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

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

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Characteristics of optically amplified optical fibre submarine cable systems

Recommendation ITU-T G.977

ITU-T

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Recommendation ITU-T G.977

Characteristics of optically amplified optical fibre submarine cable systems

Summary

Recommendation ITU-T G.977 is concerned with the system performance and interface requirements of repeatered optical submarine systems using optical fibre amplifiers (OFAs) as line repeaters. It covers the aspects related to single wavelength systems (SWS), wavelength division multiplexing systems (WDMS) and dense wavelength division multiplexing systems (DWDMS). The physical implementation of optically amplified fibre submarine systems is considered in Annex A.

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

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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FOREWORD

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

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

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

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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, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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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 optical line amplifiers (OFAs) as line repeaters. It covers the aspects related to single wavelength systems (SWS), wavelength division multiplexing systems (WDMS) and dense wavelength division multiplexing systems (DWDMS). Depending on the system specifications, such as the number of terminations, the connectivity, the total capacity, the maximum end-to-end distance, and/or the system cost, one of these three types of systems may be more appropriate to guarantee the system requirements. A high data capacity may be carried 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, performance specifications and requirements of the submerged equipment are mostly identical for SWS, WDMS and DWDMS. Indeed, SWS appears as a specific case of WDMS using one wavelength and, in turn, WDMS can be considered as a specific case of DWDMS with a small number of wavelengths. As a consequence, general statements mentioned in this Recommendation can be applied to SWS, WDMS and DWDMS. However, when necessary, more detailed Recommendations will highlight the specificity of these three types of systems.

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

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 provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

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

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

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

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

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

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

[ITU-T G.703] Recommendation ITU-T G.703 (2001), *Physical/electrical characteristics of hierarchical digital interfaces*.

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

[ITU-T G.709] Recommendation ITU-T G.709/Y.1331 (2012), *Interfaces for the optical transport network*.

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

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

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

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

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

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

[ITU-T G.870] Recommendation ITU-T G.870/Y.1352 (2012), *Terms and definitions for optical transport networks*.

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

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

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

[ITU-T G.959.1] Recommendation ITU-T G.959.1 (2012), *Optical transport network physical layer interfaces*.

[ITU-T G.971] Recommendation ITU-T G.971 (2010), *General features of optical fibre submarine cable systems*.

[ITU-T G.972] Recommendation ITU-T G.972 (2011), *Definition of terms relevant to optical fibre submarine cable systems*.

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

[ITU-T G.975.1]	Recommendation ITU-T G.975.1 (2004), *Forward error correction for high bit-rate DWDM submarine systems*.
[ITU-T G.976]	Recommendation ITU-T G.976 (2014), *Tests methods applicable to optical fibre submarine cable systems*.
[ITU-T G.978]	Recommendation ITU-T G.978 (2010), *Characteristics of optical fibre submarine cables*.
[ITU-T G.979]	Recommendation ITU-T G.979 (2012), *Characteristics of monitoring systems for optical submarine cables*.
[ITU-T G.8201]	Recommendation ITU-T G.8201 (2011), *Error performance parameters and objectives for multi-operator international paths within optical transport networks*.
[ITU-T G.8251]	Recommendation ITU-T G.8251 (2010), *The control of jitter and wander within the optical transport network (OTN)*.
[IEC 60825-1]	IEC 60825-1 (2007), *Safety of laser products – Part 1: Equipment classification and requirements*.
[IEC 60825-2]	IEC 60825-2 (2007), *Safety of laser products – Part 2: Safety of optical fibre communication systems (OFCS)*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 compression factor: See [ITU-T G.976].

3.1.2 digital line section (DLS): See [ITU-T G.701].

3.1.3 forward error correction (FEC): See [ITU-T G.972], [ITU-T G.975] and [ITU-T G.975.1].

3.1.4 gain flatness: See [ITU-T G.976].

3.1.5 maximum channel power difference: See [ITU-T G.692].

3.1.6 noise figure: See [ITU-T G.661].

3.1.7 nominal gain: See [ITU-T G.976].

3.1.8 nominal signal input power: See [ITU-T G.976].

3.1.9 nominal signal output power: See [ITU-T G.976].

3.1.10 optical fibre amplifier (OFA): See [ITU-T G.661].

3.1.11 optical transport network (OTN): See [ITU-T G.870].

3.1.12 polarization-dependent gain: See [ITU-T G.661].

3.1.13 polarization-dependent loss: See [ITU-T G.661].

3.1.14 polarization hole burning: See [ITU-T G.661].

3.1.15 polarization mode dispersion: See [ITU-T G.661].

3.1.16 S, R reference points: See [ITU-T G.955].

3.1.17 S', R' reference points: See [ITU-T G.661] and [ITU-T G.662].

3.1.18 small signal gain: See [ITU-T G.661].

3.1.19 synchronous digital hierarchy (SDH): See [ITU-T G.780].

3.1.20 synchronous transport module (STM): See [ITU-T G.780].

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms. Figures 3-1, 3-2, 3-3 and 3-4, which illustrate these definitions, describe terminal equipment for wavelength division multiplexing system (WDMS) and dense wavelength division multiplexing system (DWDMS). In case of a single wavelength system (SWS), the optical multiplexer/demultiplexer interface should be removed so that only one wavelength should be concerned as shown in Figures 3-3 and 3-4.

3.2.1 branching unit (BU): A piece of optical submarine 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.

3.2.2 dense wavelength division multiplexing (DWDM): An aggregate of a large number of line optical channel (LOCs) to be carried through part or the whole of the submarine line on the same line fibre.

3.2.3 dense wavelength division multiplexing system (DWDMS): A bidirectional optical system carried on a large number of line optical channels (LOCs).

3.2.4 fixed optical add/drop multiplexing-branching unit (FOADM-BU): A branching unit (BU) with optical add/drop multiplex (OADM) function where the wavelengths that are added, dropped and passed through are fixed.

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

3.2.6 gain equalizer: Gain equalizer is the means used to adapt the submerged plant gain profile characteristics suitable for transmission.

3.2.7 intermediate terrestrial interface (ITI): It is to be noted that the terminal transmission equipment (TTE) can be composed of two distinct pieces of equipment interfaced together, the first piece called submarine cable transmission terminal equipment (SCTTE), on the submarine cable side, and the second piece, called terrestrial network transmission terminal equipment (TNTTE), on the terrestrial network side. 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 terminal transmission equipment (TTE).

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

3.2.9 LOC-TTE: A terminal transmission equipment (TTE) whose submarine cable optical interface (SCOI) is composed of only one line optical channel (LOC).

3.2.10 N-WDM: A wavelength division multiplexing (WDM) or dense wavelength division multiplexing (DWDM) of N line optical channel (LOCs) (N being an integer).

3.2.11 optical submarine equalizer (OSE): Optical submarine equalizer is the submerged equipment used to compensate for, or to handle, the accumulative gain ripple and tilt along a submarine digital line section (SDLS) in order to be compliant with the pre-emphasis capability of the terminal transmission equipment (TTE) at the transmitter side, and with the corresponding impairment allocated in the power budget table.

