-20		-20	
Minimum input power (dBm) [3Gb/s]	-17		-17		-17		-17	
Loss budget (dB) [143Mb/s ~ 1.5Gb/s]	8		17		8		17	
Loss budget (dB) [3Gb/s]	5		14		5		14	
Distance (km) [143Mb/s ~ 1.5Gb/s]	22	32	48	68	2	5	5	11
Distance (km) [3Gb/s]	14	20	40	56	1	3	4	9

NOTE – For multimode fiber applications, the maximum distance may be limited by the signal dispersion expressed as the bitrate-length product.

Table D.2 – Medium-power (medium-haul) link applications — maximum transmission distance

	Single mode fiber			
	At minimum output power		At maximum output power	
Wavelength	1310nm	1550nm	1310nm	1550nm
Fiber loss (dB/km)	0.35	0.25	0.35	0.25
Output power (dBm)	-3		0	
Minimum input power (dBm) [143Mb/s ~ 1.5Gb/s]	-20		-20	
Minimum input power (dBm) [3Gb/s]	-17		-17	
Loss budget (dB) [143Mb/s ~ 1.5Gb/s]	17		20	
Loss budget (dB) [3Gb/s]	14		17	
Distance (km) [143Mb/s ~ 1.5Gb/s]	49	68	57	80
Distance (km) [3Gb/s]	40	56	49	68

Table D.3 – High-power (long-haul) link applications — maximum transmission distance

	Single mode fiber			
	At minimum output power		At maximum output power	
Wavelength	1310nm	1550nm	1310nm	1550nm
Fiber loss (dB/km)	0.35	0.25	0.35	0.25
Output power (dBm)	0		+10	
Minimum input power (dBm) [143Mb/s ~ 1.5Gb/s]	-20		-20	
Minimum input power (dBm) [3Gb/s]	-17		-17	
Loss budget (dB) [143Mb/s ~ 1.5Gb/s]	20		30	
Loss budget (dB) [3Gb/s]	17		27	
Distance (km) [143Mb/s ~ 1.5Gb/s]	57	80	86	120
Distance (km) [3Gb/s]	49	68	77	108

Annex E (informative)
Minimum transmission distance

The minimum transmission distance range defines the shortest interconnection that can be supported without signal distortion and can be computed by subtracting the maximum and minimum transmitter output power level from the maximum input power level (minimum input overload), of the receiver.

The power difference is then rounded up to zero if negative and the resultant minimum loss budget is multiplied by the fiber loss factor at the specific wavelength (see tables E.1, E.2 and E.3).

Receivers designed with a maximum input power of –7.5dBm will require some attenuation when used back-to-back with low-power, medium-power or high-power transmitters operating at the highest power level to avoid signal distortions and potential bit-errors.

From tables E.1, E.2 and E.3 it can be seen that:

- 4.5 dB of attenuation will be required to avoid distortion when the receiver is connected to a low-power transmitter operating at the highest power level
- 7.5 dB of attenuation will be required to avoid distortion when the receiver is connected to a medium-power transmitter operating at the highest power level
- 17.5 dB of attenuation will be required to avoid distortion when the receiver is connected to a high-power transmitter operating at the highest power level

Typical system installations will have at least this degree of attenuation due to fiber loss.

When operating back-to-back with low-power transmitters operating at the lowest power level, the receiver may be connected down to a zero-meter link length without distortion as shown in table E.1.

Receivers designed with a maximum input power of 0 dBm may be operated back-to-back down to a zero-meter link length for all transmitter applications, except high-power (long-haul) transmitters operating at the highest output power. As can be seen from table E.3 at least 10 dB of attenuation is required to avoid distortion in this condition.

