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

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

Characteristics of optically amplified optical fibre submarine cable systems

ITU-T Recommendation G.977

(Formerly CCITT Recommendation)

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ITU-T Recommendation G.977

Characteristics of optically amplified optical fibre submarine cable systems

Summary

This Recommendation is concerned with the system performance and interface requirements of repeatered optical submarine systems using OFA as a line repeater. It covers the aspects related to Single Wavelength Systems (SWS) as well as Wavelength Division Multiplexing Systems (WDMS). The physical implementation of optically amplified fibre submarine systems is considered in Annex A.

Source

ITU-T Recommendation G.977 was prepared by ITU-T Study Group 15 (1997-2000) and approved under the WTSC Resolution 1 procedure on 4 April 2000.

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 Conference (WTSC), 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 WTSC 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 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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Characteristics of optically amplified optical fibre submarine cable systems

1 Scope

This Recommendation is concerned with the system performances and interface requirements of repeatered optical fibre submarine cable systems using OFA as line repeaters. It covers the aspects related to Single Wavelength Systems (SWS) as well as Wavelength Division Multiplexing Systems (WDMS). Depending on the system specifications such as the number of terminations, the connectivity, the total capacity, the maximum end-to-end distance, the system cost, one of these two types of system may be more appropriate to guaranty the system requirements. A high data capacity may be carried on by one wavelength using a high data bit rate or by several wavelengths using a smaller one.

From a general point of view, the characteristics, the performances specifications and requirements of the submerged equipment are mostly identical for SWS and WDMS. Indeed, SWS appear as a specific case of WDMS using one wavelength. As a consequence, general statements mentioned in this Recommendation can be applied to SWS and WDMS. However, when necessary, more detailed Recommendations will highlight the specificity of these two types of systems.

The physical implementation of optically amplified fibre submarine systems is considered in Annex A.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provision 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 version of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

[1] ITU-T G.650 (1997), *Definition and test methods for the relevant parameters of single-mode fibres*.

[2] ITU-T G.652 (1997), *Characteristics of a single-mode optical fibre cable*.

[3] ITU-T G.653 (1997), *Characteristics of a dispersion-shifted single-mode optical fibre cable*.

[4] ITU-T G.654 (1997), *Characteristics of a cut-off shifted single-mode optical fibre cable*.

[5] ITU-T G.655 (1996), *Characteristics of non-zero dispersion shifted single-mode optical fibre cable*.

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

[7] ITU-T G.662 (1998), *Generic characteristics of optical fibre amplifier devices and subsystems*.

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

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

[10] ITU-T G.703 (1998), *Physical/electrical characteristics of hierarchical digital interfaces*.

[11] ITU-T G.707 (1996), *Network mode interface for the synchronous digital hierarchy (SDH)*.

[12] ITU-T G.708 (1999), *Sub STM-0 network node interface for the synchronous digital hierarchy (SDH)*.

[13] ITU-T G.783 (1997), *Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks*.

[14] ITU-T 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*.

[15] ITU-T G.823 (1993), *The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy*.

[16] ITU-T G.826 (1999), *Error performance parameters and objectives for international, constant bit rate digital paths at or above the primary rate*.

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

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

[19] ITU-T G.957 (1999), *Optical interfaces for equipments and systems relating to the synchronous digital hierarchy*.

[20] ITU-T G.958 (1994), *Digital line systems based on the synchronous digital hierarchy for use on optical fibre cables*.

[21] ITU-T G.664 (1999), *Optical safety procedures and requirements for optical transport systems*.

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

[23] ITU-T G.971 (2000), *General features of optical fibre submarine cable systems*.

[24] ITU-T G.972 (1997), *Definition of terms relevant to optical fibre submarine cable systems*.

[25] ITU-T G.975 (1996), *Forward error correction for submarine systems*.

[26] ITU-T G.976 (1997), *Tests methods applicable to optical fibre submarine cable systems*.

3 Terms and definitions

3.1 Terms defined in other Recommendations

This ITU-T Recommendation uses the following terms defined in other Recommendations.

– Cable Breaking Load: see ITU-T G.972 [24].
– Compression factor: see ITU-T G.976 [26].
– Digital Line Section (DLS): see ITU-T G.701 [8].
– Double Armoured Cable: see ITU-T G.972 [24].
– Fibre-Breaking Cable Load: see ITU-T G.972 [24].
– Forward Error Correction (FEC): see ITU-T G.972 [24] and G.975 [25].
– Gain flatness: see ITU-T G.976 [26].
– Maximum power channel difference: see ITU-T G.692 [22].
– Minimum Cable Bending Radius: see ITU-T G.972 [24].
– Multiplex Section Overhead (MSOH): see ITU-T G.783 [13].
– Noise Figure: see ITU-T G.661 [6].

– Nominal Gain: see ITU-T G.976 [26].
– Nominal Operating Tensile Strength: see ITU-T G.972 [24].
– Nominal Permanent Tensile Strength: see ITU-T G.972 [24].
– Nominal Signal Input Power: see ITU-T G.976 [26].
– Nominal Signal Output Power: see ITU-T G.976 [26].
– Nominal Transient Tensile Strength: see ITU-T G.972 [24].
– Optical Fibre Amplifier (OFA): see ITU-T G.661 [6].
– Polarization Dependent Gain: see ITU-T G.661 [6].
– Polarization Dependent Loss: see ITU-T G.661 [6].
– Polarization Hole Burning: see ITU-T G.661 [6].
– Polarization Mode Dispersion: see ITU-T G.661 [6].
– Rock Armoured Cable: see ITU-T G.972 [24].
– S', R' reference points: see ITU-T G.661 [6] and G.662 [7].
– S, R reference points: see ITU-T G.955 [18] and G.957 [19].
– Single Armoured Cable: see ITU-T G.972 [24].
– Small Signal Gain: see ITU-T G.661 [6].
– Synchronous Digital Hierarchy (SDH): see ITU-T G.708 [12].
– Synchronous Transport Module (STM): see ITU-T G.708 [12].

3.2 Definitions

For the purpose of this Recommendation the following definitions apply. Figures 1, 2 and 3, that illustrate these definitions, describe a Terminal Equipment for WDMS. In case of a SWS, the Optical multiplexer/demultiplexer interface should be removed so that only one wavelength should be concerned.

3.2.1 line optical channel (LOC): A bidirectional optical data channel carried on a specific optical frequency/wavelength for each transmission direction.

3.2.2 single wavelength system (SWS): A bidirectional optical system that carry on only one LOC.

3.2.3 wavelength division multiplexing (WDM): An aggregate of several LOCs to be carried through part or the whole of the Submarine Line on the same Line fibre.

3.2.4 wavelength division multiplexing system (WDMS): A bidirectional optical system that carry on several LOCs.

3.2.5 N-WDM: A WDM of N LOCs (N being an integer).

3.2.6 wavelength multiplexer (WM): The equipment required to combine several LOCs and/or WDM coming from different fibres into a common WDM composed of all the combined LOCs.

3.2.7 wavelength demultiplexer (WD): The equipment required to split a WDM into several LOCs and/or WDM to be carried on different fibres.

3.2.8 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 optical line signal, converting and decoding the received optical line signal in the outgoing tributaries, insuring submarine protection switching, submarine plant supervision and performing cable optical termination.

3.2.9 submarine cable optical interface (SCOI): The bidirectional optical interface between the Submarine Cable (including the terrestrial cable section) and the TTE. This signal is composed of a LOC or a WDM.