3.2.12 reconfigurable optical add/drop multiplexing-branching unit (ROADM-BU): A branching unit (BU) with optical add/drop multiplexing (OADM) function where the wavelengths that are added, dropped and passed through can be dynamically modified.

3.2.13 shunt fault: A shunt fault is a current leakage path between the power conductor and the sea water without a break in the power conductor.

3.2.14 single wavelength system (SWS): A bidirectional optical system carried on only one line optical channel (LOC).

3.2.15 slope equalizer: Slope equalizer is the means used for wavelength division multiplexing system (WDMS) to provide the equalization of the residual gain/wavelength slope which accumulates when the signal is transmitted through a chain of submerged repeaters.

3.2.16 submarine cable optical interface (SCOI): The bidirectional optical interface between the submarine cable (including the terrestrial cable section) and the terminal transmission equipment (TTE). This signal is composed of a line optical channel (LOC) or a wavelength division multiplexing (WDM).

3.2.17 submarine cable transmission terminal equipment (SCTTE): See definition on intermediate terrestrial interface (ITI).

3.2.18 submarine digital line section (SDLS): A bidirectional continuous optical path along which one line optical channel (LOC) links two terminal transmission equipments (TTEs) at the submarine electro-optic interface (SEOI) level.

3.2.19 submarine electro-optic interface (SEOI): The bidirectional interface inside the terminal transmission equipment (TTE) where an electro-optic conversion and an electrical regeneration are performed between a line optical channel (LOC) and an electrical channel.

3.2.20 terminal transmission equipment (TTE): The equipment included in 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, ensuring submarine protection switching, submarine plant supervision and performing cable optical termination.

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

3.2.22 terrestrial network transmission terminal equipment (TNTTE): See definition on intermediate terrestrial interface.

3.2.23 tilt equalizer: Tilt equalizer is the means used for wavelength division multiplexing system (WDMS) to provide the equalization of the residual gain/wavelength tilt, which accumulates when the signal is transmitted through a chain of submerged repeaters.

3.2.24 umbilical: The extra link used at intermediate terrestrial interface (ITI) to exchange information between the two pieces of terminal transmission equipment (TTE), which are the submarine cable transmission terminal equipment (SCTTE) and the terrestrial network transmission terminal equipment (TNTTE).

3.2.25 wavelength demultiplexer (WD): The equipment required to split a wavelength division multiplexing (WDM) into several line optical channels (LOCs) and/or WDM to be carried on different fibres.

3.2.26 wavelength division multiplexing (WDM): An aggregate of several line optical channels (LOCs) to be carried through part or the whole of the submarine line on the same line fibre.

3.2.27 wavelength division multiplexing system (WDMS): A bidirectional optical system carried on several line optical channels (LOCs).

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

3.2.29 wavelength division multiplexing-branching unit (WDM-BU): A branching unit (BU) where the optical interconnection between the three submarine cables is made through wavelength multiplexer (WM) and wavelength demultiplexer (WD), that is, adding and dropping one or more line optical channels (LOCs) out of the N-WDM.

3.2.30 wavelength division multiplexing-terminal transmission equipment (WDM-TTE): A terminal transmission equipment (TTE) equipped with wavelength multiplexer (WM) and wavelength demultiplexer (WD), whose submarine cable optical interface (SCOI) is a wavelength division multiplexing (WDM) or dense wavelength division multiplexing (DWDM).

