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Digital sections and digital line system – Optical fibre  
submarine cable systems

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## **Characteristics of optical fibre submarine cables**

Recommendation ITU-T G.978



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# Recommendation ITU-T G.978

## Characteristics of optical fibre submarine cables

### Summary

Recommendation ITU-T G.978 deals with the characteristics of the optical fibre submarine cables used in Recommendations ITU-T G.973, ITU-T G.973.1, ITU-T G.974 and ITU-T G.977. It covers transmission characteristics of optical fibre submarine cables, optical fibres used in submarine cables, including mechanical characteristics and resistance to the environment and other electrical characteristics. It also covers the transmission characteristics of the single- and hybrid-fibre type elementary cable sections. Any specific information regarding the characteristics of optical fibre submarine cables are included in the relevant optical submarine system's Recommendations.

### History

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G.978	2006-12-14	15
2.0	ITU-T G.978	2010-07-29	15

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

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# Recommendation ITU-T G.978

## Characteristics of optical fibre submarine cables

### 1 Scope

This Recommendation deals with the characteristics of the optical fibre submarine cables used in [ITU-T G.973], [ITU-T G.973.1], [ITU-T G.974] and [ITU-T G.977].

An optical submarine cable can be used in:

- a repeatered optical submarine system;
- a repeaterless optical submarine system.

This Recommendation specifies the characteristics of the submarine cables which can be used in the deep and shallow waters.

This Recommendation covers:

- transmission characteristics of optical fibres in submarine cables including mechanical characteristics and resistance to the environment;
- characteristics of optical fibre submarine cables including mechanical characteristics and resistance to the environment and other electrical characteristics;
- transmission characteristics of single- and hybrid-fibre type elementary cable sections.

### 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.650.1] Recommendation ITU-T G.650.1 (2004), *Definitions and test methods for linear, deterministic attributes of single-mode fibre and cable.*
- [ITU-T G.650.2] Recommendation ITU-T G.650.2 (2007), *Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable.*
- [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 (2006), *Characteristics of a dispersion-shifted single-mode optical fibre and cable.*
- [ITU-T G.654] Recommendation ITU-T G.654 (2006), *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 (2006), *Characteristics of a fibre and cable with non-zero dispersion for wideband optical transport.*
- [ITU-T G.667] Recommendation ITU-T G.667 (2006), *Characteristics of adaptive chromatic dispersion compensators.*

- [ITU-T G.671] Recommendation ITU-T G.671 (2009), *Transmission characteristics of optical components and subsystems*.
- [ITU-T G.972] Recommendation ITU-T G.972 (2008), *Definition of terms relevant to optical fibre submarine cable systems*.
- [ITU-T G.973] Recommendation ITU-T G.973 (2007), *Characteristics of repeaterless optical fibre submarine cable systems*.
- [ITU-T G.973.1] Recommendation ITU-T G.973.1 (2009), *Longitudinally compatible DWDM applications for repeaterless optical fibre submarine cable systems*.
- [ITU-T G.974] Recommendation ITU-T G.974 (2007), *Characteristics of regenerative optical fibre submarine cable systems*.
- [ITU-T G.976] Recommendation ITU-T G.976 (2010), *Test methods applicable to optical fibre submarine cable systems*.
- [ITU-T G.977] Recommendation ITU-T G.977 (2006), *Characteristics of optically amplified optical fibre submarine cable systems*.

### 3 Definitions

#### 3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

- 3.1.1 submarine portion:** See [ITU-T G.972] (1005).
- 3.1.2 optical submarine repeater:** See [ITU-T G.972] (1020).
- 3.1.3 cable breaking load:** See [ITU-T G.972] (5007).
- 3.1.4 double armoured cable:** See [ITU-T G.972] (5004).
- 3.1.5 fibre-breaking cable load:** See [ITU-T G.972] (5008).
- 3.1.6 minimum cable bending radius:** See [ITU-T G.972] (5032).
- 3.1.7 nominal operating tensile strength:** See [ITU-T G.972] (5010).
- 3.1.8 nominal permanent tensile strength:** See [ITU-T G.972] (5009).
- 3.1.9 nominal transient tensile strength:** See [ITU-T G.972] (5011).
- 3.1.10 rock armoured cable:** See [ITU-T G.972] (5005).
- 3.1.11 single armoured cable:** See [ITU-T G.972] (5003).
- 3.1.12 relative dispersion slope:** See [b-ITU-T G-Sup.40].
- 3.1.13 terminal transmission equipment:** See [ITU-T G.972] (1010).
- 3.1.14 optical fibre submarine cable:** The submarine cable using optical fibres as transmission line. (1019 in [ITU-T G.972]).

