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## Single-mode fibre optic connectors

Recommendation ITU-T L.36

ITU-T

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## Single-mode fibre optic connectors


### Summary

Recommendation ITU-T L.36 describes the main features of fibre optic connectors, in terms of types, fields of application, configurations and technical aspects. Further, this Recommendation examines the optical, mechanical and environmental characteristics of fibre optic connectors, advising on general requirements and test methods.

While taking into account Recommendation ITU-T G.671 as far as the transmission parameters are concerned, this Recommendation is based on the most recent work carried out within IEC SC86B Working Groups 4 and 6, namely the IEC 61300 and IEC 61753-series.


### History

| Edition | Recommendation | Approval | Study Group | Unique ID* |
|---|---|---|---|---|
| 1.0 | ITU-T L.36 | 1998-10-09 | 6 | 11.1002/1000/4508 |
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## Table of Contents

## Recommendation ITU-T L.36

# Single-mode fibre optic connectors

### 1 Scope

This Recommendation:

- gives general information on fundamental types of fibre optic connectors, their field of application and the main requirements about their characteristics in terms of optical, mechanical and environmental behaviour;
- makes a classification of these components in terms of the configurations used into fibre optic plants;
- gives a general description of the basic principles of operation and of technologies of fabrication of fibre optic connectors;
- describes all the most important optical parameters and gives general specifications on the optical, mechanical and environmental performance of fibre optic connectors;
- describes the main test methods of fibre optic connectors;
- is limited to factory installed connectors; these are connectors that have been applied to the fibre and/or cable in a controlled factory environment. Field mountable connectors, which are to be applied to the fibre and/or cable by an installer in field conditions, are outside the scope of this Recommendation.

### 2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.


[ITU-T G.652] Recommendation ITU-T G.652 (2009), *Characteristics of a single-mode optical fibre and cable*.

[ITU-T G.653] Recommendation ITU-T G.653 (2010), *Characteristics of a dispersion-shifted, single-mode optical fibre and cable*.

[ITU-T G.654] Recommendation ITU-T G.654 (2012), *Characteristics of a cut-off shifted single-mode optical fibre and cable*.

[ITU-T G.655] Recommendation ITU-T G.655 (2009), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.

[ITU-T G.656] Recommendation ITU-T G.656 (2010), *Characteristics of a fibre and cable with non-zero dispersion for wideband optical transport*.

[ITU-T G.657] Recommendation ITU-T G.657 (2012), *Characteristics of a bending-loss insensitive single-mode optical fibre and cable for the access network*.

[ITU-T G.671] Recommendation ITU-T G.671 (2012), *Transmission characteristics of optical components and subsystems*.

[IEC 61300-2-1] IEC 61300-2-1 (2009), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-1: Tests – Vibration (sinusoidal)*.

[IEC 61300-2-2] IEC 61300-2-2 (2009), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-2: Tests – Mating durability*.

[IEC 61300-2-4] IEC 61300-2-4 (1995), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-4: Tests – Fibre/cable retention*.

[IEC 61300-2-5] IEC 61300-2-5 (2009), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-5: Tests – Torsion*.

[IEC 61300-2-6] IEC 61300-2-6 (2010), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-6: Tests – Tensile strength of coupling mechanism*.

[IEC 61300-2-12] IEC 61300-2-12 (2009), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-12: Tests – Impact*.

[IEC 61300-2-17] IEC 61300-2-17 (2010), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-17: Tests – Cold*.

[IEC 61300-2-18] IEC 61300-2-18 (2005), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-18: Tests – Dry heat – High temperature endurance*.

[IEC 61300-2-19] IEC 61300-2-19 (2012), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-19: Tests – Damp heat (steady state)*.

[IEC 61300-2-21] IEC 61300-2-21 (2009), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-21: Tests – Composite temperature/humidity cyclic test*.

[IEC 61300-2-22] IEC 61300-2-22 (2007), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-22: Tests – Change of temperature*.

[IEC 61300-2-26] IEC 61300-2-26 (2006), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-26: Tests – Salt mist*.

[IEC 61300-2-27] IEC 61300-2-27 (1995), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-27: Tests – Dust – Laminar flow*.

[IEC 61300-2-42] IEC 61300-2-42 (2014), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-42: Tests – Static side load for strain relief*.

[IEC 61300-2-44] IEC 61300-2-44 (2013), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 2-44: Tests – Flexing of the strain relief of fibre optic devices*.