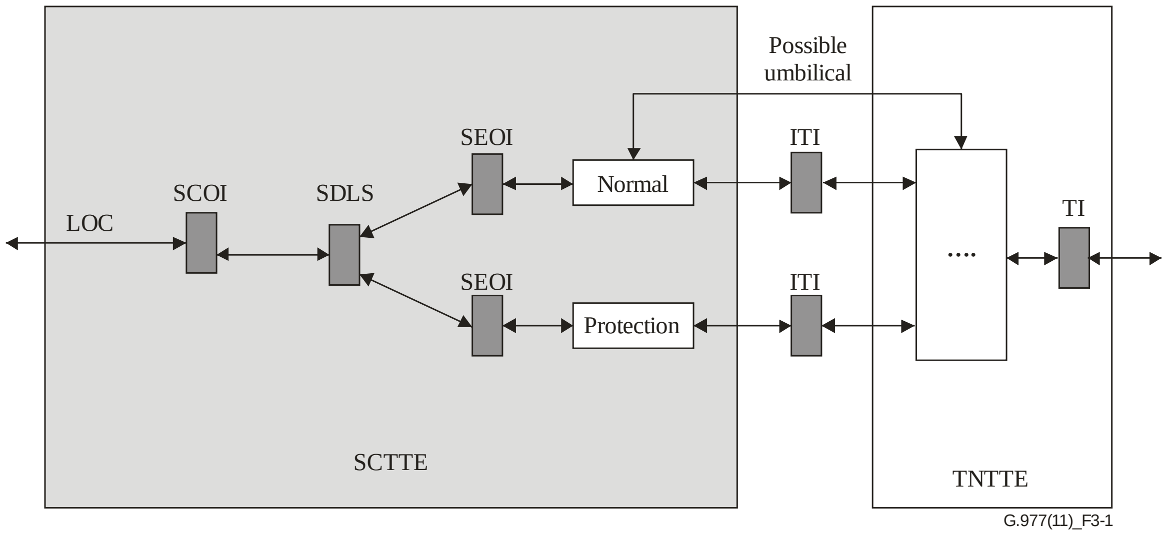

Figure 3-1 – Terms and definitions for SWS

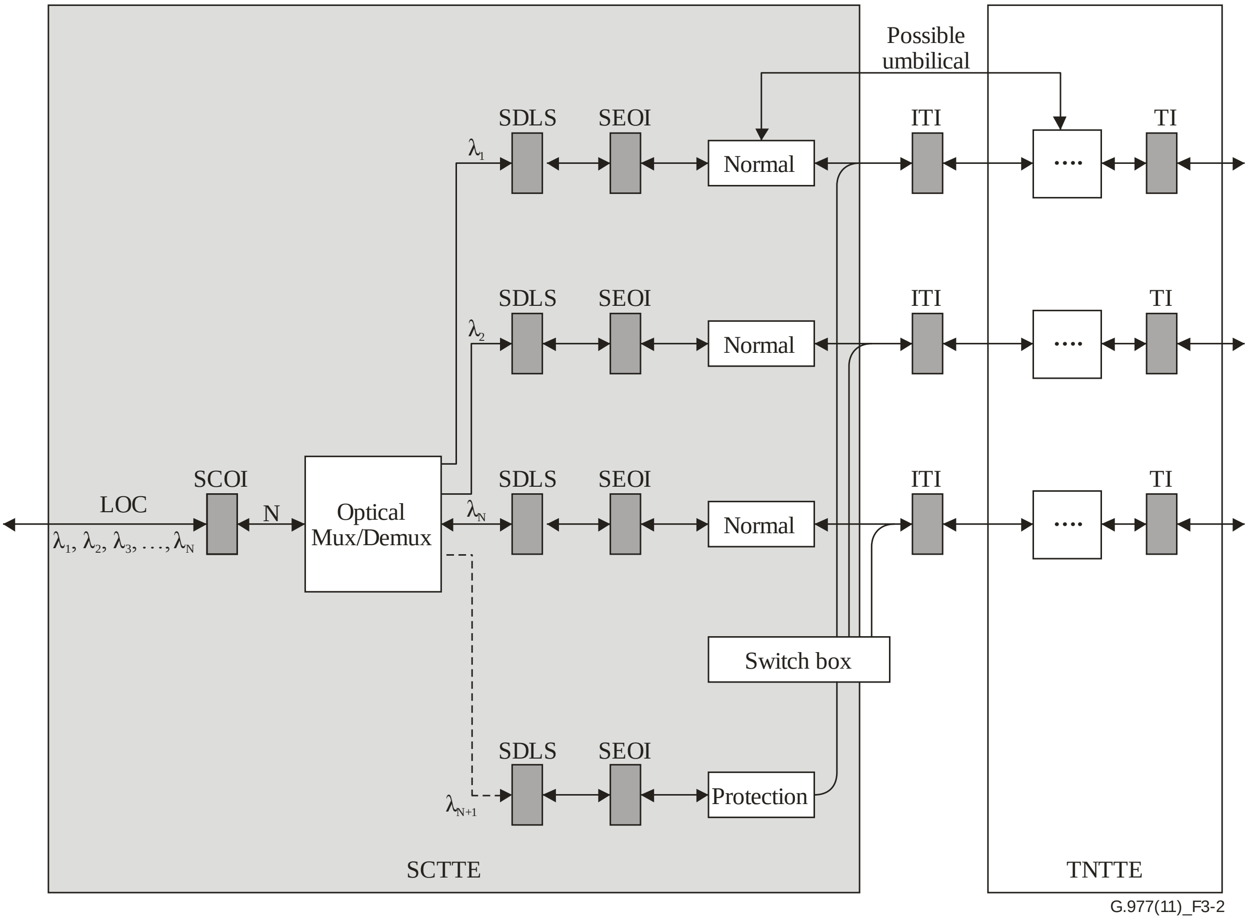

Figure 3-2 – Terms and definitions for WDMS

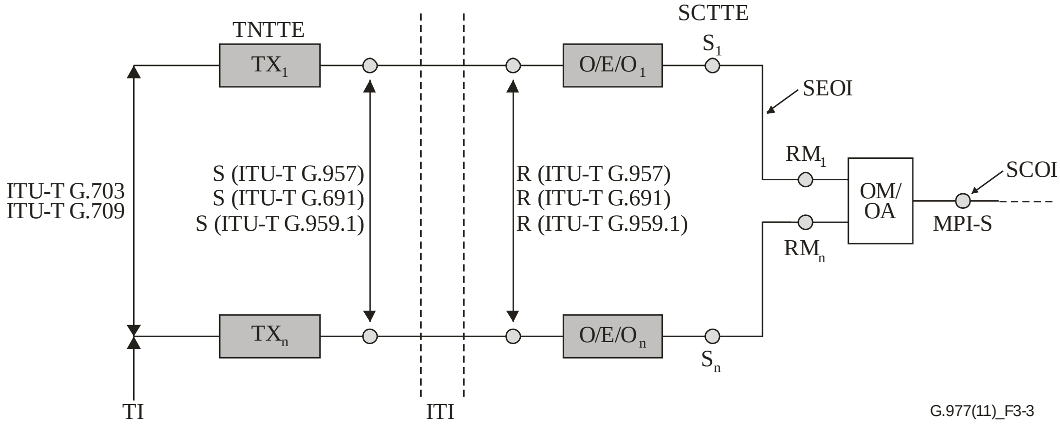

Figure 3-3 – Transmit side

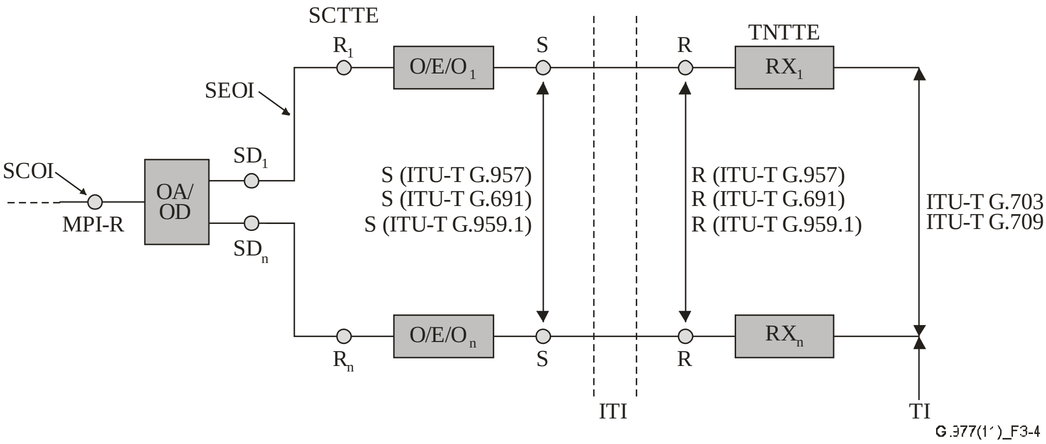

Figure 3-4 – Receive side

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

APC	Automatic Power Control
BER	Bit Error Ratio
BOL	Beginning Of Life
BU	Branching Unit
CF	Compression Factor
COTDR	Coherent Optical Time Domain Reflectometry
CRZ	Chirped Return to Zero
CS-RZ	Carrier Suppressed Return to Zero
CS-RZ-DPSK	Carrier Suppressed Return to Zero Differential Phase Shift Keying
CTE	Cable Terminating Equipment
DLS	Digital Line Section
DP-BPSK	Dual Polarization - Binary Phase Shift Keying
DP-nQAM	Dual Polarization - n Quadrature Amplitude Modulation (where n=8, 16 etc.)
DP-QPSK	Dual Polarization - Quadrature Phase Shift Keying
DPSK	Differential Phase Shift Keying
DWDM	Dense Wavelength Division Multiplexing
DWDMS	Dense Wavelength Division Multiplexing System
EDF	Erbium Doped Fibre
EOL	End Of Life
FFD-BU	Full Fibre Drop-Branching Unit
FOADM-BU	Fixed Optical Add/Drop Multiplexing-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
NF	Noise Figure
NG	Nominal Gain
NRZ	Non Return to Zero
NRZ-DPSK	Non Return to Zero Differential Phase Shift Keying
NSIP	Nominal Signal Input Power
NSOP	Nominal Signal Output Power
N-WDM	N-Wavelength Division Multiplexing
OADM	Optical Add/Drop Multiplexing
OFA	Optical Fibre Amplifier
OSE	Optical Submarine Equalizer
OSR	Optical Submarine Repeater
OTDR	Optical Time Domain Reflectometry
OTN	Optical Transport Network
PDG	Polarization-Dependent Gain
PDH	Plesiochronous Digital Hierarchy
PDL	Polarization-Dependent Loss
PFE	Power Feeding Equipment
PHB	Polarization Hole Burning
PMD	Polarization Mode Dispersion
ROADM-BU	Reconfigurable Optical Add/Drop Multiplexing-Branching Unit
RZ	Return to Zero
RZ-DPSK	Return to Zero Differential Phase Shift Keying
SCOI	Submarine Cable Output Interface
SCTTE	Submarine Cable Transmission Terminal Equipment
SDH	Synchronous Digital Hierarchy
SDLS	Submarine Digital Line Section
SEOI	Submarine Electro-Optic Interface
SNR	Signal-to-Noise Ratio
SSG	Small Signal Gain

