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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

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

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Characteristics of repeaterless optical fibre submarine cable systems

Recommendation ITU-T G.973

ITU-T

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

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Recommendation ITU-T G.973

Characteristics of repeaterless optical fibre submarine cable systems

Recommendation ITU-T G.973 is concerned primarily with the system performance and interface requirements of repeaterless optical fibre submarine cable systems. It considers both single wavelength systems (SWS), wavelength division multiplexing systems (WDMS), and dense wavelength division multiplexing systems (DWDMS). It also covers the aspects related to the applications of discrete optical fibre amplifiers (OFAs) (power amplifiers, pre-amplifiers, remote optically pumped amplifiers) and/or distributed remotely pumped OFAs using Raman amplification.

This edition of the Recommendation introduces a new power budget template for the implementation of coherent systems.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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Keywords

Repeaterless optical fibre submarine cable systems, remote optically pumped amplifier (ROPA)

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1 Scope

This Recommendation is concerned primarily with the system performance and interface requirements of repeaterless optical fibre submarine cable systems; it considers both single wavelength systems (SWS), wavelength division multiplexing systems (WDMS) and dense wavelength division multiplexing systems (DWDMS). It also covers the aspects related to the applications of discrete optical fibre amplifiers (OFAs) as power amplifiers, pre-amplifiers and/or remote optically pumped amplifiers (ROPA) (either erbium-doped transmission fibres using remote pumping from the terminal or the distributed Raman amplification pumped from the terminal).

The purpose of a repeaterless optical fibre submarine cable system is to establish transmission links between two or more terminal stations located in a restricted geographical area.

A cable system connecting only two terminal stations may be termed an "optical fibre submarine cable link". When it connects more than two terminal stations, it may be termed an "optical fibre submarine cable network".

In a repeaterless submarine cable system, no power feeding equipment (PFE) is necessary as there is no in-line OFA.

As far as the branching unit devices are concerned, those considered in this Recommendation are the passive ones, therefore avoiding electronic components and supervisory and power feeding.

Common implementation aspects of optical submarine cable systems for manufacturing, installing and maintenance are described in [ITU-T G.971]. [ITU-T G.978] contains common aspects of the characteristics of the optical fibre submarine cables. [ITU-T G.979] is also concerned with the characteristics of monitoring systems for repeaterless optical fibre submarine cable systems.

The physical implementation of repeaterless optical fibre submarine cable systems and the implications of the use of ROPA are considered respectively in Annexes A and B.

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 standalone document, the status of a Recommendation.

[ITU-T G.661] Recommendation ITU-T G.661 (2007), *Definition and test methods for the relevant generic parameters of optical amplifier devices and subsystems*.

[ITU-T G.662] Recommendation ITU-T G.662 (2005), *Generic characteristics of optical amplifier devices and subsystems*.

[ITU-T G.664] Recommendation ITU-T G.664 (2012), *Optical safety procedures and requirements for optical transport systems*.

[ITU-T G.665] Recommendation ITU-T G.665 (2005), *Generic characteristics of Raman amplifiers and Raman amplified subsystems*.

[ITU-T G.692] Recommendation ITU-T G.692 (1998), *Optical interfaces for multichannel systems with optical amplifiers*.

[ITU-T G.698.1] Recommendation ITU-T G.698.1 (2009), *Multichannel DWDM applications with single-channel optical interfaces*.

[ITU-T G.701] Recommendation ITU-T G.701 (1993), *Vocabulary of digital transmission and multiplexing, and pulse code modulation (PCM) terms*.

[ITU-T G.702] Recommendation ITU-T G.702 (1988), *Digital hierarchy bit rates*.

[ITU-T G.703] Recommendation ITU-T G.703 (2016), *Physical/electrical characteristics of hierarchical digital interfaces*.

[ITU-T G.707] Recommendation ITU-T G.707/Y.1322 (2007), *Network node interface for the synchronous digital hierarchy (SDH)*.

[ITU-T G.709] Recommendation ITU-T G.709/Y.1331 (2016), *Interfaces for the optical transport network*

[ITU-T G.780] Recommendation ITU-T G.780/Y.1351 (2010), *Terms and definitions for synchronous digital hierarchy (SDH) networks*.

[ITU-T G.821] Recommendation ITU-T G.821 (2002), *Error performance of an international digital connection operating at a bit rate below the primary rate and forming part of an Integrated Services Digital Network*.

[ITU-T G.823] Recommendation ITU-T G.823 (2000), *The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy*.

[ITU-T G.825] Recommendation ITU-T G.825 (2000), *The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH)*.

[ITU-T G.826] Recommendation ITU-T G.826 (2002), *End-to-end error performance parameters and objectives for international, constant bit-rate digital paths and connections*.

[ITU-T G.828] Recommendation ITU-T G.828 (2000), *Error performance parameters and objectives for international, constant bit-rate synchronous digital paths*.

[ITU-T G.921] Recommendation ITU-T G.921 (1988), *Digital sections based on the 2048 kbit/s hierarchy*.

[ITU-T G.955] Recommendation ITU-T G.955 (1996), *Digital line systems based on the 1544 kbit/s and the 2048 kbit/s hierarchy on optical fibre cables*.

[ITU-T G.957] Recommendation ITU-T G.957 (2006), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.

[ITU-T G.959.1] Recommendation ITU-T G.959.1 (2016), *Optical transport network physical layer interfaces*.

[ITU-T G.971] Recommendation ITU-T G.971 (2016), *General features of optical fibre submarine cable systems*.

[ITU-T G.972] Recommendation ITU-T G.972 (2016), *Definition of terms relevant to optical fibre submarine cable systems*.

[ITU-T G.975] Recommendation ITU-T G.975 (2000), *Forward error correction for submarine systems*.

[ITU-T G.975.1] Recommendation ITU-T G.975.1 (2004), *Forward error correction for high bit-rate DWDM submarine systems*.

[ITU-T G.978] Recommendation ITU-T G.978 (2010), *Characteristics of optical fibre submarine cables*.

[ITU-T G.979] Recommendation ITU-T G.979 (2016), *Characteristics of monitoring systems for optical fibre submarine cable systems*.

[ITU-T G.8201] Recommendation ITU-T G.8201 (2011), *Error performance parameters and objectives for multi-operator international paths within optical transport networks.*

[ITU-T G.8251] Recommendation ITU-T G.8251 (2010), *The control of jitter and wander within the optical transport network (OTN).*

[IEC 60825-1] IEC 60825-1 (2014), *Safety of laser products – Part 1: Equipment classification and requirements*.

[IEC 60825-2] IEC 60825-2 (2006), *Safety of laser products – Part 2: Safety of optical fibre communication systems (OCFS).*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 digital line section (DLS) [ITU-T G.701]

3.1.2 double armoured cable [ITU-T G.972]

3.1.3 intermediate terrestrial interface (ITI) [ITU-T G.972]

3.1.4 multiplex section overhead (MSOH) [ITU-T G.780]

3.1.5 optical fibre amplifier (OFA) [ITU-T G.661]

3.1.6 receive main path interface reference point (MPI-R) [ITU-T G.959.1]

3.1.7 rock armoured cable [ITU-T G.972]

3.1.8 S', R' reference points [ITU-T G.662]

3.1.9 single armoured cable [ITU-T G.972]

3.1.10 source main path interface reference point (MPI-S) [ITU-T G.959.1]

3.1.11 submarine cable optical interface (SCOI) [ITU-T G.977]

3.1.12 submarine electro-optic interface (SEOI) [ITU-T G.977]

3.1.13 synchronous digital hierarchy (SDH) [ITU-T G.780]

3.1.14 synchronous transport module (STM) [ITU-T G.780]

3.1.15 terrestrial interface (TI) [ITU-T G.972]

