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DIGITAL SYSTEMS AND NETWORKS

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

**Characteristics of repeaterless optical fibre
submarine cable systems**

ITU-T Recommendation G.973

(Previously CCITT Recommendation)

ITU-T G-SERIES RECOMMENDATIONS
TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
INTERNATIONAL ANALOGUE CARRIER SYSTEM	
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA CHARACTERISTICS	
DIGITAL TRANSMISSION SYSTEMS	
TERMINAL EQUIPMENTS	G.700–G.799
General	G.700–G.709
Coding of analogue signals by pulse code modulation	G.710–G.719
Coding of analogue signals by methods other than PCM	G.720–G.729
Principal characteristics of primary multiplex equipment	G.730–G.739
Principal characteristics of second order multiplex equipment	G.740–G.749
Principal characteristics of higher order multiplex equipment	G.750–G.759
Principal characteristics of transcoder and digital multiplication equipment	G.760–G.769
Operations, administration and maintenance features of transmission equipment	G.770–G.779
Principal characteristics of multiplexing equipment for the synchronous digital hierarchy	G.780–G.789
Other terminal equipment	G.790–G.799
DIGITAL NETWORKS	G.800–G.899
General aspects	G.800–G.809
Design objectives for digital networks	G.810–G.819
Quality and availability targets	G.820–G.829
Network capabilities and functions	G.830–G.839
SDH network characteristics	G.840–G.899
DIGITAL SECTIONS AND DIGITAL LINE SYSTEM	G.900–G.999
General	G.900–G.909
Parameters for optical fibre cable systems	G.910–G.919
Digital sections at hierarchical bit rates based on a bit rate of 2048 kbit/s	G.920–G.929
Digital line transmission systems on cable at non-hierarchical bit rates	G.930–G.939
Digital line systems provided by FDM transmission bearers	G.940–G.949
Digital line systems	G.950–G.959
Digital section and digital transmission systems for customer access to ISDN	G.960–G.969
Optical fibre submarine cable systems	G.970–G.979
Optical line systems for local and access networks	G.980–G.999

For further details, please refer to ITU-T List of Recommendations.

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 covers also the aspects related to SDH systems and applications of discrete OFAs as power amplifiers, pre-amplifiers and/or distributed OFAs as remotely pumped optical amplifiers (i.e. doped transmission fibres using "remote" pumping at the terminal ends).

Source

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FOREWORD

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CONTENTS

	Page
1	Scope..... 1
2	References..... 1
3	Terms and definitions 2
3.1	Definitions 2
3.2	Terms defined in other Recommendations 3
4	Abbreviations..... 3
5	Characteristics and performance of the system..... 4
5.1	Characteristics and performance of the digital line sections..... 4
5.1.1	Characteristics of the digital signals at the system interface 4
5.1.2	Overall error performances..... 4
5.1.3	System availability..... 4
5.1.4	Jitter performances 5
5.1.5	Performance allocation between portions of the system 5
5.2	Characteristics and performance of the optical sections..... 5
5.2.1	Optical power budget..... 5
5.2.2	Optical fibre amplifiers applications 6
5.3	System reliability performance..... 7
6	Characteristics and performance of the terminal equipment 7
6.1	General..... 7
6.2	Transmission performance..... 7
6.2.1	Characteristics of the digital signal at the system interface..... 7
6.2.2	Characteristics of the signal at the optical interface..... 7
6.2.3	Jitter performances 7
6.3	Actions consequent to an alarm 8
6.4	Automatic switching 8
7	Characteristics and performance of the submarine cable..... 8
7.1	Scope..... 8
7.2	Transmission characteristics 9
7.3	Mechanical characteristics and resistance to the environment 9
7.3.1	Fibre protection by the cable structure 9
7.3.2	Fibre mechanical performance..... 9
7.3.3	Cable mechanical performance..... 10
7.3.4	Cable protection..... 10