STM	Synchronous Transport Module
SWS	Single Wavelength System
TI	Terrestrial Interface
TNTTE	Terrestrial Network Transmission Terminal Equipment
TTE	Terminal Transmission Equipment
TVSP	Time-Varying System Penalty
VSB	Vestigial Side Band
WD	Wavelength Demultiplexer
WDM	Wavelength Division Multiplexing
WDMS	Wavelength Division Multiplexing System
WDM-BU	Wavelength Division Multiplexing-Branching Unit
WDM-TTE	Wavelength Division Multiplexing-Terminal Transmission Equipment
WM	Wavelength Multiplexer

5 Conventions

None.

6 Characteristics and performances of the system

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

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

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

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

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

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

6.1.2 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 system's designed lifetime for:

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

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

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

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

6.1.3 System availability at TI

For PDH interfaces:

– the unavailable time definition is derived from Annex A of [ITU-T G.821] and Annex A of [ITU-T G.826];

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

For SDH interfaces:

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

For OTN interfaces:

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

The system availability obviously depends on the availability at the various TIs. 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, terminal transmission equipment (TTE) power feeding or any period during which the system is de-powered for repair. Similarly, faults requiring ship intervention are not included in the unavailable time calculation.

6.1.4 Jitter performance at ITI and TI

The jitter performances of an optical fibre submarine cable system should follow [ITU-T G.823], [ITU-T G.825] and [ITU-T G.8251], as well as other relevant Recommendations at ITI and TI for the system's designed lifetime.

6.1.5 Performance allocation between portions of the system

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

6.1.6 DLS independence

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

a) *for WDMS and DWDMS*

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, WDMS and DWDMS*

1) any failure on one fibre pair should have no effect on the other fibre pairs in the system;

2) any failure on any tributary at any level of multiplexing or demultiplexing (optical or electrical) in the system should have no effect on the remaining parts of the system.

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

6.2 Optical power budget

Optical power budget tables should describe how the system performance will be met in regards to the error performance.

In submarine systems with in-line optical amplifiers, regeneration occurs only in the TTE at the submarine electro-optic interface (SEOI) level. In between, the channels will suffer impairments due, for example, to optical noise accumulation, or propagation (fibre non-linearities, chromatic dispersion, etc.). It is, therefore, recommended that an optical power budget be established at the submarine digital line section (SDLS) level. As some systems may accommodate several SDLSs 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 wavelength division multiplex-branching unit (WDM-BU), for example), the two directions may suffer different impairments: in this case, different power budgets can be established for each direction of the concerned SDLS, and the one with the largest impairments should be considered 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 the power budget be established such that beginning of life (BOL) and the end of life (EOL) performance expectations are clearly specified:

– BOL 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 include a guaranteed margin ensuring compliance with EOL conditions. The commissioning limit should define the required BOL compliance to EOL operating conditions.

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

– If the expected performance exceeds the commissioning limit, the extra margins should be used to communicate the amount by which the commissioning limit is exceeded.

The supplier should provide sufficient information in order to support the validity of the power budget tables, in particular, but not limited to the:

a) nominal repeater output power value;

b) nominal noise figure (NF) value; and

c) optical and electrical bandwidth values at the receiver side, used to calculate the power budget.

A detailed description of a typical power budget is given in [b-ITU-T G-Sup.41]. An example of a 10 Gbit/s or similar power budget table is provided in Annex A.3.1.1 (Example 1). To accurately reference modem behaviour for higher bit-rate coherent systems, the power budget table provided in Annex A.3.1.2 (Example 2) can be used.

The supplier should also clarify if any device located either at the transmitter/receiver end side, such as polarization scramblers and/or dummy channels, or within the submerged plant, such as gain equalization filters, tilt equalizers and/or slope equalizers, is supposed to improve the transmission performances.

6.2.1 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 Annex A of [ITU-T G.976] and the impairments shown in terms of Q factor degradation.

The performance of an SDLS should be characterized by the measurement of its Q factor, or by a direct BER measurement that should allow the reconciliation of the contractual Q factor commissioning limits indicated in the power budget.

6.2.2 Relevant parameters for power budget

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

– optical noise accumulation;

– propagation impairments due to the combined effects of chromatic dispersion and non-linear effects (self-phase modulation, cross-phase modulation, four-wave mixing (FWM) effects between the LOCs, stimulated Raman scattering, etc.);

– propagation impairments due to optical polarization effects such as polarization mode dispersion (PMD), polarization-dependent loss (PDL), and polarization-dependent gain (PDG). As these impairments fluctuate with time, a distinct provision should be made for performance variations over 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 or DWDM. It has to be taken into account each time wavelength multiplexing (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).

Cross-phase modulation and FWM between the LOCs, stimulated Raman scattering, non-flatness of the cumulative gain curve, and misadjustment of the relative optical powers of LOCs, are impairments, especially applicable to WDMS and DWDMS as they are due to the propagation of several optical signals on the same fibre.

Specifically for the EOL power budget, the following impairments should be considered. Impairments due to:

– repair operations (repair splices, additional loss and change in dispersion map due to extra cable length after repair, etc.);
– cable and component ageing;
– TTE ageing (the decrease of the back-to-back Q factor value of the TTE);
– the foreseen faults of some components, such as pump laser faults.

Regarding impairments due to repair operations, the different cable type repair scenarios should be taken into consideration since impairments could be different for cables located in shallow waters, deep waters and the on-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).

6.3 System reliability performance

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

– The expected number of repairs requiring intervention by a cable ship due to system component failures during the system's designed lifetime:

The usual requirement for system reliability is less than three failures requiring cable ship intervention during the system's designed lifetime.

– The system's designed lifetime. The period of time over which the submarine optical fibre cable system is designed to be operational in conformance with its performance specifications. Usually, a system's designed lifetime 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.

