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

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Characteristics of repeaterless optical fibre submarine cable systems

ITU-T Recommendation G.973

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

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ITU-T Recommendation G.973

Characteristics of repeaterless optical fibre submarine cable systems

Summary

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) and wavelength division multiplexing systems (WDMS). It also covers the aspects related to the applications of discrete OFAs (power amplifiers, pre-amplifiers, remotely pumped amplifiers) and/or distributed remotely pumped OFAs using Raman amplification.

History

1996 – Version 1.

2003 – Version 2: This revision contains the new descriptions concerned with the remotely pumped amplifiers using Raman amplification. Characteristics of fibres in a submarine cable are listed in clause 7.4. The illustrative system parameters of repeaterless optical fibre submarine cable systems for beyond 5 Gbit/s and wavelength division multiplexing systems are also included in Annex A. Moreover, common descriptions in Annex A were moved to ITU-T Rec. G.971.

As seen above, this Recommendation has evolved considerably over the years; therefore the reader is warned to consider the appropriate version to determine the characteristics of already deployed product, taking into account the year of production. In fact, products are expected to comply with the Recommendation that was in force at the time of their manufacture, but may not fully comply with subsequent versions of the Recommendation.

Source

ITU-T Recommendation G.973 was approved on 14 December 2003 by ITU-T Study Group 15 (2001-2004) under the ITU-T Recommendation A.8 procedure.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

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.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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As of the date of approval of this Recommendation, ITU had not received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

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ITU-T Recommendation G.973

Characteristics of repeaterless optical fibre submarine cable systems

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) and wavelength division multiplexing systems (WDMS). It also covers the aspects related to the applications of discrete OFAs as power amplifiers, pre-amplifiers and/or remotely pumped optical amplifiers (either erbium doped transmission fibres using remote pumping from the terminal or using 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 PFE is necessary as there are no in-line OFAs.

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

The physical implementation of repeaterless optical fibre submarine cable systems and the implications of the use of remotely pumped optical amplifiers 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 stand-alone document, the status of a Recommendation.

– ITU-T Recommendation G.650.2 (2002), *Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable*.

– ITU-T Recommendation G.652 (2003), *Characteristics of a single-mode optical fibre and cable*.

– ITU-T Recommendation G.653 (2003), *Characteristics of a dispersion-shifted single-mode optical fibre cable*.

– ITU-T Recommendation G.654 (2002), *Characteristics of a cut-off shifted single-mode optical fibre and cable*.

– ITU-T Recommendation G.655 (2003), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.

– ITU-T Recommendation G.661 (1998), *Definition and test methods for the relevant generic parameters of optical amplifier devices and subsystems*.

– ITU-T Recommendation G.662 (1998), *Generic characteristics of optical amplifier devices and subsystems*.
– ITU-T Recommendation G.664 (2003), *Optical safety procedures and requirements for optical transport systems*.
– ITU-T Recommendation G.692 (1998), *Optical interfaces for multichannel systems with optical amplifiers*.
– ITU-T Recommendation G.701 (1993), *Vocabulary of digital transmission and multiplexing, and pulse code modulation (PCM) terms*.
– ITU-T Recommendation G.702 (1988), *Digital hierarchy bit rates*.
– ITU-T Recommendation G.703 (2001), *Physical/electrical characteristics of hierarchical digital interfaces*.
– ITU-T Recommendation G.707/Y.1322 (2003), *Network node interface for the synchronous digital hierarchy (SDH)*.
– ITU-T Recommendation G.783 (2000), *Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks*.
– ITU-T Recommendation 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 Recommendation G.823 (2000), *The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy*.
– ITU-T Recommendation G.825 (2000), *The control of jitter and wander within digital networks which are based on the synchronous digital hierarchy (SDH)*.
– ITU-T Recommendation G.826 (2002), *End-to-end error performance parameters and objectives for international, constant bit-rate digital paths and connections*.
– ITU-T Recommendation G.921 (1988), *Digital sections based on the 2048 kbit/s hierarchy*.
– ITU-T Recommendation G.955 (1996), *Digital line systems based on the 1544 kbit/s and the 2048 kbit/s hierarchy on optical fibre cables*.
– ITU-T Recommendation G.957 (1999), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.
– ITU-T Recommendation G.971 (2000), *General features of optical fibre submarine cable systems*.
– ITU-T Recommendation G.972 (2000), *Definition of terms relevant to optical fibre submarine cable systems*.
– ITU-T Recommendation G.975 (2000), *Forward error correction for submarine systems*.
– IEC 60825-1:2001, *Safety of laser products – Part 1: Equipment classification, requirements and user's guide.*
– IEC 60825-2: 2000, *Safety of laser products – Part 2: Safety of optical fibre communication systems*.