	Page
Annex A – Implementation of repeaterless optical fibre submarine cable systems.....	11
A.1 Introduction.....	11
A.2 System configuration	12
A.2.1 Constituents of repeaterless optical fibre submarine cable systems.....	12
A.2.2 Transmission configuration	14
A.2.3 Supervision and remote maintenance of the system.....	14
A.2.4 System integration	16
A.3 Characteristics of the line signal.....	16
A.3.1 Structure of the line signal.....	16
A.3.2 Line error ratio.....	16
A.4 System operation.....	16
A.4.1 Terminal-to-terminal communication.....	16
A.5 Passive branching unit characteristics	17
A.5.1 General.....	17
A.5.2 BU constituents.....	17
A.6 Manufacturing and installation	17
A.6.1 Quality in repeaterless optical fibre submarine cable systems	17
A.6.2 Assembly and laying procedure.....	18
A.6.3 System commissioning	18
A.7 Maintenance.....	19
A.7.1 Routine maintenance	19
A.7.2 Maintenance at sea.....	19
Annex B – Repeaterless optical fibre submarine cable systems using remotely pumped optical amplifiers: Optical power budget between optical reference points S and R.	19
B.1 Remotely pumped optical amplifiers	19
B.2 Optical power budget for systems using remotely pumped optical amplifiers.....	20

Recommendation G.973

CHARACTERISTICS OF REPEATERLESS OPTICAL FIBRE SUBMARINE CABLE SYSTEMS

(Geneva, 1996)

1 Scope

This Recommendation is concerned primarily with the system performance and interface requirements of repeaterless optical fibre submarine cable systems. It covers also the aspects related to SDH systems and applications of discrete OFAs as power amplifiers, pre-amplifiers and/or distributed OFAs as remotely pumped optical amplifiers (i.e. doped transmission fibres using "remote" pumping at the terminal ends).

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".

In a repeaterless submarine cable system, no PFE is foreseen in order to reduce the system complexity as well as the system cost.

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; all 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.

- ITU-T Recommendation G.652 (1997), *Characteristics of a single-mode optical fibre cable.*
- ITU-T Recommendation G.653 (1997), *Characteristics of a dispersion-shifted single-mode optical fibre cable.*
- ITU-T Recommendation G.654 (1997), *Characteristics of a cut-off shifted single-mode optical fibre cable.*
- ITU-T Recommendation G.661 (1996), *Definition and test methods for the relevant generic parameters of optical fibre amplifiers.*
- ITU-T Recommendation G.662 (1995), *Generic characteristics of optical fibre amplifier devices and sub-systems.*
- CCITT Recommendation G.702 (1988), *Digital hierarchy bit rates.*

- CCITT Recommendation G.703 (1991), *Physical/electrical characteristics of hierarchical digital interfaces.*
- ITU-T Recommendation G.707 (1996), *Network node interface for the Synchronous Digital Hierarchy (SDH).*
- ITU-T Recommendation G.783 (1997), *Characteristics of Synchronous Digital Hierarchy (SDH) equipment functional blocks.*
- ITU-T Recommendation G.821 (1996), *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 (1993), *The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy.*
- ITU-T Recommendation G.826 (1996), *Error performance parameters and objectives for international, constant bit rate digital paths at or above the primary rate.*
- ITU-T Recommendation G.921 (1988), *Digital section 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 (1995), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy.*
- ITU-T Recommendation G.958 (1994), *Digital line systems based on the synchronous digital hierarchy for use on optical fibre cables.*
- ITU-T Recommendation G.971 (1996), *General features of optical fibre submarine cable systems.*
- ITU-T Recommendation G.972 (1997), *Definition of terms relevant to optical fibre submarine cable systems.*
- ITU-T Recommendation G.975 (1996), *Forward error correction for submarine systems.*
- IEC Publication 825-2 (1993), *Part 2: Safety of optical fibre communications 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): A distributed OFA consisting of a section of doped fibre which is activated by a pump beam sent from the Terminal Station.

3.1.3 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.