3.1.16 time varying system penalty (TVSP) [ITU-T G.977]

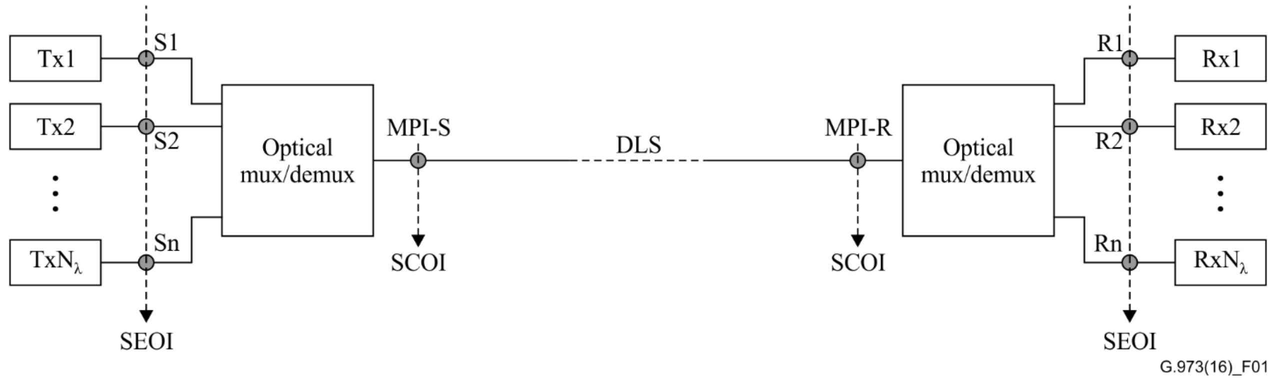

Figure 1 – Representation of optical line system interfaces (multichannel system)

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 branching unit (BU): A passive optical submarine piece of equipment inserted into the submarine portion of an optical fibre submarine cable network where the interconnection of more than two cable sections is necessary.

3.2.2 cable jointing box: Box to be installed on optical submarine or land cable, in case of junction or repair of the cable itself, which is designed to provide mechanical, electrical and optical continuity, waterproofness and storage of the fibre splices and fibre extra length.

3.2.3 distributed Raman amplifier (DRA): An OFA using the transmission fibre, as an amplifier medium, that is pumped from the terminal station. The gain is obtained all along the fibre (therefore distributed) using the Raman properties of the fibre until sufficient pump power is available.

3.2.4 remote optically pumped amplifier (ROPA): An OFA consisting of a section of erbium doped fibre that is activated by a pump beam sent from the terminal station.

3.2.5 terminal transmission equipment (TTE): The equipment included into the terrestrial portion of an optical fibre submarine cable system for terminal transmission multiplexing and demultiplexing operations, coding and converting the incoming tributaries into the optical line signal, converting and decoding the received optical line signal in the outgoing tributaries, performing cable termination operations.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ASE	Amplified Spontaneous Emission
BER	Bit Error Ratio
BOL	Beginning Of Life
BU	Branching Unit
COTDR	Coherent Optical Time-Domain Reflectometry
CSF	Cut-off Shifted single mode Fibre
DCF	Dispersion Compensation single mode Fibre
DC PDM-BPSK	Dual Carrier Polarization-Division-Multiplexed Binary-Phase-Shift-Keying

DC PDM-DBPSK	Dual Carrier Polarization-Division-Multiplexed Differential Binary-Phase-Shift-Keying
DLS	Digital Line Section
DRA	Distributed Raman Amplifier
DSF	Dispersion Shifted single mode Fibre
DWDM	Dense Wavelength Division Multiplexing
DWDMS	Dense Wavelength Division Multiplexing System
EDF	Erbium Doped Fibre
EOL	End Of Life
ITI	Intermediate Terrestrial Interface
MPI-R	Receive Main Path Interface reference point
MPI-S	Source Main Path Interface reference point
MSOH	Multiplex Section Overhead
MTC	Marinized Terrestrial Cable
NDSF	Non Dispersion Shifted single mode Fibre
NRZ	No Return to Zero
NZDSF	Non-Zero Dispersion Shifted single mode Fibre
OFA	Optical Fibre Amplifier
OSNR	Optical Signal-to-Noise Ratio
OTDR	Optical Time-Domain Reflectometry
OTN	Optical Transport Network
PDG	Polarization Dependent Gain
PDH	Plesiochronous Digital Hierarchy
PDL	Polarization Dependent Loss
PDM-DQPSK	Polarization-Division-Multiplexed Differential Quadrature-Phase-Shift-Keying
PDM-QPSK	Polarization-Division-Multiplexed Quadrature-Phase-Shift-Keying
PFE	Power Feeding Equipment
PMD	Polarization Mode Dispersion
ROPA	Remote Optically Pumped Amplifier
SCOI	Submarine Cable Optical Interface
SDH	Synchronous Digital Hierarchy
SEOI	Submarine Electro-Optic Interface
SMF	Single-Mode Fibre
STM	Synchronous Transport Module
SWS	Single Wavelength System
TI	Terminal Interface

TTE	Terminal Transmission Equipment
WDM	Wavelength Division Multiplexing
WDMS	Wavelength Division Multiplexing System
WNZDF	Wideband Non-Zero Dispersion single-mode Fibre

5 Conventions

In this Recommendation, FFS stands for 'for further study'.

6 Characteristics and performance of the system

6.1 Characteristics and performance of the digital line sections (DLS)

The digital line sections provided by the system shall be in accordance with the relevant Recommendations.

6.1.1 Characteristics of the digital signals at the system interface, at intermediate terrestrial interface (ITI) and terminal interface (TI)

For TI, the digital signals should comply, as applicable, with [ITU-T G.702], [ITU-T G.703], [ITU-T G.707], [ITU-T G.709], [ITU-T G.957] and [ITU-T G.959.1].

At ITI, it is recommended that the digital signals be compliant with the physical parameters described in [ITU-T G.957] and [ITU-T G.959.1].

Several interfaces with different bit rates may coexist for one single optical fibre submarine cable system.

6.1.2 Overall error performances at TI

The error performances of an optical fibre submarine cable system should conform to the relevant Recommendations for the design life of the systems:

– for plesiochronous digital hierarchy (PDH) interfaces: [ITU-T G.821] for systems designed prior to December 2002 and [ITU-T G.826] for the later systems;
– for synchronous digital hierarchy (SDH) interfaces: [ITU-T G.826] for systems designed prior to March 2000 and [ITU-T G.828] for the later systems;
– for optical transport network (OTN) interfaces: [ITU-T G.8201].

For PDH systems, the relevant parameters are severely errored seconds and errored seconds. They are derived from [ITU-T G.821] and [ITU-T G.826] in conjunction with the performances at 64 kbit/s on a per km basis. Information on the mapping of system performances at the 64-kbit/s level is given in Annex D of the 1988 version of [ITU-T G.821].

For SDH systems, the relevant parameters are severely errored seconds and errored seconds. They are derived from [ITU-T G.826] and [ITU-T G.828].

For OTN systems, the relevant parameters are severely errored seconds, background block error and errored block. They are derived from [ITU-T G.8201].

6.1.3 System availability at TI

For PDH systems:

– the unavailable time definition is derived from Annex A of [ITU-T G.821];
– as per Annex A of [ITU-T G.821] and Annex A of [ITU-T G.826], a period of unavailable time begins when the bit error ratio (BER) in each second is worse than 1×10^{-3} for a period of ten consecutive seconds. These ten seconds are considered to be unavailable time.

The period of unavailable time terminates when the BER in each second is better than 1×10^{-3} for a period of ten consecutive seconds. These ten seconds are considered to be available time.

For SDH systems:

– the unavailable time definition is derived from [ITU-T G.826] (for systems designed prior to March 2000) and [ITU-T G.828] (for systems designed after March 2000).