3 Terms and definitions

3.1 Definitions

This Recommendation defines the following terms:

3.1.1 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.

3.1.2 remotely pumped optical amplifier (RPOA): An OFA consisting of a section of erbium doped fibre that is activated by a pump beam sent from the Terminal Station.

3.1.3 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.

3.1.4 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.

3.1.5 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.

3.1.6 Raman gain coefficient: Under study.

3.2 Terms defined in other Recommendations

This Recommendation uses the following terms defined in other Recommendations:

– Digital Line Section (DLS): See ITU-T Rec. G.701.
– Multiplex Section Overhead (MSOH): See ITU-T Rec. G.783.
– Optical Fibre Amplifier (OFA): See ITU-T Rec. G.661.
– S, R reference points: See ITU-T Recs G.955 and G.957.
– S', R' reference points: See ITU-T Rec. G.662.
– Synchronous Digital Hierarchy (SDH): See ITU-T Rec. G.707/Y.1322.
– Synchronous Transport Module (STM): See ITU-T Rec. G.707/Y.1322.
– Single Armoured Cable: See ITU-T Rec. G.972.
– Double Armoured Cable: See ITU-T Rec. G.972.
– Rock Armoured Cable: See ITU-T Rec. G.972.
– Nominal Transient Tensile Strength: See ITU-T Rec. G.972.
– Nominal Operating Tensile Strength: See ITU-T Rec. G.972.
– Nominal Permanent Tensile Strength: See ITU-T Rec. G.972.
– Minimum Cable Bending Radius: See ITU-T Rec. G.972.
– Cable Breaking Load: See ITU-T Rec. G.972.
– Fibre-breaking Cable Load: See ITU-T Rec. G.972.

4 Abbreviations

This Recommendation uses the following abbreviations:

BER	Bit Error Ratio
BU	Branching Unit
CSF	Cut-off Shifted single mode Fibre
DCF	Dispersion Compensation single mode Fibre
DLS	Digital Line Section
DRA	Distributed Raman Amplification
DSF	Dispersion Shifted single mode Fibre
EDF	Erbium Doped Fibre
ITI	Intermediate Terrestrial Interface
MSOH	Multiplex Section Overhead
MTC	Marinized Terrestrial Cable
NRZ	No Return to Zero
NZDSF	Non-Zero Dispersion Shifted single mode Fibre
OFA	Optical Fibre Amplifier
PDH	Plesiochronous Digital Hierarchy
PFE	Power Feeding Equipment
PMD	Polarization Mode Dispersion
RPOA	Remotely Pumped Optical Amplifier
SDH	Synchronous Digital Hierarchy
SMF	Single-Mode Fibre
STM	Synchronous Transport Module
SWS	Single Wavelength System
TI	Terminal Interface
TTE	Terminal Transmission Equipment
WDM	Wavelength Division Multiplex
WDMS	Wavelength Division Multiplexing System

5 Characteristics and performance of the system

5.1 Characteristics and performance of the digital line sections

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

5.1.1 Characteristics of the digital signals at the system interface

The recommended interface bit rates are given in ITU-T Recs G.702, G.703, G.707/Y.1322, etc.