3.2.10 LOC-TTE: A TTE whose SCOI is composed of only one LOC.

3.2.11 WDM-TTE: A TTE equipped with WM and WD, whose SCOI is a WDM.

3.2.12 submarine electro-optic interface (SEOI): The bidirectional interface inside the TTE where an electro-optic conversion and an electrical regeneration are performed between a LOC and an electrical channel.

3.2.13 submarine digital line section (SDLS): A bidirectional continuous optical path along which one LOC links two TTE at the SEOI level.

3.2.14 terrestrial interface (TI): The interface between the submarine system and the terrestrial network.

3.2.15 intermediate terrestrial interface (ITI): It is to be noted that the TTE can be composed of two distinct pieces of equipment interfaced together, the first piece called Submarine Cable Transmission Terminal Equipment (SCTTE), facing with the submarine cable, and the second piece, called Terrestrial Network Transmission Terminal Equipment (TNTTE), facing the terrestrial network. In this case, an intermediate interface is required, which links the two pieces of equipment. This interface is composed of bidirectional data interfaces and, where applicable, of an extra link used to exchange information between the two pieces of TTE equipment.

3.2.16 umbilic: The extra link used at ITI to exchange information between the two pieces of TTE which are the SCTTE and the TNTTE.

3.2.17 branching unit (BU): An optical submarine piece of equipment inserted into the submarine portion of an optical fibre submarine cable network where the electrical and optical interconnection of three cable sections is necessary.

3.2.18 full fibre drop BU (FFD-BU): A BU where the optical interconnection between the three submarine cables is made by physically connecting fibre pairs between any two cables.

3.2.19 WDM-BU: A BU where the optical interconnection between the three submarine cables is made through WM and WD, that is adding and dropping one or more LOCs out the N-WDM.