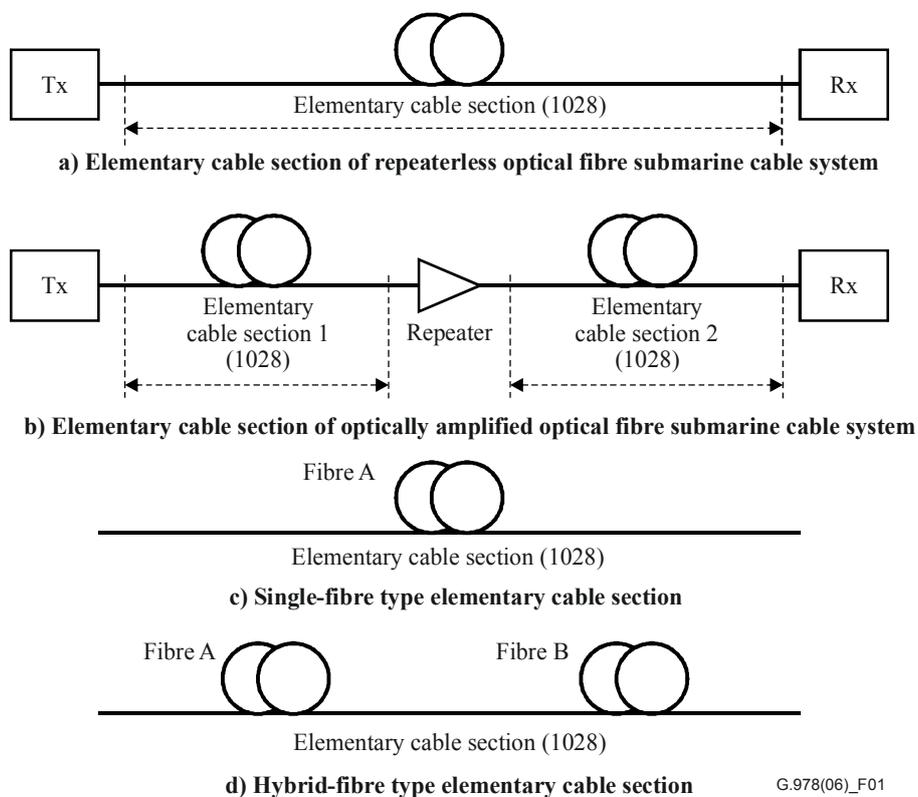
#### 3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

- 3.2.1 elementary cable section:** The whole length of optical fibre cable between two pieces of equipment (repeaters, branching units or terminal transmission equipment). (1028 in [ITU-T G.972]). In this Recommendation, two types of elementary cable section are described:
- single-fibre type elementary cable section;
  - hybrid-fibre type elementary cable section.

**3.2.1.1 single-fibre type elementary cable section:** Elementary cable section consisting of a single type of optical fibre.

**3.2.1.2 hybrid-fibre type elementary cable section:** Elementary cable section consisting of more than one type of optical fibres.



NOTE – (1028) indicates a classification number used in [ITU-T G.972].

**Figure 1 – Definitions for elementary cable section**

#### 4 Abbreviations

This Recommendation uses the following abbreviations:

$A_{eff}$	Effective area
CBL	Cable Breaking Load
CSF	Cut-off Shifted single-mode Fibre
DA cable	Double Armoured cable
DCF	Dispersion Compensating single-mode Fibre
DGD	Differential Group Delay
DSF	Dispersion Shifted single-mode Fibre
$g_R$	Raman gain coefficient
DWDM	Dense Wavelength Division Multiplexing
DWDMS	Dense Wavelength Division Multiplexing Systems
LEF	Large Effective area single-mode Fibre
LW cable	LightWeight cable

LWP cable	LightWeight Protected cable
$n_2/A_{eff}$	Non-linear coefficient
NDF	Negative Dispersion single-mode Fibre
NOTS	Nominal Operating Tensile Strength
NPTS	Nominal Permanent Tensile Strength
NTTS	Nominal Transient Tensile Strength
NZDSF	Non-Zero Dispersion Shifted single-mode Fibre
OFA	Optical Fibre Amplifier
PDF	Positive Dispersion single-mode Fibre
PMD	Polarization Mode Dispersion
RA cable	Rock Armoured cable
RDS	Relative Dispersion Slope
SA cable	Single Armoured cable
SMF	non-dispersion shifted Single-Mode Fibre
SWS	Single Wavelength Systems
TTE	Terminal Transmission Equipment
WDM	Wavelength Division Multiplexing
WDMS	Wavelength Division Multiplexing Systems
WNZDF	Wideband Non-Zero Dispersion single-mode Fibre

## 5 Characteristics of optical fibre submarine cable

### 5.1 General

The optical fibre submarine cable is designed to ensure protection of optical fibres against water pressure, longitudinal water propagation, chemical aggression and the effects of hydrogen contamination throughout the cable design life.

The optical fibre submarine cable is designed also to ensure that there will be no fibre performance degradations when the cable is laid, buried, recovered and operated using standard undersea practices.

Based on application, the optical fibre submarine cable can be:

- a repeatered submarine cable;
- a repeaterless submarine cable.

Based on cable protection, the optical fibre submarine cable can be:

- the lightweight cable (LW cable);
- the lightweight protected cable (LWP cable);
- the single armoured cable (SA cable);
- the double armoured cable (DA cable);
- the rock armoured cable (RA cable).

Typical cable structures for LW, SA and DA cables are shown in Appendix I.