3.1.4 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 Terms defined in other Recommendations

This Recommendation uses the following terms defined in other Recommendations:

- Digital Line Section (DLS): See Recommendation G.701.
- Multiplex Section Overhead (MSOH): See Recommendation G.783.
- Optical Fibre Amplifier (OFA): See Recommendation G.661.
- S, R reference points: See Recommendations. G.955 and G.957.
- S', R' reference points: See Recommendation G.622.
- Synchronous Digital Hierarchy (SDH): See Recommendation G.707.
- Synchronous Transport Module (STM): See Recommendation G.707.
- Single Armoured Cable: See Recommendation G.972.
- Double Armoured Cable: See Recommendation G.972.
- Rock Armoured Cable: See Recommendation G.972.
- Nominal Transient Tensile Strength: See Recommendation G.972.
- Nominal Operating Tensile Strength: See Recommendation G.972.
- Nominal Permanent Tensile Strength: See Recommendation G.972.
- Minimum Cable Bending Radius: See Recommendation G.972.
- Cable Breaking Load: See Recommendation G.972.
- Fibre-breaking Cable Load: See Recommendation G.972.

4 Abbreviations

This Recommendation uses the following abbreviations:

BER	Bit Error Ratio
BU	Branching Unit
DLS	Digital Line Section
MSOH	Multiplex Section Overhead
NRZ	No Return to Zero
OFA	Optical Fibre Amplifier
PDH	Plesiochronous Digital Hierarchy
PFE	Power Feeding Equipment
RPOA	Remotely Pumped Optical Amplifier
SDH	Synchronous Digital Hierarchy
STM	Synchronous Transport Module
TTE	Terminal Transmission Equipment

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 Recommendations G.702, G.703, G.707, etc.

Several interface 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. Recommendation G.821 for PDH systems and Recommendation G.826 for SDH systems).

For PDH systems, the relevant parameters are degraded minutes, severely errored seconds and errored seconds. They are derived from Recommendation G.821 in conjunction with the performances at the 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, *Blue Book*.

For SDH systems, the relevant parameters are severely errored seconds and errored seconds. They are derived from Recommendation G.826.

5.1.3 System availability

For PDH systems:

- the unavailable time performance is derived from Annex A/G.821, *Blue Book*, on a per-km basis. The DLS allocation is obtained by multiplying the per-km allocation by the DLS length;
- as per Annex A/G.821, *Blue Book*, 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 performance and its definition are derived from Recommendation 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 Recommendation G.823 for the system design life. This applies in particular to:

- the jitter tolerance, for each digital line section, at the system input interface;
- the maximum output jitter, for each digital line section, at the system output interface;
- the jitter transfer characteristic, for each digital line section, between the input and the output system interface.

The jitter performances for SDH system at the STM-1 level electrical interfaces are under study.

The jitter performances for SDH system at the STM-1 level optical interfaces should follow Recommendation G.958.

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 defined) 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.

5.2 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 power, expressed in dBm, and 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^{-x} ;
- 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^{-x} ;
- 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 can not 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 definition of S' and R' are given in Recommendation G.662.

Moreover, the application of Remotely Pumped Optical Amplifiers (RPOA) is also considered. 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 to the remote 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 cables ship 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 cables ship intervention during the system design life. A model for calculating the system reliability is under study;
- 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.

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 Recommendation G.823 throughout the system design life. In particular:

- the jitter tolerance, for each digital line section, at the system input interface;
- the maximum output jitter, for each digital line section, at the system output interface;
- the jitter transfer characteristic with the terminal in a looped configuration, for each digital line section, between the input and the output system interface,

should follow Recommendation G.823.

The jitter performances of the TTE (jitter tolerance, maximum output jitter, jitter transfer characteristic) at the optical interface need only to be compatible with the individual system specification for PDH systems.

For SDH systems, the jitter performances of the TTE (jitter tolerance, maximum output jitter, jitter transfer characteristic) at the optical interface should be in accordance with Recommendation G.958.

6.3 Actions consequent to an alarm

The terminal equipment should detect fault conditions and perform consequent actions as detailed in the relevant Recommendations (see, in particular, Table 4/G.921). Alarm indications which 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 IEC 825 Part 1 and IEC 825 Part 2 and with Recommendation G.958 for what concerns the laser shutdown procedure. For what concerns the reactivation and disactivation time values where power levels exceeding those of class 1 are involved due to the use of the Optical Fibre Amplifiers, it is necessary to amend Appendix II/G.958 accordingly in order to take into account the reactivation and disactivation time values of the OFAs inserted along the optical link.