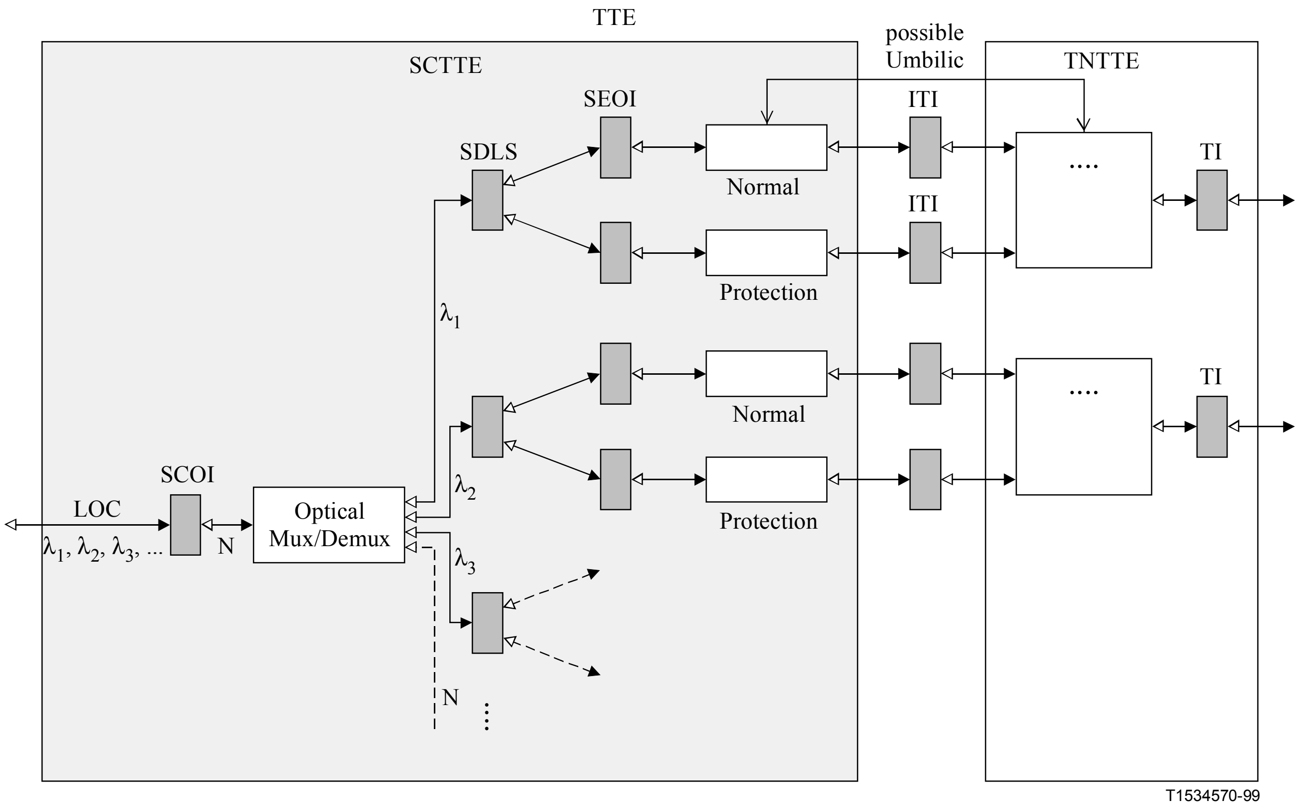

Figure 1/G.977 – Illustrations for clause 3: Terms and Definitions

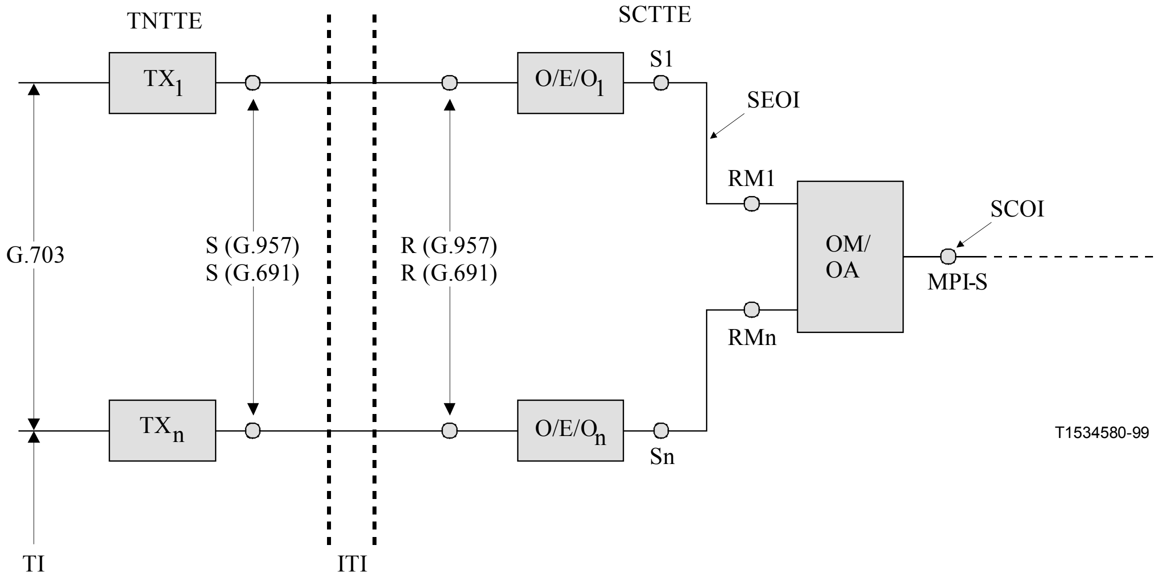

Figure 2/G.977 – Transmit side

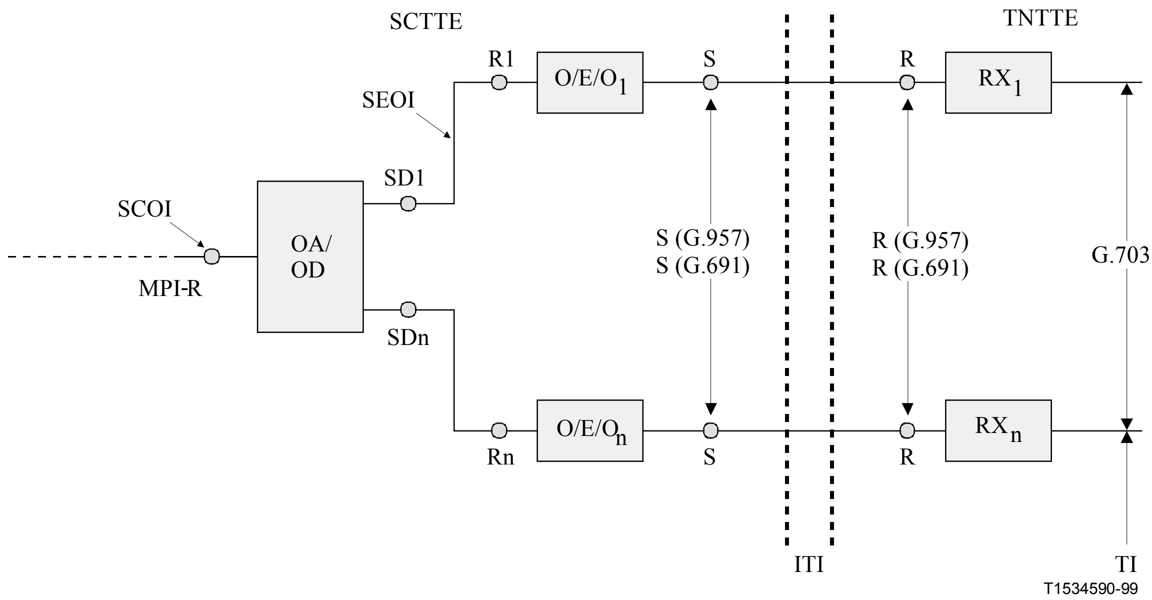

Figure 3/G.977 – Receive side

4 Abbreviations

This Recommendation uses the following abbreviations:

Aeff	Effective Area
ALC	Automatic Level Control
APR	Automatic Power Reduction
BER	Bit Error Ratio
BOL	Begin of Life
BU	Branching Unit
CF	Compression factor
COTDR	Coherent Optical Time Domain Reflectometry
CSF	Cut-off Shifted single mode Fibre
DCF	Dispersion Compensation single mode Fibre
DLS	Digital Line Section
DSF	Dispersion Shifted single mode Fibre
EDF	Erbium Doped Fibre
EOL	End Of Life
FFD-BU	Full Fibre Drop-Branching Unit
FWM	Four-Wave Mixing
GF	Gain Flatness
ITI	Intermediate Terrestrial Interface
LOC	Line Optical Channel
LOC-TTE	Line Optical Channel-Terminal Transmission Equipment

MPI	Main Path Interface
MPI-R	Receive Main Path Interface Reference Point
MPI-S	Source Main Path Interface Reference Point
MSOH	Multiplex Section OverHead
NDSF	Non-Dispersion Shifted Fibre
NF	Noise Figure
NG	Nominal Gain
NRZ	No Return to Zero
NSIP	Nominal Signal Input Power
NSOP	Nominal Signal Output Power
N-WDM	N-Wavelength Division Multiplex
NZDSF	Non-Zero Dispersion Shifted Fibre
OFA	Optical Fibre Amplifier
OSR	Optical Submarine Repeater
PDG	Polarization Dependent Gain
PDH	Plesiochronous Digital Hierarchy
PDL	Polarization Dependent Loss
PFE	Power Feeding Equipment
PHB	Polarization Hole Burning
PMD	Polarization Mode Dispersion
RZ	Return to Zero
SCOI	Submarine Cable Output Interface
SDH	Synchronous Digital Hierarchy
SDLS	Submarine Digital Line Section
SEOI	Submarine Electro-Optic Output Interface
SSG	Small Signal Gain
STM	Synchronous Transport Module
SWS	Single Wavelength Systems
TI	Terrestrial Interface
TSE	Terminal Station Equipment
TTE	Terminal Transmission Equipment
WD	Wavelength Demultiplexing
WDM	Wavelength Division Multiplex
WDM-BU	Wavelength Division Multiplex-Branching Unit
WDMS	Wavelength Division Multiplexing Systems
WDM-TTE	Wavelength Division Multiplex-Terminal Transmission Equipment
WM	Wavelength Multiplexing

5 Characteristics and performances of the system

5.1 Characteristics and performance of the Digital Line Sections (DLS)

The digital line sections provided by the system should be in accordance with the relevant ITU-T Recommendations.

5.1.1 Characteristics of the digital signals at ITI and TI

For TI, the digital signals should comply, as applicable, with ITU-T G.702 [9], G.703 [10], G.707 [11] and G.957 [19].

At ITI, it is recommended that the digital signals be compliant with the physical parameters described in ITU-T G.957 [19].

5.1.2 Overall error performance at TI

The error performances of an optical fibre submarine cable system should conform to the relevant ITU-T Recommendations for the design life of the system (e.g. ITU-T G.821 [14] for PDH interfaces and ITU-T G.826 [16] for SDH interfaces).

For PDH systems the relevant parameters are degraded minutes, severely errored seconds and errored seconds. They are derived from ITU-T G.821 [14] 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 ITU-T G.821 [14] (Annex D), Blue Book.

For SDH systems the relevant parameters are severely errored seconds and errored seconds. They are derived from ITU-T G.826 [16].

5.1.3 System availability at TI

For PDH interfaces:

– the unavailable time performance is derived from ITU-T G.821 [14] (Annex A), *Blue Book*, on a per km basis. The DLS allocation is obtained by multiplying the per km allocation by the DLS;

– as per ITU-T G.821 [14], Annex A, *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 to be considered available time.

For SDH interfaces:

– the unavailable time performance and its definition are derived from ITU-T G.826 [16].

The system availability obviously depends on the availability at the various TI. It is recommended that system unavailability in any period be defined as the time cumulation of all unavailability of any TI in this period (several TI unavailabilities occurring in the same time-frame should not be cumulated).

The unavailability specification applies to unavailable time caused by system component failure, and includes for example any switching action, terminal faults and supervisory and maintenance operation leading to interruptions of ten seconds or longer. It does not include faults caused by external factors such as trawlers, anchoring, 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 performance at ITI and TI

The jitter performances of an optical fibre submarine cable system should follow ITU-T G.823 [15] and G.957 [19] 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 (usually 125 km) 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:
   1) any failure of up to half the LOCs inside a WDM should have no effect on any of the remaining LOCs of the WDM;

b) for SWS and WDMS:
   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 Optical power budget

Optical Power Budget tables should describe how the System Performance will be met as regards the error performance.

In submarine systems with in-line optical amplifiers, regeneration occurs only in the TTE at the SEOI level. In between, the channels will suffer impairments due for example to optical noise accumulation, propagation (fibre non-linearities, chromatic dispersion, etc.). It is therefore recommended that an optical power budget be established at the SDLS level. As some systems may accommodate several SDLS with different impairments, it is further recommended that an optical power budget be established for each of those SDLS.

A further consideration is that, in some cases (WDM networks with WDM-BU for example), the two directions may suffer different impairments: in this case, different power budget can be established for each direction of the concerned SDLS, and the one with the largest impairments should be considered as the SDLS power budget.

Additionally, in case the design of a multi-landing points System has been optimized for the longest SDLS in terms of Optical Signal to Noise degradation and Repeater spacing, extra margins may be available on the shorter ones. Those extra margins, usually called unallocated Supplier margins, should be clearly reported in the Power Budget tables.