## **5.2 Transmission characteristics of the cable**

Generally, the transmission characteristics of the fibres before cabling (installation in the cable) will be similar to, or the same as, those specified in [ITU-T G.652], [ITU-T G.653], [ITU-T G.654], [ITU-T G.655] and [ITU-T G.656]. Types of fibre are chosen to optimize the system overall cost and performance.

The transmission characteristics of the fibres installed in an elementary cable section should be within a specified limit of variation from the characteristics of the fibre before cabling; in particular, the design of the cable, cable joints and fibre should be such that fibre bending and microbending create negligible attenuation increase. This is to be taken into account for determining the minimum fibre bending radius in the cable and in the equipment (optical cable joints, termination, repeaters, etc.).

The fibre attenuation, chromatic dispersion and PMD should remain stable within specified limits for the system design life; in particular, the design of the cable should minimize to acceptable levels both hydrogen penetration from outside and hydrogen generation within the cable, even after a cable break at the depth of utilization; the sensitivity of optical fibre to gamma radiation should also be taken into account.

## **5.3 Mechanical characteristics and resistance to the environment**

### **5.3.1 Fibre protection by the cable structure**

The fibre mechanical survivability is governed by the growth of flaws inside the structure of glass. It depends on the initial mechanical status of the fibre prior to cabling, dependent on the physical structure of the fibre (type of coating, internal stress), on the environmental condition during the fibre production, and on the level of proof test applied to the fibre after fibre drawing. It also depends on fibre environment in the cable, and on the cumulative effect of stress applied to the fibre during its life.

The strength of the cable structure together with that of the fibre determine the overall cable mechanical behaviour. They should be designed so as to guarantee the system design life, taking into account the cumulative effect of load applied to the cable during laying, recovery and repair, as well as any permanent load or residual elongation applied to the installed cable.

Two generic types of cable structure are commonly used to protect the optical fibres:

- the tight cable structure, where the fibres are strongly maintained in the cable, so that the fibre elongation is essentially equal to that of the cable;
- the loose cable structure, where the fibres are free to move inside the cable, so that the fibre elongation is lower than that of the cable, staying zero until the cable elongation reaches a given value.

Moreover, the cable should protect the fibre against water, humidity and external pressure, and limit the longitudinal water penetration after a cable break at the depth of utilization.

An image of tight and loose cables is shown in Appendix I.

### **5.3.2 Fibre mechanical characteristics**

The fibre mechanical performance is largely dependent on the application of a proof test to the whole length of fibre. The optical fibre proof test is characterized by the load applied to the fibre or the fibre elongation, and the time of application. The level of the proof test should be determined as a function of the cable structure. Fibre splices should be similarly proof tested. It is recommended that the duration of the proof tests be as brief as possible.

The mechanical strength of the fibre and splices is to be taken into account for determining the minimum bending radius of the fibre in the cable and in the equipment (repeaters, branching units, cable jointing boxes or cable terminations).

### 5.3.3 Cable mechanical performance

The cable, with the cable jointing boxes, the cable couplers, and the cable transitions, should be handled with safety by cable ships during laying and repair operation; it should withstand multiple passages over the bow of a cable ship.

The cable should be repairable, and the time to make a cable joint on board during a repair in good working conditions should be reasonably short.

In the event of the cable is hooked by a grapnel, an anchor or a fishing tool, it usually breaks for a load approximately equal to a fraction (depending on the cable type and the grapnel characteristics) of the breaking load in straight line conditions; there is then a risk of reduction of the fibre and cable lifetime and reliability in the vicinity of the breaking point, due in particular to the stress applied to the fibre or to water penetration; the damaged portion of cable should be replaced; its length should stay within a specified value.

Several parameters are defined in [ITU-T G.972] to characterize the cable mechanical characteristics and the ability of the cable to be installed, recovered and repaired, and to be used as guidance for cable handling:

- the cable breaking load (CBL), measured during qualification test;
- the nominal transient tensile strength (NTTS), which could be accidentally encountered, particularly during recovery operations;
- the nominal operating tensile strength (NOTS), which could be encountered during repairs;
- the nominal permanent tensile strength (NPTS), which characterizes the status of the cable after laying;
- the minimum cable bending radius, which is a guidance for cable handling.

Tables 1 and 2 contain the recommended values of cable mechanical characteristics.

**Table 1 – Recommended values of cable mechanical characteristics for repeaterless optical fibre submarine cable system**

Parameters	Detail	Recommended value (KN)			
		LW/LWP cable	SA cable	DA cable	RA cable
CBL	Minimum	TBD	TBD	TBD	TBD
NTTS	Minimum	TBD	TBD	TBD	TBD
NOTS	Minimum	TBD	TBD	TBD	TBD
NPTS	Minimum	TBD	TBD	TBD	TBD
NOTE – The recommended value is for further study.					