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 stand-by equipment is frequently 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 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 an 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 Recommendations G.652, G.653 or G.654. 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, dependant 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. A model for calculating the fibre survivability as a function of its characteristics and of the cumulative effect of the fibre stress is under study.

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 dependant 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.

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 cablesips during laying and repair operation; it should withstand multiple passages over the bow of a cablesip.

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 Recommendation 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 Recommendation 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 may 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.

ANNEX A

Implementation of repeaterless optical fibre submarine cable systems

A.1 Introduction

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

Typical system parameters are illustrated in Table A.1.

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 Recommendation G.972.

Table A.1/G.973 – Illustrative system parameters of repeaterless optical fibre submarine cable systems

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

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 preamplifiers. 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 of the main text of the present Recommendation.

NOTE 6 – It will be possible to consider WDM (Wavelength Division Multiplexing) 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.

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.

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 sea-bed, 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.

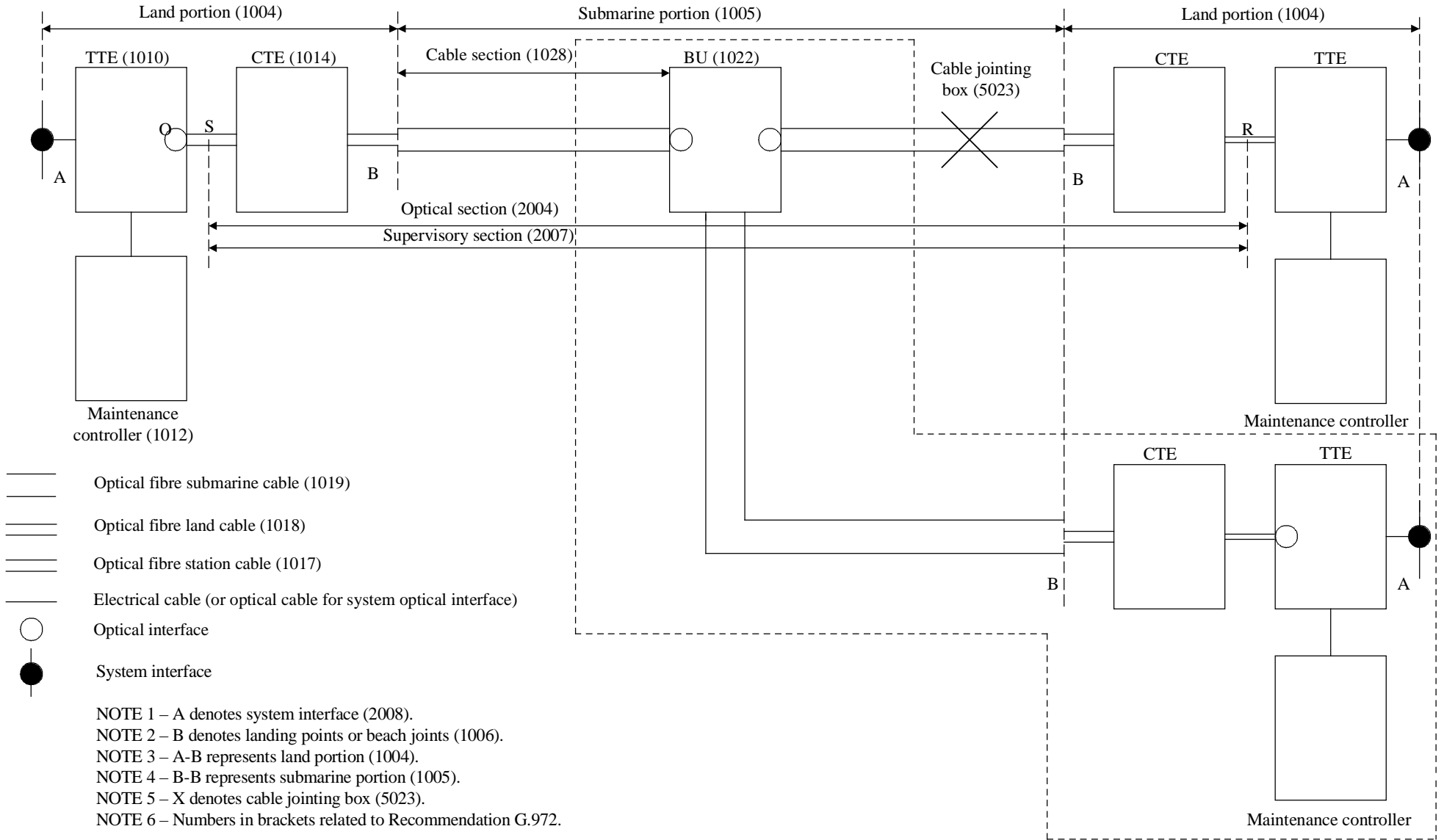


Figure A.1/G.973 – Example of repeaterless optical fibre submarine cable system

T1520620-96

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 Recommendation 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 cables ship 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.