Table E.1 – Low-power (short-haul) link applications — minimum input overload

	Single mode fiber				Multimode fiber			
	At minimum output power		At maximum output power		At minimum output power		At maximum output power	
Wavelength	1310nm	1550nm	1310nm	1550nm	850nm	1310nm	850nm	1310nm
Fiber loss (dB/km)	0.35	0.25	0.35	0.25	3.75	1.5	3.75	1.5
Output power (dBm)	-12		-3		-12		-3	
Maximum input power (dBm) [minimum input overload]	-7.5 / 0 (preferred)		-7.5 / 0 (preferred)		-7.5 / 0 (preferred)		-7.5 / 0 (preferred)	
Minimum loss budget (dB)	0 / 0		4.5 / 0		0 / 0		4.5 / 0	
Minimum link distance (km)	0	0	13 / 0	18 / 0	0	0	1 / 0	3 / 0

Table E.2 – Medium-power (medium-haul) link applications — minimum input overload

	Single mode fiber			
	At minimum output power		At maximum output power	
Wavelength	1310nm	1550nm	1310nm	1550nm
Fiber loss (dB/km)	0.35	0.25	0.35	0.25
Output power (dBm)	-3		0	
Maximum input power (dBm) [minimum input overload]	-7.5 / 0 (preferred)		-7.5 / 0 (preferred)	
Minimum loss budget (dB)	4.5 / 0		7.5 / 0	
Minimum link distance (km)	13 / 0	18 / 0	21 / 0	30 / 0

Table E.3 – High-power (long-haul) link applications — minimum input overload

	Single mode fiber			
	At minimum output power		At maximum output power	
Wavelength	1310nm	1550nm	1310nm	1550nm
Fiber loss (dB/km)	0.35	0.25	0.35	0.25
Output power (dBm)	0		10	
Maximum input power (dBm) [minimum input overload]	-7.5 / 0 (preferred)		-7.5 / 0 (preferred)	
Minimum loss budget (dB)	7.5 / 0		17.5 / 10	
Minimum link distance (km)	21 / 0	30 / 0	50 / 29	70 / 40

Annex F (informative)
Damage thresholds

Damage thresholds can be computed by subtracting the receiver detector damage input power level from the maximum transmitter output power level.

Tables F.1, F.2 and F.3 illustrate that equipment designed to work in compliance with this revision of SMPTE 297M will be fully interoperable under all operating conditions or combinations of low-power, medium power or high-power link applications except high-power (long-haul) transmitters operating at the highest output power. As can be seen from table F.3 at least 9 dB of attenuation is equired to avoid detector damage under these conditions.

It should be noted that typical system installations will have at least this degree of attenuation due to fiber loss.

If there is a risk of accidental improper cross-connection of high-power (long-haul) transmitters over circuits designed for low-power (short-haul) links, suitable optical attenuators or pads should be designed into the system.

Table F.1 – Low-power (short-haul) link applications — detector damage thresholds

	Single mode fiber		Multimode fiber	
	At minimum output power	At maximum output power	At minimum output power	At maximum output power
Output power (dBm)	-12	-3	-12	-3
Detector Damage (dB)	1	1	1	1
Minimum attenuation required to avoid detector damage (dB)	0	0	0	0

Table F.2 – Medium-power (medium-haul) link applications — detector damage thresholds

	Single mode fiber	
	At minimum output power	At maximum output power
Output power (dBm)	-3	0
Detector Damage (dB)	1	1
Minimum attenuation required to avoid detector damage (dB)	0	0

Table F.3 – High-power (long-haul) link applications - detector damage thresholds

	Single mode fiber	
	At minimum output power	At maximum output power
Output power (dBm)	0	10
Detector Damage (dB)	1	1
Minimum attenuation required to avoid detector damage (dB)	0	9

Annex G (informative)
Glossary of fiber optic terms

Absorption: That portion of optical attenuation in optical fiber resulting from the conversion of optical power to heat. Caused by impurities in the fiber such as hydroxyl ions, absorption has an effect only at certain wavelengths. Together with scattering, absorption forms the principal cause of the attenuation in an optical waveguide.

Acceptance Angle: The half-angle of the cone within which incident light is totally internally reflected by the fiber core at the core-cladding interface. The Acceptance Angle is equal to $\sin^{-1}$(NA), where NA is an abbreviation for Numerical Aperture.

Adapter: A mechanical device designed to align and join fiber optic connectors. Often referred to as a coupler or bulkhead.

Angle of Incidence: The angle between an incident ray and the normal to a reflecting surface.