**Table 2 – Recommended values of cable mechanical characteristics  
for repeatered optical fibre submarine cable system**

Parameters	Detail	Recommended value (KN)			
		LW/LWP cable	SA cable	DA cable	RA cable
CBL	Minimum	TBD	TBD	TBD	TBD
NTTS	Minimum	TBD	TBD	TBD	TBD
NOTS	Minimum	TBD	TBD	TBD	TBD
NPTS	Minimum	TBD	TBD	TBD	TBD
NOTE – The recommended value is for further study.					

#### 5.3.4 Cable protection

The optical fibre submarine cable should provide protection against the environmental hazards at its depth of utilization: protection against marine life, fish-bite and abrasion, and armours against aggression and ship activities. Different types of protected cable are defined in [ITU-T G.972], in particular:

- the lightweight cable (LW cable);
- the lightweight protected cable (LWP cable);
- the single armoured cable (SA cable);
- the double armoured cable (DA cable);
- the rock armoured cable (RA cable).

The lightweight cable is suitable for laying, recovery and operation, where no special protection is required.

The lightweight protected cable is suitable for laying, recovery and operation, where special protection is required.

The single armoured cable is suitable for laying, burial, recovery and operation and is suitably protected for specific areas in shallow water.

The double armoured cable is suitable for laying, burial, recovery and operation and is suitably protected for specific areas in shallow water.

The rock armoured cable is suitable for laying, recovery and operation and is suitably protected for specific areas in shallow water.

Table 3 contains typical application depth of each cable.

**Table 3 – Typical application depth of optical fibre submarine cable**

	LW/LWP cable	SA cable	DA cable	RA cable
Depth (m)	> 1000	> 20 – 1500	0 – 20	0 – 20

Optical fibre land cable should protect the system and personnel against electrical discharges, industrial interference and lightning. Two types of protected land cable are commonly used:

- the armoured land cable, with an armour to be maintained at earth potential, and which is suitable to be buried directly;
- the duct shielded cable, with a circumferential safety shield (which may be the fish-bite protection shield), and which is suitable to be pulled into ducts.

NOTE – The cable is recommended to have a path for providing the electroding current in its structure to locate the cable by submerged equipment. The electroding current is supplied from a terminal station with the magnitude necessary for locating the cable, and with a frequency of about 4 to 40 Hz.

## 6 Characteristics of optical fibre submarine spare cable

### 6.1 General

A spare cable used to replace a damaged optical fibre submarine cable portion should be an optical fibre submarine cable. As a consequence, it should be compliant with all the specifications relating to optical fibre submarine cables (see clause 5).

Nevertheless, some key information such as the submarine application type, the cable protection, cable length added during a repair and the cable transmission characteristics, should be taken into account in the submarine optical fibre cable repair policy.

### 6.2 Submarine application system type

The optical fibre submarine spare cable should be of the same application type as the original optical fibre submarine cable. This means that the optical fibre submarine spare cable should be:

- a repeatered submarine cable in the case of a repeatered submarine cable repair;
- a repeaterless submarine cable in the case of a repeaterless submarine cable repair.

### 6.3 Optical fibre submarine spare cable protection

The optical fibre submarine spare cable should have the same level of mechanical protection as the cable section to be replaced. In the case of the unavailability of cables with the required protection type, spare cables of other protection types may be used. However, in that specific case, the mechanical protection level of the spare cable should be higher than the one originally laid and a cable transition should be inserted between the two cable types. Table 4 presents the protection levels that are allowed for the spare cable as a function of the original protection types.

**Table 4 – Allowed protection levels for the spare cable depending on original protection types**

		Spare submarine optical fibre cable protection type				
		LW cable	LWP cable	SA cable	DA cable	RA cable
Original submarine optical fibre protection type	LW cable	A	A	A	A	A
	LWP cable		A	A	A	A
	SA cable			A	A	A
	DA cable				A	A
	RA cable					A
NOTE 1 – "A" denotes applicable.						
NOTE 2 – Maximum allowable deployment depth would be required for the spare submarine optical fibre cable.						

## **6.4 Transmission characteristics**

### **6.4.1 Optical fibre management**

The submarine optical fibre cable used for a repair should have, at least, the same number of fibres as the cable originally laid. A submarine optical fibre cable with a greater number of fibres can also be used as a spare cable. In this case, only the required number of fibres for the system is connected, the others remaining unused.

### **6.4.2 Transmission characteristics**

The optical fibres of the spare cable should have the same characteristics as the optical fibres enclosed in the optical fibre submarine cable portion to be replaced. However, some exception to this rule could be accepted if particular cable repair recommendations are clearly notified in the Maintenance Handbook which should be provided by the system supplier upon system provisioning. In particular, this document should explain in details the chromatic dispersion management policy to be applied in case of cable repairs (deep sea and shallow water).

## **7 Electrical characteristics**

### **7.1 General**

A submarine optical fibre cable is recommended to have a path for providing the electroding current in its structure to locate the cable by submerged equipment.

A repeatered submarine cable should enable remote power feeding of repeaters or branching units, and include a power conductor with a low linear resistance, and an insulator with a high voltage insulation capacity.

### **7.2 Recommended parameters for specification**

The optical fibre submarine cable used in the repeatered submarine transmission systems are recommended to specify the following electrical parameters:

- conductor resistance ( $\Omega/\text{km}$ );
- insulator resistance ( $\Omega/\text{km}$ );
- electric strength voltage (V).