For each SDLS, it is recommended that two distinct power budgets be established for the Begin of Life (BOL) and the End of Life (EOL):

– The BOL power budget is representative of the SDLS performances when the system is put into service and is used as a benchmark for test results at this time. It is recommended that this power budget includes a guaranteed margin ensuring compliance with EOL conditions.

– The EOL is representative of the system performances at the end of the design life and should include the impairments due to components ageing and failure, cable ageing and specified repair margins.

The Supplier should provide sufficient information in order to support the validity of the power budget tables, in particular but not limited to, i) the nominal Repeater output power value, ii) the nominal noise figure value, iii) the optical and electrical bandwidth values at the receiver side, used to calculate the power budget. The supplier should also clarify if any device located either at the Transmitter/Receiver end side, such as polarization scramblers, or within the submerged plant, such as equalization filters, are supposed to improve the transmission performances.

5.2.1 Quality factor (Q factor)

It is recommended that the power budget of each SDLS be based on the use of the Q factor as described in ITU-T G.976 [26] (Annex A) and the impairments shown in terms of Q factor degradation.

The performance of a SDLS should be characterized by the measurement of its Q factor or by a direct BER measurement that should allow to reconcile the contractual Q factor commissioning limits indicated in the Power budget.

5.2.2 Relevant parameters for power budget

It is recommended that the power budget takes into account, as a minimum, the impairments coming from the following effects and considerations:

– Optical noise accumulation.

– Propagation impairments due to the combined effects of chromatic dispersion, non-linear Kerr effects, Four Wave Mixing effects between the LOCs and with the noise, stimulated Raman scattering, etc.

– Propagation impairments due to optical polarization effects, such as Polarization Mode Dispersion (PMD), Polarization Dependent Loss (PDL), Polarization Dependent Gain (PDG). As these impairments fluctuate with time, a distinct provision should be taken for performance variations with time.

– Impairments due to the non-flatness of the cumulative gain curve on the whole segment.

– Impairments due to the misadjustment of the wavelength(s) of the SDLS.

– Impairments due to the misadjustment of the relative optical powers of the LOC inside a WDM. This impairment applies to submarine systems using WDM. It has to be taken into account each time a WM is performed.

– Impairments due to the supervision and fault location functions.

– Impairments due to the TTE imperfections (related to back-to-back Q factor performances of the TTE).

Four Wave Mixing between the LOCs, Stimulated Raman Scattering, non-flatness of the cumulative gain curve, misadjustment of the relative optical powers of LOCs are impairments especially applicable to WDMS as they are due to propagation of several optical signals on the same fibre.

Specifically for EOL power budget, the following impairments should be considered:

– Impairments due to repair operations (repair splices, extra cable length after repair, etc.).

– Impairments due to cable and component ageing.

– Impairments due to TTE ageing (the decrease of the back-to-back Q factor value of the TTE).

– Impairments due to the foreseen faults of some components, such as pump laser faults.

As regard impairments due to repair operations, they should take into consideration the different cable type repair scenario as far as impairments should be different for cable located in shallow waters, deep waters and land part (from the beach to the terrestrial station).

In addition, the power budget should clearly show the minimum Q factor required to obtain the specified error performances of the system and include margin improvement provided by the use of FEC (if applicable).

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 cable ship and due to system component failures during the system design life:

  the usual requirement for the system reliability is less than three failures requiring cable ship intervention during the system design life.

– The system design life:

  the period of time over which the submarine optical fibre cable system is designed to be operational in conformance with its performance specifications. 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 compliant with the performance specifications.

5.4 System capacity upgradability

Since optical fibre amplifiers (OFAs) have wide gain bandwidth and bit-rate flexibility, it may be advantageous to increase transmission capacity by increasing signal bit rate and/or the number of transmission channels (WDM). Such upgrading can be beneficial because the reuse of long cables, many in-line amplifiers, and power feed equipment can be achieved cost-effectively over the equipment's long life, typically 25 years.

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

Upgradability through WDM also demands that the initially installed cable and in-line amplifiers be applicable to the system with the maximum number of channels expected in the future.

Upgrading by increasing signal bit rate or by using WDM is much different from many viewpoints of system design including fibre-amplifier design and control, 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 TTE

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.

6.1.1 Definition of reference points of the relevant signals at the ITI, TI, SEOI and SCOI interfaces

With reference to the Figures 2 and 3, the following minimum list of parameters should be specified in correspondence to the E/O reference interfaces:

a) the TI and ITI interfaces are in accordance with ITU-T G.703 [10] and ITU-T G.957 [19];

b) points S1, Sn at the outputs of O/E/O's should be specified at least in terms of:
   1) spectral characteristics;
   2) mean launched power;
   3) extinction ratio;
   4) channel frequency;
   5) channel spacing;
   6) channel frequency deviation;
   7) modulation format (RZ, NRZ);
   8) bit rate;

c) point MPI-S should be specified at least in terms of:
   1) maximum channel power difference;
   2) channel output power;
   3) channel signal to noise ratio;

d) point MPI-R should be specified at least in terms of:
   1) channel signal to noise ratio (according to bit rate, and FEC implementation);
   2) maximum channel power difference;

e) points R1, Rn at the inputs of the O/E/O's should be specified at least in terms of:
   1) receiver sensitivity (if FEC is excluded);
   2) receiver overload;
   3) receiver wavelength range;
   4) optical signal to noise ratio.

6.2 Transmission performance

6.2.1 Characteristics of the digital signal at TI

The digital signal at TI should be in accordance with the relevant ITU-T Recommendations.

6.2.2 Characteristics of the signal at SCOI

To be completed.

6.2.3 Jitter performance at TI

The jitter performance of the TTE of an optical fibre submarine cable system should be in compliance with ITU-T G.823 [15] 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 ITU-T G.823 [15].

The jitter performances of the TTE (jitter tolerance, maximum output jitter, jitter transfer characteristic) at the output TI 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 ITU-T G.957 [19].

6.3 Actions consequent to an alarm

It is appropriate to align this Recommendation to ITU-T G.664 [21], underlining that no shutdown procedures are required if the amplifier total output power is within class 3A (< +17 dBm). In addition, no shutdown procedure should be applied to any submerged equipment, as SCOI interface is intrinsically safe. Any terminal equipment unit exceeding class 3A should include APR means to comply with G.664 [21] requirements.

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.

Depending on the TTE architecture, the stand-by equipment could be kept partly or entirely operating and monitored like the service equipment.

7 Characteristics and performance of the Optical Submarine Repeaters (OSR)

7.1 Mechanical characteristics

7.1.1 Repeater housing

Repeater housing must be designed to allow operation, laying, recovery, and re-laying of optical repeaters in large depths with no degradation in mechanical, electrical and optical performance. The joint housing must support large load transfer from the submarine cable through a flexible coupling.

7.1.2 The internal unit

Inside the repeater housing, the internal unit can contain several power feed modules and OFAs pairs to amplify in both directions optical signal from one or several fibre pairs.

7.1.3 Corrosion protection

The external housing of OSR should be designed to not suffer from corrosion due to sea water.

7.1.4 Water pressure resistance

The OSR must be designed to support large pressure strengths in deep sea water.

7.1.5 High voltage insulation

High voltage insulation is required between the repeater housing and the internal unit to ensure repeater operations.

7.1.6 Thermal management

Heat generated by the electronic components inside the OSR may be dissipated sufficiently via thermal conduction with the repeater housing.

7.1.7 Repeater housing sealing

The repeater must be provided with a protection against water and gas ingress, both directly from the surrounding sea and from axial cable leakage resulting from a cable break close to the repeater.