[IEC 61300-3-6] IEC 61300-3-6 (2008), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-6: Examinations and measurements – Return loss*.

[IEC 61300-3-28] IEC 61300-3-28 (2012), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-28: Examinations and measurements – Transient loss*.

[IEC 61300-3-34] IEC 61300-3-34 (2009), *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-34: Examinations and measurements – Attenuation of random mated connectors*.

[IEC 61753-1] IEC 61753-1 (2007), *Fibre optic interconnecting devices and passive components performance standard – Part 1: General and guidance for performance standards*.

[IEC 61755-1] IEC 61755-1 (2005), *Fibre optic connector optical interfaces – Part 1: Optical interfaces for single mode non-dispersion shifted fibres – General and guidance*.

## 3 Definitions

### 3.1 Terms defined elsewhere

None.

### 3.2 Terms defined in this Recommendation

None.

## 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

APC Angled Physical Contact

GWOA Gaussian Weighted Occluded Area

PC Physical Contact

## 5 Conventions

None.

## 6 General information

Fibre optic connectors provide a method for jointing the ends of two optical fibres. Such a joint is not a permanent one, but it can be opened and closed several times. The optical connectors are required in the points of the network in which it is necessary to have flexibility in terms of network configuration and test access.

Fibre optic connectors have applications in all types of networks, at the input and output ports of the transmission systems and are also used to connect test equipment and instrumentation.

The connection can have a plug-adapter-plug or a plug-socket configuration.

The main effects of the introduction of a connector in an optical line are an attenuation on the transmitted signal and a reflection of a part of the signal.

## 7 Types and configurations

Fibre optic connectors can be classified on the basis of the:

– type of cable;
– type of fibre;
– fibre alignment system;
– fibre end-face finish;
– number of jointed fibres;
– type of coupling mechanism;
– outer diameter of the ferrule *(2.5 mm or 1.25 mm)*, when applicable;
– connector mating lay out ("plug and socket" or "plug-adapter-plug").

### 7.1 Fibre types

The type of connector, and in particular, its grade of mechanical accuracy depends on the type of fibre to be jointed. The fibres to be considered are those specified in [ITU-T G.652], [ITU-T G.653], [ITU-T G.654], [ITU-T G.655], [ITU-T G.656] and [ITU-T G.657]. Particularly, great accuracy is necessary to align two single-mode fibres in which the light is guided in a core of approximately 9 µm.

### 7.2 Cable types

The connector can be assembled with:

– primary coated fibre (250 µm);
– secondary coated fibre (900 µm);
– single fibre cable (typically from 0.9 mm to 4.5 mm).

### 7.3 Fibre alignment system

a) *Direct alignment*: In this type of solution, the bare fibre is directly aligned by V-groove or capillary tubes.

b) *Secondary alignment*: In this case, the fibre is fixed in a structure, usually a cylindrical ferrule for single or duplex fibre connections or a rectangular section body for duplex or multiple fibre joint. These structures are aligned by means of sleeves, pins or other systems.

c) *Lens alignment*: The optical alignment of the fibres is obtained by means of a lens.

NOTE – Secondary alignment is the most commonly applied design; loss criteria of most standards are established for this type of connector.

### 7.4 Fibre and ferrule end-face finish

For both direct alignment and ferrule-based connectors, the end face of the fibre or the ferrule is prepared (normally by polishing) to give fibre to fibre contact either where the end faces are perpendicular to the fibre axis or at a small angle to the perpendicular. For ferrules, two common cases are found:

a) **Physical contact (PC)**: This finish is typically used in a single or duplex fibre connector. The end face is polished to a spherical shape in order to obtain a perfect contact between the two fibre cores and to improve the transmission performance of the connector. A typical spherical radius is 5-30 mm.

b) **Angled physical contact (APC)**: This finish is similar to the PC, but in this case the polished end surface of the ferrule is angled with respect to the fibre axis. This solution gives low values of reflected power. Typical angles are 8 or 9 degrees for ITU-T G.652-type fibres. A typical end surface radius is in the range of 5 to 12 mm.

In ferrule-less connectors, the fibre is fixed in the connector plug and the fibre ends are factory prepared (normally by cleaving, polishing or another surface shaping procedure). Fibres are aligned by means of sleeves, pins or other systems and often index matching gel is applied between the fibres.

### 7.5 Coupling mechanism

The most common systems for mating together two plugs (or the plug and the socket) are:

– push-pull mechanism;

– screw mechanism;

– bayonet mechanism.