These parameters would be specified taking into account the adopting power feeding system and the environmental temperature.

Information on power feeding sub-system design can be found in clause 7.3 of [b-ITU-T G-Sup.41].

## **8 Characteristics of fibre in a submarine cable**

### **8.1 General**

The submarine system designers may distinguish several types of optical fibre. Among them,

- single-mode fibres defined in ITU-T G.65x-series Recommendations;
- positive dispersion single-mode fibre (PDF);
- negative dispersion single-mode fibre (NDF);
- large effective area single-mode fibre (LEF);
- dispersion compensating single-mode fibre (DCF).

Depending on the system specifications (data bit rate and coding, number of wavelengths, amplifier span, amplifier output power, length of the link, etc.), various combinations of these fibre types may be used to ensure the system performances.

The main parameters that characterize the above optical fibres are:

- the attenuation coefficient at all the operating signal wavelengths for SWS and at all of them for WDMS expressed in dB/km;
- the attenuation coefficient at all the operating pump wavelengths for SWS and at all of them for WDMS expressed in dB/km;
- the chromatic dispersion coefficient at all the operating signal wavelengths in ps/nm · km;
- the zero dispersion wavelength  $\lambda_0$  in nm;
- the dispersion slope around the operating signal wavelengths in ps/nm<sup>2</sup> · km;
- the relative dispersion slope (RDS) in nm;
- the non-linear refractive index  $n_2$  in m<sup>2</sup>/W;
- the effective area  $A_{eff}$  in  $\mu\text{m}^2$ ;
- the non-linear coefficient  $n_2/A_{eff}$  in W<sup>-1</sup>;
- the Raman gain coefficient  $g_R$  in m/W;
- the ensemble average polarization mode dispersion (PMD) in ps/ $\sqrt{\text{km}}$ .

## 8.2 Optical fibre

### 8.2.1 ITU-T G.65x series fibre

ITU-T Recommendations contain five type single-mode fibres, these are:

- non-dispersion shifted single-mode fibre (SMF) defined in [ITU-T G.652];
- dispersion shifted single-mode fibre (DSF) defined in [ITU-T G.653];
- cut-off shifted single-mode fibre (CSF) defined in [ITU-T G.654];
- non-zero dispersion shifted single-mode fibre (NZDSF) defined in [ITU-T G.655];
- wideband non-zero dispersion single-mode fibre (WNZDF) defined in [ITU-T G.656].

The SMF described in [ITU-T G.652] was originally optimized for use in the 1310 nm wavelength region, which has a nominal zero-dispersion wavelength close to 1310 nm. This SMF can also be used in the 1550 nm region.

The DSF described in [ITU-T G.653] was originally optimized for use in the 1550 nm region, which has a nominal zero-dispersion wavelength close to 1550 nm.

The CSF described in [ITU-T G.654] is loss-minimized and cut-off shifted single-mode optical fibre, and which is optimized for use in the 1530-1625 nm region.

The NZDSF described in [ITU-T G.655] was originally optimized for use in the 1530 to 1565 nm wavelength region, and has some non-zero chromatic dispersion value around 1550 nm. This dispersion reduces the growth of non-linear effects that can be particularly deleterious in DWDMS.

The WNZDF described in [ITU-T G.656] was originally optimized for use in the 1460 to 1625 nm wavelength region, which has a non-zero chromatic dispersion value in this wavelength region. This dispersion reduces the growth of non-linear effects that can be particularly deleterious in DWDMS.

### 8.2.2 Positive dispersion single-mode fibre

The PDF has a chromatic dispersion value  $D_{min}$  with a positive sign in the operating signal wavelength region. This dispersion reduces the growth of non-linear effects that can be particularly deleterious in DWDMS.

Most of ITU-T G.65x-series Recommendations single-mode fibres are considered to be PDFs at an operating signal wavelength of around 1550 nm.

### 8.2.3 Negative dispersion single-mode fibre

NDF has a chromatic dispersion value  $D_{max}$  with a negative sign in the operating signal wavelength region. This dispersion reduces the growth of non-linear effects that can be particularly deleterious in DWDMS.

The NZDSF described in [ITU-T G.655] with a negative dispersion can be considered an NDF at an operating signal wavelength of around 1550 nm.

A combination of PDF and NDF can be used to form a hybrid-fibre type elementary cable section.

### 8.2.4 Large effective area single-mode fibre

LEF has an enlarged  $A_{eff}$  at the operating signal wavelength. This enlarged  $A_{eff}$  reduces the non-linear effects that can be particularly deleterious in DWDMS.

### 8.2.5 Dispersion compensating single-mode fibre

The chromatic dispersion sign of the DCF depends on dispersion management in the system. Typically, the DCF has a large chromatic dispersion value at the operating signal wavelength. The DCF is used to compensate for the cumulative chromatic dispersion of PDF or NDF.