6.4 System capacity upgradeability

Since optical fibre amplifiers (OFAs) have wide gain bandwidth and bit-rate flexibility, it may be advantageous to increase transmission capacity by increasing the signal bit-rate and/or the number of transmission channels (WDM or DWDM). 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 upgradeability 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 or OTN specifications to ensure compatibility with standard terrestrial equipment. Upgradeability through WDM or DWDM 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 or DWDM, is very different from many viewpoints of system design. These include fibre-amplifier design and control, power budget, signal-to-noise ratio (SNR), fibre chromatic dispersion and fibre non-linearities. It is, therefore, recommended that the systems be designed appropriately considering the possibility of future upgrades.

7 Characteristics and performance of the TTE

7.1 General

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

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

With reference to Figures 3-3 and 3-4, the following minimum list of parameters should be specified with regard to the E/O reference interfaces:

a) The TI and ITI are in accordance with [ITU-T G.703], [ITU-T G.709], [ITU-T G.957] and [ITU-T G.959.1].

b) The transmit side of SEOI (points S_1, S_n at the outputs of O/E/Os) should be specified at least in terms of:

   1) spectral characteristics;
   2) mean launched power;
   3) extinction ratio, if applicable;
   4) channel frequency;
   5) channel spacing;
   6) channel frequency deviation;
   7) modulation format (return to zero (RZ), non-return to zero (NRZ), chirped return to zero (CRZ), carrier suppressed return to zero (CS-RZ), vestigial side band (VSB), non-return to zero differential phase shift keying (NRZ-DPSK), return to zero differential phase shift keying (RZ-DPSK), carrier suppressed return to zero differential phase shift keying (CS-RZ-DPSK), dual polarization - binary phase shift keying (DP-BPSK), dual polarization - quadrature phase shift keying (DP-QPSK), dual polarization - n quadrature amplitude modulation (DP-nQAM), etc.);
   8) baud rate and bit-rate;
   9) use of phase modulation (if applicable);
   10) use of polarization scrambler (and the type, if applicable);
   11) pre-dispersion compensation value;
   12) post-dispersion compensation value.

c) The transmit side of SCOI (point - source main path interface reference 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) The receive side of SCOI (point - receive main path interface reference 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) The receive side of SEOI (points R_1, R_n at the inputs of the O/E/Os) 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.

7.2 Transmission performance

7.2.1 Characteristics of the digital signal at TI

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

7.2.2 Characteristics of the signal at SCOI

For further study.

7.2.3 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], [ITU-T G.825], [ITU-T G.8251] and other relevant Recommendations throughout the system's designed lifetime.

7.3 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 of [ITU-T 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 [ITU-T G.664], [IEC 60825-1] and [IEC 60825-2].

7.4 Automatic switching

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

– the traffic degradation due to switching should be minimized and compatible with the overall system performance;
– indication should be given of the in-service equipment;
– manual override of the automatic switching should be feasible with a minimal degradation of system performance.

Depending on the TTE architecture, the stand-by equipment is recommended to be kept operating and monitored as per the service equipment.

8 Characteristics and performance of the optical submarine repeaters (OSRs)

8.1 Mechanical characteristics

8.1.1 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 or optical performance. The joint housing must support large load transfer from the submarine cable through a flexible coupling.

8.1.2 The internal unit

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

8.1.3 Corrosion protection

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

8.1.4 Water pressure resistance

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

8.1.5 High voltage insulation

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

8.1.6 Thermal management

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

8.1.7 Repeater housing sealing

The repeater must be provided with 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.

8.1.8 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.

8.2 Electrical characteristics

8.2.1 Power modules

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

8.2.2 Surge protection

OSRs must be protected against power surges, which may result from sudden interruption of the high voltage supply on the cable (cable break, shunt fault or power feeding equipment (PFE) short circuit).

8.3 Optical characteristics

8.3.1 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 good characteristics regarding the filtering of optical reflections. Automatic power control (APC) may be used to regulate the output optical power or pump power level.

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

8.3.2 Relevant parameters

[ITU-T G.661] deals with definition and test methods for the relevant generic parameters of OFAs. More specifically, for a long haul SWS, WDMS or DWDMS 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 and DWDMS, it is also necessary to take into account:

– gain flatness (GF).

8.3.3 Polarization effects

The individual optical components of an OFA may be chosen to ensure that its performance is reasonably insensitive to polarization effects such as PDL and PMD, depending on the system requirements. Some other polarization effects such as PDG and polarization hole burning (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.

8.4 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 performance. The characteristics of monitoring systems for optical fibre submarine cable systems with repeaters are described in [ITU-T G.979].

8.5 Fault location

A cable-break point is usually located in an out-of-service condition. Generally, an optical time domain reflectometry (OTDR) is employed for this purpose, a coherent optical time domain reflectometry (COTDR) is used especially in a long distance OFA system 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 for solving this problem is the use of a return path (COTDR path) that should not disturb the in-service traffic as shown in Figures 8-1, 8-2 and 8-3. 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 the potential to monitor the gain status of each OFA.

Two different ways may be chosen to implement a COTDR path inside a repeater:

– The first consists of connecting both outputs of one amplifier pair through optical couplers (refer to Figure 8-1).
– The second consists of connecting the output of one optical amplifier (OA) to the input of the OA located in the reverse direction (refer to Figures 8-2 and 8-3).

Both solutions allow a bidirectional monitoring.

The definitions and parameters for OTDR and COTDR and related test methods are described in [ITU-T G.976].

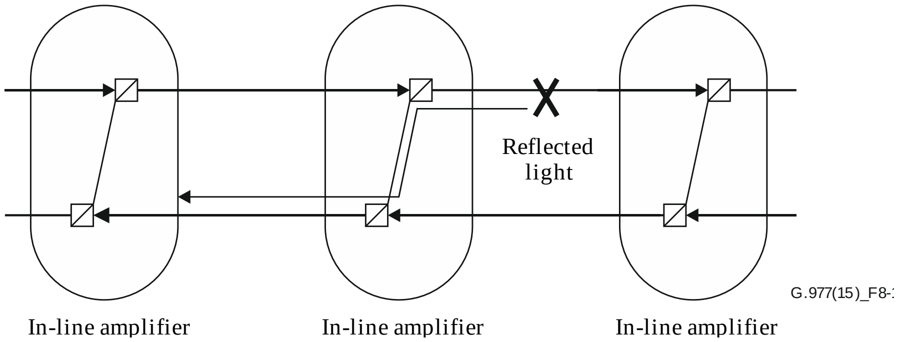

Figure 8-1 – Example of fault location using COTDR for OFA with output-to-output loopback coupling