7.1.8 Ambient atmosphere control

Reliability and good operating of components may require a controlled internal atmosphere regarding relative humidity or any expected gas that may be generated inside the repeater.

7.2 Electrical characteristics

7.2.1 Power modules

OSR are powered from the terminal end station at a constant current via the electrical conductor on the cable. Power modules feed the OFAs pairs to ensure the optical amplification. OSR may accept both electrical polarities.

7.2.2 Surge protection

OSR must be protected against power surges which may result from sudden interruption of the high voltage supply on the cable (cable break or PFE short circuit).

7.3 Optical characteristics

7.3.1 OFA design

OFAs use Erbium Doped Fibre (EDF) to achieve amplification of the optical signal. The EDF may be pumped in a co-propagating way and/or in a contra-propagating way by one or several redundant pump lasers. Optical isolators may be included to ensure a good stability against optical reflections. Automatic Level Control (ALC) may be used to regulate the output optical level.

Supervisory facilities must be provided to monitor remotely the status and performance of the OFAs.

7.3.2 Relevant parameters

ITU-T G.661 [6] deals with definition and tests methods for the relevant generic parameters of OFAs. More specifically, for long haul SWS or WDMS amplified optical link, it is necessary to take into account the following parameters:

- Small Signal Gain (SSG);
- Nominal Gain (NG);
- Noise Figure (NF);
- Nominal Signal Output Power (NSOP);
- Nominal Signal Input Power (NSIP);
- Compression Factor (CF).

Moreover, especially for WDMS, it is also necessary to take into account:

- Gain Flatness (GF).

7.3.3 Polarization effects

The individual optical components of an OFA may be chosen to ensure that its performance is reasonably insensitive to polarization effects as PDL, PMD, depending on the system requirements. Some other polarization effects as PDG, PHB are intrinsic effects and can only be avoided or limited by the use of external means such as signal polarization scrambling in the TTE transmitter.

7.4 Supervisory facilities

A supervisory system is required to monitor from the land station the status and performance of the OFAs. This supervisory system must be able to operate when the link is in service without disturbing system performances.

7.5 Fault location

A cable-break point is usually located in an out-of-service condition. Generally, an OTDR is employed for this purpose, especially a COTDR has good potential in long distance OFA systems fault location because of its higher sensitivity and higher frequency selectivity.

If optical isolators are used within each OFA, the back-scattered optical pulse, which is indispensable for OTDR measurement, is blocked. One solution to solve this problem is the use of a return path (COTDR path) that should not disturb the in-service traffic as shown in the figure. The transmission penalty induced by the COTDR path should be taken into account in the power budget. By using such a solution, COTDR facilities may be implemented in OFA systems to monitor the fibre span status. Moreover, if COTDR is employed in an in-service condition in the OFA systems via a return path, this method will have a potential to monitor the gain status of each OFA.

Two different ways may be chosen to implement COTDR path inside a Repeater.

- First one consists of connecting both outputs of one amplifier pair though optical couplers (refer to Figure 4).
- Second one consists of connecting the output of one OA to the input of the OA located in the reverse direction (refer to Figures 5 and 6).

Both solutions allow a two-directional monitoring.

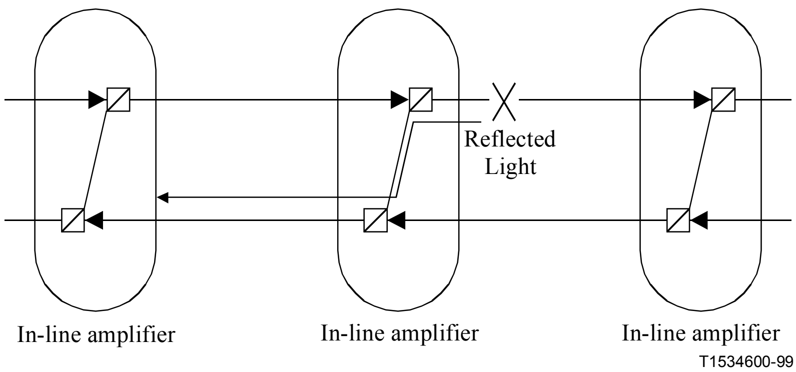

Figure 4/G.977 – Example of fault location using COTDR for OFA with output-to-output loopback coupling

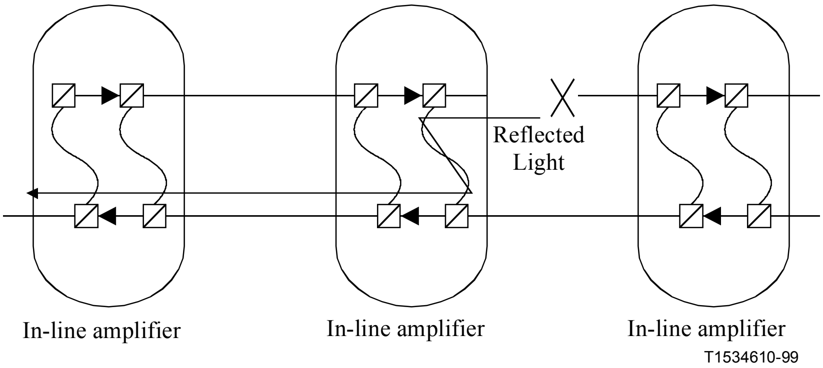

Figure 5/G.977 – Example of fault location using COTDR for OFA systems using output-to-input coupler

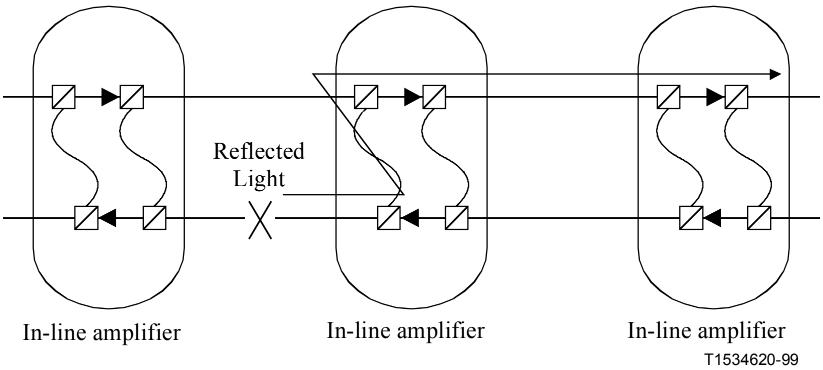

Figure 6/G.977 – Example of fault location using COTDR for OFA systems using output-to-input coupler

7.6 Reliability

All of the repeater components must be qualified and life tested to ensure the reliability requirements.

8 Characteristics and performance of the in-line Branching Unit (BU)

8.1 General

Optical submarine cable systems may use BU where multiple landing points are required. A BU is designed to terminate three line cables. One of them, the branch termination, permits to extract a part of the traffic coming from the two other terminations called the trunk terminations. Different BU designs may exist to answer particular requirements depending of the specific system configuration.

In that way, a BU may offer:

i) Full Fibre Drop functions for SWS.

ii) Full Fibre Drop functions and/or WDM Add/Drop functions for WDMS.

Optical amplification as well as other facilities like power switching function, supervisory system, Automatic Gain Control, optical filtering and coupling for COTDR may be provided.

8.2 Mechanical characteristics

8.2.1 BU housing

The BU mechanical housing is terminated by three-cable entries and an attached sea earth. It must be designed to allow operation, laying, recovery, and re-laying of BU in large depths with no degradation in mechanical, electrical and optical performances. The joint housings must support large load transfer from the submarine cable through a flexible coupling.