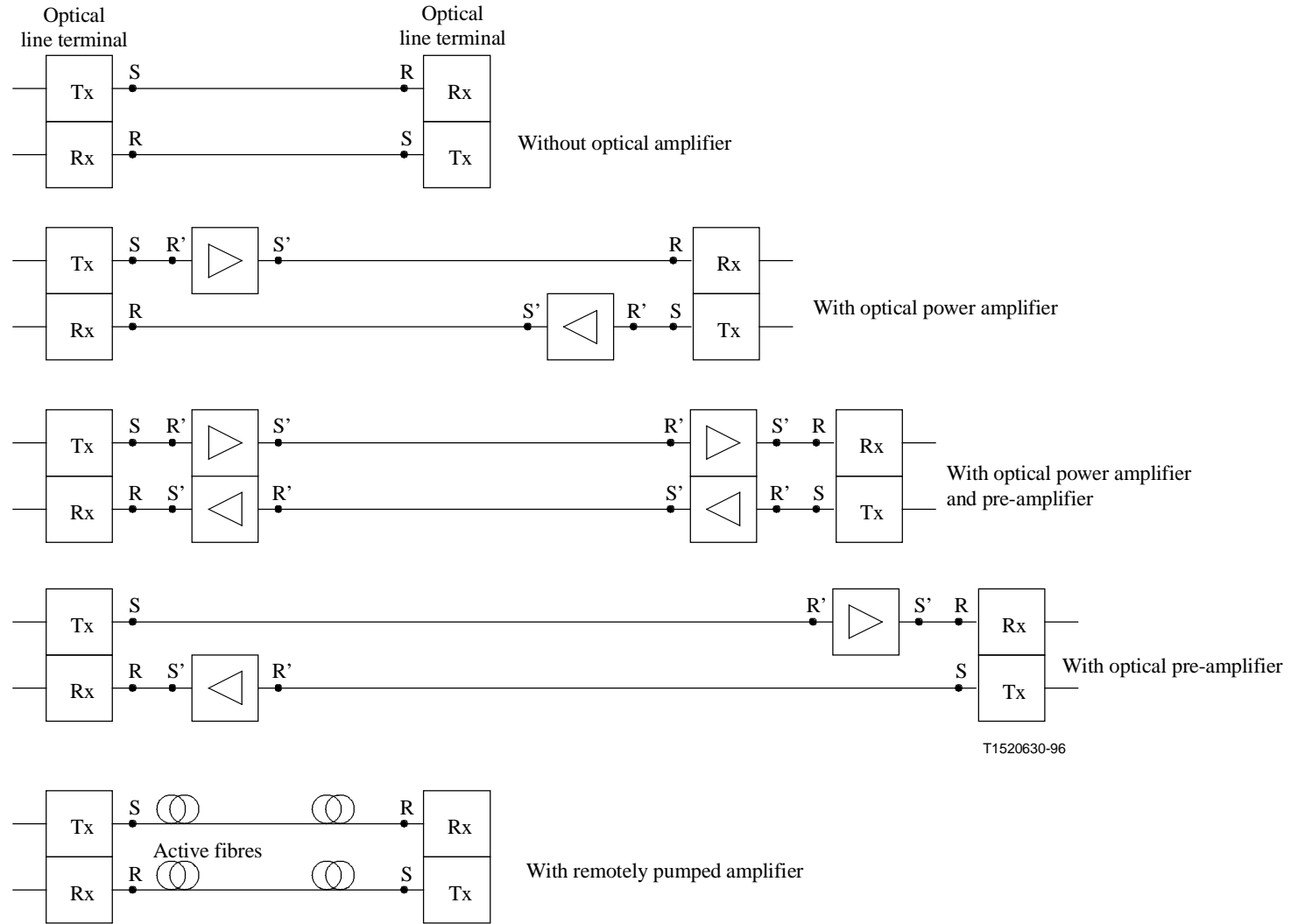


Figure A.2/G.973 – Possible system configurations

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 Recommendation 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 $n \cdot 10^{-p}$ 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 supervisory.

At least one order wire channel is 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 are:

- 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.

A.6 Manufacturing and installation

A.6.1 Quality in repeaterless optical fibre submarine cable systems

The high performance and reliability requirement established for a repeaterless optical fibre submarine cable system can be fulfilled only if stringent quality procedures are applied during designing, manufacturing and laying of a system. Although quality procedures are particular to each optical fibre submarine cable supplier, the following basic principles generally apply.

A.6.1.1 Qualification of the designs and technologies

This activity, part of the development process, is intended to demonstrate that the performance of a technology, a component or an assembly is compatible with meeting the overall system performance and gives reasonable confidence that the reliability target can be met. Qualification includes high stress testing, intended to estimate the ruggedness of the technology, component or sub-assembly and to determine the screening procedure, and long term life testing (some of which might be accelerated for instance by the temperature), the purpose of which is to confirm the validity of the screening procedure and to evaluate the lifetime and/or the reliability of the technology, component or assembly. Qualification of a cable or submarine equipment may also include sea trials.

A.6.1.2 Certification of components and sub-assemblies

This activity, part of the manufacturing process, is intended to assure the ability of each component or assembly to comply with its performance and reliability specifications once installed. For submarine equipment, each component is certified.

The certification is based on the results of the screening tests, intended to remove any unsatisfactory item or component, and particularly those likely to exhibit early failures.