APC: Abbreviation for Angled Physical Contact. A style of fiber optic connector manufactured or polished with a 5°-15° angle on the connector tip for the minimum possible back reflection.

Aramid Yarn: Strength elements that provide tensile strength, support, and additional protection of an optical fiber bundle. Kevlar™ is a particular widely-used brand of aramid yarn.

AR Coating: Antireflection coating. A thin, dielectric or metallic film applied to an optical surface to reduce its reflectance and thereby increase its transmittance.

Attenuation: The reduction of average optical power in an optical waveguide. The main causes are scattering and absorption, as well as optical losses in connectors and splices. This term is normally expressed in decibels (dB). Attenuation (also known as loss) is expressed by: $x \text{ dB} = -10 \log_{10} (Po/Pi)$ where Pi is the optical power measured at the input and Po is the optical power measured at the output. Since Po is less than Pi, a negative sign is placed before the 10 to yield a positive number for x.

Attenuation Coefficient: The rate of optical power loss with respect to distance along the optical fiber, usually measured in decibels per kilometer (dB/km) at a specific wavelength. The lower the number, the better the fiber.

Attenuator: A passive optical element that reduces intensity of an optical signal passing through it without otherwise affecting the signal.

Avalanche Photodiode (APD): A photodiode designed to take advantage of avalanche multiplication of photocurrent. As the reverse-bias voltage across the diode junction approaches the breakdown voltage, hole-electron pairs created by absorbed photons acquire sufficient energy to create additional hole-electron pairs when they collide with ions; thus a multiplication or signal gain is achieved.

Axial Ray: A light ray that travels along the central axis of an optical fiber.

Backscattering: The process whereby a small fraction of light that is scattered and deflected out of the original direction of propagation in the optical waveguide suffers a reversal of direction and propagated directly back toward the transmitter.

Bandwidth: The lowest frequency at which the magnitude of the waveguide transfer function decreases to 3 dB (optical power) below its zero frequency value. This is often referred to as the “3 dB Bandwidth.” The Bandwidth will be a function of length of the waveguide, but may not be directly proportional to the length.

Bandwidth-Length Product: Used for determining a fiber’s ability to transfer a signal of a given bandwidth and distance, the Bandwidth-Length product is equal to the product of the length of the fiber in kilometers and the maximum 3 dB bandwidth that the fiber can sustain in megahertz or gigahertz at a particular optical wavelength.

Beam splitter: A device used to divide or split an optical beam into two or more separate beams.

Bend Radius: The smallest radius an optical fiber or fiber cable can be bent before causing excessive attenuation or fiber breakage.

Bending Loss: Attenuation that occurs at the location where a fiber is bent around a small radius.

BER (Bit Error Rate): In digital applications, the ratio of bits received in error to bits sent. BERs of one errored bit per billion $1x10^{-9}$ sent are typical in fiber optic systems.

Buffer: Material used to protect optical fiber from physical damage, providing mechanical isolation and protection. Fabrication techniques include tight or loose tube buffering, as well as multiple buffer layers.

Butt Splice: The result of permanently or semi-permanently coupling two fibers end to end without using a de-mateable connector.

Center Wavelength: The nominal central wavelength of a laser or the central point between the two half-amplitude wavelengths of an LED.

Chromatic Dispersion: Spreading of a light pulse caused by the difference in refractive indices at different wavelengths. This spreading reduces the effective bandwidth of the fiber by affecting the rise/fall times of digital signals at the optical receiver.

Cladding: The dielectric material surrounding the core of an optical fiber. Cladding features a lower refractive index than the core material, trapping light in the core and causing it to travel down the length of the fiber.

Coarse Wavelength Division Multiplexing (CWDM): CWDM combines up to eight widely-spaced optical carrier frequencies on a single fiber, typically at a lower cost than Dense Wavelength Division Multiplexing systems because of relaxed tolerances on lasers and WDM couplers.

Coherent Light Source: A light source in which the amplitude and phase of all waves is exactly identical. Lasers are examples of Coherent Light Sources.

Core: The central region of an optical fiber through which light is transmitted, possessing a higher index of refraction than the cladding surrounding it.