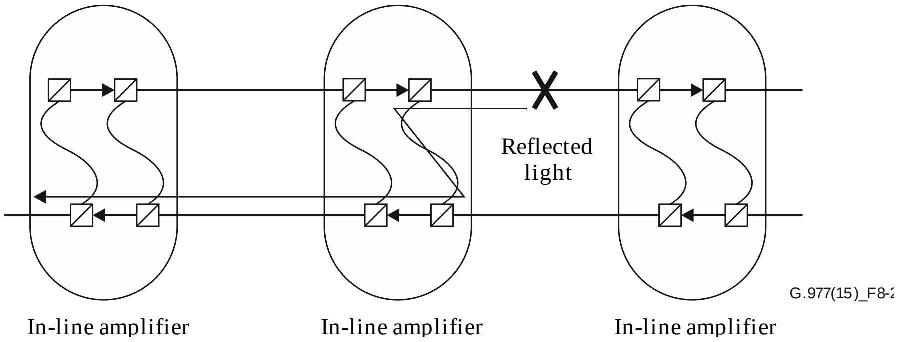

Figure 8-2 – Example of fault location in the first fibre using COTDR for OFA systems using output-to-input coupler

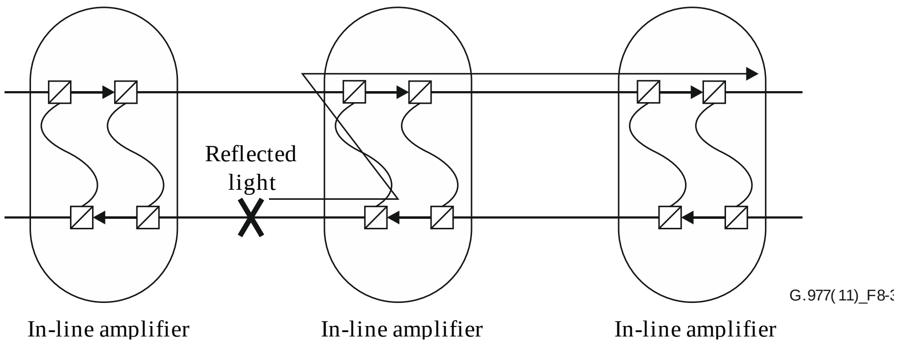

Figure 8-3 – Example of fault location in the second fibre using COTDR for OFA systems using output-to-input coupler

8.6 Reliability

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

9 Characteristics and performance of the in-line branching unit (BU)

9.1 General

Optical submarine cable systems may use branching units (BUs) where multiple landing points are required. A BU is designed to terminate three line cables. One of them, the branch termination, permits the extraction of 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:

1. full fibre drop functions for SWS;
2. full fibre drop functions and/or WDM add/drop functions for WDMS and DWDMS;
3. fixed (fixed optical add/drop multiplexing-branching unit (FOADM-BU)) or reconfigurable optical add/drop multiplexing-branching unit (ROADM-BU) add/drop functions for WDMS and DWDMS.

Optical amplification, as well as other facilities, such as the power switching function, supervisory system, automatic gain control, optical filtering and coupling for COTDR, may be provided.

9.2 Mechanical characteristics

9.2.1 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 at great 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 power switching circuitry and OFAs to amplify optical signals from one or several fibre pairs. It may also contain add/drop modules to ensure the WM and WD functions.

9.2.2 Corrosion protection

Protection must prevent the BU from corrosion due to sea water.

9.2.3 Water pressure resistance

The BU must be designed to support large pressure strengths.

9.2.4 High voltage insulation

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

9.2.5 Thermal management

Heat generated by the electronic components inside the BU should be dissipated sufficiently via thermal conduction within the BU housing.

9.2.6 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.

9.2.7 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.

9.3 Electrical characteristics

9.3.1 Sea electrode

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

9.3.2 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 cases of PFE failure or 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 the presence of this fault, or during the repair operation.

9.3.3 Power modules

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

9.3.4 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).

9.4 Optical characteristics

9.4.1 Functionalities

A BU may be a full fibre drop-branching unit (FFD-BU), a WDM-BU or an aggregate of both. In all cases, the BU functionalities may guarantee, as far as possible, the DLS independence to ensure that any failure of a LOC will not disturb the remaining ones. In the case of a WDM-BU, specific optical components may ensure the multiplexer and demultiplexer functions.

9.4.2 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.

9.4.3 Polarization effects

The individual optical components of a BU may be chosen to ensure that its performance is reasonably insensitive to polarization effects such as PDL and PMD. Some other polarization effects, such as PDG and 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.

9.5 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.

9.6 Fault location

Fault location in the systems, including a BU, can generally be performed using COTDR. When a BU offers a 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 clause 8.5, can be applied for fault location beyond the OFA.

The definitions and parameters for COTDR and related test methods are described in [ITU-T G.976].

9.7 Reliability

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

10 Characteristics and performance of the optical submarine equalizer (OSE)

WDM and DWDM optical submarine cable systems may use optical submarine equalizers (OSEs) in the system DLS to reach the performance requirements for all channels. The equalization module's design is specific to each submarine cable system. It mainly depends on the SDLS characteristics and the sea temperature.

Two distinct types of OSE may exist:

a) gain shape equalizer;

b) tilt or slope equalizer.

Adjustable equalizations, as well as other facilities such as the power monitoring function and supervisory system, may be also provided.

10.1 Mechanical characteristics

10.1.1 Submarine gain equalizer housing

OSE housing must be designed to allow operation, laying, recovery, and re-laying in large depths with no degradation in mechanical, electrical and optical performance.

10.1.2 The internal unit

Inside the OSE housing, the internal unit can contain several equalization modules dedicated to the optical signal from one or several fibre pairs related to each direction.

10.1.3 Corrosion protection

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

10.1.4 Water pressure resistance

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

10.1.5 High voltage insulation

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

10.1.6 Thermal management

Heat generated by the electronic components inside the OSE (particularly in the case of an adjustable equalizer) may be dissipated sufficiently via thermal conduction within the OSE housing.

10.1.7 OSE housing sealing

The OSE 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 OSE.

10.1.8 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 OSE.

10.2 Electrical characteristics (for adjustable OSEs only)

10.2.1 Power modules

Adjustable OSEs are powered from the terminal end station at a constant current via the electrical conductor on the cable. Power modules feed the adjustable equalization modules to obtain the optical gain profile required. OSE may accept both electrical polarities.

10.2.2 Surge protection

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

10.3 Optical characteristics

10.3.1 Functionalities

Each equalization module realizes an optical filtering function on the WDM spectrum to provide the equalization of the residual gain/wavelength ripple and/or tilt which accumulates when the optical signal is transmitted through a chain of optical submarine repeaters. Adjustable functionalities may be added to adjust the response of the filtering function of the equalization module. In that case, supervisory facilities must be provided to remotely monitor the status of such adjustable OSEs.

10.3.2 Relevant parameters

The optical specification of the submarine equalization modules should be completed by further studies.

10.3.3 Polarization effects

The individual optical components of an OSE may be chosen to ensure that its performance is reasonably insensitive to polarization effects such as PDL and PMD.

10.4 Supervisory facilities

A supervisory system is required to monitor, from the land station, the status of adjustable OSEs. This supervisory system must be able to operate when the link is in service without impacting the performance of the systems.