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

5.1.2 Overall error performances

The error performances of an optical fibre submarine cable system should conform to the relevant Recommendations for the design life of the systems (e.g., ITU-T Rec. G.821 for PDH systems and ITU-T Rec. G.826 for SDH systems).

For PDH systems, the relevant parameters are severely errored seconds and errored seconds. They are derived from ITU-T Rec. G.821 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/G.821.

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

5.1.3 System availability

For PDH systems:

– the unavailable time definition is derived from Annex A/G.821;

– as per Annex A/G.821, 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 Rec. G.826.

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 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.

5.1.4 Jitter performances

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

5.1.5 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 an amount equal to the difference between the DLS specification and the terminal allocation.

5.1.6 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 WDMS and DWDMS:
   - any failure of up to half number of wavelengths should have no effect on any of the remaining wavelengths;

b) for SWS, WDMS and DWDMS:
   1) any failure on one fibre pair should have no effect on the other fibre pairs in the system;
   2) 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.

5.2 Characteristics and performance of the optical sections

5.2.1 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, as 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.

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, 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 cableship, and which is equal to the sum of ageing, repair and unassigned margins.

5.2.2 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 5.2.1 between the optical reference point S'-R, S-R', S'-R', respectively, where the definitions of S′ and R′ are given in ITU-T Rec. G.662.

Moreover, the application of Remotely Pumped Optical Amplifiers (RPOA) and Distributed Raman Amplifiers is also considered. A remotely pumped optical amplifier consists of a section of erbium doped fibre pumped from the terminal station at an appropriate wavelength, whereas the distributed Raman amplifiers use the fibre itself as an amplification medium and require the fibre pumped from the terminal station at appropriate wavelength. There is no electrical power feeding to the discrete remote amplifier or distributed Raman amplifier. 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. In this last case, the definition of the optical power budget, given on the basis of the parameters listed in 5.2.1, 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.

5.3 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 cableship and due to system component (e.g., splices, BU, transitions, etc.) failures during the system design life:

  The usual requirement for the reliability of a repeaterless system is less than one failure requiring cableship intervention during the system design life;

– the system design life:

  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.

5.4 System capacity upgradeability

It may be advantageous to increase the transmission capacity by increasing signal the 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 lowerbit-rate TTE may be initially used. Even after upgrading, the bit rate of TTE output must comply with SDH 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, and fibre non-linearities. It is therefore recommended that the systems be designed properly considering the possibility of future upgrades.

6 Characteristics and performance of the terminal equipment

6.1 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.

6.2 Transmission performance

6.2.1 Characteristics of the digital signal at the system interface

The digital signal at the system interface should be in accordance with the relevant Recommendations.

6.2.2 Characteristics of the signal at the optical interface

The signal at the optical interface should be in agreement with the power budget of the optical section. In particular, at the time of the system installation, certain limits should be respected:

– minimum receive terminal equipment mean input power (dBm):

  the mean optical power in the optical line signal which must be present at the terminal optical input interface so that the optical power budget of the cable section offers a guaranteed system margin;

– minimum transmit terminal equipment mean output power (dBm):

  the mean optical power in the optical line signal which must be present at the terminal optical output interface so that the optical power budget of the cable section offers a guaranteed system margin.

6.2.3 Jitter performances

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

6.3 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 Rec. G.664, IEC 60825-1 and IEC 60825-2.

6.4 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.

7 Characteristics and performance of the submarine cable

7.1 Scope

An underwater optical fibre cable can be:

– a repeatered submarine cable;

– a repeaterless submarine cable;

– a marinized terrestrial cable.

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

The repeaterless submarine cable is equally suitable for use in both shallow and deep waters. It is normally tested extensively to show that it can be installed and repaired in situ, even in worst weather conditions, without any impairment of optical, electrical or mechanical performance or reliability.