## 8.3 Transmission characteristics of the fibre

### 8.3.1 Optical loss

The loss of an optical fibre is characterized by the attenuation coefficient expressed in dB/km (log value) or in  $\text{km}^{-1}$  (linear value).

The maximum attenuation coefficient of each ITU-T G.65x fibre is specified in the corresponding ITU-T G.65x-series Recommendations.

The method for measuring the optical loss in a single-mode fibre is described in [ITU-T G.650.1].

### 8.3.2 Chromatic dispersion coefficient

Chromatic dispersion coefficient deals with the wavelength dependence of group velocity so that all the spectral components of an optical signal will propagate at different velocities. This induces pulse spreading and can be a major impairment. Dispersion slope against the wavelength also influences the transmission performance, especially in the WDMS and/or high bit rate transmission systems. Chromatic dispersion coefficient of an optical fibre in a unit length is expressed by  $\text{ps/nm} \cdot \text{km}$ . Dispersion slope at an operating wavelength is also expressed by  $\text{ps/nm}^2 \cdot \text{km}$ . A relative dispersion slope (RDS) expressed by nm is also used to consider the dispersion impairments in the operating signal wavelength region, especially in the WDMS.

The chromatic dispersion characteristic in each ITU-T G.65x fibre is specified in the corresponding ITU-T G.65x-series Recommendations.

Additional information regarding the chromatic dispersion impairment can be found in [b-ITU-T G-Sup.39].

The method for measuring the chromatic dispersion in a single-mode fibre is described in [ITU-T G.650.1].

### 8.3.3 Polarization mode dispersion (PMD)

Small departures from perfect cylindrical symmetry in the fibre core lead to birefringence because of different mode index associated with the orthogonal polarized components of the fundamental mode. PMD induces pulse spreading and should be bounded to a maximum value. PMD of a single-mode fibre and/or optical link is expressed in  $\text{ps}/\sqrt{\text{km}}$ . PMD in a single-mode fibre and/or optical link is dealt with statistically. Particularly, a PMD link design value,  $\text{PMD}_Q$ , is used as an upper bound for the PMD coefficient of the concatenated fibre cables with a defined possible link of M

cable sections. The upper bound is defined in terms of a small probability level,  $Q$ , which is the probability that a concatenated PMD coefficient value exceeds  $\text{PMD}_Q$ .

The  $\text{PMD}_Q$  value in each ITU-T G.65x fibre cable is specified in the corresponding ITU-T G.65x-series Recommendations.

Additional information about PMD impairment can be found in [b-ITU-T G-Sup.39].

The measurement method and statistical treatment of the PMD in both single-mode fibre and cables are described in [ITU-T G.650.2].

### 8.3.4 Fibre non-linearity

Non-linear effects should be considered when a long haul optical link is designed with high output power OFAs. These effects are cumulative along the optical link and may degrade significantly the propagation. In the SWS, the predominant non-linear effect is generally self-phase modulation of the signal proportional to the non-linear coefficient (ratio  $n_2/A_{eff}$ ) multiplied by the square of its normalized amplitude. This non-linearity, in the presence of chromatic dispersion, induces a pulse broadening in the time domain, and a consequent impairment of system performances. However, in WDMS or DWDMS, the predominant effect is normally four-wave mixing and/or cross-phase modulation due to the presence of adjacent wavelengths. This non-linearity induces performance degradation.

The Raman gain coefficient  $g_R$  in a single-mode fibre is also considered in certain submarine systems, which utilize distributed Raman amplification. Raman gain is proportional to  $g_R$  and pump power. The  $g_R$  value of pure silica glass is about  $2.8 \times 10^{-14}$  m/W at 1500 nm, and this depends on the material used in the fibre.

Further information on fibre non-linearity can be found in [b-ITU-T G-Sup.39].

The method for measuring the effective area  $A_{eff}$  in a single-mode fibre is described in [ITU-T G.650.2].

The methods used for measuring the non-linear coefficient  $n_2/A_{eff}$  and Raman gain coefficient  $g_R$  in a single-mode fibre are described in [b-IEC/TR 62285] and [b-IEC/TR 62324], respectively.

Appendix II of [ITU-T G.976] introduces a test method for measuring Raman gain efficiency distribution.

## 8.4 Recommended parameters for specification

Optical fibres and cables used in the submarine transmission systems are recommended to specify the following parameters. These parameters would be specified at an operating signal and/or pump wavelength region.

Fibre parameters:

- maximum attenuation coefficient (dB/km);
- maximum and minimum chromatic dispersion coefficient,  $D_{max}$  and  $D_{min}$ , (ps/nm · km);
- maximum chromatic dispersion slope (ps/nm<sup>2</sup> · km);
- minimum effective area,  $A_{eff}$ , (µm<sup>2</sup>).

Cable parameters:

- maximum attenuation coefficient (dB/km);
- maximum  $\text{PMD}_Q$  coefficient (ps/√km).

NOTE 1 – Fibre parameters of the ITU-T G.65x series fibres are specified in the corresponding ITU-T G.65x-series Recommendations, except for the effective area.