Inside the BU housing, the internal unit can contain a power switching circuitry and OFAs to amplify optical signal from one or several fibre pairs. It may also contain Add/Drop modules to ensure the WM and WD functions.

8.2.2 Corrosion protection

A protection must prevent the BU from corrosion due to sea water.

8.2.3 Water pressure resistance

The BU must be designed to support large pressure strengths.

8.2.4 High voltage insulation

High voltage insulation is required between the BU housing and the internal unit to ensure BU operations.

8.2.5 Thermal management

Heat generated by the electronic components inside the BU may be dissipated sufficiently via thermal conduction with the repeater housing.

8.2.6 BU housing sealing

The BU must be provided with a protection against water and gas ingress, both directly from the surrounding sea and from axial cable leakage resulting from a cable break close to the BU.

8.2.7 Ambient atmosphere control

Reliability and good operating of components may require a controlled internal atmosphere regarding relative humidity or any expected gas that may be generated inside the BU.

8.3 Electrical characteristics

8.3.1 Sea electrode

A sea electrode connection will permit to connect one or several of the three cable terminations to the sea potential.

8.3.2 Power switching

Any two incoming cables with power feed conductors may be connected together and isolated from the BU sea electrode on which the third cable is connected. Different possible configurations may exist to ensure traffic recovery in some case of PFE failure of cable break.

In case of a faulty Segment within a Submarine Network using BUs, the System and in particular the BU electrical power switching circuitry should provide the capability to restore the traffic in all the other Segments either in presence of this fault or during the repair operation.

8.3.3 Power modules

BU are powered from the terminal end station at a constant current via the electrical conductor on the cable. If applicable, power modules feed the OFAs pairs to ensure the optical amplification. BU may accept both electrical polarities.

8.3.4 Surge protection

The BU must be protected against power surges which may result from sudden interruption of the high voltage supply on the cable (cable break or PFE short circuit).

8.4 Optical characteristics

8.4.1 Functionalities

A BU may be a FDD-BU or a WDM-BU or an aggregate of both. In all the case, the BU functionalities may guarantee as far as possible the DLS independence to avoid that any failure of a LOC will disturb the remaining ones. In case of a WDM BU, specific optical components may ensure the multiplexer and demultiplexer functions.

8.4.2 Relevant parameters

When a BU contains optical amplifiers, the relevant optical parameters defined for the OSR should be applied. Moreover the whole characterization of the Add/Drop modules should be completed.

8.4.3 Polarization effects

The individual optical components of a BU may be chosen to ensure that its performance is reasonably insensitive to polarization effects as PDL, PMD. Some other polarization effects such as PDG, PHB are intrinsic effects to OFAs possibly contained in the BU and can only be avoided or limited by the use of external means such as signal polarization scrambling in the TTE transmitter.

8.5 Supervisory facilities

A supervisory system is required to monitor from the land station the status and performance of the BU. This supervisory system must be able to operate when the link is in service without disturbing system performances.

8.6 Fault location

Fault location in the systems including a BU can generally be performed using COTDR. When a BU offers full fibre drop function, COTDR can directly locate a fault inside and beyond the BU. When a BU offers WDM add/drop functions, COTDR with a wavelength tunable source can monitor a main line and a branched line independently by setting the source wavelength at the transmission wavelength of each line. If an OFA is included in the BU, a return path as described in 7.5 can be applied for fault location beyond the OFA.

8.7 Reliability

All of the BU components must be qualified and life tested to ensure the reliability requirement.

9 Characteristics and performance of the submarine cable

9.1 Scope

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

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

9.2 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 G.652 [2], ITU-T G.653 [3], ITU-T G.654 [4] or ITU-T G.655 [5]. Types of fibre are chosen to optimize the system overall cost and performance.

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

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

9.3 Characteristics of fibre in a submarine cable

9.3.1 General

The main parameters that characterize an optical fibre are:

- the attenuation coefficient at the operating wavelength for SWS and at all of them for WDMS expressed in dB/km;
- the chromatic dispersion coefficient in ps/nm.km;
- the zero dispersion wavelength λ_0 in nm;
- the dispersion slope around the operating wavelengths in $ps/nm^2.km$;
- the non-linear refractive index n_2 in m^2/W;
- the effective area Aeff in μm^2;
- the non-linear coefficient n_2/Aeff in W^{-1};
- the polarization mode dispersion (PMD) in $ps/(km)^{½}$.

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

- Non-Dispersion Shifted single mode Fibre (NDSF) defined in ITU-T G.652 [2].
- Dispersion Shifted single mode Fibre (DSF) defined in ITU-T G.653 [3].
- Cut-off Shifted single mode Fibre (CSF) defined in ITU-T G.654 [4].
- Non-Zero Dispersion Shifted single mode Fibre (NZDSF) defined in ITU-T G.655 [5].
- Dispersion Compensation single mode Fibre (DCF).

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

9.3.2 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).

9.3.3 Fibre non-linearity

Non-linear effects should be considered when long haul optical link are designed with high output power OFAs. These effects are cumulative along the optical link and may degrade significantly the propagation. The non-linearity causes a self-phase modulation of the signal proportional to the non-linear coefficient (ratio n_2/Aeff) 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.

9.3.4 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 time-slot. PMD may also be expressed in $ps/(km)^{1/2}$.

9.3.5 Chromatic dispersion

Chromatic dispersion deals with the wavelength dependence of group velocity so that all the spectral components of an optical signal will propagate at different velocities. This induces pulse spreading and can be a major impairment. Depending on the system design and especially on the number of wavelengths (WDM system), 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.

9.3.5.1 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 cumulative dispersion, at a given operating wavelength, as a function of distance from the optical transmitter. Typically two dispersion regions (anomalous and normal) are used along the link corresponding to long sections of the main in-line fibre and to shorter sections of dispersion compensation fibre. The aim of this management is to keep near zero the cumulative dispersion of the whole link while keeping to the "adequate value" the in-line mean dispersion. This value may depend on the nature of the transmission knowing that it could be interesting to keep it:

– to a chromatic dispersion value near zero for SWS;
– to a chromatic dispersion value far from zero for WDMS in order to limit the four wave mixing products.

9.3.5.2 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 spreading, etc.).

At the receiver end of a link, cumulative dispersion for each wavelength may be compensated to zero by using a length of equalization fibre or other passive dispersion compensation devices in the 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 and EDF;
– 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; and
– ageing;
– repair operations.

9.4 Mechanical characteristics and resistance to the environment

9.4.1 Fibre protection by the cable structure

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

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

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

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

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

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

9.4.3 Cable mechanical performance

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

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

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

Several parameters are defined in ITU-T G.972 [24] 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 transitory cable load, which could be accidentally encountered, particularly during recovery operations;
- the operational cable load, which could be encountered during repairs;
- the permanent cable elongation, which characterizes the status of cable after lay;
- the minimum cable bending radius, which is a guidance for cable handling.

9.4.4 Cable protection

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

- the 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 cable 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 (which may be the fish-bite protection shield), and which is suitable to be pulled into ducts.

9.5 Electrical characteristics

Repeatered optical fibre submarine cable systems using OFAs must be power fed through an electrical conductor inside the cable with a low lineic resistance and an insulator with a high voltage insulation capacity.

This conductor may also be useful to perform electroding in service or out service test.

ANNEX A

Implementation of repeatered optical fibre submarine cable systems using Optical Fibre Amplifier

A.1 Introduction

This annex outlines various aspects of submarine cable system practice as commonly employed on optical amplifier systems. It covers SWS as well as WDMS implementation.

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.