Coupler (Optical Coupler): An optical component used to split or combine optical signal power. Some examples of Couplers are "Splitters","T-couplers", "2x2s", or "1x2s".

Coupling Loss: The power loss suffered when coupling light from one optical device to another.

Coupling Ratio: The ratio, in percentage, of optical power from one output port of an optical coupler to the total optical coupler output power.

Critical Angle: The smallest angle from the fiber axis at which a ray may be totally reflected at the core/cladding interface.

Cutoff Wavelength: The shortest wavelength at which a single-mode fiber will operate as such.

Dark Current: The external current that, under reverse-bias conditions, flows in a photodetector when there is no incident radiation.

Data Rate: The maximum number of bits of information that can be transmitted per second across a data transmission link. Often expressed as Megabits per second (Mb/s) or Gigabits per second (Gb/s).

Decibel (dB): The standard unit of measurement that expresses relative gain or loss of optical or electrical power on a logarithmic scale as per the formula $dB = 10 \log_{10}(P1/P2)$, where P1 and P2 are the two power levels being ratioed.

Dense Wavelength Division Multiplexing (DWDM): DWDM combines numerous closely-spaced wavelengths in the 1550nm region onto a single optical fiber. Wavelength spacings are specified at 100 GHz or 200 GHz.

Detector: A transducer that provides an electrical output current in response to an incident optical power. The output current depends on the amount of light received and the type of device.

Detector Damage Threshold: The guaranteed maximum power level the detector may receive without being damaged.

Dispersion: Temporal spread of the signal in an optical waveguide. Dispersion consists of various components: modal dispersion, material dispersion, and waveguide dispersion. As a result of its dispersion, an optical waveguide low-pass filters transmitted signals.

Dispersion Compensating Fiber: A fiber that has dispersion opposite of other fibers in a transmission system, thus compensating for dispersion effects in other fibers.

Dispersion Shifted Fiber: A type of single-mode fiber tailored to exhibit zero dispersion near 1550 nm. This fiber type works very poorly for DWDM applications because of high fiber nonlinearity at the zero-dispersion wavelength.

Extinction Ratio: Regarding LEDs and laser diodes, the Extinction Ratio is ratio of the power emitted by the diode when it is sending a low signal (minimum power) to the power transmitted when it is sending a high signal (maximum power).

Extrinsic Losses: Losses that are caused by imperfections in the mechanical connectorization or splicing of two fibers. See Intrinsic Losses.

Ferrule: A component of a fiber optic connection that rigidly holds a fiber in place and aids in its alignment.

Fiber Optic Link: A fiber optic cable with connectors attached to a transmitter (source) and receiver (detector).

Fresnel Reflection: The reflection, and resultant loss, of a portion of the light incident on a planar surface between two homogeneous media having different refractive indices. Fresnel reflection occurs at the air/glass interfaces at the entrance and exit ends of an optical fiber. Maximum Fresnel reflection losses at an air/glass interface is 4% of the incident light.

Fundamental Mode: The lowest order mode of an optical waveguide.

Graded Index Fiber: An optical fiber with a refractive index that is a parabolic function of the radial distance from the fiber axis, decreasing in the direction from the axis to the cladding.

Incoherent Light: LEDs emit incoherent light, unlike laser diodes, which emit coherent light.

Index Matching Material: A material, often a liquid or gel, whose refractive index is nearly equal to the core index. It can be used to reduce Fresnel reflections from a fiber end face.

Index of Refraction (Refractive Index): The ratio of the velocity of light in free space to the velocity of light in an optical fiber, the Index of Refraction is always greater than or equal to one.

Injection Laser Diode (ILD): A laser diode in which the stimulated emission that characterizes such devices occurs at a semiconductor junction under conditions of a forward bias that injects electrons and holes into the junction.

Insertion Loss: The attenuation caused by the insertion of an optical component, such as a connector or coupler, into an optical transmission system.

Innerduct: A reinforced flexible plastic tube designed for (1) providing multiple inner conduits within a single large conduit, (2) providing physical protection to a fiber cable in a cable tray or underfloor installation, or (3) providing plenum rating for a non-plenum rated fiber cable. Innerduct is typically corrugated in construction and brightly colored to permit rapid eye detection in a cable tray or underfloor installation.