NOTE 2 – Maximum attenuation coefficients at 1550 nm of cabled ITU-T G.65x fibres are specified in the range of 0.22 to 0.4 dB/km in ITU-T G.65x-series Recommendations. It should be noted that typical submarine transmission system requires smaller attenuation coefficient value. Typical attenuation coefficient in an installed submarine link is for further study.

NOTE 3 – Maximum PMDQ coefficients of cabled ITU-T G.65x fibres are specified in the range of 0.20 to 0.5 ps/ $\sqrt{\text{km}}$  in ITU-T G.65x-series Recommendations. It should be noted that typical submarine transmission system requires smaller PMDQ coefficient value.

## **9 Transmission characteristics of elementary cable section**

### **9.1 General**

Elementary cable section is the whole length of optical fibre cable between two pieces of equipment (repeaters, branching units or terminal transmission equipment). Elementary cable sections are classified into:

- single-fibre type elementary cable section;
- hybrid-fibre type elementary cable section.

Depending on the system design and especially on the number of wavelengths (WDMS), various optical fibre types may be used to ensure the system performances. Particularly, various optical fibres are combined in order to reduce cumulative dispersion at signal wavelength. In that case, the system is said to be dispersion managed. Generally, this management leads to a dispersion map that shows how dispersion is managed along the whole optical fibre submarine cable link.

The dispersion map is the principal tool for describing the chromatic dispersion characteristics of a system. Cumulative dispersion is defined as the dispersion measured between the output of the terminal transmitter and any other point in the optical path. The dispersion map is the plot of cumulative local chromatic dispersion, at for a given operating wavelength, as a function of distance from the optical transmitter to the optical receiver. Dispersion map will depend mainly on the type of system (SWS, WDMS or DWDMS).

Regarding "dispersion mapping" and "dispersion management implementation", further description can be found in [ITU-T G.973] and [ITU-T G.977].

In this clause, the transmission characteristics of an elementary cable section required to design optical fibre submarine cable systems are stated. Transmission characteristics of single- and hybrid-fibre type elementary cable sections are respectively described in clauses 9.2 and 9.3, and the required parameters for specification are recommended in clause 9.4.

### **9.2 Transmission characteristics of the single-fibre type elementary cable section**

A single-fibre type elementary cable section consists of a single type of optical fibre, and it is utilized as the main transmission line of the signals. At intervals of several elementary cable sections, optical fibres with chromatic dispersion reversed from the main transmission line are used for the purpose of dispersion compensation in the wavelengths of the signals. These dispersion compensative fibres also compose the other elementary cable section for the signal transmission. This type of elementary cable section will usually require separate dispersion compensating devices into the TTE, which are considered separately from the elementary cable sections. The characteristics of chromatic dispersion compensator can be found in [ITU-T G.671] and [ITU-T G.667].

### 9.3 Transmission characteristics of the hybrid-fibre type elementary cable section

A hybrid-fibre type elementary cable section consists of more than one type of optical fibres.

The typical combinations of optical fibres are classified into two types:

- One is the combination of optical fibres with different  $A_{eff}$  and with the same sign of dispersion slope.

For example, optical fibres with larger  $A_{eff}$  and dispersion slope are combined with those with smaller  $A_{eff}$  and dispersion slope which reduces the total dispersion slope of the elementary cable section and allows acceptable optical input power higher. However, the total dispersion slope cannot be close to zero because of the same sign of dispersion slope of the fibres. This type of elementary cable section will usually require separate dispersion compensating devices in the TTE, which are considered separately from the elementary cable sections.

- The other is the combination of optical fibres with the opposite sign of dispersion and dispersion slope, adjusting relative dispersion slope (RDS) and the length of the combined optical fibres, which allows a reduction of the total dispersion and dispersion slope of the elementary cable section to close to zero.

In this case, for example, larger  $A_{eff}$  fibres with positive dispersion and dispersion slope are combined with those with smaller  $A_{eff}$ , negative dispersion and dispersion slope.

In general, hybrid-fibre type elementary cable section can implement larger maximum transmission capacity and distance compared to those of single-fibre type elementary cable section.

### 9.4 Recommended parameters for specification

The following parameters are recommended to specify in the single- or hybrid-fibre type elementary cable section:

- maximum and minimum overall attenuation at 1550 nm or specified wavelength (dB), (Note 1);
- maximum and minimum chromatic dispersion coefficient (ps/nm · km);
- maximum chromatic dispersion slope (ps/nm<sup>2</sup> · km);
- maximum cumulative chromatic dispersion at specified wavelength range (ps/nm);
- minimum non-linear coefficient,  $n_2/A_{eff}$ , (1/W);
- maximum PMD<sub>Q</sub> coefficient (ps/√km);
- maximum overall DGD at 1550 nm or specified wavelength (ps).

NOTE 1 – Attenuation coefficient and length of the transmission line could be given as alternative information.

NOTE 2 – In case of hybrid-fibre type elementary cable section, each parameter should be recommended both for individual fibres and total elementary cable section.

