International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R BT.1367-2
(10/2015)

Serial digital fibre transmission system for signals conforming to Recommendations ITU-R BT.656, ITU-R BT.799, ITU-R BT.1120 and ITU-R BT.2077 (Part 3)

BT Series
Broadcasting service (television)

150
1865 - 2015

International Telecommunication Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Recommendations

(Also available online at http://www.itu.int/publ/R-REC/en)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	**Broadcasting service (television)**
F	Fixed service
M	Mobile, radiodetermination, amateur and related satellite services
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note*: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2015

RECOMMENDATION ITU-R BT.1367-2

Serial digital fibre transmission system for signals conforming to Recommendations ITU-R BT.656[1], ITU-R BT.799[2], ITU-R BT.1120[3] and ITU-R BT.2077 (Part 3)[4]

(Question ITU-R 42/6)

(1998-2007-2015)

Scope

This Recommendation provides information relating to the use of single and multi-mode fibre optical cable carrying the serial data defined in Recommendations ITU-R BT.656, ITU-R BT.799, ITU-R BT.1120 (270 Mbit/s through 2.97 Gbit/s) and ITU-R BT.2077 (Part 3).

This Recommendation also provides information concerning the connectors that should be used.

Keywords

Optical interface, fibre optics, optical wavelengths

The ITU Radiocommunication Assembly,

considering

a) that the development of digital production facilities has resulted in the increasing use of serial digital interfaces;

b) that a worldwide compatible digital approach will permit the development of equipment with many common features, permit operating economies and facilitate the international exchange of programmes;

c) that to implement the above objectives, agreement has been reached on the digital image format parameters of digital television for studios in the form of Recommendations ITU-R BT.601, ITU-R BT.709, ITU-R BT.2020, ITU-R BT.1847 and ITU-R BT.1543;

d) that to implement the above objectives, agreement has been reached on the transmission of signals in their electrical serial digital form in the form of Recommendations ITU-R BT.656, ITU-R BT.799, ITU-R BT.1120 and ITU-R BT.2077 (Part 3);

e) that in the practical implementation of Recommendations ITU-R BT.656, ITU-R BT.799 and ITU-R BT.1120 it is desirable that interfaces be defined also in an optical interface form;

f) that optical interfaces allow a higher noise immunity for the signals to be transmitted and the transmission of signals over greater distances than with electrical interfaces,

---

1 Recommendation ITU-R BT.656 – Interface for digital component video signals in 525-line and 625-line television systems operating at the 4:2:2 level of Recommendation ITU-R BT.601.

2 Recommendation ITU-R BT.799 – Interface for digital component video signals in 525-line and 625-line television systems operating at the 4:4:4 level of Recommendation ITU-R BT.601.

3 Recommendation ITU-R BT.1120 – Digital interfaces for HDTV studio signals.

4 Recommendation ITU-R BT.2077 – Real-time serial digital interfaces for UHDTV signals.

recommends

that where optical interfaces are required for conformity with Recommendations ITU-R BT.656, ITU-R BT.799, ITU-R BT.1120 and ITU-R BT.2077 (Part 3) they should be in accordance with Annex 1.

Annex 1

1 Introduction

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure e.g. interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met.

2 Normative references

The following Standards/Recommendations contain provisions which, through reference in this text, constitute provisions of this Recommendation:

- Recommendation ITU-R BT.656;
- Recommendation ITU-R BT.799;
- Recommendation ITU-R BT.1120;
- Recommendation ITU-R BT.2077 (Part 3);
- IEC 61169-8 (2007-2) – Part 8: Sectional specification – RF coaxial connectors with inner diameter of outer conductor 6.5 mm (0.256 in) with bayonet lock-characteristic impedance 50 Ω (type BNC)**,** Annex A (Normative) Information for interface dimensions of 75 Ω characteristic impedance connector with unspecified reflection factor[5];
- Recommendation ITU-T G.651 (2007) – Characteristics of a 50/125 µm multimode graded index optical fibre cable for the optical access network;
- Recommendation ITU-T G.652 (2009) – Characteristics of a single-mode optical fibre and cable;
- IEC 60793-2 (2011) Part 2: Product Specifications – General;
- IEC 60825-1 (2014), ed. 3, Safety of laser products – Part 1: Equipment classification and requirements;
- IEC 61754-20 (2012), Fibre Optic Connector Interfaces – Part 20: Type LC Connector Family.
- IEC 60793-1-1 (2008), Measurement methods and test procedures – General and guidance;
- IEC 60793-1-40 (2001-07), Optical fibres – Part 1-40: Measurement methods and test procedures – Attenuation.

[5] Please note that the title of this normative reference may be misleading. This Recommendation requires the use of the 75-ohm connector defined in this reference.

3 Optical transmission system specifications

(See Appendix G for definition of fibre terms used in this Recommendation or related normative references.)

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 should be LC/PC as per IEC 61754-20.

Other application specific connector types, such as SC, ST, FC, MU, etc. may optionally be specified.

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

Other application specific connector polishes such as SPC, UPC and APC may optionally be specified, provided the polish is clearly labelled as described in §§ 3.3.1 and 3.5.

The Tx/Rx unit product documentation should 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, 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 fibre as specified in Recommendation ITU-T G.652 should 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.