For OTN systems:

– the unavailable time definition is derived from [ITU-T G.8201].

The system availability depends on the combined aspects of the reliability performance, the maintainability performance and the maintenance support performance of the system equipment, and particularly of the system terminal equipment.

The unavailability specification applies to unavailable time caused by system component failure, and includes, for example, laser switching, terminal faults and supervisory and maintenance operation leading to interruptions of ten seconds or longer. It does not include faults caused by trawlers or other external factors including terminal transmission equipment (TTE) power feeding and any period during which the system is de-powered for repair. Similarly, faults requiring ship intervention are not included in the unavailable time calculation.

6.1.4 Jitter performances at TI and ITI

The jitter performances of an optical fibre submarine cable system should follow [ITU-T G.823], [ITU-T G.825] and [ITU-T G.8251] and other relevant Recommendations at ITI and TI for the system design life.

6.1.5 Performance allocation between portions of the system

The end-to-end performance for a given digital line section (DLS) is obtained by multiplying the specified per-km allocation by the DLS length. When it is necessary to allocate performance degradation to various portions in the DLS, an amount corresponding to a fixed length (to be determined) is allocated to each station terminal equipment, and the submarine portion is allocated on a per-km basis at an amount equal to the difference between the DLS specification and the terminal allocation.

6.1.6 DLS independence

It is recommended that any failure, maintenance operation, supervisory operation, etc., on any DLS should have no impact on the specified performances of any other DLS in the system. In particular:

a) for wavelength division multiplexing system (WDMS) and dense wavelength division multiplexing system (DWDMS):
   i) any failure of up to half the number of wavelengths should have no traffic disruption on any of the remaining wavelengths;

b) for single wavelength system (SWS), wavelength division multiplexing system (WDMS) and dense wavelength division multiplexing system (DWDMS):
   i) any failure on one fibre pair should have no effect on the other fibre pairs in the system;
   ii) any failure on any tributary at any level of multiplexing or demultiplexing (optical or electrical) in the system should have no effect on the remaining parts of the system.

The short-term effects of transients should normally be considered tolerable, in their unlikely event.

6.2 Characteristics and performance of the optical sections

6.2.1 Optical power budget

The optical performance of the optical section is characterized by its optical power budget, which is the difference between the mean optical powers, expressed in dBm, at the two ends of a submersible optical fibre cable section. This can be obtained taking into account the characteristics of the optical components in the equipment at both ends of the cable section. The optical power budget can be used to calculate the length of the submersible optical fibre cable section which permits fulfilment of the overall error performance requirement for the digital line section in the submarine optical fibre cable system.

Several approaches can be used to calculate the optical power budget. They can be classified into worst-case approach, statistical approach and semi-statistical approach. A detailed example of these different approaches is given in [b-ITU-T G.Sup39].

The optical power budget should take into account part or all of the following parameters:

– receiver sensitivity (dBm):

  the mean optical power in the optical signal modulated by a pseudo-random electrical signal with a specified mark density at the input of the optical fibre pigtail of a receiver, below which the receive equipment would exhibit a bit error ratio higher than 10^{-12};

– receiver optical overload (dBm):

  the mean optical power in the optical signal modulated by a pseudo-random electrical signal with a specified mark density at the input of the optical fibre pigtail of a receiver, above which the receive equipment would exhibit a bit error ratio higher than 10^{-12};

– receiver dynamic range (dB):

  the difference between the receiver optical overload and the receiver sensitivity;

– mean launched power (dBm):

  the mean optical power in the optical line signal at the output of the optical fibre pigtail of the transmitter;

– the equipment internal loss (dB);

– the optical section loss (dB);

– the system performance penalty (dB):

  taking into account the difference between the performance of an "ideal" line terminal equipment and a "real" line terminal equipment associated with its full cable section. The phenomena to be considered in its value include optical feedback, signal patterning effects, non-ideal equalization, partition noise, chromatic dispersion, polarization mode dispersion, non-linearities, ASE noise, etc.;

– the ageing margin (dB):

  taking into account the variation of the optical component attenuation, including that of fibres, due to ageing during the system design life;

– the repair provision (dB):

  taking into account the possible increase of attenuation of the cable fibre due to cable repair during the system design life. The value of the repair provision depends on the sea depth. The repair provision for the shallow water portions can be obtained as the product of a repair number and of the mean attenuation per repair, equal to the attenuation of two cable joints with the addition of the loss of a length of cable proportional to the sea depth;

– an unassigned margin (dB):

  a provision for phenomena which cannot be precisely foreseen;

– the overload margin (dB):

the minimum difference between the receive power and the receive optical overload for a given BER.

An important parameter which should be specified to help in system commissioning is the guaranteed margin that is the minimum margin in the power budget of the optical section which should be measured at a specific point in time, i.e., system assembly in factory or on board the cable ship, and which is equal to the sum of ageing, repair and unassigned margins. Examples on margins that can be taken into account in the power budget calculation are given in [b-ITU-T G.Sup41].

6.2.2 Optical power budget for high bit rate coherent system

The power budget tables for high bit rate coherent system should compute margins that should be considered as a minimum requirement for the system at BOL. These margins should be expressed in terms of a Q factor value. The suppliers should provide, as a minimum, the values of the parameters used to compute the power budget and specify all necessary complementary relevant information such as: channel power, optical signal-to-noise-ratio and method for obtaining TTE Q factor as function of OSNR.

An example of a possible power budget template is shown in Table 1.

Table 1 – An example of a possible coherent power budget template

Item	Description	dB/0.1 nm
A	BOL OSNR at full loading[1] (XX dBm channel power)	
B	EOL OSNR at full loading[1] (XX dBm channel power)	
Item	**Description**	**Q (dB)**
1	Back-to-back Q at BOL OSNR	
2	Propagation impairments	
3	Other impairments	
3.1	Non-optimal optical pre-emphasis	
3.2	Wavelength tolerance impairment	
3.3	Mean penalty due to polarization-dependent effects	
3.4	Manufacturing and environmental impairment	
3.5	Unspecified impairment	
4	Margin for Q time variations (5σ)	
5	BOL segment Q	
6	Repair and ageing impairments	
6.1	Cable repair and ageing	
6.2	TTE ageing	
7	EOL segment Q	
8	FEC limit	
9.1	Customer segment EOL margin	
9.2	Extra margin	
10	Commissioning limit	

[1] Full loading implies design capacity.

Table 1 should be completed as follows:

– Line A: The BOL OSNR is given for the full loading condition with a specified channel power. The supplier should provide key parameters for the system that would allow estimation of OSNR for the given channel power. For new system builds, this OSNR value is given as a reference only.

– Line B: The EOL OSNR is given for the full loading condition with a specified channel power. The supplier should provide key parameters for the system that would allow estimation of OSNR for the given channel power. For new system builds, this OSNR value is given as a reference only.

– Line 1: The back-to-back (i.e., no fibre propagation) Q factor should be specified at the OSNR given in line A, for a TTE with average performance. The supplier should provide the method for obtaining TTE Q as function of OSNR.

– Line 2: The propagation impairment is specified as follows:
  – Through measurement or simulation of a transmission representative of the SDLS, obtain the expected Q factor after propagation (including all modem implementation penalties), at the OSNR listed in line A for a TTE with average performance. If Line 1 lists TTE Q for a single channel loading, then Line 2 should include penalty due to the cross-talk between WDM channels.
  – Subtract the propagated Q factor from the back-to-back Q factor in line 1.