Such reparability is a necessary feature as span lengths increase and make the cable too expensive or difficult to replace. Full (high) reparability is usually essential for any cable laid in a hostile environment.

The high level of tensile strength/performance provided (in both cable and jointing box) takes into account the ability of a ship to hold station in poor weather conditions, as well as water depth.

7.2 Transmission characteristics

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 Recs G.652, G.653, G.654 or G.655. Types of fibre are chosen to optimize the system overall cost and performance.

The transmission characteristics of the fibre 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, optical distribution frame, branching unit, etc.).

The fibre attenuation and the chromatic dispersion 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.

7.3 Mechanical characteristics and resistance to the environment

7.3.1 Fibre protection by the cable structure

The fibre survivability is governed by the propagation 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 screen test applied to the fibre after fibre drawing. It also depends on fibre environment in the cable, and on 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 fibre is strongly maintained in the cable, so that the fibre elongation is essentially equal to that of the cable;

– the loose cable structure, where the fibre is 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 cable break at the depth of utilization.

7.3.2 Fibre mechanical performance

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

7.3.3 Cable mechanical performance

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

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.

Should the cable become hooked to break by a grapnel, a large anchor or fishing tool, the load at break can be 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 the cable should be replaced; its length should stay within a specified value.

Several parameters are defined in ITU-T Rec. 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, measured during qualification test;
– the fibre-breaking cable load, measured during qualification test;
– the nominal transient tensile strength, which could be accidentally encountered, particularly during recovery operations;
– the nominal operating tensile strength, which could be encountered during repairs;
– the nominal permanent tensile strength, which characterizes the status of the cable after laying;
– the minimum cable bending radius, which is a guidance for cable handling.

7.3.4 Cable protection

The optical fibre submarine cable should provide a good protection against the environmental hazards at its depth of utilization: protection against marine life, fishbite and abrasion, and armours against aggression and ship activities. Different types of protected cable are defined in ITU-T Rec. G.972, typically:

– the single armoured cable;
– the double armoured cable;
– the rock armoured cable.

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

– the armoured land cable with an armour to be maintained at earth potential, and which is suitable to be directly buried;

– the duct shielded cable, with a circumferential safety shield (with may be the fishbite 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.

7.4 Characteristics of fibres in a submarine cable

7.4.1 General

The main parameters that characterize an optical fibre are:

- the attenuation coefficient at all the operating signal wavelengths expressed in dB/km;
- the attenuation coefficient at all the operating pump wavelengths expressed in dB/km;
- the chromatic dispersion coefficient at all the operating signal wavelengths in ps/nm·km;
- the zero dispersion wavelength λ_0 in nm;
- the dispersion slope around the operating signal wavelengths in ps/nm^2·km;
- the non-linear refractive index n_2 in m^2/W;
- the effective area A_{eff} in µm^2;
- the non-linear coefficient n_2/A_{eff} in W^{-1};
- the ensemble average polarization mode dispersion (PMD) in ps/(km)$^{1/2}$;
- the Raman gain coefficient in m/W in case of distributed Raman amplification used.

Regarding those parameters, submarine system designers may distinguish several types of optical fibre. Among them,

- single-mode fibre (SMF) defined in ITU-T Rec. G.652;
- Dispersion Shifted single mode Fibre (DSF) defined in ITU-T Rec. G.653;
- Cut-off Shifted single mode Fibre (CSF) defined in ITU-T Rec. G.654;
- Non-Zero Dispersion Shifted single mode Fibre (NZDSF) defined in ITU-T Rec. G.655;
- Dispersion Compensation single mode Fibre (DCF);
- negative dispersion slope fibres;
- very large effective area fibres;
- pure silica core fibres.

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. In that case, the system is said to be dispersion managed.

7.4.2 Fibre loss

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

7.4.3 Fibre non-linearity

Non-linear effects should be considered when long-haul optical links are 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 the systems with several wavelengths, the predominant effect is normally cross-phase modulation due to the presence of adjacent wavelengths. This non-linearity induces performance degradation.