A short pigtail of multi-mode 50/125 fibre as specified in Recommendation ITU-T G.651 is acceptable if the Tx unit is intended exclusively for multi-mode link applications.

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

3.1.4 A short pigtail of 62.5/125 multi-mode fibre specified in IEC 60793-2-10 should 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.

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

3.2 Transmitter unit for low-power (short-haul), medium-power (medium-haul) or high-power (long-haul) links

3.2.1 The transmitter unit should 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 defined by Recommendation ITU-R BT.656, or Recommendation ITU-R BT.799, Recommendation ITU-R BT.1120 and Recommendation ITU-R BT.2077 (Part 3).

Refer to informative Appendix D for link budget calculations and information.

TABLE 1

Transmitter unit output signal specifications

	High-power (long-haul) link	**Medium-power (medium-haul) link**	**Low-power (short-haul) link**	
Transmission circuit fibre[1]	SM (9.0/125 µm)	SM (9.0/125 µm)	SM (9.0/125 µm)	MM[2] (50.0/125 µm, 62.5/125 µm)
Light source type[3, 4]	Laser	Laser	Laser	Laser or LED[5, 6]
Optical wavelength	1 310 nm ± 40 nm	1 310 nm ± 40 nm	1 310 nm ± 40 nm	1 310 nm ± 40 nm
	1 550 nm ± 40 nm	1 550 nm ± 40 nm	1 550 nm ± 40 nm	850 nm ± 30 nm
Maximum spectral line width between half-power points for up to 3 Gbit/s interfaces	≤ 1 nm	≤ 2 nm	≤ 8 nm	≤ 30 nm
Maximum spectral line width between half-power points for 6 and 12 Gbit/s interfaces	≤ 1 nm	≤ 2 nm	≤ 4 nm	≤ 30 nm
Maximum spectral line width between half-power points for 24 Gbit/s interfaces	≤ 1nm			
Maximum optical power for up to 3 Gbit/s interfaces[7]	+10 dBm	0 dBm	–3 dBm	
Minimum optical power for up to 3 Gbit/s interfaces[7]	0 dBm	–3 dBm	–12 dBm	
Maximum optical Power for 6 and 12 Gbit/s interfaces	+10 dBm	+0.5 dBm	–3 dBm	
Maximum optical power for 24 Gbit/s interfaces	+10 dBm	+3 dBm	–3 dBm	
Minimum optical power for 6 and 12 Gbit/s interfaces	0 dBm	–3 dBm	–12 dBm	
Minimum optical power for 24 Gbit/s interfaces	0 dBm	–1 dBm	–12 dBm	
Minimum extinction ratio[8]	5:1 (10:1 preferred)			
Rise and fall times for Recs ITU-R BT.656 and ITU-R BT.799[9]	As defined by Recommendations ITU-R BT.656, ITU-R BT.799 for the electrical signal < 1.5 ns (20% to 80%)			
Rise and fall times for Rec. ITU-R BT.1120	As defined by Recommendation ITU-R BT.1120 for the electrical signal 1.5 Gbit/s < 270 ps (20% to 80%), for 3.0 Gbit/s < 135 ps (20%-80%)			

TABLE 1 (*end*)

	High-power (long-haul) link	**Medium-power (medium-haul) link**	**Low-power (short-haul) link**
Rise and Fall times for Rec. ITU-R BT.2077 (Part 3)	As defined by Recommendation ITU-R BT.2077 (Part 3) For a 6G interface < 80 ps and should not differ by more than 30 ps (20%-80%) For a 12G interface < 45 ps and should not differ by more than 18 ps (20%-80%) For a 24G interface < 28 ps and should not differ by more than 8 ps (20%-80%)		
Maximum intrinsic jitter (optical)	As specified in Recommendations ITU-R BT.656, ITU-R BT.799, ITU-R BT.1120, ITU-R BT.2077 (Part 3)		
Maximum reflected power	–14 dB		
Electrical/optical transfer function	Logic “1” maximum intensity/Logic “0” minimum intensity		

(1) Optical fibre specification defined by IEC 60793-2 (2011).

(2) See Recommendation ITU-T G.651 and IEC 60793-2-(2011) – Part 2: Product Specifications – General.

(3) Lasers are all class 1 as defined in IEC 60825-1 (2014).

(4) A laser warning label that is clearly visible during maintenance, operations, and servicing should be present on equipment. Text borders and symbols must be black on a yellow background. The laser warning label should be as illustrated:

(5) LEDs may not function reliably at higher bit rates specified in Recommendations ITU-R BT.656, ITU-R BT.799, ITU-R BT.1120 and ITU-R BT.2077 (Part 3).

(6) Tx units intended solely for multi-mode transmission link applications should be so marked.

(7) Power is average power measured with an average-reading power meter.

(8) Is the ratio between the maximum and minimum output power of the transmitter.

(9) Rise/fall times are measured following a fourth-order Bessel-Thompson filter with a 3 dB point at 0.75 × data rate in MHz, i.e. 0.75 × 270 Mbit/s = 203 MHz.

NOTE – Refer to Appendix C for further information.

3.3 Transmitter unit labelling

3.3.1 Transmitter units should be labelled 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 labelling should have the format <application>-<polish>-<signal type>-<wavelength>.