10.5 Reliability

All of the OSE components must be qualified and life tested to guarantee the reliability requirements.

11 Characteristics and performance of the submarine cable

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

11.1 Dispersion mapping

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

For a SWS, typically the fibres with low negative chromatic dispersion close to zero but not zero are used along the link corresponding to main sections, and the fibres with higher positive chromatic dispersion are used for the link corresponding to a few sections of dispersion compensation. The aim of this management is to keep a cumulative dispersion close to zero for the whole link, while keeping local chromatic dispersion at non-zero.

For a WDMS, fibres with low negative chromatic dispersion but far from zero (around –2 ps/nm.km) are typically used for most sections (sometimes two types of fibre can be used, at the beginning of the section with a large effective area fibre and at the end with low slope fibre), while fibres with higher positive chromatic dispersion are regularly used for dispersion compensation sections. The aim of this management is to keep the cumulative dispersion of the whole link close to zero, while keeping local chromatic dispersion higher and non-zero, to limit the FWM and cross-phase modulation.

For a DWDMS at 10 Gbit/s, fibres with large chromatic dispersion are typically used along the link for all the sections. One portion of the section is typically positive dispersion with positive slope (normally with a very large effective area) and the remaining portion is negative dispersion with negative slope (normally a very small effective area). The aim of this management is to keep the cumulative dispersion in each section for all the wavelengths close to zero, while keeping local chromatic dispersion very high to limit the cross-phase modulation.

11.2 Dispersion management implementation

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

Residual cumulative dispersion for each wavelength may be compensated to zero by using a length of equalization fibre or other passive dispersion compensation devices at the transmit (pre-compensation) and/or receive (post-compensation) side in TTE. Typically, the compensation is made at the receive end only for a SWS, and at the transmit and receive ends for a WDMS and DWDMS. In transmission systems designed for coherent detection, dispersion may not need to be compensated.

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

Annex A

Implementation of repeatered optical fibre submarine cable systems using optical fibre amplifiers

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

A.1 Introduction

This annex outlines various aspects of submarine cable system practice as commonly employed on optical amplifier systems. It covers SWS, WDMS and DWDMS 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, it may be termed an optical fibre submarine cable link. If more than two are connected, then it may be termed an optical fibre submarine cable network.

Figure A.1 shows the basic concept of optical fibre submarine cable systems and boundaries. OSRs and/or optical submarine branching units and/or OSEs could be included, depending on each system's requirements.

In Figure A.1, 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 clauses refer to Figure A.1.

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., OSR(s), BU(s), OSE (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 OSRs 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.

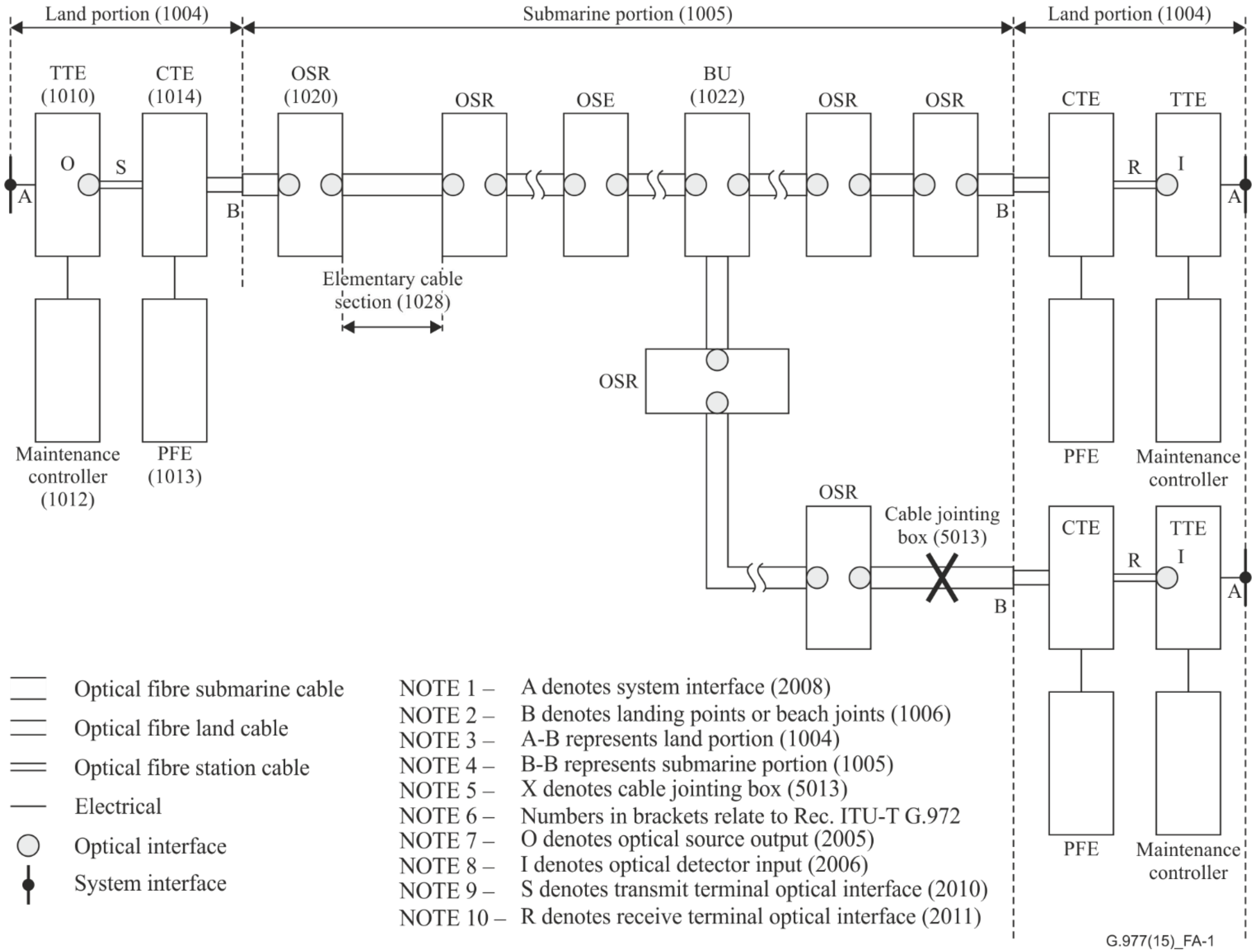

Figure A.1 – Example of repeatered optical fibre submarine cable system

An optical submarine 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 sub-assemblies: 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 and DWDMS with signal interchange functionality between optical signal paths; it is then termed a WDM-BU.

An OSE may be inserted into the submarine portion of an optical submarine cable to mitigate the cumulated gain inhomogeneity when the pre-emphasis capability of the TTE at the transmitter side is not sufficient to guarantee the performance requirements for all WDM channels. This equipment may include different schemes of equalization units according to the shape of the input WDM signal spectrum: shape equalizer for spectral ripple correction and/or tilt (or slope) equalizer for tilt compensation. Adjustable equalizations as well as other facilities such as power monitoring functions and supervisory systems may be also provided.