– Line 3: The supplier margin allocations are specified as follows:
  – Lines 3.1: The non-optimal pre-emphasis impairment corresponds to the imperfect Q factor equalization over the full spectral range.
  – Line 3.2: The wavelength tolerance impairment corresponds to the degradation due to the non-optimal wavelength setting.
  – Line 3.3: Mean penalty due to polarization-dependent effects such as PDL, PDG, and PMD.
  – Line 3.4: The manufacturing and environmental impairment provides margin for normal product fluctuations due to the manufacturing process and environmental conditions. For new system builds, this parameter includes impairments both from the DLS transmission path and the TTE. For system upgrades, this parameter includes only impairments from the TTE.
  – Line 3.5: Unspecified impairment is allocated for any other impairment not listed in lines 3.1 to 3.4.

– Line 4: The Q-time variations margin (or time varying system penalty (TVSP)) defines an additional impairment due to performance fluctuations around the mean performance. Five standard deviations of Q factor should be allocated.

– Line 5: The BOL segment Q is defined as:
  – Line 5 = line 1 – (sum of line 2 to lines 3.1-3.5) – line 4

– Lines 6.1and 6.2: Allocation for repairs and ageing in Q (dB). The supplier should detail method of estimating this penalty and how it relates to the OSNR degradation defined as the difference between Line A and Line B.

– Line 7: EOL segment Q is defined as:
  – Line 7 = line 5 – (sum of lines 6.1 and 6.2)

– Line 8: FEC Limit in Q (dB) for compliance with [ITU-T G.826] or [ITU-T G.8201] after FEC correction. 10^{-13} is commonly used as BER after FEC correction in submarine systems.

– Line 9.1: Customer margin is the specified margin required at EOL by the cables' customer.

– Line 9.2: Extra margin is the margin available after all repair, ageing and customer-required margins are allocated, and is calculated as the difference between the BOL segment Q and the commissioning limit.

– Line 10: This line gives the contractual commissioned Q limit for each DLS. If performance of each channel is measured to be above the commissioning limit, then adequate margin for repair, ageing, and customer provisions have been demonstrated.

Beside the power budget tables, the loss budget table should also be provided by suppliers to specify the loss at BOL and EOL.

An example of a possible loss budget template is shown in Table 2.

Table 2 – An example of a possible loss budget template

Item	Description	Unit	Value
1.1	Submarine cable length	km	
1.2	Submarine cable attenuation coefficient	dB/km	
1.3	Land cable length	km	
1.4	Land cable attenuation coefficient	dB/km	
1.5	Manufacturing and installation margin	dB	
1.6	Cable ageing	dB	
1.7	Repair margin	dB	
1.8	Unassigned margin	dB	
1.9	Total segment loss for BOL	dB	1.1*1.2+1.3*1.4+1.5+1.8
1.10	Total segment loss for EOL	dB	1.6+1.7+1.9

NOTE – Item 1.5 Manufacturing and installation margin is for the total segment.

6.2.3 Optical fibre amplifiers applications

The available power budget can be increased considerably by adding optical fibre amplifiers (OFAs) to the terminal equipment. They may be used as power amplifiers inserted just after the laser transmitter to increase the terminal output power or pre-amplifiers inserted just before the optical receiver to reduce the minimum optical signal power at the input of a composite receiver (pre-amplifier plus terminal receiver). In general, system enhancement can be achieved by power amplifier only, pre-amplifier only, or a combination of both. In these cases, the definition of the optical power budget is given taking into account the parameters described in clause 6.2.1 between the optical reference points S'-R, S-R' and S'-R', where the definitions of S' and R' are given in [ITU-T G.662].

Moreover, the application of remote optically pumped amplifiers (ROPAs) and distributed Raman amplifiers (DRAs) is also considered. A ROPA consists of a section of erbium doped fibre (EDF) pumped from the terminal station at an appropriate wavelength, whereas the DRA uses the fibre itself as an amplification medium and requires the fibre pumped from the terminal station at appropriate wavelength. There is no electrical power propagation into the submarine portion. This technique can be employed at either the transmit or the receive side of a link although it is generally considered more efficient at the receive side. Generic characteristics of DRAs are given in [ITU-T G.665]. In the case of the use of ROPAs or DRAs, the definition of the optical power budget, given on the basis of the parameters listed in clause 6.2.1, cannot be applied, as there is an amplification of the optical signal before the terminal end. The optical power budget is therefore no longer equal to the power difference between the two ends but to the allocable loss between the two ends of the link (see Annex B).

The possible system configurations are shown in Figure A.2.

6.3 System reliability performance

The reliability of the submarine portion of an optical fibre submarine cable system is generally characterized by:

– the expected number of repairs requiring intervention by a cable ship and due to system component failures during the system design life (e.g., splices, branching unit (BU), transitions, etc.). The usual requirement for the reliability of a repeaterless system is less than one failure requiring cable ship intervention during the system design life;

– the system design life, which is the period of time over which the optical fibre submarine cable system is designed to be operational in conformance with its performance specification. Usually, the system design life is a period of 25 years starting at the provisional acceptance date of the system, i.e., the date following installation when the system is claimed to be compliant with the performance specifications.

6.4 System capacity upgradeability

It may be advantageous to increase the transmission capacity by increasing the signal bit rate and/or the number of transmission channels (WDMS or DWDMS). Such upgrading can be beneficial because the reuse of cables can be achieved cost-effectively over the equipment's long life, typically 25 years.

Bit-rate upgradeability demands that systems be constructed with cables optimized for the higher bit rate, while the lower bit-rate TTE may be initially used. Even after upgrading, the bit rate of TTE output must comply with SDH or OTN specifications to ensure compatibility with standard terrestrial equipment.

Upgradeability also demands that the initially installed cable be capable of carrying the maximum number of channels expected in the future.

Upgrading by increasing signal bit rate or by adding more channels is much different from many viewpoints of system design, including the post-amplifier output power, pre-amplifier input power, power budget, signal-to-noise ratio, fibre chromatic dispersion, fibre polarization mode dispersion, and fibre non-linearities. It is therefore recommended that the systems be designed properly considering the possibility of future upgrades.

7 Characteristics and performance of the TTE

7.1 General

The terminal equipment is designed to assemble the tributaries for transmission over the optical fibre submarine cable system and to provide monitoring and maintenance facilities.

7.2 Transmission performance

7.2.1 Characteristics of the digital signal at the TI

The digital signal at the TI should be in accordance with [ITU-T G.703], [ITU-T G.709], [ITU-T G.957] and [ITU-T G.959.1].

7.2.2 Characteristics of the signal at the submarine cable optical interface (SCOI) and submarine electro-optic interface (SEOI)

The signal at the SCOI and SEOI interfaces should be in agreement with the power budget of the optical section. The following minimum list of parameters should be specified.

Parameters	Units	Defined in
General information		
Bit rate/line coding of optical tributary signals	–	clause 7.2.1.2 of [ITU-T G.959.1]
Modulation format	–	FFS
Maximum number of channels	–	clause 7.2.1.1 of [ITU-T G.959.1]
Maximum bit error ratio	–	clause 7.2.1.3 of [ITU-T G.959.1]
Operating wavelength range	nm	clause 7.2.2.6 of [ITU-T G.959.1]
Fibre type	–	clause 7.2.1.4 of [ITU-T G.959.1]
Interface at point S (transmit side of SEOI)		
Channel spacing	GHz	clause 7.2.2.4 of [ITU-T G.959.1]
Maximum mean channel output power	dBm	clause 7.2.1 of [ITU-T G.698.1]
Minimum mean channel output power	dBm	clause 7.2.1 of [ITU-T G.698.1]
Central frequency	THz	clause 7.2.2.3 of [ITU-T G.959.1]
Maximum central frequency deviation	GHz	clause 7.2.2.5 of [ITU-T G.959.1]
Minimum channel extinction ratio	dB	clause 7.2.5 of [ITU-T G.698.1]
Interface at point MPI-S (transmit side of SCOI)		
Maximum mean total output power	dBm	clause 7.2.2.2 of [ITU-T G.959.1]
Maximum channel power difference	dB	clause 7.2.4.4 of [ITU-T G.959.1]
Channel signal-to-noise ratio	dB	FFS
Interface at point MPI-R (receive side of SCOI)		
Maximum mean total input power	dBm	clause 7.2.4.3 of [ITU-T G.959.1]
Maximum channel power difference	dB	clause 7.2.4.4 of [ITU-T G.959.1]
Channel signal-to-noise ratio	dB	FFS
Maximum cumulated chromatic dispersion	ps/nm	FFS
Maximum differential group delay	ps	clause 7.2.3.7 of [ITU-T G.959.1]
Interface at point R (receive side of SEOI)		
Minimum channel back-to-back Q factor	dB	clause 7.2.3
Maximum mean channel input power	dBm	clause 7.4.1 of [ITU-T G.698.1]
Receiver sensitivity	dBm	clause 7.4.2 of [ITU-T G.698.1]