The element <application> should 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> should 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> should have the value:

– S to indicate support of Recommendation ITU-R BT.656
– P to indicate support of Recommendation ITU-R BT.799
– H to indicate support of Recommendation ITU-R BT.1120
– E to indicate support of Recommendation ITU-R BT.2077 (Part 3) 6G signals
– F to indicate support of Recommendation ITU-R BT.2077 (Part 3) 12G signals
– G to indicate support of Recommendation ITU-R BT.2077 (Part 3) 24G signals.

The element <wavelength> should have the value:

– 850 for 850 nm transmitters
– 1 310 for 1 310 nm transmitters
– 1 550 for 1 550 nm transmitters
– 1 310-1 550 nm transmitters.

NOTE 1 − Equipment designed in compliance with previous revisions of this Recommendation may not conform to this label requirement.

3.4 Receiver unit

The receiver unit should output an electrical signal as per Recommendations ITU-R BT.656, ITU-R BT.799, ITU-R BT.1120 and ITU-R BT.2077 (Part 3) when receiving an optical signal per Table 2.

TABLE 2

Optical receiver input signal specifications

Transmission circuit fibre	Single-mode	Multi-mode[(1)]
Minimum input overload power[(2), (3)]	–7.5 dBm, 0 dBm preferred (270 Mb/s-3 Gbit/s) + 0.5 dBm (6, 12 and 24 Gbit/s)	
Minimum input power	–20 dBm (270 Mb/s-1.5 Gbit/s) –17 dBm (3 Gbit/s) –14 dBm (6 Gbit/s) –14 dBm (12 Gbit/s) –9 dBm (24 Gbit/s)	
Detector damage threshold[(3)]	+1 dBm (minimum)	

(1) Multi-mode fibre is not recommended for high-power (long-haul), or medium-power (medium-haul), link applications for Recommendation ITU-R BT.1120.

(2) Within the receiver input range, a BER < 10^{-12} is the recommended minimum value. A BER < 10^{-14} is a desired target.

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

3.5 Receiver unit labelling

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

a) The element <polish> should 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

b) For each support signal type, the element <signal type> should have the value:
- S to indicate support of Recommendation ITU-R BT.656
- P to indicate support of Recommendation ITU-R BT.799
- H to indicate support of Recommendation ITU-R BT.1120
- E to indicate support of Recommendation ITU-R BT.2077 (Part 3) 6G signals
- F to indicate support of Recommendation ITU-R BT.2077 (Part 3) 12G signals
- G to indicate support of Recommendation ITU-R BT.2077 (Part 3) 24G signals

c) The element <wavelength range> should have the value:
- 850 for 850 nm transmitters
- 1 310 for 1 310 nm transmitters
- 1 550 for 1 550 nm transmitters
- 1 310-1 550 nm transmitters

Example: A PC polished receiver that supports Recommendation ITU-R BT.656 signals at a wavelength of 850 nm only is labelled PC-S-850.

3.6 Optical fibre circuit and connector specifications

3.6.1 Optical fibre type options

The user may use single-mode fibre for medium-power/medium-haul applications and either single-mode or multi-mode fibre 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 fibre in cables, jumpers, and/or patch cords. Mixing fibre 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 Recommendation.

Single-mode optical fibre should comply with Recommendation ITU-T G.652 (2009; Characteristics of a single-mode Optical Fibre Cable).

Multi-mode optical fibre should comply with IEC 60793-2 (2011) Optical Fibres – Part 2: Product Specifications – General.

NOTE – For multi-mode fibres, the maximum distance may be limited by the signal dispersion, which can be expressed as a bit-rate-length product. For 50/125 fibre, typical bit-rate-length product values are in the range of 500 MHz*km to 2 GHz*km, and for 62.5/125 fibre 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 multi-mode fibres may be optimized for specific wavelengths.

3.7 Optical connector return loss

3.7.1 Optical connectors should 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

Fibre type	Minimum return loss
62.5/125 or 50/125 micron multi mode	20 dB
8-10/125 micron single-mode	26 dB

NOTE 1 – The minimum return loss figures are specified to accommodate multiple in-line reflections.

Appendix A
(Informative)

Definition of optical domain transmission media and connector terms

A.1 Optical fibre and cable assemblies

Cables contain one or more sheathing-encased individual optical fibres, arranged in a bundle or flat ribbon configuration. Fibre 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 fibre cable management.

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

Hybrid optical/copper cables are assemblies of one or more multimode and/or single-mode sheathed fibres, 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.

Pigtails are single fibres encased in a plastic material, but not including a protective sheath. They are fabricated for installation within terminal equipment to extend a fibre 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 § 0.3 and 3.1.4).

A.2 Optical connector components

Connectors are installed at both ends of all fibres in single, duplex, or multiple fibre patch cords, and sheath- protected multi-fibre 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 inter-mate connector-terminated fibres. 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 fibre connector ferrules. They are used to physically establish circuits consisting of serially connected lengths of multimode and single-mode cable fibres or pigtails.

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

Appendix B
(Informative)

Optical transmission circuit design and performance options

B.1 Tx and Rx unit selection criteria

The power budget of a fibre 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 fibre'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 fibre throughout the circuit. However, the "minimum fibre bandwidth" of multimode fibres (expressed as a maximum "bandwidth-kilometre" value in the fibre specification) forces the use of single-mode fibre in any medium-power/medium-haul link that may eventually be required to transport Recommendation ITU-R BT.1120 signals. This fibre type choice requirement has no equivalent in coaxial transmission circuit loss calculations.