## 8 Characterization parameter definitions

### 8.1 Optical parameters

The fibre optic connectors are characterized by several parameters; the most important are:

#### 8.1.1 Attenuation

The attenuation, *A*, introduced by the fibre optic connector is defined as:

$$A = -10 \cdot \log \frac{P_i}{P_0} \qquad [\text{dB}]$$

where $P_0$ is the optical power just before the connection and $P_i$ is the optical power just after the connection.

#### 8.1.2 Return loss

The return loss, *RL*, introduced by the fibre optic connector is defined as:

$$RL = -10 \cdot \log \frac{P_r}{P_0} \qquad [\text{dB}]$$

where $P_0$ is the optical power measured at the connection interface and $P_r$ is the optical power reflected by the connector.

#### 8.1.3 Classes of wavelength

Connector assemblies should be suitable to operate in the wavelength range of at least 1'260 to 1'625 nm.

### 8.2 Mechanical parameters

#### 8.2.1 Vibrations

This parameter assesses the resistance of the connector during the applications of sinusoidal oscillations along three orthogonal axes.

#### 8.2.2 Strength of the coupling mechanism

This is the pulling force withstood by the coupling mechanism just before the disconnection of the connector.

### 8.2.3 Mechanical resistance of the attachment of the fibre/cable to the plug connector

This is the resistance of the attachment point of the fibre or cable to the plug when it is subjected to mechanical stress such as pulling and torsion.

### 8.2.4 Mechanical endurance

This parameter assesses the number of connections that the connector shall guarantee without deteriorating its optical performance.

## 8.3 Environmental parameters

### 8.3.1 Operating temperature

This is the range of temperature in which the performance of the fibre optic connector is guaranteed.

### 8.3.2 Climatic effects

This is the range of variation of environmental conditions that is applied when evaluating changes in mechanical and optical performance. This includes changes in temperature and humidity, as well as the rate of change of these conditions.

# 9 Performance criteria and test methods

For the characterization or validation of a connector system, fibres with the same nominal mode field diameter should be used, in order to avoid incorrect results due to mismatches between different fibres. For single-mode fibre, more details on fibre dimensions and tolerances can be found in [IEC 61755-1].

Unless otherwise stated in the individual test details, all attenuation and return los measurements shall be performed at both 1'310 nm ± 30 nm and 1'550 nm ± 30 nm.

Unless the context requires otherwise, numerical limits in this standard are to be taken as exact, irrespective of the number of significant digits or trailing zeros.

Before starting each test, the plugs and the adaptor shall be cleaned according to manufacturers' instructions.

## 9.1 Optical performance requirements

### 9.1.1 Attenuation [IEC 61300-3-34]

Four grades of attenuation can be defined according to [IEC 61755-1]:

**Table 9-1 – Attenuation grades**

| Attenuation grade | Attenuation [IEC 61300-3-34] |
|---|---|
| Grade A | Not defined yet |
| Grade B | ≤ 0.12 dB mean<br>≤ 0.25 dB max. for > 97% of samples |
| Grade C | ≤ 0.25 dB mean<br>≤ 0.5 dB max. for > 97% of samples |
| Grade D | ≤ 0.5 dB mean<br>≤ 1 dB max. for > 97% of samples |

These values are referred to random mating between randomly selected plugs from production.

### 9.1.2 Return loss [IEC 61300-3-6]

Four grades of return loss can be defined according to [IEC 61755-1]:

**Table 9-2 – Return loss grades**

| Return loss grade | Return loss random mated [IEC 61300-3-6] |
|---|---|
| Grade 1 | ≥ 60 dB (mated) and ≥ 55 dB (unmated) |
| Grade 2 | ≥ 45 dB |
| Grade 3 | ≥ 35 dB |
| Grade 4 | ≥ 26 dB |

These values are referred to random mating between randomly selected plugs from production.

Grades 2, 3 and 4 are referred to the physical contact fibre end-face finish while grade 1 is referred to the angled physical contact fibre end-face finish.

A methodology for estimating reflectance from optical connectors deployed in the field is described in Appendix II.