## Appendix I

### Optical fibre submarine cable structures and related information

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

#### I.1 Cable structures

The optical fibre submarine cable is designed to protect optical fibres against water pressure, longitudinal water propagation, chemical aggression and the effects of hydrogen contamination throughout the design life. It is also designed to prevent from transmission performance degradation due to the cable laying, burying and repairing procedure.

##### I.1.1 Fibre protection

In order to protect the optical fibres, two types of cable structure are commonly used. These are:

- tight cable structure;
- loose cable structure.

Figure I.1 shows the example structures of tight and loose cables. The optical fibres are strongly maintained in the tight cable structure, so that the optical fibre elongation is essentially equal to that of the cable. The optical fibres in the loose cable are free to move inside the cable.

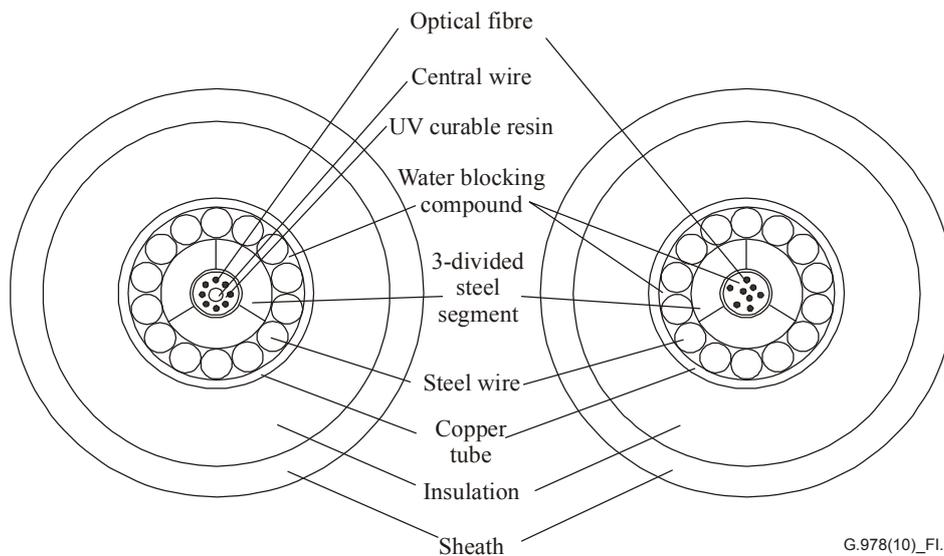


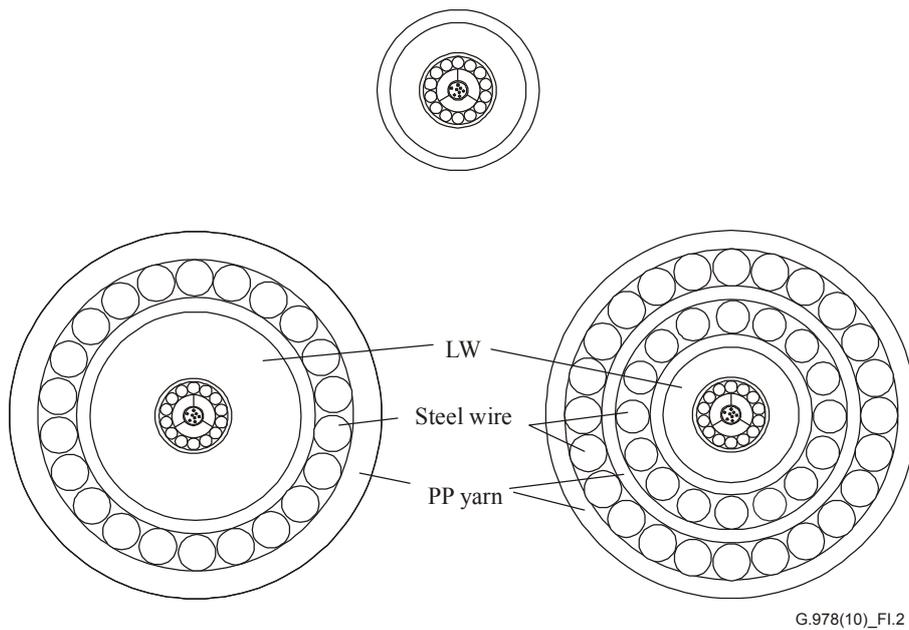
Figure I.1 – Example structures of tight (left) and loose (right) cables

##### I.1.2 Cable protection

In order to protect the optical fibre submarine cables, different types of protection are utilized taking into account the applied environmental condition. These are:

- LW cable;
- LWP cable;
- SA cable;
- DA cable;
- RA cable.

Figure I.2 shows the example structures of LW, SA and DA cables. In the SA and DA cables, a LW cable is protected with steel wire and PP yarn appropriately.



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**Figure I.2 – Example structures of LW (upper), SA (lower-left) and DA (lower-right) cables**

## Bibliography

- [b-ITU-T G-Sup.39] ITU-T G-series Recommendations – Supplement 39 (2008), *Optical system design and engineering considerations*.
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- [b-IEC/TR 62324] IEC/TR 62324 (2007), *Single-mode optical fibres – Raman gain efficiency measurement using continuous wave method – Guidance*.





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