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

B.2 Multimode and single-mode fibre transmission characteristics

The distances over which digital signals can be transmitted on multimode and single-mode fibres without errors have "cliff effect" circuit length limits caused by "modal" and "chromatic" dispersion phenomena, respectively. Multimode fibres 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 fibre. Propagation delays of the pulse-carrying rays reflected from boundary to boundary in the core increase with distance. The "cliff effect" distance of multimode fibre, calculated from its "bandwidth-kilometre" 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 belief, 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 8-nm maximum spectral line width output of the laser (Table 1). The "cliff effect" point of single-mode fibre, many kilometres further down the fibre, 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 signals according to Recommendations ITU-R BT.656 and ITU-R BT.799 can contain substantial low-frequency energy.

Appendix C
(Informative)

Laser safety information

Visible and non-visible radiation from laser diodes and LEDs used in optical fibre communications systems is considered to be a safe application of laser technology. Light output is entirely confined to the core of the interconnected fibre, and does not leak through the cladding or 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 fibre at close range for an extended period of time.

Publications of the IEC provide guidance on practices to be followed in working with optical fibre communications systems. They also contain information on labelling requirements for modules containing a laser/LED light source coupled to the outside via a pigtail or optical connector.

Appendix D (Informative)

Link Budgeting

When designing an optical fibre link to cover a known distance, there are two factors that will decide whether a particular transmit-receive pair will be adequate to successfully transport data while meeting or exceeding the minimum BER requirements of Recommendation ITU-R BT.1367.

These factors are the *power budget* and the *dispersion tolerance* of the Tx/Rx pair.

D.1 Power budget

The power budget is composed of two principal elements:

Transmit power – This is the guaranteed end of life (EOL) average output optical power of the transmit laser, normally expressed in mW or dBm. Start of Life (SOL) values will typically be larger, allowing for some relaxation in the output power as the device ages.

Receive sensitivity – This is the guaranteed end of life (EOL) power level at which satisfactory error performance can be achieved with a known data pattern. Sensitivity levels for pathological signals will typically be poorer than for PRBS signals (Pseudo Random Bit Sequence).

When determining the loss-limited reach of the system, subtracting the receive sensitivity from the transmit power will provide the power budget (sometimes referred to as "link budget").

TABLE D-1

Power budget calculation

TX: Optical Output Power	-7dBm to +7dBm
Rx: Optical Sensitivity	-11dBm to -32dBm
Power Budget	Tx - Rx

An estimate of the loss-limited reach can be attained from dividing the power budget by an estimate of the fibre loss at the wavelength of interest. For a 1 310 nm-centred FP source, a typical SM fibre optic cable loss can be estimated at 0.35 dB/km and for 1 550 nm-centred DPB source a typical SM fibre optical cable loss can be estimated at 0.25 dB/km

It is also important to consider the number of connection points, splice points, and passive optical devices, such as optical multiplexers and splitters which will introduce power loss into the system. Loss at a connector can be estimated at 0.5 dB, while devices such as MUXs can contribute anywhere from 1 dB to 12 dB of loss depending on the wavelength and the device itself. It is also prudent in these calculations to account for system margin before calculating the loss-limited reach to account for other system issues such as fibre loss due to bending, source wavelength drift etc.

TABLE D-2

Typical passive device power loss

Single Mode Fiber Loss FP (1310nm) DFB (1550nm)	 0.35dB/km 0.25dB/km
Insertion Loss Connectors Splices Patch Panels	 0.5dB 0.2dB 1dB
Passive Device Attenuation WDM CWDM 16 DWDM 32 Splitter 80% Splitter 20%	 2dB 7dB 12dB 2dB 9dB

A more accurate estimate of system reach can be achieved by measuring the fibre loss at the desired wavelength prior to deploying the link.

D.2 Dispersion

Chromatic Dispersion (CD) is the change in mode effective index, and hence energy propagation velocity, with respect to wavelength. That is, every wavelength of light propagating along an optical fibre will experience a different propagation velocity. The presence of dispersion leads to an "erosion" of the unit interval as the energy from neighbouring pulses spread into the current bit period. Similarly, energy from the current bit period is redistributed into the bits before and after.

The dispersion tolerance of the Tx/Rx pair is composed of several elements:

Source line width – Source line width is very dependent on the laser technology used in the transmitter. Fabry-Perot sources (FP) have a very broad spectral line width on the order of several nanometres. Distributed Feed Back (DFB) lasers have a narrow line width on the order of only tenths of a nanometre. The broader the line width of the laser, the more susceptible the data transmission will be to dispersion.

Source wavelength and fibre type – All the various fibre types in existence have a wavelength point at which the dispersion crosses through zero. Depending on the type of fibre and the wavelength of the transmitter, the data is subjected to a certain amount of dispersion as it propagates through the fibre. The most common single-mode fibre type is SMF28 which has a zero-dispersion wavelength centred at 1 310 nm.

Receive tolerance to inter-symbol interference (ISI) – Typically, receivers can tolerate a finite amount of interference from the leading/trailing bits into the current bit period. A typical ISI design value is 49% of the unit interval which results in a 2 dB reduction in receiver sensitivity.