7.4.4 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. This value may be expressed for the whole link and is generally fixed to a certain ratio of the bit timeslot. PMD is expressed in $ps/(km)^{1/2}$.

7.4.5 Chromatic dispersion

Chromatic dispersion is the wavelength dependency 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. Depending on the system design and especially on the number of wavelengths, it may be of interest to manage it quite differently to limit pulse spreading and other propagation effects. Generally, this management leads to a dispersion map that shows how dispersion is managed along the whole link.

7.4.5.1 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. Dispersion map will depend on the number of wavelengths in the system

7.4.5.2 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.

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 DSF, NDSF, DCF, NZDSF, CSF, 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; and
– repair operations.

Annex A

Implementation of repeaterless optical fibre submarine cable systems

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 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.

The definition of terms used in this Recommendation can be found in ITU-T Rec. G.972.

Table A.1/G.973 – 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)	7560-7680	7560-7680	30 240-30 720	60 480-61 440
Information bit rate [Mbit/s]	~560	~560	~2240	~4480
Line bit rate [Mbit/s] (Note 4)	~591	~622	~2488	~4977
Line code (Note 3)	max. flexibility	Scrambled NRZ (SDH)	Scrambled NRZ (SDH)	Scrambled NRZ (SDH)
Maximum system length [km] (Note 2)	>120	>120	>100	>80
Water depth [m]	down to ~4000			
Fibre type	G.652; G.653; G.654			
Operating wavelength [nm]	~1550			
System design life [year]	25			
Reliability (Note 5)	<1 repair in 25 years			
Error performance	G.821	G.826		
Jitter	G.823	G.958 (optical interfaces) FFS (electrical interfaces) (Note 1)		

Table A.1/G.973 – Illustrative system parameters of repeaterless optical fibre submarine cable systems up to 5 Gbit/s and single wavelength

NOTE 1 – FFS means "for further study".

NOTE 2 – 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. Remotely pumped optical amplifiers can also be used for increasing the length (see Figure A.2).

NOTE 3 – In SDH systems, scrambled 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 4 – For PDH systems, the line bit rate value is only indicative.

NOTE 5 – Refer to 5.3.

NOTE 6 – 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/G.973 – Illustrative system parameters of repeaterless optical fibre submarine cable systems for beyond 5 Gbit/s and wavelength multiplexed systems (FFS)

Systems	**10 G**			
Transmission capacity (ch. 64 kbit/s)				
Information bit rate [Mbit/s]				
Line bit rate [Mbit/s] (Note 4)				
Line code (Note 3)				
Maximum system length [km] (Note 2)				
Water depth [m]	down to ~4000			
Fibre type	G.652; G.653; G.654; G.655			
Operating wavelength [nm]	~1550			
System design life [year]	25			
Reliability (Note 5)	<1 repair in 25 years			
Error performance				
Jitter				

Table A.2/G.973 – Illustrative system parameters of repeaterless optical fibre submarine cable systems for beyond 5 Gbit/s and wavelength multiplexed systems (FFS)

NOTE 1 – FFS means "for further study".
NOTE 2 – 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. Remotely pumped optical amplifiers can also be used for increasing the length (see Figure A.2).
NOTE 3 – In SDH systems, scrambled NRZ code is used. In PDH systems, max. 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 4 – For PDH systems, the line bit rate value is only indicative.
NOTE 5 – Refer to 5.3.