A.6.1.3 Manufacturing inspection

This activity, during the manufacturing process, is intended to verify that the quality plan is respected, that each operation is accomplished along the agreed procedure, and the result is satisfactory.

The responsibility for manufacturing inspection can be shared between the manufacturer and the purchasers of an optical fibre submarine cable system.

A.6.2 Assembly and laying procedure

Route survey is performed prior to cable laying so as to select the cable route and means of cable protection (lightweight protection, armour, burial). The route survey consists in studying the sea depth profile, the sea bottom temperature and seasonal variations, the morphology and nature of the sea bottom, the position of existing cables and pipes, the cable fault history, fishing and mining activities, sea current, seismic activity, laws, etc.

Link assembly consists of jointing the cable sections and the branching units, together with monitoring that the guaranteed margin is present for each fibre in each cable section, so as to constitute the submarine portion. Link assembly can be performed in the cable factory prior to loading, on board the cables ship after loading, or shared between the factory and the cables ship.

Ship loading consists of installing the submarine portion, or fraction of it, on board the cables ship, prior to laying. Ship loading is generally performed with the link unpowered. Tests are made periodically during loading to confirm that the performance of the assembled equipment has not been affected by loading process.

The system is tested at the end of laying, and may be tested during laying, so as to ensure that no significant system degradation has been induced. Laying testing include transmission and functional tests, and may include tests on redundant sub-assemblies.

During laying, a predetermined cable overlength (slack) is laid so as to ensure that the cable is properly laid on the sea bottom.

Laying is normally undertaken only when weather and sea conditions do not create severe risk of damage to the submarine portion, cables ship and laying equipment, or of injury to the personnel.