## 9.2 Mechanical performance requirements

### 9.2.1 Vibration [IEC 61300-2-1]

The vibration test has the following characteristics:

– frequency range: 10 to 55 to 10 Hz change at 1 octave/min

– number of axis: three, orthogonal

– number of cycles (10 to 55 to 10): 15

– vibration amplitude: 0.75 mm (or 1.5 mm peak-to-peak)

The change in attenuation during the test shall be measured by means of transient monitoring at 1'550 nm ± 30 nm for single-mode connectors according to [IEC 61300-3-28]. The maximum allowed change in attenuation shall be ≤ 0.2 dB. The return loss shall meet the specified grade after the vibration test.

### 9.2.2 Strength of the coupling mechanism [IEC 61300-2-6]

The test is performed applying a specified axial load between the plug and the adapter.

The value of the load and the duration of the test are specified according to the specific coupling mechanism and the manufacturer's rating for the specific connector design. The recommended minimum load value is 40 N during 120 seconds.

During and after the test the change in attenuation shall not exceed 0.2 dB and the return loss shall satisfy the requirement for the specified grade.

### 9.2.3 Fibre/cable retention [IEC 61300-2-4]

The test is performed applying an axial load between the cable and the plug.

The load should be:

– 2 N for primary coated fibre;

– 5 N for secondary coated fibre;

– 50 N for aramid reinforced cable ≤ 2 mm diameter;

– 100 N for aramid reinforced cable > 2 mm diameter.

The load shall be applied smoothly and be kept constant for a duration of 60 seconds (2 N and 5 N) or 120 seconds (50 N or 100 N).

During and after the test, the change in attenuation shall not exceed 0.2 dB and the return loss shall satisfy the requirement for the specified grade.

#### 9.2.4 Torsion [IEC 61300-2-5]

The test is performed applying a torque on the cable at the distance of 20 cm from the connector. The cable is kept taut by a load of 15 N. In total 25 torsion cycles of ±180° shall be applied.

During and after the test, the change in attenuation shall not exceed 0.2 dB and the return loss shall satisfy the requirement for the specified grade.

#### 9.2.5 Flexing of strain relief [IEC 61300-2-44]

The test is performed on aramid yarn reinforced cables. A load of 5 N is applied on the cable at the distance of 20 cm from the connector. The connector is rotated ±90° about an axis perpendicular to the axis of the attached cable. Gentle rotational movements are used, not exceeding 20 cycles/min. In total, 100 cycles shall be performed. The dwell at each extreme shall not be greater than 5 seconds.

The change in attenuation during and after the test shall be measured by means of transient monitoring at 1'550 nm ± 30 nm for single-mode connectors according to [IEC 61300-3-28]. The maximum allowed change in attenuation shall be ≤ 0.3 dB. The return loss shall meet the specified grade after the vibration test.

#### 9.2.6 Static side load [IEC 61300-2-42]

The test is performed by applying a load on the fibre or cable at the distance of 20 cm from the connector. The load should be:

– 0.2 N for secondary coated fibre;

– 1 N for aramid yarn reinforced cable.

The load shall be applied smoothly at 90° to the connector axis and kept constant for a duration of 5 minutes at 0.2 N or 1 hour at 1 N.

During and after the test, the change in attenuation shall not exceed 0.2 dB and the return loss shall satisfy the requirement for the specified grade.

#### 9.2.7 Impact [IEC 61300-2-12] Method A

An unmated connector with a 2 m cable length is dropped five times from a height of 1.5 m.

– drop height: 1.5 m;

– drop surface: metal plate (or concrete floor);

– number of cycles: 5.

The connector will be protected with a dust cap during the test.

Attenuation and return loss shall be measured before and after the test and shall meet the requirements in Table 9-1 and Table 9-2.

#### 9.2.8 Mating durability [IEC 61300-2-2]

The test is carried out by connecting a plug and an adapter 500 times (one side of the connector set only in the case of a plug-adapter-plug configuration).

The variation of the attenuation shall be less than 0.2 dB and the return loss shall not fall below the minimum for the grade.

In the event that the change in attenuation increases above or the return loss below the allowable limit, the connector may be cleaned as necessary but not more than 25 times during the course of the test. The measurement at which the cleaning takes place shall be discounted from the test results.

### 9.3 Environmental performance requirements

The recommended temperature ranges in which the connector performance should be guaranteed are from –40°C to +70°C for outdoor applications ("outdoor protected environment") and –10°C to +60°C for indoor applications ("controlled environment").

Patch cords shall be tested by placing the complete test assembly in the climatic test chamber. A typical test assembly contains two connections plus the necessary cables: two to five metres of cable between connectors plus the leads to connect the patch cord to the equipment outside the climatic test chamber.