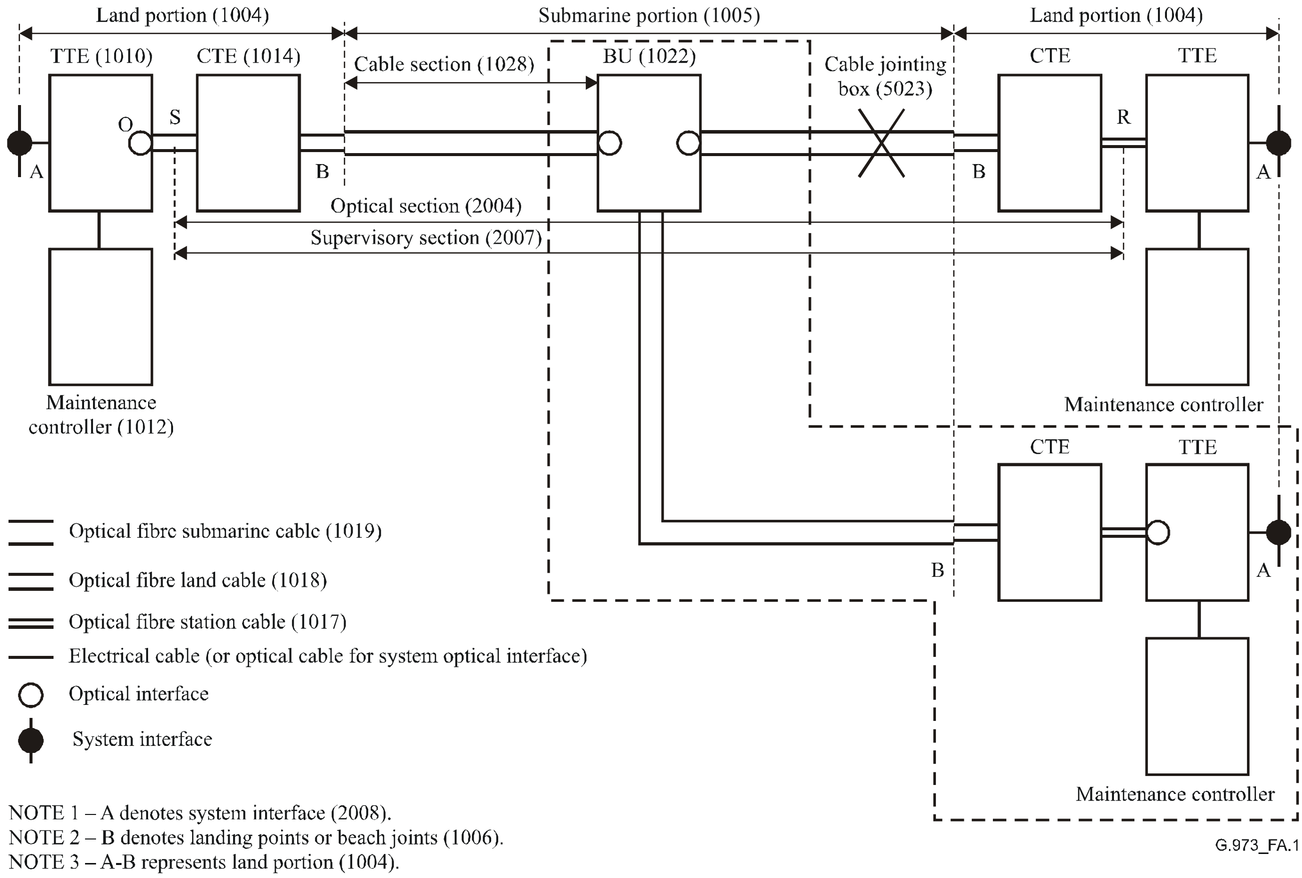
A.2 System configuration

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.



NOTE 1 – A denotes system interface (2008).
NOTE 2 – B denotes landing points or beach joints (1006).
NOTE 3 – A-B represents land portion (1004).
NOTE 4 – B-B represents submarine portion (1005).
NOTE 5 – X denotes cable jointing box (5023).
NOTE 6 – Numbers in brackets related to ITU-T Rec. G.972.

Figure A.1/G.973 – 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. Letter in brackets in the following sections 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 remotely pumped optical amplifier 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 Rec. G.975 on "Forward error correction for submarine systems");
– 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 cableship, may permit the accuracy of fault localization to be increased.