The cable may be buried in the seabed to increase cable protection. Burial can be undertaken during laying using plow towed by laying cables ship, or after laying using a self-propelled submersible robot or other means.

A.6.3 System commissioning

Commissioning testing is performed prior to installing traffic on the system to ensure that the system meets its overall transmission performance, and that the functions are operating.

If redundancy is used in the design to meet the reliability performance, redundant component could be used for correcting faults occurring during laying or prior to commissioning. However, the objective is to ensure that the number of redundant devices remaining available is sufficient to meet, with a high probability, the target for the number of ship repairs.

A.7 Maintenance

A.7.1 Routine maintenance

Routine maintenance is performed from the terminal stations using the supervisory system. It consists of periodic monitoring of the system parameters and, when required, in preventive redundancy switching.

A.7.2 Maintenance at sea

Optical fibre submarine cable systems can be subject to faults due in particular to external aggression and to component failure. It is important to define and develop well-established and efficient repair procedures and equipment, to facilitate repair and limit loss of traffic.

Maintenance at sea is usually performed using dedicated repair cables.

A.7.2.1 Fault localization

For the end cable sections, cable fault localization may be achieved from the terminal stations, using adequate electrical measurement (resistance, capacitance, insulation, etc.) and optical reflectometry.

Similarly, cable fault localization may be achieved from the cable after cable recovery using the same methods.

A.7.2.2 Cable recovery

During cable recovery it may be necessary, in order to limit the mechanical tension applied to the cable, to cut the cable on the sea bottom prior to recovery of both ends separately.

A.7.2.3 Sea repair

The repair (in shallow and deep waters) may necessitate the addition of a cable length. A repair margin is generally included in the optical power budget and it is usually proportional to the cable failure rate (derived from a statistical analysis of the already laid cables) in shallow water and deep water, respectively. Repair safety procedures are applied on board the cable and in the terminal station, so as to ensure the safety of the personnel operating on board the cable.

ANNEX B

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

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.

The doped fibre in combination with an optical isolator make up a wholly passive device which could be implemented 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.

It has been experienced 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.

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).

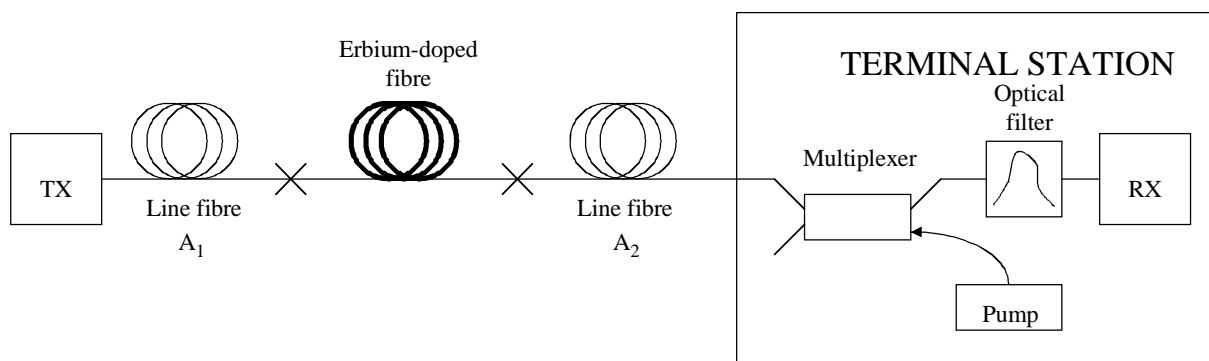
With reference to the example given in Figure B.1, the link gain is expressed in the following way:

$$\text{Link gain} = \text{Budget (with RPOA)} - \text{Budget (without RPOA)}$$

$$\text{Link gain} = (A_1 + A_2) (\text{with RPOA}) - A_1 (\text{without RPOA})$$

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).



T1520640-96

$$\text{Link gain} = \text{Budget (with RPOA)} - \text{Budget (without RPOA)} = (A_1 + A_2) (\text{with RPOA}) - A_1 (\text{without RPOA})$$

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

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