#### 9.3.1 Cold [IEC 61300-2-17]

- temperature: –10°C (for indoor applications) or –40°C (for outdoor applications)
- duration: 16 hours
- preconditioning and recovery: 2 hours in room temperature condition

Attenuation shall be measured before, at a maximum interval of one hour during and after the test. The maximum allowed change in attenuation during and after the test shall be ≤ 0.5 dB for the complete assembly.

Return loss shall be measured before, during and after the test and shall satisfy the requirements for the specified class.

#### 9.3.2 Dry heat [IEC 61300-2-18]

- temperature: 60°C (for indoor applications) or 70°C (for outdoor applications)
- duration: 96 hours
- preconditioning and recovery: 2 hours in room temperature condition

Attenuation shall be measured before, at a maximum interval of one hour during, and after the test. The maximum allowed change in attenuation during and after the test shall be ≤ 0.5 dB for the complete assembly.

Return loss shall be measured before, during and after the test and shall satisfy the requirements for the specified class.

Strength of coupling mechanism shall be measured on completion of test after recovery procedure.

#### 9.3.3 Damp heat (steady state) [IEC 61300-2-19]

- high humidity exposure (for indoor applications only)
- temperature: 40°C ± 2°C
- relative humidity: 93% ± 3%
- duration: 96 hours
- preconditioning and recovery: 2 hours in room temperature condition

Attenuation shall be measured before, at a maximum interval of one hour during and after the test. The maximum allowed change in attenuation during and after the test shall be ≤ 0.5 dB for the complete assembly.

Return loss shall be measured before, during and after the test and shall satisfy the requirements for the specified class.

### 9.3.4 Composite temperature/humidity cyclic test [IEC 61300-2-21]

Change of temperature and humidity cycle profile with exposure to cold (for outdoor applications only).

– temperature extremes: –10°C ± 2°C to +65°C ± 2°C
– relative humidity: 93% ± 3% at the maximum temperature
– dwell time: 3 hours at the temperature extremes
– duration: 10 cycles

Attenuation shall be measured before, at a maximum interval of one hour during and after the test. The maximum allowed change in attenuation during and after the test shall be ≤ 0.5 dB for the complete assembly.

Return loss shall be measured before, during and after the test and shall satisfy the requirements for the specified class.

### 9.3.5 Change of temperature [IEC 61300-2-22]

– high temperature: 60°C (for indoor applications) or 70°C (for outdoor applications)
– low temperature: –10°C (for indoor applications) or –40°C (for outdoor applications)
– duration at extreme temperature: 1 hour
– temperature rate of change: 1ºC/min.
– number of cycles: 12
– preconditioning and recovery: 2 hours in room temperature condition

Attenuation shall be measured before, at a maximum interval of 10 minutes during and after the test. The maximum allowed change in attenuation during and after the test shall be ≤ 0.5 dB for the complete assembly.

Return loss shall be measured before, at a maximum interval of 10 minutes during and after the test and shall satisfy the requirements for the specified class.

### 9.3.6 Dust [IEC 61300-2-27]

Exposure to dust (for outdoor applications)

– dust type: talc
– dust particle size: d < 150 µm
– dust concentration: 10.6 µm ± 7.0 µm
– temperature: 35°C
– duration: 10 minutes

The test shall be done with mated pairs of connectors which once mated for the initial measurements shall not be disconnected until after the completion of the test.

Attenuation and return loss shall be measured before and after the test and shall meet the requirements in Table 9-1 and Table 9-2.

### 9.3.7 Salt mist [IEC 61300-2-26]

Exposure to corrosive atmosphere (for outdoor applications only)

– solution: 5% NaOH with pH between 6.5 and 7.2
– temperature: 35°C
– duration: 96 hours

The test shall be done with mated pairs of connectors which once mated for the initial measurements shall not be disconnected until after the completion of the test.

Attenuation and return loss shall be measured before and after the test and shall meet the requirements in Table 9-1 and Table 9-2.

## 10 Connector identification

It is important to be able to distinguish cable assemblies by their characteristics such as fibre and cable type, polishing type and attenuation and return loss grades.

While no complete international standard is approved at this time, the general trend is to colour code the plastic body connectors to distinguish the PC type from the APC type independently of the return loss performance.

The blue colour is used for the PC and the green colour for the APC.