Intensity: The square of the electric field strength of an electromagnetic wave. Intensity is proportional to irradiance.

Intensity Modulation: A modulation scheme in which the optical power intensity of a source varies with a modulating signal. Intensity Modulation is often used in digital transmission systems where digital “ones” and “zeros” are signaled by turning a laser or LED on and off.

Intermodal Distortion: Waveform distortion in multimode fiber systems due to propagation of multiple optical modes in such systems and the subsequent temporal dispersion of light propagating in these multiple optical modes

Integrated Optical Components/Circuits (IOCs): External optical devices that perform signal processing on light transmitted through waveguides. IOCs contain waveguides that structure and confine the propagating light to a region with one or two very small dimensions, of the order of the wavelength of light. A common material used in the fabrication process of an IOC is Lithium Niobate ($LiNbO_2$).

Intrinsic Losses: Losses inherent in optical fiber splices that are caused by minute differences between the fibers being spliced. See Extrinsic Losses.

Irradiance: Power density at a surface through which radiation passes at the radiating surface of a light source or at the cross section of an optical waveguide. The normal unit is Watts per centimeters squared, or W/cm^2.

Jumper Cable: A fiber optic cable, fitted with de-mateable connectors, which is of limited length. Jumper cables are used to interconnect between fiber optic equipment and/or other fiber optic cables.

Laser Diode (LD): Semiconductor diode, which emits coherent light when forward biased above a threshold current.

Launch Angle: Angle between the propagation direction of the incident light and the optical axis of an optical waveguide.

Launching Fiber: A fiber that connects a laser or LED to another fiber, typically a jumper cable.

Light Emitting Diode (LED): A semiconductor device that emits incoherent light from a p-n junction when forward-biased. Light may exit from the junction strip edge or from its surface, depending on the device's structure.

Light: In the laser and optical communication fields, the portion of the electromagnetic spectrum that can be handled by the basic optical techniques used for the visible spectrum extending from the near ultraviolet region of approximately 0.3 micron, through the visible region and into the mid-infrared region of about 30 microns.

Lightguide: Synonym for optical fiber.

Lightwaves: Electromagnetic waves in the region of optical frequencies that propagate in a direction normal to the optical wavefront.

Link Budget (Optical Link Budget, Link Loss Budget, Power Budget): The range of optical power over which a fiber optic link will operate within performance specifications. It is computed by subtracting the optical power launched into an optical fiber from the minimum optical receiver sensitivity at the link endpoint. A link budget typically accounts for all interconnect panels and jumper cables in the system and permits the system designer a verification of system performance prior to installation.

Macrobending: Macroscopic axial deviations of a fiber from a straight line that cause light to leak out of the fiber, resulting in optical attenuation,

Material Dispersion: Dispersion resulting from variation of propagation velocity as a function of wavelength in an optical fiber.

Microbending: Curvatures of the fiber that involve axial displacements of a few micrometers and spatial wavelengths of a few millimeters. Microbends cause light to leak out of the fiber and consequently increase the attenuation of the fiber.

Micron: Micrometer (mm). One millionth of a meter ($1x10^{-6}$ m).

Modal Dispersion (Multimode Dispersion): Pulse spreading due to multiple light rays traveling different distances and speeds through an optical fiber.

Modal Noise: Disturbance in multimode fibers fed by laser diodes. It occurs when the fibers contain elements with mode-dependent attenuation, such as imperfect splices, and varies with the coherence of the laser light.

Mode: A single electromagnetic wave propagating in an optical waveguide.

Mode Filter: Used in multimode fiber systems, a Mode Filter strips high-order modes off of the power at the launch end, simulating the mode distribution of light in a fiber as it would be if it were measured hundreds of meters into the fiber. This mode distribution, referred to as the “equilibrium mode distribution,” is valuable when testing optical receivers as it eliminates the need for long pieces of fiber in the receiver test bed.