7.2.3 Minimum (channel) back-to-back Q factor

– The minimum (channel) back-to-back Q factor at reference point MPI-R is the minimum Q factor value for all channels when the MPI-S and MPI-R interfaces are directly connected (back-to-back configuration). An optical attenuator could be used between the two interfaces so that the input optical signal at MPI-R is compliant with nominal working conditions.

7.2.4 Jitter performances

The jitter performances of the TTE of an optical fibre submarine cable system should be in compliance with [ITU-T G.823], [ITU-T G.825], [ITU-T G.8251] and other relevant Recommendations throughout the system design life.

7.3 Actions consequent to an alarm

The terminal equipment should detect fault conditions and perform consequent actions as detailed in the relevant Recommendations. Alarm indications that could be taken into consideration for optical amplifiers utilized in the system should be limited to the critical parameters (e.g., input and output signal optical power, operating conditions of the pump laser, such as bias current and temperature). The laser safety aspects should be in accordance with [ITU-T G.664], [IEC 60825-1] and [IEC 60825-2].

7.4 Automatic switching

Where automatic switching is used to meet the overall availability requirement:

– the traffic degradation due to switching should be minimized and compatible with the overall system performance;

– indication should be given of the in-service equipment;

– manual override of the automatic switching should be feasible with a minimal degradation of system performance.

The standby equipment is recommended to be kept operating and monitored like the in-service equipment.

8 Characteristics and performance of the submarine cable

The recommended characteristics and performance of the submarine cable are given in [ITU-T G.978].

For certain repeaterless optical fibre submarine systems (usually for lakes or river crossings), the submarine cable or a part of it can be replaced by a marinized terrestrial cable (MTC).

Repeatered submarine cables can be used in all underwater applications, and repeaterless submarine cables in all MTC applications.

8.1 Dispersion mapping

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 local chromatic dispersion, for a given operating wavelength, as a function of distance from the optical transmitter to the optical receiver. The dispersion map will depend on the number of wavelengths in the system.

8.2 Dispersion management implementation

The design of the dispersion map for each optical section must be in accordance with the transmission requirements (limitation of non-linear effects, pulse broadening, etc.).

Residual cumulative dispersion for each wavelength may be compensated to zero by using a length of equalization fibre or other passive dispersion compensation devices at the transmit (pre-compensation) and/or receive side (post-compensation) in TTE.

For 100 Gbit/s coherent systems with large chromatic dispersion tolerance, the optical dispersion compensation may not be needed.

The system design should take into consideration all causes of variation from the planned dispersion map, both random and systematic, including, but not limited to:

– uncertainty in the measurements of zero dispersion wavelength, dispersion and dispersion slope of constituent dispersion shifted single mode fibre (DSF), non dispersion shifted single mode fibre (NDSF), dispersion compensation fibre (DCF), non-zero dispersion shifted single mode fibre (NZDSF), cut-off shifted single mode fibre (CSF), wideband non-zero dispersion single-mode fibre (WNZDF), negative slope fibres, EDF, etc.;

– uncertainty in temperature, pressure, and strain coefficients of these fibres in the cable and pressure vessels;
– uncertainty of the exact temperature and strain of these fibres during dispersion measurements;
– uncertainty of the temperature of the installed fibre;
– uncertainty resulting from reordering and "random" selection of portions of fibre sets in the assembly of elementary cable sections;
– ageing;
– repair operations.

Annex A

Implementation of repeaterless optical fibre submarine cable systems

(This annex forms an integral part of this Recommendation.)

A.1 Introduction

This annex outlines various aspects of the submarine cable system practice, as commonly employed in repeaterless systems, taking into account the OFAs application as power amplifiers and pre-amplifiers.

Typical system parameters are illustrated in Table A.1 up to 5 Gbit/s with single wavelength and in Table A.2 beyond this bit rate and in Table A.3 with wavelength division multiplexing systems (WDMS).

The information provided in this annex is intended as a guide to current practice and is not intended as a recommendation relating to existing or future systems.

Table A.1 – Illustrative system parameters of repeaterless optical fibre submarine cable systems up to 5 Gbit/s and single wavelength

Systems	**560 M (PDH)** 4 × 140 [Mbit/s]	**622 M (SDH)** 4 × 140/155 [Mbit/s]	**2488 M (SDH)** 16 × 140/155 [Mbit/s]	**4977 M (SDH)** 32 × 140/155 [Mbit/s]
Transmission capacity (ch. 64 kbit/s)	7'560-7'680	7'560-7'680	30'240-30'720	60'480-61'440
Information bit rate [Mbit/s]	~560	~560	~2'240	~4'480
Line bit rate [Mbit/s] (Note 3)	~591	~622	~2'488	~4'977
Line code (Note 2)	Max. flexibility	Scrambled NRZ (SDH) (Note 2)	Scrambled NRZ (SDH) (Note 2)	Scrambled NRZ (SDH) (Note 2)
Maximum system length [km] (Note 1)	>120	>120	>100	>80
Water depth [m]	Down to ~4'000			
Fibre type	ITU-T G.652; ITU-T G.653; ITU-T G.654			
Operating wavelength [nm]	~1'550			
System design life [year]	25			
Reliability (Note 4)	<1 repair in 25 years			
Error performance	ITU-T G.821	ITU-T G.826		
Jitter	ITU-T G.823	ITU-T G.825 (optical interfaces) FFS (electrical interfaces)		

Table A.1 – Illustrative system parameters of repeaterless optical fibre submarine cable systems up to 5 Gbit/s and single wavelength

NOTE 1 – The maximum system length is only indicative. The length can be increased considerably by using both non-standard PDH and SDH systems or optical booster amplifiers and/or optical pre-amplifiers. Remote optically pumped amplifiers can also be used for increasing the length (see Figure A.2).
NOTE 2 – In SDH systems, scrambled no return to zero (NRZ) code is used. In PDH systems, maximum flexibility is given to the line code to be adopted. It is also possible to combine these line codes with error correction coding in order to improve the system performances.
NOTE 3 – For PDH systems, the line bit-rate value is only indicative.
NOTE 4 – Refer to clause 6.3.
NOTE 5 – It will be possible to consider WDM technology to increase the transmission capacity and network flexibility of the systems. System parameters of repeaterless optical submarine cable systems with WDM technology are for future study.