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 optimally meet 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 DLSs. The number of DLSs carried by an optical fibre cable section is given by the product of these two numbers.

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

A.2.3 Supervision and remote maintenance of the system

A 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; and
– the means to locate hard faults and intermittent faults of duration and frequency that cause the system to fail, to ensure the performance requirement is met.

Other means, such as COTDR, if OSRs and BUs are loopback 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 including cable, repeater, terminal equipment, BU, OSE, 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

A.3.1.1 Example 1

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 a Q factor 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, 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 – An example of a possible power budget template

	Parameter	BOL Q in dB	EOL Q in dB
1	Mean Q value (from a simple SNR calculation)		
1.1	Propagation impairments due to combined effects of chromatic dispersion, non-linear effects, FWM 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 penalty (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 [ITU-T G.826] or [ITU-T G.8201] after FEC		

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

	Parameter	BOL Q in dB	EOL Q in dB
7	Repair margin, component- 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 completed as follows:

– Line 1: Mean Q value (simple SNR calculation). (There exist different formulas: simple noise accumulation with constant signal power or total output power with/without extinction ratio, etc. Some calculation examples are given in [b-ITU-T G-Sup.41].)

– Lines 1.1 to 1.9: Give a non-exhaustive list of impairment sources that impact system performances. Those impairments have to be deduced from line 1.

– Line 2: Time-varying system performance. This defines an additional impairment due to polarization 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 BOL and EOL.

– Line 5: Segment Q value. This line gives the segment Q factor calculated from lines 3 and 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 BER before forward error correction.

– Line 5.2: BER corresponding to segment Q with FEC. BER after FEC.

– Line 5.3: Effective segment Q value with FEC. Line 5.2 converted into Q factor.

– Line 6: Q limit for compliance with [ITU-T G.826] or [ITU-T G.8201] after FEC. Q factor corresponding to the worst allowable BER before correction by FEC. For example, 11.2 dB corresponds to a BER of 2.4×10^{-4}. A BER of 2.4×10^{-4} is converted by the first generation FEC defined in [ITU-T G.975] to a BER better than 10^{-11}. Therefore, a Q factor of all 11.2 dB covers all DLS lengths for the first generation FECs. With advanced FEC schemes defined in [ITU-T G.975.1] a BER of 10^{-3} is converted to a BER better than 10^{-13} after correction.

– Line 7: Repairs, ageing and pump failures. Line 7 is given by line 5 (BOL) minus line 5 (EOL).

– Line 8: Segment margins. Line 8 (EOL), the segment margins are usually 1 dB contractually at EOL. Line 8 (BOL), is given by line 7 plus line 8 (EOL).

– Line 9: Unallocated supplier margins. Margin for other and unknown impairments.

– Line 10: Commissioning limits. This line gives the contractual commissioned Q limit for each DLS.

A.3.1.2 Example 2

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 a Q factor value. The suppliers should provide, as a minimum, the values of the parameters used to compute the power budget and specify all necessary complementary relevant information such as channel power, optical SNR and method for obtaining TTE Q factor as function of OSNR.

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

Table A.2 – An example of a possible coherent power budget template

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

Table A.2 should be completed as follows:

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

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

[1] Full loading implies design capacity.

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

– Line 2: The propagation impairment is specified as follows:

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

  – Subtract the propagated Q factor from the back-to-back Q factor in line 1.

– Line 3: The supplier margin allocations are specified as follows:

  – Line 3.1: The non-optimal pre-emphasis impairment corresponds to the imperfect Q factor equalization over the full spectral range.

  – Line 3.2: The wavelength tolerance impairment corresponds to the degradation due to the non-optimal wavelength setting.

  – Line 3.3: Mean penalty due to polarization-dependent effects such as PDL, PDG, and PMD.

  – Line 3.4: The supervisory impairment accounts for system degradation due to the presence of a supervisory system.

  – Line 3.5: The manufacturing and environmental impairment provides margin for normal product fluctuations due to the manufacturing process and environmental conditions. For new system builds, this parameter includes impairments both from the DLS transmission path and the TTE. For system upgrades, this parameter includes only impairments from the TTE.

  – Line 3.6: Unspecified impairment is allocated for any other impairment not listed in lines 3.1 to 3.5.

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

– Line 5: The BOL segment Q is defined as:

line 5 = line 1 – (sum of line 2 to lines 3.1-3.6) – line 4

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

– Line 7: EOL segment Q is defined as:

line 7 = line 5 – (sum of lines 6.1 and 6.2)

– Line 8: FEC Limit in Q (dB) for compliance with [ITU-T G.826] or [ITU-T G.8201] after FEC.

– Line 9: Customer margin is the specified margin required at EOL by the cables' customer.

– Line 10: Extra margin is the margin available after all repair, ageing, and customer required margins are allocated, and is calculated as the difference between the BOL segment Q and the commissioning limit.

– Line 11: This line gives the contractual commissioned Q limit for each DLS. If performance of each channel is measured to be above the commissioning limit, then adequate margin for repair, ageing and customer provisions have been demonstrated.

A.3.2 Digital line section performance

The performance of each DLS should at least conform to [ITU-T G.826] or [ITU-T G.8201].

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 either external means or other route for ring network systems, 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;
– provide information on the status of the system and of the DLSs;
– provide information on the ongoing supervisory activity so as to help in overall system monitoring; and
– provide information for supervisory or fault location purposes.

One order wire channel may be 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 (PFE)

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 OSR(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 transients 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 keep 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 earth station if the system power feed electrode becomes disconnected or changes to an excessive potential difference from the earth potential. 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 voltages, 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 (CTE), 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), branching unit (BU) and optical submarine equalizer (OSE) characteristics

A.5.1 General

OSRs, BUs and OSEs are capable of being operated in accordance with the system performance specifications during the system's designed lifetime and in the sea depth environmental conditions (temperature, pressure, etc.).

OSRs, BUs and OSEs are designed to be handled, i.e., laid, recovered and re-layed, without impairment of the performance of the cable, cable jointing boxes, repeaters, BUs, and cable terminations, provided that handling specifications are respected.

OSRs, BUs and OSEs are designed to be transported and stored under specified temperature conditions without affecting the system's designed lifetime, provided that storage and transport specifications are respected.

OSRs, BUs and OSEs are capable of being operated on board a cable ship during laying and repair operations without affecting the system's designed lifetime.

The size of OSRs, BUs and OSEs 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 or OSE) constituents

The main OSR (or BU or OSE) constituents are:

– the OSR (or BU or OSE) 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 or OSE), high voltage insulation and low thermal impedance between the OSR (or BU or adjustable OSE) electronic unit and the sea.

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

  the piece part, 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 or adjustable OSE) supervisory unit permits repeater performance monitoring. Optical loopbacks may provide facilities to monitor the cable sections between two OSRs with the use of COTDR.

Bibliography

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

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