As an alternative method, labels may be applied for connector type/class/grade identification, as they are independent of regional differences in colour code conventions. This may be an especially good alternative for metallic body connectors.

In any case, an appropriate identification system is to be agreed upon between the customer and the supplier.

Appendix I shows different regional conventions and the IEC standard on this subject.

# Appendix I

## Overview of international and regional conventions for colour coding of single-mode fibre optic connectors

(This appendix does not form an integral part of this Recommendation.)

In IEC (international) and Cenelec (European) standards, the colour coding of connectors is limited to the difference in fibre end-face angle: PC (=blue body) and APC (=green body).

For other connector properties (e.g., return loss properties), no colour coding is defined in these standards.

Table I.1 shows the colour code of the various parts of plastic body as per Telcordia GR-326, which is generally adopted in the United States.

**Table I.1 – Colour code for optical connectors (United States of America, Telcordia GR-326)**

| Plug type | Attenuation | Return loss class | Plug body | Boot |
|---|---|---|---|---|
| PC | Not specified | ≥ 30 dB<br>≥ 40 dB<br>≥ 55 dB | Blue | Red<br>White<br>Dark Blue |
| APC 8° | Not specified | ≥ 60 dB | Green | Green |
| APC 9° | Not specified | ≥ 60 dB | Green | Green |

Table I.2 shows the colour code of the various parts of plastic body connector used in China.

**Table I.2 – Colour code for optical connectors (China)**

| Plug type | Attenuation | Return loss class | Plug body | Boot |
|---|---|---|---|---|
| PC | ≤ 0.3 dB | ≥ 45 dB<br>≥ 55 dB | Blue | White |
| APC 8° | ≤ 0.3 dB | ≥ 60 dB | Green | Green |

Note that a colour code standardization for the single fibre cable may also be desirable in order to distinguish the ITU-T G.652 and ITU-T G.653 fibres. For example, Italy uses blue and orange respectively for ITU-T G.652 and ITU-T G.653 fibres. However, operating companies in some other countries do not use single fibre cables with ITU-T G.653 fibres. In the United States and Spain, yellow has universally been the colour code for single fibre cables with ITU-T G.652 fibres; this has been the case for as long as ITU-T G.652 fibres have been in existence.

# Appendix II

## Methodology for estimating reflectance from optical connector end-face contamination

(This appendix does not form an integral part of this Recommendation.)

Optical connector end-face contamination is known to increase optical reflectance and to cause optical system performance degradation. The reflectance from the optical connector must be quite low to satisfy the requirements for optical systems specified in ITU-T Recommendations. However, direct measurement of low optical reflectance is not easy once the connectors are in use, and automated visual measurement is often used to evaluate the quality of the optical connector. A method, based on similar work on cleanliness specifications for single-mode connectors by iNemi (International Electronics Manufacturing Initiative) reported in the technical report [b-IEC 62627-05], is proposed to estimate the reflectance of a connection based on the visual inspection of the connectors.

The connector end-face is divided into the four zones defined in Figure II.1. Zones A and B correspond to the core and cladding regions, respectively. Zone C is the adhesive region and Zone D is the ferrule region. Dust-particle size is also categorized into four classes; less than 2 µm, 2 to 5 µm, 5 to10 µm, and larger than 10 µm.

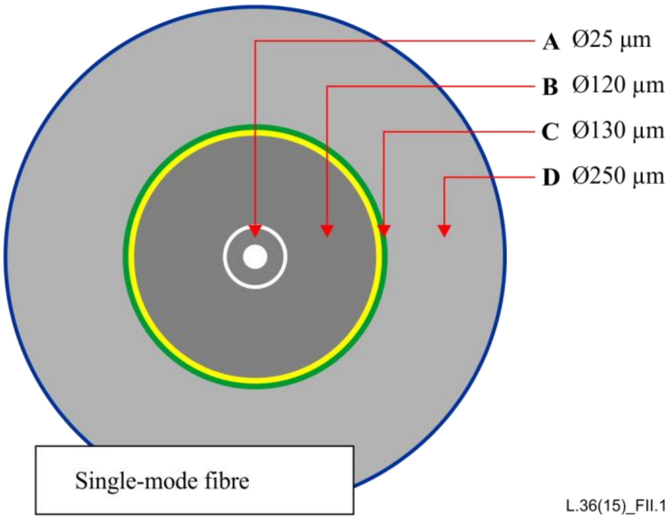


**Figure II.1 – Zones in connector end-face**

The size and position of a dust particle that adheres to the connector end-face are key factors that determine optical connector performance. The impact of dust on optical connector performance can be larger as the distance of the dust from the centre core area becomes shorter. This tendency can be evaluated with a Gaussian weighting factor Γ, which is expressed as:

$$\Gamma = \exp\left(\frac{-2r^2}{{\omega_f}^2}\right) \qquad \text{(II.1)}$$

where r is the radial position of a dust particle and $\omega_f$ is the mode-field radius of a single-mode optical fibre. The Gaussian weighted occluded area (GWOA) can then be defined as an evaluation parameter for optical connector end-face contamination, which is expressed as:

$$GWOA = \sum_{i=1}^{i=N} a_i \Gamma_i \qquad \text{(II.2)}$$

where *N* is the total number of dust particles, and $a_i$ is the sectional area of each dust particle.

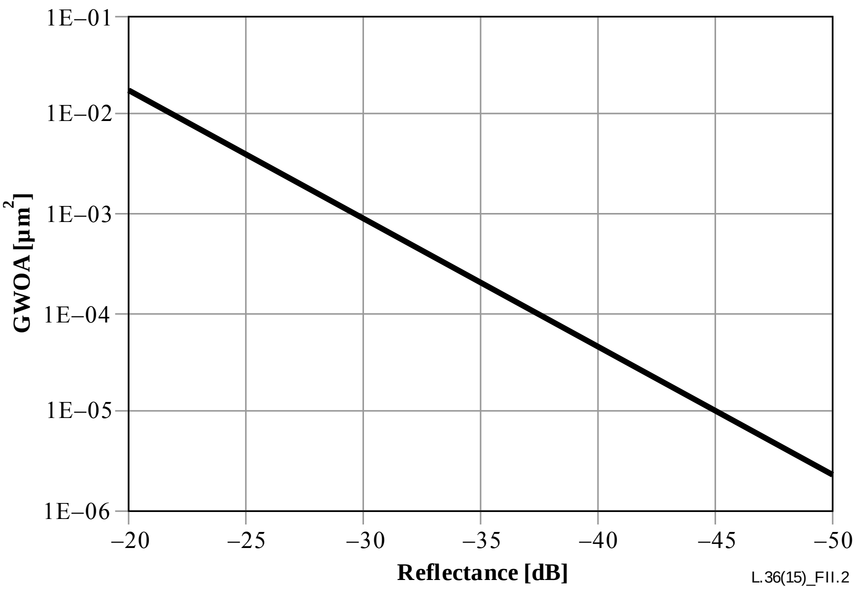


**Figure II.2 – GWOA vs. reflectance**

Based on an experimental investigation, the relation between the GWOA and reflectance is found to be:

$$GWOA = 6.04\exp(0.294R) \quad \text{(II.3)}$$

where R is the reflectance (a negative value in dB), which is plotted in Figure II.2. If the acceptable reflectance is set to −40 dB, for example, the GWOA is calculated as $5 \times 10^{-5}$ using Equation (II.3). Then, the acceptable number of dust particles of a specific size to remain below the GWOA for a fibre with a mode-field radius of 4.5 μm is calculated using Equation (II.2), as illustrated in Figure II.3.

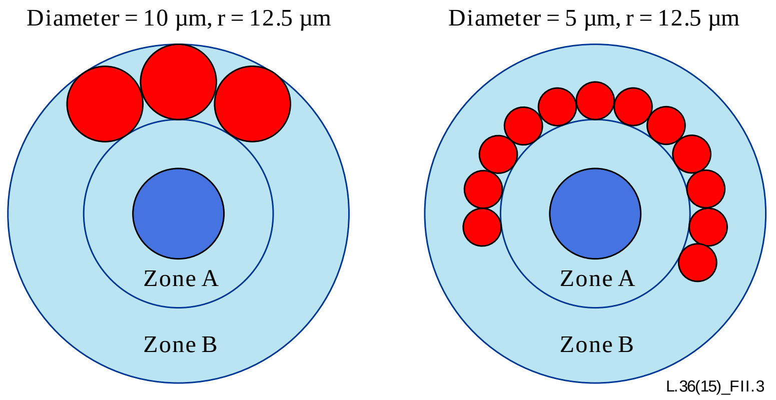


**Figure II.3 – Graphical mapping of acceptable number of dust particles for reflectance of −40 dB and a fibre mode-field radius of 4.5 μm**

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