Table A.2 – Illustrative system parameters of repeaterless optical fibre submarine cable systems beyond 5 Gbit/s

Systems	**10 G (SDH)** 32 × 140/155 [Mbit/s]		
Transmission capacity (ch. 64 kbit/s)	120'960-122'880		
Information bit rate [Mbit/s]	~8'960		
Line bit rate [Mbit/s]	~9'953		
Line code	Scrambled NRZ (Note 2)		
Maximum system length [km] (Note 1)	>70		
Water depth [m]	Down to ~4'000		
Fibre type	ITU-T G.652; ITU-T G.653; ITU-T G.654		
Operating wavelength [nm]	~1'550		
System design life [year]	25		
Reliability (Note 3)	<1 repair in 25 years		
Error performance	ITU-T G.821	ITU-T G.826	
Jitter	ITU-T G.823	ITU-T G.825 (optical interfaces) FFS (electrical interfaces)	
NOTE 1 – The maximum system length is only indicative. The length can be increased considerably by using both non-standard PDH and SDH systems or optical booster amplifiers and/or optical pre-amplifiers. Remote optically pumped amplifiers can also be used for increasing the length (see Figure A.2). NOTE 2 – In SDH systems, scrambled NRZ code is used. NOTE 3 – Refer to clause 6.3. NOTE 4 – It will be possible to consider WDM technology to increase the transmission capacity and network flexibility of the systems. System parameters of repeaterless optical submarine cable systems with WDM technology are for future study.			

Table A.3 – Illustrative system parameters of repeaterless optical fibre submarine cable systems with wavelength division multiplexing technology

Systems	100 G		
Transmission capacity	N × 100Gbit/s		
Information bit rate [Gbit/s]	[Note 1]		
Line bit rate [Gbit/s]	[Note 2]		
Line code	PDM-QPSK DC-PDM-BPSK PDM-DQPSK DC-PDM-DBPSK		
Maximum system length [km] (Note 3)	>70		
Water depth [m]	Down to ~4000		
Fibre type	ITU-T G.652; ITU-T G.653; ITU-T G.654		
Operating wavelength [nm]	~1550		
System design life [year]	25		
Reliability (Note 4)	<1 failure in 25 years		
Error performance	ITU-T G.8201		
Jitter	FFS		

NOTE 1 – The information bit rate is according to the client signal transported by the one wavelength of the system, including CBR, Ethernet, SDH and OTN services.

NOTE 2 – Line bit rate depends on the FEC redundancy added by the system.

NOTE 3 – The maximum system length is only indicative. The length can be increased considerably by using OTN systems (high gain FEC and digital signal processing function) or optical booster amplifiers and/or optical pre-amplifiers. Distributed Raman amplifiers and/or remote optically pumped amplifiers can also be used for increasing the length (see Figure A.2).

NOTE 4 – Refer to clause 6.3.

A.2 System configuration

A.2.1 Constituents of repeaterless optical fibre submarine cable systems

The purpose of a repeaterless optical fibre submarine cable system is to establish transmission links between two or more terminal stations located in a restricted geographical area.

When only two terminal stations are connected by the cable system, then it may be termed an "optical fibre submarine cable link". In the other case it may be termed an "optical fibre submarine cable network".

Figure A.1 shows the basic concept of repeaterless optical fibre submarine cable system and boundaries. Optical submarine branching units could be included, depending on each system requirement.

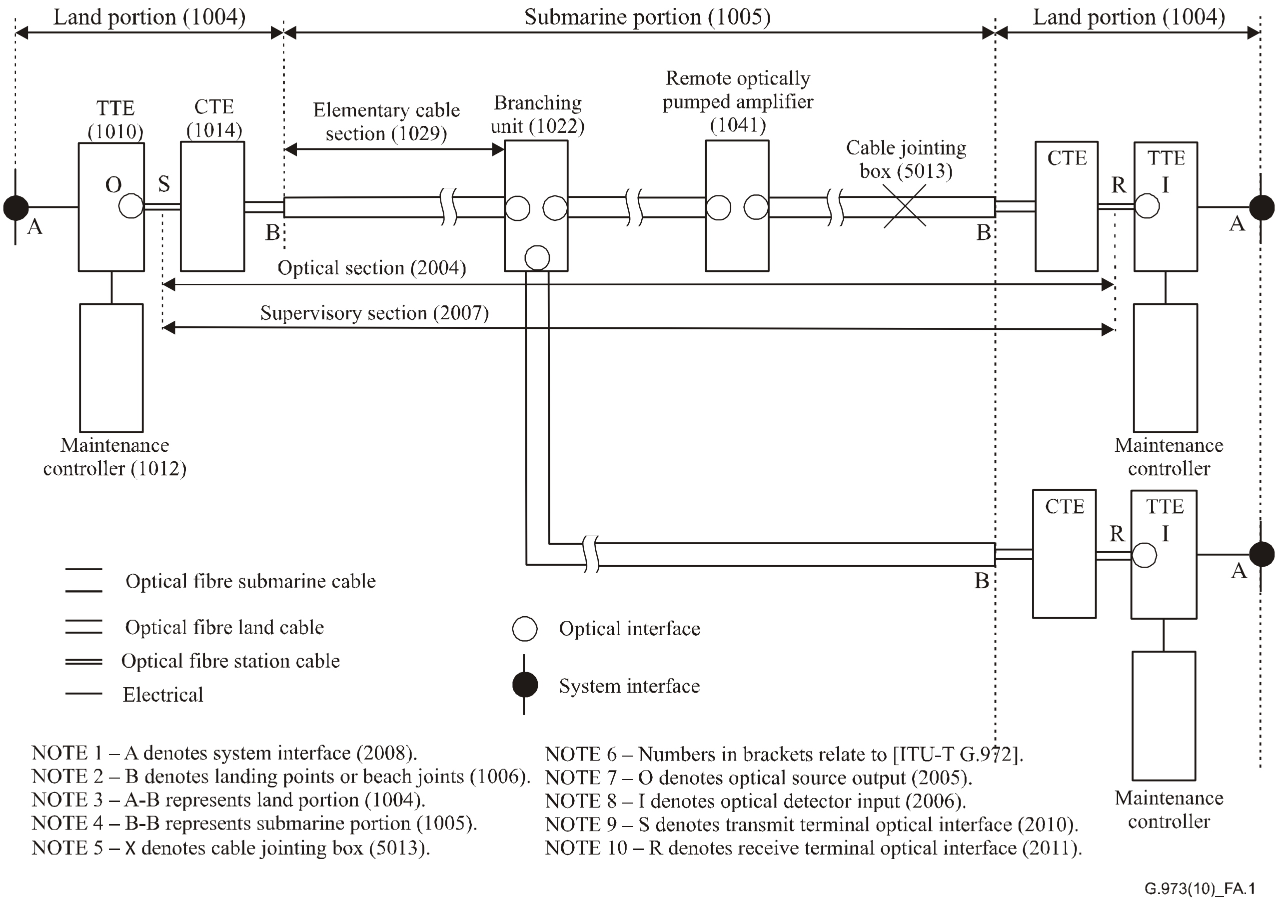

Figure A.1 – Example of repeaterless optical fibre submarine cable system

In Figure A.1, "A" denotes the system interface at the terminal station (where the system can be interfaced to terrestrial digital links or to other submarine cable systems), and "B" denotes beach joints or landing points. Letters in brackets in the following paragraphs refer to Figure A.1.

A repeaterless optical fibre submarine cable system consists of:

– a land portion, between the system interface in the terminal station (A) and the beach joint or landing point (B), which includes the optical fibre land cable, land joints, and the system terminal equipment, eventually in combination with OFAs (power amplifier and/or pre-amplifier) and/or in combination with the appropriate electronic components necessary to perform the remote pumping for the distributed amplifiers;

– a submarine portion on the seabed, between the beach joints or landing points (B), which includes the optical fibre submarine cable and, where necessary, submarine equipment, i.e., branching unit(s) and cable jointing box(es), and eventually a doped fibre to be used as ROPA, which could be implemented either in a special box laid on the seabed or incorporated in the cable.

The cable contains one or more optical fibre pairs (an optical fibre pair is used to establish transmission in both directions).