Data rate – Since dispersion manifests itself as a delay in the signal between the start and end of the pulse, it becomes more of a problem at higher data rates where the unit interval is correspondingly shorter.

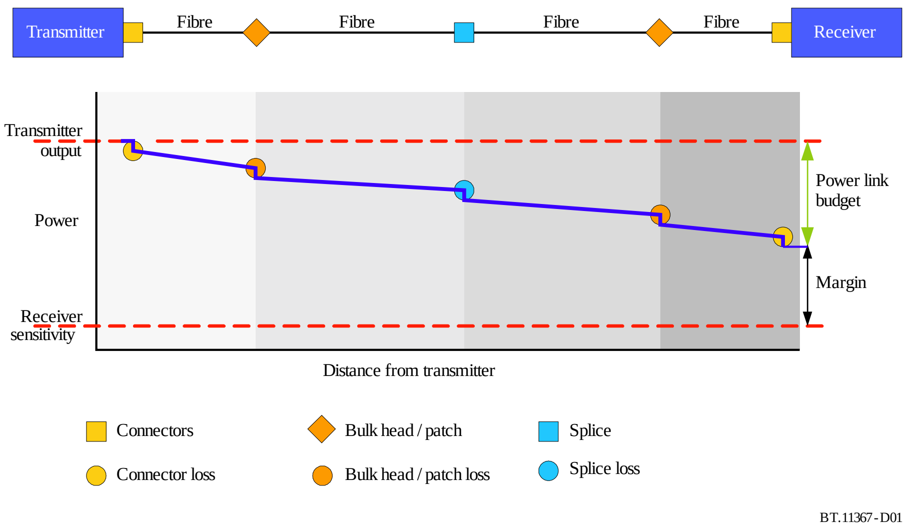
D.3 Calculating Link Distance

For a full design consideration, it is necessary to determine whether a Tx/Rx pair will be power limited or dispersion limited. Calculating a reach for both power and dispersion will highlight the fibre length at which the system becomes limited for one of these phenomena.

By way of example, the following optical network is considered for calculating the link distance.

FIGURE D-1

Signal loss in a typical Optical SDI installation



D.4 Single Mode link distance calculation

For this example, the following basic assumptions apply:

The SM fibre loss is fixed at a uniform, worst case 0.35 dB/km

1 310 nm FP transmitter – minimum output power → –5 dBm, spectral width 4 nm

PIN Receiver – minimum sensitivity (pathological) of –18 dBm

2 connectors with .5 dB loss / connector

2 patch losses with 1 dB loss / patch

1 splice loss with 0.3 dB loss / splice

3 dB system margin added

The worst case, EOL power budget for this example would therefore be:

Transmitter power	–5 dBm
Receiver Sensitivity	– (–18 dBm)
Connector loss (2 × .5 dB)	–1
Patch loss (2 × 1 dB)	–2
Splice loss (0.3 dB)	–0.3
System margin	–3
EOL power budget	6.7 dB

The *estimated* reach is 6.7/0.35 = **19.14 km**

D.5 Dispersion

For a SMF having a zero-dispersion wavelength centred at 1 302 nm and a laser optical wavelength of 1 310 nm ±40 nm, the dispersion coefficient can be calculated using the zero-dispersion slope parameter which can be obtained from the fibre data sheet.

NOTE – Zero-dispersion wavelength and zero-dispersion slope parameters are normally provided in the optical fibre data sheets from manufacturers.

For this example it is assumed that a zero-dispersion slope of 0.092 ps/(nm.km) is specified.

Calculating dispersion at 1 270 nm (1 310 nm – 40 nm) = –2.94 ps/nm.km

Calculating dispersion at 1 350 nm (1 310 nm + 40 nm) = 4.416 ps/nm.km

The dispersion limited link length is determined by the following equation:

$$L = \frac{0.491}{B.D.\Delta\lambda}$$

Where B is the bit rate, D is the dispersion (ps/nm.km) and $\Delta\lambda$ is the source line width (nm).

Choosing the worst case absolute dispersion of 4.416/nm.km, then for 1.5 Gbit/s data, we get a dispersion-limited link length of 18.7 km, and the length is reduced to 9.3 km at 3.0 Gbit/s.

In this example it is clear that the link is dispersion limited at both 1.5 Gbit/s and 3 Gbit/s.

D.6 Multimode link distance calculation

In the case of Multimode fibre, the link distances are not often limited by overall power budget, but by intermodal dispersion.

Optical fibre manufactures specify the Effective Modal Bandwidth for multimode fibre at a given wavelength and this property is expressed in units of MHz.km.

There are several different multimode fibre types with differing core sizes and modal bandwidths. It is important to select the appropriate fibre for the required application.

Table D-3 below contains values for attenuation and minimum modal bandwidth for various fibre types. Actual values will be provided by the fibre manufacturer.