A.2 System configuration

A.2.1 Constituents of repeatered optical fibre submarine cable systems

The purpose of an optical fibre submarine cable system is to establish transmission links between two or more terminal stations. Where 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 1/G.974 shows the basic concept of optical fibre submarine cable systems and boundaries. Optical submarine repeaters and/or optical submarine branching units could be included depending on each system requirement.

In Figure 1/G.974, A denotes the system interfaces at the terminal station (where the system can be interfaced to terrestrial digital links or to other submarine cable systems), and B denotes beach joints or landing points. Letters in brackets in the following sections refer to the above figure.

An 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;
– 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. optical submarine repeater(s), branching unit(s) and cable jointing box(es).

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, light armoured cable, single armoured cable, double armoured cable, and rock armoured cable.

The optical fibre land cable also requires protection. In particular, the optical fibre land cable carries the OSR and BU power feeding current and in these conditions a high potential difference may exist between the cable conductor and the ground, so that personnel protection is necessary.

The optical submarine repeaters include optical amplifiers which are designed to accept an incoming optical signal constrained within certain limits and to amplify it so that the optical output signal is constrained within certain limits. The repeaters also include units to provide supervisory, protection and power feeding functions. These circuits constitute the repeater electronic unit and are contained within the watertight and pressure-resistant repeater housing.

An 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. According to the network requirement this equipment may include some or all of the following subassemblies: direct fibre connection, a fibre switching unit, optical amplifier for each fibre, and a power feeding path switching unit. Moreover, the BU can provide WDMS with signal interchange functionality between optical signal paths, it is then termed a WDM-BU.

A.2.2 Transmission configuration

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

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. The line code is chosen so as to meet at the best the system requirements.

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 digital line sections carried by an optical fibre cable section is given by the product of these two numbers.

The digital line sections supported by the same optical fibre pair follow the fibre pair across the repeaters and the branching units. They may be separated between different fibre pairs when crossing an undersea branching multiplexer.

A.2.3 Supervision and remote maintenance of the system

Supervisory and maintenance controller located in the terminal, in association with the repeater (or BU) supervisory unit, normally provides for fault localization, repeater performance monitoring and remote controlled redundancy switching.

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

– provision, on an in-service basis, of sufficient information to enable preventive maintenance, particularly if switchable redundancy is provided;
– provision for further out-of service fault location or system monitoring through loopback remotely controlled from appropriate terminals;
– indication of approaching failure of the in-service equipment, so that preventive action may be undertaken or planned;
– 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 COTDR, if OSRs and BUs are loop-back equipped, and electrical measurement using equipment installed in the terminal stations or on board the cable 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.

A.2.4 System integration

A submarine optical fibre cable link or network may be constructed using two or more submarine optical fibre systems (i.e. sets of equipment – cable, repeater, 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 specification.

A.3 System performance

A.3.1 Power budget

The power budget tables should compute margins that should be considered as a minimum requirement for the system at BOL. These margins should be expressed in terms of factor Q value. The contractors should provide, as a minimum, the values of the parameters used to compute the power budget and specify all necessary complementary relevant information such as, for instance, the use of any optical polarization scrambling or phase modulation to minimize the polarization effects or non-linear effects.

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

Table A.1/G.977 – An example of a possible power budget template

	Parameter	BOL Q in dB	EOL Q in dB
1	Mean Q value (from simple SNR calculation)		
1.1	Propagation impairments due to combined effects of chromatic dispersion, non-linear effect, four-wave mixing effects, stimulated Raman scattering effects, etc.		
1.2	Gain flatness impairments		
1.3	Non-optimal optical pre-emphasis impairment		
1.4	Wavelength tolerance impairment		
1.5	Mean PDL penalty		
1.6	Mean PDG penalty		
1.7	Mean PMD penalty		
1.8	Supervisory impairment		
1.9	Manufacturing and environmental impairment		
2	Time varying system performance (5 sigma rule)		
3	Line Q value (1-1.1 to 1.9-2)		
4	Specified TTE Q value (back to back)		
5	Segment Q value (computed from 3 and 4)		
5.1	BER corresponding to segment Q without FEC		
5.2	BER corresponding to segment Q with FEC		
5.3	Effective Segment Q value with FEC		
6	Q limit compliance with G.826 after FEC correction		
7	Repairs margins Components and fibre ageing penalty Pump(s) failure penalty Non-optimal decision threshold		
8	Segment Margins		
9	Unallocated supplier margin		
10	Commissioning limits		

Table A.1 should be fed as follows:

- Line 1 – Mean Q value (Simple SNR calculation).
- Line 1.1 to Line 1.9 give a non-exhaustive list of impairment sources that impact System performances. Those impairment have to be deduced from Line 1.
- Line 2 – Time varying system performance:

  This defines an additional impairment due to polarisation fluctuation phenomena that decrease the mean performances.

- Line 3 – Line Q value:

  This line gives the line Q factor. It is the result of this operation:

  Line 3 = Line 1 – (Line 1.1 to line 1.9) – Line 2.

- Line 4 – Specified TTE Q value:

  This line gives the SLTE back Q factor at SOL and EOL.

- Line 5 – Segment Q value:

  This line gives the Segment Q factor calculated from line 3 and line 4 using the following formula:

$$\frac{1}{Q^2 segment} = \frac{1}{Q^2 line} + \frac{1}{Q^2 TTEbacktoback}$$

- Line 5.1 – BER corresponding to segment Q without FEC:

  Line 5 converted into Bit Error Rate (BER) before Forward Error Correction.

- Line 5.2 – BER corresponding to segment Q with FEC:

  BER after FEC correction.

- Line 5.3 – Effective Segment Q value with FEC:

  Line 5.2 converted into Q factor.

- Line 6 – Q limit for compliance with G.826 after correction:

  Q factor corresponding to the worst allowable bit error rate before correction by FEC. 11.2 dB corresponds to a BER of $2.4.10^{-4}$. A BER of $2.4.10^{-4}$ is converted by FEC correction to a BER better than 10^{-11}. Therefore a Q factor of all 11.2 covers all DLS lengths.

- Line 7 – Repairs, ageing and pump failures:

  Line 7 is given by line 5 (SOL) minus Line 5 (EOL).

- Line 8 – Segment margins:

  Line 8 (EOL) the segment margins are usually 1 dB contractually at EOL.

  Line 8 (SOL) is given by Line 7 plus Line 8 (EOL).

- Line 9 – Unallocated supplier margins:

  Margin for other and unknown impairments.

- Line 10 – Commissioning limit:

  This line gives the contractual commissioned Q limit for each DLS.

A.3.2 Digital line section performance

The performance of each digital line section should at least conform to ITU-T G.826.

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 the two terminal stations in case of system fault.

In particular, a service channel is normally provided to permit 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 or fault location.

At least one order wire channel is established between terminal stations exchanging traffic for communication between the staff of the terminal stations.

A.4.2 Function and characteristics of the power feeding equipment

A.4.2.1 PFE normal operating condition

The PFE provides, through the cable power conductor with return through the sea, a stabilized electric current to power the electrical circuits of the optical submarine repeater(s) and/or optical submarine branching unit(s). This current is generally adjustable and is a slightly decreasing function of the PFE resistive load.

The variations in time of the PFE current, which may be caused by ambient temperature changes within a specified range, variations and transient in the power source voltage, or redundancy switching in the PFE, are maintained between specific limits. The PFE current stability is defined so as to meet the overall stability requirement of the optical fibre submarine cable system. The PFE current stability is usually expressed as a percentage of the PFE nominal current.

The PFE output voltage is automatically adjusted to maintain the PFE current constant in the presence of naturally induced voltages. It is usually considered that these naturally induced voltages which accumulate along a link may reach a value of 0.3 V/km (East-West) and that they vary slowly with time (less than 10 V/s).