The optical fibre submarine cable is protected where appropriate: there are several different types of cable characterized by their mechanical structure, such as lightweight cable, lightweight protected cable, lightwire armoured cable, single armoured cable, double armoured cable and rock armoured cable.

The optical fibre land cable also requires protection.

A.2.2 Transmission configuration

The transmission configuration characterizes the flow of information between the terminal stations across the optical fibre submarine cable system.

An optical fibre cable section may contain a number of optical fibre pairs, and an optical fibre pair may support a number of digital line sections. The number of a digital line sections carried by an optical fibre cable section is given by the product of these two numbers.

A passive optical submarine branching unit (BU) is inserted into the submarine portion of an optical fibre submarine cable network, where it is necessary to interconnect more than two cable sections.

A.2.3 Supervision and remote maintenance of the system

Supervisory and remote maintenance equipment located in the terminal, in association with the BU supervisory unit, normally provides for fault localization.

The supervisory facilities commonly include one or more of the following:

– provision, on an in-service basis, of sufficient information to enable preventive maintenance;
– indication of approaching failure of the in-service equipment, so that preventive action may be undertaken or planned (e.g., by means of error correction coding in accordance with [ITU-T G.975]);
– the means to locate hard faults and intermittent faults of duration and frequency that cause the system to fail to meet the performance requirement.

Other means, such as optical reflectometry and electrical measurement using equipment installed in the terminal stations or on board the cable ship may permit increased accuracy of fault localization.

Supervision of the system may be facilitated by computerized equipment, located at one or both ends.

When using OFAs, for the control of their critical parameters, it is preferable that the OFAs' maintenance channels are connected to the existing maintenance circuitry of the TTE. In fact, in the amplified system configurations (see Figure A.2) it is not necessary to adopt a dedicated service channel independent from the SDH and PDH frame in order to transfer and manage the power amplifiers and pre-amplifiers alarms.

For the ROPA in which the submersible plant is wholly passive and where the total active part (electro-optic components as well as pump(s) lasers) is located in the transmit or receive side of the TTE, no specific maintenance policy different from the one adopted for the TTE should be considered.

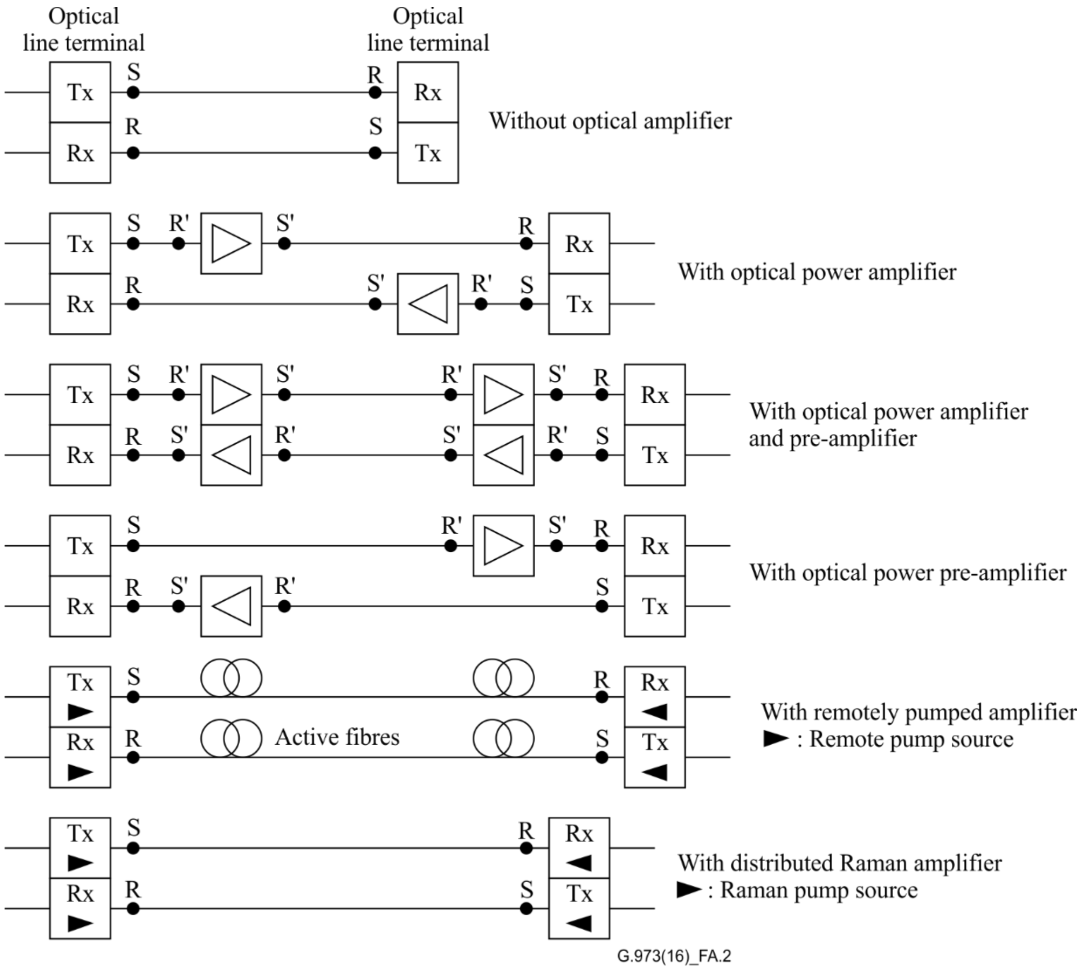

Figure A.2 – Possible system configurations

A.2.4 System integration

A submarine optical fibre cable link or network may be constructed using two or more submarine optical fibre cable systems (i.e., sets of equipment, cable, terminal equipment, BU, etc.) designed independently by different suppliers.

To integrate the submarine optical fibre network, it is necessary to ensure the compatibility of these designs. This is the purpose of the integration specifications.

A.3 Characteristics of the line signal

A.3.1 Structure of the line signal

The line frame and the line bit rate result from the multiplexing and coding operations performed by the TTE, taking into account the inclusion of the service and supervisory channels.

For PDH systems, the line code is chosen so as to suit the characteristics of the submarine portion. It can be used for such purposes as adapting the frequency spectrum on the optical line signal at the optical interface, and monitoring the line bit error rate at the receive terminal equipment. Violations of the line code may be used for supervisory purposes (system monitoring and/or transmission of supervisory information).

For SDH systems, the line code and its violation should comply with the relevant Recommendations.

For OTN systems, the line code and its violation should comply with the relevant Recommendations.

For PDH, SDH and OTN systems, the line code could be utilized in combination with an error correction coding (e.g., in accordance with [ITU-T G.975] or [ITU-T G.975.1] relating to forward error correction for submarine systems) in order to improve the system performances.

A.3.2 Line error ratio

Numerical values of the line error ratio are expressed in the form $n \times 10^{-p}$, where p is an integer.

For PDH systems, generally the supervisory equipment detects violations of the line code. The apparent line error ratio is directly calculated from the result of this observation. A more accurate value, the actual line error ratio, can be obtained by eliminating deliberate violations of the line code from the calculation. Violations of the line code may be used for supervisory or monitoring purposes.

For SDH systems, the line error ratio is evaluated on the received line signal based on parity violations on the bytes B2 [Multiplex Section Overhead (MSOH)] of the SDH frame.

For OTN systems, the line error ratio is evaluated on the received line signal.

A.4 System operation

A.4.1 Terminal-to-terminal communication

Generally, at least two service channels are established between two terminal stations: one through the optical fibre submarine cable system for the purpose of operating and maintaining the system, the other through external means for the purpose of maintaining the communication between two terminals stations in case of system fault.