TABLE D-3

Multimode fibre parameters

Parameter	**50/125 um**			**62.5/125 um**
ISO/IEC 11801 Performance Category	OM2	OM3	OM4	OM1
Attenuation (dB/km) @ 850 nm @ 1 300 nm	<3.0 <1.0			<3.5 <1.0
Effective Modal Bandwidth (MHz.km) @ 850 nm @ 1 300 nm	>500 >500	>1500 >500	>3500 >500	>200 >600

For this example, the following basic assumptions apply:

The worst case fibre loss for OM3 fibre at 850 nm is 3 dB/km

850 nm FP transmitter – minimum output power → –5 dBm

PIN Receiver – minimum sensitivity (pathological) of –18 dBm

2 connectors with .5 dB loss / connector

2 patch losses with 1 dB loss / patch

1 splice loss with 0.3 dB loss / splice

3 dB system margin added

The worst case, EOL power budget for this example would therefore be:

Transmitter power	–5 dBm
Receiver Power	– (–18 dBm)
Connector loss (2 × .5 dB)	–1
Patch loss (2 × 1 dB)	–2
Splice loss (0.3 dB)	–0.3
System margin	–3
EOL power budget	6.7 dB

The *estimated* reach is 6.7 dB / 3 dB/km = 2.23 km

D.7 Intermodal Dispersion

The formula for calculating the maximum link distance as a function of data rate is as follows:

Maximum distance = (Modal Bandwidth of Fibre) / (Datal Rate).

For OM3 MM fibre with a 50 um core, the effective modal bandwidth is 1 500 MHz.km at 850 nm.

For 1.5 Gbit/s data, we get a dispersion-limited link length of 1 km.

At 3.0 Gbit/s, the length is reduced to ~500 m.

Appendix E
(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 E-1 to E-3 illustrate that equipment designed to work in compliance with Recommendation ITU-R BT.1367 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 E-3, at least 9 dB of attenuation is required 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 fibre 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 E-1

Low-power (short-haul) link applications – detector damage thresholds

	Single-mode fibre		**Multi-mode fibre**	
	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-E-2

Medium-power (medium-haul) link applications – detector damage thresholds

	Single-mode fibre	
	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 E-3

High-power (long-haul) link applications – detector damage thresholds

	Single-mode fibre	
	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

Appendix F
(Informative)

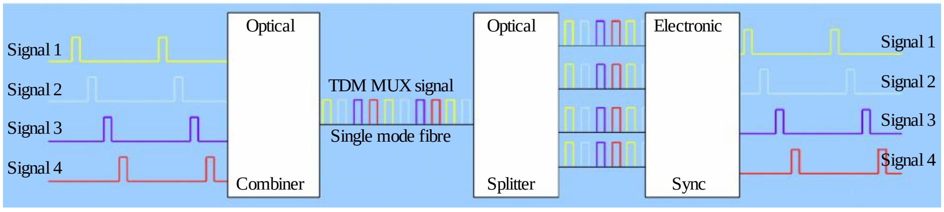
Fibre Optic Multiplexing

The optical fibre has a large bandwidth and is capable of carrying multiple signals. To accomplish this multiplexing is required. Time division and wavelength division multiplexing are the two most commonly used.

F.1 Time division multiplexing (TDM)

The TDM multiplex is controlled in the electrical domain and is synchronous. A typical TDM system is shown in Fig. F-1 below.

FIGURE F-1
TDM system



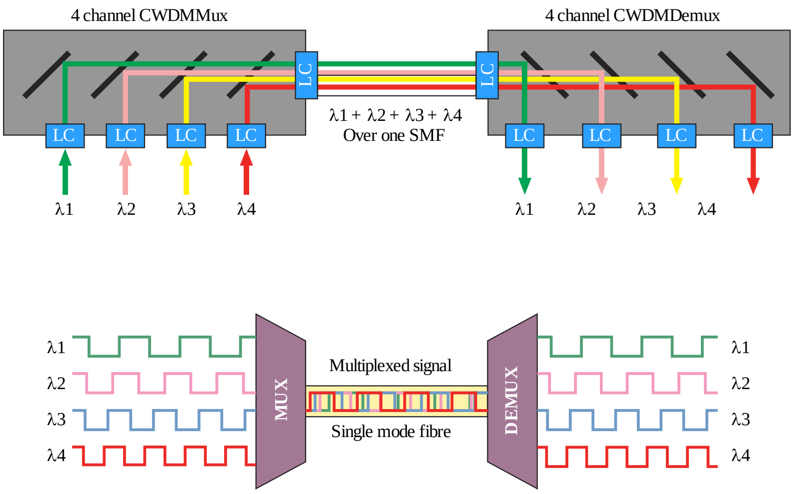
BT.11367-F01

The optical requirements for a TDM system are inexpensive, but there are disadvantages. There is a high cost of synchronization; a limited number of signals can be used based on the maximum link rate, and the distance is limited by the dispersion within the fibre.

F.2 Wavelength Division Multiplexing (WDM)

In wavelength division multiplexing (WDM) multiple DFB lasers are tuned to specific wavelengths which are grouped together with optical filters (Optical MUX) and travel independently along the fibre. At the end of the fibre filters are used to separate (Optical Demux) the individual wavelengths. A typical WDM system is depicted in Fig. F-2 below.

FIGURE F-2
WDM system



BT.11367-F02

The Optical mux and optical demux consist of a Series of passive optical filters made with prisms, thin film filters, dichroic filters or interference filters.

Each filter reflects a single wavelength of light and pass all others almost transparently (Average loss/filter ≅ .5 dB)

4 channel CWDM → Total Mux+Demux loss/channel ≅ 2 dB

8 channel CWDM → Total Mux+Demux loss/channel ≅ 4 dB

16 channel CWDM → Total Mux+Demux loss/channel ≅ 7 dB

It is important to note that each wavelength can operate at an independent bit rate and will not interfere with any of the other signals. This allows multiple different image formats and signal types, such as AES, MADI, DVB-ASI, 3G/HD/SD SDI or Ethernet to be carried simultaneously on a single fibre.