Monochromatic: Consisting of a single wavelength. In practice, radiation is never perfectly monochromatic but, at best, displays a narrow band of wavelengths.

Multimode Distortion: The signal distortion in an optical waveguide resulting from the superposition of modes with differing delays.

Multimode Fiber: Optical waveguide whose core diameter is large compared with the optical wavelength and in which more than a single mode is capable of propagation.

Nanometer (nm): One billionth of a meter ($1x10^{-9}m$).

Noise Equivalent Power (NEP): The RMS value of optical power which is required to produce an RMS signal-to-noise ratio of 1. Noise Equivalent Power is an indication of a noise level that defines the minimum detectable signal level.

Non Zero Dispersion Shifted Fiber (NZDSF): A dispersion-shifted single-mode fiber that exhibits near the 1550 nm window, but outside the window actually used to transmit signals, maximizing fiber bandwidth while minimizing the effect of fiber nonlinearities on the signal being transmitted.

Numerical Aperture (NA): A measure of the range of angles of incident light transmitted through a fiber. NA is determined by the differences in index of refraction between the core and the cladding.

Optical Fiber: Any filament or fiber, made of dielectric materials, which guide light.

Optical Time Domain Reflectometer (OTDR): A device that tests a fiber by transmitting an optical pulse through the fiber and the measuring the resulting backscatter and reflections to the input as a function of time. Useful in estimating attenuation coefficient as a function of distance and identifying defects and other localized losses.

Optoelectronic: Any device that functions as an electrical-to-optical or optical-to-electrical transducer.

Optoelectronic Integrated Circuits (OEICs): Combine electronic and optic functions in a single chip. Peak Wavelength: The wavelength at which the optical power of a source is at a maximum.

Photocurrent: The current that flows through a photosensitive device, such as a photodiode, as the result of exposure to optical power.

Photodiode: A semiconductor diode that produces photocurrent by absorbing light. Photodiodes are used for the detection of optical power and for the conversion of optical power into electrical current.

Photon: A quantum of electromagnetic energy.

Physical Contact Connector: A type of optical connector that maintains physical contact between fibers mounted in ferrules so as to minimize Fresnel reflection effects at the connector endfaces.

Pigtail: A short length of optical fiber for coupling optical components. It is usually permanently fixed to the component at one end and connectorized with a de-mateable connector at the other end.

PIN-FET Receiver: Optical receiver with a PIN photodiode and low noise amplifier with a high impedance input, whose first stage incorporates a Field-Effect Transistor (FET).

PIN Photodiode: A diode with a large intrinsic region sandwiched between p-doped and n-doped semiconducting regions. Photons entering this region create electron-hole pairs that are separated by an electric field and swept away by a bias current, thus generating an electric current in the load circuit that varies depending on the intensity of light impinging on the intrinsic region of the diode.

Plenum Cable: A fire-code rating for indoor cable that allows it to be installed directly in an air-handling space such as is found above drop-ceiling tiles or under raised floors without the use of conduit.

Polarization Maintaining Fiber: Single-mode optical fiber that maintains a single launched light polarization along its length. Since it does not convert light from one polarization to another, Polarization Maintaining Fiber exhibits excellent dispersion characteristics that make it suitable for extremely high-speed data transfers.

Preform: A glass structure from which an optical fiber waveguide may be drawn.

Primary Coating: The plastic coating applied directly to the cladding surface of the fiber during manufacture to preserve the integrity of the surface.

UPC / SPC: Abbreviation for Ultra Physical Contact / Super Physical Contact. A style of fiber optic connector manufactured or polished with a convex rounded finish allowing the fibers to touch on a high point near the fiber core where light travels.

Ray: A geometric representation of a light path through an optical medium; a line normal to the wave front indicating the direction of radiant energy flow.

Rayleigh Scattering: Scattering by refractive index fluctuations (inhomogeneities in material density or composition) that are small with respect to wavelength.

Receiver: A detector and electronic circuitry that changes optical signals into electrical signals.

Receiver Overload: The maximum optical power allowed by a receiver for acceptable Bit Error Rates. In the case of digital signal transmission, the mean optical power is usually quoted in Watts or dBm (decibels referenced to 1 milliwatt).