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

In case of utilization of OFAs, for the control of their critical parameters, it should be preferred that the OFAs' maintenance channels will be 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 to manage the power amplifiers and pre-amplifiers alarms.

For the remotely pumped optical amplifiers in which the submersible plant is wholly passive and where the total active part (electro-optic components as well as pump(s) lasers) are 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.

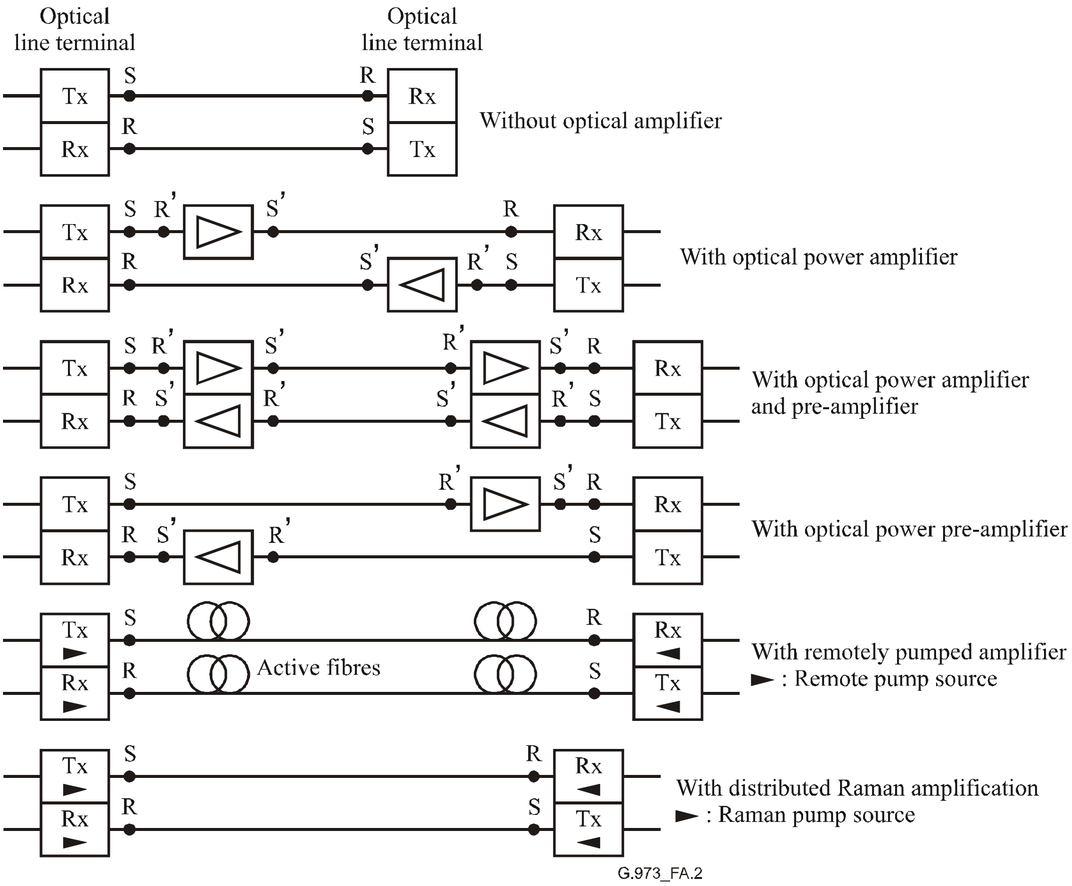


Figure A.2/G.973 – Possible system configurations

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 both PDH and SDH systems, the line code could be utilized in combination with an error correction coding (e.g. in accordance with ITU-T Rec. G.975 on "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.

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 cableship 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 cableship equipment.