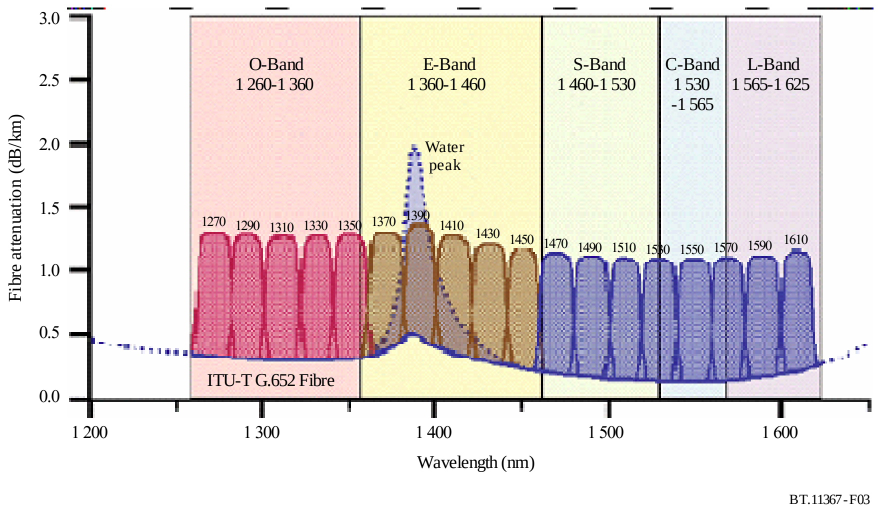
Coarse Wavelength Division Multiplexing (CWDM) uses wavelengths separated by 20 nm beginning at 1 271 nm to 1 611 nm as defined in ITU-T G.694.2 Spectral grids for WDM applications: CWDM wavelength grid.

There are a total of 18 wavelengths available but 2 wavelengths (1 390 nm and 1 410 nm as specified in ITU-T G.652a/b) are not typically used as they overlap the water absorption peak.

To use all 18 wavelengths, a special "low water peak fibre" ITU-T G.652c/d is required. Figure F-3 below depicts the CWDM bands.

FIGURE F-3

CWDM wavelength bands

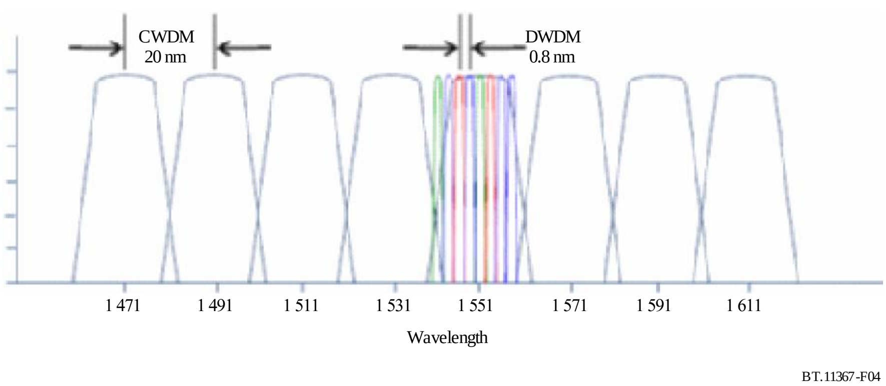


In a Dense Wavelength Division Multiplexing (DWDM) system, wavelengths are separated by 0.2 nm to 3.2 nm from 1 550 nm to 1 610 nm as defined in ITU-T G.694.1 Spectral grids for WDM applications: DWDM frequency grid.

This allows up to 160 wavelengths per fibre. The narrow spacing requires high stability lasers and more complex filters to MUX and DEMUX the signals leading to a much higher system implementation cost. This generally makes DWDM too expensive to implement for point-to-point and campus applications.

FIGURE F-4

DWDM wavelength bands and spacing



Typically CWDM is used for regional or metro installations with link distances less than 60 km, while DWDM is generally used for long haul applications.

Appendix G
(Informative)

Glossary of fibre optic terms

(The terms defined here are used in this Recommendation and associated normative references.)

Absorption: That portion of optical attenuation in optical fibre resulting from the conversion of optical power to heat. Caused by impurities in the fibre 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 fibre core at the core-cladding interface. The Acceptance angle is equal to $\sin^{-1}$(NA). Where NA is the numeric aperture.

Adapter: A mechanical device designed to align and join fibre 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 fibre 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 fibre 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 dB = $-10 \log_{10} (P_o/P_i)$ where P_i is the optical power measured at the input and P_o is the optical power measured at the output. Since P_o is less than P_i, 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 fibre, usually measured in decibels per kilometre (dB/km) at a specific wavelength. The lower the number, the better the fibre.

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 fibre.

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 fibre'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 fibre in kilometres and the maximum 3 dB bandwidth that the fibre 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 fibre or fibre cable can be bent before causing excessive attenuation or fibre breakage.

Bending loss: Attenuation that occurs at the location where a fibre 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 error per billion bits (1×10^{-9}) sent are typical in fibre optic systems.