A.4.2.2 System protection

The PFE is normally equipped with facilities designed to protect the PFE itself and the submarine portion from excessive current or excessive voltage in case of electrical fault in the PFE itself or anywhere in the system.

In particular, a PFE earth protection is provided to automatically route the power feeding current to the station earth if the system power feed electrode becomes disconnected, or changes to an excessive potential difference from the station earth. The operation of this device is designed to avoid interruption of the optical fibre submarine cable system and to prevent a rise in the power equipment earth potential sufficient to damage the equipment or endanger personnel.

A.4.2.3 PFE personnel protection

PFE personnel protection is provided to prevent personnel from gaining access to dangerous potentials whether generated at the near end or at the far end of the optical fibre submarine cable system. The protection equipment includes in particular interlocks at the cable terminating equipment, emergency shut-down at the PFE, and earthing devices enabling the cable power conductor to be discharged to earth before handling.

A.5 Optical Submarine Repeater (OSR) and Branching Unit (BU) characteristics

A.5.1 General

The OSRs and BUs 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.).

The OSRs and BUs are designed to be capable of being handled, i.e. laid, recovered and relayed, without impairment of the performance of the cable, cable jointing boxes, repeaters, branching units, and cable terminations, provided that handling specifications are respected.

The OSRs and BUs are designed to be transported and stored under specified temperature condition without affecting the system design life, provided that storage and transport specifications are respected.

The OSRs and BUs are capable of being operated on board a cable ship during laying and repair operations without affecting the system design life.

The size of the OSRs and BUs is such that they can be handled by appropriate cable ship equipment.

The repeater optical input interface (point R) on each incoming fibre is defined where the repeater fibre is spliced to the cable fibre.

The repeater optical output interface (point S) on each outgoing fibre is defined where the repeater fibre is spliced to the cable fibre.

A.5.2 OSR (or BU) constituents

The main OSR (or BU) constituents are:

– the OSR (or BU) housing:

  the mechanical part, containing the electronic unit. The housing is designed to provide resistance to the sea depth pressure, water tightness, high mechanical strength, electrical and optical connection to the cable sections on each side of the OSR (or BU), high voltage insulation and low thermal impedance between the OSR (or BU) electronic unit and the sea;

– the OSR (or BU) electronic/optical unit:

  the piecepart, made of the optical amplifier(s), and/or the supervisory circuit(s), and/or the power supply and protection circuit(s), and/or optical multiplexer(s) and demultiplexer(s), and/or redundancy switch(es).

A.5.3 Supervisory and monitoring

In association with the maintenance controller in the terminal, the OSR (or BU) supervisory unit permits repeater performance monitoring. Optical loop-backs may provide facilities to monitor the cable sections between two OSRs with the use of COTDR.

A.6 Manufacturing

A.6.1 Quality in repeatered optical fibre submarine cable systems

The high performance and reliability requirement established for an optical fibre submarine cable system can be fulfilled only if stringent quality procedures are applied during designing, manufacturing, and laying 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 life time 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 individually certified.

The certification is based on the results of 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 that 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.6.1.4 Factory Acceptance Tests

After completion of the manufacturing of each item (TSE and Submerged Equipment), functional and performance tests must be carried out in order to release the equipment from the Factory.

This activity, conducted in Factory, should comprise all tests necessary to confirm that TSE (including final software) and Submerged Equipment (Repeater and Cable sections) are ready for installation or assembly. The tests should demonstrate that the requirements of the Technical Specification will be met by the Segments and the full Network once installed or assembled if no discrepancy occurs during installation or assembly period.

On completion of factory testing, Equipment may be tested during a confidence trial period to control its stability.

A.6.2 Assembly and loading procedure

Link assembly consists of jointing the cable sections, the repeaters 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 is usually performed in the cable factory prior to loading.

Ship loading consists of installing the submarine portion, or fractions of it, on board the cable 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 the loading process.

A.7 System installation

A.7.1 Submarine route survey

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.

A cable route study should normally be carried out prior to the start of a route survey to determine all environmental, political, economic and practical aspects related to the route. Discussions should be held with local authorities and fishing bodies for this purpose, together with inspection of landing sites and access points as necessary.

An assessment of burial feasibility can also be carried out as part of the route survey, either through direct continuous measurement (Burial Assessment Survey, BAS) or discrete periodic measurement (Cone Penetrometer Testing, CPT).

A.7.2 Submarine cable installation

Cable laying is normally performed using a recognized cable-ship after any necessary route clearance in shallow water has been carried out (e.g. pre-lay grapnel run, PLGR).

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

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

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

The system should be tested during the laying and at the end of laying, so as to ensure that no significant system degradation has been induced. Laying testing includes transmission and functional tests, and may include tests on redundant subassemblies. To permit test during cable laying, the link may be powered, provided that safety regulations are respected.

A.7.3 Land cable installation and testing

Land Cable tests will be performed after the completion of Land Cable installation at each site to confirm performances.

Especially, the Return Earth System shall be tested after its installation.

A.7.4 Terminal station equipment installation and testing

After completion of Terminal Station Equipment installation activities in the Cable Terminal Station, a Site Acceptance Testing program should be conducted based on the Factory Acceptance Test program already performed. Results of both periods should be compared. In the event of an unfavourable comparison between the two sets of results, the cause of the irregularities should be determined.

All equipment units provided as spares shall be tested for correct operation by substitution with working units.

On completion of the suite tests, the equipment shall be subject to a continuous confidence trial period to be defined depending of the equipment type.

Following the Site Acceptance Testing period for each item, interconnection of Equipment should be carried out to control their interoperability. A specific integration test plan should then be conducted. The results obtained could be compared with previous results (including Technology Demonstration). In the event of an unfavourable comparison between the two sets of results, the cause of the irregularities should be determined.

A.8 System commissioning

Commissioning testing is performed prior to installing traffic on the system to ensure that the system meets its overall transmission performance contractual requirement, and that all functionalities with respect to the Network Management are operating. When extra margins are available at BOL, it is recommended to assess those ones in order to track the ageing of the system.

If redundancy is used in the design to meet the reliability performance, redundant component could be used for correcting faults occurring during lay 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.

On completion of the System commissioning period, a continuous Transmission Segment out of service Confidence Trial should followed. Carefully controlled procedures should be established to prevent introduction of errors through human action. Any irregularity, variation alarm or non-routine event observed should be investigated.

A.9 Maintenance

A.9.1 Routine maintenance

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

A.9.2 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 cable ships.

A.9.2.1 Fault localization

For systems equipped with optical submarine repeaters, a first localization to within one supervisory section is obtained using the supervisory system.

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 ship after cable recovery, using the same methods.

Electroding can be used to locate the cable route.

A.9.2.2 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 recovering both ends separately.

A.9.2.3 Sea repair

Several methods can be used for sea repair according to the sea depth:

– the shallow water repair may necessitate the addition of a cable length, but not that of a repeater; a repair margin is generally included in the shallow water optical power budget since the shallow water sections are the most exposed at risk from external aggression, even though precautions are taken;

– the deep sea repair usually necessitates the addition of a cable length and sometimes of a repeater to compensate for the extra attenuation, if the extra attenuation incurred cannot be accommodated in the available margin; generally, a very low repair margin is included in the deep water optical power budget since deep sea repairs are not frequent.

When a fault is identified to within one supervisory section, the section may be replaced by a mini-system, without further localization. This method may save time, but requires more spare equipment.

Repair safety procedures are applied on board the cable ship and in the terminal station, so as to ensure the safety of the personnel operating on board the cable ship. In particular, power safety procedures involve earthing the cable in the terminal station, on board the cable ship and at branching unit.

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