Receiver Sensitivity: The minimum optical power required by a receiver for acceptable Bit Error Rates. In the case of digital signal transmission, the mean optical power is usually quoted in Watts or dBm (decibels referenced to 1 milliwatt).

Reflection: The abrupt change in direction of a light beam at an interface between two dissimilar media so that the light beam returns into the media from which it originated.

Reflectance: The ratio of power reflected back to the incident power at a connector junction/interface or other component or device, usually measured in decibels (dB). Reflectance is stated as a negative value; e.g., -30 dB. A connector that has a better reflectance performance would be a -40 dB connector or a value less than -30 dB. The terms Return Loss, Back Reflection, and Reflectivity are also used in the industry to describe device reflections, but stated as positive values.

Refraction: The bending of a beam of light at an interface between two dissimilar media or in a medium whose refractive index is a continuous function of position (graded index medium).

Refractive Index: The ratio of the velocity of light in a vacuum to that in an optically dense medium.

Repeater: In a lightwave system, an optoelectronic device or module that receives an optical signal, converts it to electrical form, amplifies or reconstructs it, and retransmits it in optical form.

Responsivity: The ratio of detector output to input, usually measured in units of amperes per watt (or microamperes per microwatt).

Return Loss: See Reflectance.

SC Connector: A type of connector used on a fiber optic cable that employs a rectangular cross section of molded plastic. It has a push–to-insert and pull-to-remove locking mechanism instead of threaded coupling, preventing rotational misalignment. An audible click indicates that the connector is fully engaged.

Single Mode Fiber: Optical fiber with a small core diameter in which only a single mode, the fundamental mode, is capable of propagation. This type of fiber is particularly suitable for wideband transmission over large distances, since its bandwidth is limited only by chromatic dispersion.

Source: The means (usually LED or laser) used to convert an electrical information carrying signal into a corresponding optical signal for transmission by an optical waveguide.

Splice: A permanent joint between two optical waveguides.

Spontaneous Emission: This occurs when there are too many electrons in the conduction band of a semiconductor. These electrons drop spontaneously into vacant locations in the valence band, a photon being emitted for each electron. The emitted light is incoherent.

ST Connector: A type of connector used on fiber optic cable utilizing a spring-loaded twist and lock coupling similar to the BNC connectors used with coax cable.

Step Index Fiber: A fiber having a uniform refractive index within the core and a sharp decrease in refractive index at the core/cladding interface.

Stimulated Emission: This occurs when photons in a semiconductor stimulate available excess charge carriers, causing the emission of more photons. The emitted light is identical in wavelength and phase with the incident coherent light.

T (or tee) Coupler: A coupler with three ports.

Threshold Current: The driving current above which the amplification of the lightwave in a laser diode becomes greater than the optical losses, so that stimulated emission commences. The threshold current is strongly temperature-dependent.

Total Internal Reflection: The total reflection that occurs when light strikes an interface at angles of incidence greater than the critical angle.

Transmission Loss: Total loss encountered in transmission through a system.

Transmitter: A driver and a source used to change electrical signals into optical signals.

Y Coupler: A variation on the T coupler in which input light is split between two channels (typically planar waveguide) that branch out like a Y from the input.

Waveguide: A substance that confines and guides a propagating electromagnetic wave.

Waveguide Dispersion: The component of chromatic dispersion arising from the different speeds light travels in the core and cladding of a single-mode fiber.

Wavelength Division Multiplexing (WDM): Simultaneous transmission of several signals in an optical waveguide at differing wavelengths.

Wavelength Chirp: A shifting of a laser diode's Center Wavelength as it is switched on and off in digital fiber optic systems.

Window: The term window refers to ranges of wavelengths matched to the properties of the optical fiber. The window ranges for fiber optics are the following: First window: 820 to 850 nm, second window: 1300 to 1310 nm, the third window: 1550 nm.

Zero Dispersion Wavelength (Zero Dispersion Point): In a single-mode optical fiber, the wavelength at which material dispersion and waveguide dispersion cancel one another, equating to the point at which fiber bandwidth is maximized.

Annex H (informative)
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