In particular, a service channel is normally provided to allow transmission of terminal-to-terminal messages between the supervisory equipment of corresponding terminal stations to provide information on the status of the system and of the digital line sections, and on the ongoing supervisory activity, so as to help in overall system monitoring and in supervision.

One order wire channel may be established between terminal stations exchanging traffic for communication between the staff of the terminal stations.

A.5 Passive branching unit characteristics

A.5.1 General

The optical submarine passive branching units are:

– capable of being operated in accordance with the system performance recommendations during the system design life and at the sea depth environment conditions (temperature, pressure, etc.);
– designed to be capable of being handled, i.e., laid, recovered and relayed, without impairment of the performance of the cable, cable jointing boxes, branching units and couplers, provided that handling specifications are respected;
– designed to be transported and stored under specified temperature conditions without affecting the system design life, provided that storage and transport specifications are respected;
– capable of being operated on board a cable ship during laying and repair operations without affecting the system design life.

The size of the optical submarine branching units is such that it can be handled by appropriate cable-ship equipment.

A.5.2 BU constituents

The main BU constituents are:

– the BU housing:

  the mechanical piece part. The housing is designed to provide resistance to the sea depth pressure, watertightness, high mechanical strength and optical connection to the cable sections on each side of the BU.

Annex B

Repeaterless optical fibre submarine cable systems using ROPA: optical power budget between optical reference points S and R and line monitoring

(This annex forms an integral part of this Recommendation.)

B.1 Remote optically pumped amplifiers (ROPA)

The use of ROPA is a technique very likely to provide great benefit to repeaterless submarine systems.

A ROPA consists of a section of doped fibre which is activated by a pump beam sent from the terminal station. There is no electrical power feeding of the remote optical amplifier.

This technique can be employed at either the transmit or receive side of a link (all the electro-optic components, mainly pump lasers, will be placed in the terminal stations), although experience has shown that it is more efficient at the receive side.

i) The doped fibre in combination with an optical isolator make up a wholly passive device which could be implemented as shown in Figure B.1, either in a special box laid on the seabed or incorporated in the cable.

   The optimum placement of the doped fibre along the link is fixed by a compromise between the following parameters:

   – noise factor of the doped fibre;
   – remotely pumped optical amplifier gain;
   – available pump laser(s) optical power;
   – optical line fibre loss;
   – repair cable margin of the fibre between the doped fibre and the transmit or receive terminal station.

   Experience has shown that a good compromise is to have the doped fibre located some tens of kilometres from the receive side. This allows for an allocation of about 1 dB of repair cable margin for the entire system design life. Moreover, the repair cable margin can be increased following the increase of the pump laser optical power without causing any consequence to the submersible part of the system.

ii) Distributed Raman amplification

   Under study.

B.2 Optical power budget for systems using ROPA

In order to increase the optical section length, it is necessary to optimize the location of the doped fibre along the link.

The definition of the optical power budget as given in clause 6.2.1 cannot be applied in this case since there is an amplification of the optical signal along the link.

The optical power budget is therefore no longer equal to the optical power difference between the two ends of the link, but it is equal to the allowable loss between the two ends of the links (i.e., between the optical reference points S and R).

With reference to the example given in Figure B.1, the link gain is expressed in the following way:

– Link gain = Budget (with ROPA) – Budget (without ROPA)

– Link gain = (A_1 + A_2) (with ROPA) – A_1 (without ROPA)

where A_1 and A_2 are the attenuations of the fibre before and after the doped fibre, respectively.

The above formula shows that the evolution of the budget gain is a function of the pump laser optical power and of the fibre attenuation between the doped fibre amplifier and the receive station (A_2). (See Figure B.1.)

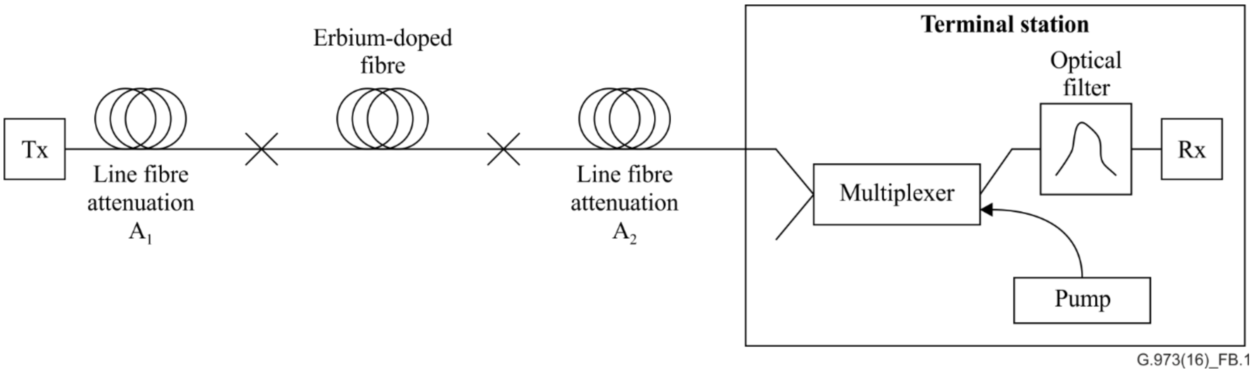

Figure B.1 – Example of system configuration with ROPA from the receiver end

B.3 Line monitoring for pumping portion

The performance of the repeaterless system with a distributed Raman amplifier and ROPA is singularly dependent on pump power, fibre losses in the pumped fibre section and fault conditions. A line monitoring system of the remote pumping portion is required to monitor the status and performance from the land station. This line monitoring system must be able to operate when the link is in-service and/or out-of-service without disturbing the system performance.

Figure B.2 shows the basic configuration of line monitoring in the repeaterless optical fibre submarine cable system. Optical time domain reflectometer (OTDR) is one of the candidate systems and is used primarily for the characterization and the fault localization of optical fibres, and can be achieved as a monitoring system of optical amplifier gain characteristics.

Two valuable characteristics are obtained in accordance with line monitoring:

– distributed Raman amplification gain (optical amplifier gain distribution);

– optical amplification gain of ROPA.

NOTE 1 – No optical isolator in ROPA is required to determine the optical amplifier gain. For applications of ROPA with optical isolators, the determination of the amplifier gain cannot be performed.

NOTE 2 – The line monitoring capability of the distributed Raman amplification gain will not be affected by optical isolators in ROPA.

OTDR can be classified into two detection categories. These two categories are direct-detection and coherent-detection techniques. Coherent OTDR (COTDR) is more advantageous than direct detection type for line monitoring, because it can achieve high detection sensitivity and excellent selectivity for a weak backscatter signal in the presence of the accumulated spontaneous emission noise.

For the probe light requirement for OTDR, the probe light having a weak signal power, probe shape and wavelength that will not affect the transmission performance is required. In particular, the launch of a high-power probe light into the amplifier systems raises degradations on the transmission performance. (See Figure B.2.)

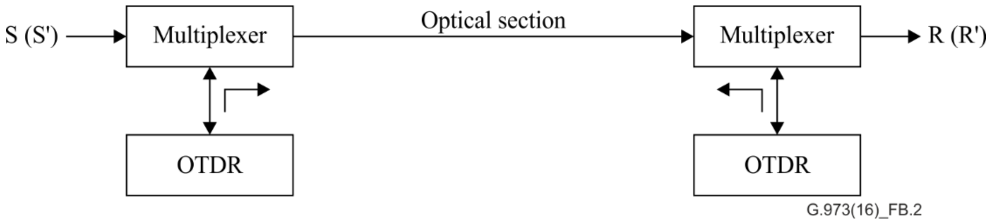

Figure B.2 – Example of line monitoring using OTDR

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[b-ITU-T G.Sup41] ITU-T G-series Supplement 41 (2010), *Design guidelines for optical fibre submarine cable systems.*

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