Buffer: Material used to protect optical fibre 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 of two fibres end to end, without a connector.

Centre wavelength: The nominal centre 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 fibre by affecting the rise/fall times of digital signals at the optical receiver.

Cladding: The dielectric material surrounding the core of an optical fibre. 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 fibre.

Coarse wavelength division multiplexing (CWDM): CWDM combines up to eighteen widely-spaced optical carrier frequencies on a single fibre, 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 fibre 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", "2 × 2s", or "1 × 2s".

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 fibre axis at which a ray may be totally reflected at the core/cladding interface.

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

Dark current: The external current that, under reverse-bias conditions, flows in a photo detector 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 (Mbit/s) or Gigabits per second (Gbit/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 $\log_{10}(P_1/P_2)$, where P_1 and P_2 are the ratio of the two power levels.

Dense wavelength division multiplexing (DWDM): DWDM combines numerous closely-spaced wavelengths in the 1 550 nm region onto a single optical fibre. Wavelength spacing is 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 fibre: A fibre that has dispersion opposite of other fibres in a transmission system, thus compensating for dispersion effects in other fibres.

Dispersion shifted fibre: A type of single-mode fibre tailored to exhibit zero dispersion near 1 550 nm. This fibre type works very poorly for DWDM applications because of high fibre 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 connector or splicing of two fibres. See Intrinsic Losses.

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

Fibre optic link: A fibre 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 fibre. 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 fibre: An optical fibre with a refractive index that is a parabolic function of the radial distance from the fibre 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 fibre 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 fibre, 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.

Inner-duct: A reinforced flexible plastic tube designed for:

– providing multiple inner conduits within a single large conduit,

– providing physical protection to a fibre cable in a cable tray or under floor installation, or

– providing plenum rating for a non-plenum rated fibre cable. Inner-duct is typically corrugated in construction and brightly coloured to permit rapid eye detection in a cable tray or under floor installation.

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

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 ($LiNbO_2$).

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 signalled by turning a laser or LED on and off.

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

Intrinsic losses: Losses inherent in optical fibre splices that are caused by minute differences between the fibres 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 centimetres squared, or W/cm^2.

Jumper cable: A fibre optic cable fitted with connectors that is of limited length. Jumper cables are used to interconnect between fibre optic equipment and/or other fibre 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 fibre: A fibre that connects a laser or LED to another fibre, typically a jumper cable.

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.

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.

Lightguide: Synonym for optical fibre.

Lightwave: Electromagnetic waves in the region of optical frequencies that propagate in a direction normal to the optical wave front.

Link BUDGET (optical link budget, link loss budget, power budget): The range of optical power over which a fibre optic link will operate within performance specifications. It is computed by subtracting the optical power launched into an optical fibre 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 fibre from a straight line that cause light to leak out of the fibre, resulting in optical attenuation.

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

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

Micron: Micrometre (mm). One millionth of a metre (1×10^{-6} m).

Modal dispersion (multimode dispersion): Pulse spreading due to multiple light rays travelling different distances and speeds through an optical fibre.

Modal noise: Disturbance in multimode fibres fed by laser diodes. It occurs when the fibres 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 fibre systems, a mode filter strips high-order modes off of the power at the launch end, simulating the mode distribution of light in a fibre as it would be if it were measured hundreds of metres into the fibre. 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 fibre 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 fibre: Optical waveguide whose core diameter is large compared with the optical wavelength and in which more than a single mode is capable of propagation.

Nanometre (nm): One billionth of a metre (1×10^{-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 fibre (NZDSF): A dispersion-shifted single-mode fibre that exhibits near the 1550 nm window, but outside the window actually used to transmit signals, maximizing fibre bandwidth while minimizing the effect of fibre nonlinearities on the signal being transmitted.

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

Optical fibre: Any filament or fibre made of dielectric materials that guides light.

Optical time domain reflectometer (OTDR): A device that tests a fibre by transmitting an optical pulse through the fibre 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 fibres mounted in ferrules so as to minimize Fresnel reflection effects at the connector endfaces.

Pigtail: A short length of optical fibre for coupling optical components. It is usually permanently fixed to the component at one end and a 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 Fibre: Single-mode optical fibre that maintains a single launched light polarization along its length. Since it does not convert light from one polarization to another, polarization maintaining fibre exhibits excellent dispersion characteristics that make it suitable for extremely high-speed data transfers.

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

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

UPC/SPC: Abbreviation for ultra physical contact/super physical contact. A style of fibre optic connector manufactured or polished with a convex rounded finish allowing the fibres to touch on a high point near the fibre 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: 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 fibre optic cable that employs a rectangular cross section of moulded 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 fibre: Optical fibre with a small core diameter in which only a single mode, the fundamental mode, is capable of propagation. This type of fibre 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 fibre optic cable utilizing a spring-loaded twist and lock coupling similar to the BNC connectors used with coax cable.

Step Index fibre: A fibre 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 fibre.

Wavelength chirp: A shifting of a laser diode's Centre Wavelength as it is switched on and off in digital fibre optic systems.

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

Window: The term window refers to ranges of wavelengths matched to the properties of the optical fibre. The window ranges for fibre optics are the following: First window: 820 to 850 nm, second window: 1 300 to 1 310 nm, the third window: 1 550 nm.

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