A.5.2 BU constituents

The main BU constituents is:

– the BU housing:

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

Annex B

Repeaterless optical fibre submarine cable systems using remotely pumped optical amplifiers: Optical power budget between optical reference points S and R and line monitoring

B.1 Remotely pumped optical amplifiers

The use of remotely pumped optical amplifiers is a technique very likely to provide great benefit to repeaterless submarine systems.

A remotely pumped optical amplifier 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 it has been experienced 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 at some tens of kilometres from the receive side. This allows to allocate 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 remotely pumped optical amplifiers

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 5.2.1 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 RPOA) – Budget (without RPOA)

Link gain = $(A_1 + A_2)$ (with RPOA) – A_1 (without RPOA) 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.)

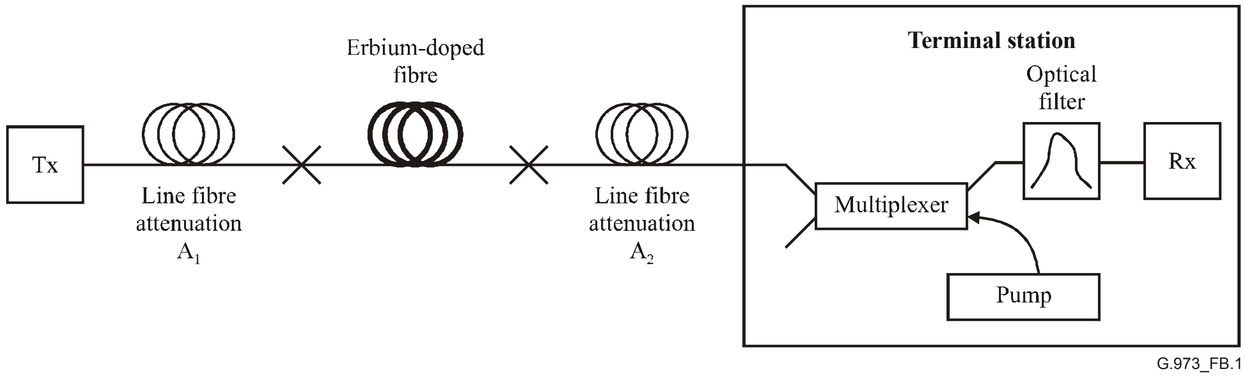


Figure B.1/G.973 – Example of system configuration with remotely pumped optical amplifier from the receiver end

B.3 Line monitoring for pumping portion

The performance of the repeaterless system with a distributed Raman amplifier and remotely pumped amplifier 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 the line monitoring:

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

– optical amplification gain of remotely pumped amplifier.

NOTE 1 – No optical isolator in remotely pumped optical amplifiers is required to determine the optical amplifier gain. For applications of remotely pumped optical amplifiers 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 remotely pumped amplifier.

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 are required. Especially, the launch of a high-power probe light into the amplifier systems raises degradations on the transmission performance. (See Figure B.2.)

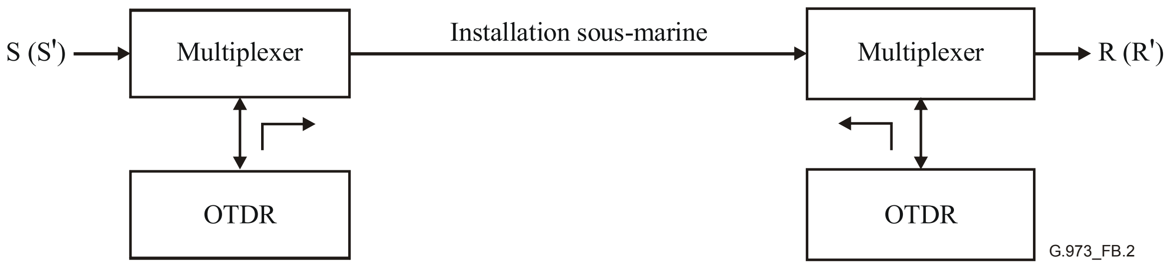


Figure B.2/G.973 – Example of line monitoring using OTDR

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